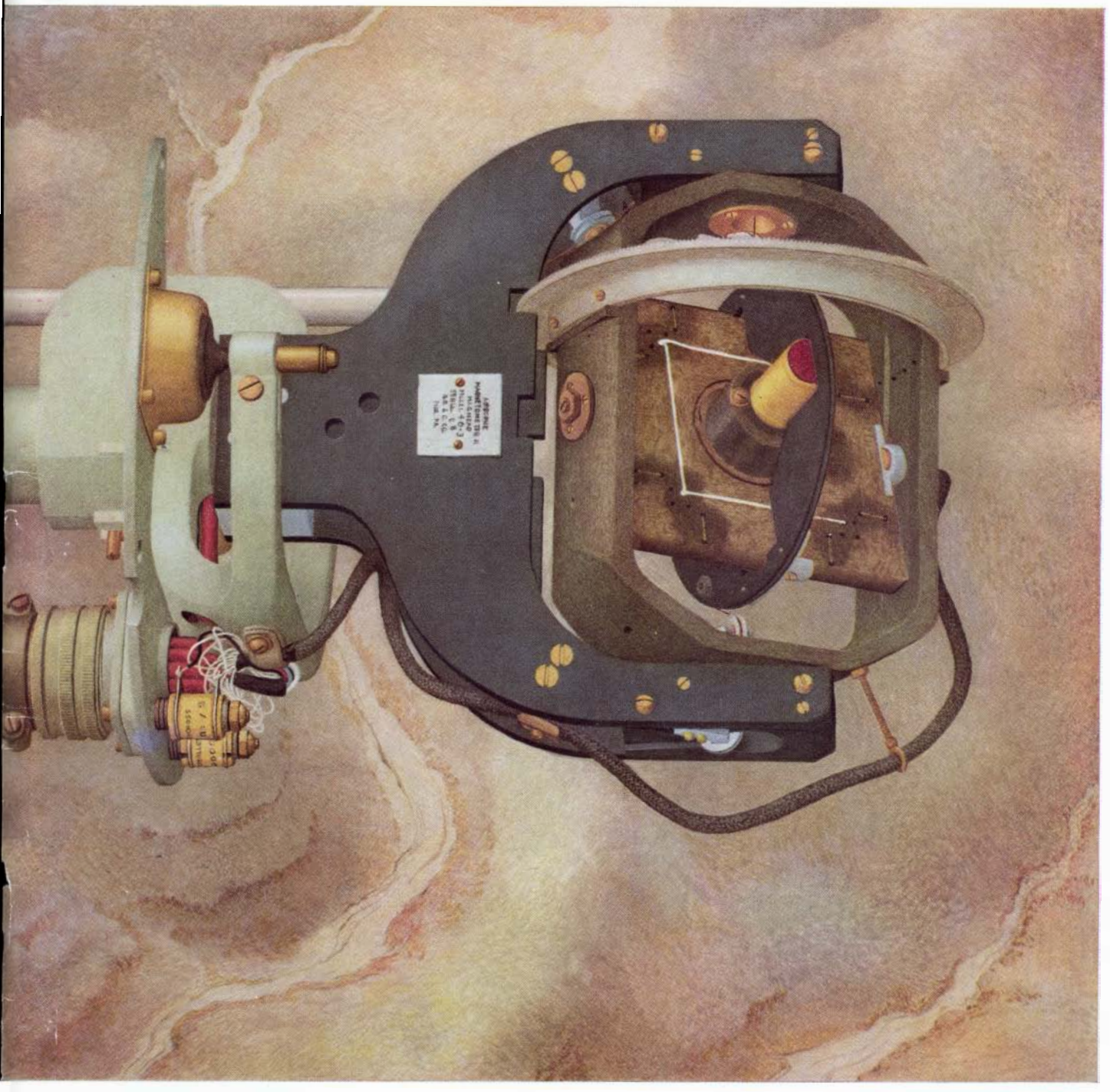
SCIENTIFIC AMERICAN



AIRBORNE MAGNETOMETER

FIFTY CENTS

June 1961

HOW 60 SECONDS AFFECT "40 WINKS": The years of deep comfort and quality in urethane foams are established within the first minute of "one-shot" production. Success depends on predictable catalysis for the proper relationship between rates of gassing and polymerization. As the pioneer and leader in development of U-Foam catalysts, M&T has installed an actual foam machine in its laboratories to evaluate production behavior of catalysts and expand technical service to foam producers.

SOMETHING NEW ON DECK IN COATINGS: Imagine a coating up to 5 times thicker than usual finishes, which mirrors the pattern of metal underneath, protects against corrosion, stands abusive service without marring. Here is the kind of coating that should cover a station wagon deck. And it is. Heavy duty vinyl coatings for metal have been an M&T specialty for 20 years.

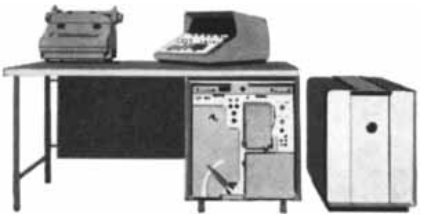
PLASTICS GAIN BUILT-IN "FIREMAN": Small quantities of antimony oxide in normally combustible materials—particularly plastics—retard flame, prevent fires, assure required safety for items ranging from plastic sheeting to boat hulls. M&T produces a line of antimonyflame retarders compatible with all formulation requirements of polyolefins, polystyrene, vinyls, polyesters, acrylates, epoxies and U-foams.

Metals meet Chemistry at M&T... Chemistry is the key to M&T's diversified business. It opens many doors... in one case to a better organic coating for metal; another to fire-safety for plastics; another to unique tin-based catalysts for U-foams. There's something progressive going on all the time when chemistry and metal meet at M&T. **Metal & Thermit Corporation**

General Offices: Rahway, N. J. • CHEMICALS • COATINGS • MINERALS • WELDING PRODUCTS • PLATING PRODUCTS • DETINNING

ANOTHER IN THE CAUTIONARY SERIES ABOUT RECOMP II [in which we reveal nearly all the computer's subtle enticements]

Here, for the very first time, is an unexpurgated listing of the allurements of Recomp II. They are potent. They are persuasive. They are enticing. Indeed, in reading them it would be wise to exercise a decent restraint... for you may find yourself falling in love with a computer:



1] The *first* solid-state digital computer on the market was Recomp II. The *finest* computer on the market is still Recomp II. Recomp II's dedicated engineers are determined that the situation shall remain this way; they have an obsessive regard for this precise machine they have so carefully developed.

2] Recomp II is the *only* compact computer with built-in floating point arithmetic. It defies being hemmed in on a problem. With its large capacity it obviates computer-claustrophobia.

3] Always the darling of the medium-scale computer user, Recomp II has been so well accepted that it can now be offered at a *significantly lower price.* It still provides the identical quality, solid-state performance, and features that can't be found on computers costing three times what Recomp II *used* to cost.

4] Recomp's memory, employing the new optional Recomp Magnetic Tape Transport units, would stagger an elephant. Each unit has a memory of over 600,000 words. Up to eight of these transport units can be connected to Recomp II, giving you a computer with a total memory capacity of over 5,000,000 words. Remarkable!

5] The speed of the new magnetic tape control described above is quite remarkable, too. Read and write speed is 1850 characters a second; bidirectional search speed is 55 inches per second.

6] Always the darling of the medium-scale computer user, Recomp II has been so well accepted that it can now be offered at a *significantly lower price.* It still provides the identical quality, solid state performance, etc.

7] Recomp II seems to have more built-in features than a dream-home kitchen. It has built-in square root command. Built-in automatic conversion from decimal to binary.

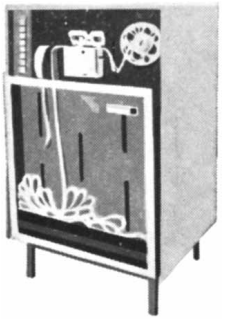
8] Would you say that a RUG is important to a computer? Well, it is. The RUG we mean is Recomp Users Group. This is a highly active group, sharing up-to-date information, and keeping in close contact by monthly bulletins. A consideration not to be overlooked when buying a computer.

9] Always the darling of the medium-scale computer user, Recomp II has been so well accepted that it can now be offered at a *significantly lower price.* It still provides, etc., etc.

10] Recomp's keyboard, which you can see above, looks easy to operate. It is. And because it requires no specialized talents, anyone with computer problems can be taught to use Recomp II. Quite a handy machine to have around.

11] Recomp II can easily be installed anywhere, requiring no more electricity than an ordinary electric toaster.

12] Another new optional feature for your Recomp II is the Facitape tape punch and reader console, shown below. It punches 150 characters a second, reads 600 characters a second, and stops on a character. It adjusts to read and punch from 5 through 8 channels. Quite uncanny.



13] A visual readout on the control panel allows you to check any information about to be entered into Recomp II before you press the "enter" button. The information can be corrected easily if necessary. This is further evidence of Recomp II's staunch adherence to efficiency.

14] Recomp II's programming is highly efficient. It has 49 basic instructions, expandable to 72. Word length is 40 binary bits; very large, indeed.

15] Always the darling of the medium-scale computer user, etc., etc., etc.

16] Recomp II has a large sub-routine and program library, and a large program exchange.

17] Each word programmed into Recomp II contains two instructions.

Recomp II has many other features, but as you can see, space is running short. We would have liked to have lingered upon the details of Recomp II's own full scale compiler called SALT, and even maybe discuss the high-speed loops a little... but. Perhaps, if you are beginning to feel the stirrings of your acquisitive instinct toward Recomp II, you should see it in action. We can arrange a demonstration for you through our local offices in New York, Chicago, Boston, San Francisco, and Long Beach. Or, at the very least write for more information. We have some nice brochures you will enjoy reading.

Write AUTONETICS INDUSTRIAL PRODUCTS, Dept. 061, 3400 E. 70th St., Long Beach, Calif.

The Autonetics Division of North American Aviation.

Dmitri Mendeleev...on the edifice of science

"The edifice of science not only requires material, but also a plan... without the material, the plan alone is but a castle in the air — a mere possibility; whilst the material without a plan is but useless matter.... In the work of science, the artisan, architect, and creator are very often one and the same individual; but sometimes, as in other walks of life, there is a difference between them; sometimes the plan is preconceived, sometimes it follows the preparation and accumulation of the raw material. Free access to the edifice of science is not only allowed to those who devised the plan, worked out the detailed drawings, prepared the materials, or piled up the brickwork, but also to all those who are desirous of making a close acquaintance with the plan, and wish to avoid dwelling in the vaults or in the garrets where the useless lumber is stored.

"Knowing how contented, free, and joyful is life in the realm of science, one fervently wishes that many would enter its portals." —*The Principles of Chemistry, 1868.*

Established 1845 **SCIENTIFIC AMERICAN** June 1961 Volume 204 Number 6

ARTICLES

DEPARTMENTS

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THE COVER

The painting on the cover shows part of an airborne magnetometer, the device that is used to prospect for minerals and petroleum by detecting variations in the earth's magnetic field (*page 151*). Here the magnetometer is fancifully shown out in the open 1,000 feet above a desert landscape; normally it is enclosed in a housing at the wing tip or tail of the airplane that carries it. The sensing elements of the magnetometer are "flux gates"; they are mounted on the square platform at right in the painting. Two flux gates underneath the platform sense the direction of lines of force in the earth's field; by actuating two servomotors they keep the platform at right angles to the lines of force. A third flux gate inside the yellow cylinder, which goes through the platform, measures the strength of the magnetic field. In exploring a region of the earth's surface the airplane bearing the magnetometer flies a regular pattern at fairly low altitude. Variations in the earth's magnetic field are recorded and later plotted on a map. Contour lines indicating changes in the strength of the field are associated with magnetic minerals.

THE ILLUSTRATIONS

Cover painting by John Langley Howard

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54	David Linton (*top*), James Egleson (*bottom*)
56–58	James Egleson
59	Arthur L. Schawlow, Bell Telephone Laboratories
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111	Mount Wilson and Palomar Observatories
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160	Eric Mose (*top*), David Linton (*bottom*)
162	Eric Mose
166–174	Alex Semenoick
182–192	Roger Hayward

The contact adhesive for bonding foamed plastics

Many advantages of solvent-type contact cements are now available in a non-flammable latex adhesive—Armstrong LD-780.

In the manufacture of insulating panels, LD-780 meets the need for a high-strength adhesive that will bond foamed polystyrene and similar plastic foams to metal or other skin materials.

Solvent type adhesives cannot be used in these panels because they attack and disintegrate the insulating foam. Conventional water-based cements lack sufficient strength to produce rigid panels.

LD-780 solves both problems. Its combination of neoprene rubber and synthetic resins is compatible with the foams. And it has high dead-load strength, with exceptional resistance to fatigue.

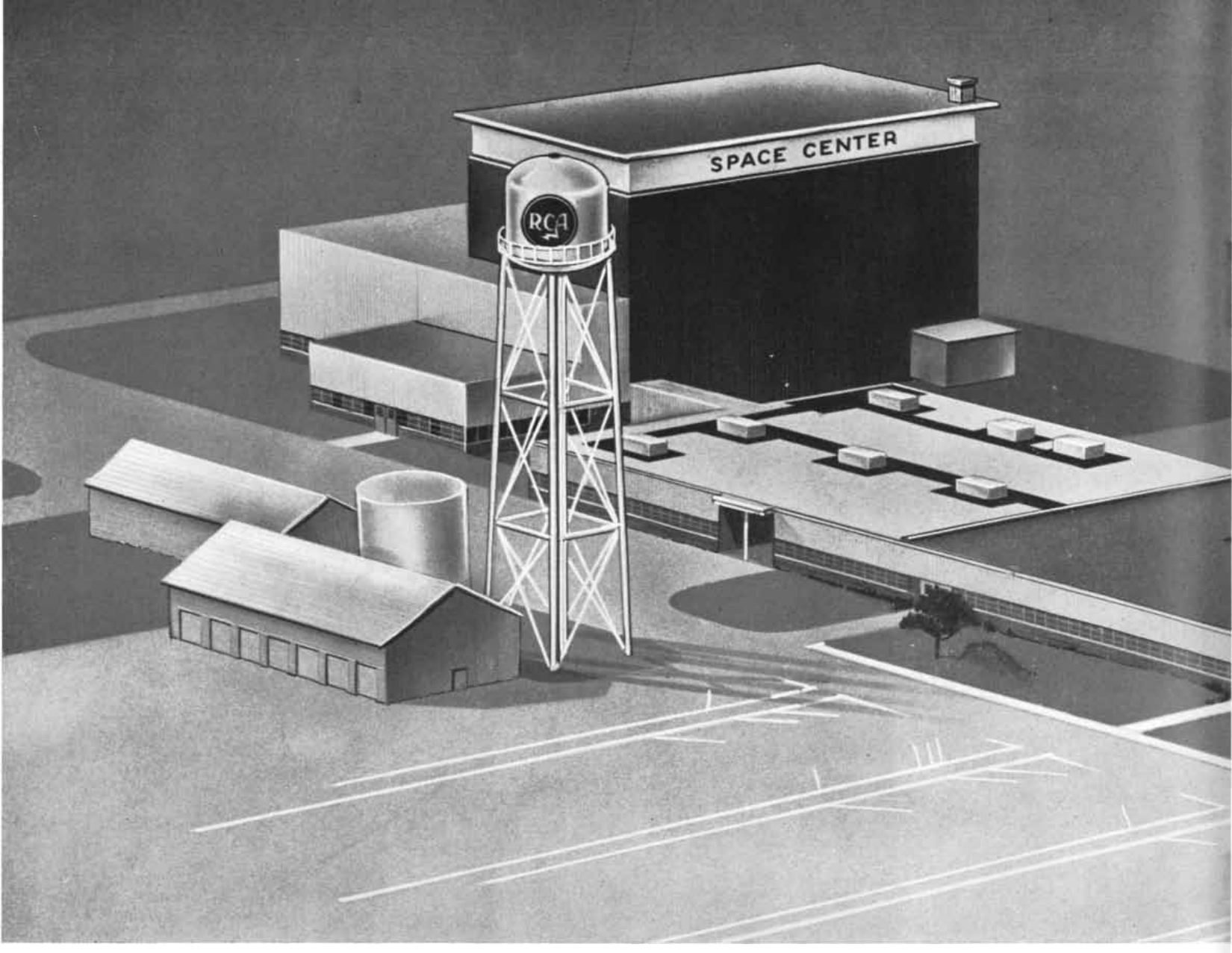
The resilient bond of LD-780 also resists the deteriorating effect of water. For example, a test "sandwich" made of a foamed polystyrene core faced on either side with porcelain steel and galvanized steel was immersed in water for six months. At the end of this period, there was no bond failure.

LD-780 has ample strength for bonding plastic laminates and other sheet materials to various cores. And it is easy to use. Apply to both surfaces by brush, spray, or roller coater; allow to dry; join the surfaces by hand rolling or passing through pinch rolls. The bond is instantaneous. Its immediate strength is high enough to permit handling or further processing of the panel without delay. And the strength of the bond increases with time.

Because LD-780 is a water-based adhesive, it completely eliminates the hazard of fire or explosion. Special ventilating systems, usually needed where volatile solvents are used, are not required with LD-780.

You may have a bonding job that can best be done by LD-780's unusual combination of strength and easy, safe handling. Give us details of the application on your business letterhead and we will be glad to supply you with a test sample and additional information. Armstrong Cork Company, 8006 Inland Road, Lancaster, Pa.

Armstrong ADHESIVES



New RCA Space Environment Facility Brings Outer Space Down to Earth...

...Will pretest coming generations of U.S. space vehicles and satellites at environmental extremes assuring reliable long life operation and optimum performance.

RCA expands its proved capability to meet the challenges of space-age technology with the construction of an advanced space environment center at Princeton, N. J. Here, today's *and* tomorrow's space vehicles and satellites can undergo a new degree of intensive and thorough testing prior to "launch" to achieve greater reliability in space.

Included in the new environmental equipment and facilities being built and installed at the RCA Space Center are the following advanced testing devices:

Vacuum-Thermal Chamber—measuring 28 feet in diameter and 25 feet high to accommodate the coming generations of space vehicles and satellites and meet all vacuum-thermal requirements.

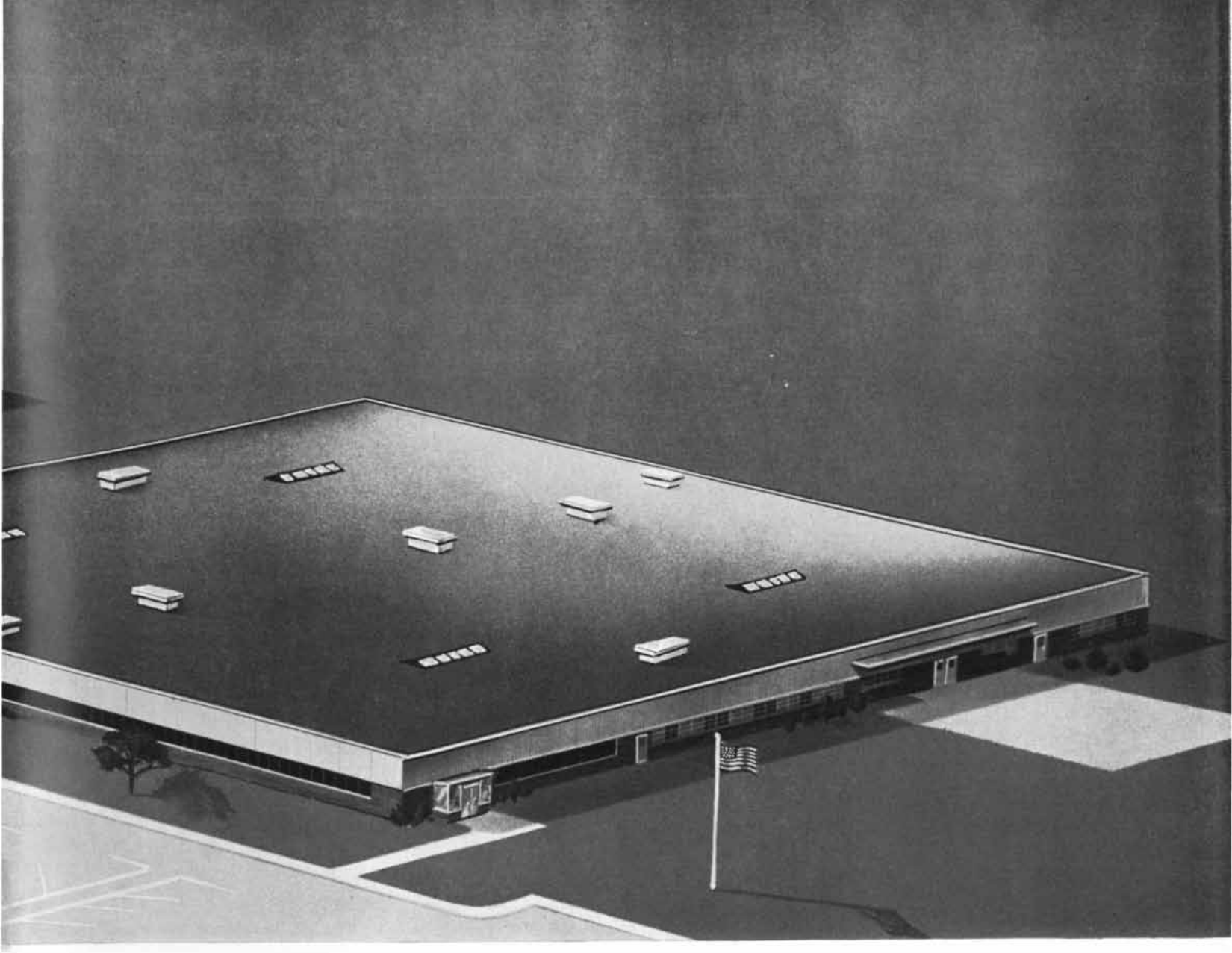
Vibration System—provides 28,000 pounds peak force for sinusoidal, and 28,000-pound rms force for random motion testing.

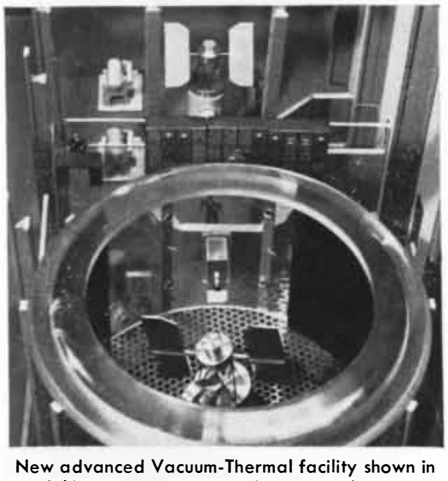
Temperature-Humidity Chamber—so versatile it can create virtually any thermal-humidity condition desired. Temperatures may be varied from —50° F to 250° F; humidity from nil to maximum.

Rotary Accelerator—subjects subsystems of space vehicles and satellites to forces as high as 2500 g lbs.

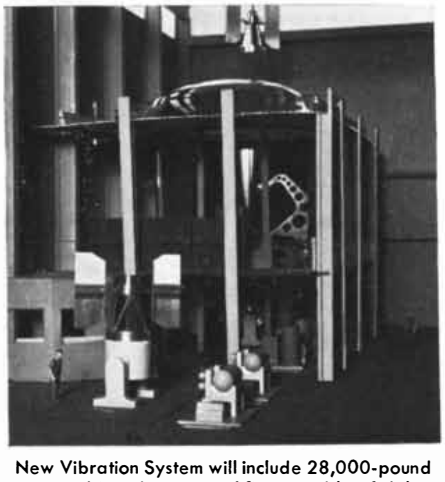
The entire RCA Space Center, which contributed to the success of projects such as SCORE, TIROS I, TIROS II and ECHO I, continues to be dedicated to the conception, development and production of earth satellites, space vehicles and ground support and information handling equipment. For additional information about RCA's engineering talents and proved capabilities, contact the Manager, Marketing, RCA Space Center, Box 800, Princeton, N. J. And, for a complete description of the new environmental facilities, write for your copy of the brochure "RCA Space Environment Center."

If you are interested in participating in the challenging opportunities that exist at the RCA Space Center, contact the Employment Manager, Astro-Electronics Division, Defense Electronic Products, Princeton, N. J. All qualified applicants are considered regardless of race, creed, color or national origin.

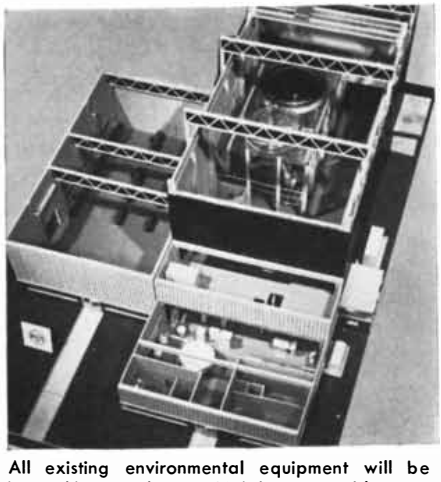




New advanced Vacuum-Thermal facility shown in model has pumping system that can reduce pressure to 5 x 10^{-6} mm Hg within 24 hours with a 3500-pound payload in the enclosure.



New Vibration System will include 28,000-pound exciter driven by an amplifier capable of delivering 140 KW over a frequency range of 25 to 10,000 cps.



All existing environmental equipment will be housed here and a new high-bay assembly area provides facilities for assembly of an increased number of space systems.

RCA®

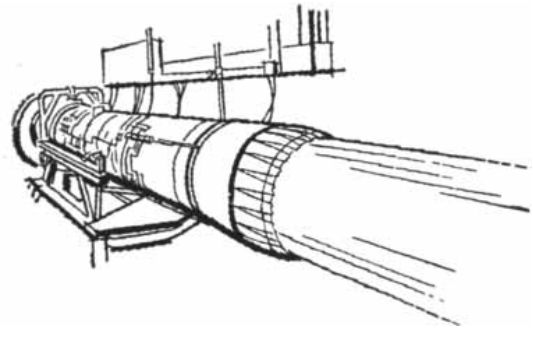
The Most Trusted Name in Space

RADIO CORPORATION OF AMERICA

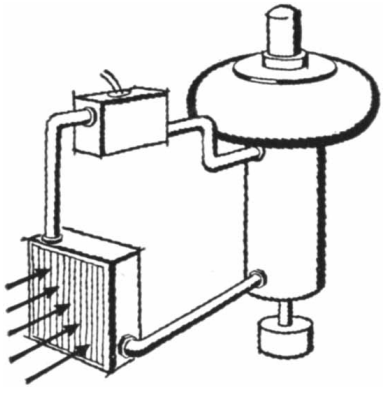
SILICONES

GOING INTO HUNDREDS OF PRODUCTS
WHICH NEED THE THERMAL STABILITY,
LONG LIFE, CONSTANT VISCOSITY
AND COMPRESSIBILITY OF

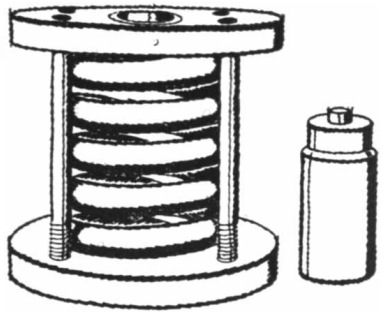
General Electric Silicone Fluids



Extreme temperature lubricants For high temperature lube applications, General Electric silicone lubricating fluid Versilube F-50 gives unmatched thermal and oxidative stability over the temperature range of —100°F to 600°F. Its lubricity is unequalled at temperatures as high as 600°F, and comparable to other fluids in the moderate ranges. Excellent hydrolytic stability. Not corrosive to common metals.



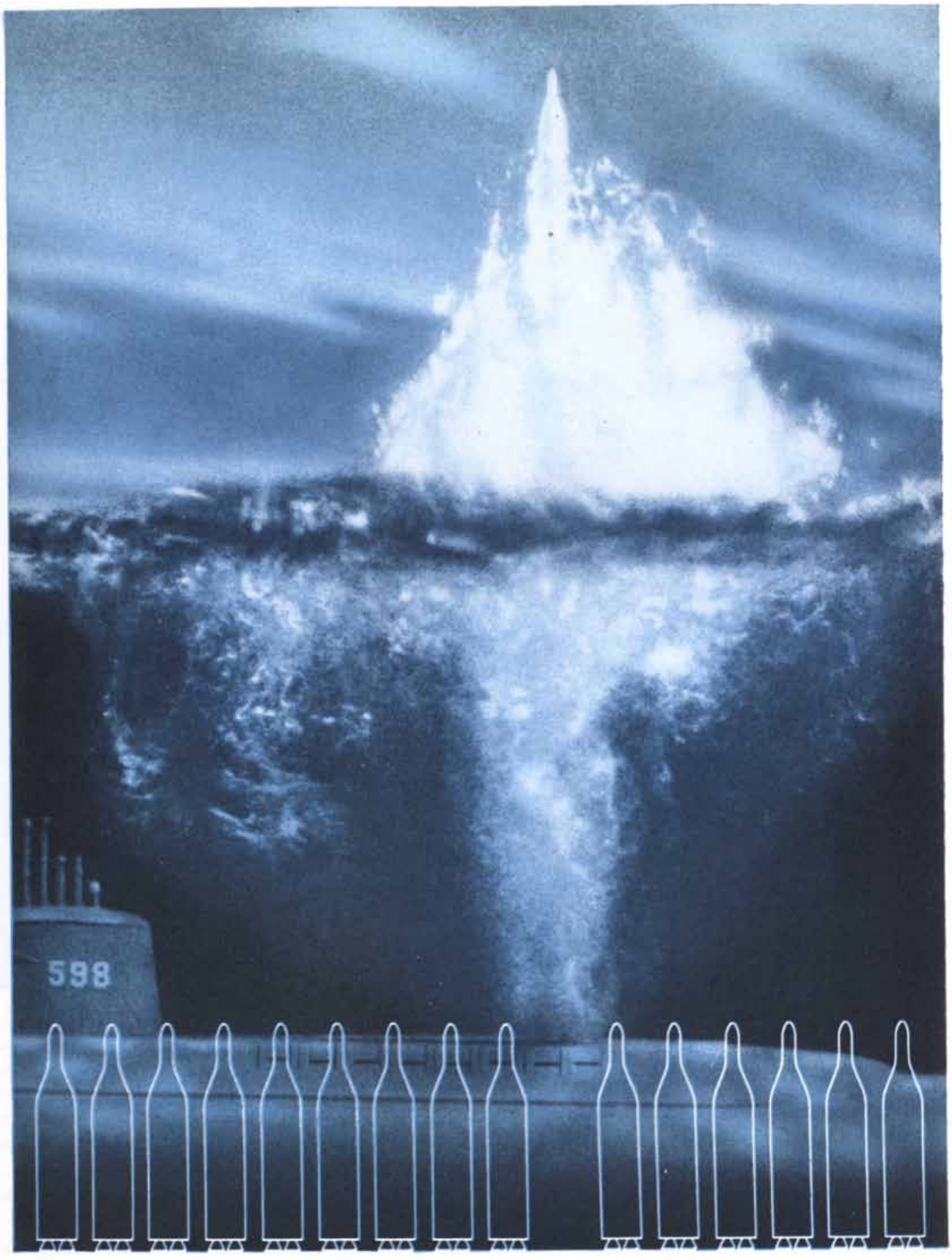
Dielectric coolants The extreme long life and thermal stability of G-E silicone fluids make them ideal as heat transfer media. Fluids of the SF-97 series can be pumped over a wide temperature range and will last indefinitely at 300°F in the presence of air, and more than 500 hours at 570°F in the absence of air. Further benefits include low volatility, chemical inertness, resistance to oxidation, and high dielectric strength.



Compressible fluids This liquid spring, which utilizes the compressibility of G-E silicone fluids, can do the same work as a conventional spring five times as heavy. All G-E silicone fluids have relatively constant viscosity over wide temperature ranges, and high-temperature stability. Viscosities range from 5 to 100,000 centistokes at 25°C. Ideal for hydraulic fluids, fluid drives, dashpots, and dampers.

The benefits of General Electric silicone fluids find uses in hundreds of products, from jet engines to suntan lotions. To learn more about these versatile, problem-solving fluids, write: General Electric Company, Silicone Products Dept., Section U647, Waterford, New York.

GENERAL ELECTRIC

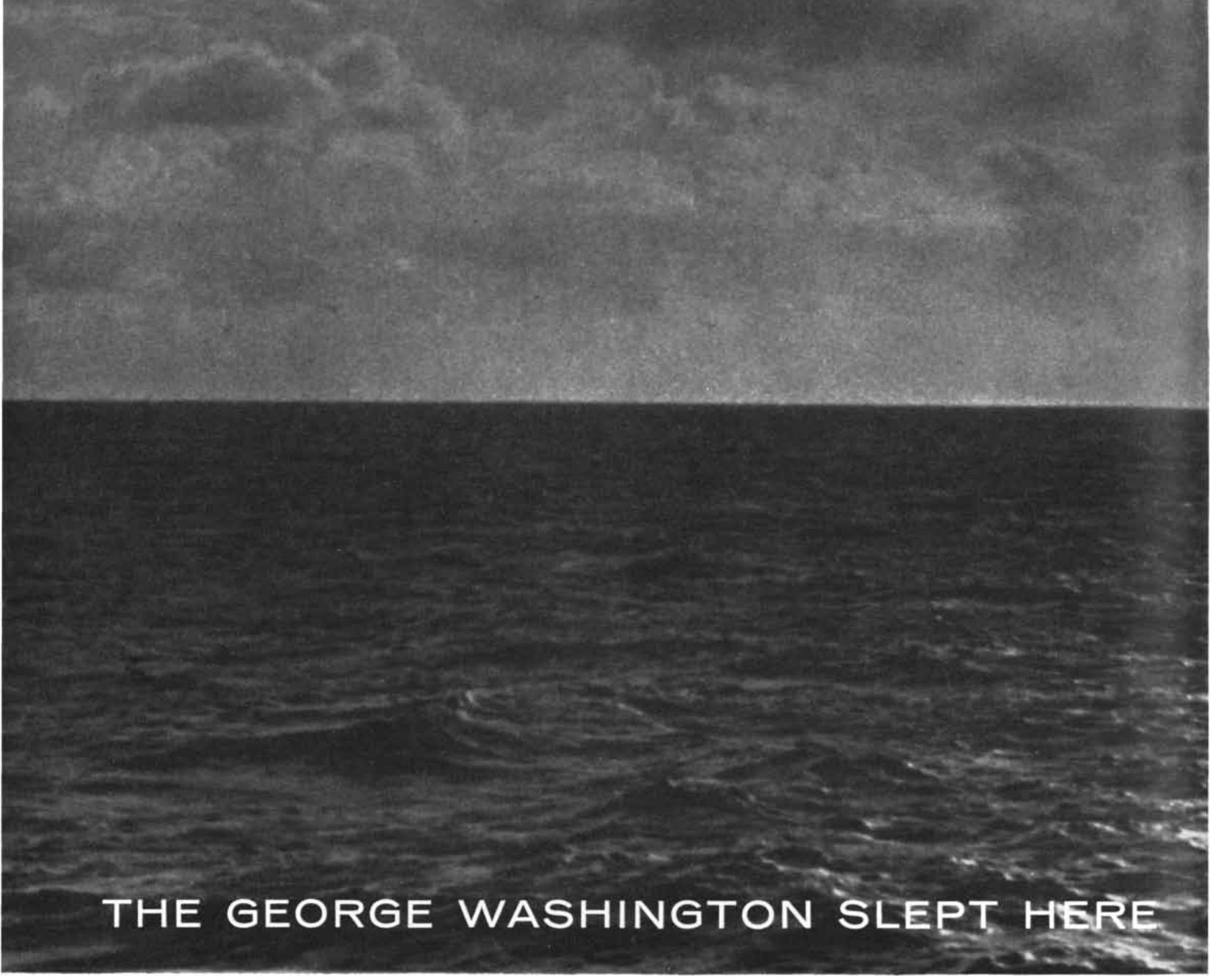


Priming the Polaris missile. Now on duty, or shortly to be, are the nuclear submarines George Washington, Patrick Henry, Robert E. Lee, Theodore Roosevelt, and Abraham Lincoln. Their mission: deterrence. Aboard each sub, giving muscle to the mission, will be sixteen Polaris missiles. These missiles are armed and fuzed by Avco's Electronics and Ordnance Division, working as a team with the Naval Ordnance Laboratory.

UNUSUAL CAREER OPPORTUNITIES FOR QUALIFIED SCIENTISTS AND ENGINEERS...REGARDLESS OF RACE, CREED, COLOR, OR NATIONAL ORIGIN...WRITE AVCO TODAY.

Avco

AVCO CORPORATION, 750 THIRD AVENUE, NEW YORK 17, NEW YORK



THE GEORGE WASHINGTON SLEPT HERE

BUT NOT FOR LONG. Somewhere off the Atlantic coast the big nuclear-powered *George Washington* catnapped between vibration tests made during submarine launchings of the first two Polaris missiles.

The firings were made part of "first-of-a-class" tests conducted by the Navy's David Taylor Model Basin during a 2-month period last summer. Vibration characteristics of the sub's hull, fairwater, missile and propulsion systems were recorded.

Mounted in the torpedo room of the *George Washington* were two oscillographs and a 14-channel magnetic tape recorder for recording the output from 38 velocity transducers—all products of Consolidated Electrodynamics Corporation. Output of the transducers, recorded on the tape recorder and oscillographs, was electrically integrated to produce signals proportional to displacement.

CAPABLE... RUGGED—The Electric Boat Division of General Dynamics Corporation built the *George Washington.* Electric Boat was responsible for the design and construction phase, and tested the sub at dockside and at sea in builder's trials that included tests of the torpedo system, missile firing, maneuvering and vibration characteristics, and the electrical and hydraulic systems.

At Electric Boat, CEC equipment has proved its capability—and ruggedness—in the highly important area of design measurement. The two oscillographs with DATARITE Magazines have been moved in and out of a sub as many as 25 times to help solve problems of malfunctioning systems. They've operated at 25 to 30-degree pitch and roll angles at sea and at 70-degree angles in the laboratory.

THE SEARCH FOR A TRUE SUBMARINE—CEC's role in the development of submarines as a stronger arm in the nation's defense began with the habitability cruise of the *Nautilus,* the first U.S. nuclear-powered sub. On board was a "specialist" in atmospheric hydrocarbons: a CEC mass spectrometer. It had been modified for use by the U.S. Naval Research Laboratory on the *Nautilus* to detect and measure contaminants that affect the underwater capability of submarines—contaminants from paints, floor wax, and cleaning solvents, from the breakdown of fuel oils and lubricants, even from cooking.

The mass spectrometer was converted by CEC at the Naval Research Laboratory for continuous analysis of gaseous and liquid samples in a mass range broadened to include masses from 2 to 150.

The instrument faced measurement problems never encountered in a labora-

tory: the roll of the ship, ambient temperatures as low as 50°F., humidities ranging as high as 80 to 90%. Even routine tests became tedious, but the mass spectrometer continued to collect and analyze gas vapor trace contaminants—contaminants that might make the atmosphere aboard nuclear subs unwholesome for crew members to live and work in during long periods of submergence.

HISTORY IN HEADLINES—When the habitability cruise ended, the Navy had many facts it needed and immediately launched a similar program for each of its nuclear subs. The use of cleaning solvents was rigidly controlled. Later, all painting was terminated several weeks before a long submergence period. Finally, all materials containing undesirable contaminants that could not be eliminated aboard ship were simply left ashore.

What has happened since in the Navy's search for a true submarine is headline history. In the fall of 1957, the *Nautilus* was submerged for 5½ days under the Arctic ice pack. In the months that followed, her sister subs set 16-day and 30-day endurance records . . . then a 2-month record . . . then a circumnavigation of the world that lasted 84 days and 41,519 miles.

CEC's applications of mass spectrometry and data recording to underseas problems are perhaps unprecedented. Mass spectrometry and data recording continue to have countless applications in other vital military and defense programs, in research laboratories and throughout industry. There are endless uses for CEC mass spectrometers, oscillographs, tape recorders and transducers. The widespread use of these instruments tells only part of the company's product story.

As one of the world's principal suppliers of precision electronic instrumentation, Consolidated Electrodynamics continues to develop the techniques and electronic tools that give man the ability to measure, and in part control, the dynamic and expanding boundaries of his physical environment.

Since 1937, through research and advances in technology, CEC has helped speed U.S. development of aircraft, missiles, nuclear reactors, and automatic petrochemical plants. With the dawn of an era of automation, CEC's capabilities in instrumentation are available to all men of science and industry. It is an era in which man will be limited only by his imagination.

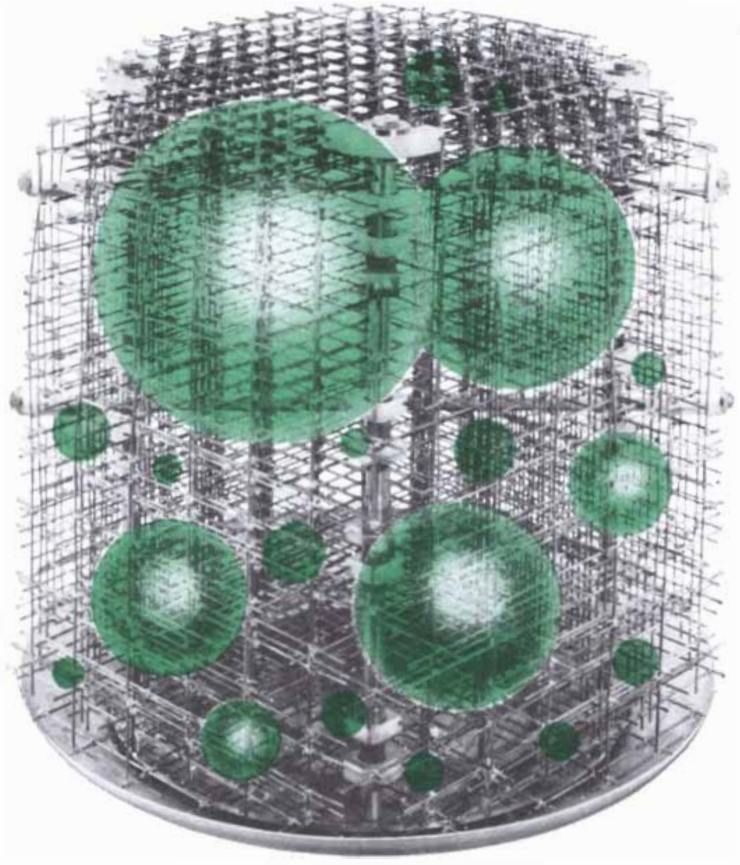
CEC

CONSOLIDATED ELECTRODYNAMICS / pasadena, california

DATA RECORDERS DIVISION • DATALAB DIVISION • TRANSDUCER DIVISION • ANALYTICAL & CONTROL DIVISION • CONSOLIDATED SYSTEMS CORP. • CONSOLIDATED VACUUM CORP.

A SUBSIDIARY OF **Bell & Howell** • *FINER PRODUCTS THROUGH IMAGINATION*

Another measure of the competence of Liquidometer in advanced instrumentation



FLUID, FOAM, OR FLOATING GLOBULES . . .

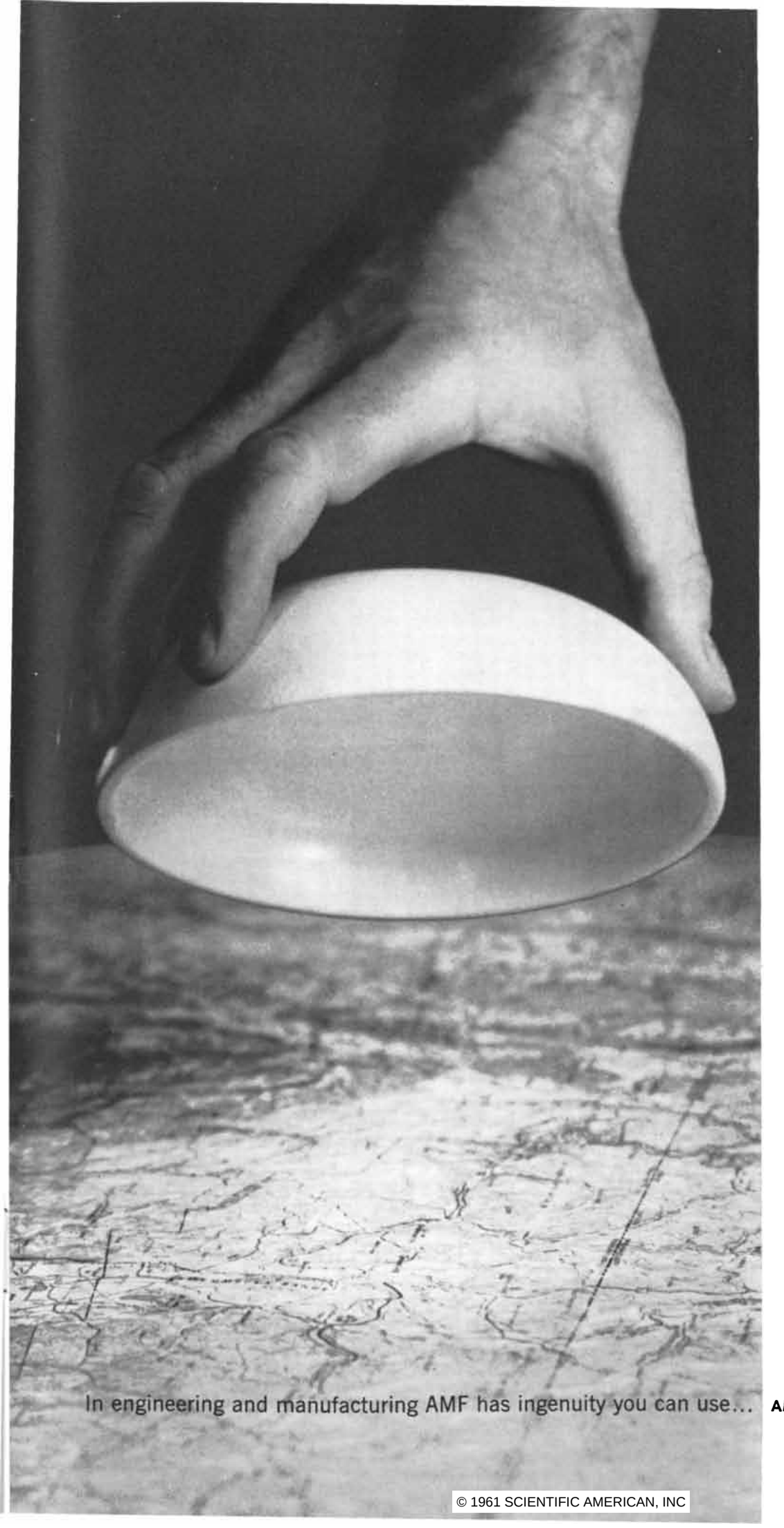
whatever a liquid's state or attitude, whether still or in agitation, the volume indication is the same with the Liquidometer Matrix Liquid Quantity Gauge. A capacitor type measuring probe — intercellular in construction — is the heart of the system. In addition to actuating an indicator, output can be telemetered, used for control purposes, or fed into computers. Potential applications: measuring liquid oxygen for astronauts; gauging liquids in advanced rocket propulsion systems; all-attitude gauging of aircraft fuels. Technical details in Booklet 694.

In the design and production of advanced instrumentation — electronic and electromechanical — Liquidometer offers many widely demonstrated capabilities, plus the talent and the willingness to pioneer. We welcome the opportunity to apply these qualifications, and our 40 years of experience, to your instrumentation requirements. Write for our capabilities brochure.

THE LIQUIDOMETER CORP.

DEPT. W3, LONG ISLAND CITY 1, NEW YORK

Since 1920 LIQUIDOMETER INSTRUMENTS --of proven quality



He built the strongest roof in the world

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

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

Single Command Concept

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

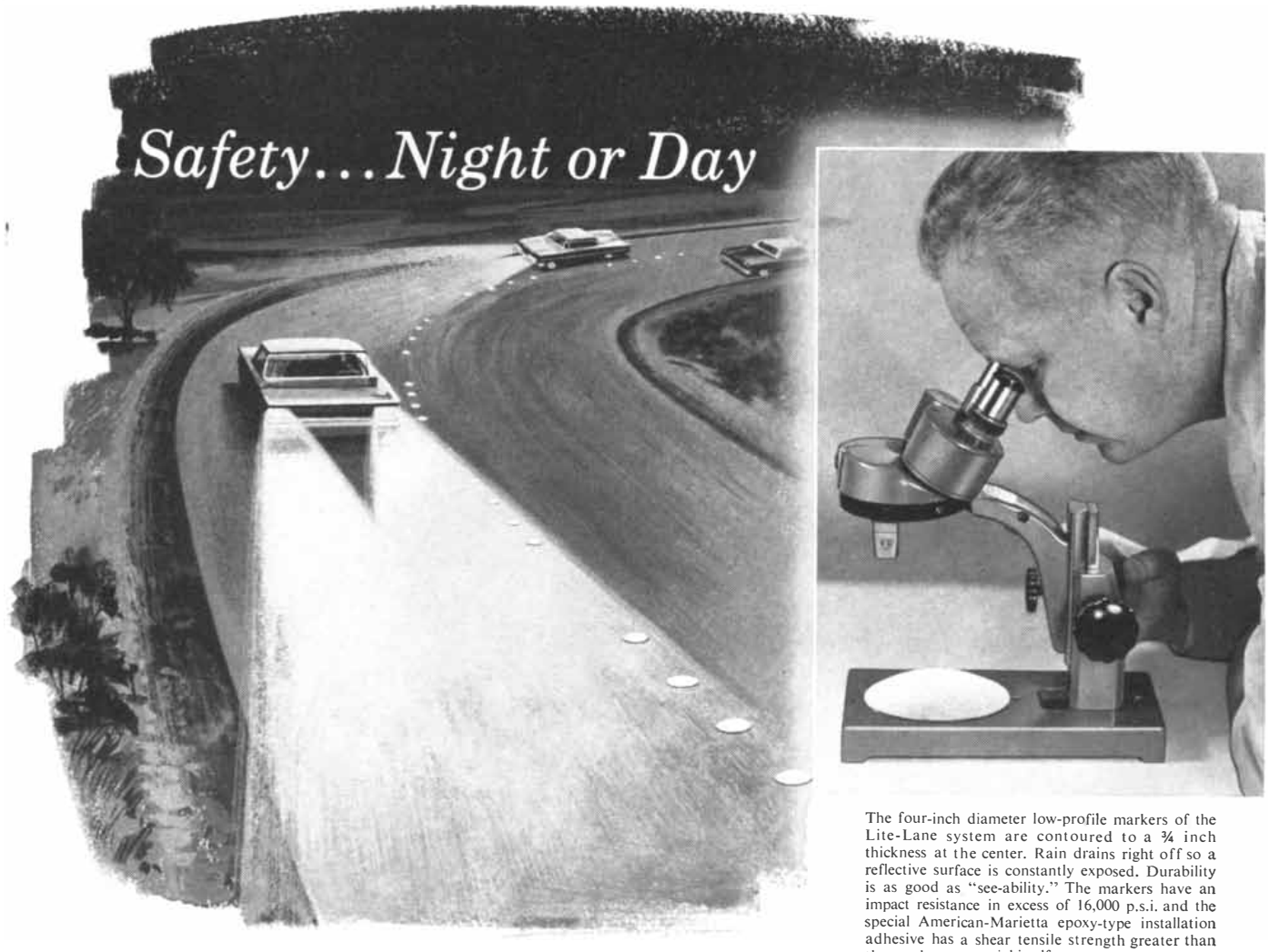
AMF people are organized in a *single operational unit* offering a wide range of engineering and production capabilities. Its purpose: to accept assignments at any stage from concept through development, production, and service training... and to complete them faster...in

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

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

AMF

AMERICAN MACHINE & FOUNDRY COMPANY



The four-inch diameter low-profile markers of the Lite-Lane system are contoured to a ¾ inch thickness at the center. Rain drains right off so a reflective surface is constantly exposed. Durability is as good as "see-ability." The markers have an impact resistance in excess of 16,000 p.s.i. and the special American-Marietta epoxy-type installation adhesive has a shear tensile strength greater than the roadway material itself.

AMERICAN-MARIETTA

Lite-Lane Traffic Guide System

Saving lives and saving costs is the dual role of the new American-Marietta Lite-Lane Traffic Guide System.

Far better than reflective painted lines, which virtually vanish from sight when wet, Lite-Lane contoured safety markers brilliantly identify traffic lanes in either the dark mugginess of fog or rain at night or the brilliant sunlight of a clear day. By alternating markers—beaded ones for night and ultra white glazed ones for day—the system is effective under a wide range of conditions.

Product of American-Marietta's resin research center, Lite-Lane markers have a normal life expectancy of from five to twenty years and can be bonded to the pavement in just minutes with a minimum of traffic interruption. Special application equipment, devised by American-Marietta engineers, provides economical and uniform installation.

First night-day marker system, American-Marietta's new Lite-Lane provides extra driving safety for motorists.

PAINTS • CHEMICAL COATINGS • SYNTHETIC RESINS
ADHESIVES • SEALANTS • METALLURGICAL PRODUCTS
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REFRACTORIES • CONSTRUCTION MATERIALS • CEMENT

Progress through Research

A-M

American-Marietta Company
Chicago 11, Illinois

New Powers of Decision for Men in Command

For military commanders and governmental leaders this is a new era of decision and control. Many of their decisions and actions must be made with great speed as events occur. They must be based on huge amounts of information. And they affect world-wide and continental forces. To help command groups exercise their powers of decision and control, a new technology has been developed—large-scale systems that involve automated information processing assistance. ■ Acting in the public interest, we have made major contributions to a number of these systems. SAGE was the first. The SAC Control System is in development. And we are beginning work on two other extremely large systems. Our main efforts are in analysis and synthesis of these systems, training men for their use, instructing great computers on which the systems are based—and research into future generations of these systems. ■ In developing these systems we follow a close interdisciplinary approach. Operations Research, Engineering, Computer Programming and Human Factors are the essential disciplines. Our expanding programs have created a number of new positions at our facilities in Santa Monica, Calif., Lexington, Mass., Washington, D.C., and Paramus, N.J. Inquiries are invited from those who wish to contribute to this new technology. ■ All qualified applicants will receive consideration for employment without regard to race, creed, color or national origin. ■ Address Mr. Robert L. Obrey, SDC, 2430 Colorado Ave., Santa Monica, Calif.

SYSTEM DEVELOPMENT CORPORATION

SDC

All components of Vickers auxiliary power units are subjected to thorough inspection by skilled technicians following evaluation tests. New size of standard element is shown being inspected following 40,000 rpm cycle test.

A. Battery motorpump developed for each stage of the Air Force Minuteman ICBM.

B. Integrated motorpump for Navy Polaris IRBM.

C. Integrated A.C. motor-hydraulic power supply for the B-52 inter-continental bomber turret drive.

Final testing, evaluation and assembly is performed in a special, surgically clean room. Thus, once parts are super-cleaned, no additional contamination is introduced.

CAPABILITY
is spelled
a-u-x-i-l-i-a-r-y
p-o-w-e-r

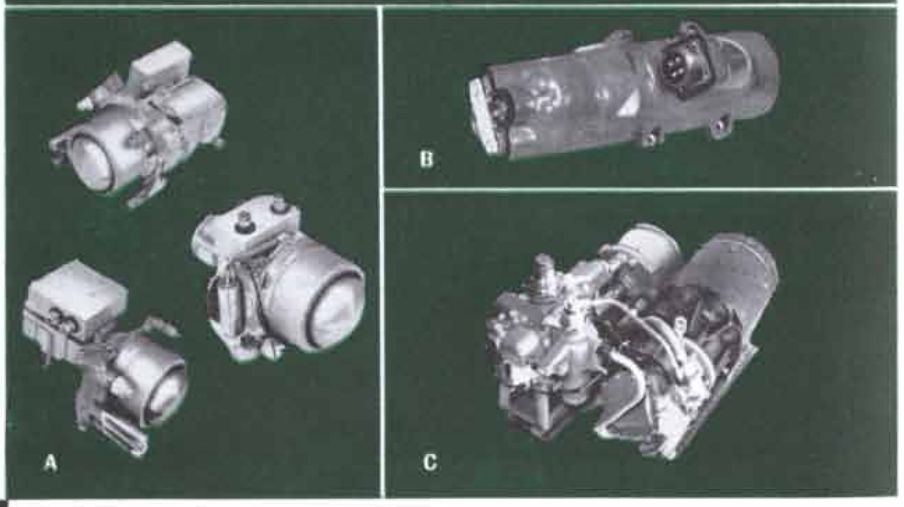
In technology and facility, Vickers continually matches your need

Experience gained on every type of military aircraft and commercial airliner plus numerous missile applications assures top performance from every Vickers auxiliary power package. Either complete and separate power generating systems or motorpumps can be provided depending on specific application requirements.

Precise performance evaluation—particularly on motorpumps—can often be provided even before the final package is developed from proved standard elements by building up prototype units and subjecting them to feasibility and performance tests. From these prototypes come the ultimate custom designed packages providing a high order of reliability and requiring minimum input power—all in a compact, lightweight envelope.

Additional data is available in two new Vickers bulletins: A-5239 "Power Systems" and A-5258 "Motorpumps". Write for your copies to either address listed below.

TYPICAL AUXILIARY POWER PACKAGES DEVELOPED BY VICKERS:



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AERO HYDRAULICS DIVISION
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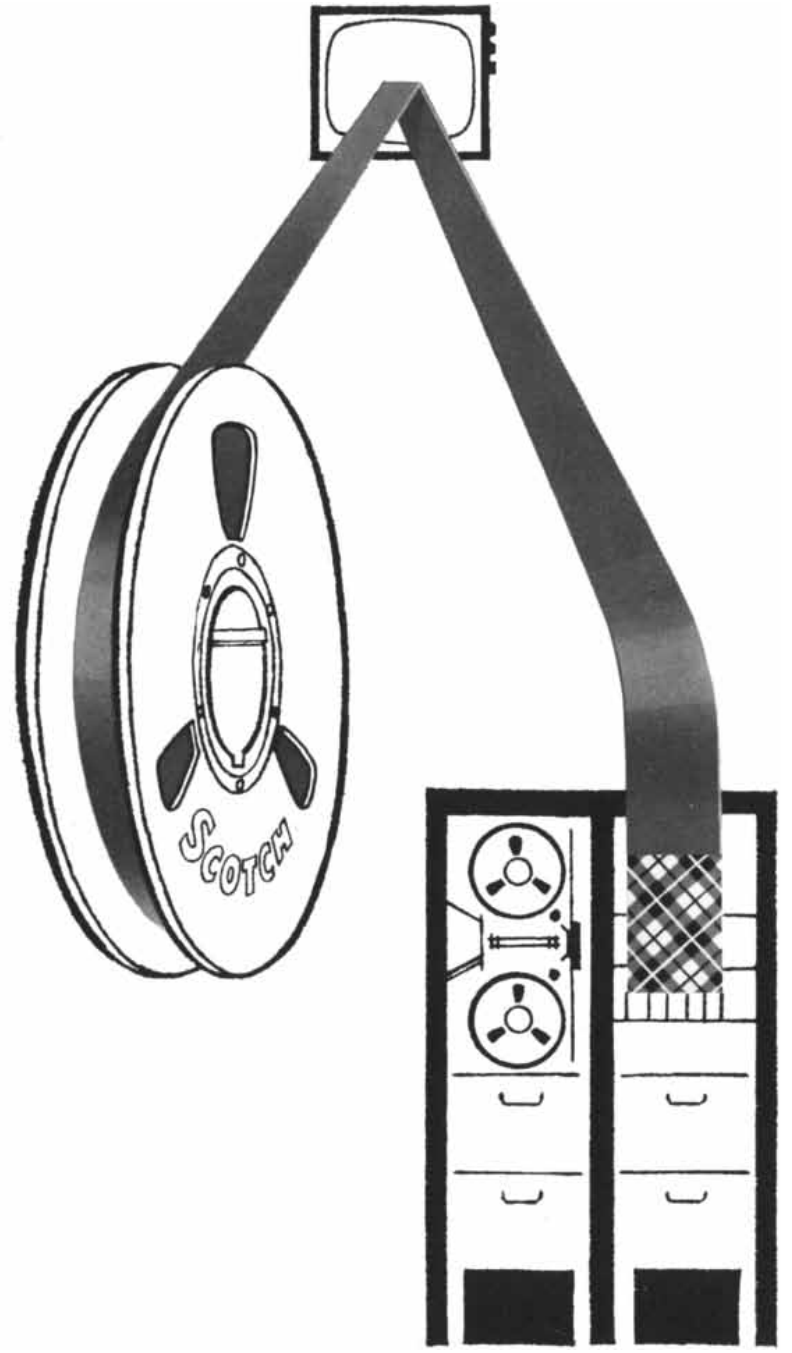
POWER TRANSMISSION
ENERGY CONVERSION
FLUID TRANSFER

THE TAPE THAT CHANGED TV FOR ALL TIME

leads you right to rugged
SCOTCH® BRAND Heavy Duty Tape



THE TIE that binds television's top performer to instrumentation tape is strong—and it goes beyond the fact that the same expert team produces the best of both. "SCOTCH" BRAND Heavy Duty Tapes share a common heritage—and uncommon endurance—with "SCOTCH" BRAND Video Tape, the tape that puts a network TV show on the same "clock time" from Maine to California.

Similarities worth noting between the two: a similar high-temperature binder system, famous "SCOTCH" BRAND high potency oxides, a similar ability to resist tremendous speeds, pressures and temperatures while providing high resolution.

Let's look at the record of "SCOTCH" BRAND Video Tape and see what message it has for the user of instrumentation tape. On a standard reel of video tape like that shown here, some 1½ million pulses per second must be packed to the square inch—on a total surface area equal to the size of a tennis court. The tape must provide this kind of resolution while defeating the deteriorating effects of high speeds, pressure as high as 10,000 psi and temperatures up to 250°F.

The fact is that video tape must be essentially perfect. And it's a matter of record that thus far only the 3M experts have mastered the art of making commercial quantities of video tape that consistently meet the demands of the application.

Significantly, the high-temperature binder system developed for "SCOTCH" Video Tape is first cousin, only slightly removed, to that used in the Heavy Duty Tapes. It's this special feature that has given Heavy Duty Tapes their exceptional wear life.

The moral emerges: for tape that provides the best resolution of high and low frequencies under the severest conditions, turn to "SCOTCH" BRAND Heavy Duty Tapes 198 and 199.

They offer the high temperature binder system, plus the same high quality and uniformity that distinguish all "SCOTCH" BRAND Tapes. As the most experienced tape-makers in the field, 3M research and manufacturing experts offer tape of highest uniformity—from reel to reel and within the reel. Check into the other "SCOTCH" BRAND constructions: High Resolution Tapes 158, 159 and 201; High Output Tape 128; Sandwich Tapes 188 and 189; and Standard Tapes 108 and 109.

Your 3M Representative is close at hand in all major cities. For more information, consult him or write Magnetic Products Division, 3M Co., St. Paul 6, Minnesota.

REG U.S. PAT. OFF.
SCOTCH BRAND MAGNETIC TAPE
FOR INSTRUMENTATION

MINNESOTA MINING AND MANUFACTURING COMPANY
...WHERE RESEARCH IS THE KEY TO TOMORROW
3M COMPANY

LETTERS

Sirs:

R. S. Scorer's article "Lee Waves in the Atmosphere" [SCIENTIFIC AMERICAN, March] explains the remarkable "Washoe Zephyr" described by Mark Twain in *Roughing It*. The rotor that forms in the lee of the Sierra Nevada answers exactly to Twain's description, with only a slight allowance for exaggeration.

It is Twain's first day in Carson City, the capital of Nevada Territory: "This was all we saw that day, for it was two o'clock, now, and according to custom the daily 'Washoe Zephyr' set in; a soaring dust-drift about the size of the United States set up edgewise came with it, and the capital of Nevada Territory disappeared from view. Still there were sights to be seen which were not wholly uninteresting to new comers; for the vast dust-cloud was thickly freckled with things strange to the upper air—things living and dead, that flitted hither and thither, going and coming, appearing and disappearing among the rolling billows of dust—hats, chickens and parasols sailing in the remote heavens; blankets, tin signs, sage-brush and shingles a shade lower; door mats and buffalo-robes lower still; shovels and coal scuttles on the next grade; glass doors, cats and little children on the next; disrupted lumber yards, light buggies and wheelbarrows on the next; and down only thirty or forty feet above ground was a scurrying storm of emigrating roofs and vacant lots....

"But seriously a Washoe wind is by no means a trifling matter. It blows flimsy houses down, lifts shingle roofs occasionally, rolls up tin ones like sheet music, now and then blows a stage coach over and spills the passengers.... The 'Washoe Zephyr' (Washoe is a pet nickname for Nevada) is a peculiarly Scriptural wind, in that no man knoweth 'whence it cometh.' That is to say, where it originates. It comes right over the mountains from the West, but when one crosses the ridge he does not find any of it on the other side! *It probably is manufactured on the mountain-top for the occasion, and starts from there.* It is a pretty regular wind, in the summer time. Its office hours are from two in the afternoon till two the next morning." (Italics mine.)

ROBERT B. DEAN

The Borden Chemical Company
Bainbridge, N.Y.

Sirs:

About your note on viewing the "Titchener illusion" stereoscopically ["Science and the Citizen"; SCIENTIFIC AMERICAN, April].

These are the Ebbinghaus circles. Of course younger psychologists go to E. B. Titchener (*Experimental Psychology*, Vol. 1, Part 1, page 169; 1901) to find reproductions of this and 92 other geometrical illusions, but Titchener was copying these circles from E. C. Sanford (*Course in Experimental Psychology*, 1898), who attributes them to the great Hermann Ebbinghaus. Already, since your note came out, I have had an important psychologist ask me about "the Titchener illusion." Too bad to get that error established....

The discovery by Sonoko Ohwaki described in your note is not new. Nearly 40 years ago E. Lau in Germany (*Psychologische Forschung*, Vol. 2, pages 1–2; 1922. Vol. 6, pages 121–126; 1924) reported that separate binocular presentation of the principal stimulus and the inducing stimulus to the two eyes in a stereoscope either simply destroyed the illusion or else changed it into a three-dimensional figure, in which the apparent size of the principal stimulus was not altered any more than the perceived size of an object is when its distance from the observer is altered. Usually changed distance does not affect the apparent size of an object (or else

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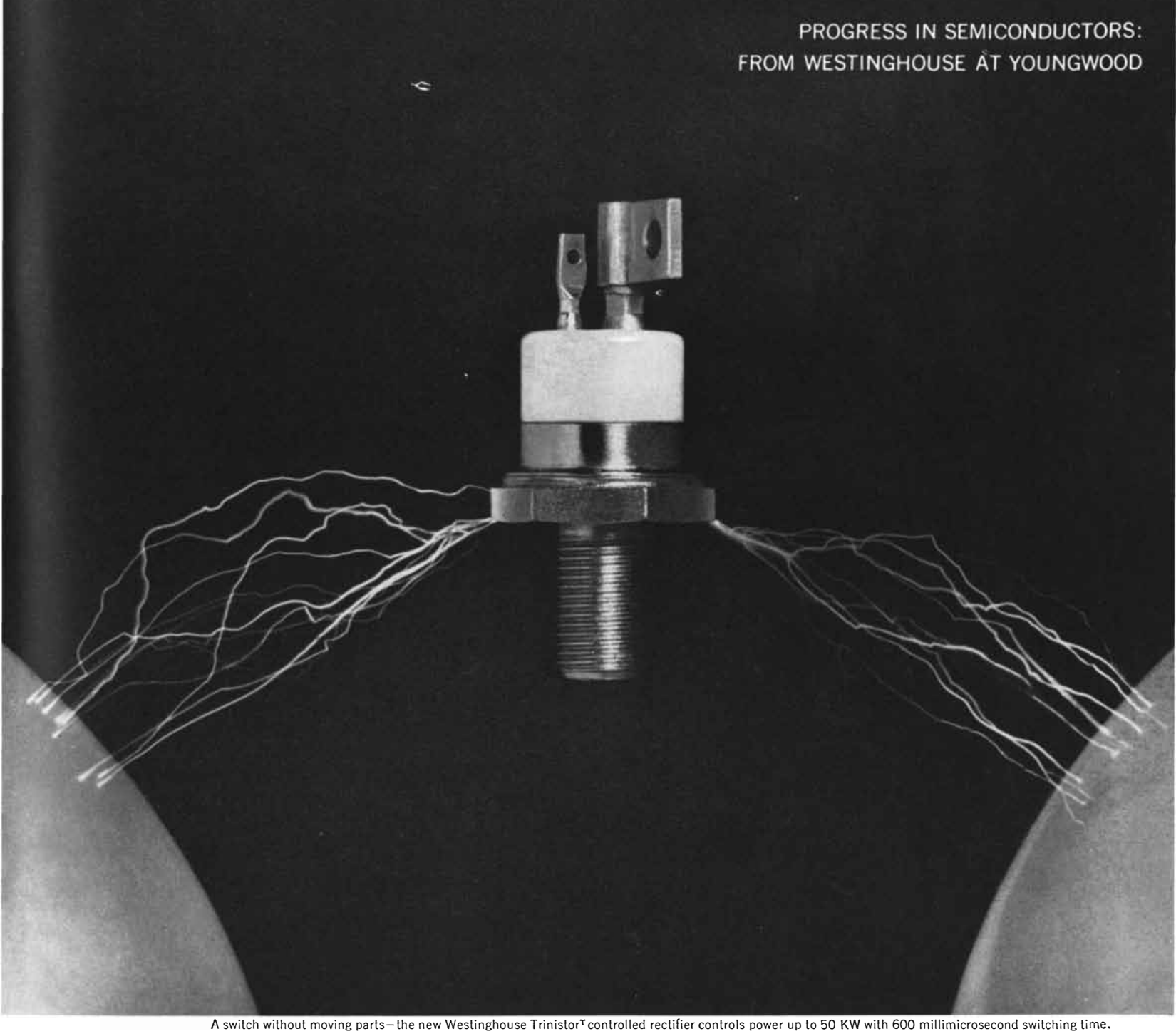


A switch without moving parts—the new Westinghouse Trinistor™ controlled rectifier controls power up to 50 KW with 600 millimicrosecond switching time.

Westinghouse pioneers advances in high-power semiconductor devices

The intrinsic advantages of semiconductors, such as long service life, high efficiency, space and weight savings, have revolutionized the design of low-power control and communications equipment. Now, Westinghouse high-power semiconductor devices are making an equally profound impact on industrial apparatus.

With its unique research and design facilities, Westinghouse has led the way in the development of high power semiconductors made of silicon. This material, because of its ability to withstand higher operating temperatures, has proved to be the key to high power applications.

Today the Westinghouse product line includes silicon rectifiers with rated currents to 240 amperes, voltages to 1000 volts; silicon transistors with a gain of 1000 at currents over 2 amperes; high-power silicon transistors rated at 30 amperes, up to 200 volts; Trinistor controlled rectifiers which handle currents up to 100 amperes, voltages to 400 volts. The new Trinistor controlled rectifier units are of special interest since they make feasible the large scale generation of high frequency power. Assemblies of these devices utilize series and parallel connections for still higher-power handling capabilities.

All of these high power devices are widely used in military and industrial applications formerly served by vacuum tube rectifiers, magnetic and rotating amplifiers, saturable reactors and thyratrons. They offer high efficiency, require less space and weight, and frequently result in lower initial equipment costs. Their reliability is a most important advantage.

Westinghouse high power semiconductors may provide the answers to some of your problems. For complete information please call or write: **Westinghouse Electric Corp., Semiconductor Dept., Youngwood, Penna.** SC-1038

You can be sure...if it's Westinghouse

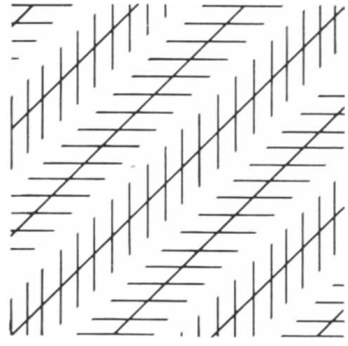
affects it much less than the size of its image on the retina changes). That fact itself shows that the brain plays an important role in the perception of size, a role that cannot be carried by the retina.

In general the Lau-Ohwaki experiment seems to me to show the opposite of what Miss Ohwaki is reported as believing. Again and again the brain contrives to circumvent illusion, as it does when it perceives a receding object as remaining constant in size, while its retinal image is shrinking rapidly. Or else the brain avoids illusion, as in the case of the Ebbinghaus circles, when the images of the principal stimulus and the inducing stimulus are not tied together in projection by being delivered to the brain in a single pattern but are forwarded separately by the two eyes. The brain may then reject the invitation to combine the two, so that the illusion fails. Often it resolves the conflict by creating a figure in depth that avoids the illusion by placing the object that is made smaller by induction at a greater distance away in the perceptual pattern.

On this latter point, look at the Zöllner figure [*below*]. Usually the eye delivers this flat pattern to the brain, and you see the truly parallel diagonals converging and diverging. It is possible (with one eye or without a stereoscope) to see this figure in depth. The horizontal crosslines then appear to be lying down like railroad ties. The vertical crosslines appear to be standing up like fence pickets. The illusion of convergence disappears as the figure goes into depth, and presenting the parallel diagonals to one eye in a stereoscope and the crosslines to the other eye assures this figure's looking tridimensional. In other words, the brain has many devices for rejecting contradiction and making sense out of nonsense.

EDWIN G. BORING

Harvard University
Cambridge, Mass.



The Zöllner figure

READY

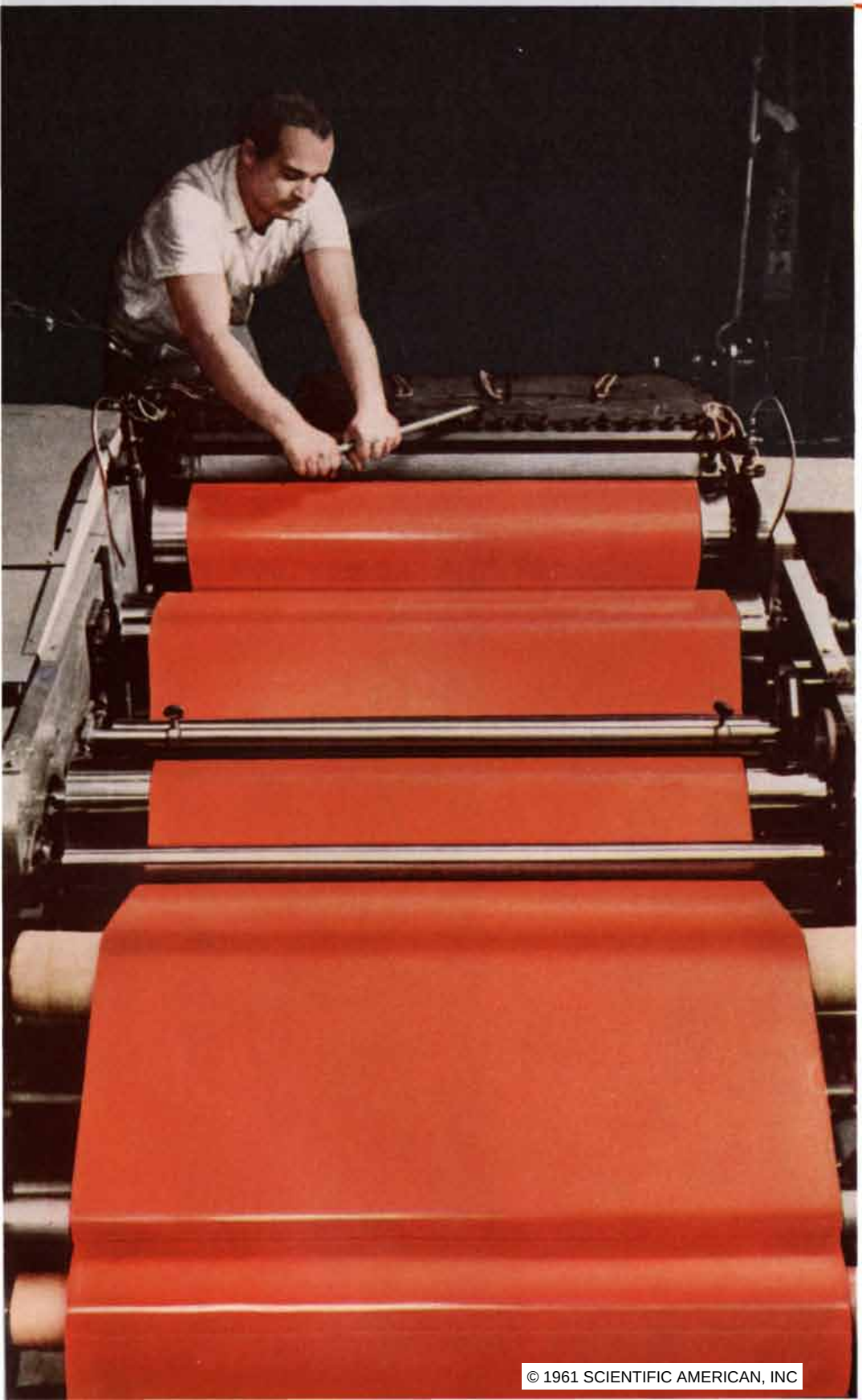
...to help you plan new products
...to help you improve existing products
...to help you cut manufacturing costs

Since February, 1961, Tenite Polypropylene has been in commercial production at Eastman's new plant in Longview, Texas. This is the newest member of the Eastman family of thermoplastics, all bearing the trade name "Tenite."

In Tenite Polypropylene, industry has a versatile new plastic that will replace conventional materials in many traditional applications . . . a plastic that will improve the performance of hundreds of existing products . . . a plastic that could markedly reduce material, fabricating and assembly costs.

And it's a material that's now available in carload quantities.

Tenite Polypropylene offers a broad range of useful properties



High Strength — Tenite Polypropylene has good tensile and impact strength, plus rigidity and surface hardness.

Light Weight — Tenite Polypropylene is the lightest of all solid plastics. This plastic produces more molded or extruded product per pound than most other plastics.

Heat Resistance — The high melting point of Tenite Polypropylene permits objects made from this plastic to be sterilized without suffering distortion. This feature makes it well-suited for hospital and laboratory ware.

Chemical Resistance — Tenite Polypropylene resists the attack of acids and alkalies and a broad range of other chemicals.

Fatigue Resistance — Because it can take innumerable flexings, Tenite Polypropylene can be designed as one-piece moldings with integral hinges.

Resistance to Moisture Vapor Transmission — Tenite Polypropylene is an effective barrier to moisture vapor transmission. In film for packaging, this feature is a vital factor in prolonging the freshness of many foods.

Red polypropylene sheet rolls off an extruding machine in Eastman's plastics development laboratory. For two full years before launching polypropylene production on a full-scale commercial basis, Eastman engaged in exhaustive research and study of the characteristics and properties of polypropylene, thoroughly pretesting the material in actual molding and extrusion operations and developing a number of formulations for use in plastics fabrication.

Tenite Polypropylene can be used in all these ways

Dielectric Strength — Tenite Polypropylene has excellent dielectric properties and retains these properties even under adverse moisture and temperature conditions.

Abrasion Resistance — Tenite Polypropylene has excellent abrasion resistance. Its surface hardness suggests its use as gears or bearings. Conveniently, it also has a low coefficient of friction.

Resistance to Environmental Stress Cracking — Tenite Polypropylene has excellent resistance to stress cracking. No environment has yet been discovered in which stress cracking of polypropylene occurs.

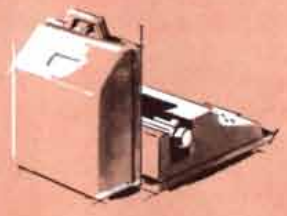
High Gloss — Articles molded of Tenite Polypropylene have a natural lustrous finish, and film extruded of Tenite Polypropylene exhibits a sparkling surface.

Heat Sealability — Tenite Polypropylene is relatively easy to "tack" or "weld." This can be accomplished in many cases with existing equipment.

Printability—With a simple treatment, film of Tenite Polypropylene can be easily printed by conventional methods.

Resistance to Mold and Mildew—Tenite Polypropylene resists the growth of mold or mildew, and is not attacked by insects or marine organisms.

Processability — Tenite Polypropylene has excellent flow properties, permitting good mold-fill in injection molding.

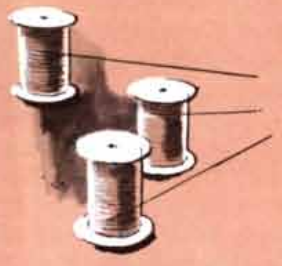


Injection Molding

Tenite Polypropylene can easily be molded into a wide variety of durable low-cost parts with high gloss and surface hardness—for example, appliance housings, automotive accessories, toys and housewares.

Extruded Film and Sheeting

Tenite Polypropylene can be extruded into sparkling clear film and sheeting, with the excellent protective characteristics so important for durable packaging. It can also be extruded in opaque, translucent, or transparent colors.



Monofilament

Tenite Polypropylene can be extruded into monofilament offering high strength, wet or dry, and excellent flexibility at low temperatures. Webbing for outdoor furniture and cordage are among the many possible end uses for this tough material.

Thermoforming

Sheet of Tenite Polypropylene can be used in vacuum forming, pressure forming and skin packaging, with existing equipment.

Wire and Cable Covering

Excellent electrical, thermal, and mechanical characteristics make Tenite Polypropylene desirable for either primary insulation or jacketing. Formulas are available for solid coatings, or for cellular coatings of extra-low dielectric constant.

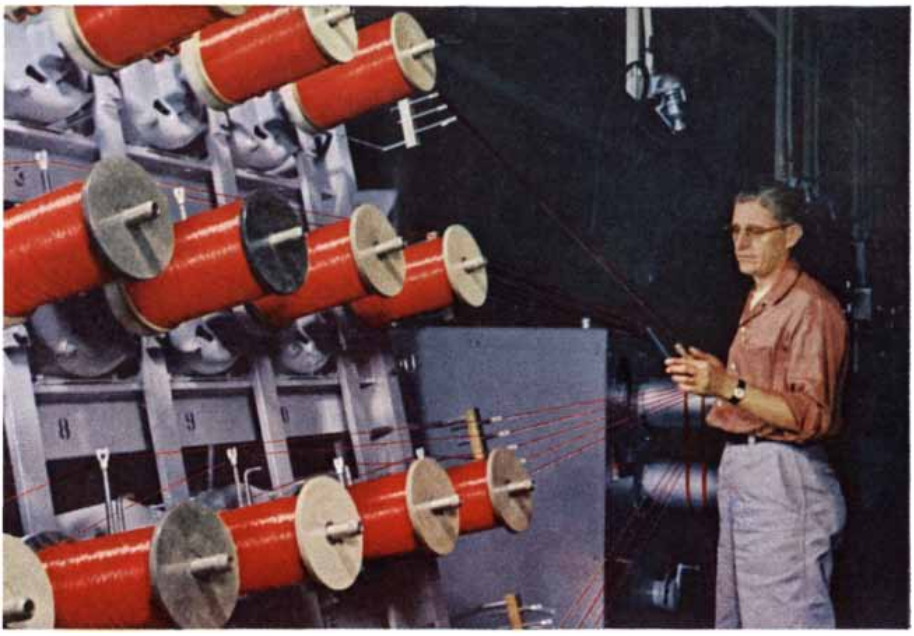
Pipe

Chemical inertness, resistance to stress cracking, and heat resistance make pipe of Tenite Polypropylene a good choice for industrial use.

Blow Molding

Tenite Polypropylene in special formulations can be blow-molded into many articles possessing exceptional wall strength, resilience, and chemical resistance.

Spools of lustrous red polypropylene filament, extruded for testing purposes in Eastman's development laboratories. Eastman's work over many years in producing plastics of almost unlimited colors has been of significant value in developing superior polypropylene formulations for monofilament extrusion.



A special word about this new polypropylene

The process for manufacturing Tenite Polypropylene was developed by Eastman scientists, engineers and production staff. This exclusive process yields a polypropylene that is superior in several characteristics to other polypropylenes. We base this statement not only on our own laboratory findings but on the opinions expressed by those users who have had the opportunity to evaluate Tenite Polypropylene from our semicommercial plant during the past year.

Since the first Tenite plastic was produced, in 1932, over 42,000 color effects have been formulated in the Tenite color laboratory. This experience, plus pre-eminence in color photography and textile dye technology, enables Eastman to offer the broadest range of colors available in the entire plastics industry. We believe that Tenite Polypropylene represents an improvement in quality and stability of color in this type of plastic. And Tenite Polypropylene color concentrates now offer molders and extruders a clean, easy way to color polypropylene. Use of these concentrates virtually eliminates color contamination and color uncertainty.

We have given you only the highlights on this promising new plastic. For further information, call a Tenite sales office or send this coupon to EASTMAN CHEMICAL PRODUCTS, INC., subsidiary of Eastman Kodak Company, KINGSPORT, TENNESSEE.

This glimpse into the color chip storage room at the Tenite Color Laboratory gives some indication of the variety of colors that has been developed by Eastman since 1932.

Measuring the optical properties of Tenite plastics is but one phase of the diverse and thorough testing done in the Tenite Quality Control Laboratory.

Eastman technical service representatives are ready to work with any customer in finding the most efficient way in which to fabricate products of Tenite Polypropylene.

EASTMAN CHEMICAL PRODUCTS, INC.
subsidiary of Eastman Kodak Company, Kingsport, Tennessee

Please send me more information on Tenite Polypropylene,

for_____
(product or purpose)

Name_____ Title_____

Company_____

Street_____

City & State_____ Tel._____

TENITE®

POLYPROPYLENE

an Eastman plastic

Other plastics made by Eastman include Tenite Polyethylene, Tenite Butyrate, Tenite Propionate, Tenite Acetate, and Tenite Polyester. Information on any of these materials is also available on request.

Bendix radar beacons enable B-58 (left), world's first supersonic bomber, to rendezvous day or night with KC-135 jet tanker. This aerial refueling makes it possible for the B-58 to reach any target in the world and return.

HOW BENDIX HELPS EXTEND B-58's GLOBAL STRIKING POWER

Radar beacons developed by our Bendix-Pacific Division are enabling the world's first supersonic bomber—the B-58 "Hustler"—to reach any target on the globe and return.

The Bendix radar beacons permit the B-58 "Hustler" to rendezvous with its jet tanker day or night . . . giving the "Hustler" a virtually unlimited range. Combined with a record-breaking speed of better than 1300 miles per hour, this added range makes the B-58 unmatched by any bomber in the world.

Developed under contracts to Convair Division of General Dynamics and Boeing, the Bendix-Pacific radar beacons are installed in the B-58 and in the KC-135 jet tanker. By receiving appropriate radar signals and transmitting a proper reply, the beacons enable the two planes to pinpoint each other's position in the outer reaches of the sky.

These coded replies provide range and bearing information to the plane commanders when displayed on the radar screens. The pilots then set their courses to the refueling rendezvous. Thus pilots can overcome the problems posed by "space myopia"—the difficulty of judging distance with the eyes at high altitudes, where there is only space on which to focus.

The operational speed and altitude of the B-58 require the use of special aids for automatic control. Providing such aid is a revolutionary Bendix control system, which literally thinks ahead of the pilot, preventing him from any maneuver that—at the B-58's fantastic speed—could instantly destroy it.

This automatic control system, developed by the Eclipse-Pioneer Division of Bendix, includes the hydraulic control system supplied by our Bendix-Pacific Division.

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

A THOUSAND DIVERSIFIED PRODUCTS SERVING THESE FIELDS:
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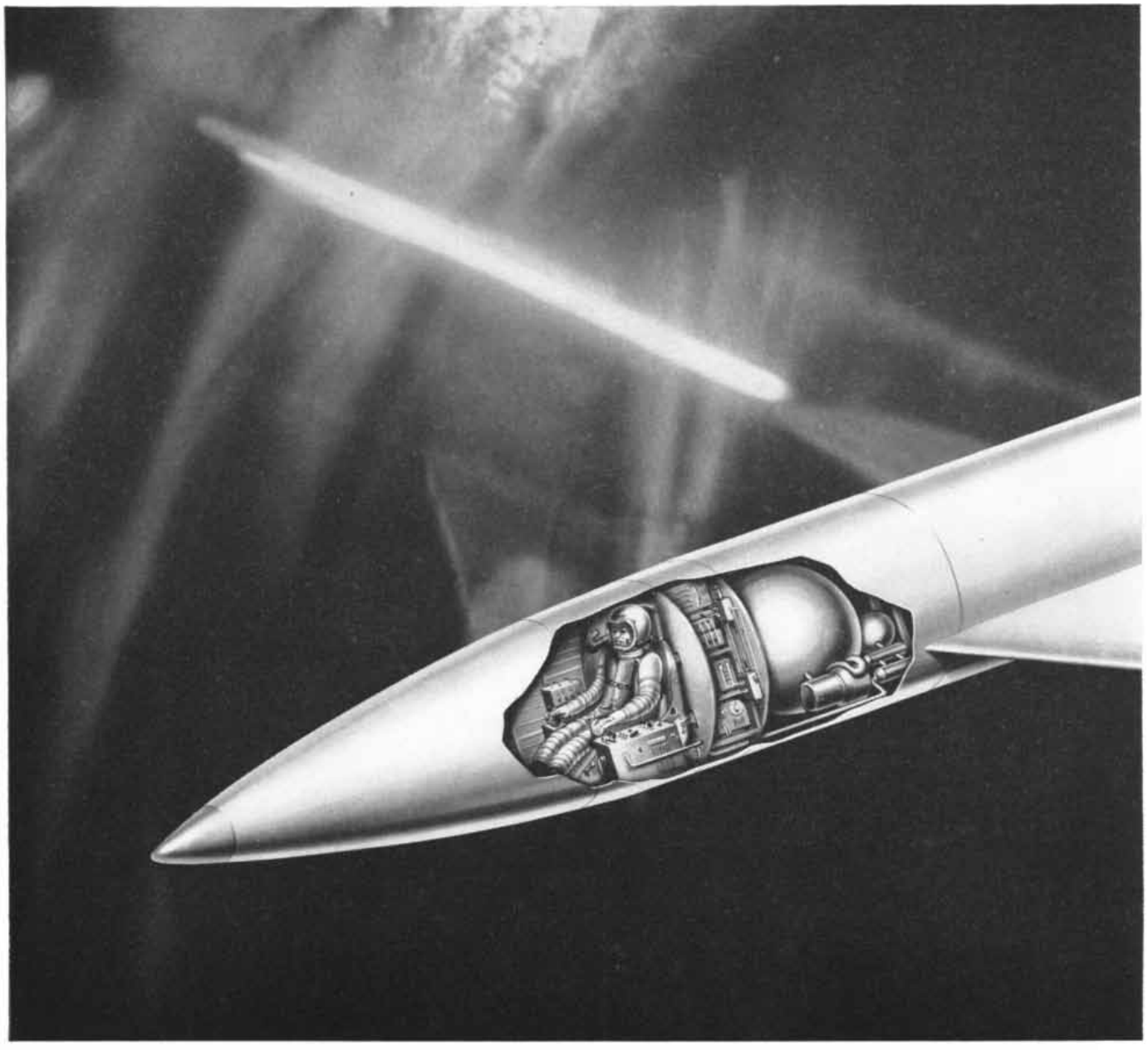
OUT OF THE LABORATORY



Forthcoming space exploration will require exotic fuels and new concepts in energy conversion to keep men alive and equipment operating for long periods of time beyond the earth's atmosphere. Advanced hydrogen systems recently developed by The Garrett Corporation have solved this problem of providing the electrical, hydraulic and pneumatic power, plus cooling and heating required aboard a satellite or space capsule during launching, outer space flight and re-entry... another contribution by Garrett to man's conquest of space.

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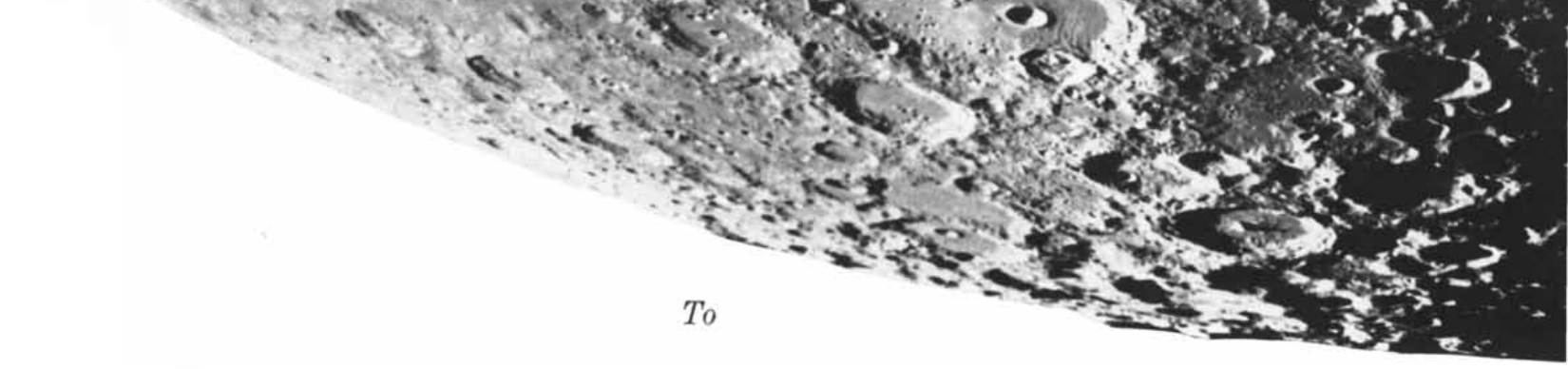

To

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Motorola

systems

reliability

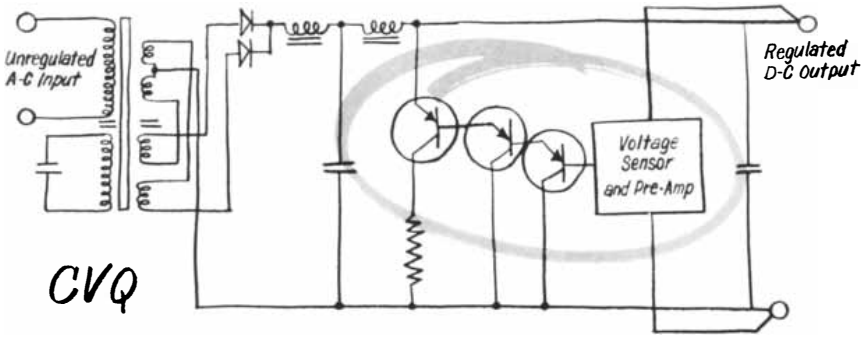
CALTECH'S JPL RANGER, to carry research instrument packages to the moon, will rely upon precision design, construction, testing and performance of Motorola electronic equipment. Comprehensive measurements of operational and navigational data aboard will be assembled for transmission by its Flight Data Encoder. An all solid state Transponder generates the telemetry carrier, receives ground commands, and translates carrier frequencies for two-way Doppler velocity measurements. ☆ In laboratories and at launch site, Payload Test Sets will check out the spacecraft RF communications system. At NASA's transmitter and receiver sites, Calibration Beacons will check command transmitter performance and radiate precise signals to test telemetry receivers. ☆ Motorola's participation in Ranger lunar probes demonstrates its space communications capabilities for frontier programs.

Military Electronics Division **MOTOROLA**

Qualified technical personnel are invited to apply

CHICAGO 51, Illinois, 1450 North Cicero Avenue
SCOTTSDALE, Arizona, 8201 East McDowell Road
RIVERSIDE, California, 8330 Indiana Avenue

SOLA writes this new Rx for reliable d-c power



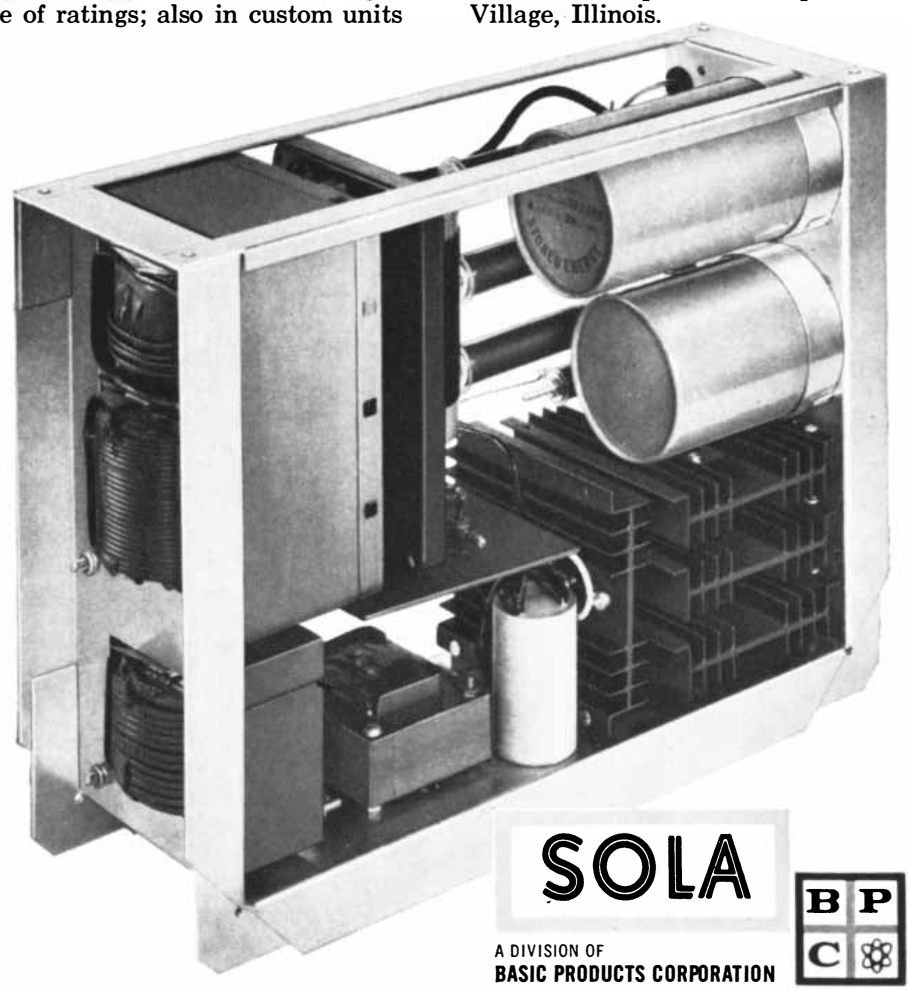
This schematic tells "CVQ's" secret at a glance . . . how SOLA's remarkably reliable new power supply achieves d-c output ideal for computers and other voltage-sensitive equipment. "CVQ" integrates the advantages of shunt-circuit regulation with the *inherent* high stability of the SOLA static-magnetic transformer. And the result is transistorized voltage regulation *with split-cycle response!*

"CVQ" answers the demands of dynamic loading. Voltage variations are ironed out down to the last transient — even to the last ripple of the a-c source. And the SOLA static-magnetic transformer *automatically* prevents damage in event of a short circuit.

SOLA "CVQ" d-c power supplies are available *right now,* in a wide range of ratings; also in custom units built to your specific requirements. Advantages include:

- More watts per dollar.
- Continuous automatic protection without fuses, both for output short circuits, and for open circuits in the voltage-sensing circuitry.
- Output regulated within ±0.04% for line voltage variations ±15%; 0.2% static-load regulation, 0 to full load. Excellent response time.
- Standard models available in the 120-watt range for 5, 6, 10 and 12 volts d-c (100-130/181-235/200-260 volt input).
- Compact mechanical layout — only 12¼ x 5¼ x 19".

Get full facts by writing for new SOLA Catalog DCX-361A. Or telephone HEmpstead 9-2800, Elk Grove Village, Illinois.



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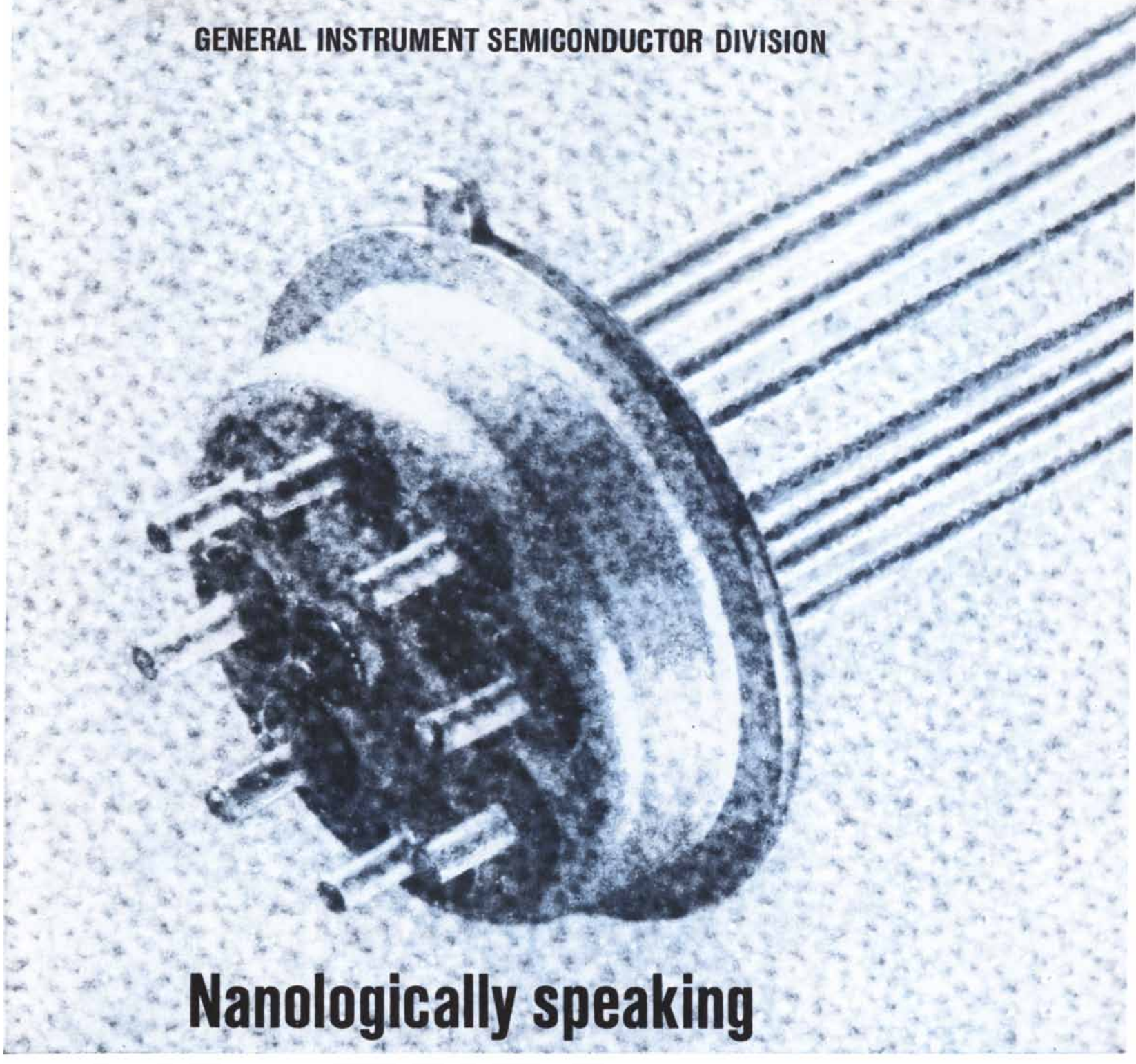
GENERAL INSTRUMENT SEMICONDUCTOR DIVISION



Nanologically speaking

THINK ABOUT IT: six diodes interconnected in a single, standard-size transistor can. General Instrument Research Labs thought about it . . . then produced it along with a whole new array of computer logic "nanocircuits" that offer unusual design flexibility. ■ The General Instrument concept permits nanocircuits to be transferred directly to conventional-component circuitry. This approach frees the circuit designer of the limitations of ordinary micro-circuitry. And, because the heat-generating elements are kept outside the can, circuit reliability is increased. ■ It is this applied imagination, which General Instrument brings to all semiconductors, that underlines the distinction between rhetoric and reason. ■ If you desire more specific information on nanocircuitry, or if you would like to participate in the research that made nanocircuits possible, please write today to Dept. NC-10, General Instrument Semiconductor Division, 65 Gouverneur Street, Newark 4, New Jersey.

GENERAL INSTRUMENT CORPORATION

50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

JUNE, 1911: "The flying machine and the airship have brought us face to face with new legal problems, which affect not only local conditions but interstate and international politics as well. The first question that must be decided is this: Has the air-man any right to the atmosphere at all? In view of some accidents that have occurred at Paris, it seems unlikely that air-craft in Europe will be permitted to fly at will over large cities and communities with the possibility of being compelled to descend because of crippled motors or lack of fuel. On the other hand, the open country and navigable streams will probably be free. To ensure careful control of aircraft as far as possible, licenses to navigate the air will undoubtedly be necessary. Most of the bills that are now pending before legislatures provide for such licenses."

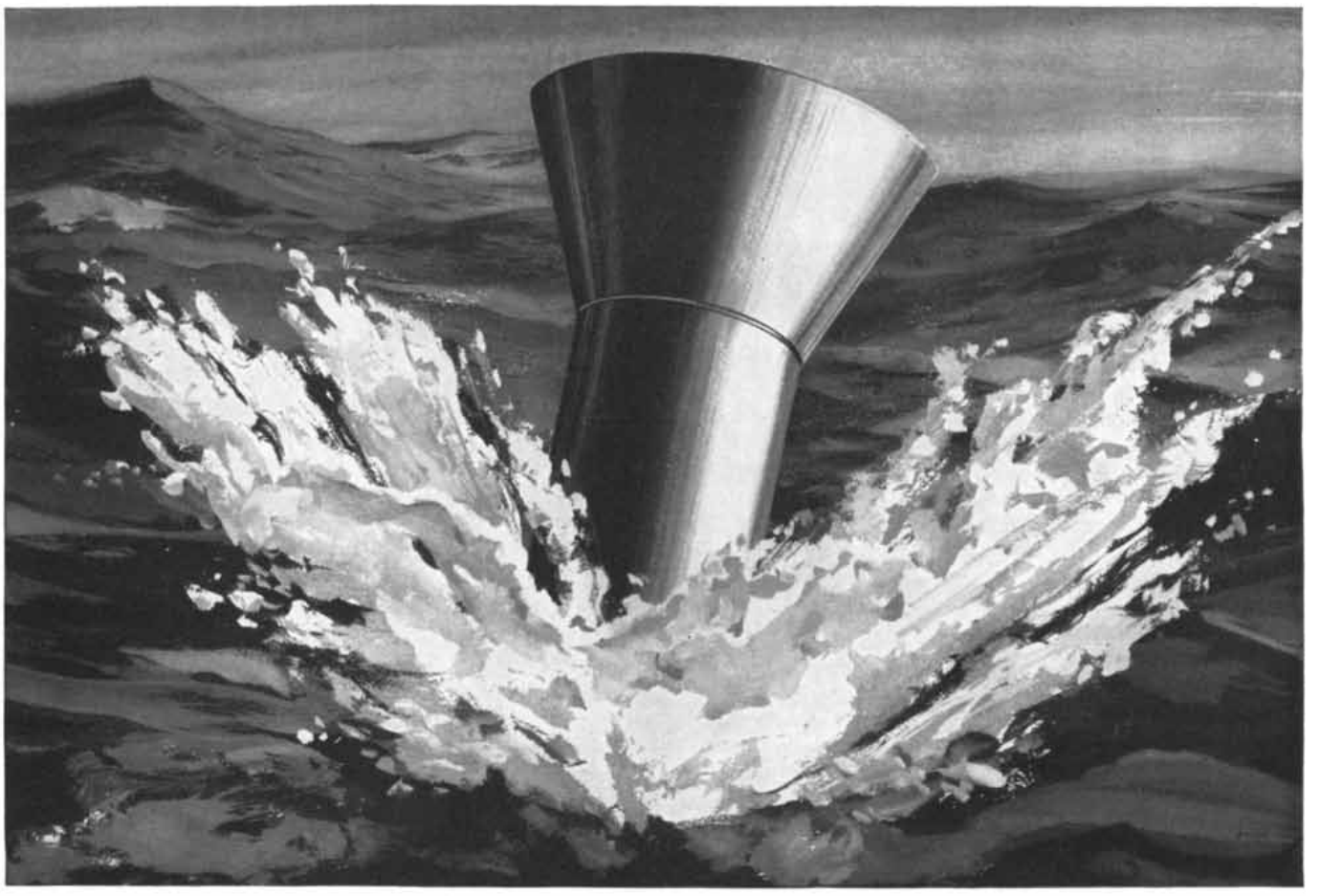
"Next to Panama the most important and extensive engineering work now under way by the Federal Government is the new ship canal at the falls of the St. Marys River. This waterway of the North, connecting Lake Superior with the lower lakes, already floats in its two canals with three locks the greatest commerce of any inland waters of the globe. In 1910 the tonnage amounted to 62,363,218, which was two and one-half times greater than that passing the Suez Canal. It exceeds the commerce borne by all the ships, British and foreign, entering the ports of Great Britain in an entire year. The lake merchant marine in tonnage and value is more than one-half of the entire shipping under American registry, and exceeds the whole marine of every foreign nation, excepting England and Germany. The new Davis lock, now under construction, will be 1,350 feet in length, 80 feet in width, and afford 24.5 feet depth at extreme low water datum."

"Svante Arrhenius has advanced an ingenious theory to account for the glacial periods that have marked several stages of geological history. According to the experiments of Langley, the carbon dioxide and the water vapor that the atmosphere contains are more opaque to the heat rays of great wave length emitted by the earth than to the waves of various lengths emanating from the sun. Arrhenius infers that any increase in the proportion of carbon dioxide and water vapor in the atmosphere will increase the protection of the earth against cooling and will consequently raise the temperature of its surface. The theory assumes that the earth's atmosphere was poor in carbon dioxide and water vapor during the glacial periods and rich in these gases during hot periods."

"Although there may be a touch of the morbid in the widespread interest that has been aroused by the present attempt to recover the *Maine* from the waters that for so many years have given it sepulture, the public interest is something more than morbid. If it shall be proved that the first explosion came from within, it will be cause for congratulation, since in that event no reflection will be cast either upon the good ship *Maine* or its personnel, whereas the elimination of the theory that the ship was deliberately blown up from without will take from a proud and friendly nation the sting of a charge that they, at least, have always claimed to be unjust and unwarranted by the facts."

JUNE, 1861: "The regular Paris correspondent of the Mobile *Register,* in a recent letter to that influential journal, states as one of the reasons why the Confederate States will not be recognized by the French Government, that the news of the export duty on cotton, to be imposed by the Confederate States, has been received with no more favor than the Morrill tariff. An article recently published in the *Moniteur* would seem to indicate that King Cotton may be indulging in some illusions. The *Moniteur* shows that should any obstacle arise to diminish the supply from America, England will be able to get along with 45 per cent of the number of bales received in 1860 from the cotton States, and 'Algeria will find, in the new condition of affairs, a powerful encouragement to develop her fine qualities of cotton, rivaling the best long, silky Georgian.' "

"The blockade of the Southern ports is being rapidly organized. Already all



HOW THE OCEAN GREW "EARS" TO PINPOINT MISSILE SHOTS

A quarter of the world away from its launching pad an experimental missile nose cone enters its ocean target area.

How close has it come to the desired impact point?

Where actually did the nose cone fall?

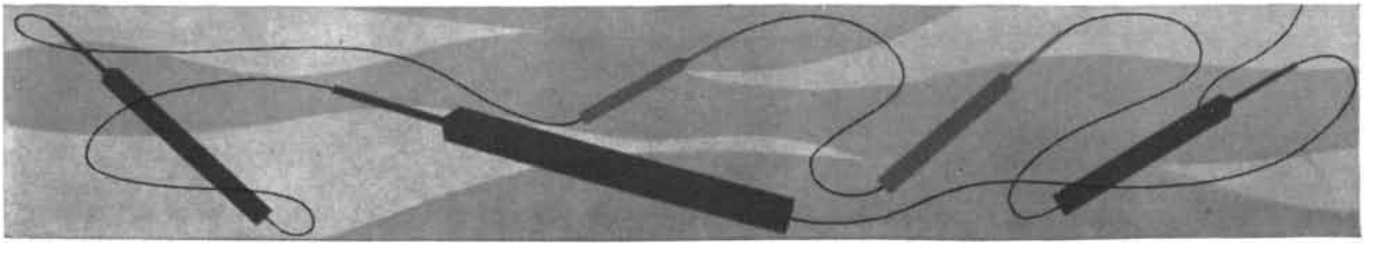
To answer these questions quickly and accurately, Bell Laboratories developed a special system of deep-sea hydrophones—the Missile Impact Locating System (MILS) manufactured by Western Electric and installed by the U. S. Navy with technical assistance from Western Electric in both the Atlantic and Pacific Missile ranges. MILS involves two types of networks.

- One is a long-distance network which utilizes the ocean's deep sound channel. It monitors millions of square miles of ocean. The impacting nose cone releases a small bomb which sinks and explodes at an optimum depth for the transmission of underwater sounds. Vibrations from the explosion are picked up by hydrophones stationed at the optimum depth and carried by cables to shore stations. Time differences in arrivals between these vibrations at different hydrophones are measured and used to compute location of the impact.
- The other is a "bull's-eye" network that monitors a restricted target area with extraordinary precision. This network is so sensitive it does not require the energetic explosion of a bomb but can detect the mere splash of a nose cone striking the ocean's surface—and precisely fix its location.

The universe of sound—above the earth, below the ocean—is one of the worlds of science constantly being explored by Bell Laboratories. The Missile Impact Locating System reflects the same kind of informed ingenuity which constantly reveals new ways to improve the range of Bell System services.

BELL TELEPHONE LABORATORIES

World center of communications research and development

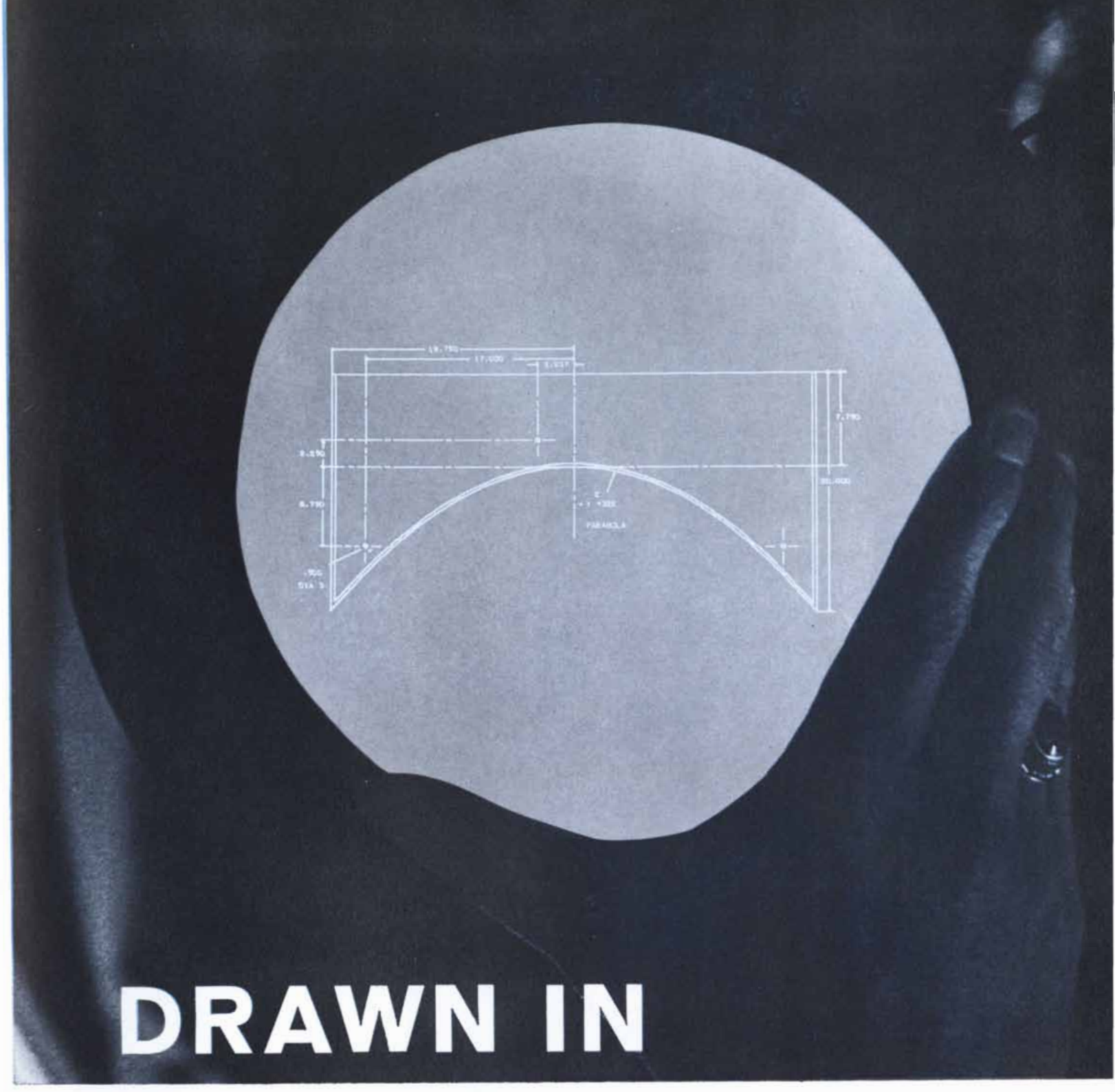


the ports of Virginia, as well as Charleston, S.C., and Pensacola and Key West, Fla., are guarded by ample naval forces. Several vessels have been seized in attempting to leave the blockaded ports, and those attempting to enter are ordered away. The steamer *Niagara* is stationed off the port of Charleston. The Charleston *Courier* reports that on the 12th ult. the British bark *Hilja* was refused entrance into the port by the *Niagara*. The British ships *Monmouth* and *General Parkhill* were also ordered off. The British ship *A and A* was pursued but ran into shoal water and was towed up to the city. The British ship *Susan G. Owens*, for Liverpool, was boarded but finally allowed to pass."

"The Paris correspondent of the London *Photographic News* says upon the subject of zinc and steam: 'The employment of electricity as a motive power depends on its relative economy with steam, or the difference between the cost of zinc and coal; for in the electric battery it is the zinc that is consumed. But a remarkable feature in the question is that, while ordinary steam engines render only .052 of chemical power, the electromotive machine yields .20 to .25, which is enormous, and gives it an undoubted superiority over steam. Yet, even at this rate, electromotive power is 20 times dearer than that of steam. The question to be solved, therefore, is the economic production of electricity.' "

"In a late number of *Comptes Rendus* a new color, called Paris Blue, is described. This blue resists acids; is deepened in tone with feeble alkalies, but becomes a purple with concentrated alkalies. This is a most important discovery and is another addition to the remarkable series of rich colors derived from the products of coal tar. We would not be much surprised if all the colors and shades were yet to be produced on textile fabrics by the products that have been obtained from our oil wells and coal mines."

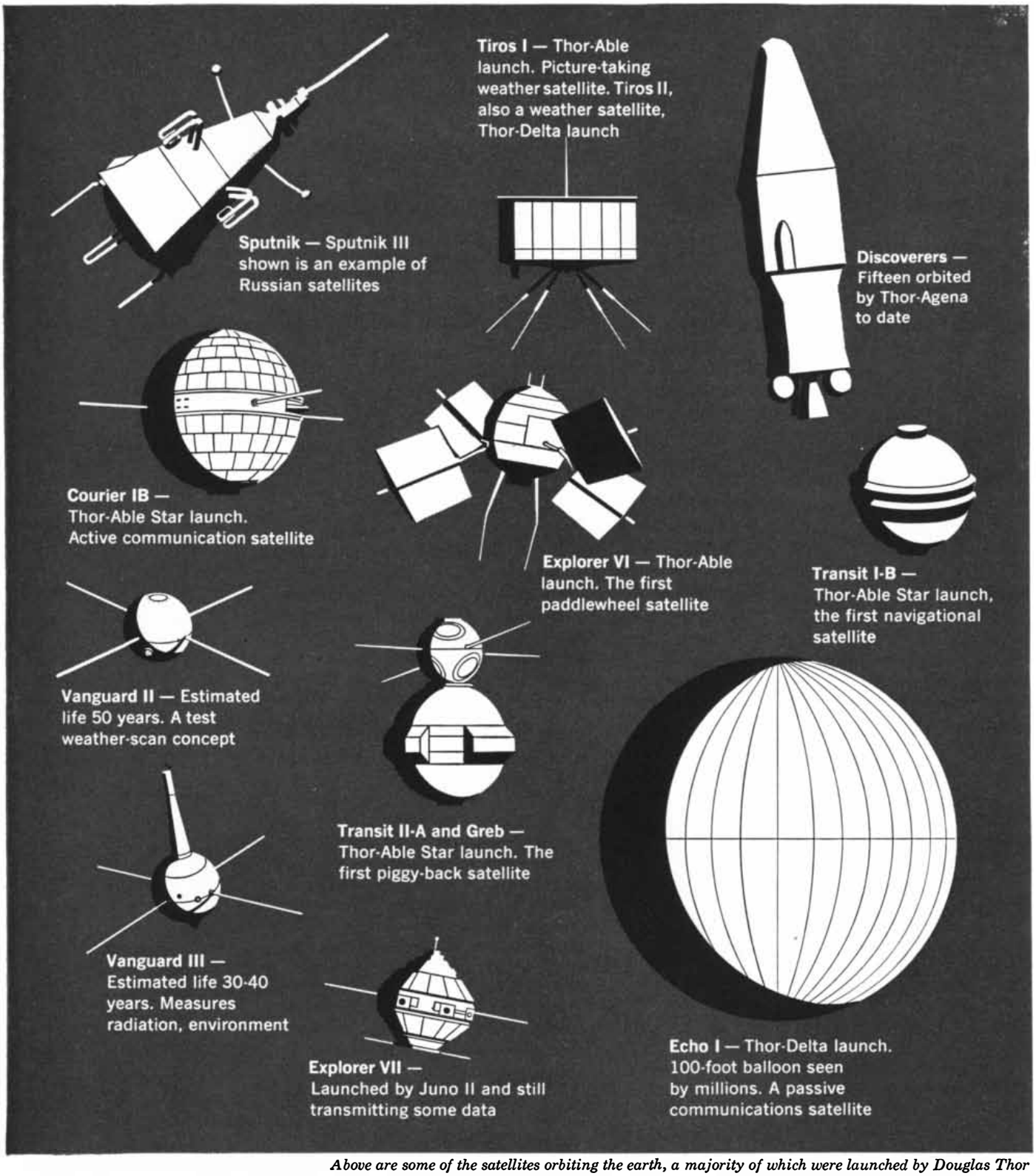
"Messrs. R. Napier & Sons, of Glasgow, are now building the steamer *Scotia*, which is intended to be a consort for the *Persia* and will, when finished, be the largest merchant steamship, next to the *Great Eastern*, in the world. Her length is 396 feet; breadth of beam, 47½ feet; depth, 33½ feet; tuns burden, 4,050. The engine will be nominally 883 horsepower but actually a great deal more. Her hull is of iron like the *Persia*, which vessel she will exceed in capacity by 500 tuns."



DRAWN IN ½ SECOND!

You are looking at the face of a CHARACTRON® Shaped-Beam Tube, heart of the remarkable S-C 4020 High-Speed Microfilm Recorder. The part drawing you see was made by electron beams from computer logic and recorded on 35-mm film in a fraction of a second! After the design has been approved, output of the computer can be used to operate an automatically programmed tool and produce the part. In addition to the S-C 4020's capabilities for automatic drafting and numerical control tool path drawings, the system can be utilized as a computer printer, recording data at 6000 lines per minute, or as a graph plotter, recording highly-accurate curves at 12,500 points per second. Write for details to General Dynamics/Electronics, Information Technology Division, Dept. B-34, P.O. Box 2449, San Diego 12, California.

GENERAL DYNAMICS | ELECTRONICS



Above are some of the satellites orbiting the earth, a majority of which were launched by Douglas Thor

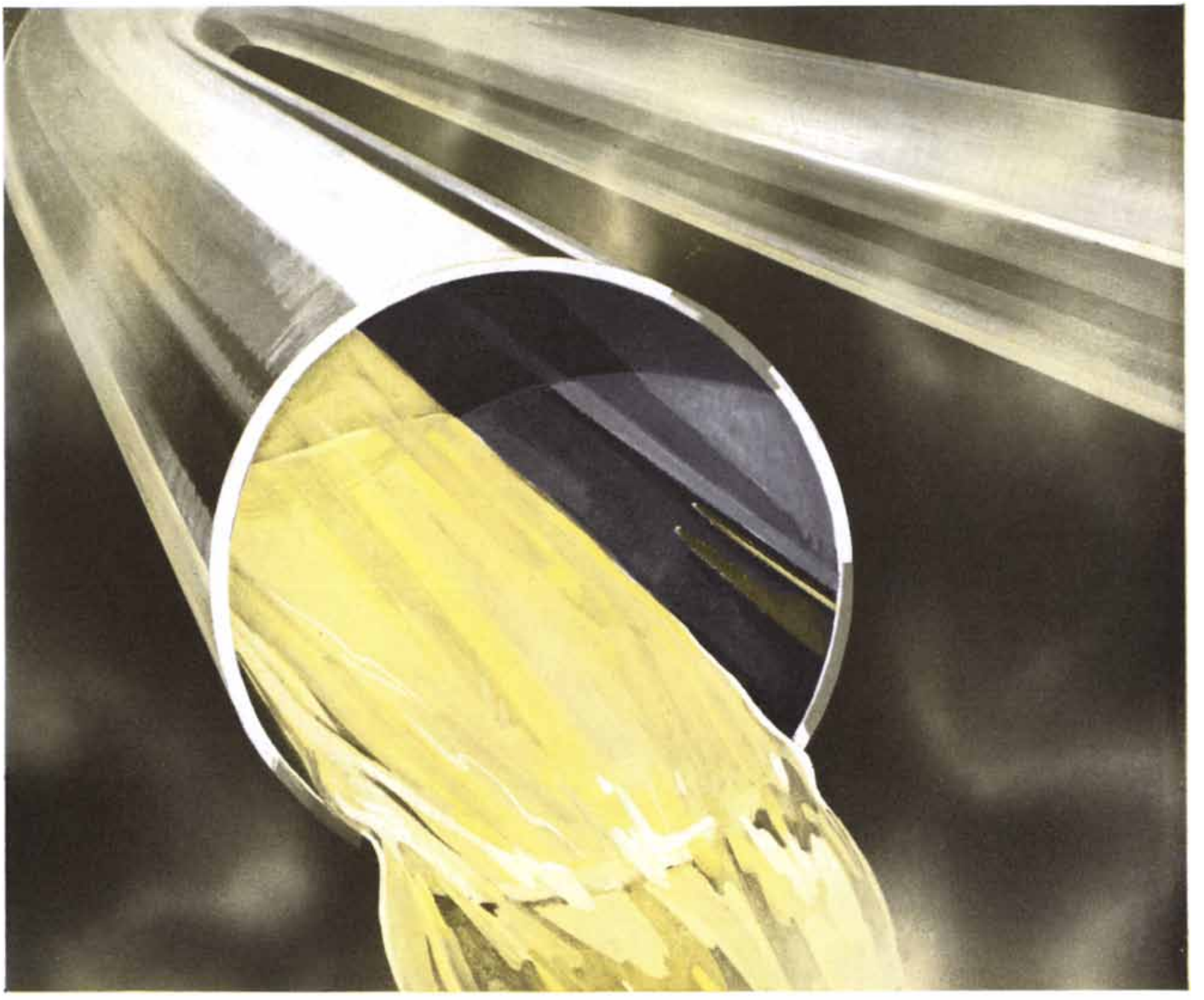
The Douglas Thor rocket has orbited more satellites than all other rockets combined!

Of all satellites put in orbit since 1958, 55% were launched by the Air Force-NASA Thor IRBM. In its last 83 tactical and space firings by the Air Force, Navy and NASA, 86% have been completely successful—a reliability inherited from forty years of Douglas experience in aviation and 21 years in missiles and space.

DOUGLAS

MISSILE AND SPACE SYSTEMS • MILITARY AIRCRAFT • DC-8 JETLINERS • RESEARCH AND DEVELOPMENT PROJECTS • GROUND SUPPORT EQUIPMENT • AIRCOMB® • ASW DEVICES

This is FLUIDICS in action—one aspect of Pfaudler Permutit's comprehensive program to help industry solve problems in the handling of liquids and gases.



DON'T FIGHT CORROSION, FORGET IT...WITH Ta, Ti, Zr

The fight could be over today.

And tantalum, titanium or zirconium—fabricated into equipment by Pfaudler—could be the way it ends.

The reason is simple: these "reactive" metals in many applications are immune to corrosion. Under pre-evaluated conditions, they offer you the fundamental advantage of essentially zero corrosion loss.

Which means that equipment made from such metals requires little or no maintenance and operates with an almost endless service life.

You can put the anti-corrosion performance of Ta, Ti, and Zr to work in many Pfaudler® products—heat exchangers, burners, vessels, columns, heaters, and accessories including pipes and fittings, agitators, pump parts, etc.

The conquest of corrosion is one phase of our FLUIDICS program. And these metals are some, but by no means all, of the materials. Your corrosion problem might best be solved by such other Pfaudler products as Glasteel—a material that combines the corrosion resistance of glass with the working strength of steel; Pfaudlon 301*—a bonded plastic coating; or Nucerite*—a new, high-temperature-resistant ceramic-metal.

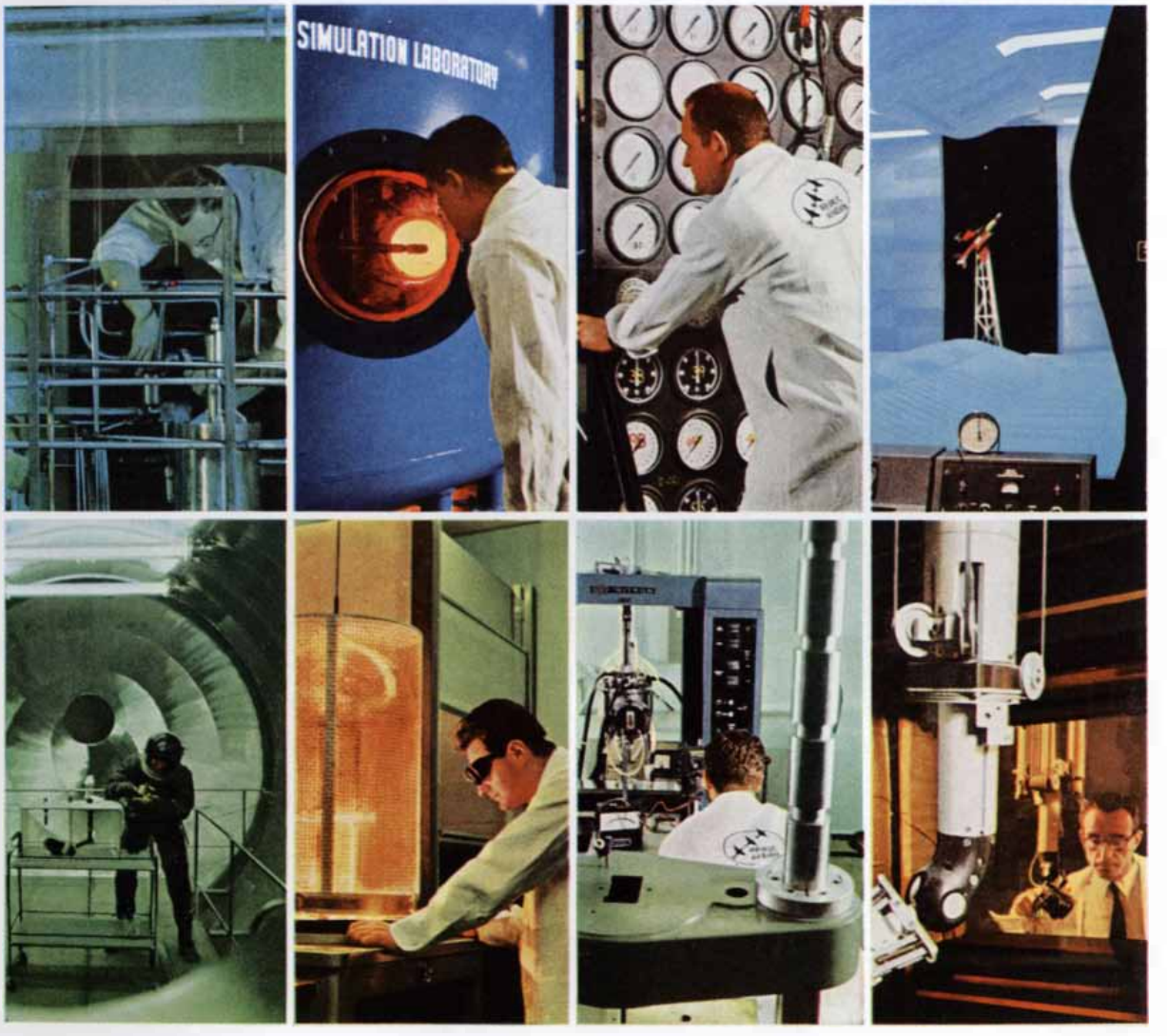
For more facts on how to forget—not fight—corrosion, write for Bulletin 978, *Tantalum, Titanium, and Zirconium Process Equipment by Pfaudler*. Or ask for full details on the scope of our complete corrosion engineering facilities. Write to our Pfaudler Division, Department SA-61, Rochester 3, New York.

*Patent applied for

PFAUDLER PERMUTIT INC.

Specialists in FLUIDICS . . . the science of fluid processes

IN THIS NEW HOME
REPUBLIC LIVES EVERY DAY IN THE FUTURE—YOUR FUTURE



Republic has just dedicated its newest contribution to the space age, the Paul Moore Research and Development Center. ➤➤➤ This is the only fully integrated research complex engaged in every vital area of space investigation.

Eight laboratories comprise the Center: Space Environment and Life Sciences, Re-Entry Simulation, Fluid Systems, Guidance and Control Systems, Materials Development, Nuclear Radiation, Electronics, and Wind Tunnels.

Man is now ready to probe further into the larger, unknown vastness of space. We believe that he must search for ways, not to conquer space, but to use it. ➤➤➤ The biggest job of Republic's new R&D Center is to help him in this search.

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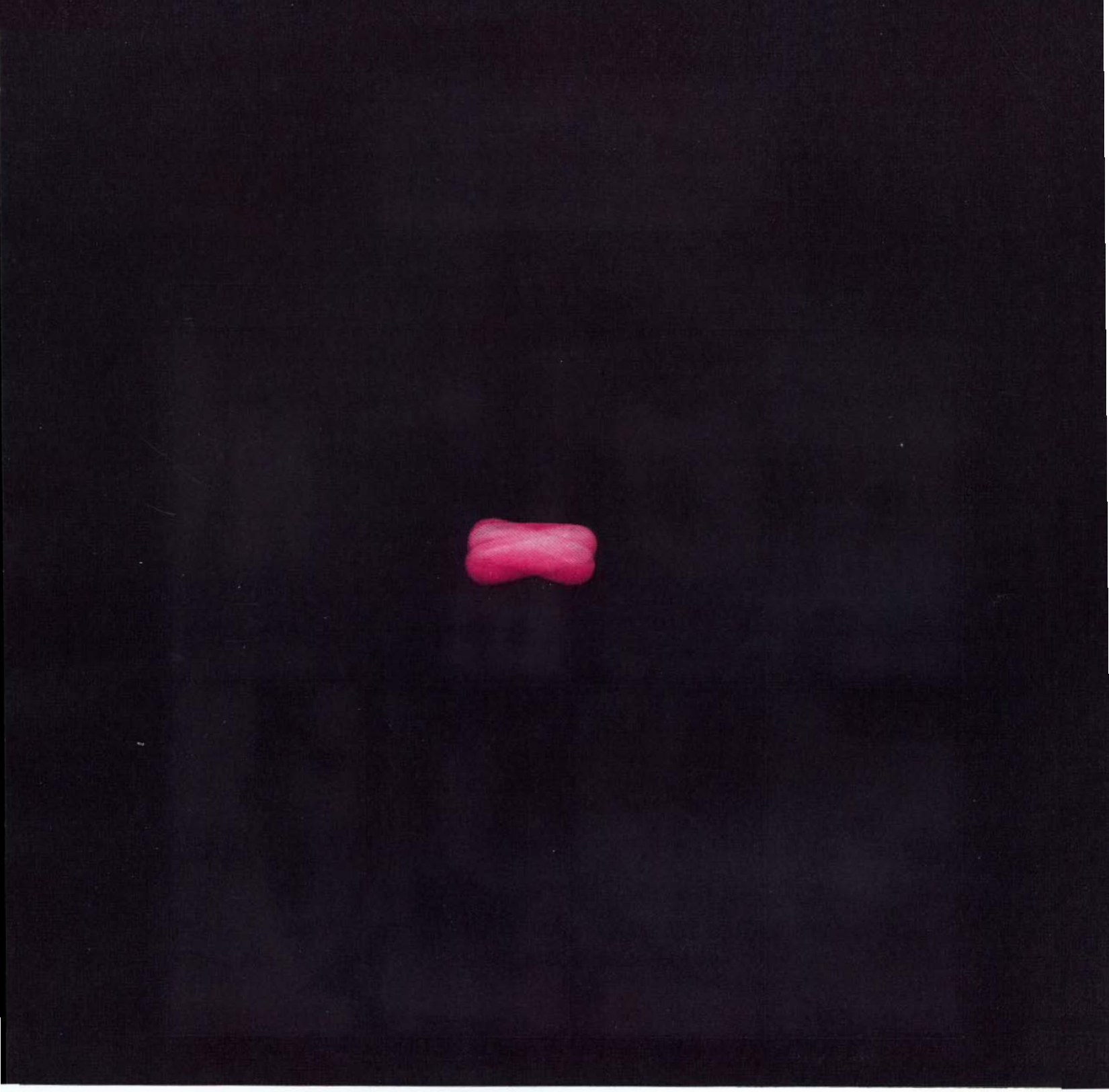
AVIATION CORPORATION
FARMINGDALE, LONG ISLAND, N.Y.



Who stopped the battle inside the vitamin tablet?

The vitamin tablet above, wearing the inviting pink coat, is called Vigran M. In it, 10 vitamins and 7 minerals live peacefully together.

Some vitamins are natural-born fighters. Dump them together in a tablet and eventually they'll destroy each other. About 3 billion vitamin tablets ago, the Squibb Division of Olin figured out how to keep vitamins from scrapping. They put A and D into separate granules. They put B_1, B_2 and C into their own private wrap. They took B_{12}, the one *all* the other boys pick on, and tucked it safely into one of the tablet's coatings. And they set up a system that checks quality and potency more than 200 different times. All this was done to help make sure that a Squibb vitamin tablet maintains its full strength not just until it goes into the bottle (that's easy) but right up to the moment you pop it into your mouth. ▪ Another creative solution to a problem...from the Squibb Division of Olin.

Olin

OLIN MATHIESON CHEMICAL CORPORATION, 460 PARK AVENUE, NEW YORK • CHEMICALS • ENERGY • INTERNATIONAL • METALS • PACKAGING • SQUIBB • WINCHESTER-WESTERN

What's News in Rubber...

Faster-curing new Butyl cushions playground tumbles

New Enjay Butyl HT 10-66 gave Mitchell Rubber Products, Inc. of Los Angeles, California, a big jump ahead in its "Safety-Surf" playground mat (shown above). Mitchell has combined this new Butyl rubber with their engineering "know-how" for an abrasion, weather and shock resistant mat that makes playgrounds safer for children.

New Enjay Butyl HT 10-66 is an isobutylene-isoprene copolymer containing chlorine. It can be cross-linked by a variety of vulcanizing techniques, using either the carbon-to-carbon double bonds, the allylic chloride, or both. Vulcanization is usually more rapid than with unhalogenated Butyl, but vulcanizates show the same inertness to environmental attack. More stable cures make Butyl HT 10-66 outstanding for high-temperature uses.

Butyl HT 10-66 is now in full-scale commercial production, proving its worth in many demanding uses. For test samples and performance data, write to Enjay, 15 West 51st Street, New York 19, N. Y.

EXCITING NEW PRODUCTS THROUGH PETRO-CHEMISTRY

ENJAY CHEMICAL COMPANY

A DIVISION OF HUMBLE OIL & REFINING COMPANY

ENJAY

THE AUTHORS

ARTHUR L. SCHAWLOW ("Optical Masers") is a staff member in the Physical Research Department of Bell Telephone Laboratories. Schawlow was born in Mount Vernon, N.Y., and raised in Canada. His studies at the University of Toronto were interrupted by World War II, during part of which he was engaged in research on microwave guides and antennas. At the end of the war he resumed his graduate work under the direction of M. F. Crawford at Toronto and received his Ph.D. in 1949. He then went to Columbia University as a postdoctoral fellow and research associate. It was there that he began his association with Charles H. Townes, which resulted in the formulation of the basic principles of optical masers. Schawlow joined the Bell Telephone Laboratories in 1951.

S. L. WASHBURN and IRVEN DEVORE ("The Social Life of Baboons") are respectively professor and acting assistant professor of anthropology at the University of California. Washburn, a past president of the American Association of Physical Anthropologists and editor of the association's journal since 1955, was educated at Harvard University. He received his Ph.D. from Harvard in 1940, taught anatomy at Columbia University from 1939 to 1942 and then joined the department of anthropology at the University of Chicago. Washburn became a member of the California faculty in 1959. DeVore, who is currently completing his Ph.D. degree at Chicago, received a B.A. from the University of Texas in 1956 and an M.A. from Chicago in 1959. The study described in the article by Washburn and DeVore was made possible by a grant from the Ford Foundation.

ROY M. PRITCHARD ("Stabilized Images on the Retina") is a research associate at McGill University in Montreal, where he is an investigator in the departments of psychology and physiology. Pritchard served with the Royal Air Force from 1950 to 1952; then he entered the University of Reading to study physics. At Reading he collaborated with R. W. Ditchburn in the development of the first system to compensate completely for all eye movements in stabilizing images on the retina. He taught at Reading Technical College from 1955 to 1957 and received his Ph.D. in physics the following year. After developing the stabilizing system discussed in his article, Pritchard became interested in applying it to problems of perception theory. He joined the staff of McGill in 1959.

FRANÇOIS JACOB and ELIE L. WOLLMAN ("Viruses and Genes") are respectively head of the Department of Microbial Genetics and *chef de laboratoire* in the Department of Microbial Physiology at the Pasteur Institute in Paris. Jacob's medical studies at the University of Paris were interrupted by World War II. In 1940 he escaped to England to join the Free French forces there and he later fought in both Africa and France. Jacob completed his M.D. degree after the war and went to the Pasteur Institute in 1950. In 1954 he received a D.Sc. degree from the Sorbonne. Wollman, whose parents were microbiologists at the Pasteur Institute, studied medicine and biology at the University of Paris until war intervened. During the German occupation of France, in which both of his parents were killed, Wollman finished his medical degree at the University of Lyon and served as a physician with the resistance forces and later with the French army. He became a staff member of the Pasteur Institute in 1945.

MARGARET and GEOFFREY BURBIDGE ("Subdwarf Stars") are a husband-and-wife team on the staff of the University of Chicago's Yerkes Observatory at Williams Bay, Wis. The Burbidges met and married while she, an astronomer, was working at the University of London Observatory and he, a physicist, was studying meson physics. The marriage resulted in Geoffrey Burbidge's conversion to astrophysics. He received his Ph.D. from the University of London in 1951 and came to the Harvard College Observatory as an Agassiz Fellow, while his wife became a fellow at the Yerkes Observatory. In 1953 they returned to England, where he worked in the Cavendish Laboratory of the University of Cambridge. They both joined the Yerkes Observatory in 1957. The present article is the third they have written for SCIENTIFIC AMERICAN.

GEORGE M. A. HANFMANN ("Excavations at Sardis") is professor of fine arts at Harvard University and curator of classical art at Harvard's Fogg Art Museum. Since 1958 he has been field director of the joint Harvard and Cornell University expeditions to Sardis. Born in

Russia and educated in Germany, he came to the U. S. in 1934 as a Vogeler Fellow of Johns Hopkins University. He holds one Ph.D. degree from the University of Berlin and another from Johns Hopkins. An early interest in the Etruscans, who supposedly came from Lydia in Asia Minor, led him to study archaeology. The capital of Lydia was Sardis; thus when Hanfmann went to Harvard in 1935, George H. Chase, a member of the first expedition to Sardis in 1914, found it easy to interest him in the site. Hanfmann has also done archaeological field work in Italy, Greece and Cyprus.

JOHN D. WOODWARD ("Biotin") teaches biochemistry at the University of Reading. After serving two years as a pilot in the Royal Air Force, Woodward attended the University of Birmingham, where he acquired a B.Sc. in 1956. He took a Ph.D. in biochemistry at the same institution and remained there another year to do research with S. V. Perry. He first became interested in biotin while studying biotin-deficient yeasts. Woodward is currently engaged in research on chicks that are deficient in this vitamin.

HOMER JENSEN ("The Airborne Magnetometer"), director of the Systems Engineering Division of Aero Service Corporation, is a physicist and inventor who has played a pioneering role in the development of airborne geophysical devices, particularly those involving the airborne magnetometer. A graduate of the University of Cincinnati, Jensen joined the Naval Ordnance Laboratories in 1941. There he worked for a time on degaussing projects protecting ships against magnetic mines. In 1943 he was assigned to the project of developing the airborne magnetometer into a device for detecting submarines. As part of his war work, Jensen later participated in aeromagnetic surveys in Pennsylvania, Minnesota and northern Alaska. He went to Aero Service in 1946 to establish that company's Airborne Geophysics Division, which under his direction has done more than three million miles of aeromagnetic surveying. Among his inventions are a gyro-stabilized flight-path recording camera, a 360-degree camera and stabilized binoculars.

A. J. AYER, who in this issue reviews Ernest Nagel's *The Structure of Science*, is Grote Professor of the Philosophy of Mind and Logic at the University of London. His writings include *The Problem of Knowledge*, which appeared in 1956.

HIGH PURITY ELEMENTS

SOUTH PLAINFIELD, N. J., June 1 — ASARCO'S CENTRAL RESEARCH LABORATORIES ANNOUNCED THAT HIGH PURITY ELEMENTS ANTIMONY, ARSENIC, BISMUTH, CADMIUM, GOLD, INDIUM, SELENIUM AND TELLURIUM ARE NOW AVAILABLE IN COMMERCIAL QUANTITIES FOR EXPANDING PRODUCT APPLICATIONS. SINCE THESE AND OTHER ELEMENTS ARE PRODUCED FROM MATERIALS BASIC TO ASARCO'S DAILY OPERATIONS, CUSTOMERS ARE ASSURED OF CONTINUOUS SUPPLIES.

ASARCO HIGH PURITY ELEMENTS ANALYSES as of JUNE 1, 1961

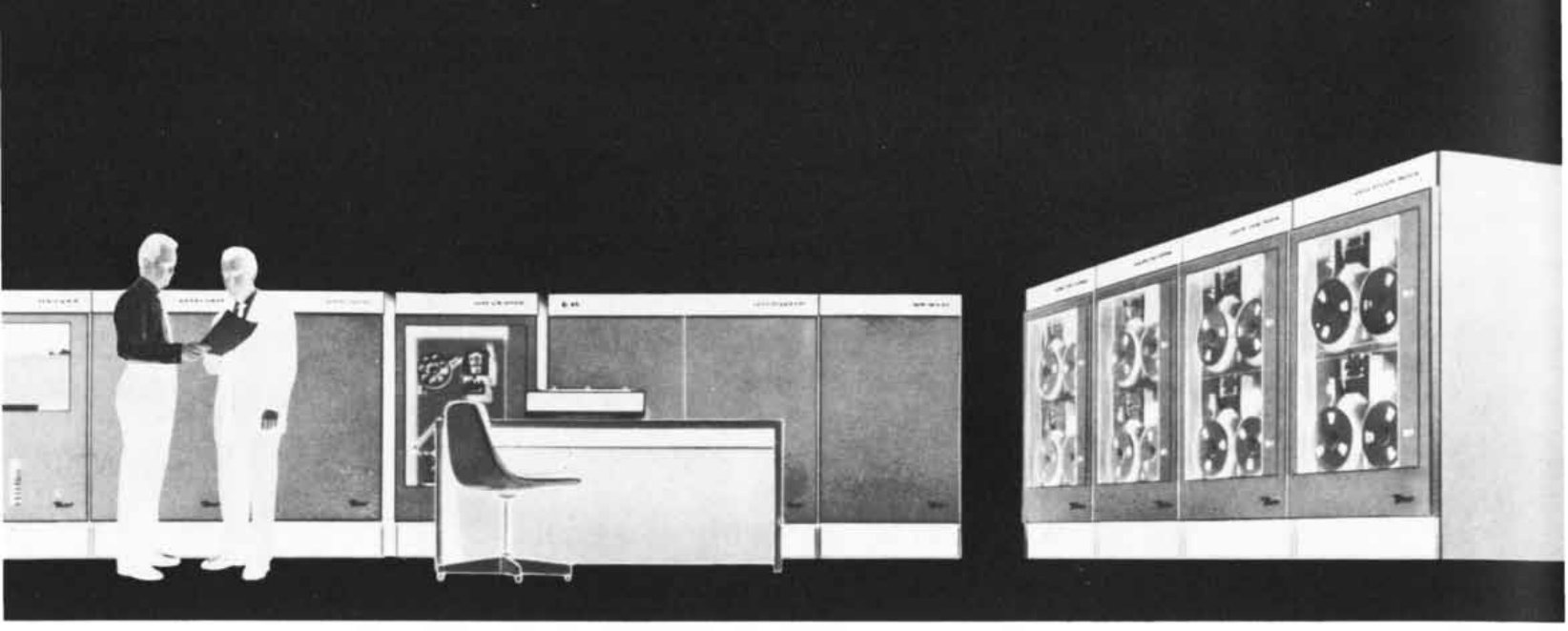
Impurities sometimes found at maximum levels in parts per million
(< denotes less than ppm indicated)

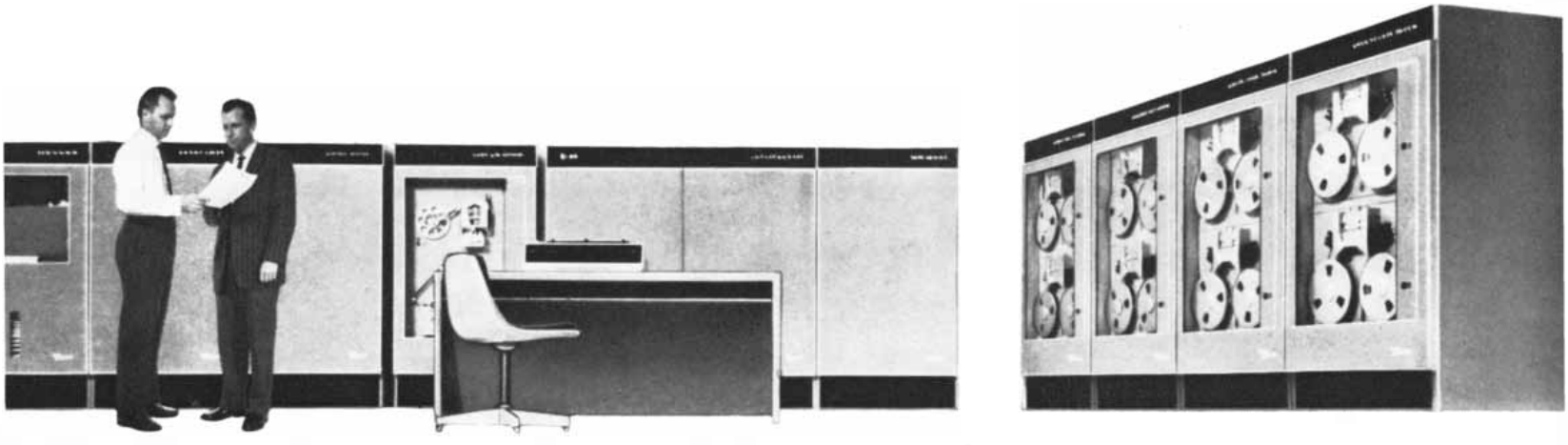
	Element and Grade		Bi	Cu	Fe	As	Pb	Ag	Tl	Sn	Te	Au	Na	Cl	Cd
	ANTIMONY	A-60	<1	<1	<1	2	<1								
✓	ARSENIC	A-60		<1											
	BISMUTH	A-58		2	1		1	2						<1	
	CADMIUM	A-60		<1	<1		1								
	COPPER	A-58	No Impurities Detectable by Spectrographic Analysis												
	GOLD	A-59		<1	<1		<1	1							
	INDIUM	A-58		<1			1		<1	1					
	LEAD	A-59	<1	<1	<1										
	SELENIUM	A-58		<1		<1					1			<1	
	SILVER	A-59		<1	<1		<1								
	SULFUR	A-58											1	1	
	TELLURIUM	A-58		<1	<1										
✓	THALLIUM	A-60		1	1		<1	<1					2	<1	
	ZINC	A-59		<1	<1		<1								<1

✓ *Denotes element improved since last published analyses.*

ASARCO

The analyses above are among pertinent data compiled by Asarco's Central Research Laboratories in an up-to-date catalogue now available to users of high purity elements. For a copy, write on your company letterhead to American Smelting and Refining Company, 120 Broadway, New York 5, N. Y.





DOUBLE YOUR COMPUTING PRODUCTIVITY WITH THE

Bendix G-20

With the Bendix G-20 you are a two computer company. Incorporating both commercial and scientific data handling capabilities, the G-20 computing system permits all functions of your organization—engineering and administration, manufacturing and marketing—to meet their combined data processing needs in a single cost saving move. ▪ The G-20 contains a complete automatic programming "package"—including algebraic and business-language compilers which allow engineers and EDP personnel to write computer programs quickly and easily . . . in the natural language of the problem. The G-20's "packaged intelligence" masterminds the automatic scheduling of multiple problem processing—commercial and scientific intermixed—and maintains maximum system use and efficiency. ▪ And your G-20 configuration can always **match exactly** the changing requirements of your particular computing/data processing "mix"... assuring maximum utilization of your specific system. ▪ Consult your own engineers and methods people. They'll recognize the multiple-purpose capabilities of the Bendix G-20 . . . and the budget wisdom of using one computer to handle the data processing demands of your entire organization. ▪ For application bulletin "A Solution to the Profit Squeeze," write:

THE Bendix CORPORATION

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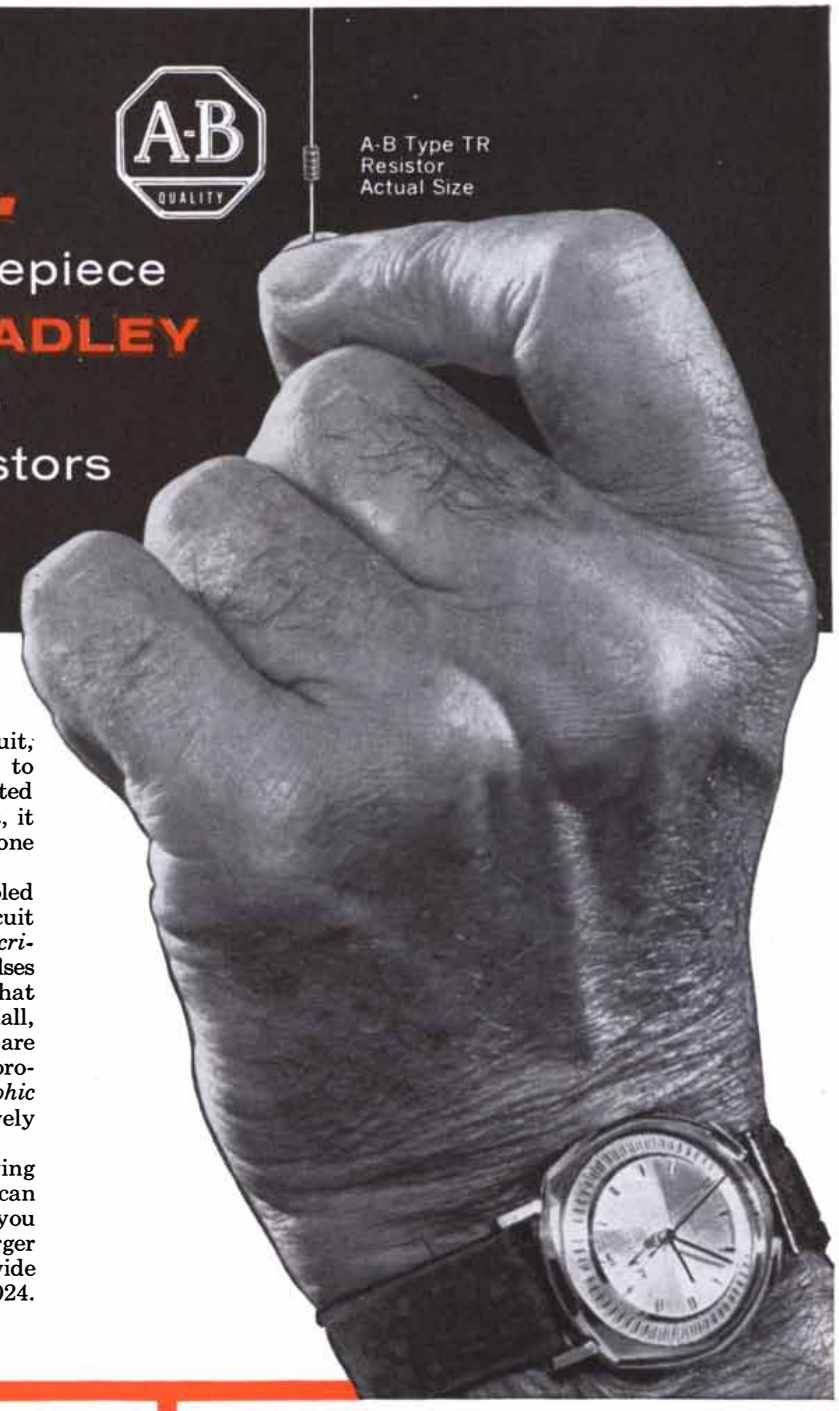
DEPT. C-32, LOS ANGELES 45, CALIFORNIA

Accutron...*

new electronic timepiece uses ALLEN-BRADLEY Type TR Miniature Composition Resistors

A-B QUALITY



With its miniature tuning fork and electronic circuit, Accutron introduces an entirely new principle to timekeeping—one which promises unprecedented wrist timepiece accuracy. Strapped to your wrist, it is guaranteed not to gain or lose more than one minute a month.

Allen-Bradley Type TR tiny resistors enabled Accutron designers to achieve the required circuit miniaturization for a wrist timepiece—*without sacrificing reliability*. This circuit controls the 360 pulses of power each second—31 million per day—that drive the tuning fork. Although incredibly small, these Type TR miniature composition resistors are made by Allen-Bradley's exclusive hot molding process that *guarantees complete freedom from catastrophic failures!* A-B Type TR resistors are conservatively rated 1/10 watt at 70°C.

There are also other Allen-Bradley space-saving potentiometers, capacitors, and h-f filters that can help solve your miniaturization problem. And you obtain the same reliability for which the larger Allen-Bradley components have earned a world-wide reputation. For full details, send for Publication 6024.

** TRADEMARK BULOVA WATCH CO., INC.*

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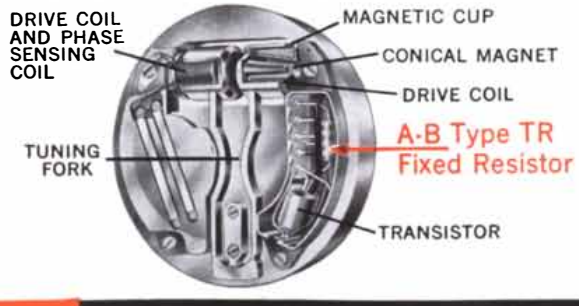

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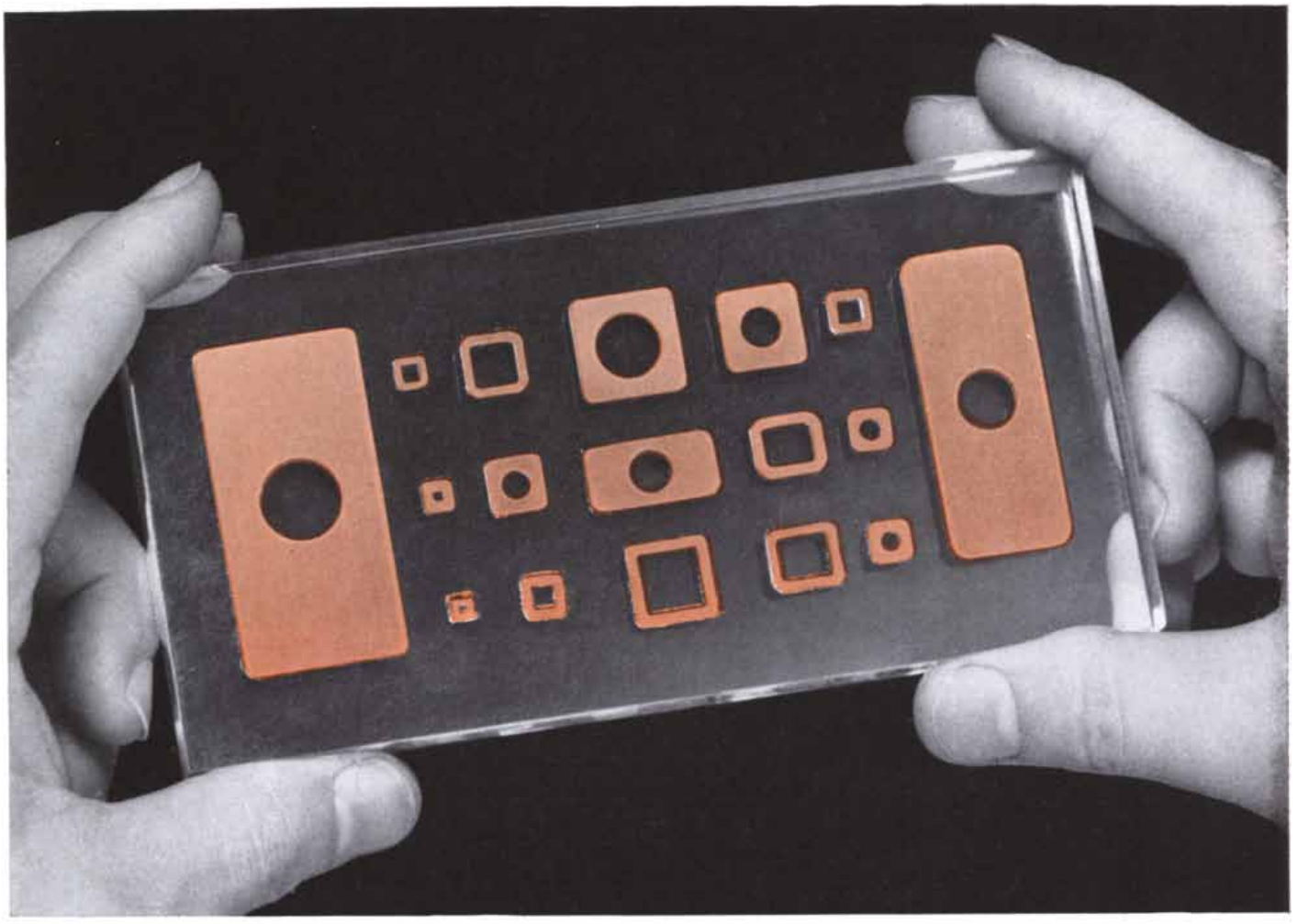
a new look at hollow conductors



Cross sections of some typical hollow copper conductors produced by Anaconda American Brass Company

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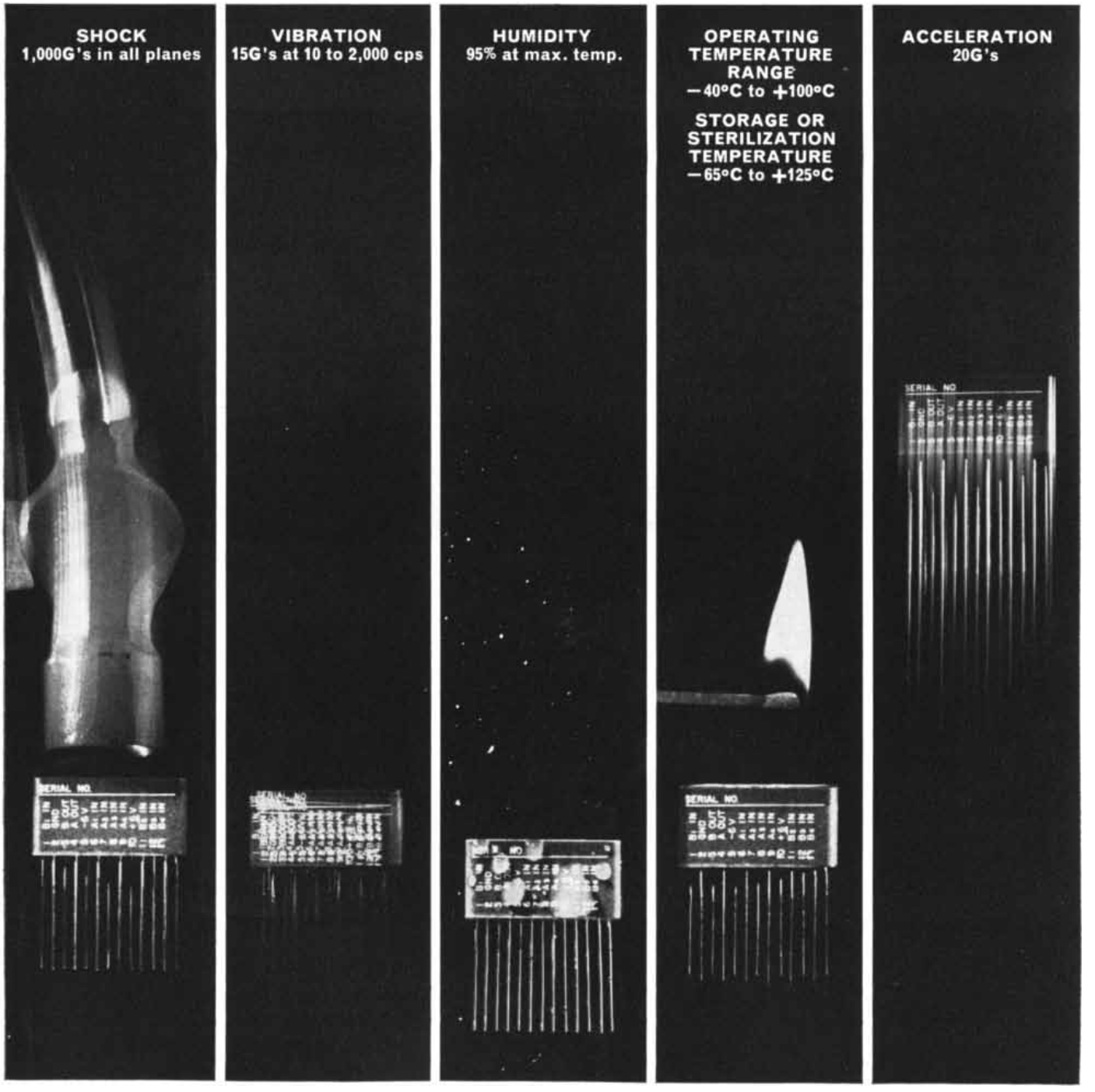

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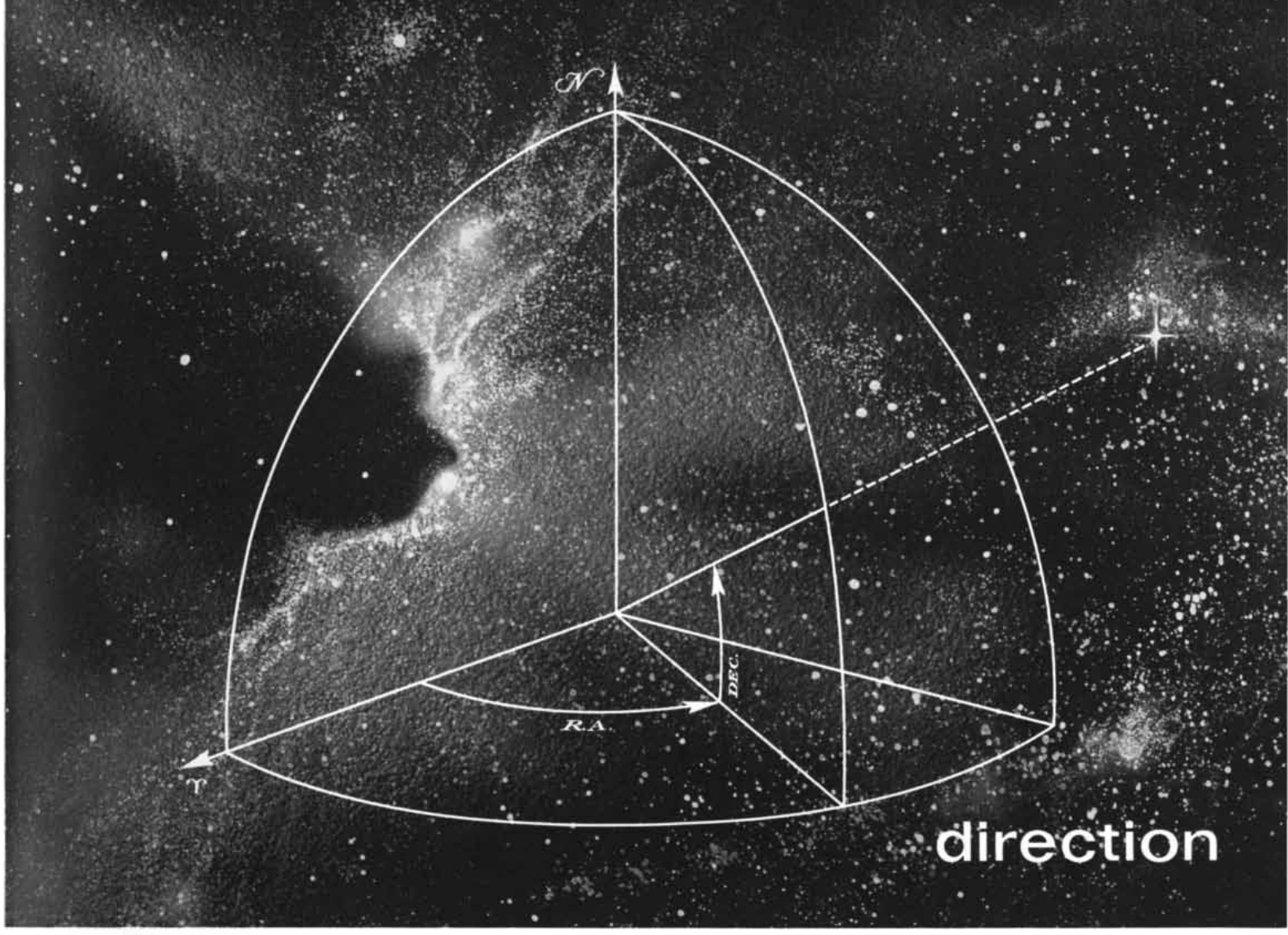

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SPERRY

Doctor checks "out" on one of the Executone Register Panels at St. Vincent's Hospital, Montclair, N. J., and receives intercom messages.

Executone developed this simplified relay design to lower initial expense and reduce maintenance costs, and they utilized palladium for the twelve contacts shown to insure reliability.

Where any metal but Palladium

Electronic messenger using palladium contacts improves hospital service and safety.

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They found the answer by using palladium for the all-important contact points of their new Printact* permanent magnet relays on the memory modules. Palladium was the practical choice for handling the intricate switching combinations on the system's rhodium-plated printed circuit boards.

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At the Message Center Console, the operator passes on to the doctor by Executone any messages which were automatically signalled by the memory unit.

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Established 1845 SCIENTIFIC AMERICAN June 1961 Volume 204 Number 6

Optical Masers

These devices generate light in such a manner as to open up a whole new realm of applications for electromagnetic radiation. The salient feature of the light they produce is that its waves are all in step

by Arthur L. Schawlow

For at least half a century communications engineers have dreamed of having a device that would generate light waves as efficiently and precisely as radio waves can be generated. The contrast in purity between the electromagnetic waves emitted by an ordinary incandescent lamp and those emitted by a radio-wave generator could scarcely be greater. Radio waves from an electromagnetic oscillator are confined to a fairly narrow region of the electromagnetic spectrum and are so free from "noise" that they can be used for carrying signals. In contrast, all conventional light sources are essentially noise generators that are unsuited for anything more than the crudest signaling purposes. It is only within the last year, with the advent of the optical maser, that it has been possible to attain precise control of the generation of light waves.

Although optical masers are still very new, they have already provided enormously intense and sharply directed beams of light. These beams are much more monochromatic than those from other light sources; at their best optical masers rival the very finest electronic oscillators as a source of a single frequency. The development of optical masers is moving so rapidly that they should soon be ready for a wide variety of applications. These may range from space communications and radar to accelerating specific reactions in chemical technology.

To appreciate the limitations of light waves as they are ordinarily found, let us consider how they are produced. All light sources—incandescent lamps, arcs and so on—are essentially hot matter. In the familiar neon tube, it is true, the glass walls remain cool, but the electrons and gas atoms within the tube are accelerated to the high speeds normally associated with high temperatures. The atoms are continuously "pumped" to an excited state; then they fall back, losing energy and radiating visible light. They fall back, however, one atom at a time. The disorderly atomic motion we associate with a heated gas is paralleled by a disorderly outpouring of light quanta, or photons. Just which atoms radiate at any instant is purely a random affair. The excited electrons in the hot tungsten filament of an incandescent lamp also radiate randomly and independently.

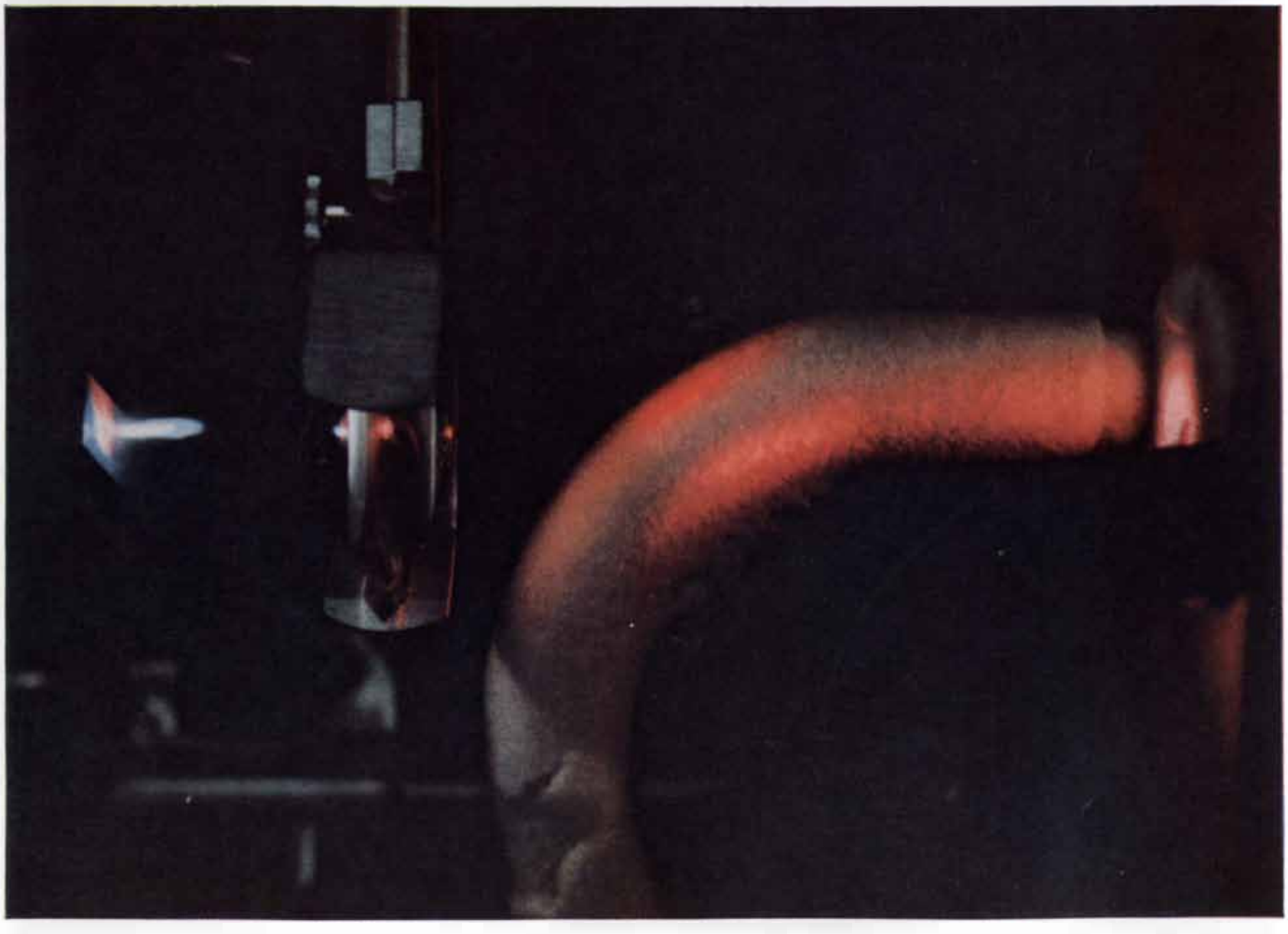
Thus the light that comes from any conventional light source is called spatially incoherent. This means that the light emerges in a jumble of tiny, separate waves that reinforce or cancel each other in random fashion; the wave front so produced varies from point to point and changes from instant to instant. The wave front resembles one that would be produced by throwing a handful of pebbles into a pool. If, on the other hand, only a single pebble were dropped into the pool, a coherent circular wave front would be produced. By the same token one can imagine a point source of light that could generate coherent waves whose fronts would form spherical surfaces. Alternatively, a suitable source might generate coherent light waves whose fronts were plane surfaces; at every point on the plane the strength of the electric field would be the same. As the wave fronts traveled past a given point in space, the field strength would be seen to rise and fall smoothly and rhythmically in phase, swinging from positive to negative in value.

If a conventional electronic oscillator that produces radio waves is connected to a small radiator of suitable design, the radiator will send out spherical coherent waves. If one wishes, the oscillator can be connected to feed a number of radiating antennas that will send out a directional wave, much like a plane wave.

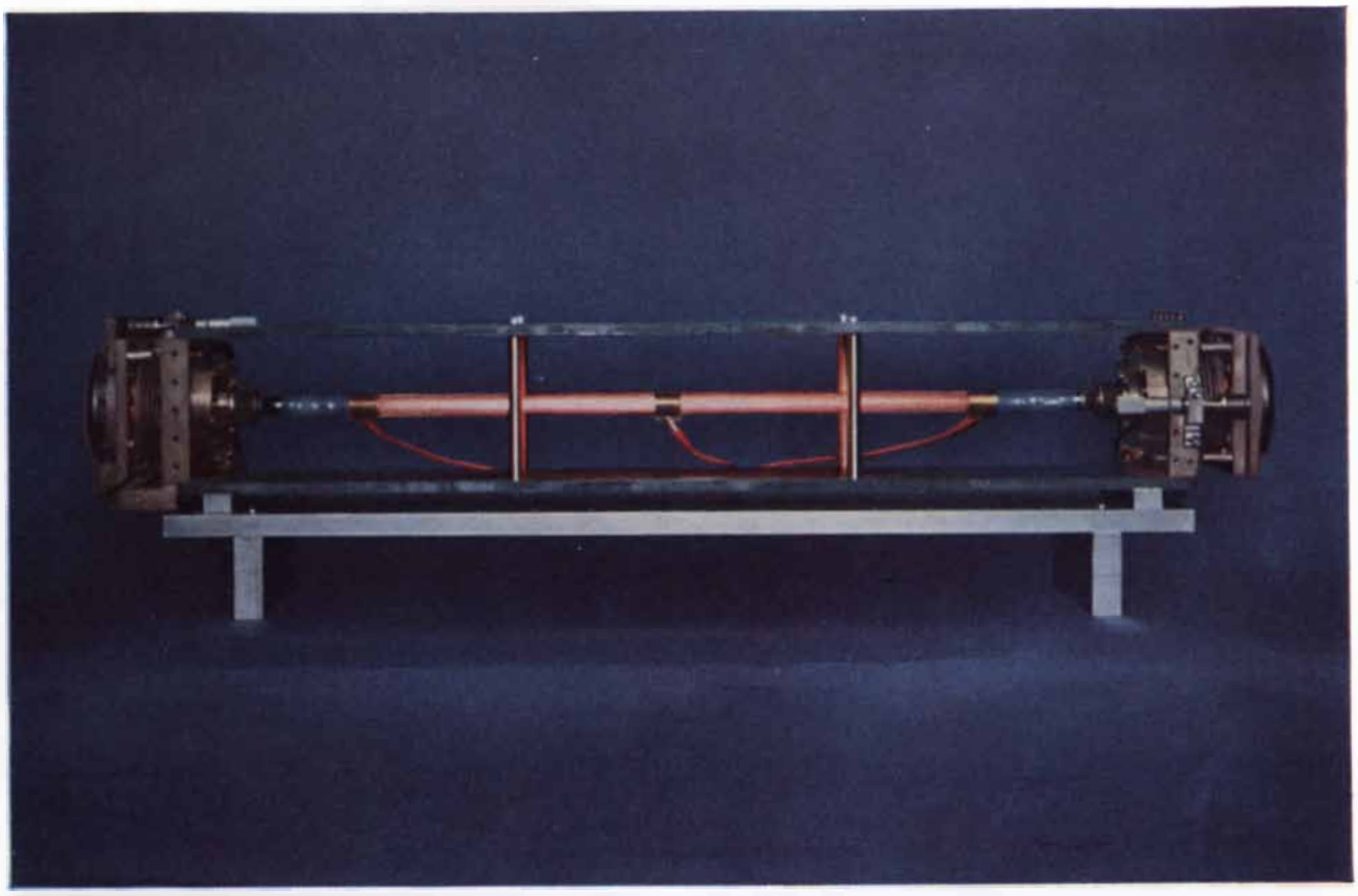
To obtain a directional wave from an incoherent light source one must start with a source of small dimensions. Then, by placing a screen with a hole in it some distance from the source, we can select the segment of the wave that happens to be going in the desired direction. Alternatively, the light emitted by a small source can be focused with a larger mirror or lens to yield a beam with sides that are roughly parallel. The sides of a beam produced by an arc lamp and a six-foot mirror diverge at an angle of about one degree. As we shall see, the output of an optical maser is both more directional and more coherent.

Perhaps the most important limitation of ordinary light sources is their inherent low brightness. No matter how

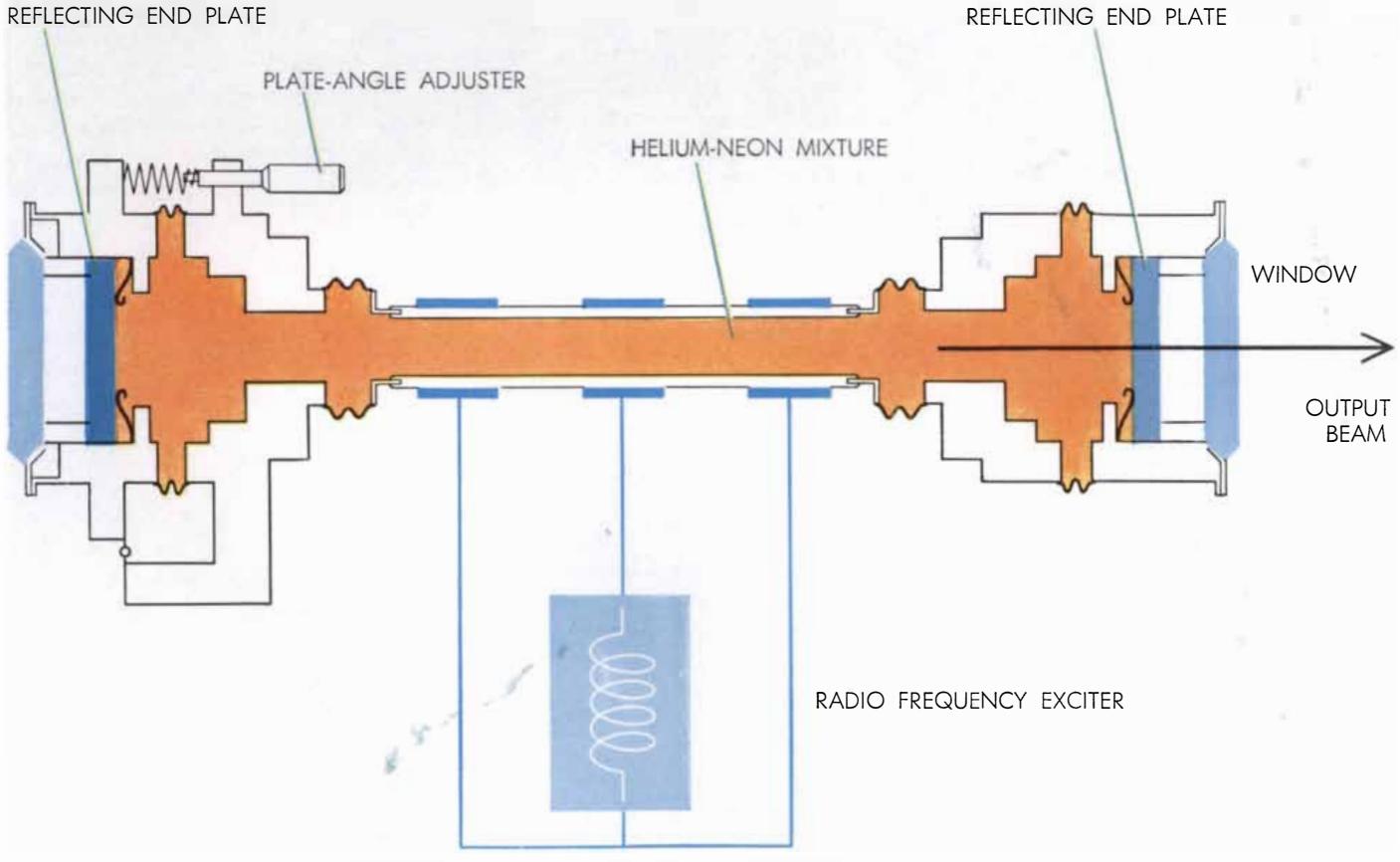
BEAM FROM RUBY OPTICAL MASER makes a thin streak of red light as it passes through smoke. Upper end of curved cooling tube at right is attached to front end of the maser housing, which here cannot be seen. The ruby crystal is mounted in the housing.



BRILLIANT BLUE-WHITE FLAME at left is incandescent carbon vapor produced by focusing a ruby-maser beam on a carbon target. The beam heated a spot on the target to about 8,000 degrees centigrade in .0005 second. The large curved object to the right is the same cooling tube seen in the photograph at top. The small lens used to focus the beam is mounted at the left of the tube.



GAS OPTICAL MASER employs a helium-neon mixture to produce an infrared beam. Reddish glow results from gas discharge of mixture. The gas maser, designed by Ali Javan, W. R. Bennett, Jr., and D. R. Herriott, was the first to operate continuously.



OPERATION OF GAS MASER depends on right mixture of helium and neon gases to provide an active medium. Radio frequency exciter puts energy into the medium. The output beam is built up by repeated passes back and forth between reflecting end plates.

high their temperature, they cannot emit more energy than a perfect radiator. The theoretical output of a perfect radiator, called a black body, is given by the famous black-body radiation curve first derived by Max Planck. The visible surface of the sun, for example, behaves much like a black body with a temperature of 6,000 degrees centigrade. The sun's total radiation, at all wavelengths, is seven kilowatts per square centimeter of its surface, and no matter how we collect and concentrate sunlight it is impossible to achieve any greater radiation density.

Although seven kilowatts may seem a substantial amount of energy, it is really not very much if one considers the tremendous width of the solar spectrum. To bring this point home let us compare the width of the visible portion of the electromagnetic spectrum with the width of a standard television channel, which is four megacycles. A little calculation shows that the visible region between the wavelengths of 4,000 and 7,000 angstrom units could contain 80 million television channels. In other words, each angstrom unit is about 100,000 megacycles wide. If one were able to filter out a narrow band of green light one megacycle wide from the region where the sun has its peak energy output (4,800 angstrom units), one would find that each square centimeter of solar surface produces only .00001 watt. To obtain as much as a single watt of green light one megacycle wide one would have to collect and filter the output from 10 square yards of solar surface. In contrast, man-made transmitters operating in the television region of the radio spectrum can easily generate 10,000 watts in a band much less than one megacycle wide.

Ordinary light sources are like the sun: they are broad-band noise generators that spread their output over a wide range of frequencies without supplying much power at any particular frequency. Even gas-discharge lamps, which emit light at a restricted number of narrow lines in the spectrum, do not approach the best electronic oscillators as sources of power at a single frequency.

There has been, of course, a great effort to extend electronic oscillators to shorter wavelengths. The length of the shortest waves that can be generated by electronic means is about one millimeter, or 10 million angstrom units. Any attempt to reach shorter wavelengths with conventional electronic designs meets with formidable difficulties. Foremost among these is the difficulty of fabricating the resonant structures that tune the oscillator. These structures can seldom be much larger than a wavelength in size. At millimeter wavelengths they are already so small that they are hard to make with uniform accuracy. To produce optical wavelengths, which are three orders of magnitude shorter, a radically different approach is needed.

An attractive solution to the problem would be to stop trying to build these tiny resonators and to replace them by atomic or molecular resonators. Nature has provided us with a wide variety of such resonators through the entire infrared, visible and ultraviolet spectrum. Indeed, engineers are accustomed to using atomic oscillators in gas-discharge lamps. A single atom, however, radiates very little power, and that only intermittently. What is needed is some way to synchronize a large number of atoms so that they can work together to produce a powerful, coherent wave.

Such an approach has been made possible by the maser principle, discovered by Charles H. Townes at Columbia University [see "The Maser," by James P. Gordon; SCIENTIFIC AMERICAN, December, 1958]. Maser stands for "microwave amplification by stimulated emission of radiation." The original maser, completed in 1954 by James P. Gordon, H. J. Zeiger and Townes, used the vibrations of ammonia molecules to provide microwave oscillations of precisely determined frequency. Subsequently Nicolaas Bloembergen of Harvard University indicated a practical way to build the so-called three-level solid-state maser for use as a low-noise microwave amplifier. The first maser of this type was built at the Bell Telephone Laboratories by George Feher, H. E. D. Scovil and H. Seidel, and since then many others have been constructed. Radio astronomers have found them extremely valuable for amplifying very faint radio signals from space. Last year masers were also used to amplify the weak signals received on the bounce from the *Echo* satellite.

Stimulated emission, which is the basis of maser operation, is the reverse of the process in which electromagnetic waves, or photons, are absorbed by atomic systems. When a photon is absorbed by an atom, the energy of the photon is converted to internal energy of the atom. The atom is then raised to an "excited" quantum state. Later it may radiate this energy spontaneously, emitting a photon and reverting to the "ground" state or to some state in between. During the period in which the atom is still excited it can be stimulated to emit a photon if it is struck by an outside photon having precisely the energy of the one that would otherwise be emitted spontaneously. As a result the incoming photon, or wave, is augmented by the one given up by the excited atom. More important and more remarkable, the wave, upon release, falls precisely in phase with the wave that triggered its release. This phenomenon lies at the heart of the maser principle [*see illustration on following page*].

The problem in designing a maser is to prepare an "active medium" in which most of the atoms can be placed in an excited state, so that an electromagnetic wave of the right frequency passing through them will stimulate a cascade of photons. There must be an excess of excited atoms to enable stimulated emission to predominate over absorption. Atoms are raised to an excited state by injecting into the system electromagnetic energy at a wavelength different from the stimulating wavelength; the activating process is called "pumping."

Once an active medium has been prepared it can be enclosed in a reflecting box, or cavity resonator. Then a wave that starts out at one wall of the box will grow in amplitude until it reaches another wall, where it will be reflected back into the mass of excited atoms. Inevitably there are losses at the walls due to imperfect reflection. If the amplification by stimulated emission is great enough to make up for these reflection losses, a steady wave will build up in the box. At centimeter wavelengths it is not difficult to build a box having the dimensions of a wavelength and so designed that the wave will build up with only one mode of oscillation. A single mode of oscillation corresponds to a single frequency of output; extraneous modes create extra frequencies, or noise, and compete with the desired mode in extracting energy from the supply of excited atoms.

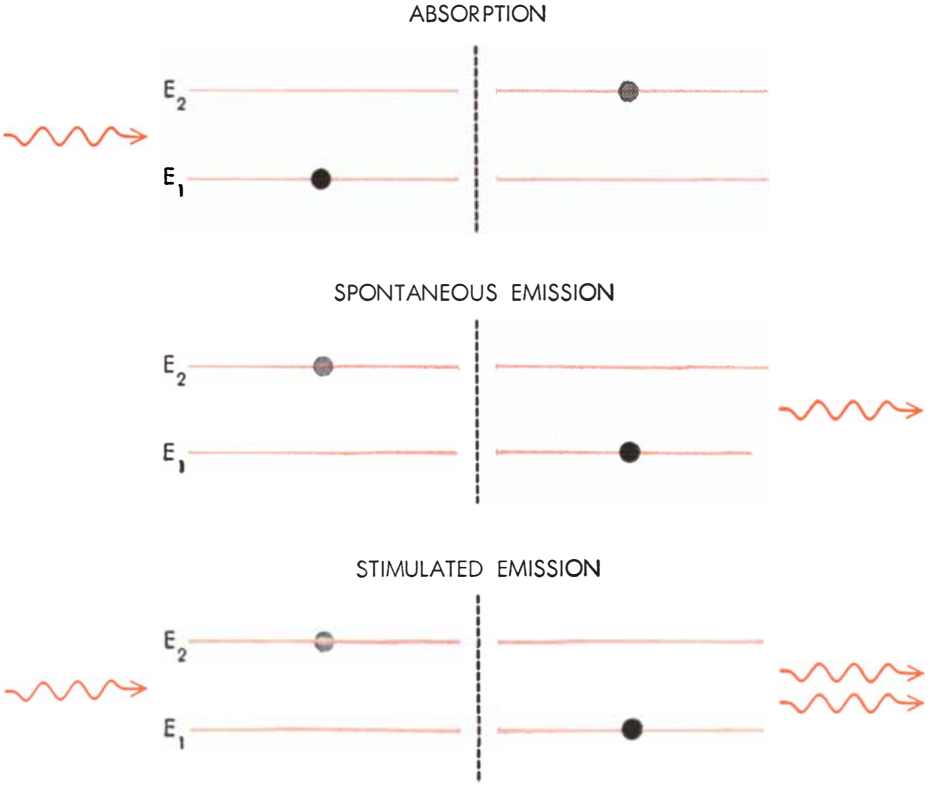
At optical wavelengths a single-wavelength resonator would have dimensions inconveniently small. To surmount this problem, Townes and the author proposed in 1958 that a maser for optical wavelengths could be built by making a special kind of resonator with dimensions thousands of times greater than the emission wavelength but which nevertheless would favor a particular mode of oscillation. In the optical maser the reflecting box is replaced by a device or structure with two small mirrors facing each other. A wave that starts out near one mirror and travels along the axis of the system will grow by stimulated

emission until it reaches the other mirror. There it will be reflected back into the active medium so that growth can continue. If the gain on repeated passages is enough to make up for the losses at the mirrors, a steady wave will be built up. If one of the mirrors is semitransparent, a portion of the wave can escape through it, constituting the output of the maser.

It is perhaps evident that a wave inclined at an angle to the axis will leave the system after only a few reflections, or perhaps without ever striking one of the mirrors. Such a wave will not have the same opportunity to build up as does a wave that travels straight along the axis of the system. Like other maser oscillators, the optical maser Townes and I described would be triggered off by the first photons to be emitted spontaneously after the system had been "pumped up" to the active state. (A maser designed to operate as an amplifier, on the other hand, uses an input signal as a stimulating wave.)

We had every reason to expect that the output of an ideal optical maser constructed in this manner would be extremely directional, very powerful, essentially monochromatic and, above all, coherent. The output would be directional because the only waves emitted would have had to make repeated passages—perhaps thousands—without deviating very far from the axis of the maser. It would be very powerful because stimulated emission forces excited atoms to radiate much earlier than they would spontaneously. It would be very monochromatic because stimulated emission is a resonant process and takes place most strongly at the center of the band of frequencies that can be emitted in spontaneous radiation. These favored frequencies will in turn cause emission at the same frequency, so that the wave built up in the maser will contain only an extremely narrow range of frequencies or wavelengths.

Finally, the output of the optical maser, if it is a good approximation of a plane wave traveling in a single direction, will be spatially coherent because all the wave fronts are planes perpendicular to the direction of propagation. Since the maser output is nearly monochromatic, it also has time coherence. This means that there is a fixed phase relation between the portion of the wave emitted at one instant and the wave emitted after a fixed time interval. For a wave whose period is one second, crests follow each other at one-second intervals. On the other hand, if the frequency varies, the interval between crests is irregular. The more nearly the wave holds to a single, fixed frequency, the more nearly it exhibits time coherence.

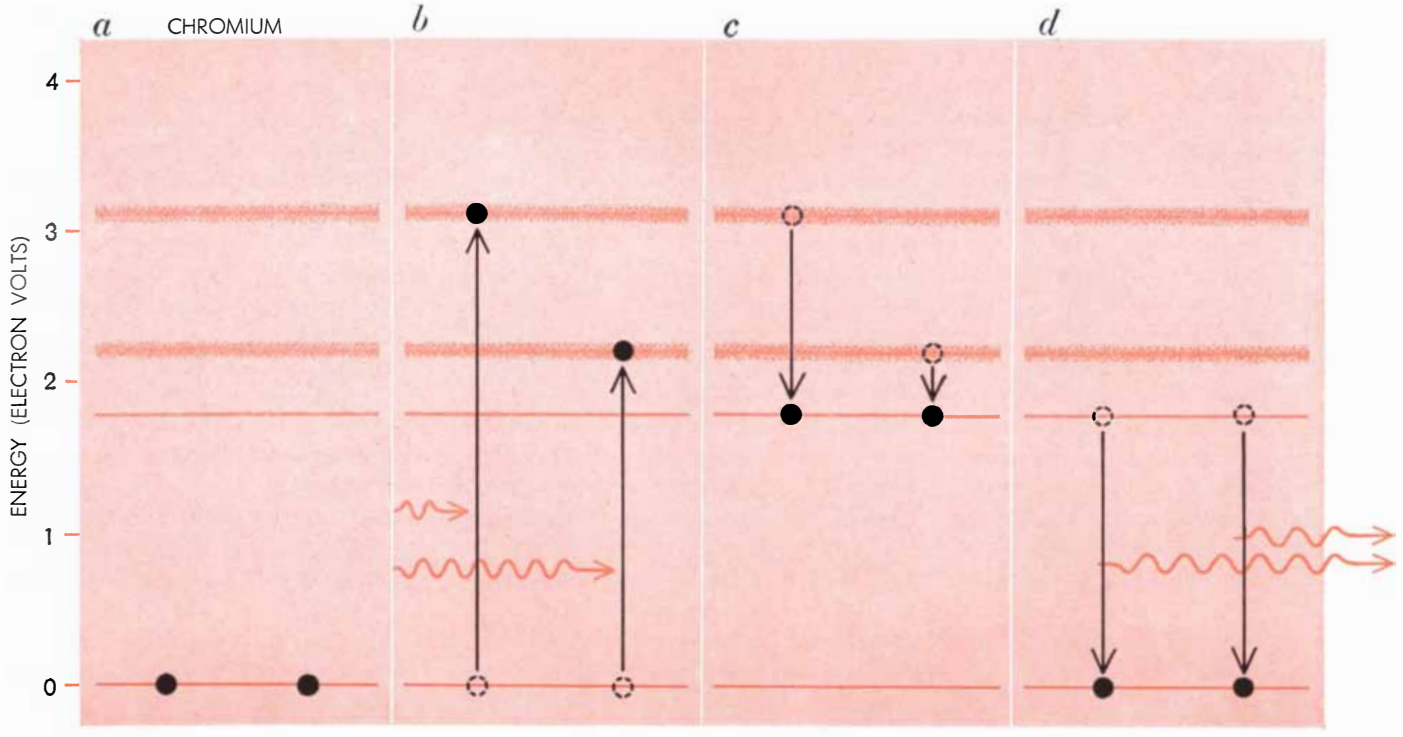


STIMULATED EMISSION of photons (*bottom*), the basis of maser operation, is contrasted with absorption (*top*) and spontaneous emission (*middle*). When an atom in the "ground" state (*black dot at top left*) absorbs a photon (*wavy colored arrow*), it is excited, or raised to a higher energy state (*gray dot at top right*). The excited atom (*middle left*) may then radiate energy spontaneously, emitting a photon and reverting to the ground state (*middle right*). An excited atom (*bottom left*) can also be stimulated to emit a photon when it is struck by an outside photon. Thus in addition to the stimulating photon there is now a second photon of the same wavelength (*bottom right*) and the atom reverts to the ground state.

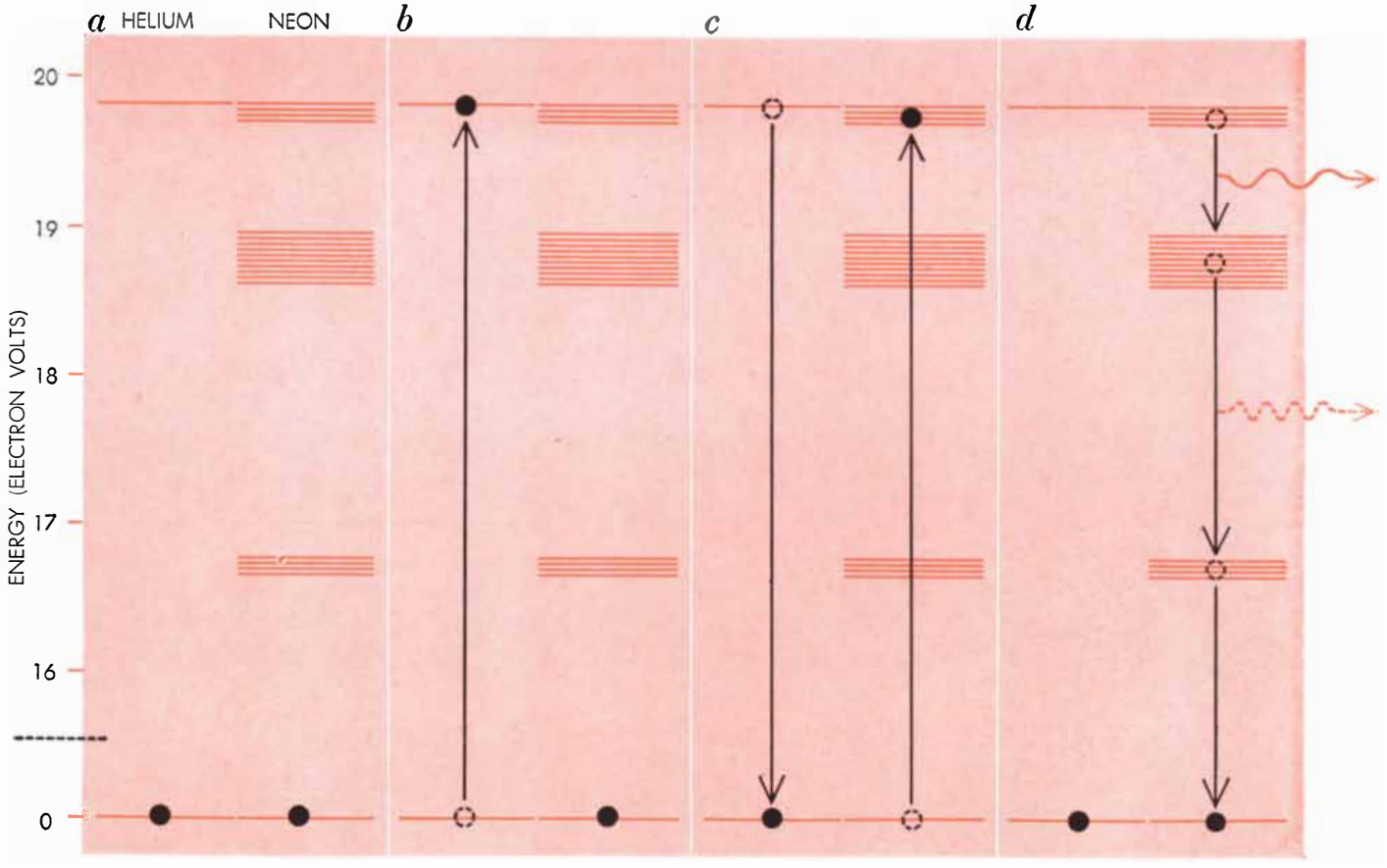
Testing these predictions required preparation of an active medium that would actually display maser action in the optical region of the spectrum. The first announcement of success was made last July by T. H. Maiman of the Hughes Aircraft Company, whose device used a ruby crystal. Between July and the end of 1960 four other substances were tested successfully by various investigators. These devices all embodied the concept of reflecting end walls, described above. At last count optical maser oscillations had been obtained at 11 different wavelengths. It seems likely that these wavelengths will soon be joined by many others.

Maiman's ruby maser is typical of those using crystals. Ruby is aluminum oxide in which a few of the aluminum atoms have been replaced by chromium atoms; the more chromium, the deeper the color. Maiman used a pale pink ruby containing about .05 per cent chromium. The color results from the fact that the chromium atoms in the crystal absorb a broad band of green and yellow light, along with ultraviolet light, and let only the red and blue pass through. Moreover, the light that is absorbed raises the chromium atoms to an excited state from which two steps are required to carry them back to the ground state. In the first step they give up some of their energy to the crystal lattice and land temporarily in what is called a metastable state. If they are not subjected to stimulation, their stay at this level lasts a few milliseconds while they drop at random to the ground state. Photons emitted during this final drop have a wavelength (at room temperature) of 6,943 angstrom units, which accounts for the characteristic red fluorescence of ruby crystals. In an optical maser, however, the first few photons released at this wavelength stimulate the still excited chromium atoms to give up photons and tumble to the ground state much sooner than they would normally; the result is a cascade of photons all at the 6,943-angstrom wavelength.

For use in an optical maser the pink ruby is machined into a rod about four centimeters long and half a centimeter



CHROMIUM ATOMS (*black dots*) in a ruby maser crystal are "pumped" to higher energy levels and then stimulated to emit photons, producing a maser beam. Atoms in the ground state (*a*) absorb photons (*wavy colored arrows*), which pump them to one of two energy "bands" (*b*). The atoms give up some of their energy to the crystal lattice and fall to a metastable energy level (*c*). When stimulated by photons from other chromium atoms, they emit photons of a characteristic wavelength and fall to ground state (*d*).



HELIUM AND NEON ATOMS (*black dots*) constitute the active medium of the gas maser. At the start both are in the ground state (*a*). Electron bombardment pumps helium to a higher energy level (*b*). When helium and neon atoms collide, the helium loses its energy to the neon, which is raised to one of four distinct energy levels (*c*). When stimulated by an outside photon, the neon contributes a photon (*wavy colored arrow at top in "d"*) to the maser beam and falls to one of 10 energy levels. The neon then reverts to the ground state in steps; the photon emitted in the first step (*wavy broken arrow*) does not contribute to the maser beam.

across. Its ends are polished optically flat and parallel and are partially silvered. The rod is placed near an electronic flash tube that provides broadband pumping light. What Maiman discovered before anyone else is that the most powerful of these lamps, when connected to a large power supply, is capable of raising most of the chromium atoms to the excited state. Up to a certain critical flash intensity, all that happens is that the ruby emits a burst of its typical red fluorescence spread over the usual decay period for the excited atoms. But above a critical level maser action takes over, and an intense red beam, lasting for about half a thousandth of a second, flashes out from the partially silvered ends of the rod. This shows that a sufficient excess of atoms has been pumped up to the excited state to make up for the losses at the ends.

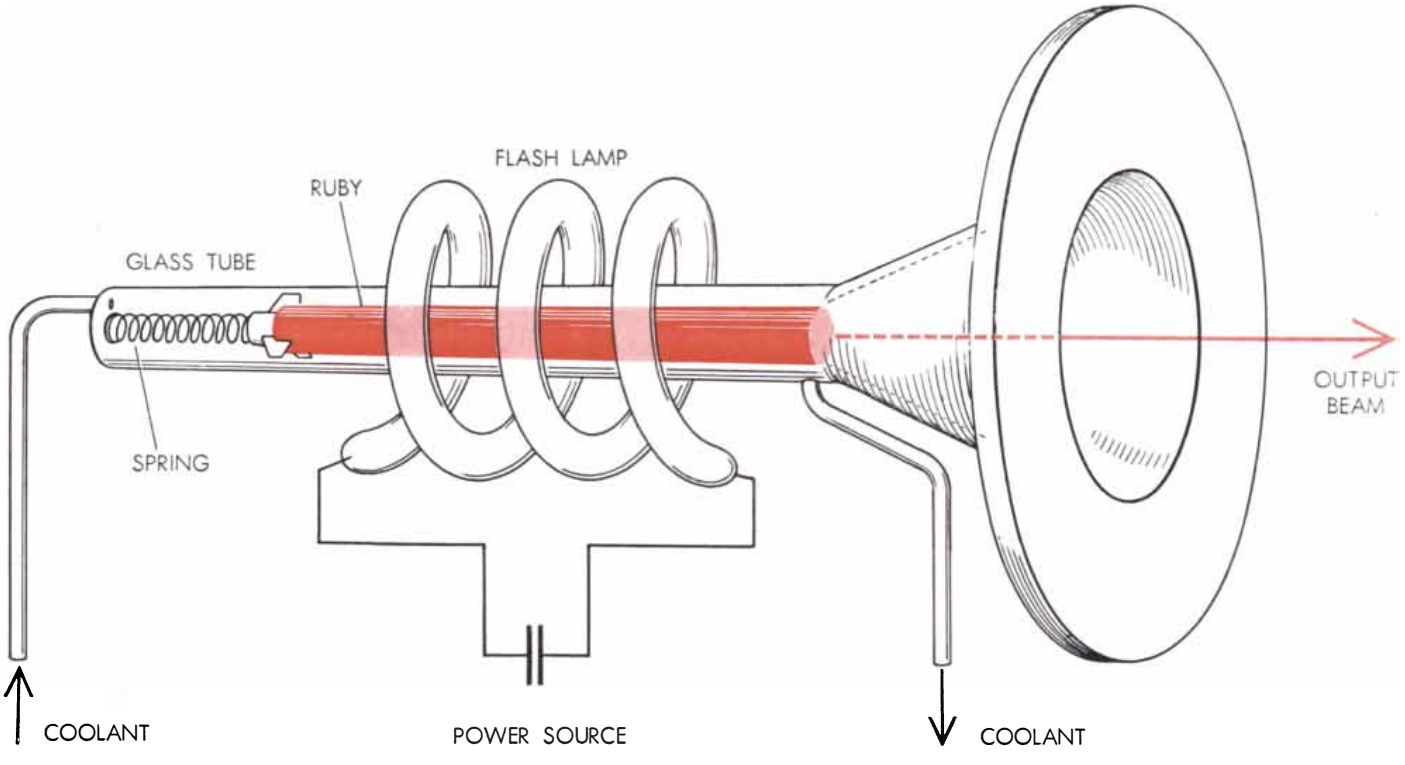
In 1959 the author had predicted that it should be possible to build an optical maser using a dark red ruby that contains about 10 times as much chromium as the pink ruby. It was predicted that at this higher concentration maser action would take place simultaneously at two different wavelengths—7,009 and 7,041 angstroms [*see illustration on opposite page*]. This mode of operation was recently demonstrated in a maser built by G. E. Devlin and the author, and in another built by I. Wieder and L. R. Sarles of Varian Associates. Still other solid optical masers, using samarium or uranium ions in a calcium fluoride crystal, have been constructed by P. P. Sorokin and M. J. Stevenson of the International Business Machines Research Laboratory. These masers oscillate at wavelengths of 7,080 and 25,000 angstroms respectively.

All these masers were first operated in short bursts, but they seem potentially capable of continuous operation. The active medium used by Maiman, however, is less well suited than the others in which the stimulated emission comes in a transition to an intermediate energy level that is some distance above the ground state. It is not necessary, therefore, to expend a lot of energy pumping half the atoms out of the ground state so that emission can predominate over absorption. In the newer materials the intermediate state—where the atoms land after emitting photons of the desired frequency—can be emptied simply by cooling. Hence the active medium contains very few atoms "tuned" to absorb the photons produced by maser action. Only enough pumping is needed for this action to begin.

A totally different way to obtain excited atoms for an optical maser employs gas atoms in an electric glow-discharge under very special conditions. In a mixture of helium and neon gas it is possible to secure maser oscillation at several wavelengths in the infrared region around 10,000 angstroms. This system was proposed in 1959 by Ali Javan of the Bell Telephone Laboratories. A successful prototype, constructed by him in collaboration with W. R. Bennett, Jr., and D. R. Herriott, was demonstrated early this year. The principal feature of this maser is its ability to operate continuously and with a very low energy input—about 50 watts in the first model.

In Javan's maser the stimulated emission occurs when a neon atom falls between two intermediate levels, the lower of which is well above the ground state. Only a modest input of energy is required to produce a gas discharge—essentially like that in an ordinary neon sign—and this in turn provides a continuous supply of neon atoms at the proper level of excitation needed to produce a continuous maser beam [*see illustrations on page 54*]. As in the ruby masers, the beam is built up and made coherent by bouncing back and forth between reflecting end plates.

The helium-neon maser exemplifies the increasing subtlety of maser designs. The energy needed to raise the neon atom to an excited state is not supplied directly by an incoming photon; it is supplied by collision with an excited helium atom. Many other possibilities remain to be explored. Energy levels suitable for masers may be found in many different kinds of system. For ex-



RUBY MASER is powered by a flash lamp, which provides pumping energy. Output beam is emitted through partially silvered end of ruby crystal; other end is completely silvered. Beam builds up by repeated reflection between the ends. Liquid nitrogen is used to cool the ruby, though it can also be operated at room temperature. Only the front end of the maser housing (*right*) is shown.

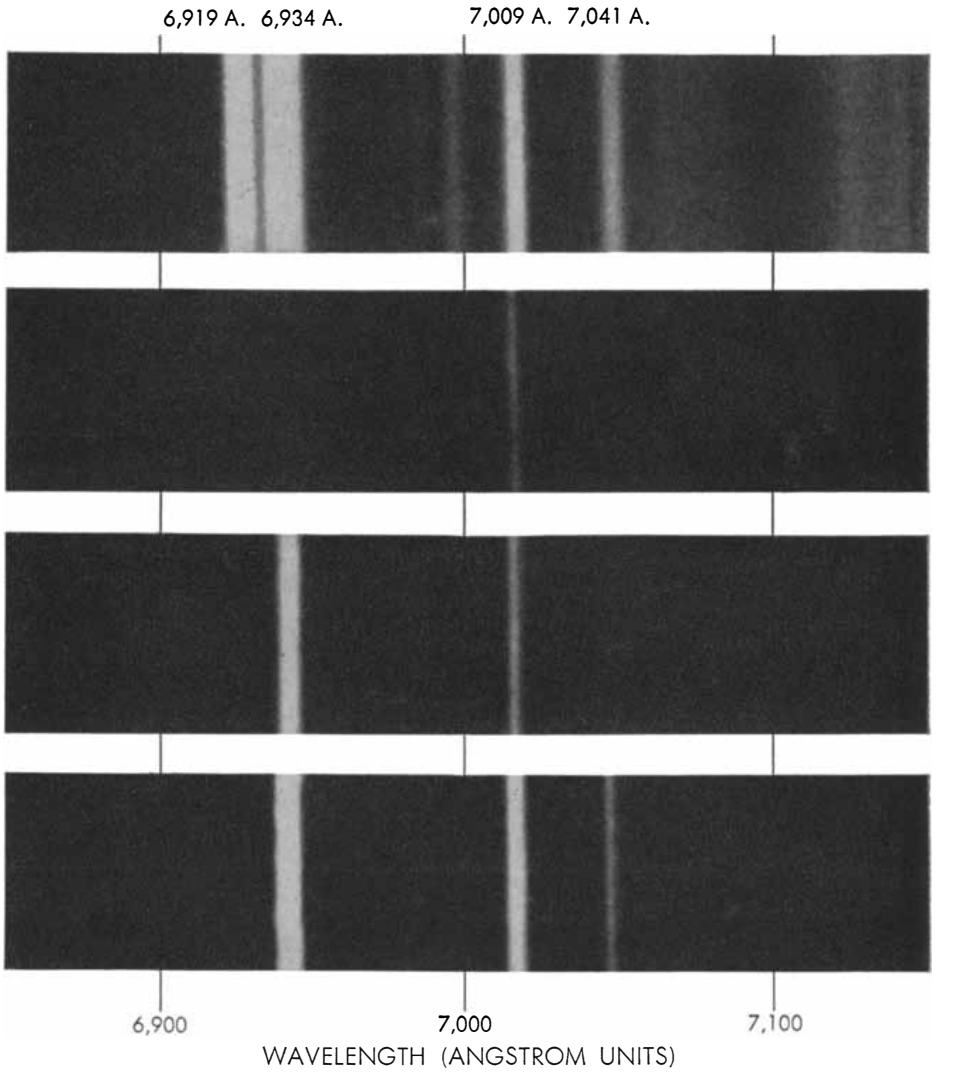
ample, in the infrared region spectral lines are produced by vibrations of gas molecules, by vibrations of crystals and by electronic excitations of certain atoms in crystals. Which of these may be usable in a maser can be discovered only by a detailed study of a system's spectrum.

Now that optical masers have been built, how closely do they match expectations in power, directionality, coherence and the narrowness of the band of wavelengths produced? We know most about the pink ruby. In short bursts its power output reaches 10,000 watts for a beam measuring less than a square centimeter in cross section. The sides of the beam are parallel to within less than half a degree; at lower power the divergence drops to about a twentieth of a degree. The latter divergence corresponds to a spread of only five feet per mile, and it could be reduced by running the beam through a telescope backward. With telescopic demagnification it should not be difficult to project on the moon a spot of light only two miles in diameter.

If desired, the maser's power can be focused to produce intense heating. For instance, a lens with a focal length of one centimeter will focus the beam to a spot only a hundredth of a centimeter in diameter, corresponding to an area of one ten-thousandth of a square centimeter. In this spot the maser beam will deliver power at a density of 100 million watts per square centimeter. Brief though the flash is, its power is thousands of times greater than could be obtained by focusing sunlight and is enough to melt or vaporize a spot on the surface of even the most refractory material. This was first demonstrated by my colleague W. S. Boyle [*see bottom illustration on page 53*].

It is not surprising that the ruby maser falls short of ideal performance in some respects, particularly in the narrowness of the band of wavelengths it produces. Because it is violently pulsed, the ruby rod heats appreciably. Nevertheless, when the maser threshold level is reached, the band of wavelengths narrows to about .02 angstrom, or about 1,000 megacycles. This is as narrow as the sharpest spectral line from any nonmaser light source.

The ruby is far surpassed in the narrowness of its output of wavelengths by the gas maser of Javan, Bennett and Herriott. This maser produces spectral lines less than one kilocycle wide at a carrier frequency of 100,000 megacycles. The gas maser's power output per kilocycle of band-width is about 100 million



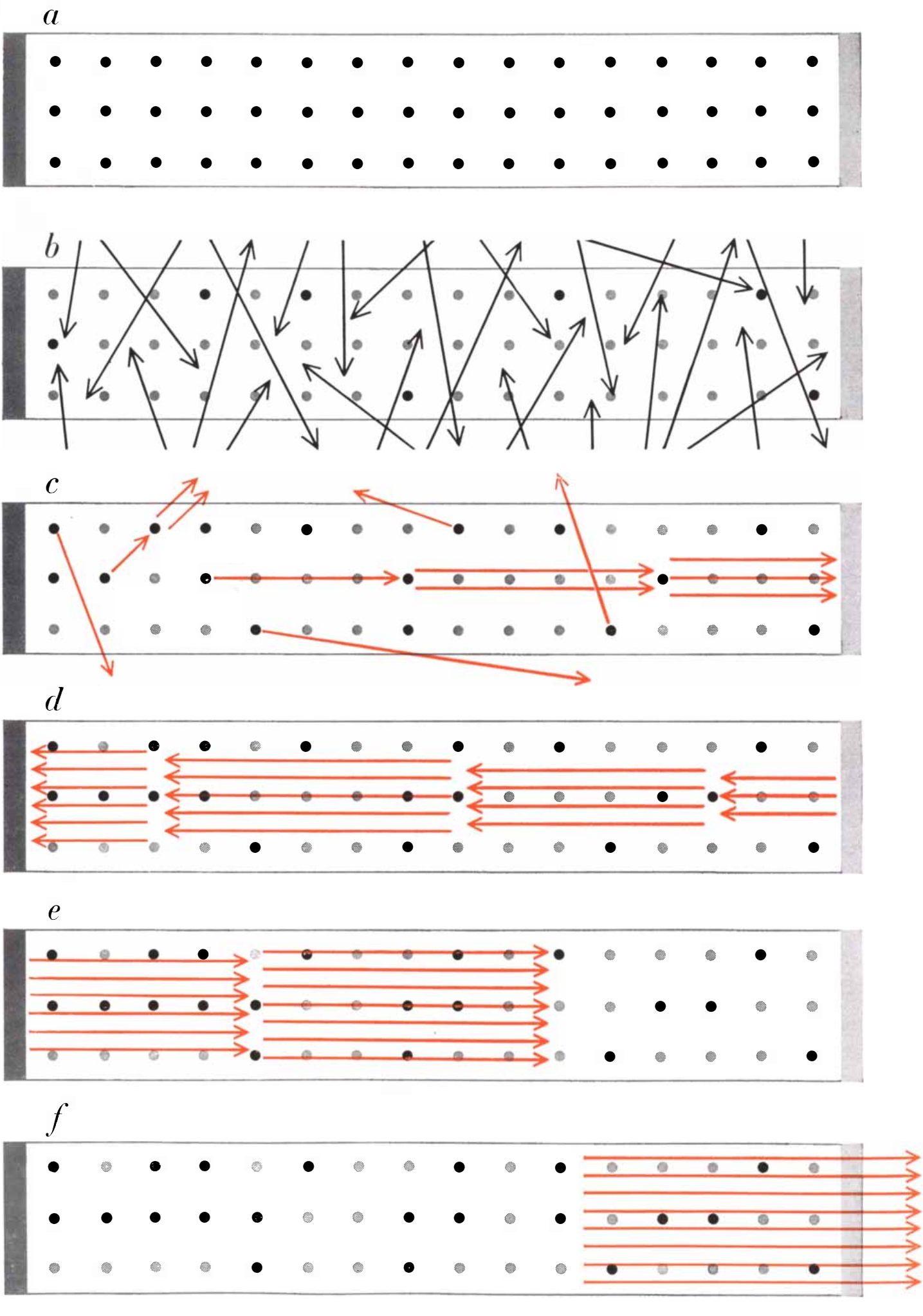
RUBY-MASER SPECTRA in three lower photographs are compared with spectrum of spontaneous (unstimulated) ruby fluorescence at top. As pumping power reaches first threshold for maser action (*second from top*), the ruby "mases" at 7,009 angstrom units (A.), at two wavelengths as power increases (*third from top*), then at three (*bottom*). Maser oscillation never occurs at 6,919 A. Sequence in which spectral lines appear varies with the maser crystal used and operating conditions. A 30-second exposure was required to photograph the fluorescent spectrum. Three lower photographs show single flashes of .0005 second.

times that of a square centimeter of the sun's surface. It is possible that the frequency of a maser's output will drift slightly over a period of time, but over a short period it is remarkably stable; in the radio range this stability is equaled only by the finest frequency standards and by atomic clocks.

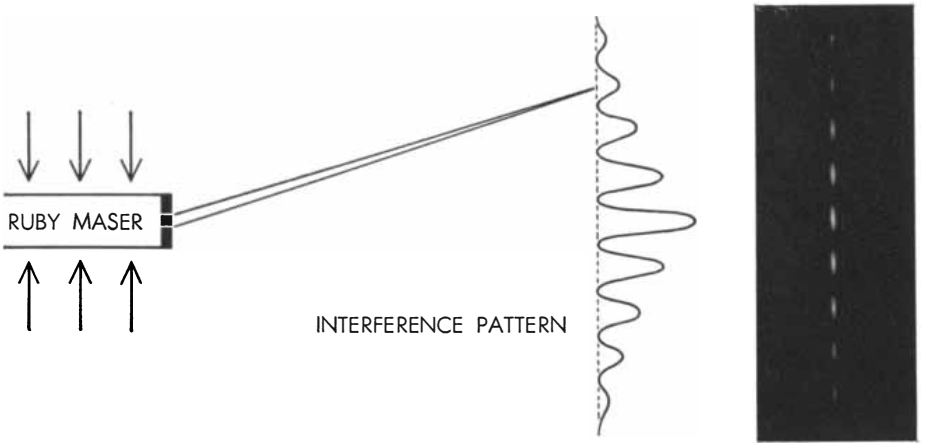
Of all the properties of the optical maser, none is more striking than the spatial coherence of its light. This is readily demonstrated by using the maser to repeat the classic two-slit interference experiment first performed in 1806 by Thomas Young to show that light consists of waves. In Young's experiment light passes through two parallel slits and then falls on a distant screen. If light waves from one slit reach a point on the screen in phase with light waves from the other slit, the two sets of waves reinforce, producing a bright spot. At a nearby point on the screen, where the light from one slit has traveled half a wavelength farther than the light from the other slit, the waves cancel out, producing a dark spot. Thus a pattern of alternating light and dark spots appears on the screen.

As the experiment is usually performed, a small light source is placed some distance from the slits, so that the wave fronts reaching them travel nearly perpendicularly to their plane. If the source is too large or too close to the slits, the pattern fails to appear. Young's experiment is therefore a good test for the perpendicularity of wave fronts and for wave coherence.

When the experiment is performed with an optical maser, the slits can be placed directly against the surface from which the beam emerges and a clear interference pattern will result [*see illus-*



tration at right]. The pattern agrees well with one calculated on the assumption of perfect coherence across the distance between the slits. Actually, in a ruby rod the region of coherence is usually limited by crystalline imperfections to about a tenth of the rod's diameter. In the gas maser, however, coherence extends across the whole width of the end plates.



TWO-SLIT INTERFERENCE EXPERIMENT demonstrates that the light waves leaving a ruby maser are spatially coherent, or in step. When two coherent waves strike a screen, after traveling paths of slightly different length, they reinforce and cancel each other in symmetrical fashion to produce an interference pattern. The photograph of the interference pattern at right was made by D. F. Nelson and R. J. Collins of Bell Telephone Laboratories.

The optical maser is such a radically new kind of light source that it taxes the imagination to canvass its possible applications. Message-carrying, of course, is the most obvious use and the one that is receiving the most technological attention. Signaling with light, although it has been used by men since ancient times, has been limited by the weakness and noisiness of available light sources. The amount of information light signals can carry is thereby quite limited. An ordinary light beam can be compared to a pure, smooth carrier wave that has already been modulated with noise by short bursts of light randomly emitted by the individual atoms in the light source. The maser, on the other hand, can provide an almost ideally smooth wave, carrying nothing but what one puts on it.

If suitable methods of modulation can be found, coherent light waves should be able to carry an enormous volume of information. This is so because the frequency of light is so high that even a very narrow band of the visible spectrum includes an enormous number of cycles per second; the amount of information that can be transmitted is directly proportional to the number of cycles per second and therefore to the width of the band. One must distinguish here between the spectral band-width of the unmodulated maser beam, or carrier wave (which, as we have seen, is extremely narrow), and the band-width after a signal has been impressed upon it. In television transmission the carrier wave (which is also narrow) carries a signal that produces an effective band-width of four megacycles. A single maser beam might reasonably carry a signal with a frequency, or band-width, of 100,000 megacycles, assuming a way could be found to generate such a signal. A signal of this frequency could carry as much information as all the radio-communication channels now in existence. It must be admitted that no light beam will penetrate fog, rain or snow very well. Therefore to be useful in earthbound communication systems light beams will have to be enclosed in pipes.

There will certainly be other uses for optical masers. The very intense heat spot produced by focusing an optical maser might be used for fabricating all sorts of electronic devices. For instance, it would be possible to weld a small joint after the joint had been sealed inside a glass envelope. But, in addition to sheer power, the maser provides an intense source of coherent radiation with very high electric-field strength. In such strong fields atoms or molecules may react in strange and unpredictable ways. The beams should therefore be useful in many areas of research. One can also conceive of using maser beams in harmonic generators or mixers. With a suitable mixer one could put in two light waves of different frequency and take out a third wave whose frequency would be the difference of the two original frequencies. In this way it should be possible to synthesize wavelengths that cannot be produced directly. This should lead eventually to superheterodyne receivers capable of translating optical wavelengths into any desired longer wavelength.

It has been known for some years that if one had a strong enough source of infrared radiation of the right frequency, it would be possible to excite vibrations in a particular species of molecule. Any other molecules that might be present would not be affected. Because the excited molecules would react more vigorously than the others, it should be possible to exert a highly selective control over some chemical reactions. Up to now all available light sources have been far too weak for such possibilities to be taken seriously, but optical masers may eventually make such control a reality.

It should be realized that we are talking about a whole family of devices embracing a wide range of frequencies, power ratings and band-widths. The family will include not only oscillators but also amplifiers. One type will be useful for amplifying a light signal that has been weakened by traveling a long distance, perhaps through pipes or through interplanetary space. Another type of amplifier will be able to intensify an entire image—for example, the faint image of a star—that is fed into it.

The list of potential applications of the optical maser could be extended almost indefinitely. With the advent of the optical maser, man's control of light has reached an entirely new level. Indeed, one of the most exciting prospects for workers in the field is that this new order of control will open up uses for light that are as yet undreamed of.

PHOTON CASCADE in a solid optical maser amplifies a light wave by stimulated emission. Before the cascade begins (*a*), the atoms in the maser crystal are in the ground state (*black dots*). Pumping light (*black arrows in "b"*) raises most of the atoms to the excited state (*gray dots*). The cascade begins (*c*) when an excited atom spontaneously emits a photon (*colored arrow*) parallel to the axis of the crystal. (Photons emitted in other directions pass out of the crystal.) The photon stimulates another atom to contribute a second photon. This process continues (*"d" and "e"*) as the photons are reflected back and forth between the ends of the crystal. When the amplification is great enough, some of the beam passes out through partially silvered end of crystal (*f*).

The Social Life of Baboons

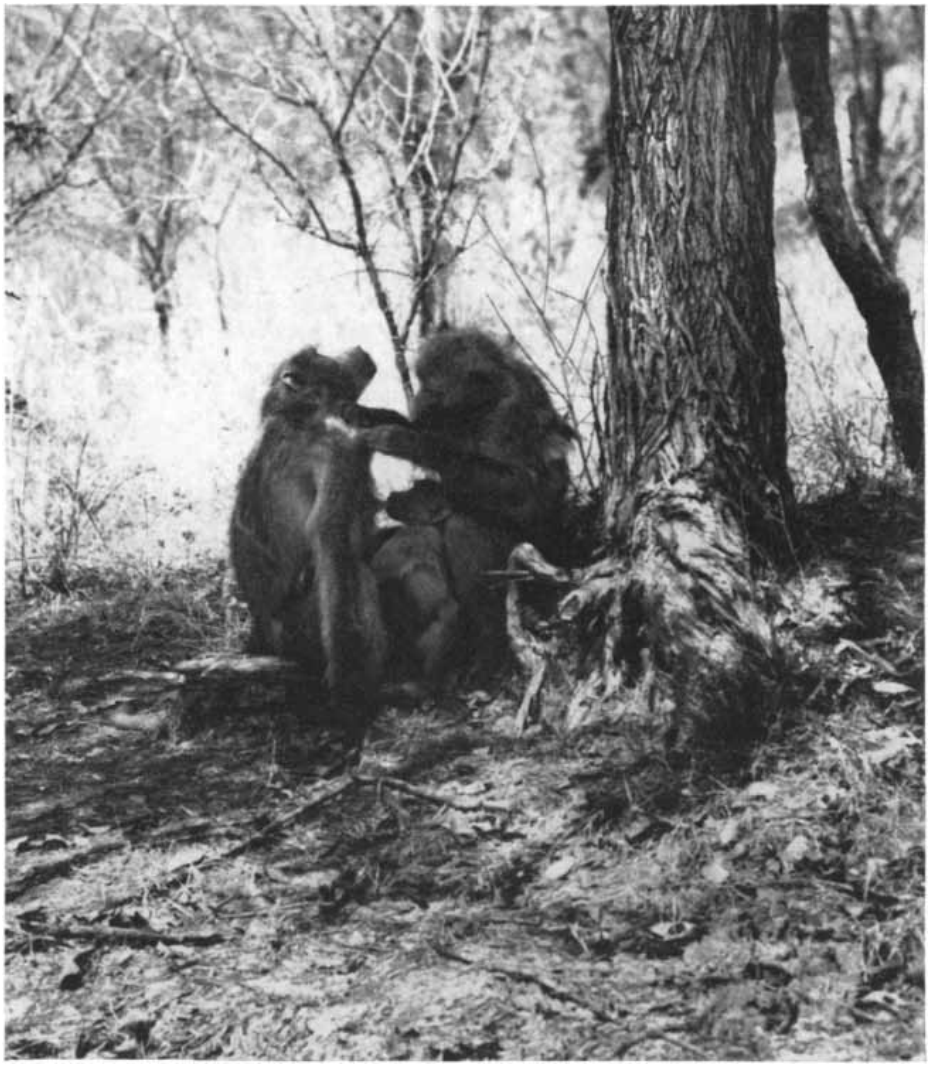
A study of "troops" of baboons in their natural environment in East Africa has revealed patterns of interdependence that may shed light on the early evolution of the human species

by S. L. Washburn and Irven DeVore

The behavior of monkeys and apes has always held great fascination for men. In recent years plain curiosity about their behavior has been reinforced by the desire to understand human behavior. Anthropologists have come to understand that the evolution of man's behavior, particularly his social behavior, has played an integral role in his biological evolution. In the attempt to reconstruct the life of man as it was shaped through the ages, many studies of primate behavior are now under way in the laboratory and in the field. As the contrasts and similarities between the behavior of primates and man—especially preagricultural, primitive man—become clearer, they should give useful insights into the kind of social behavior that characterized the ancestors of man a million years ago.

With these objectives in mind we decided to undertake a study of the baboon. We chose this animal because it is a ground-living primate and as such is confronted with the same kind of problem that faced our ancestors when they left the trees. Our observations of some 30 troops of baboons, ranging in average membership from 40 to 80 individuals, in their natural setting in Africa show that the social behavior of the baboon is one of the species' principal adaptations for survival. Most of a baboon's life is spent within a few feet of other baboons. The troop affords protection from predators and an intimate group knowledge of the territory it occupies. Viewed from the inside, the troop is composed not of neutral creatures but of strongly emotional, highly motivated members. Our data offer little support for the theory that sexuality provides the primary bond of the primate troop. It is the intensely social nature of the baboon, expressed in a diversity of interindividual relationships, that keeps the troop together. This conclusion calls for further observation and experimental investigation of the different social bonds. It is clear, however, that these bonds are essential to compact group living and that for a baboon life in the troop is the only way of life that is feasible.

Many game reserves in Africa support baboon populations but not all were suited to our purpose. We had to be able to locate and recognize particular troops and their individual members



GROOMING to remove dirt and parasites from the hair is a major social activity among baboons. Here one adult female grooms another while the second suckles a year-old infant.

and to follow them in their peregrinations day after day. In some reserves the brush is so thick that such systematic observation is impossible. A small park near Nairobi, in Kenya, offered most of the conditions we needed. Here 12 troops of baboons, consisting of more than 450 members, ranged the open savanna. The animals were quite tame; they clambered onto our car and even allowed us to walk beside them. In only 10 months of study, one of us (DeVore) was able to recognize most of the members of four troops and to become moderately familiar with many more. The Nairobi park, however, is small and so close to the city that the pattern of baboon life is somewhat altered. To carry on our work in an area less disturbed by humans and large enough to contain elephants, rhinoceroses, buffaloes and other ungulates as well as larger and less tame troops of baboons, we went to the Amboseli game reserve and spent two months camped at the foot of Mount Kilimanjaro. In the small part of Amboseli that we studied intensively there were 15 troops with a total of 1,200 members, the troops ranging in size from 13 to 185 members. The fact that the average size of the troops in Amboseli (80) is twice that of the troops in Nairobi shows the need to study the animals in several localities before generalizing.

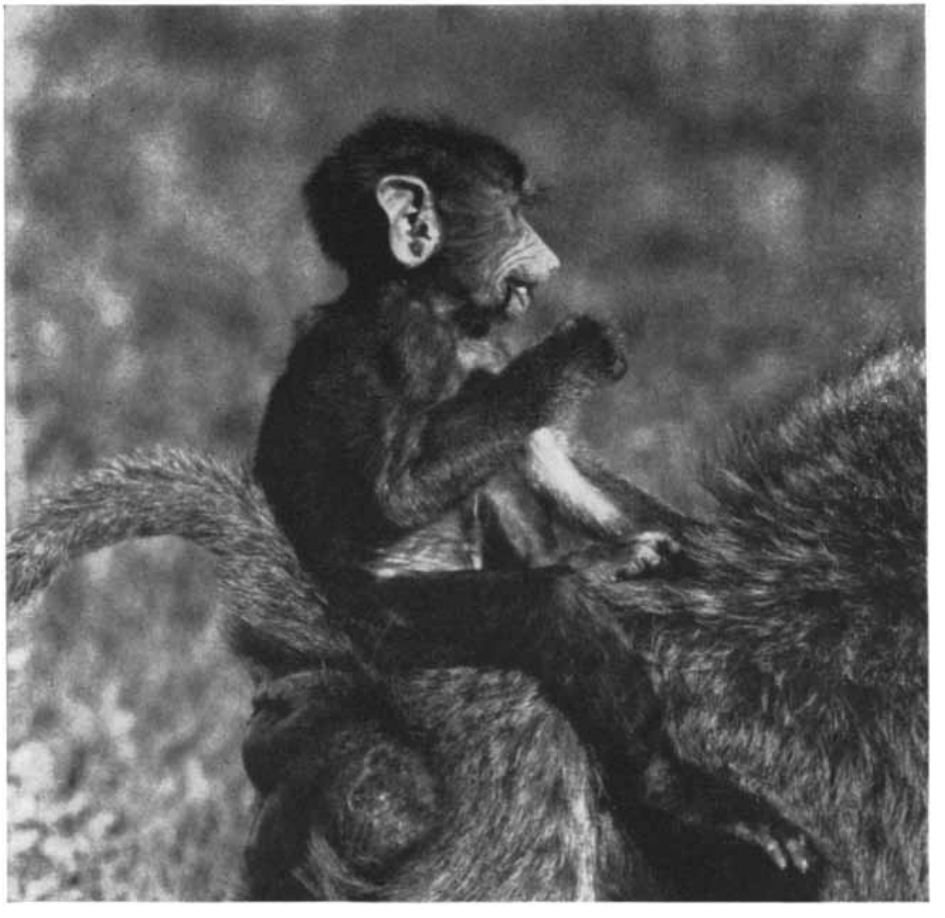
A baboon troop may range an area of three to six square miles but it utilizes only parts of its range intensively. When water and food are widely distributed, troops rarely come within sight of each other. The ranges of neighboring troops overlap nonetheless, often extensively. This could be seen best in Amboseli at the end of the dry season. Water was concentrated in certain areas, and several troops often came to the same water hole, both to drink and to eat the lush vegetation near the water. We spent many days near these water holes, watching the baboons and the numerous other animals that came there.

On one occasion we counted more than 400 baboons around a single water hole at one time. To the casual observer they would have appeared to be one troop, but actually three large troops were feeding side by side. The troops came and went without mixing, even though members of different troops sat or foraged within a few feet of each other. Once we saw a juvenile baboon cross over to the next troop, play briefly and return to his own troop. But such behavior is rare, even in troops that come together at the same water hole day after day. At the water hole we saw no fighting between troops, but small troops slowly gave way before large ones. Troops that did not see each other frequently showed great interest in each other.

When one first sees a troop of baboons, it appears to have little order, but this is a superficial impression. The basic structure of the troop is most apparent when a large troop moves away from the safety of trees and out onto open plains. As the troop moves the less dominant

MARCHING baboon troop has a definite structure, with females and their young protected by dominant males in the center of the formation. This group in the Amboseli reserve in Kenya includes a female (*left*), followed by two males and a female with juvenile.

BABOON EATS A POTATO tossed to him by a member of the authors' party. Baboons are primarily herbivores but occasionally they will eat birds' eggs and even other animals.



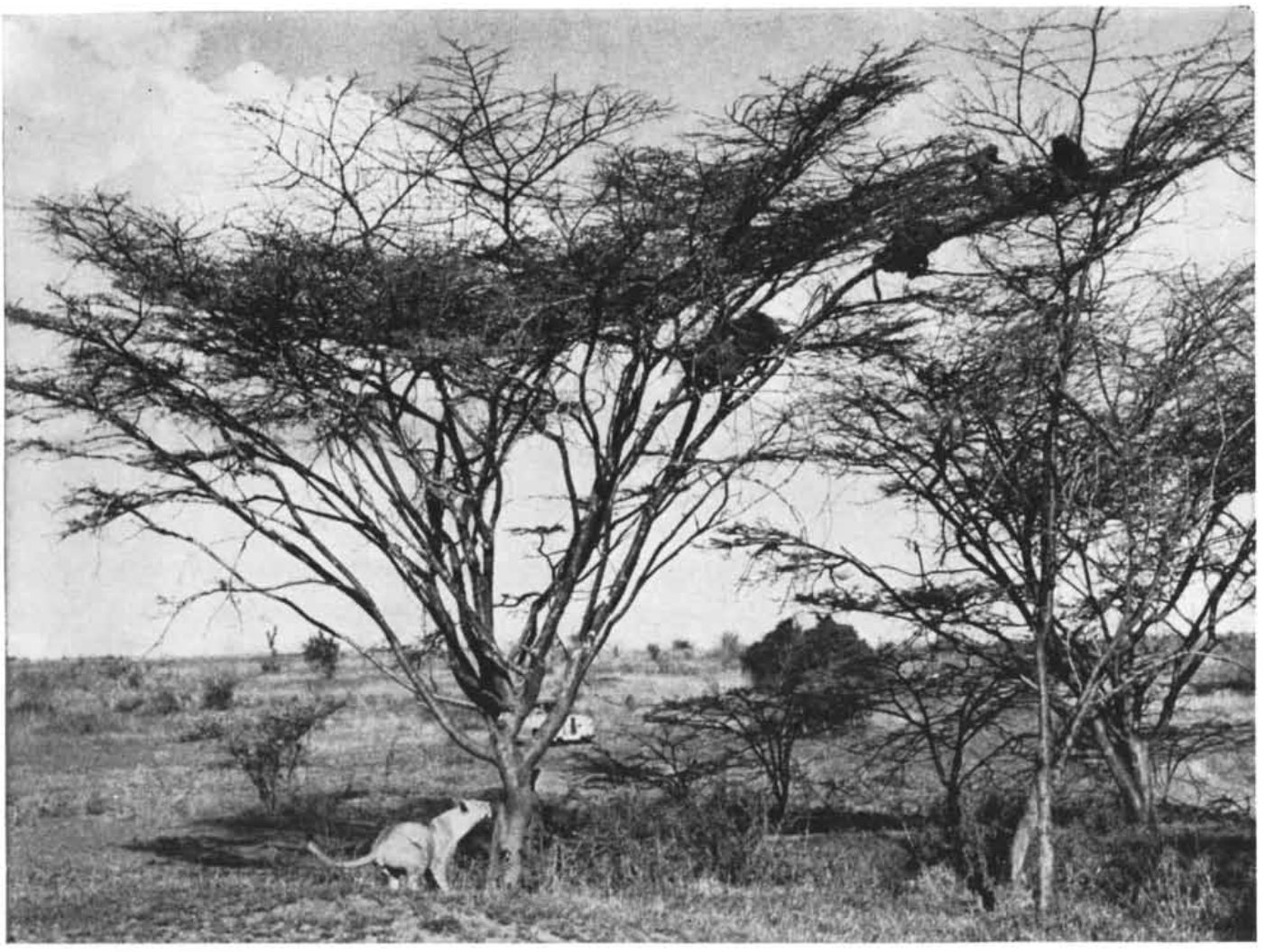
INFANT BABOON rides on its mother's back through a park outside Nairobi. A newborn infant first travels by clinging to its mother's chest, but soon learns to ride pickaback.

adult males and perhaps a large juvenile or two occupy the van. Females and more of the older juveniles follow, and in the center of the troop are the females with infants, the young juveniles and the most dominant males. The back of the troop is a mirror image of its front, with less dominant males at the rear. Thus, without any fixed or formal order, the arrangement of the troop is such that the females and young are protected at the center. No matter from what direction a predator approaches the troop, it must first encounter the adult males.

When a predator is sighted, the adult males play an even more active role in defense of the troop. One day we saw two dogs run barking at a troop. The females and juveniles hurried, but the males continued to walk slowly. In a moment an irregular group of some 20 adult males was interposed between the dogs and the rest of the troop. When a male turned on the dogs, they ran off. We saw baboons close to hyenas, cheetahs and jackals, and usually the baboons seemed unconcerned—the other animals kept their distance. Lions were the only animals we saw putting a troop of baboons to flight. Twice we saw lions near baboons, whereupon the baboons climbed trees. From the safety of the trees the baboons barked and threatened the lions, but they offered no resistance to them on the ground.

With nonpredators the baboons' relations are largely neutral. It is common to see baboons walking among topi, eland, sable and roan antelopes, gazelles, zebras, hartebeests, gnus, giraffes and buffaloes, depending on which ungulates are common locally. When elephants or rhinoceroses walk through an area where the baboons are feeding, the baboons move out of the way at the last moment. We have seen wart hogs chasing each other, and a running rhinoceros go right through a troop, with the baboons merely stepping out of the way. We have seen male impalas fighting while baboons fed beside them. Once we saw a baboon chase a giraffe, but it seemed to be more in play than aggression.

Only rarely did we see baboons engage in hostilities against other species. On one occasion, however, we saw a baboon kill a small vervet monkey and eat it. The vervets frequented the same water holes as the baboons and usually they moved near them or even among them without incident. But one troop of baboons we observed at Victoria Falls pursued vervets on sight and attempted, without success, to keep



LIONESS LEAPS AT A THORN TREE into which a group of baboons has fled for safety. Lions appear to be among the few animals that successfully prey on baboons. The car in the background drove up as the authors' party was observing the scene.

them out of certain fruit trees. The vervets easily escaped in the small branches of the trees.

The baboons' food is almost entirely vegetable, although they do eat meat on rare occasions. We saw dominant males kill and eat two newborn Thomson's gazelles. Baboons are said to be fond of fledglings and birds' eggs and have even been reported digging up crocodile eggs. They also eat insects. But their diet consists principally of grass, fruit, buds and plant shoots of many kinds; in the Nairobi area alone they consume more than 50 species of plant.

For baboons, as for many herbivores, association with other species on the range often provides mutual protection. In open country their closest relations are with impalas, while in forest areas the bushbucks play a similar role. The ungulates have a keen sense of smell, and baboons have keen eyesight. Baboons are visually alert, constantly looking in all directions as they feed. If they see predators, they utter warning barks that alert not only the other baboons but also any other animals that may be in the vicinity. Similarly, a warning bark by a bushbuck or an impala will put a baboon troop to flight. A mixed herd of impalas and baboons is almost impossible to take by surprise.

Impalas are a favorite prey of cheetahs. Yet once we saw impalas, grazing in the company of baboons, make no effort to escape from a trio of approaching cheetahs. The impalas just watched as an adult male baboon stepped toward the cheetahs, uttered a cry of defiance and sent them trotting away.

The interdependence of the different species is plainly evident at a water hole, particularly where the bush is thick and visibility poor. If giraffes are drinking, zebras will run to the water. But the first animals to arrive at the water hole approach with extreme caution. In the Wankie reserve, where we also observed baboons, there are large water holes surrounded by wide areas of open sand between the water and the bushes. The baboons approached the water with great care, often resting and playing for some time in the bushes before making a hurried trip for a drink. Clearly, many animals know each other's behavior and alarm signals.

A baboon troop finds its ultimate safety, however, in the trees. It is no exaggeration to say that trees limit the distribution of baboons as much as the availability of food and water. We observed an area by a marsh in Amboseli where there was water and plenty of food. But there were lions and no trees and so there were no baboons. Only a quarter of a mile away, where lions were seen even more frequently, there were trees. Here baboons were numerous; three large troops frequented the area.

At night, when the carnivores and snakes are most active, baboons sleep high up in big trees. This is one of the baboon's primary behavioral adaptations. Diurnal living, together with an

BABOONS AND THREE OTHER SPECIES gather near a water hole (*out of picture to right*). Water holes and the relatively lush vegetation that surrounds them are common meeting places for a wide variety of herbivores. In this scene of the open savanna of

arboreal refuge at night, is an extremely effective way for them to avoid danger. The callused areas on a baboon's haunches allow it to sleep sitting up, even on small branches; a large troop can thus find sleeping places in a few trees. It is known that Colobus monkeys have a cycle of sleeping and waking throughout the night; baboons probably have a similar pattern. In any case, baboons are terrified of the dark. They arrive at the trees before night falls and stay in the branches until it is fully light. Fear of the dark, fear of falling and fear of snakes seem to be basic parts of the primate heritage.

Whether by day or night, individual baboons do not wander away from the troop, even for a few hours. The importance of the troop in ensuring the survival of its members is dramatized by the fate of those that are badly injured or too sick to keep up with their fellows. Each day the troop travels on a circuit of two to four miles; it moves from the sleeping trees to a feeding area, feeds, rests and moves again. The pace is not rapid, but the troop does not wait for sick or injured members. A baby baboon rides its mother, but all other members of the troop must keep up on their own. Once an animal is separated from the troop the chances of death are high. Sickness and injuries severe enough to be easily seen are frequent. For example, we saw a baboon with a broken forearm. The hand swung uselessly, and blood showed that the injury was recent. This baboon was gone the next morning and was not seen again. A sickness was widespread in the Amboseli troops, and we saw individuals dragging themselves along, making tremendous efforts to stay with the troop but falling behind. Some of these may have rejoined their troops; we are sure that at least five did not. One sick little juvenile lagged for four days and then apparently recovered. In the somewhat less natural setting of Nairobi park we saw some baboons that had lost a leg. So even severe injury does

the Amboseli reserve there are baboons in the foreground and middle distance. An impala moves across the foreground just left of center. A number of zebras are present; groups of gnus graze together at right center and move off toward the water hole (*right*).

not mean inevitable death. Nonetheless, it must greatly decrease the chance of survival.

Thus, viewed from the outside, the troop is seen to be an effective way of life and one that is essential to the survival of its individual members. What do the internal events of troop life reveal about the drives and motivations that cause individual baboons to "seek safety in numbers"? One of the best ways to approach an understanding of the behavior patterns within the troop is to watch the baboons when they are resting and feeding quietly.

Most of the troop will be gathered in small groups, grooming each other's fur or simply sitting. A typical group will contain two females with their young offspring, or an adult male with one or more females and juveniles grooming him. Many of these groups tend to persist, with the same animals that have been grooming each other walking together when the troop moves. The nucleus of such a "grooming cluster" is most often a dominant male or a mother with a very young infant. The most powerful males are highly attractive to the other troop members and are actively sought by them. In marked contrast, the males in many ungulate species, such as impalas, must constantly herd the members of their group together. But baboon males have no need to force the other troop members to stay with them. On the contrary, their presence alone ensures that the troop will stay with them at all times.

Young infants are equally important in the formation of grooming clusters. The newborn infant is the center of social attraction. The most dominant adult males sit by the mother and walk close beside her. When the troop is resting, adult females and juveniles come to the mother, groom her and attempt to groom the infant. Other members of the troop are drawn toward the center thus formed, both by the presence of the pro-

BABOONS AND IMPALAS cluster together around a water hole. The two species form a mutual alarm system. The baboons have keen eyesight and the impalas a good sense of smell. Between them they quickly sense the presence of predators and take flight.

tective adult males and by their intense interest in the young infants.

In addition, many baboons, especially adult females, form preference pairs, and juvenile baboons come together in play groups that persist for several years. The general desire to stay in the troop is strengthened by these "friendships," which express themselves in the daily pattern of troop activity.

Our field observations, which so strongly suggest a high social motivation, are backed up by controlled experiment in the laboratory. Robert A. Butler of Walter Reed Army Hospital has shown that an isolated monkey will work hard when the only reward for his labor is the sight of another monkey [see "Curiosity in Monkeys," by Robert A. Butler; SCIENTIFIC AMERICAN, February, 1954]. In the troop this social drive is expressed in strong individual preferences, by "friendship," by interest in the infant members of the troop and by the attraction of the dominant males. Field studies show the adaptive value of these social ties. Solitary animals are far more likely to be killed, and over the generations natural selection must have favored all those factors which make learning to be sociable easy.

The learning that brings the individual baboon into full identity and participation in the baboon social system begins with the mother-child relationship. The newborn baboon rides by clinging to the hair on its mother's chest. The mother may scoop the infant on with her hand, but the infant must cling to its mother, even when she runs, from the day it is born. There is no time for this behavior to be learned. Harry F. Harlow of the University of Wisconsin has shown that an infant monkey will automatically cling to an object and much prefers objects with texture more like that of a real mother [see "Love in Infant Monkeys," by Harry F. Harlow; SCIENTIFIC AMERICAN, June, 1959]. Experimental studies demonstrate this clinging reflex; field observations show why it is so important.

In the beginning the baboon mother and infant are in contact 24 hours a day. The attractiveness of the young infant, moreover, assures that he and his mother will always be surrounded by attentive troop members. Experiments show that an isolated infant brought up in a laboratory does not develop normal social patterns. Beyond the first reflexive clinging, the development of social behavior requires learning. Behavior characteristic of the species depends therefore both on the baboon's biology and on the social situations that are present in the troop.

BABOONS AND ELEPHANTS have a relationship that is neutral rather than co-operative, as in the case of baboons and impalas. If an elephant or another large herbivore such as a rhinoceros moves through a troop, the baboons merely step out of the way.

As the infant matures it learns to ride on its mother's back, first clinging and then sitting upright. It begins to eat solid foods and to leave the mother for longer and longer periods to play with other infants. Eventually it plays with the other juveniles many hours a day, and its orientation shifts from the mother to this play group. It is in these play groups that the skills and behavior patterns of adult life are learned and practiced. Adult gestures, such as mounting, are frequent, but most play is a mixture of chasing, tail-pulling and mock fighting. If a juvenile is hurt and cries out, adults come running and stop the play. The presence of an adult male prevents small juveniles from being hurt. In the protected atmosphere of the play group the social bonds of the infant are widely extended.

Grooming, a significant biological function in itself, helps greatly to establish social bonds. The mother begins grooming her infant the day it is born, and the infant will be occupied with grooming for several hours a day for the rest of its life. All the older baboons do a certain amount of grooming, but it is the adult females who do most. They groom the infants, juveniles, adult males and other females. The baboons go to each other and "present" themselves for grooming. The grooming animal picks through the hair, parting it with its hands, removing dirt and parasites, usually by nibbling. Grooming is most often reciprocal, with one animal doing it for a while and then presenting itself for grooming. The animal being groomed relaxes, closes its eyes and gives every indication of complete pleasure. In addition to being pleasurable, grooming serves the important function of keeping the fur clean. Ticks are common in this area and can be seen on many animals such as dogs and lions; a baboon's skin, however, is free of them. Seen in this light, the enormous amount of time baboons spend in grooming each other is understandable. Grooming is pleasurable to the individual, it is the most important expression of close social bonds and it is biologically adaptive.

The adults in a troop are arranged in a dominance hierarchy, explicitly revealed in their relations with other members of the troop. The most dominant males will be more frequently groomed and they occupy feeding and resting positions of their choice. When a dominant animal approaches a subordinate one, the lesser animal moves out of the way. The observer can determine the order of dominance simply by watch-

ing the reactions of the baboons as they move past each other. In the tamer troops these observations can be tested by feeding. If food is tossed between two baboons, the more dominant one will take it, whereas the other may not even look at it directly.

The status of a baboon male in the dominance hierarchy depends not only on his physical condition and fighting ability but also on his relationships with other males. Some adult males in every large troop stay together much of the time, and if one of them is threatened, the others are likely to back him up. A group of such males outranks any individual, even though another male outside the group might be able to defeat any member of it separately. The hierarchy has considerable stability and this is due in large part to its dependence on clusters of males rather than the fighting ability of individuals. In troops where the rank order is clearly defined, fighting is rare. We observed frequent bickering or severe fighting in only about 15 per cent of the troops. The usual effect of the hierarchy, once relations among the males are settled, is to decrease disruptions in the troop. The dominant animals, the males in particular, will not let others fight. When bickering breaks out, they usually run to the scene and stop it. Dominant males thus protect the weaker animals against harm from inside as well as outside. Females and juveniles come to the males to groom them or just to sit beside them. So although dominance depends ultimately on force, it leads to peace, order and popularity.

Much has been written about the importance of sex in uniting the troop, it has been said, for example, that "the powerful social magnet of sex was the major impetus to subhuman primate sociability" [see "The Origin of Society," by Marshall D. Sahlins; SCIENTIFIC AMERICAN, September, 1960]. Our observations lead us to assign to sexuality a much lesser, and even at times a contrary, role. The sexual behavior of baboons depends on the biological cycle of the female. She is receptive for approximately one week out of every month, when she is in estrus. When first receptive, she leaves her infant and her friendship group and goes to the males, mating first with the subordinate males and older juveniles. Later in the period of receptivity she goes to the dominant males and "presents." If a male is not interested, the female is likely to groom him and then present again. Near the end of estrus the dominant males become very interested, and the female and a male form a consort pair. They may stay together for as little as an hour or for as long as several days. Estrus disrupts all other social relationships, and consort pairs usually move to the edge of the troop. It is at this time that fighting may take place, if the dominance order is not clearly established among the males. Normally there is no fighting over females, and a male, no matter how dominant, does not monopolize a female for long. No male is ever associated with more than one estrus female; there is nothing resembling a family or a harem among baboons.

Much the same seems to be true of other species of monkey. Sexual behavior appears to contribute little to the cohesion of the troop. Some monkeys have breeding seasons, with all mating taking place within less than half the year. But even in these species the troop continues its normal existence during the months when there is no mating. It must be remembered that among baboons a female is not sexually receptive for most of her life. She is juvenile, pregnant or lactating; estrus is a rare event in her life. Yet she does not leave the troop even for a few minutes. In baboon troops, particularly small ones, many months may pass when no female member comes into estrus; yet no animals leave the troop, and the highly structured relationships within it continue without disorganization.

The sociableness of baboons is expressed in a wide variety of behavior patterns that reinforce each other and give the troop cohesion. As the infant matures the nature of the social bonds

	ECOLOGY			ECONOMIC SYSTEM	
	GROUP SIZE, DENSITY AND RANGE	HOME BASE	POPULATION STRUCTURE	FOOD HABITS	ECONOMIC DEPENDENCE
	GROUPS OF 50–60 COMMON BUT VARY WIDELY. ONE INDIVIDUAL PER 5–10 SQUARE MILES. RANGE 200–600 SQUARE MILES. TERRITORIAL RIGHTS; DEFEND BOUNDARIES AGAINST STRANGERS.	OCCUPY IMPROVED SITES FOR VARIABLE TIMES WHERE SICK ARE CARED FOR AND STORES KEPT.	TRIBAL ORGANIZATION OF LOCAL, EXOGAMOUS GROUPS.	OMNIVOROUS. FOOD SHARING. MEN SPECIALIZE IN HUNTING, WOMEN AND CHILDREN IN GATHERING.	INFANTS ARE DEPENDENT ON ADULTS FOR MANY YEARS. MATURITY OF MALE DELAYED BIOLOGICALLY AND CULTURALLY. HUNTING, STORAGE AND SHARING OF FOOD.
	10–200 IN GROUP. 10 INDIVIDUALS PER SQUARE MILE. RANGE 3–6 SQUARE MILES; NO TERRITORIAL DEFENSE.	NONE: SICK AND INJURED MUST KEEP UP WITH TROOP.	SMALL, INBREEDING GROUPS.	ALMOST ENTIRELY VEGETARIAN. NO FOOD SHARING, NO DIVISION OF LABOR.	INFANT ECONOMICALLY INDEPENDENT AFTER WEANING. FULL MATURITY BIOLOGICALLY DELAYED. NO HUNTING, STORAGE OR SHARING OF FOOD.

APES AND MEN are contrasted in this chart, which indicates that although apes often seem remarkably "human," there are fundamental differences in behavior. Baboon characteristics, which may be taken as representative of ape and monkey behavior in

changes continually, but the bonds are always strong. The ties between mother and infant, between a juvenile and its peers in a play group, and between a mother and an adult male are quite different from one another. Similarly, the bond between two females in a friendship group, between the male and female in a consort pair or among the members of a cluster of males in the dominance hierarchy is based on diverse biological and behavioral factors, which offer a rich field for experimental investigation.

In addition, the troop shares a considerable social tradition. Each troop has its own range and a secure familiarity with the food and water sources, escape routes, safe refuges and sleeping places inside it. The counterpart of the intensely social life within the troop is the coordination of the activities of all the troop's members throughout their lives. Seen against the background of evolution, it is clear that in the long run only the social baboons have survived.

When comparing the social behavior of baboons with that of man, there is little to be gained from laboring the obvious differences between modern civilization and the society of baboons. The comparison must be drawn against the fundamental social behavior patterns that lie behind the vast variety of human ways of life. For this purpose we have charted the salient features of baboon life in a native habitat alongside those of human life in preagricultural society [*see chart below*]. Cursory inspection shows that the differences are more numerous and significant than are the similarities.

The size of the local group is the only category in which there is not a major contrast. The degree to which these contrasts are helpful in understanding the evolution of human behavior depends, of course, on the degree to which baboon behavior is characteristic of monkeys and apes in general and therefore probably characteristic of the apes that evolved into men. Different kinds of monkey do behave differently, and many more field studies will have to be made before the precise degree of difference can be understood.

For example, many arboreal monkeys have a much smaller geographical range than baboons do. In fact, there are important differences between the size and type of range for many monkey species. But there is no suggestion that a troop of any species of monkey or ape occupies the hundreds of square miles ordinarily occupied by preagricultural human societies. Some kinds of monkey may resent intruders in their range more than baboons do, but there is no evidence that any species fights for complete control of a territory. Baboons are certainly less vocal than some other monkeys, but no nonhuman primate has even the most rudimentary language. We believe that the fundamental contrasts in our chart would hold for the vast majority of monkeys and apes as compared with the ancestors of man. Further study of primate behavior will sharpen these contrasts and define more clearly the gap that had to be traversed from ape to human behavior. But already we can see that man is as unique in his sharing, cooperation and play patterns as he is in his locomotion, brain and language.

The basis for most of these differences may lie in hunting. Certainly the hunting of large animals must have involved co-operation among the hunters and sharing of the food within the tribe. Similarly, hunting requires an enormous extension of range and the protection of a hunting territory. If this speculation proves to be correct, much of the evolution of human behavior can be reconstructed, because the men of 500,000 years ago were skilled hunters. In locations such as Choukoutien in China and Olduvai Gorge in Africa there is evidence of both the hunters and their campsites [see "Olduvai Gorge," by L. S. B. Leakey; SCIENTIFIC AMERICAN, January, 1954]. We are confident that the study of the living primates, together with the archaeological record, will eventually make possible a much richer understanding of the evolution of human behavior.

SOCIAL SYSTEM					COMMUNICATION
ORGANIZATION	SOCIAL CONTROL	SEXUAL BEHAVIOR	MOTHER-CHILD RELATIONSHIP	PLAY	
BANDS ARE DEPENDENT ON AND AFFILIATED WITH ONE ANOTHER IN A SEMIOPEN SYSTEM. SUBGROUPS BASED ON KINSHIP.	BASED ON CUSTOM.	FEMALE CONTINUOUSLY RECEPTIVE. FAMILY BASED ON PROLONGED MALE-FEMALE RELATIONSHIP AND INCEST TABOOS.	PROLONGED; INFANT HELPLESS AND ENTIRELY DEPENDENT ON ADULTS.	INTERPERSONAL BUT ALSO CONSIDERABLE USE OF INANIMATE OBJECTS.	LINGUISTIC COMMUNITY. LANGUAGE CRUCIAL IN THE EVOLUTION OF RELIGION, ART, TECHNOLOGY AND THE CO-OPERATION OF MANY INDIVIDUALS.
TROOP SELF-SUFFICIENT, CLOSED TO OUTSIDERS. TEMPORARY SUBGROUPS ARE FORMED BASED ON AGE AND INDIVIDUAL PREFERENCES.	BASED ON PHYSICAL DOMINANCE.	FEMALE ESTRUS. MULTIPLE MATES. NO PROLONGED MALE-FEMALE RELATIONSHIP.	INTENSE BUT BRIEF; INFANT WELL DEVELOPED AND IN PARTIAL CONTROL.	MAINLY INTERPERSONAL AND EXPLORATORY.	SPECIES-SPECIFIC, LARGELY GESTURAL AND CONCERNED WITH IMMEDIATE SITUATIONS.

general, are based on laboratory and field studies; human characteristics are what is known of preagricultural Homo sapiens. The chart suggests that there was a considerable gap between primate behavior and the behavior of the most primitive men known.

Stabilized Images on the Retina

When the involuntary movements of an image across the retina are prevented, the image fades and reappears in a manner that provides new information on two major theories of perception

by Roy M. Pritchard

In normal vision the eye is constantly in motion. Small involuntary movements persist even when the eye is "fixed" on a stationary object. As a result the image of the object on the retina of the eye is kept in constant motion. One movement of the eyeball makes the image drift slowly away from the center of the fovea, the region of maximum visual acuity in which the cone receptor cells are most densely concentrated. The drifting motion terminates in a flick that brings the image back toward the center of the fovea. Superimposed on the drift motion is a tremor with frequencies up to 150 cycles per second and an amplitude of about half the diameter of a single cone receptor.

These three involuntary movements of the eyeball, all much smaller than the voluntary movements involved in looking at the visual world or in reading, have been known to physiologists for many years. During the past decade Lorrin A. Riggs of Brown University and R. W. Ditchburn of the University of Reading in England succeeded in measuring them with great accuracy. Though the movements cannot be stopped without incapacitating the subject or endangering the eye, Ditchburn and Riggs found ways to circumvent them and so make an image stand still on the retina. They were thereby able to show that the motion of the image plays a significant role in the sensory function of the eye. When an image is stabilized on the retina by one means or another, it soon fades and disappears. Just how this happens is not yet completely understood.

It was also observed, however, that the stabilized image regenerates after a time and again becomes visible to the subject in whole or in part. The image—or fragments of it—alternately fades and regenerates over prolonged periods of observation. This finding has attracted the attention of psychologists interested in the perceptual aspects of vision, those aspects which involve the functioning of the brain as well as the cells of the retina. At McGill University, D. O. Hebb, Woodburn Heron and I have been investigating the stabilized visual image as a source of data for the formulation of a comprehensive theory of visual perception. We have found that the fragmentation, or the alternate partial fading and partial regeneration, of the image is related to the character and content of the image itself.

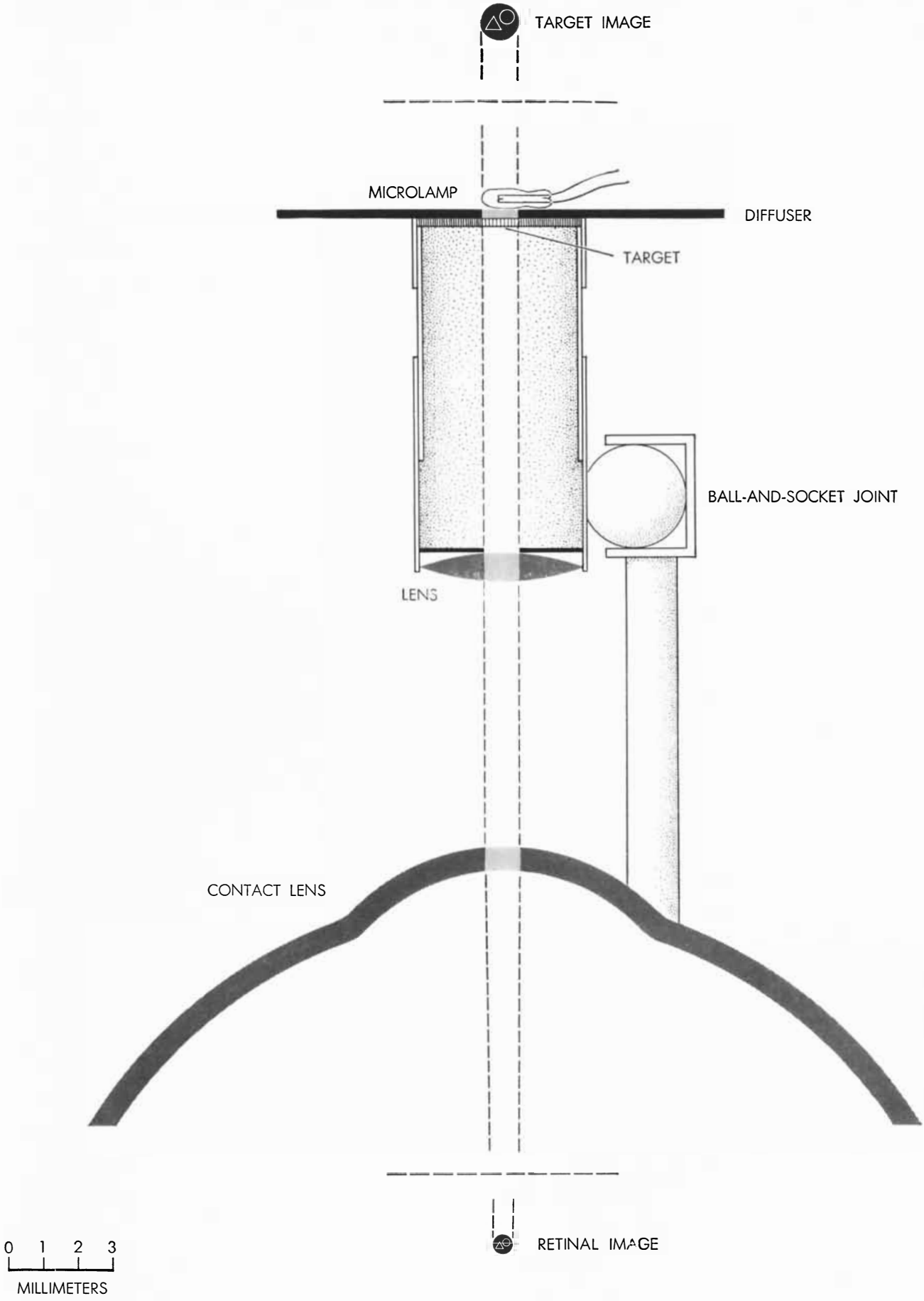
Our evidence supports to some extent the "cell assembly" idea that experience is needed to develop the innate potential of perception: a pattern is perceived through the combination in the brain of separate neural impressions that have been established there and correspond to various learned elements. But the evidence also sustains the Gestalt, or holistic, theory, which holds that perception is innately determined: a pattern is perceived directly as a whole and without synthesis of parts, a product of unlearned capacity to perceive "form," "wholeness" and "organization." It is becoming apparent that the complete explanation of perception must be sought in a resolution of these opposing views.

We stabilize the image by attaching the target to be viewed to the eyeball itself. The device we use for this purpose consists of a tight-fitting contact lens on which is mounted a tiny, self-contained optical projector [*see illustration on opposite page*]. With the subject lying on a couch, the device is set in place on the cornea and focused to project an image on the retina. The experimenter changes the target film from time to time, and he keeps a continuous record of the subject's report of what he sees.

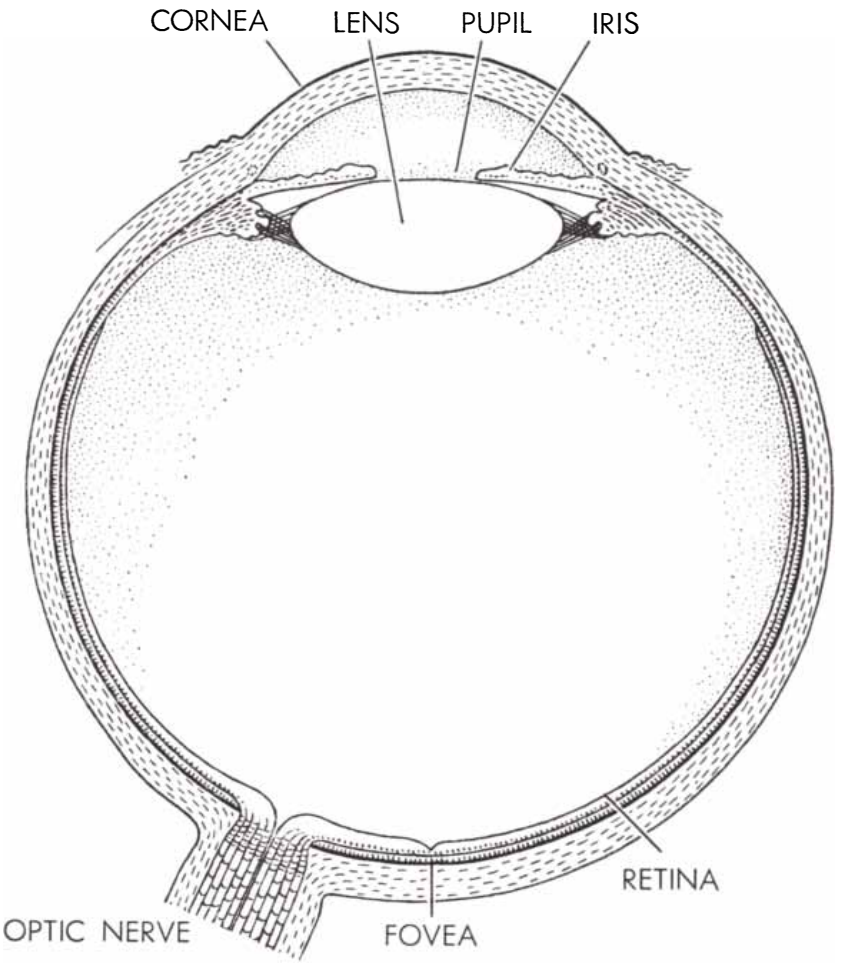
What the subject sees, before fading sets in, is an image located at apparent infinity and subtending a visual angle of two degrees in a patch of light that subtends an angle of five degrees in the surrounding darkness. Provided that the contact lens does not slip on the cornea, the image remains fixed on the retina and does not move with movement of the eyeball.

After a few seconds of viewing, the image disappears progressively and bit by bit, leaving a structureless gray field of light. Later this gray field may darken, and with complete loss of sensation of light the field becomes intensely black. When the image disappears or reappears the uninitiated subject at first rotates his eyes in an effort to bring the image or a center of interest in the image back to the center of the fovea. These movements are, of course, futile because they cannot change the geometrical relationship between the target, the lens of the eye and the retina. Soon the subject learns to view the image passively and discovers that he can still transfer his attention from point to point over the limited visual field.

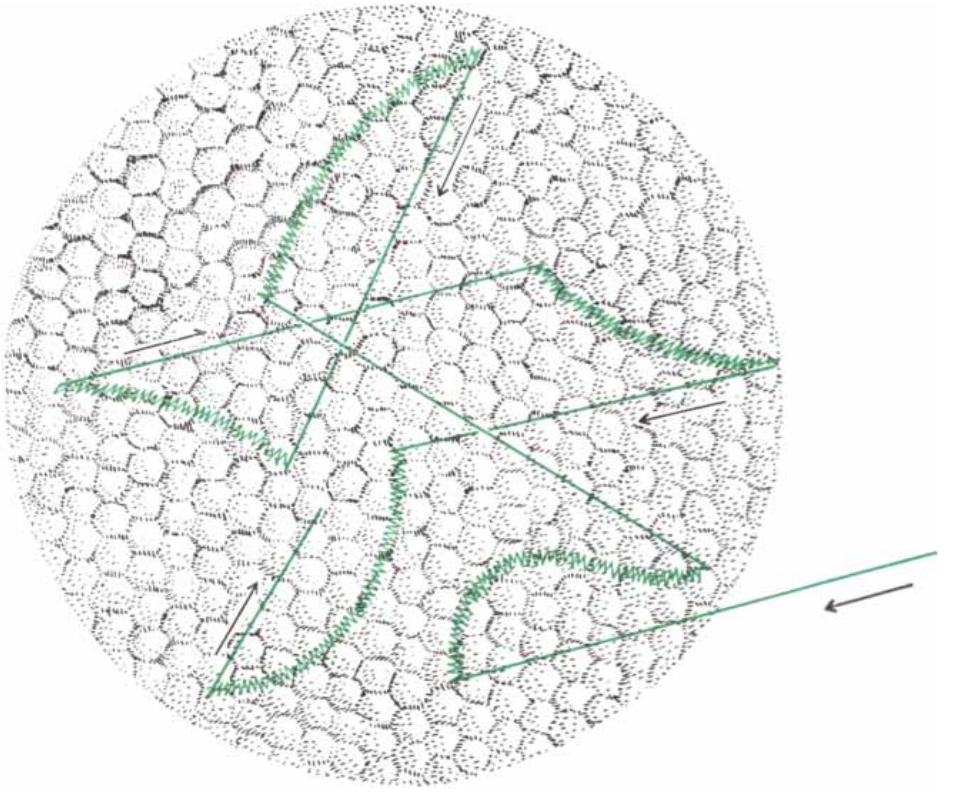
In general we have found that the image of a simple figure, such as a single line, vanishes rapidly and then reappears as a complete image. A more complex target, such as the profile of a face or a pattern of curlicues, may similarly disappear and reappear as a whole; on the other hand, it may vanish in fragments, with one or more of its parts fading independently. We have found in addition that the length of time an image persists is also a function of its complexity. A single line may be visible for only 10 per cent of the aggregate view-



STABILIZED-IMAGE DEVICE is a tiny projector mounted on a contact lens worn by the subject. The contact lens moves with every movement of the eyeball; so, therefore, does the projector, and as a result the target image (*at top of illustration*) is kept fixed at one point on the retina (*as suggested at bottom of illustration*). The convex lens focuses parallel rays of light on the retina, so the target is viewed by the subject as if it were at an infinite distance. The entire optical system weighs only .25 gram.



HUMAN EYE, seen here in horizontal cross section, works much like a camera. Light entering through the pupil is focused by the lens upon the retina's light-sensitive receptor cells, from which impulses travel via the optic nerve to the brain. The fovea, the area of most acute vision, is 1.5 millimeters in diameter and subtends a visual angle of five degrees.



EYE MOVEMENTS that are halted in stabilized vision normally carry an image across the receptors of the retina as shown here. The three movements are a drift (*curved lines*) away from the center of vision, a faster flick (*straight lines*) back toward the center and a high-frequency tremor superimposed on the drift. The magnitude of all these movements is very small; the diameter of the patch of the fovea shown above is only .05 millimeter.

ing time, whereas a more complex figure may remain visible in whole or in part for as much as 80 per cent of the time.

The contrasting manner in which complex images fade and regenerate lends support to the role of learning in perception. For example, the figure of the human profile invariably fades and regenerates in meaningful units. The front of the face, the top of the head, the eye and the ear come and go as recognizable entities, separately and in various combinations. In contrast, on first presentation a meaningless pattern of curlicues is described as extremely "active"; the individual elements fade and regenerate rapidly, and the subject sees almost every configuration that can be derived from the original figure. After prolonged viewing, however, certain combinations of curlicues become dominant and these then disappear and reappear as units. The newly formed groupings persist for longer periods than other combinations, and the figure can no longer be considered unorganized and meaningless.

In the cell-assembly approach to a theory of perception these observations are explained in terms of "perceptual elements," as opposed to purely sensory elements. The "organized," "meaningful" or "recognizable" parts of the image correspond to perceptual elements previously learned or established by experience. The parts of the human profile would thus function as perceptual elements at the outset in the behavior of the stabilized image. Given time for learning, parts of the originally meaningless curlicue pattern become recognizable in turn and operate as perceptual elements. These elements may be excited, it is argued, by the minimum retinal stimulation provided by the stabilized image. To evoke and maintain the image of the entire figure would require the additional information normally supplied by the movement of the image across the retinal receptors.

This interpretation gains additional support from what subjects report about the stabilized images of monograms that combine such symbols as the letters *H* and *B*. One or the other letter, or a fragment such as *P*, constitutes the unit that is perceived from one period to the next, with periods of complete fadeout intervening. When entire words are presented, the partial fragmentation of letters can cause different words to be perceived [*see bottom illustration on opposite page*]. In a figure that presents a meaningful symbol such as *B* obscured by hatching lines, the subject sees either

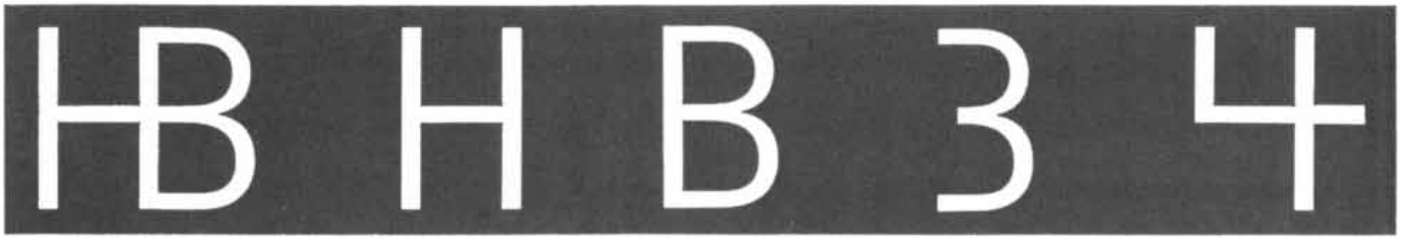
the intact *B* or the hatching lines independently. He may also on occasion see the two elements together, but then the *B* appears to float in a plane in front of the one containing the hatching lines. There is nothing haphazard about the fading of such figures, and these effects cannot be attributed to random fluctuation of threshold in various parts of the retina. Even if such fluctuation is thought to occur in the retinal system, the organized or meaningful unit remains visible longer than the unorganized one, in keeping with the presumed importance of learning in visual perception.

But the Gestalt psychologist can argue that it is unnecessary to bring learning and experience into the explanation of these effects. The same effects show up in experiments with meaningless or only semimeaningful figures and can be explained in terms of the Gestalt concept of perception as a process that works by "the whole." If an irregular shape, like that of an amoeba, is obscured by hatching lines, for example, the subject may report the same unitary and separate fading of the amoeba shape and of the hatching lines that he reports in the case of a letter of the alphabet. The two parts of the complete figure may also appear separated in different planes. More commonly in this case, however, parts of both the amoeba shape and the obscuring lines disappear together, and the remaining elements amalgamate to form a new composite figure. The hybrid is a more compact, tidy figure, with fewer disrupting elements.

When the amoeba shape is presented alone, parts of the figure tend to disappear. One or more of the bulges in the figure fade from view, and a line or lines are hallucinated to seal off the gaps produced by their disappearance. The limb or limbs that fade are invariably the grosser or more distorted features of the figure, and their disappearance, together with the closures, produces a "better" or more rounded figure. Any other comparatively irregular or jagged figure similarly appears unstable on first

STABILIZED IMAGES typically fade as in the illustrations on this and the following two pages. The parts of a profile drawing that stay visible are invariably specific features or groups of features, such as the front of the face or the top of the head.

MEANINGLESS CURLICUES first come and go in random sequence. But after a while small groups of curlicues organized in recognizable patterns start to behave as units. This suggests that they have themselves become meaningful perceptual elements.



MONOGRAM formed of the letters *H* and *B* also seems to illustrate the importance of elements that are meaningful because of past experience. When the monogram breaks up it is the recognizable letters and numbers within it that come successively into view.

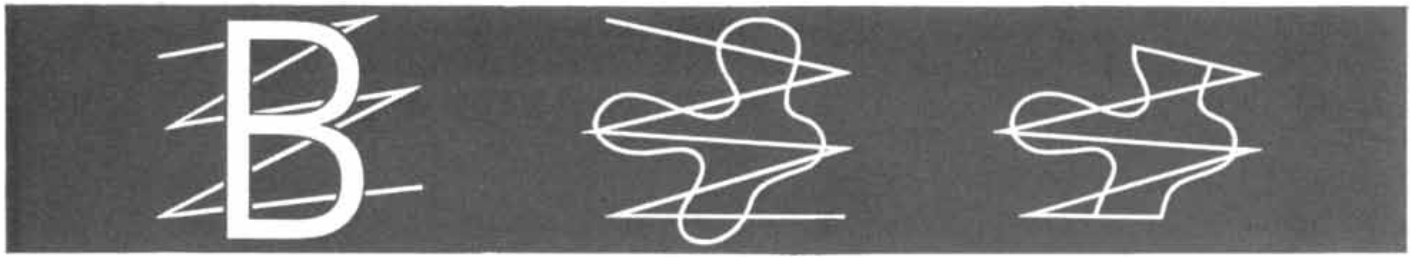
WORDS containing other words behave in much the same manner as the monogram. Here, for example, the subject sees new words made up of letters and parts of letters in the original. He is far less likely to report seeing meaningless groups of letters such as *EER*.

viewing. Its individual elements come and go until the holistic "editing" process reduces it to a more rounded configuration. A smooth, rounded figure, in contrast, appears more stable at the outset and tends to operate more as a whole in the alternate process of fading and regeneration.

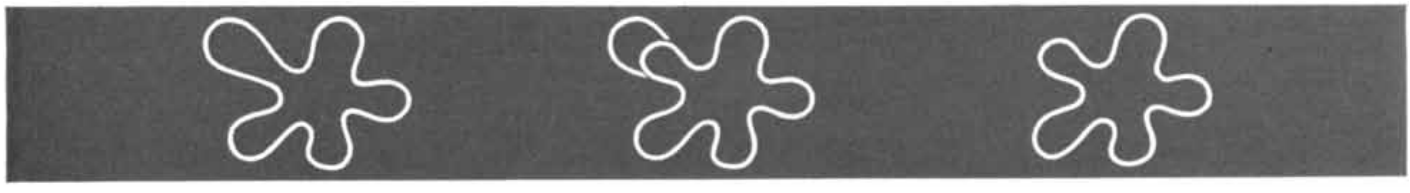
As Gestalt theory would predict, contiguity and similarity strongly determine the functioning of the groups as entities isolated from the total figure. A target consisting of rows of small squares usually fades to leave one whole row—horizontal, diagonal or vertical—visible. Similarly a random collection of dots will fade to leave only those dots which lie approximately in a line, and it is the disappearance of the remainder that reveals this linear association. At the same time it must be emphasized that the original figure as well as each configuration that can be derived from it may function as a single unit, disappearing and reappearing as a whole.

Our experiments with stabilized images have thus produced evidence to sustain both of the major theoretical approaches to visual perception, which have for so long been considered mutually exclusive. It may be, however, that the two concepts are really complementary. As in the historic clash of the wave and the particle concepts in physics, the apparent opposition may arise solely from a difference in approach to the same problem. We have performed a number of experiments that conform equally well to both interpretations. This supports our expectation that a modern theory of perception will eventually result from a mating of the two systems.

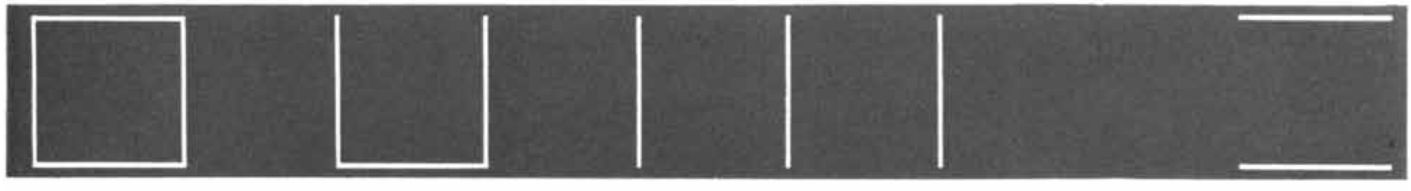
In experiments with simple straight-line figures the cell-assembly approach is supported by the observation that the line is the apparent unit of perception just as the line is the unit of structure in the figure. It is always the whole line that fades or reappears, independently or in association with others, and the breaking, when fading occurs, is always at the intersection of lines. In fact, the overwhelmingly independent action of



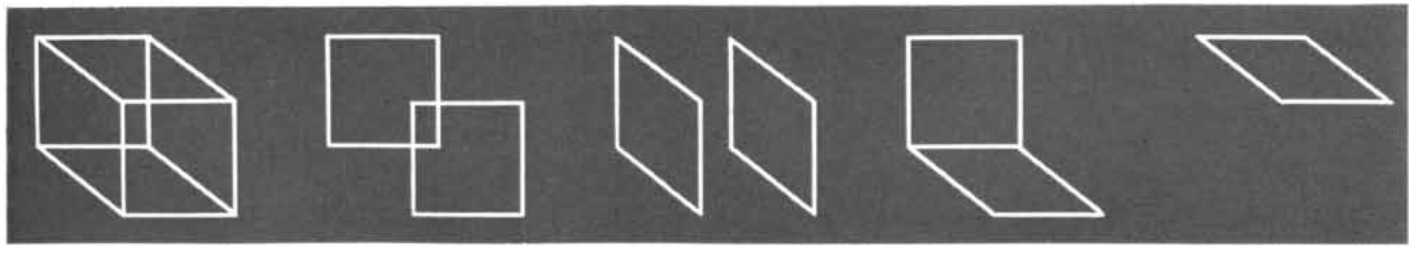
OBSCURING LINES drawn over a figure act in various ways. In the case of the *B*, the lines often drop into a plane behind the meaningful letter. But lines over a less meaningful amoeba shape usually combine with the amoeba to form a more compact figure.



AMOEBA SHAPE standing alone usually fades by losing one or more bulges. What fades, as in this case, is always the most distorted feature, and it is replaced by a new closure "ghosted" by the subject and tending to form a more symmetrical and rounded figure.



LINES act independently in stabilized vision, with breakage in the fading figure always at an intersection of lines. Adjacent or parallel lines may operate as units. This independent action of lines tends to support the cell-assembly theory of perception.



PLANES operate as units in three-dimensional figures. In this Necker cube (which gives an illusion of reversing in stabilized as well as in normal vision) a line may act alone. But usually lines defining a plane operate together, leaving parallel planes.

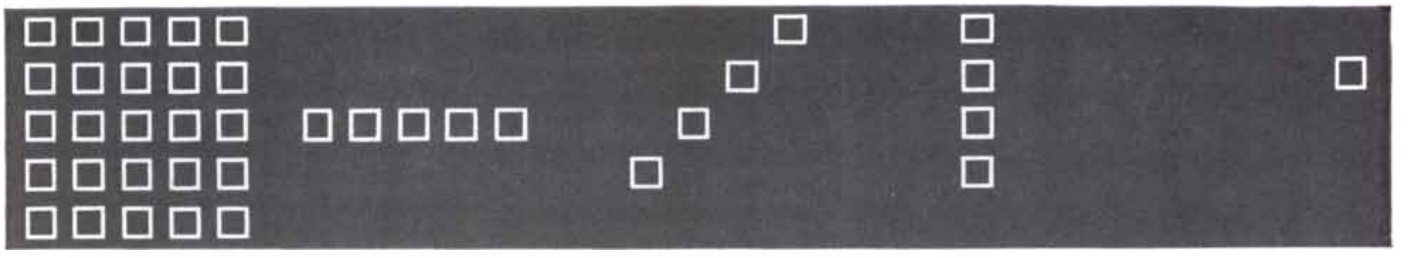
lines makes inevitable the inclusion of some cell-assembly concepts in any complete theory of perception.

In a figure composed of a circle and a triangle, either the circle or the triangle may fade to leave the other visible. One could take this independent action of meaningful figures as evidence for the role of learning in perception. On the other hand, the Gestalt psychologist can just as readily explain the unitary action of the circle or triangle as evidence of the behavior of wholes.

But the fading process may also dissect the figure in other ways—for example, it may leave only one side of the triangle and the segment of the circle closest or most nearly parallel to it in view. Gestalt theory explains this report by the so-called field effect. The minimal sensory stimulus provided by the stabilized image is said to excite a perceptual response that goes well beyond the region of actual stimulation. In straight-line figures, furthermore, there is a tendency for noncontiguous parallel lines to operate together, and lines of the Necker cube [*see bottom illustration on preceding page*] usually vanish to leave parallel planes visible in space, with one of the planes in advance of the other. These observations can also be advanced as evidence of a field effect.

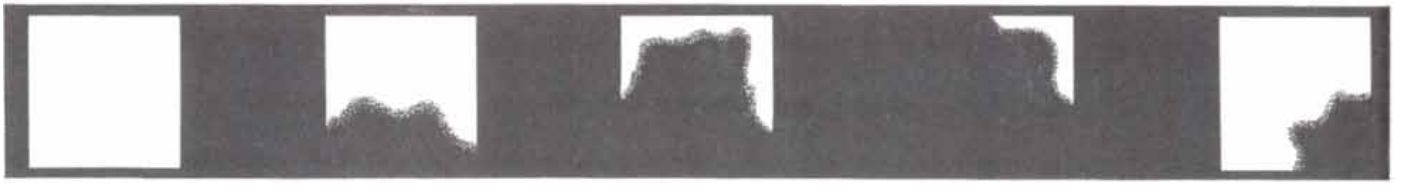
Most figures are seen as three-dimensional when viewed as a stabilized image. Most line drawings appear at some stage as "wires" suspended in space. The small squares in a repetitive pattern are perceived as protrusions or depressions. And a simple hexagon has been reported to be the outline of a cube in three dimensions that "reverses" in the same manner as the Necker cube.

In the case of figures drawn in solid tones as distinguished from those drawn in outline, the behavior of the stabilized image seems more consistent with cell-assembly theory. The corner now replaces the line as the unit of independent action. A solid square will fade from its center, and the fading will obliterate first one and then another corner, leaving the remaining corners sharply outlined and isolated in space. Regeneration

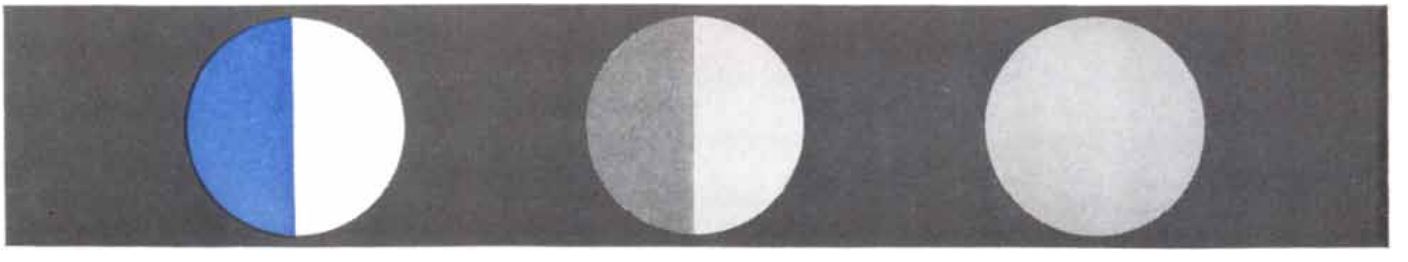


LINEAR ORGANIZATION is emphasized by the fading of this target composed of rows of squares. The figure usually fades to leave one whole row visible: horizontal, diagonal or vertical. In some cases a three-dimensional "waffle" effect is also noted.

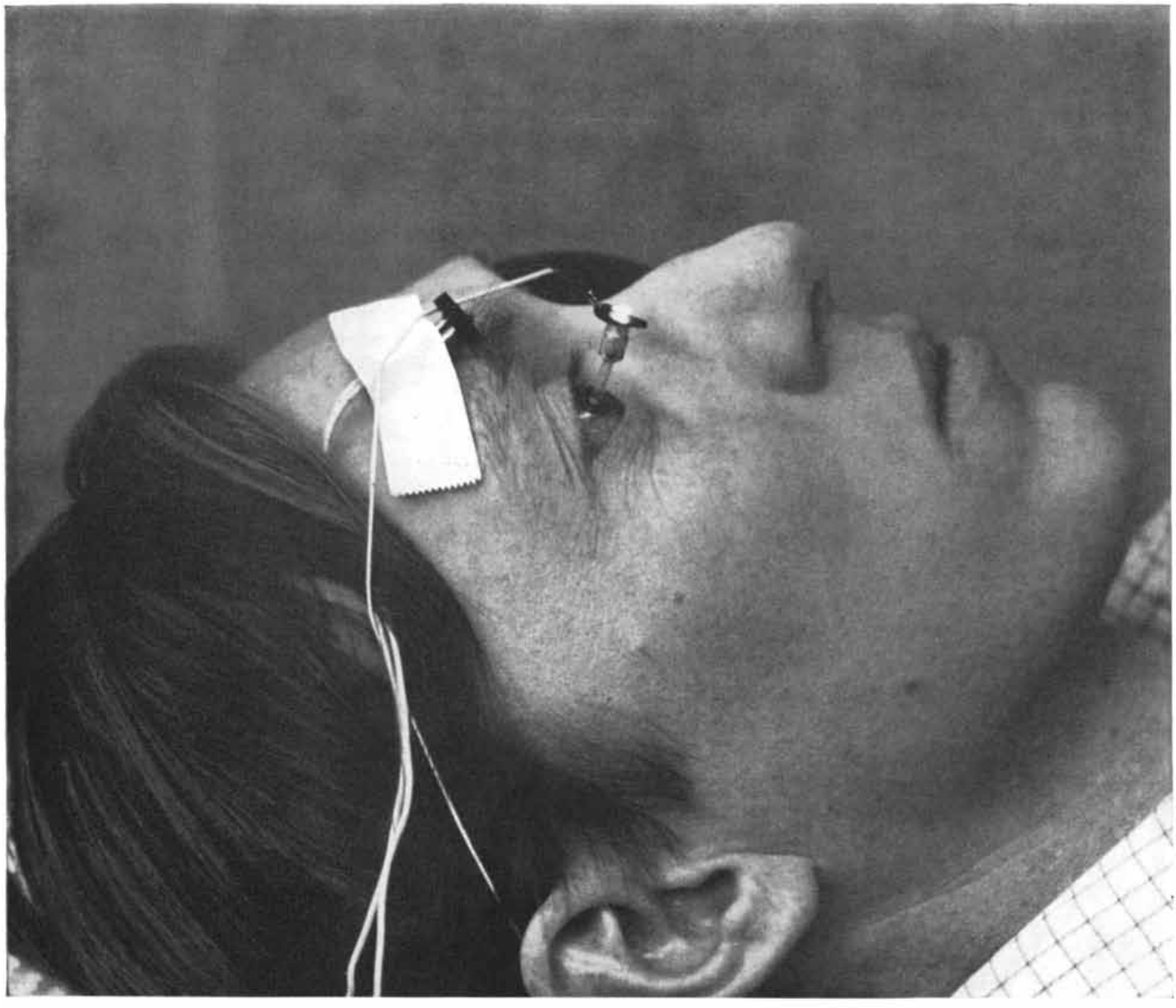
CIRCLE AND TRIANGLE may fade as units, leaving one or the other in view. When there is partial fading, a side of the triangle may remain in view along with a parallel segment of the circle, suggesting the "field effect" postulated in Gestalt visual theory.



CORNERS are the basic units when solid-tone figures are used. The fading starts in the center and the sharply defined corners disappear one by one. This target, like the others in the series, was presented to subjects both in white-on-black and black-on-white.



SENSE OF COLOR is lost with particular speed. A two-color field like this fades almost immediately when stabilized, to leave two values of gray; then the brightness difference disappears. The stabilized technique promises to be useful for studying color vision.



TAKING TURN AS SUBJECT in a stabilized-vision experiment, the author wears on his right eye a contact lens on which the projector is mounted. The other eye is occluded by a patch. Wires lead from the small projector lamp to a battery through a connecting jack taped to his forehead. The experimenter inserts a target film under the diffuser. At first the image is clear to the subject, but it soon fades and then regenerates. The subject makes a continuous report of what he sees, and the experimenter records his comments.

correspondingly begins with the reappearance of first one and then another corner, yielding a complete or partial figure with the corners again sharply outlined.

The basic concepts of Gestalt theory receive strong support in our experiments from the observed importance of field effects, from the dominance of "good" figures and from the action of whole figures and of groups of design elements as perceptual entities. But it is the independent action of the parts and not the whole of a figure that is paramount in stabilized vision. This observation agrees with cell-assembly theory and the perceptual elements it postulates. On the other hand, the perceptual elements themselves appear as organized entities and so conform to Gestalt concepts. Perhaps the Gestalt perception-by-the-whole theory can best be used in interpreting perception in a broad sense, while the cell-assembly idea of perception by parts may turn out to be most useful for analysis of perception in detail.

Meanwhile stabilized images have opened up a promising approach to another significant problem in the field of perception: color vision. Color disappears quickly in the stabilized image of a colored figure. In a field composed of the three primary colors, the red, green and blue hues disappear to leave a colorless field of three different brightnesses. These brightness differences also disappear with time, but it is the color that goes first. This supports the suggestion that the hue of a color is produced by radiation of a given wavelength on the retina and that the perception of hue is maintained by continuous changes in the luminosity of the radiation falling on a receptor cell or cells. Movement of the edges of a patch of color across the retina, produced by normal eye movements, would therefore be necessary for continuous perception of color. We are now making an investigation of the amplitude, frequency and form of movement necessary to sustain or regenerate a particular color.

20,000 GOOD CHARACTERS PER SECOND

EACH CHARACTER ON THIS PAGE WAS DRAWN INDIVIDUALLY IN ITS PROPER PLACE BY A BEAM OF ELECTRONS AND PHOTOGRAPHED IN 50 MICROSECONDS. A MAGNETIC TAPE GAVE THE COMMANDS. THE BEAM WAS TAUGHT HOW TO DRAW BY A PHOTOGRAPHIC DEVICE. FOR NEAT COLUMN EDGES THE COPYWRITER WAS TOLD TO EXPRESS WHATEVER NEEDED TO BE EXPRESSED IN LINES OF EXACTLY 47 CHARACTERS AND SPACES. A MERE TOUR DE FORCE, OF COURSE, BUT IT SERVES AS AN INTRODUCTION TO THE DACOM SYSTEM OF GETTING ALONG IN AN AGE THAT WANTS TO DANCE TO THE TUNE OF THE COMPUTING MACHINE.

WITH THE DACOM SYSTEM WE PUT THE TUNE INTO A BETTER TEMPO FOR HUMANS TO DANCE TO. COMPUTERS PLAY INHUMAN LYRICS TOO FAST. AMONG THE TRANSLATING DEVICES NOW AVAILABLE, A FEW OFFER PROSPECT OF ADEQUATE SPEED. BUT SPEED ALONE IS NOT THE WHOLE PROBLEM. THERE ALSO ARISES THE PROBLEM OF COPING WITH ALL THE PAPER GENERATED FROM THE TRANSLATING DEVICE.

THE DACOM SYSTEM HOLDS OFF ON THE GENERATING OF PAPER AT THIS STAGE. THE OUTPUT OF THE COMPUTER GOES DIRECTLY ON MICROFILM. MICROFILM IS THE PERFECT MEDIUM FOR MASSIVE DETAIL. WE SUGGEST THAT PAPER NEED COME IN ONLY AT THE END OF THE LINE, WHEN A HUMAN DECISION-MAKER CAN REACH A DECISION AFTER LOOKING AT A FEW SHEETS OF IT.

THIS IS THE HEART OF THE MICROFILM APPROACH. NOW DACOM MICROFILM BRIDGES THE GAP BETWEEN THE CAPABILITIES OF THE ELECTRONIC COMPUTER AND THE VIRTUES OF THE OLD BOOKKEEPER ON THE HIGH STOOL WITH GREEN EYESHADE AND BEAUTIFUL PENMANSHIP.

WE HOPE YOU AGREE THAT THE DACOM PENMANSHIP, AS YOU READ IT HERE MAGNIFIED FROM A TINY FRAME OF 16MM MICROFILM, IS OF A QUALITY THAT EVEN AN EXTRAORDINARILY CONSERVATIVE FISCAL INSTITUTION MIGHT UNHESITATINGLY USE IN COMMUNICATIONS WITH IMPORTANT CLIENTS. SHOULD THE CLIENT DESIRE TO SEE MORE THAN THE SUMMARY OF HIS POSITION, SUPPORTING DETAILS IN THEIR FULL COMPLEXITY CAN BE PRESENTED FOR HIS INSPECTION SIMILARLY ENLARGED FROM THE MICROFILM RECORD.

OUR SUBSIDIARY, RECORDAK, HAS WORKED OUT ALL MANNER OF SCHEMES FOR ALL SORTS OF ENTERPRISES, WITH OR WITHOUT ELECTRONIC COMPUTERS, TO PERMIT SUPPORTING DATA TO BE KEPT ON MICROFILM INSTEAD OF CLUTTERING UP THE CHANNELS OF COMMUNICATION. TO THE RECORDAK ARMAMENTARIUM IS NOW ADDED THIS NEW TOOL. WITH THE COMPUTERS RAPIDLY EXTENDING THEIR SWAY OVER THE BUSINESS WORLD, OFFICE WORK MORE AND MORE WILL CONSIST OF LOOKING UP INFORMATION FROM QUICK-ACCESS MICROFILM READERS SUCH AS RECORDAK ALREADY MARKETS. FOR EFFICIENCY IT BEATS PAPER-SHUFFLING.

THE PRESENT DACOM SYSTEM UTTERS ONLY ENGLISH LETTERS--NO FOREIGN ACCENT MARKS AS YET--, ARABIC NUMERALS, AND # @ / , % - $ * & * . PLUS ¤, A CUTE LITTLE CHARACTER OF UNSPECIFIED SIGNIFICANCE. THE NEXT GENERATION OF DACOM EQUIPMENT. AS THEY SAY IN THE MISSILE TRADE-- WILL BE ABLE TO PLOT POINTS FROM TAPED DATA, 2500 POINTS PER SECOND, VERY CLOSE, VERY LINEAR, QUITE REPEATABLY. TO SAY MORE AT PRESENT HERE WOULD BE PREMATURE.

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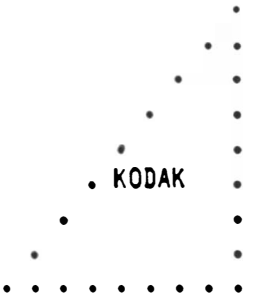

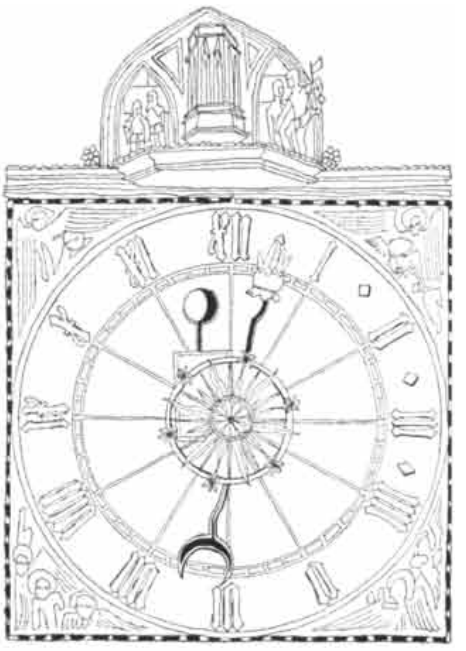

SCIENCE AND

Space

As a step toward the goal of a manned U. S. earth satellite, one of Project Mercury's prospective astronauts was sent last month on a 15-minute rocket ride that carried him 115 miles above the ground and deposited him at sea, 302 miles from the launching pad at Cape Canaveral. The test achieved its major purpose of demonstrating a man's ability to function under some of the stresses of space flight. During a five-minute interval of weightlessness, the passenger, Navy Commander Alan B. Shepard, Jr., operated levers to control the attitude, or position (but not the path), of his vehicle. He withstood an acceleration of six "g" on the way up and of more than 11 on the return.

Meanwhile the extensive U. S. program of instrumental space exploration continues to produce a wealth of new data. By means of a little satellite called *Lofti* the Naval Research Laboratory has discovered that very low frequency radio waves (three to 30 kilocycles) can pass through the ionosphere, but at a mysteriously low speed. Previously it had been thought that the portion of their energy not reflected would be totally absorbed. The new finding resulted in part from a happy accident. *Lofti* was sent up pickaback on a *Transit* satellite and scheduled to separate from it in orbit. When the separating mechanism failed, the two objects took up an orbit much more elongated than had been planned, ranging in altitude from 100 to 600 miles and passing repeatedly into and out of the ionosphere.

Explorer X, probing a region extending from 100 miles to 145,000 miles above the earth, has returned the information that the magnetic field of nearby space is frequently directed almost radially outward from the sun. This points to a solar origin for the field and confirms a suspicion that a "wind" of charged particles streaming outward from the sun carries the magnetic lines with it. At times this field proved stable and unexpectedly strong, reaching values up to .06 per cent of the field at the surface of the earth. At other times it varied erratically both in strength and direction. The variation was not connected with any apparent change on the solar surface. The satellite also made the first direct measurement of the density of the plasma, or ionized gas, in interplanetary space. It contains about 10 particles per cubic centimeter, with an average velocity of 180 miles per second.

A few days before the Mercury flight *Explorer XI* was put into orbit. This is a "telescope" that will measure the intensity of gamma rays in primary cosmic radiation coming from different parts of the Milky Way and from other galaxies. Gamma rays are presumably formed by the same processes that give rise to primary cosmic ray particles, but unlike the latter they can never be detected at the surface of the earth. Carrying no charge, gamma radiation travels in straight lines and is not deflected by electric or magnetic fields. Hence this radiation should provide the first direct evidence of the directions of the sources of cosmic rays. The detector consists of an array of scintillation counters mounted on a long, polelike vehicle that tumbles end over end, thereby scanning different regions of the sky.

Smallest World?

As physicists examine atomic particles with "microscopes" of higher and higher power, the quest for the ultimate microcosm seems as far from its goal as ever. At the recent meeting of the American Physical Society in Washington, Robert Hofstadter of Stanford University described the rich structure of the proton and neutron, the "elementary" particles in atomic nuclei.

These particles have virtually identical masses (about 1,840 times that of an

electron), but the proton is positively charged and the neutron is neutral. Hofstadter's group has discovered that they are both essentially aggregates of pi mesons, or pions. At their center is a dense core of mesons, some .00000000000002 centimeter across. Around the core are two concentric shells of mesons; the density of mesons in the shells is much less than that in the core. In the proton all three components are positive; the core contains 12 per cent of the total charge, the inner shell 60 per cent and the outer shell 28 per cent. The neutron has an identical plan except that the inner shell bears an opposite, but equal, negative charge.

This structure, Hofstadter says, agrees with the magnetic as well as the electrical properties of proton and neutron. Moreover, the results show that the laws of electromagnetism and of quantum theory are still good at distances of the order of the diameter of the core. It has frequently been suggested that there is a minimum length below which these laws no longer apply. If so, that limit has not yet been reached.

Hofstadter arrived at his picture by studying the way in which hydrogen nuclei (consisting of single protons) and deuterium nuclei (which consist of one proton and one neutron) deflected electrons from Stanford's billion-electron-volt linear accelerator. At Cornell University, Robert R. Wilson is carrying out similar experiments with an electron synchrotron.

Protein Assembly Line

Biochemists have begun to do time-and-motion studies in the protein factory of the living cell. At the Massachusetts Institute of Technology, Howard M. Dintzis is looking into the detailed program by which amino acids are assembled into the hemoglobin molecule.

In the past few years it has become clear that protein is made in the cellular bodies called ribosomes, which contain the ribonucleic-acid templates for its assembly. But the actual manufacturing process has been a matter for conjecture. Does the template act like a "stamping machine," assembling all the amino acid units and then locking them together in one operation? Do the units drift onto the template at random, joining together

whenever a gap is filled? Does the template somehow pick up and attach the units one by one, starting from one end of the protein chain and proceeding to the other? According to Dintzis' experiments, reported in *Proceedings of the National Academy of Sciences,* the last mechanism is the most likely.

If amino acids are added serially one by one, Dintzis argues, fragments obtained from protein molecules that were manufactured in the presence of a single radioactively labeled amino acid should exhibit a recognizable pattern. In finished protein that has been delivered by the ribosomes to the cellular fluid radioactivity should at first be restricted to the end of the chain made last. As the period of incubation is lengthened, the distribution of radioactivity in sample molecules should gradually even out over their whole length as more and more complete chains are manufactured from raw material containing the labeled amino acid. On the other hand, growing fragments taken from ribosomes should at first show about the same radioactivity regardless of their length, since radioactive links could have been added only near the growing end. But after long periods, when all the original nonradioactive work in process has been removed from the templates, total radioactivity of a sample should be higher in the fragments near the starting end than those near the finishing end. This is because at any time there are more "early" units on the assembly lines than "late" ones.

To check these conjectures requires a cell in which all, or nearly all, of the ribosomes are engaged in manufacturing a single protein at a high rate of production. Dintzis found such a cell in the reticulocytes (hemoglobin-producing cells) of rabbits with experimentally induced anemia. He incubated these cells for various times with a radioactively labeled amino acid—leucine—and then extracted samples of finished hemoglobin and of growing chains from the ribosomes. After splitting the samples with an enzyme and separating the fragments, he analyzed each one for radioactivity. The pattern of variation with time was exactly as predicted. The ends of a protein chain are distinguishable: one has a free amino (NH_2) group and the other a carboxyl (COOH) group. By identifying the amino acids near the ends of the hemoglobin molecule, Dintzis determined that the assembly probably starts at the amino end and finishes at the carboxyl end. From the rate of uptake of radioactive material he also estimated the rate of production at one hemoglobin every 90 seconds in each ribosome. This

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agrees with a figure based on the overall rate of production by the cell.

The results so far, Dintzis cautioned, do not constitute proof of the link-by-link mechanism but strongly suggest it. Only when the entire sequence of amino acids in the hemoglobin molecule has been worked out can the experiment actually identify each unit as it is added to the chain. Dintzis is now at work on this problem.

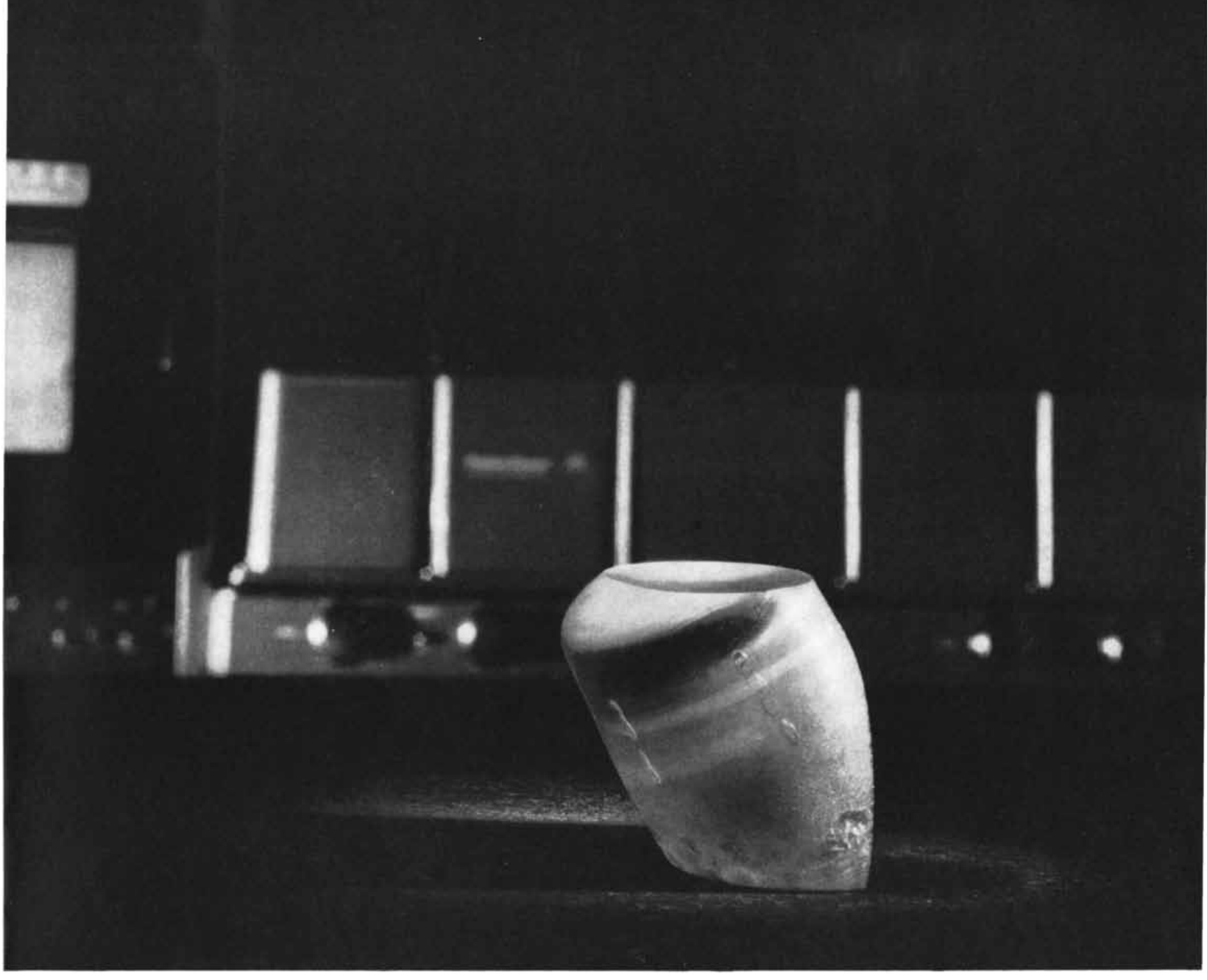
Soviet Science Directorate

A new agency has displaced the Academy of Sciences as the peak organization for the co-ordination of scientific activities in the U.S.S.R. Under the State Committee for Co-ordination of Scientific Research Work, the Academy is now to devote itself to basic research. Institutes of the Academy concerned with applied research are being transferred to the control of the industrial ministries concerned. The new agency, headed by Mikhail V. Khrunichev, a lieutenant-general formerly in charge of aircraft production, has among its assignments the co-ordination of the international contacts of all Soviet scientific agencies.

103

Element 103, the 11th beyond uranium, has been made at the Lawrence Radiation Laboratory of the University of California. It was prepared by bombarding californium (element 98) with nuclei of boron (element 5). Estimated to have an atomic weight of 257, the atom of element 103 has a half life of about eight seconds and decays to mendelevium (element 101). Its creators—Albert Ghiorso, Torbjørn Sikkeland, Almon E. Larsh and Robert M. Latimer—proposed naming it lawrencium (symbol Lw) in honor of the late Ernest O. Lawrence, who founded the laboratory that bears his name.

In their experiments Ghiorso and his colleagues used a target consisting of three-millionths of a gram of californium, deposited over an area a tenth of an inch in diameter. The material, enclosed in a helium-filled container, was exposed to a beam of 70-million-electron-volt (Mev) boron nuclei from a heavy-ion linear accelerator. Each californium nucleus that captured a boron nucleus released a few neutrons and flew out of the target as a nucleus of element 103. After slowing down through collisions with helium atoms, the lawrencium nuclei landed on a copper conveyer belt. At intervals the belt was pulled a short distance to bring the newly created



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atoms opposite a detector. Theoretical calculations showed that in the process of decay the nucleus of element 103 should give off an alpha particle (helium nucleus) with an energy of 8.6 Mev. The detection of such particles (never at a rate higher than five per hour) was proof of the existence of lawrencium.

Up to and including element 103, the man-made, transuranic elements form part of a group whose members should have closely similar chemical properties. (Obviously no chemical tests can be made with the few atoms of lawrencium available so far at any one time.) The group, called the actinide series, begins at actinium (element 89). All the elements in the series are thought to have identical outer electron shells, which determine their chemical properties. Successively heavier members add electrons to an incomplete inner shell. At element 103 that shell is filled. Hence the next element, when and if it is made, should have a different outer structure and different properties.

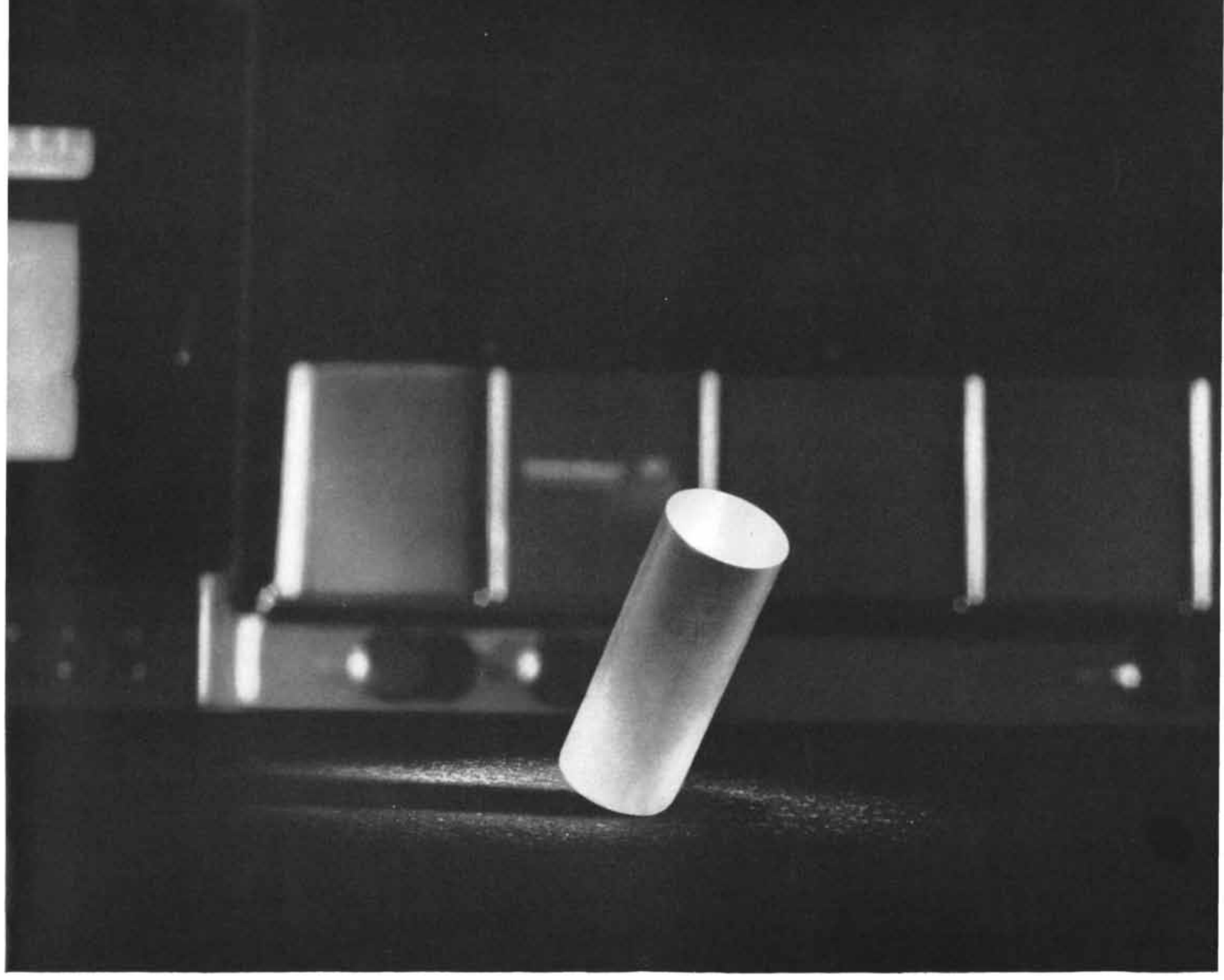
The complete list of transuranic elements, from element 93 through element 103, now reads: neptunium, plutonium, americium, curium, berkelium (which some pronounce berkeelium, some burkleum and some barkleum), californium, einsteinium, fermium, mendelevium, nobelium and lawrencium.

Earthglass or Moonglass?

Important new evidence on the origin of the mysterious, glassy objects called tektites was presented at a recent meeting of the American Geophysical Union in Washington. Although the long-standing debate as to whether they come from the earth or the moon is far from over, the data reported in Washington seems to favor the earth.

Tektites, which are strewn widely over several regions of the world, consist chiefly of silica, together with small amounts of metallic oxides. Despite their chemical resemblance to the volcanic glass obsidian, they are apparently not formed by volcanic action; the "strewn fields" in which they lie are not close to known volcanoes. Ranging up to three inches in diameter, tektites look as though they had been shaped in flight while molten. According to one school they were created by meteorites that struck the moon and propelled molten lunar debris earthward. The other leading view holds that they were formed on the earth by some unknown process.

In the past year John H. Reynolds of the University of California and J. Zahringer of the Max Planck Institute



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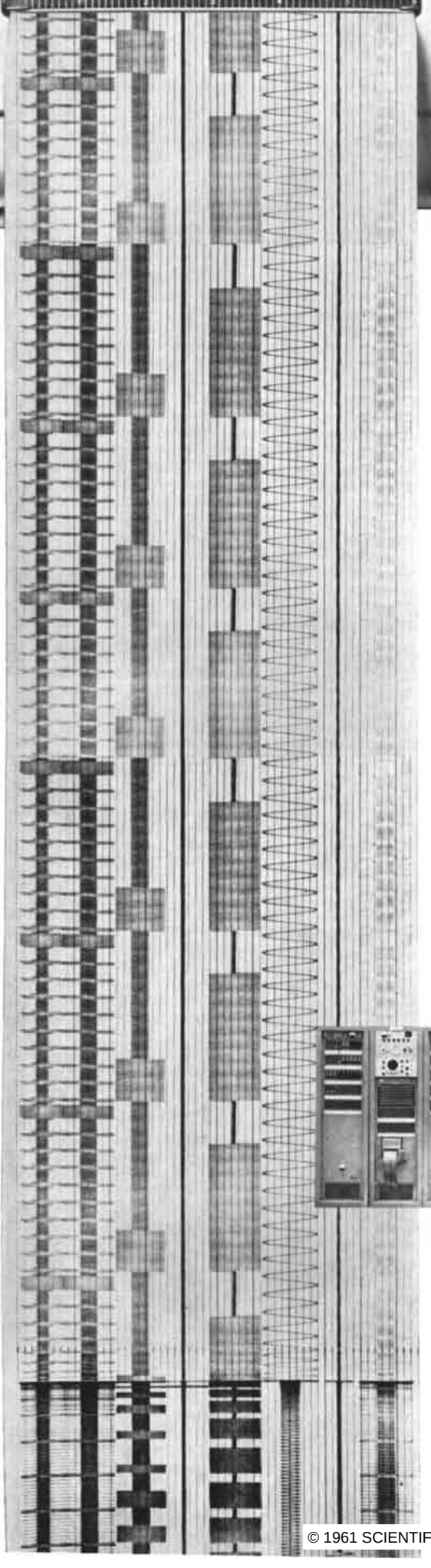
for Physics in Germany have dated the tektites in three of the major strewn fields by measuring their content of the radioactive isotope potassium 40. The three groups have widely different ages, but the members of each one are apparently all equally old. Tektites found in Georgia and Texas are about 30 million years old; those in Czechoslovakia are eight to nine million years old; those in the biggest field of all, stretching from Laos to Australia, date back only 600,000 years. This suggests that the fields originated in three separate cataclysms but it says nothing about the nature or location of the events.

Alvin J. Cohen of the Mellon Institute in Pittsburgh thinks he may have found the answer. He suggests that tektites represent molten material splashed high in the atmosphere on a ballistic trajectory by huge meteorites striking the earth. The Czechoslovakian tektites, Cohen believes, were created by a meteorite that produced the 16-mile crater, called the Ries Kessel (Giant Kettle), near Nordlingen in southern Germany. The crater had always been regarded as volcanic in origin until Edward T. C. Chao and his associates of the U. S. Geological Survey showed last year that it contains a high-pressure form of silica—coesite—which clearly indicates meteoritic impact. The Czechoslovakian tektites are strewn along a narrow track beginning 150 miles almost due east from the crater and extending out to 250 miles. The entire field lies within an angle 10 degrees wide centering on the Ries Kessel. Cohen's detailed examination of the tektites shows that their aerodynamic shaping and chemical composition vary from west to east in a manner consistent with ejection from the crater in a molten stream that soared skyward. Geological evidence places the Ries Kessel in the late Miocene period, which agrees with the tektite age of eight or nine million years.

Cohen has found another crater, now a lake in Ghana, that he connects with a strewn field, still undated, along the Ivory Coast some 150 miles to the west. This field forms a 12-degree sector centering on the crater. As to the Georgia-Texas field, he guesses that its crater lies in the Gulf of St. Lawrence, and he has a hunch that there is an enormous crater in southwest China that accounts for the Laos-to-Australia field.

Among all known tektites, those in Australia are unique in that they seem to have melted twice. Cohen suggests that these bodies, after originating in the molten state, were blown so high that they solidified after leaving the atmos-

Visicorder and record shown approx. ½ actual size.



Record speed changed during recording.

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phere and then melted again on re-entry. According to the lunar hypothesis, he points out, all tektites should have passed through two molten phases: once when they were formed on the moon and again when they entered the earth's atmosphere.

First Fliers

The story of Icarus—who flew, moth-like, too close to the sun—is told again and again of other heroes in ancient chronicles. Historians of aviation have classified them all as legendary and credit the first successful flights by heavier-than-air machines to the glider pilots John Montgomery of California (1884) and Otto Lilienthal of Germany (1891).

Lynn White, Jr., of the University of California at Los Angeles has looked closer at the chronicles and contemporary supporting evidence and now advances two much earlier claimants to the title of first aviator. It appears that sometime between A.D. 1000 and 1010 a Benedictine monk, Eilmer of Wiltshire Abbey in England, donned a pair of large wings, and "collecting the breeze on the summit of a tower, he flew for more than the distance of a furlong." The account comes from William of Malmesbury, according to White "the best informed and most reliable historian in 12th-century England." Though not a contemporary of Eilmer, William was also a monk in Wiltshire Abbey and "was almost certainly acquainted with monks who had known the halt and aged Eilmer in their own youth and who had heard from him and from others the account of his flight."

White also finds reason to credit the story of a Moslem physician, Ibn Firnās of Cordoba, who "covered himself with feathers . . . attached a couple of wings to his body, and, getting on an eminence, flung himself down into the air, when, according to the testimony of several trustworthy writers who witnessed the performance, he flew a considerable distance, as if he had been a bird." The account in this case comes from al-Maqqarī, a Moroccan historian who died in 1632. From evidence bearing on the reliability of al-Maqqarī's sources, White concludes that Ibn Firnās "was the first man to fly successfully."

Unlike Icarus, Ibn Firnās and Eilmer survived their heroic adventures—but not without injury: Ibn Firnās injured his back and Eilmer was lamed for life. The chronicles attribute the abrupt termination of both flights to the same cause: the fliers failed to equip themselves with tails.

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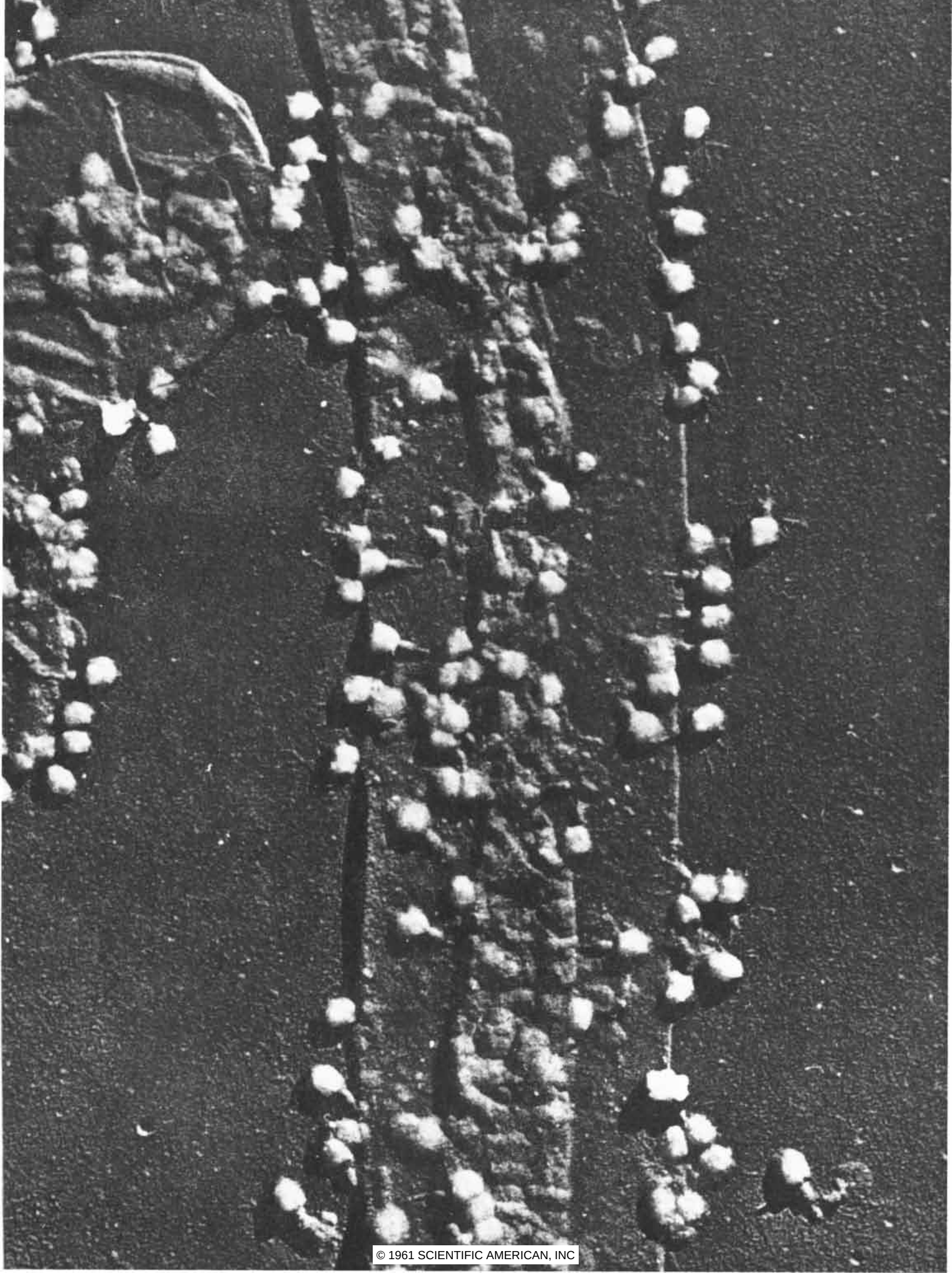


VIRUSES AND GENES

When a virus infects a bacterium, the genes of the virus sometimes act as genes of their host. The phenomenon has illuminated the mechanism of both heredity and infection

by François Jacob and Elie L. Wollman

Almost everyone now accepts the unity of the inanimate physical world. Physicists do not hesitate to extrapolate laboratory results obtained with a small number of atoms to explain the source of the energy produced by stars. In the world of living things a comparable unity is more difficult to demonstrate; in fact, it is not altogether conceded by biologists. Nevertheless, most students of bacteria and viruses are inclined to believe that what is true for a simple bacillus is probably true for larger organisms, be they mice, men or elephants.

Accordingly we shall be concerned here with seeking lessons in the genetic behavior of the colon bacillus (*Escherichia coli*) and of the still simpler viruses that are able to infect the bacillus and destroy it. Viruses are the simplest things that exhibit the fundamental properties of living systems. They have the capacity to produce copies of themselves (although they require the help of a living cell) and they are able to undergo changes in their hereditary properties. Heredity and variation are the subject matter of genetics. Viruses, therefore, possess for biologists the elemental qualities that atoms possess for physicists. When a virus penetrates a cell, it introduces into the cell a new genetic structure that interferes with the genetic information already contained within the cell. The study of viruses has thus become a branch of cellular genetics, a view that has upset many old notions, including the traditional distinction between heredity and infection.

For a long time geneticists have worked with such organisms as maize and the fruit fly *Drosophila*. They have learned how hereditary traits are transmitted from parents to progeny, they have discovered the role of the chromosomes as carriers of heredity and they have charted the results of mutations—the events that modify genes. Complex organisms, however, multiply too slowly and in insufficient numbers for the high-resolution analyses needed to clarify such problems as the chemical nature of genes and the processes by which a gene makes an exact copy of itself and influences cellular activity. These detailed problems are most readily studied in bacteria and in viruses. Within the space of a day or two the student of bacteria or bacterial viruses can grow and study more specimens than the fruit-fly geneticist could study in a lifetime. An operation as simple as the mixing of two bacterial cultures on a few agar plates can provide information on a billion or more genetic interactions in which genes recombine to form those of a new generation.

It is the events of recombination, together with mutations, that model and remodel the chromosomes, the structures that contain in some kind of code the entire pattern of every organism. In recent years geneticists and biologists have clarified the nature of the hereditary message and have gained some clues as to what the letters of the code are. The primary, and perhaps the unique, bearers of genetic information in all forms of life appear to be molecules of nucleic acid. In living organisms, with the exception of some of the viruses, these long-chain molecules are composed of deoxyribonucleic acid (DNA). In all plant viruses and in some animal viruses the genetic substance is not DNA but its close chemical relative ribonucleic acid (RNA). DNA molecules are built up of hundreds of thousands or even millions of simple molecular subunits: the nucleotides of the four bases adenine, thymine, guanine and cytosine. These subunits, in an almost infinite variety of combinations, seem capable of encoding all the characteristics that all organisms transmit from one generation to the next. RNA molecules, which are somewhat shorter in length and not so well understood, act similarly for the viruses in which RNA is the genetic material.

Ultimately the role of the genes—the words of the hereditary message—is to specify the molecular organization of proteins. Proteins are long-chain molecules built up of hundreds of molecular subunits: the 20 amino acids. The sequence of nucleotides in the nucleic acid that contains the hereditary message is thought to determine the sequence of amino acids in the protein it manufactures. This process involves a "translation" from the nucleic-acid code into the protein code through a mechanism that is not yet understood.

The Bacterial Chromosome

Before considering viruses as cellular genetic elements, we shall summarize the present knowledge of the genetics of the bacterial cell. In bacteria the hereditary message appears to be written in a

SCORES OF VIRUSES of the strain designated T_2 are attached to the wall of a colon bacillus in this electron micrograph. The viruses are fastened to the bacterial wall by their tails, through which they inject their infectious genetic material. (Walls of the cell collapsed when the specimen was dried by freezing. "Shadowing" with uranium oxide makes objects stand out in relief.) The electron micrograph was made by Edouard Kellenberger of the University of Geneva. The magnification is 70,000 diameters.

single linear structure, the bacterial chromosome. For the study of this chromosome an excellent tool was discovered in 1946 by Joshua Lederberg and Edward L. Tatum, who were then working at Yale University. They used the colon bacillus, which is able to synthesize all the building blocks required for the manufacture of its nucleic acids and proteins and therefore to grow on a minimal nutrient medium containing glucose and inorganic salts. Mutant strains, with defective or altered genes, can be produced that lack the ability to synthesize one or more of the building blocks and therefore cannot grow in the absence of the building block they cannot make. If, however, two different mutant strains are mixed, bacteria like the original strain reappear and are able to grow on a minimal medium.

Lederberg and Tatum were able to demonstrate that such bacteria are the result of genetic recombination occurring when a bacterium of one mutant strain conjugates with a bacterium of another mutant strain. Further work by Lederberg, and by William Hayes in London, has shown that the colon bacillus also has sex: some individuals act as males and transmit genetic material by direct contact to other individuals that act as recipients, or females. The difference between the two mating types may be ascribed to the fertility factor (or sex factor) *F*, present only in males. Curiously, females can easily be converted into males; during conjugation certain types of male, called F^+, transmit their sex factor to the females, which then become males.

The Chromosome "Essay"

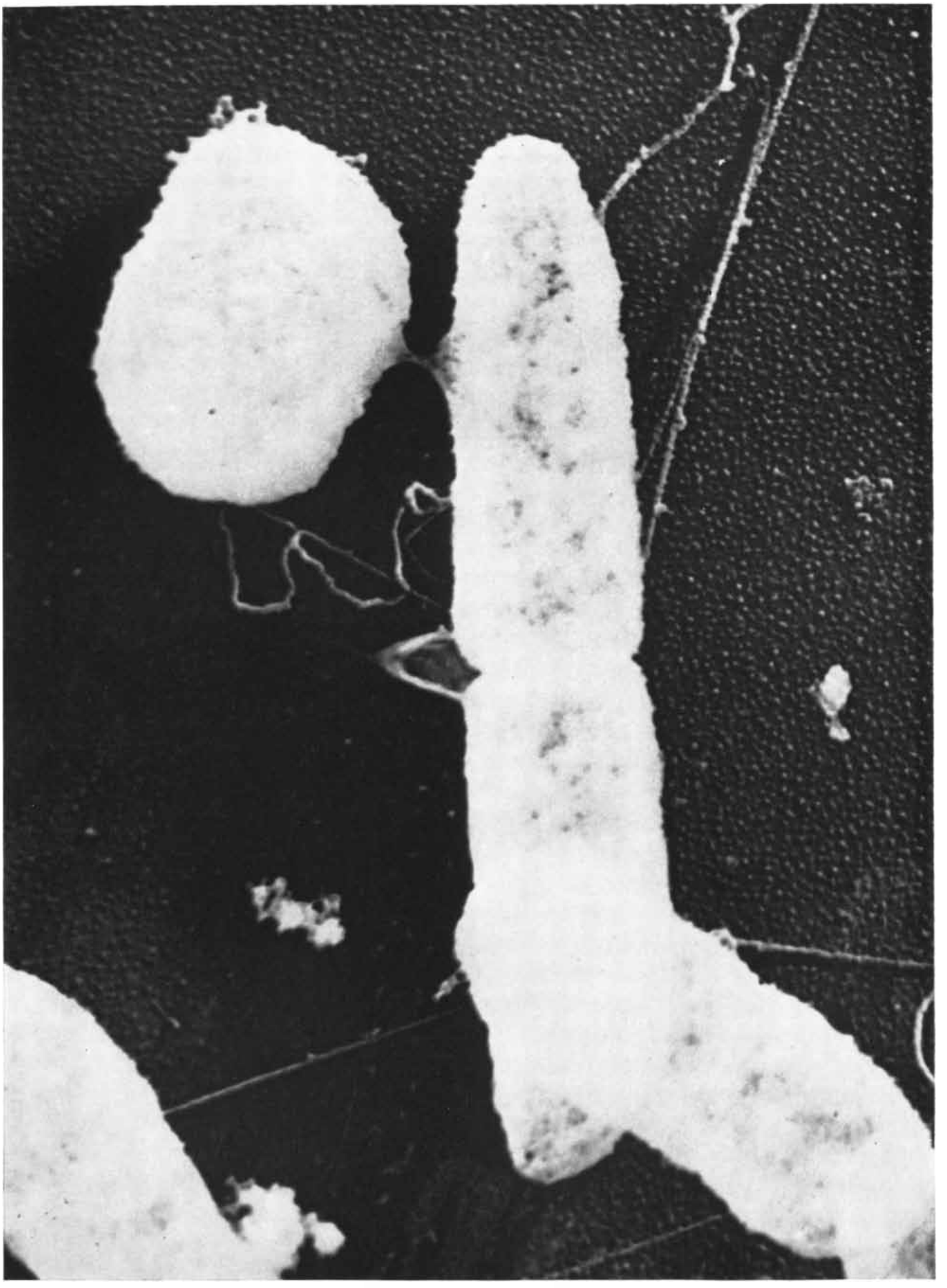
Our own work at the Pasteur Institute in Paris has shed light on the different steps involved in bacterial conjugation and on the mechanism ensuring the transfer of the chromosome from certain strains of male, called *Hfr*, to females. When cultures of such males and of females are mixed, pairings take place between male and female cells through random collisions. A bridge forms between the two mating bacteria; one of the chromosomes of the male (bacteria have generally two to four identical chromosomes during growth) begins to migrate across the bridge and to enter the female. In the female, portions of the male chromosome have the ability to recombine with suitable portions of one of the female chromosomes. The chromosomes may be compared to written essays that differ only by a few letters, or a few words, corresponding to the mutations. Portions of the two essays may become paired, word for word and letter for letter. Through the process known as genetic recombination, which is still very mysterious and challenging, fragments of the male chromosome, which can be anything from a word or a phrase up to several sentences, may be exactly substituted for the corresponding part of the female chromosome. This process gives rise to a complete new chromosome that contains a full bacterial essay in which some words from the male have replaced corresponding words from the female. The new chromosome is then replicated and transmitted to the daughter cell.

Perhaps the most remarkable feature of bacterial conjugation is the way in which the male chromosome migrates across the conjugation bridge. For a given type of male the migration always starts at the same end of the chromosome, which, if we represent the bacterial chromosome by the letters of the alphabet, we can call *A*. Then, with the chromosome proceeding at constant speed, it takes two hours before the other end, *Z*, has penetrated the female. After the mating has begun, conjugation can be interrupted at will by violently stirring the mating mixture for a minute or so in a blender. The mechanical agitation does not kill the cells but it disrupts the bridge and breaks the male chromosome during its migration. The fragment of the male chromosome that has entered the female before the interruption is still functional and has the ability to provide words or sentences for a chromosome [*see illustration on pages 96 and 97*]. If conjugation is mechanically interrupted at various intervals after the onset of mating, it is found that any gene carried by the male chromosome, from *A* to *Z*, enters the female at a precise time. We have therefore been able to draw two kinds of detailed chromosome map showing the location of genes. One map, the conventional kind, is based on the observed frequency of different sorts of genetic recombination; the second is a new kind of map reflecting the time at which any gene penetrates the female cell. The latter can be compared to a road map drawn by measuring the times at which a car proceeding at a constant speed passes through various cities.

Finally, the mode of the male chromosome's migration has provided a unique opportunity for correlating genetic measurements with chemical measurements of the chromosome. In collaboration with Clarence Fuerst, who is now working at the University of Toronto, we have grown male bacteria in a medium containing the radioactive isotope phosphorus 32, which is incorporated into the DNA of the bacterial chromosome. The labeled bacteria are then frozen and kept in liquid nitrogen to allow some of the radioactive atoms to disintegrate. At various times samples are thawed and the labeled males are then mated with unlabeled females. The experiments show that the radioactive disintegrations sometimes break the chromosomes. If the break occurs between two markers, say *E* and *F*, the head part, *ABCDE*, is transferred to the female, but the tail part, *FGHIJKLMNOPQRSTUVWXYZ*, is not. Therefore the greater the number of phosphorus atoms between the *A* extremity of the chromosome and a given gene, the greater the chance that a break will prevent this gene from being transferred to the female. It is thus possible to draw a chromosomal map showing the location of the genes in terms of numbers of phosphorus atoms contained in the chromosome between the known genes. When we compare this map with those obtained by genetic analysis or by mechanical interruption, we find that for a given type of male all three maps are consistent.

In some types of male mutant the genetic characters have the same sequence along the chromosome but the character injected first differs from one mutant to another. The characters can also be injected either in the forward direction or in the backward direction, that is, from *A* to *Z* or from *Z* to *A*, with the alphabet capable of being broken at any point. These observations can be explained most simply by assuming that all the genetic "letters" of the colon bacillus are arranged linearly in a ring and that the ring can be opened at various points by mutation. It seems, furthermore, that the opening of the ring is a consequence of the attachment of the sex factor to the chromosome. The ring opens at precisely the point where the factor *F*, which is free to move, happens to affix itself. A cell with the *F* factor affixed to the chromosome is called an *Hfr* male, or "supermale," because it enhances the transmission of chromosomal markers. *Hfr* stands for "high frequency of recombination." When the chromosome is opened by the *F* factor, one of the free ends initiates the penetration of the chromosome into the female, carrying the sequence of characters after it. The other end carries the sex factor itself and is the last to enter the female. The sex factor has other remarkable properties and we shall bring it back into our story later.

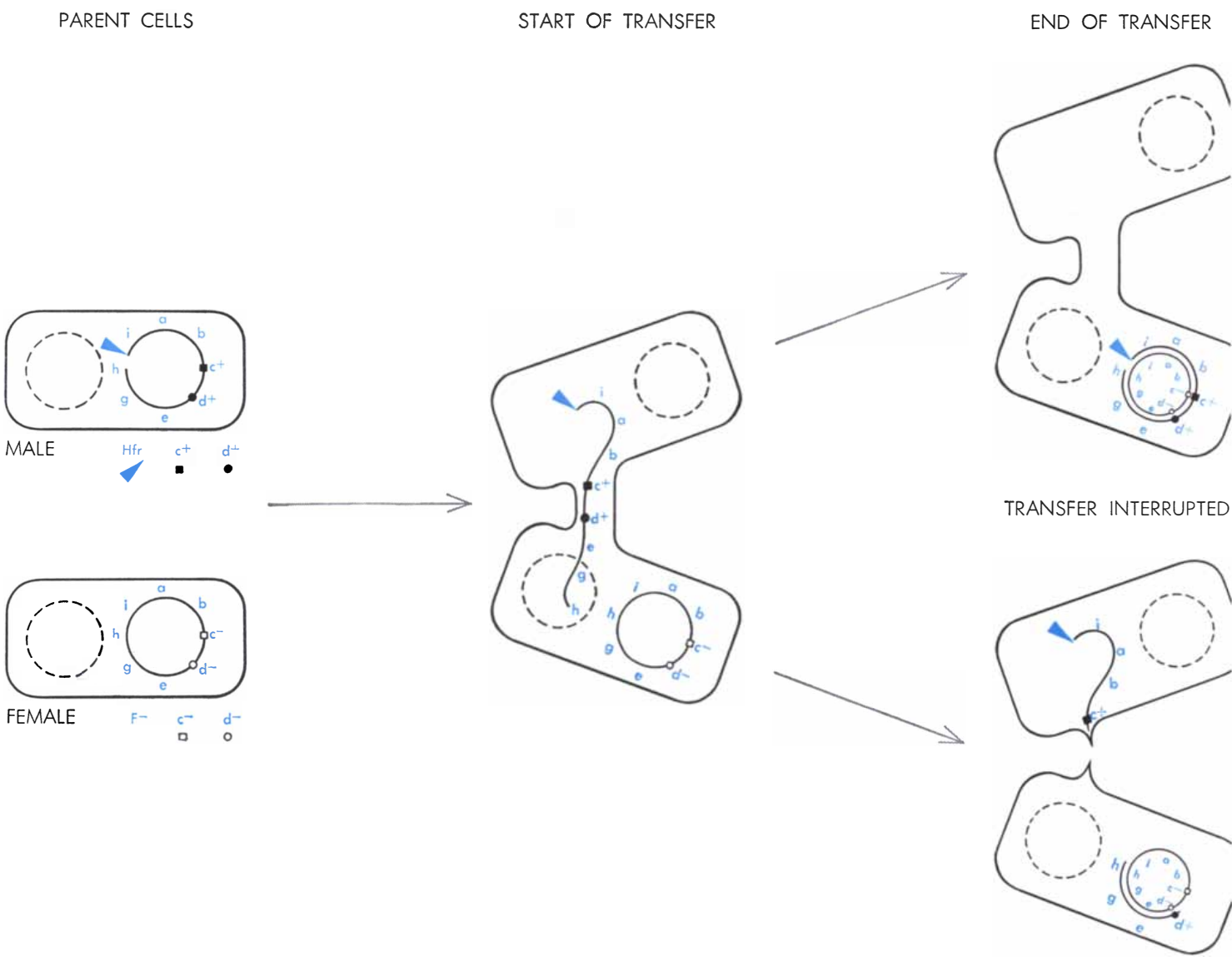
The long-range objective of such stud-



CONJUGATING BACTERIA conduct a transfer of genetic material. Long cell (*right*) is an *Hfr* "supermale" colon bacillus, which is attached by a short temporary bridge to a female colon bacillus (*see illustration on next two pages*). This electron micrograph, shown at a magnification of 100,000 diameters, was made by Thomas F. Anderson of the Institute for Cancer Research in Philadelphia.

ies is to learn how the thousands of genes strung along the chromosome control the molecular pattern of the bacterial cell: its metabolism, growth and division. These processes imply precise regulatory mechanisms that maintain a harmonious equilibrium between the cellular constituents. At any time the bacterial cell "knows" which components to make and how much of each is needed for it to grow in the most economical way. It is able to recognize which kind of food is available in a culture medium and to manufacture only those protein enzymes that are required to get energy and suitable building blocks from the available food.

At the Pasteur Institute, in collaboration with Jacques Monod, we have recently found new types of gene that determine specific systems of regulation. Mutants have been isolated that have become "unintelligent" in the sense that they cannot adjust their syntheses to their actual requirements. They make, for example, a certain protein in large amounts when they need only a little of it or even none at all. This waste of energy decreases the cells' growth rate. It seems that the production of a particular protein is controlled by two kinds of gene. One, which may be called the structural gene, contains the blueprint for determining the molecular organization of the protein—its particular sequence of amino acid subunits. Other genes, which may be called control genes, determine the rate at which the information contained in the structural gene is decoded and translated into protein. This control is exercised by a signal embodied in a repressor molecule, probably a nucleic acid, that migrates from the chromosome to the cytoplasm of the cell. One of the control genes, called the regulator gene, manufactures the repressor molecule; thus it acts as a transmitter of signals. These are picked up by the operator gene, a specific receiver able to switch on or off the activity of the adjacent structural genes. Metabolic

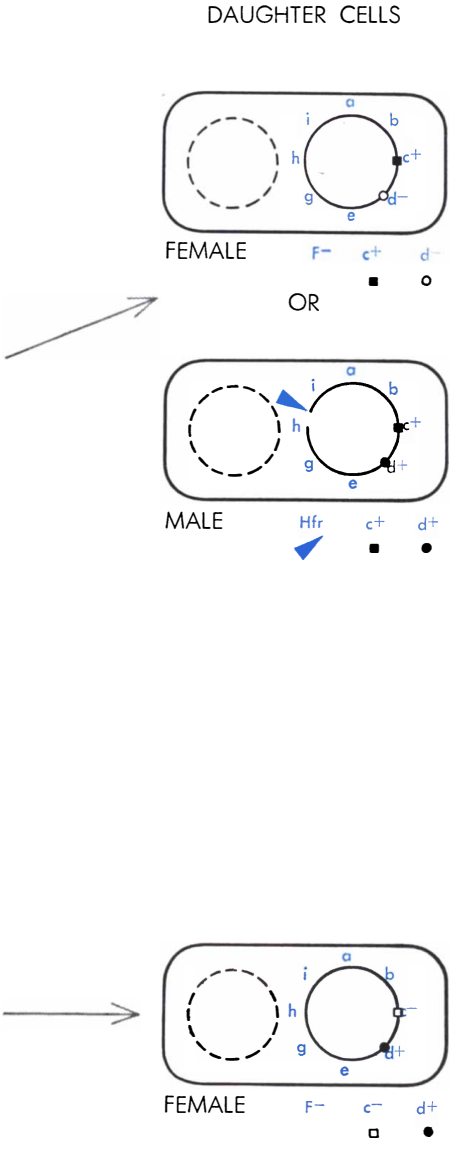


CHROMOSOMAL TRANSFER provides a primitive sexuality for colon bacillus. The bacterial chromosome, which appears to be ring-shaped, carries genetic markers (*designated by letters*), the presence or absence of which can be determined by studying cell's nutritional requirements. When the sex, or *F*, agent is attached to the chromosome, opening the ring, the cell is called an *Hfr* supermale. Two markers, labeled c^+ and d^+ when present and c^- and d^- when absent, can be traced from parents to daughter cells. When male and female cells conjugate, one of the male chromosomes (there are usually several, all identical) travels through the bridge.

products can interfere with the signals, either activating or inactivating the proper repressor molecules and thereby initiating or inhibiting the production of proteins.

Within the bacterial cell, then, there exists a complex system of transmitters and receivers of specific signals, by means of which the cell is kept informed of its metabolic requirements and enabled to regulate its syntheses. The bacterial chromosome contains not only a series of blueprints for the manufacture of individual molecular components but also a plan for the co-ordinated production of these components.

Let us now turn to the events that take place when a bacterial virus of the strain designated T_2 infects the colon bacillus. A T_2 virus is a structure shaped like a tadpole; by weight it is about half protein and half DNA. The DNA is enclosed in the head, the outside of which is protein; the tail is also composed of protein. The roles of the DNA and the protein in the infective process were clarified in 1952 by the beautiful experiments of Alfred D. Hershey and Martha Chase of the Carnegie Institution of Washington's Department of Genetics in Cold Spring Harbor, N. Y. By labeling the DNA fraction of the virus with one radioactive isotope and the protein fraction with another, Hershey and Chase were able to follow the fate of the two fractions. They found that the DNA is injected into the bacterium, whereas the protein head and tail parts of the virus remain outside and play no further role. Electron micrographs reveal that the tail provides the method of attachment to the bacterium and that the DNA is injected through the tail. The Hershey-Chase experiment was a landmark in virology because it demonstrated that the nucleic acid carries into the cell all the information necessary for the production of complete virus particles.



If transfer is complete, daughter cells may be male or female and carry any marker of the male. If transfer is interrupted, daughters are all female and can carry only those markers passed before bridge was broken.

How Viruses Destroy Bacteria

A bacterium that has been infected by virus DNA will break open, or lyse, within about 20 minutes and release a new crop of perhaps 100 particles of infectious virus, complete with protein head and tail parts. In this brief period the virus DNA subverts the cell's chemical facilities for its own purposes. It brings into the cell a plan for the synthesis of new molecular patterns and the cell faithfully carries it out. The infected cell creates new protein subunits needed for the virus head and tail, and filaments of nucleic acid identical to the DNA of the invading particle. These pools of building blocks pile up more or less at random, and in excess amounts, inside the cell. Then the long filaments of virus DNA suddenly condense and the protein subunits assemble around them, creating the complete virus particle. The whole process can be compared to the occupation of one country by another; the genetic material of the virus overthrows the lawful rule of the cell's own genetic material and establishes itself in power.

A virus can therefore be considered a genetic element enclosed in a protein coat. The protein coat protects the genetic material, gives it rigidity and stability and ensures the specific attachment of the virus to the surface of the cell. As André Lwoff of the Pasteur Institute has pointed out, viruses can be uniquely defined as entities that reproduce from their own genetic material and that possess an apparatus specialized for the process of infection. The definition excludes both the cell and the specialized particles within the cell that serve its normal functions.

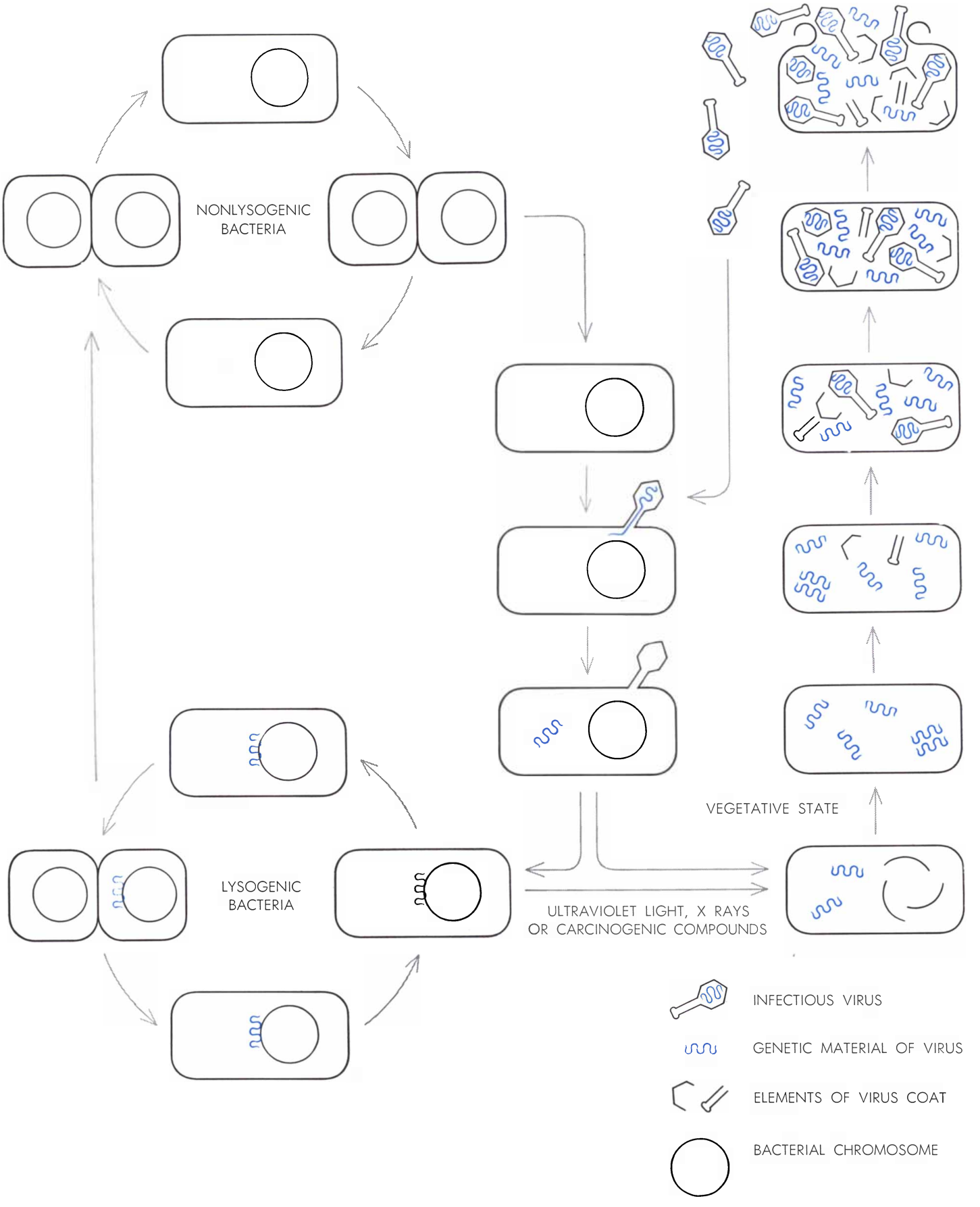
Another important criterion of viral growth is that of unrestricted synthesis. Infection with a virus is a sort of molecular cancer. The replication of the genetic material of the virus and the synthesis of the viral building blocks do not appear to be subject to any control system at all.

Lysogenic Bacteria

When a T_2 virus infects a bacterium, it forces the host to make copies of it and ultimately to destroy itself. Such a virus is said to be virulent, and when it is inside the cell, reproducing itself, it is said to be in the vegetative state.

There are, however, other bacterial viruses, called temperate viruses, which behave differently. After entering a cell the genetic material of a temperate virus can take two distinct paths, depending on the conditions of infection. It can enter the vegetative state, replicate itself and kill the host, just as a virulent virus does. Under other circumstances it does not replicate freely and does not kill the host. Instead it finds its way to the bacterial chromosome, anchors itself there and behaves like an integrated constituent of the host cell. Thereafter it will be transmitted for years to the progeny of the bacterium like a bacterial gene. We know that the bacterial host has not destroyed the invading particle, because from time to time one of the daughter cells in the infected line will break open and yield a crop of virus particles, as it would if it had been freshly attacked by a virulent virus. When the virus is in the subdued and integrated state, it is called a provirus. Bacteria carrying a provirus are called lysogenic, meaning that they carry a property that can lead to lysis and death.

Lysogeny was discovered in the early 1920's, soon after the discovery of the bacterial virus itself, and it remained a profound mystery for some 25 years. The mystery was explained by the fine detective work of Lwoff and his colleagues [see "The Life Cycle of a Virus," by André Lwoff; SCIENTIFIC AMERICAN, March, 1954]. Lwoff found that when he exposed certain types of lysogenic bac-



LIFE CYCLE OF BACTERIAL VIRUS shows that, for the bacterium attacked, infection and death are not inevitable. After the genes of the virus (*color*) enter a cell descended from a completely healthy line (*top left*), the cell may take either of two paths. One (*far right*) leads to destruction as the virus enters the vegetative state, makes complete copies of its infective self and bursts open the cell, a process called lysis. The other path leads to the so-called lysogenic state, in which the viral genes attach themselves to the bacterial chromosome and become a provirus; the cell lives. Exposure to ultraviolet light, however, can dislodge the provirus and induce the vegetative state. The provirus is sometimes lost during cell division, returning the cell to the nonlysogenic state.

teria to ultraviolet light, X rays or active chemicals such as nitrogen mustard or organic peroxides, the whole bacterial population would lyse within an hour, releasing a multitude of infectious virus particles. When a provirus is thus activated, or "induced," it leaves the integrated state and enters the vegetative state, eventually destroying the cell [*see illustration on opposite page*].

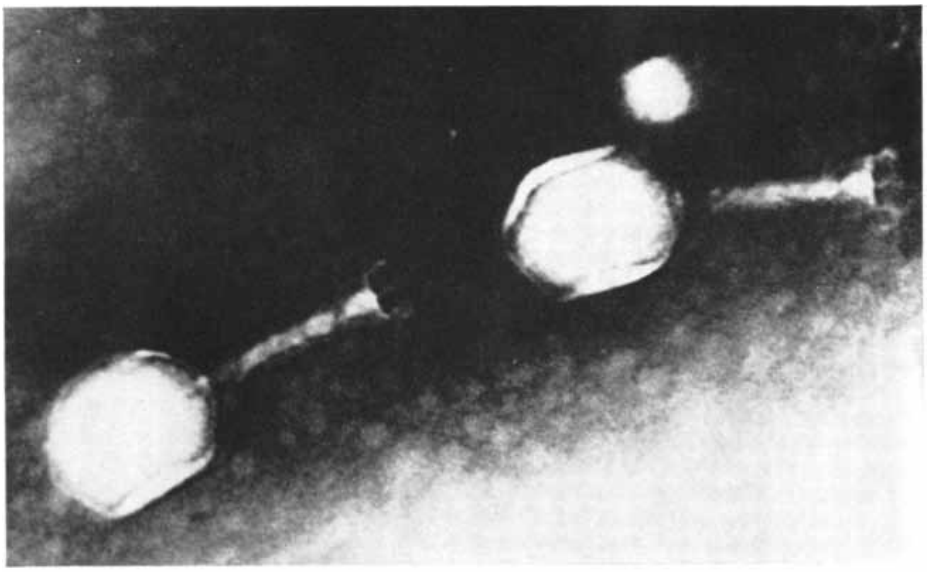
To determine the position of the provirus inside the host cell, we can apply the method of interrupting the sexual conjugation of bacteria that carry a provirus and are therefore lysogenic. In this way we can correlate the location of the provirus with that of known characters on the bacterial chromosome. Each of 15 different types of provirus takes a particular position at a specific site on the bacterial chromosome. Only one is an exception; it seems free to take a position anywhere. In the proviral state the genetic material of the virus has not become an integral part of the bacterial chromosome; instead it appears to be added to the chromosome in an unknown but specific way. However it may be hooked on, the genetic material of the virus is replicated together with the genetic material of the host. It behaves like a gene, or rather as a group of genes, of the host.

Nonviral Effects of Provirus

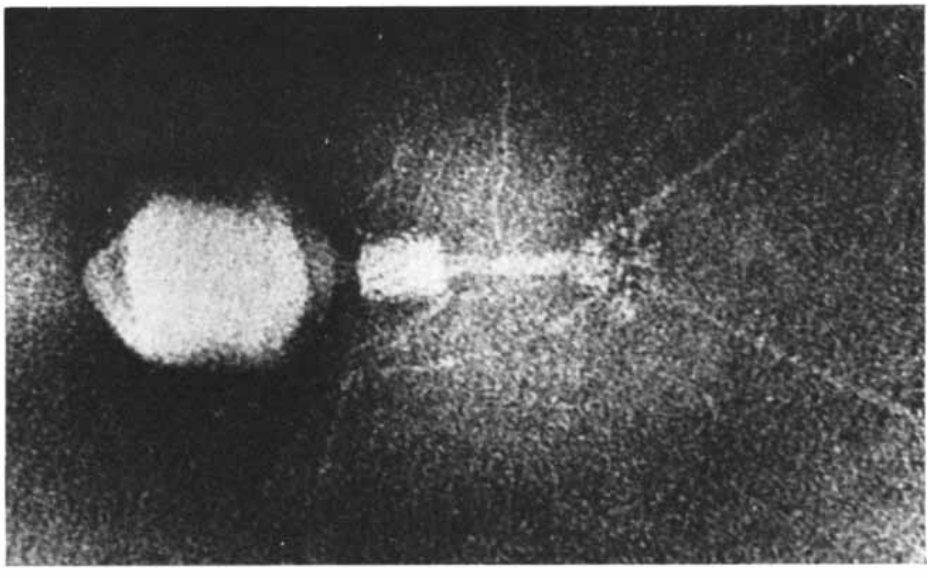
The presence of this apparently innocuous genetic element, the provirus, can confer on the lysogenic bacteria that harbor it some new and striking properties. It is not at all obvious why some of these properties should be related to the presence of a provirus. As one example, diphtheria bacilli are able to produce diphtheria toxin only if the bacilli carry certain specific types of provirus. The disease diphtheria is caused solely by this toxin.

In other instances the presence of a provirus is responsible for a particular type of substance coating the surface of a bacterium. The substance can be identified by various immunological tests (typically by noting if a precipitate forms when a certain serum is added). The nonlysogenic strain, carrying no provirus, will bear a different substance. In such cases the genes of the virus are responsible for hereditary properties of the host. They can scarcely be distinguished from the genes of the bacterium.

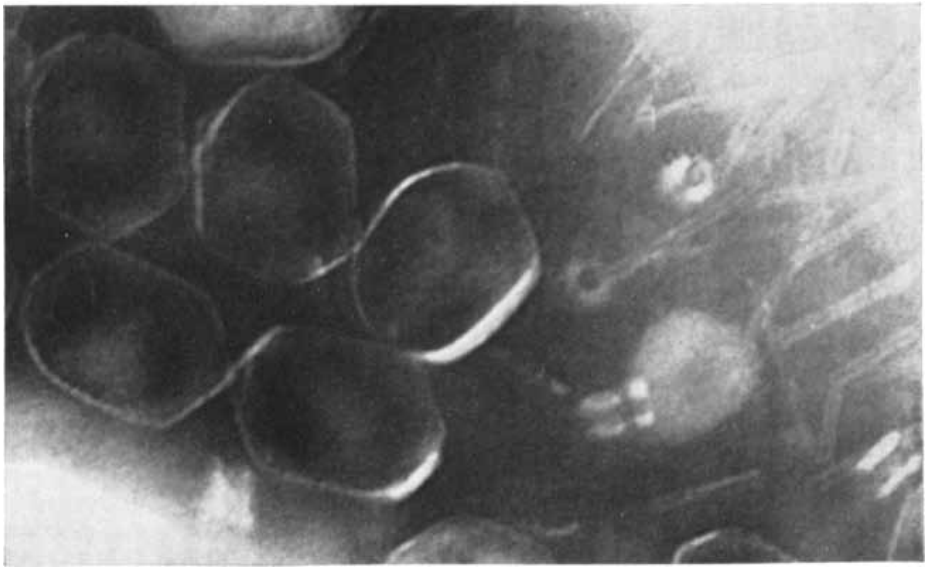
The most striking property the provirus confers on its bacterial host is immunity from infection by external viruses of the same type as the provirus. When



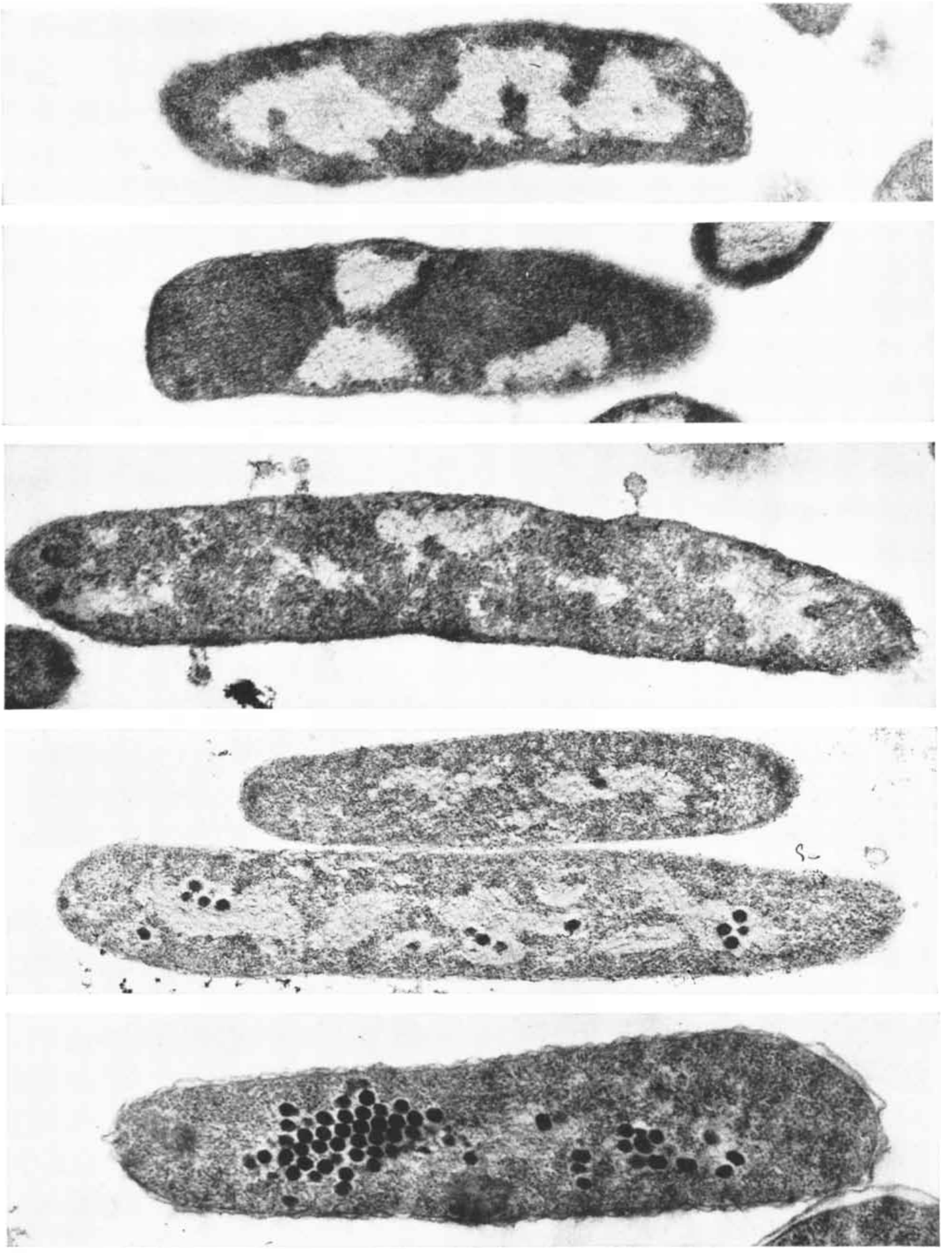
INTACT T_2 VIRUS has polyhedral head membrane and a curious pronged device at the end of its tail. The magnification is 200,000 diameters. This electron micrograph and the two below were made by S. Brenner and R. W. Horne at the University of Cambridge.



"TRIGGERED" T_2 VIRUS results from exposure to a specific bacterial substance that causes contraction of the tail sheath (*stubby cylinder*) and discharge of viral genes.



ISOLATED T_2 PARTS can be found still unassembled if host cell is forced to burst open before synthesis of virus particles is complete. Parts include head membranes and tails.



GROWTH OF T_2 VIRUS inside bacterial host is revealed in a striking series of electron micrographs by Kellenberger. Top picture shows the colon bacillus before infection. Four minutes after infection (*second from top*) characteristic vacuoles form along the cell wall. Ten minutes after infection (*third from top*) the virus has reorganized the entire cell interior and has created pools of new viral components. Twelve minutes after infection (*fourth from top*) new virus particles have started to condense. Thirty minutes after infection (*bottom*) more than 50 fully developed T_2 viruses have been produced and the cell is about ready to burst open.

lysogenic cells are mixed with such viruses, the virus particles adsorb on the cell and inject their genetic material into the cell, but the cell survives. The injected material is somehow prevented from multiplying vegetatively and is diluted out in the course of normal bacterial multiplication.

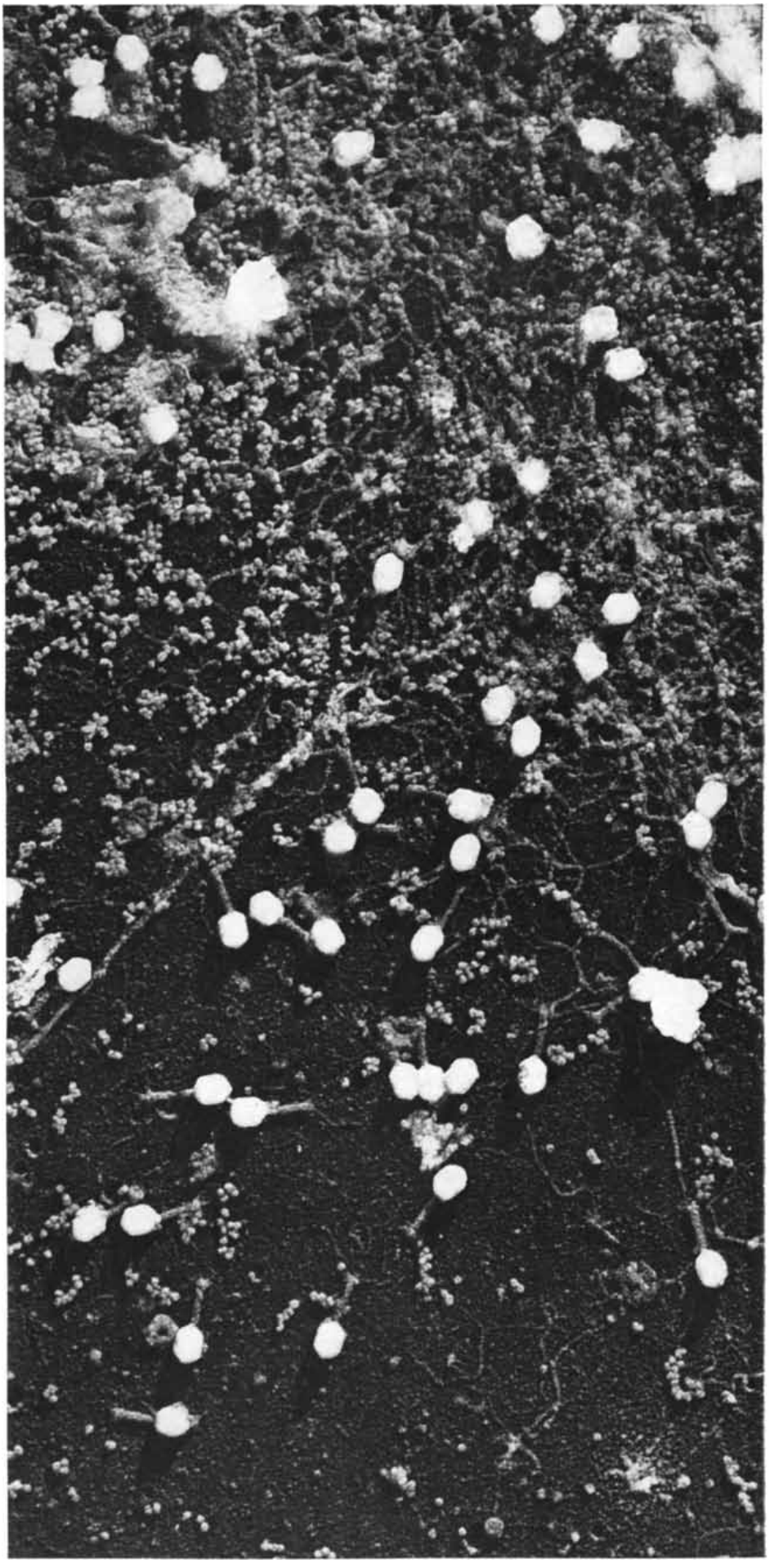
In the past two years we have attempted to learn more about the mechanism of this immunity. It seems clear that the mere attachment of the provirus to the host chromosome cannot account for the immunity of the host. The provirus must do something or produce something. We have evidence that the immunity is expressed by a substance or factor not tied to the chromosome. Remarkably enough, the system of immunity appears to be similar to the cellular systems already described that regulate the synthesis of protein in growing bacteria. It seems that the provirus produces a chemical repressor capable of inhibiting one or several reactions leading to the vegetative state. Thus immunity can be visualized as a specific system of regulation, involving the transmission of signals (repressors), which are received by an invading virus particle carrying the appropriate receptor.

Transduction

The close association that may take place between the genetic material of the virus and that of the host becomes even more striking in the phenomenon of transduction, discovered in 1952 by Norton D. Zinder and Lederberg at the University of Wisconsin [see "'Transduction' in Bacteria," by Norton D. Zinder; SCIENTIFIC AMERICAN, November, 1958]. They found that when certain proviruses turn into infective viruses, thereby killing their hosts, they may carry away with them pieces of genetic material from their dead hosts. When the viruses infect a host that is genetically different, the genes from the old host—the transduced genes—may be recombined with the genes of the new host. The transduction process seems able to move any sort of gene from one bacterial host to another.

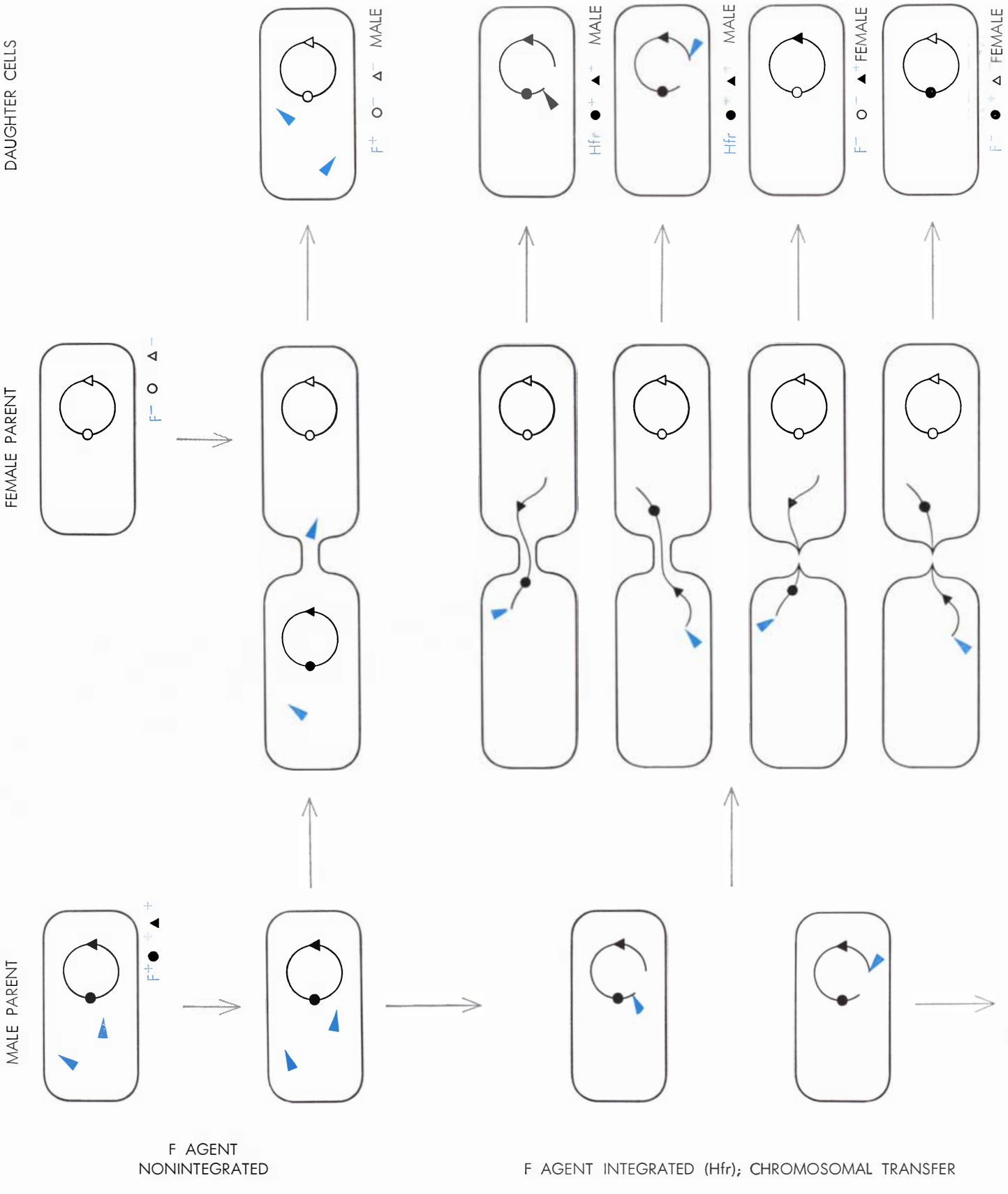
Lysogeny and transduction therefore represent two complementary processes. In lysogeny the genes of the virus become an integral part of the genetic apparatus of the host and replicate at the pace of the host's chromosome. In transduction genes of the host become linked to the genes of the virus and can replicate at the unrestricted viral pace when the virus enters the vegetative state.

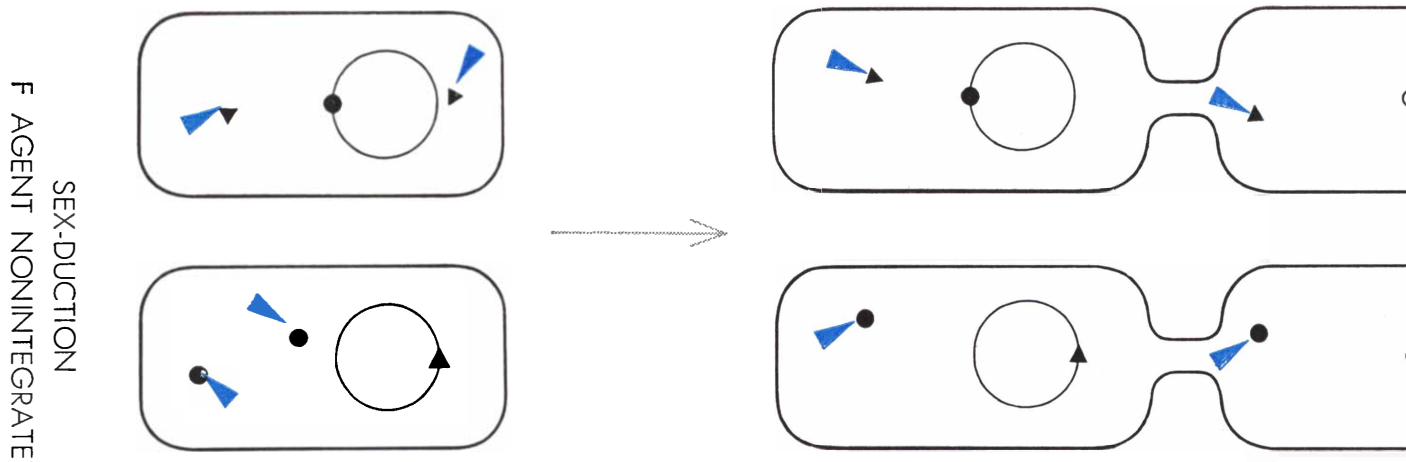
Viruses, like all other genetic ele-



DEATH OF A BACTERIUM occurs when T_2 virus particles, having multiplied inside their host (*see sequence on opposite page*), dissolve the walls of the bacterial cell and spill out—a phenomenon called lysis. Viruses are the large white objects; the other matter is cellular debris. The electron micrograph (magnification: 50,000 diameters) is by Kellenberger.

ments, can undergo mutations, and these produce a variety of stable, heritable changes. The mutations of particular interest are those that prevent the formation of mature, infectious virus particles. Lysogenic bacteria in which such mutations have taken place are called defective lysogenic bacteria. These bacteria hereditarily perpetuate a mutated provirus, which is perfectly able to replicate together with the host's chromosome. If these cells are exposed to ultraviolet radiation, which activates the provirus, we observe that the defective lysogenic cells die without releasing any infectious viruses. Examination of such bacteria usually shows that virus subunits have started to appear inside the cell but have failed to reach maturity [*see illustrations on pages 106 and 107*]. Evidently some essential step in the formation of





F, OR SEX, AGENT, indicated by colored wedge, is a versatile and busy "broker" in genes. It can be attached to the bacterial chromosomes (*integrated*) or unattached (*nonintegrated*) and can alternate between the two states. When nonintegrated, it usually transmits only itself when bacteria con-

jugate (*top sequer*
last marker trans
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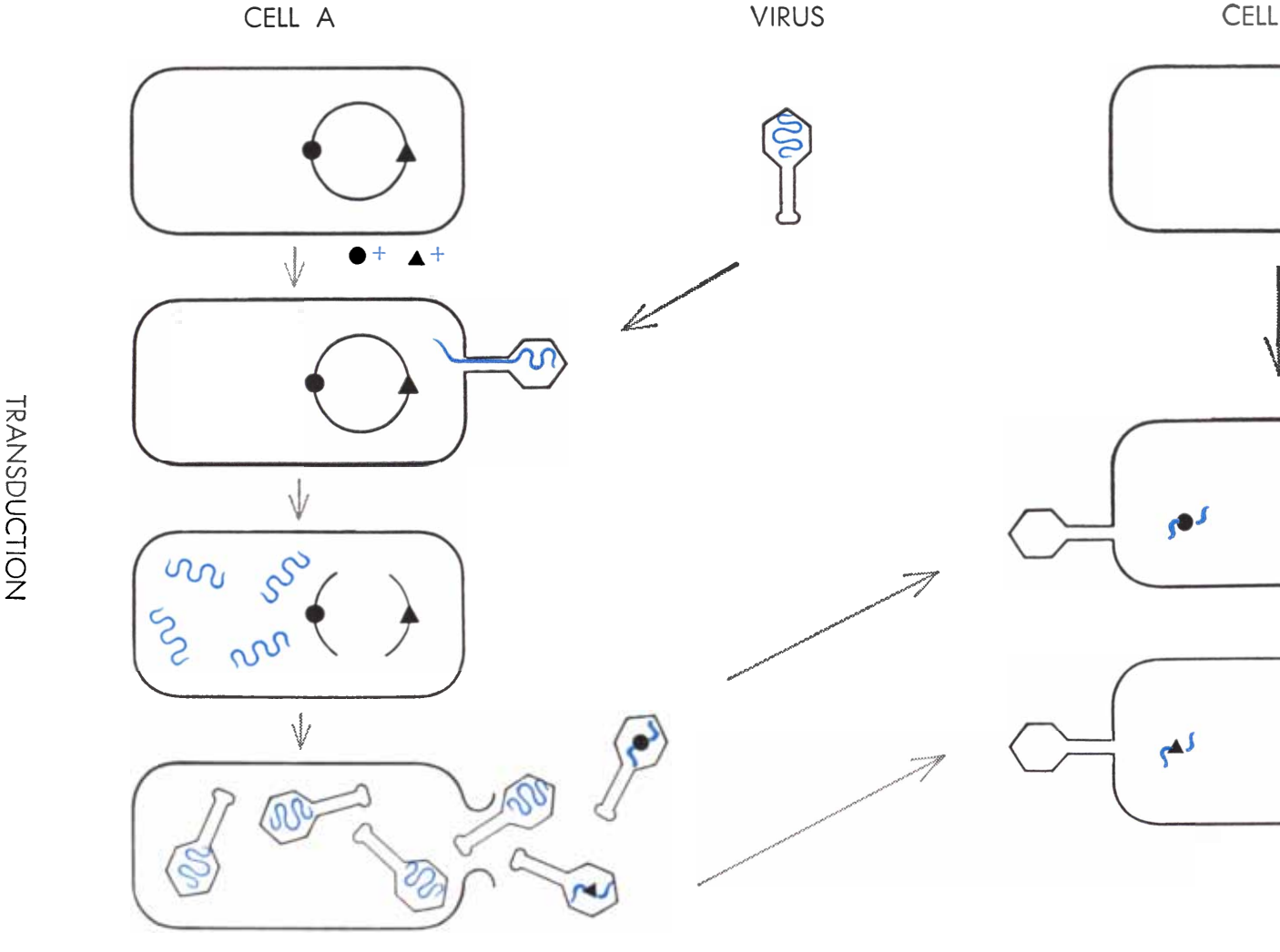
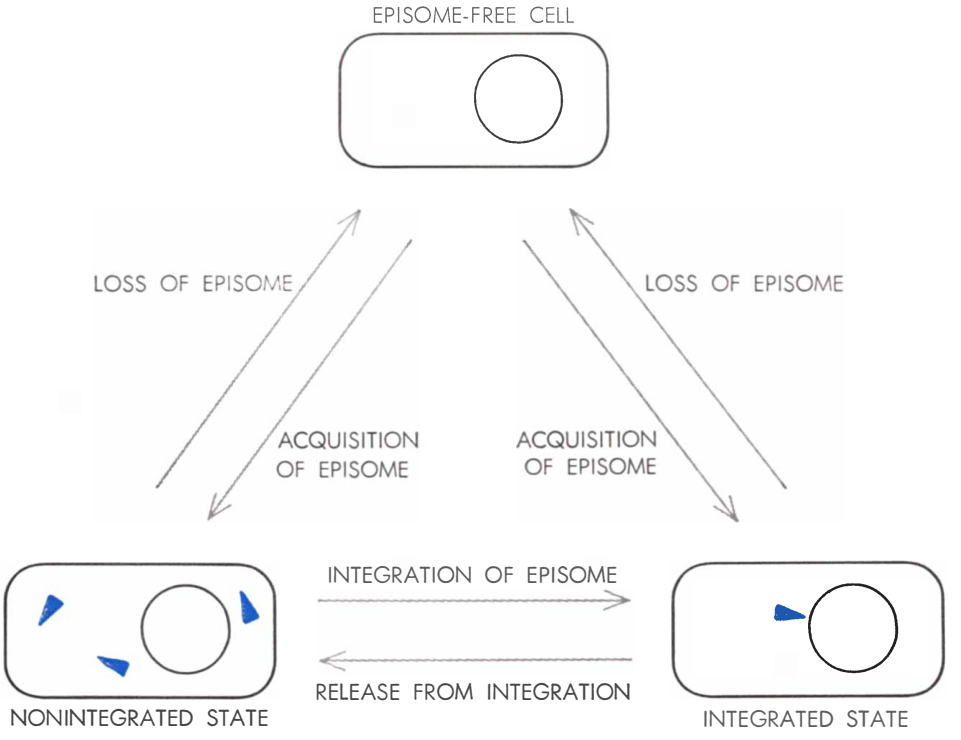
integrated state (*b*



TRANSDUCTION is similar to sex-duction and was discovered earlier. In transduction the agent for transferring bacterial genes is a virus particle rather than an *F* agent. The virus injects its genes (*color*) into bacterial cell *A* and the genes create new copies of the virus. Occasionally the new virus particles so

formed enclose a f
with a few viral ge
into another cell
(*solid black shape*



CONCEPT OF THE "EPISOME," as put forward by the authors, describes a genetic element, such as the *F* agent, that may be either attached to the chromosome or unattached. When integrated, it replicates at host's pace; nonintegrated, it replicates autonomously.

cate when attached to the host chromosome, becomes unable to replicate on its own. A second group of genes is involved in the manufacture of the protein molecules that provide the coat and infectious apparatus of a normal virus. We have examples in which there is plenty of viral DNA, and many components of the coat material, but one or another essential protein is missing.

This study leads us to conclude that what distinguishes the genetic material of a virus from genetic elements of other types is that the virus carries two sets of information, one of which is necessary for the unrestricted multiplication of the viral genes and the other for the manufacture of an infectious envelope and traveling case.

The concept of a virus as it has emerged from the study of bacterial viruses is far more complex and more fascinating than the concept that prevailed only a decade ago. As we have seen, a virus may exist in three states; the only thing common to the virus in the three states is that it carries at all times much the same genetic information encoded in DNA. In the extracellular infectious state the nucleic acid is enclosed in a protective, resistant shell. The virus then remains inert like the spore of a bacterium, the seed of a plant or the pupa of an insect. In the vegetative state of autonomous replication the genetic material is free of its shell, overrides the regulatory mechanism of the host and imposes its own commands on the synthetic machinery of the cell. The viral genes are fully active. Finally, in the proviral state the genetic material of the virus has become subject to the regulatory system of the host and replicates as if it were part of the bacterial chromosome. A specific system of signals prevents the genes of the virus from expressing themselves; complete virus particles are therefore not manufactured.

The Concept of the "Episome"

Less than a decade ago there was no reason to doubt that virus genetics and cell genetics were two different subjects and could be kept cleanly apart. Now we see that the distinction between viral and nonviral genetics is extremely difficult to draw, to the point where even the meaning of such a distinction may be questionable.

As a matter of fact there appear to be all kinds of intermediates between the "normal" genetic structure of a bacterium and that of typical bacterial viruses. Recent findings in our laboratory have shown that phenomena that once seemed unrelated may share a deep identity. We note, for example, that certain genetic elements of bacteria, which we have no reason to class as viral, actually behave very much like the genetic material of temperate viruses. One of these is the fertility, or *F*, factor in colon bacilli; in the so-called *Hfr* strains of males the *F* agent is attached to one of various possible sites on the host chromosome. In the males bearing the *F* agent designated F^+ the agent is not fixed to the chromosome and so it replicates as an autonomous unit. It bears one other striking resemblance to provirus. The integrated state of the *F* factor excludes the nonintegrated replicating state, just as a provirus immunizes against the vegetative replication of a like virus.

Another genetic agent resembling provirus is the factor that controls the production of colicines. These are extremely potent protein substances that are released by some strains of colon bacillus; the proteins are able to kill bacteria of other strains of the same or related species. The colicinogenic factors also seem to exist in two alternative states: integrated and nonintegrated. In the latter state they seem able to replicate freely and eventually at a faster rate than does the bacterial chromosome. Bacteria that lack these genetic elements—*F* agents and colicinogenic factors—cannot, so far as we know, gain them by mutation but can only receive them (by sexual conjugation, for example) from an organism that already possesses them. They may replicate either along with the chromosome or autonomously. Such genetic elements, which may be present or absent, integrated or autonomous, we have proposed to call "episomes," meaning "added bodies" [*see illustration on this page*].

The concept of episomes brings together a variety of genetic elements that differ in their origin and in their behavior. Some are viruses; others are not. Some are harmful to the host cell; others are not. The important lesson, learned from the study of mutant temperate bacterial viruses, is that the transition from viral to nonviral, or from pathogenic to nonpathogenic, can be brought about by single mutations. We also have impressive evidence that any chromosomal gene of the host may be incorporated in an episome through some process of genetic recombination. During the past year, in collaboration with Edward A. Adelberg of the University of California, we have shown that the sex factor, when integrated, is able to pick up the adjacent genes of the bacterial chromosome. Then this new unit formed by the sex factor and a few bacterial genes is able to return to the au-

tonomous state and to be transmitted by conjugation as a single unit. This process, in many respects similar to transduction, has been called sex-duction [*see illustration at left on pages 102 and 103*].

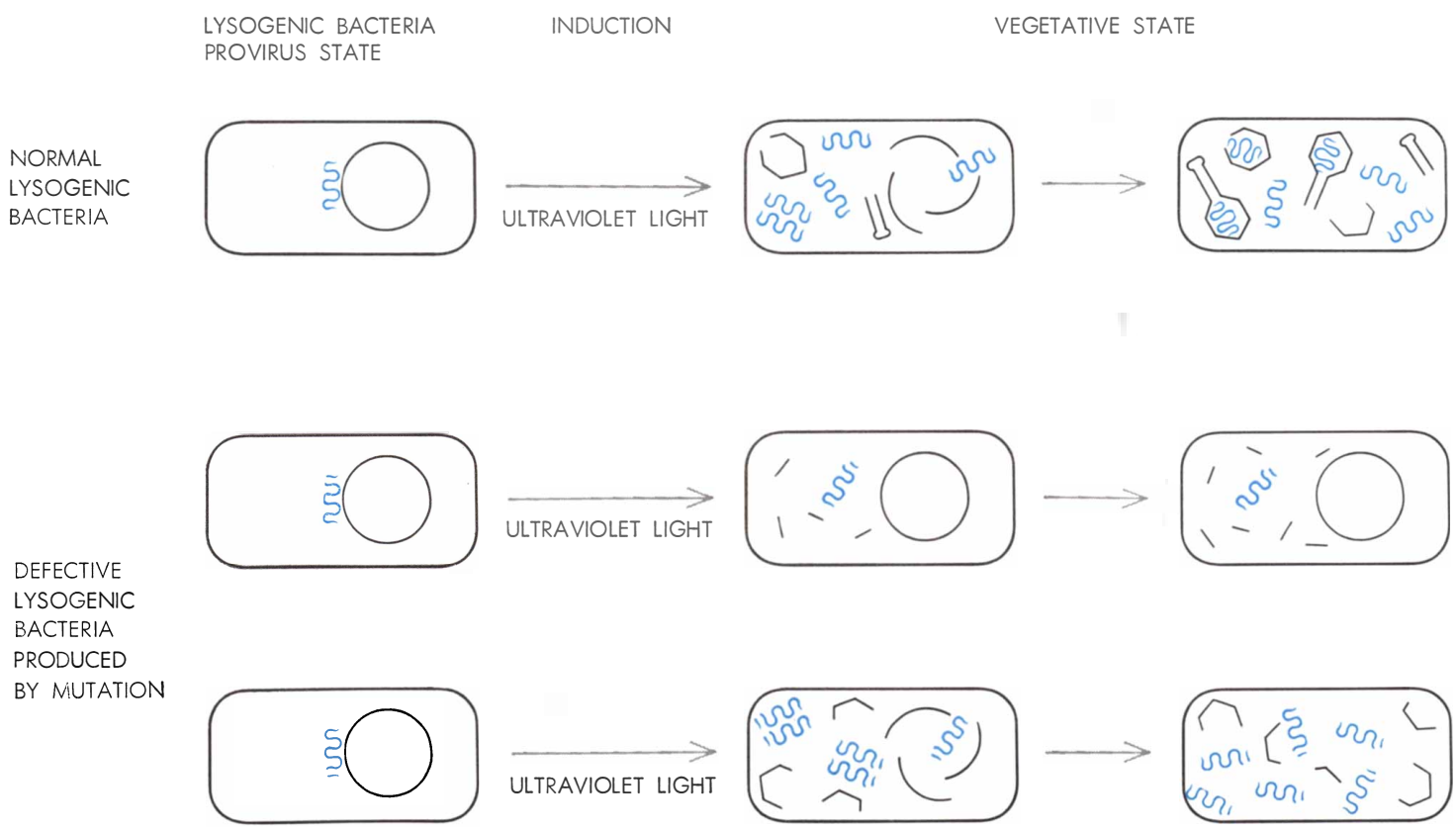
Do episomes exist in organisms higher than bacteria? We do not know; but if we accept the basic unity of all cellular biology, we should be confident that the answer is yes and that mice, men and elephants must harbor episomes. So far the great precision and resolution that can be achieved in the study of bacterial viruses cannot be duplicated for more complex organisms. There is, nevertheless, evidence for episome-like factors in the fruit fly and in maize. There have been reports of two viruses in the fruit fly, transmitted through the egg to the offspring, which may exist either as nonintegrated or as integrated elements. Although it does not seem that the virus is actually located on the chromosome in the latter state, the resemblance to provirus is striking. Barbara McClintock, of the Carnegie Institution of Washington's laboratory at Cold Spring Harbor, has discovered in maize "controlling elements" that are able to switch a gene off or on. (A gene responsible for a reddish color in corn may be switched on and off so fast that a single kernel may turn out speckled.) The controlling elements in maize are not always present, but when they are, they are added to specific chromosomal sites and can move from one site to another or even from one chromosome to another. These elements, therefore, act like episomes.

The discovery of proviruses and episomes has brought to light a phenomenon that biologists would scarcely have considered possible a few years ago: the addition to the cell's chromosome of pieces of genetic material arising outside the cell. The bacterial episomes provide new models to explain how two cells that otherwise possess an identical heredity can differ from each other. The episome brings into the cell a supplementary set of instructions governing additional biochemical reactions that can be superimposed on the basic metabolism of the cell.

The episome concept has implications for many problems in biology. For example, two main hypotheses have been advanced for the origin of cancer. One assumes that a mutation occurs in some cell of the body, enabling the cell to escape the normal growth-regulating mechanism of the organism. The other suggests that cancers are due to the presence in the environment of viruses that can invade healthy cells and make

INCOMPLETE VIRUS PARTICLES are created by defective proviruses (*see illustration below*). The electron micrograph at left shows virus heads and tails that remain unassembled because of some defect. Occasionally (*right*) only heads can be found. Electron

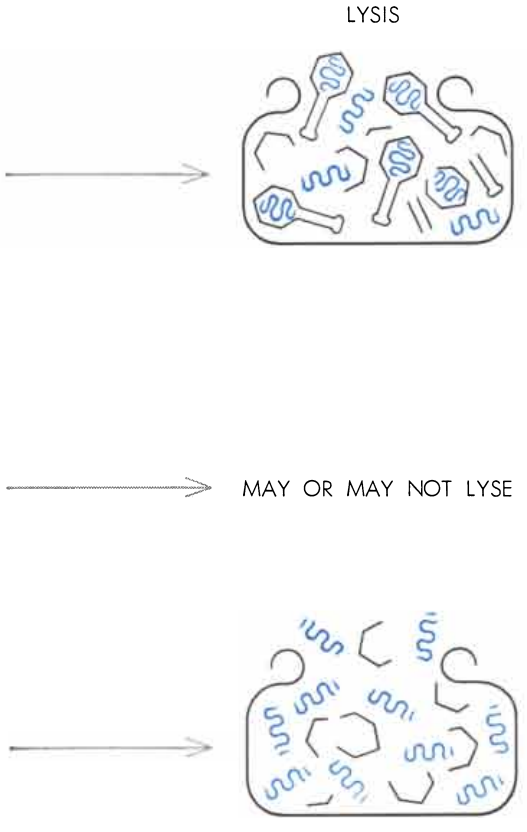
them malignant [see "The Polyoma Virus," by Sarah E. Stewart; SCIENTIFIC AMERICAN, November, 1960]. In the light of the episome concept the two hypotheses no longer appear mutually exclusive. We have seen that proviruses, living peacefully with their hosts, can be induced to turn to the vegetative, replicating state by radiation or by certain strong chemicals—the very agents that can be used to produce cancer experimentally in mice. If defective, the provirus will not even make viral particles. Malignant transformation involves a heritable change that allows a cell to escape the growth control of the organism of which it is a part. We can easily conceive that such a heritable change may result from a mutation of the cell, from an infection with some external virus or from the action of an episome,



DEFECTIVE LYSOGENIC BACTERIA appear as mutations among normal lysogenic bacteria. Upon induction with ultraviolet light a normal provirus (*color, top left*) leaves the bacterial chromosome, replicates, produces infectious virus particles and kills its host. When defective proviruses are induced, the host cell may also be killed, but no infectious viruses appear at lysis. In

micrographs (magnification: 57,000) were made by Kellenberger and W. Arber.

viral or not. Thus in the no man's land between heredity and infection, between physiology and pathology at the cellular level, episomes provide a new link and a new way of thinking about cellular genetics in bacteria and perhaps in mice, men and elephants.



some cases (*middle*) the viral genes fail to replicate. In others (*bottom*) they replicate but the jacketing components are defective.

In ASW aircraft, new signal processing equipment will extract sub's signal out of the noise

Sifting sounds from the sea

Lockheed Electronics signal processing equipment to aid airborne sub-hunters

Detecting sound from a distant submarine out of the noise of the sea is as tough as hearing a bumblebee above the roar of a jet engine. The sub can lurk within range of a listening sonobuoy, yet still not be discovered by the ASW aircraft. The general noise level of the restless sea – the motion of waves, the rumble of ships or the squeal of porpoises, for instance – may mask the faint target signal.

To lift the target signal out of the noise, Lockheed Electronics is developing airborne detection and locating equipment utilizing advanced signal processing techniques. These techniques hinge on modern information theory and noise theory–disciplines employed in optimizing the design of filters, detectors, time integrators and computers to gain improved signal-to-noise ratios.

Lockheed Aircraft, LEC's parent company, has a notable record of achievement in ASW systems. These capabilities are now augmented by the talents of Lockheed Electronics, applied to underseas warfare components and systems.

MINDING THE FUTURE

LOCKHEED ELECTRONICS COMPANY

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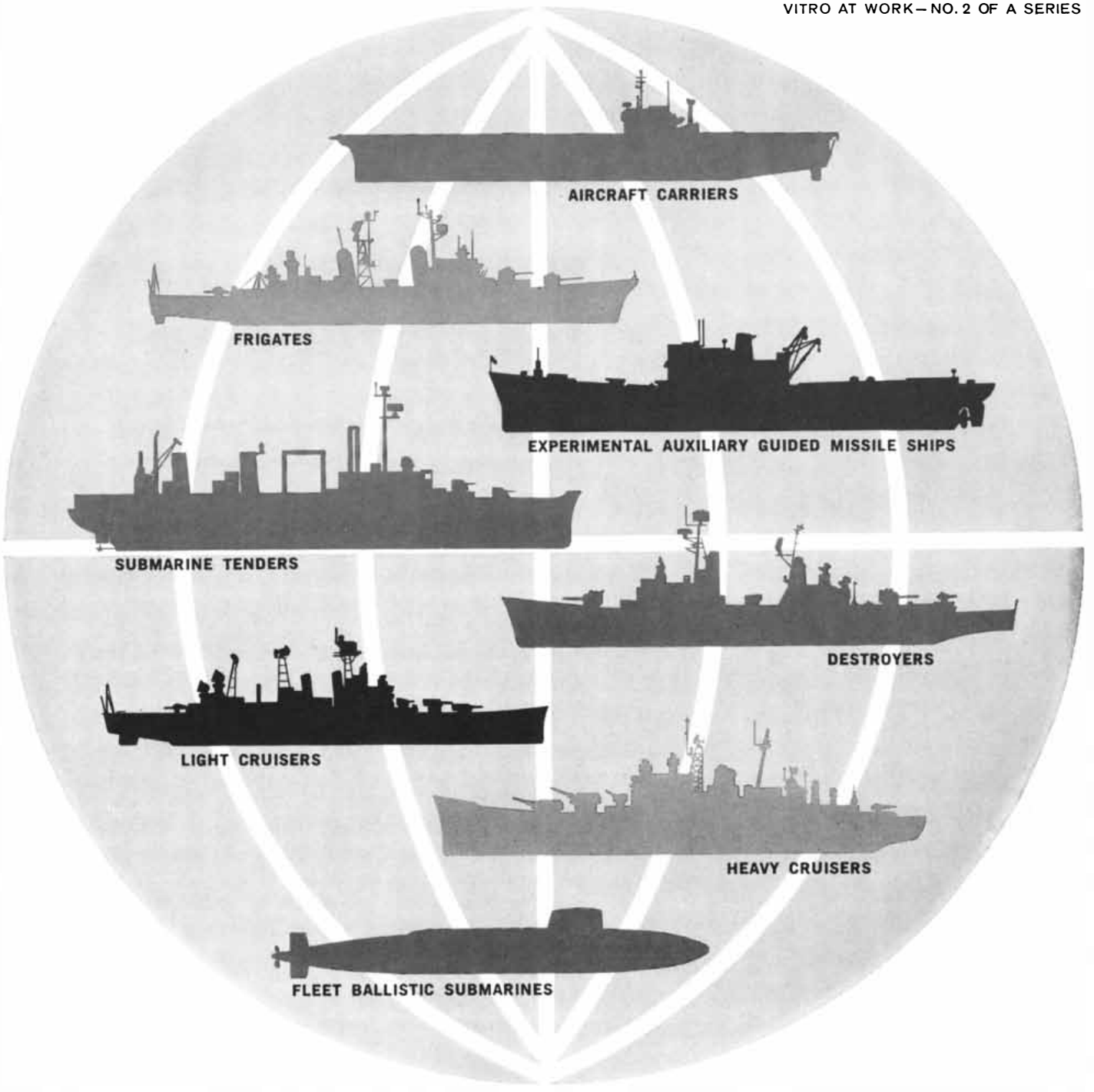

assignment: make a complex missile system work

That was, and is, Vitro's key role in our nation's surface and undersea missile fleet. For Vitro has had the job of combining the many talents involved in converting and outfitting each missile ship shown above. With that experience and with special techniques it developed for those jobs, Vitro has the ability to fit the many parts together into an effective system. Working with DOD personnel, other contractors and shipyards, Vitro's experienced technical men solve perennial interface problems and handle complex modern weapon systems from concept through checkout. □ This is Vitro – 1961.

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SUBDWARF STARS

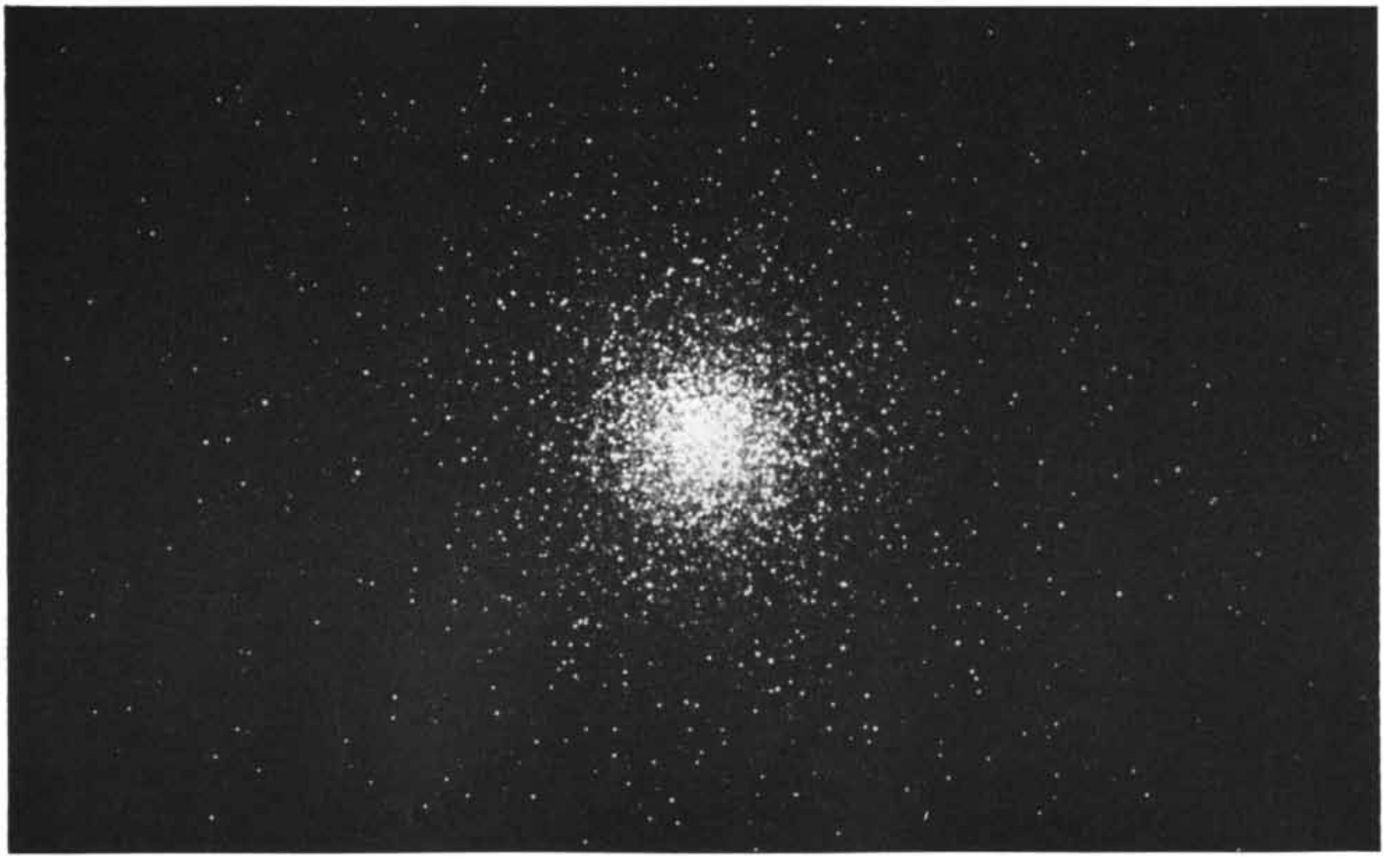
Certain stars seem dimmer than normal stars having the same temperature. It now appears that they are not less luminous but are bluer because they are poorer in the heavier elements

by Margaret and Geoffrey Burbidge

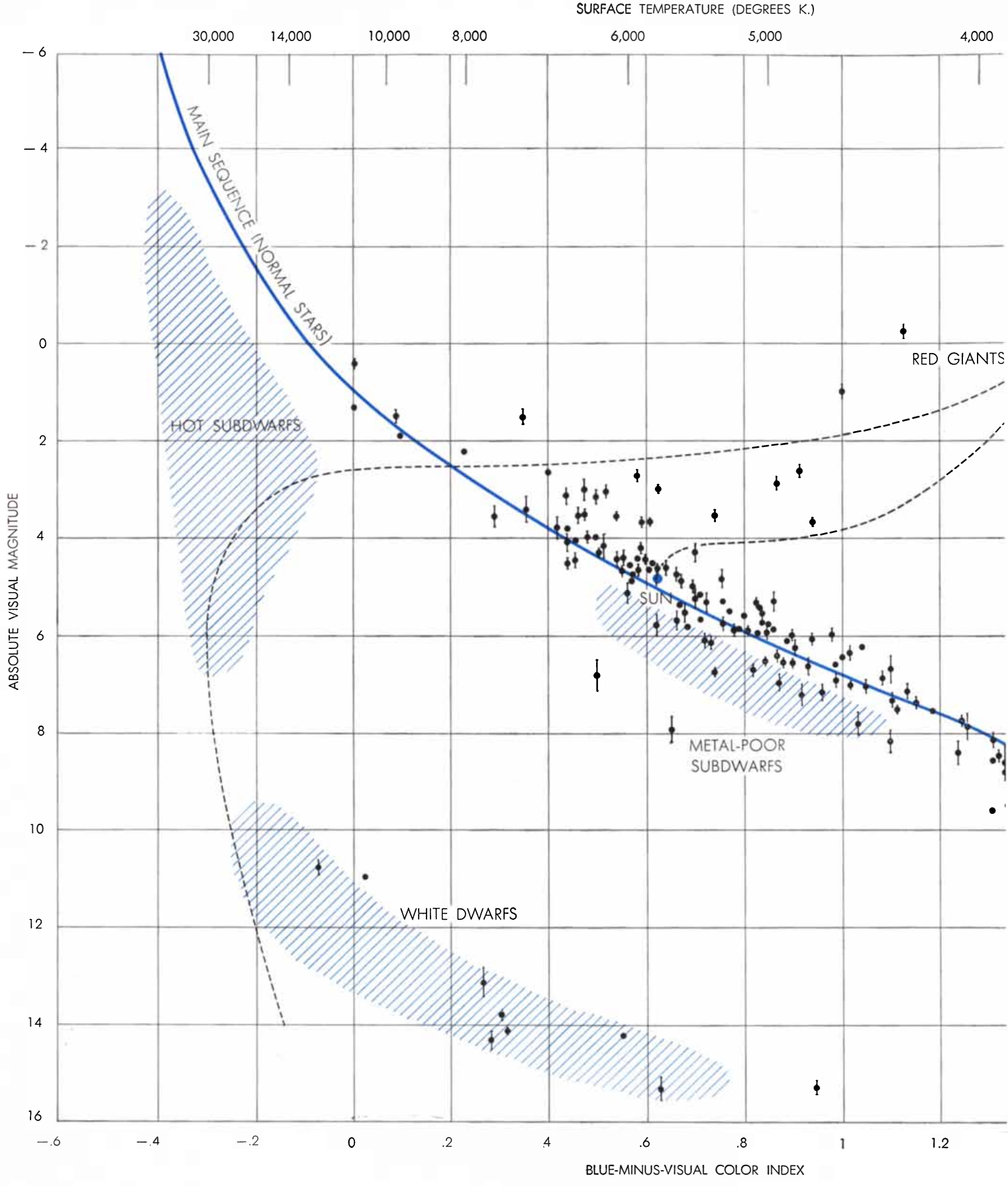
Man's knowledge of the nature and structure of stars rests on a complex interplay between observation and theory. Before the observations, patiently collected over the years, can even be analyzed theoretically they must be fitted together in ways that permit significant relationships to emerge. Perhaps the most useful way of arranging stellar data is the one invented independently about half a century ago by Ejnar Hertzsprung of Denmark and Henry Norris Russell of Princeton University. In this scheme the absolute luminosity of a star (meaning its brightness as referred to a standard distance) is plotted against its spectral type. Spectral types are obtained by examining the spectra of stars and arranging them in a sequence according to the relative strength of the spectral lines that provide the basic clues to a star's composition. The sequence chosen is one that reflects increasing temperature, so the Hertzsprung-Russell diagram—H-R diagram, as it is usually called—is essentially a plot of total energy output against surface temperature.

In this diagram the stars lie in certain well-defined regions. The principal feature is the concentration of stars along a narrow band called the main sequence, running from the upper left of the diagram (as conventionally plotted) to the lower right. The stars at the upper left are very hot, very bright and bluish-white; the stars at the lower right are cool, dim and reddish.

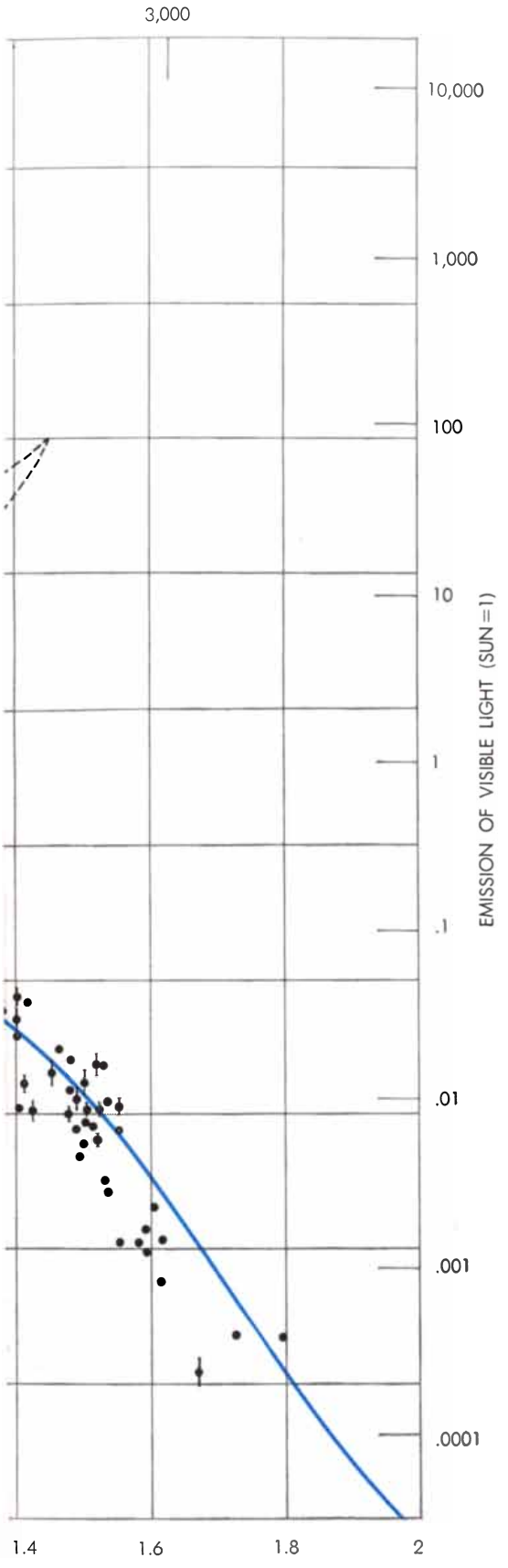
There are also stars above the main



GLOBULAR CLUSTER M3, lying some 36,000 light-years off the plane of our galaxy, contains about 200,000 stars, the great majority of which resemble the metal-poor subdwarfs that are relatively rare within the galaxy. Presumably the stars in M3 and the nearby subdwarfs are much older than the sun and its sister stars and represent a condensation from primitive gas clouds composed mostly of hydrogen. The metals in the sun are believed to have been formed in earlier generations of stars that evolved rapidly.



COLOR-MAGNITUDE DIAGRAM locates stars according to an index based on color and visual magnitude (referred to a standard distance, not as seen from earth). A decrease in color-index value signifies increasing blueness and inferentially an increase in surface temperature. (The scale at top refers to normal stars.) The location of metal-poor subdwarfs is puzzling because they seem less bright than main-sequence stars of comparable surface temperature and hence lie below the main sequence. Actually these so-called subdwarfs would lie on the main sequence if true temperature were plotted; they seem too blue when color is plotted because their metal-deficient atmospheres absorb less ultraviolet radiation and blue light than do the atmospheres of normal stars. Black dots in the diagram represent stars lying within 50 light-years of earth, as plotted by Allan R. Sandage of the Mount Wilson



and Palomar Observatories. The broken line is a forecast by Sandage of probable evolutionary path of the sun. After some billions of years the sun will rapidly become larger and more radiant. Then, in a brief period (perhaps 500 million years), the earth will heat up and life will come to a fiery end.

sequence—relatively few in number compared with those on the main sequence—that have the same surface temperature but greater luminosity. Because this separation into different brightnesses at the same temperature must mean that the brighter stars have much larger diameters than the fainter ones, the two types were originally named giants and dwarfs. Although the giants do have much larger diameters than the dwarfs, their masses are actually not much different, which implies that the dwarfs have much higher densities. The sun is a middling star, technically a dwarf, lying near the middle of the main sequence.

Because astronomers tend to be conservative in their nomenclature, the terms giant and dwarf are still preserved. (Indeed, astronomers often call all the stars on the main sequence dwarfs, although it would seem more appropriate to describe the massive, hot ones at the upper left end as blue giants.) Stars that lie elsewhere in the H-R diagram have been given various descriptive names: supergiants, subgiants, white dwarfs and subdwarfs. The subdwarfs are of two varieties: one very hot, at the far left of the H-R diagram; the other lying below the central region of the main sequence.

In a variation of the H-R diagram luminosity is plotted against the color of stars, as measured at selected wavelengths; the result is a "color-magnitude diagram" [*see illustration at left*]. Color, of course, can also be used as an indicator of surface temperature. As we shall see, the subdwarf problem hinges on the detailed validity of the color-temperature relationship.

The theoretician's job is to find a satisfying explanation for the positions occupied by stars having various combinations of total energy output and surface temperature. The more separate sequences of stars there are in the H-R diagram, the harder his task. He is delighted, consequently, when his colleagues, the observers, discover that sequences that once seemed to be separate actually have an underlying identity. This article will present the case for removing the term subdwarf from some of the stars that appear to lie below the main sequence, and will show that they can be related to the main-sequence stars or normal dwarfs like the sun. It now seems that the entire difference between normal dwarfs and the so-called subdwarfs can be traced to differences involving 1 per cent or less of the star's entire mass.

Twenty years ago "dwarf," "giant" and various subcategories were simply labels for different kinds of star; they were like the different species of animal before Darwin. Since then, however, astronomers have developed a comprehensive theory of stellar evolution that depicts how stars, in the course of their long lifetimes, change drastically in composition, temperature and even in mass, so that they progress from point to point in the H-R diagram.

When a star first forms out of the cold interstellar dust and gas, it slowly contracts in response to gravity, and as a result of compression its interior gets hot. When the temperature of the interior reaches a few million degrees Kelvin (degrees centigrade above absolute zero), thermonuclear reactions begin. At this point the star has reached the main sequence, the particular region being determined by its mass and chemical composition. The star will stay on or near the main sequence for the greater part of its life until it has converted an appreciable fraction of its basic nuclear fuel, hydrogen, into helium. Toward the end of this period the star becomes a little brighter. It must then undergo a radical structural readjustment, as a result of which it moves off to the right of the main sequence and becomes a red giant. In general, except for the more massive stars, this entails further brightening; the star is forced by nature to become more spendthrift of its energy just when its fuel reserves have begun to decline.

We do not yet understand in detail how the star evolves after this red giant stage. But we know in general that it moves back to the left in the H-R diagram, crosses over the main sequence and, continuously fading, eventually arrives in the region occupied by white dwarfs [see "Dying Stars," by Jesse L. Greenstein; SCIENTIFIC AMERICAN, January, 1959]. A white dwarf having a mass equal to that of the sun, or some 300,000 earth masses, may be no larger than the earth, which has only a millionth of the volume of the sun. If a typical white dwarf were located at the same distance from the earth as the sun is, it would appear no larger than an ordinary star. On the way to becoming a white dwarf, while it is still very hot and just before its thermonuclear reactions cease, a star may find temporary stability in the region below the main sequence, during which time it can properly be called a subdwarf.

There is, however, a second group of stars, much cooler than the subdwarfs just mentioned, which have also carried the designation "subdwarf," and it is

this classification that now seems questionable. In the course of a 20-year program of classification of stellar spectra at the Mount Wilson Observatory a few stars—less than half a dozen—were found whose spectra suggested that they were of lower luminosity, and hence of greater density, than normal main-sequence stars. The Mount Wilson catalogue of 1935 called these stars intermediate white dwarfs. In the next few years more of the class were discovered, notably by Gerard P. Kuiper at the McDonald Observatory, and they came to be called subdwarfs. They appeared to lie in a band slightly below and parallel to the main sequence, stretching to the right and left of the position occupied by the sun. Today the total number of stars in this class is about 200—not a very great number, to be sure, but too many to be left unexplained by an adequate theory of stellar evolution or stellar energetics.

Aside from their position in the color-magnitude diagram, these subdwarfs have two other distinguishing characteristics. The first, known for many years, is that they are moving with high speeds with respect to the sun and most of its neighboring stars. We shall return to the significance of this later. The second characteristic concerns their chemical composition. This was determined in 1951 for two typical subdwarfs by Lawrence H. Aller and Joseph W. Chamberlain of the University of Michigan. They found, to begin with, that the subdwarfs were rather cooler (hence less blue) than had been thought by the Mount Wilson workers; the effect of this finding was to shift the subdwarfs closer to the main sequence in the color-magnitude diagram. Their most exciting discovery, however, was an explanation for the peculiarities in the spectra of the subdwarfs that had puzzled the Mount Wilson workers and had led them to think that the stars were denser and much dimmer than stars of normal mass. Aller and Chamberlain showed that these spectral peculiarities are actually caused by a deficiency in metallic elements, particularly iron, and indeed in all the observable elements with respect to hydrogen [*see illustration below*]. Although it would be useful to know the helium content of subdwarfs, this can be observed spectroscopically only in much hotter stars (except for the sun, where it can be measured in the chromosphere, the hot layer just above the surface).

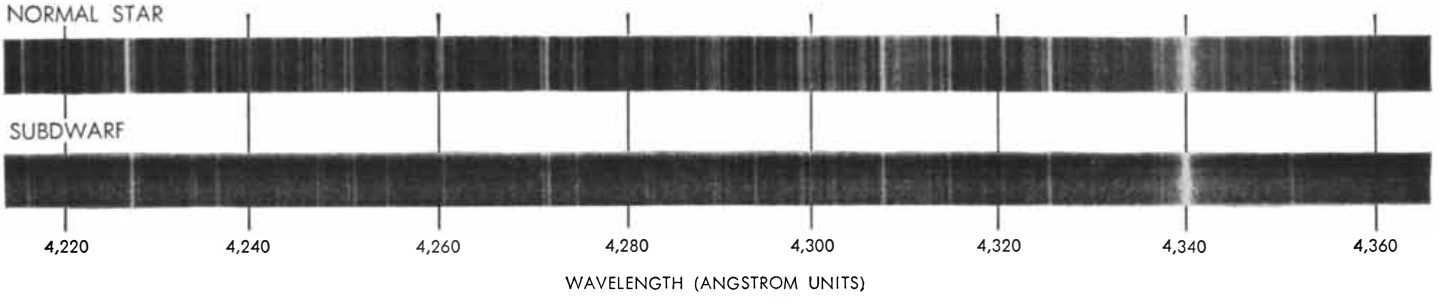
The subdwarfs, therefore, seemed to be still unevolved stars that gave no sign of having consumed very much of their original store of hydrogen fuel. The deficiency in heavy elements, which we will lump together and call "metals," provides the basic clue to the anomalous position of the subdwarfs in the color-magnitude diagram. The sun, a normal main-sequence star, contains about 1 per cent metals by weight. (It also contains about 74 per cent hydrogen and 25 per cent helium, but we will neglect these ratios for the moment.) The subdwarfs, about a dozen of which have now been studied in detail, contain only about .01 per cent metals. In spite of this 100-to-1 difference in metal content, the sun and a subdwarf, if otherwise alike in size and composition, will have almost precisely the same surface temperature. Why, then, will the subdwarf look bluer and, inferentially, hotter?

The answer is that the metals in the atmosphere of the sun are powerful absorbers of blue light and ultraviolet radiation. This shows up clearly in photographs of the solar spectrum; metals such as iron and calcium produce progressively more and stronger absorption lines in the blue and ultraviolet regions than at longer wavelengths. This is known as the blanketing effect because the surface layer of gas producing the absorption lines acts as a blanket, stopping radiation of certain wavelengths from coming out, and throwing it back toward the sun, where it heats up the layer just below the surface by a small amount and finally emerges in other wavelengths. In the subdwarf, which lacks absorbing metals, the short wavelengths come out virtually unimpeded [*see illustrations on opposite page*].

As a result of these differences in metal content, sunlike stars and subdwarfs are assigned to different positions in the color-magnitude diagram as it is conventionally drawn. For purposes of systematic comparison, a star's energy output is often measured in three narrow bands, or regions of the spectrum: in the ultraviolet (designated U), in the blue (B) and near the center of the visual region (V). In the color-magnitude diagrams used to illustrate this article, stars are located horizontally according to the color index computed from their blue output minus their visual output, or B—V. (Since these values are expressed in astronomical fashion as magnitudes, the lower the number, the higher the output; moving down the scale one unit of magnitude represents a multiplication in brightness by a factor of 2.5.)

The two most widely used color measures for stars are B—V and U—B (ultraviolet minus blue). For the sun these two indexes are .6 and .09 respectively. If the sun contained no metals to absorb ultraviolet and blue light, its B—V would be shifted to about .44 and its U—B to about —.25. These values, as it turns out, are very close to the actual values obtained for a typical metal-poor subdwarf, designated HD 19445, which has nearly the same visual brightness as the sun. If the sun were assigned a B—V of .44 in plotting a color-magnitude diagram, it would move off the main sequence to the left and fall very near HD 19445 [*see bottom illustration on page 116*].

Thus it seems that the subdwarf sequence paralleling the main sequence is

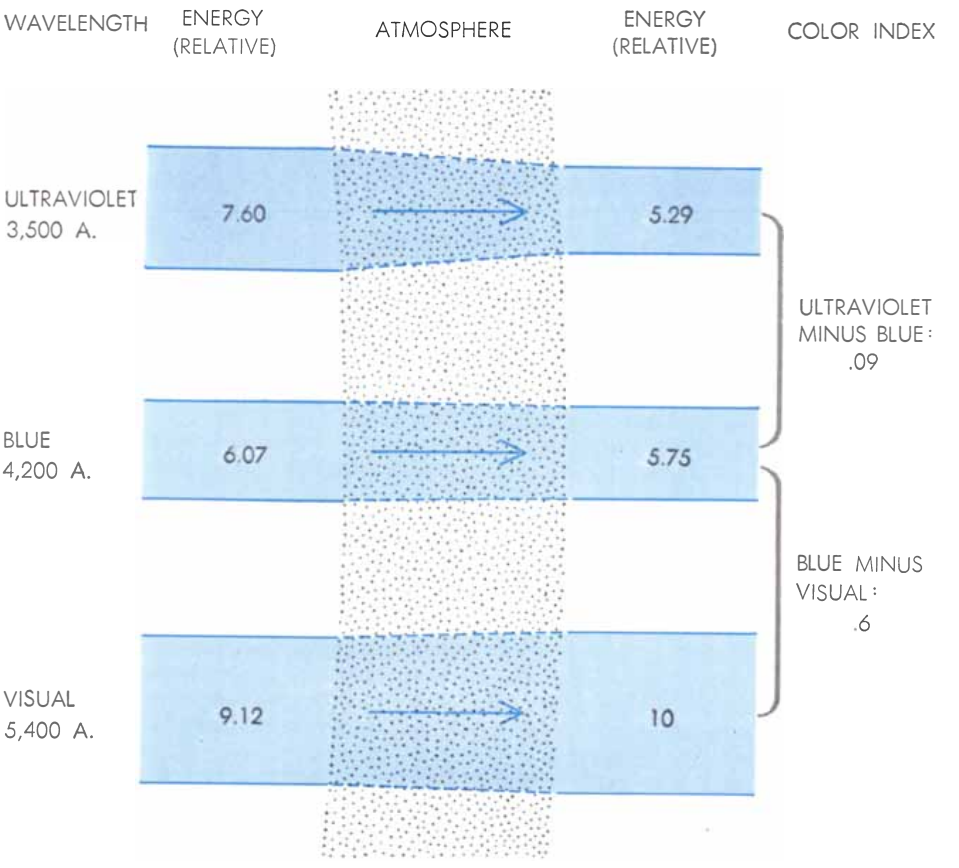


COMPARISON OF SPECTRA of a normal main-sequence star and of a metal-poor subdwarf shows a great contrast in the blue region of the visible spectrum. Heavy elements, chiefly metals, in the atmosphere of the normal star account for almost all the white absorption lines in its spectrum; the strong lines at 4,340 angstrom units in both spectra, however, are due to hydrogen. Because absorption lines are fainter in the subdwarf it appears bluer than a normal star. Hence blueness is not a true measure of temperature.

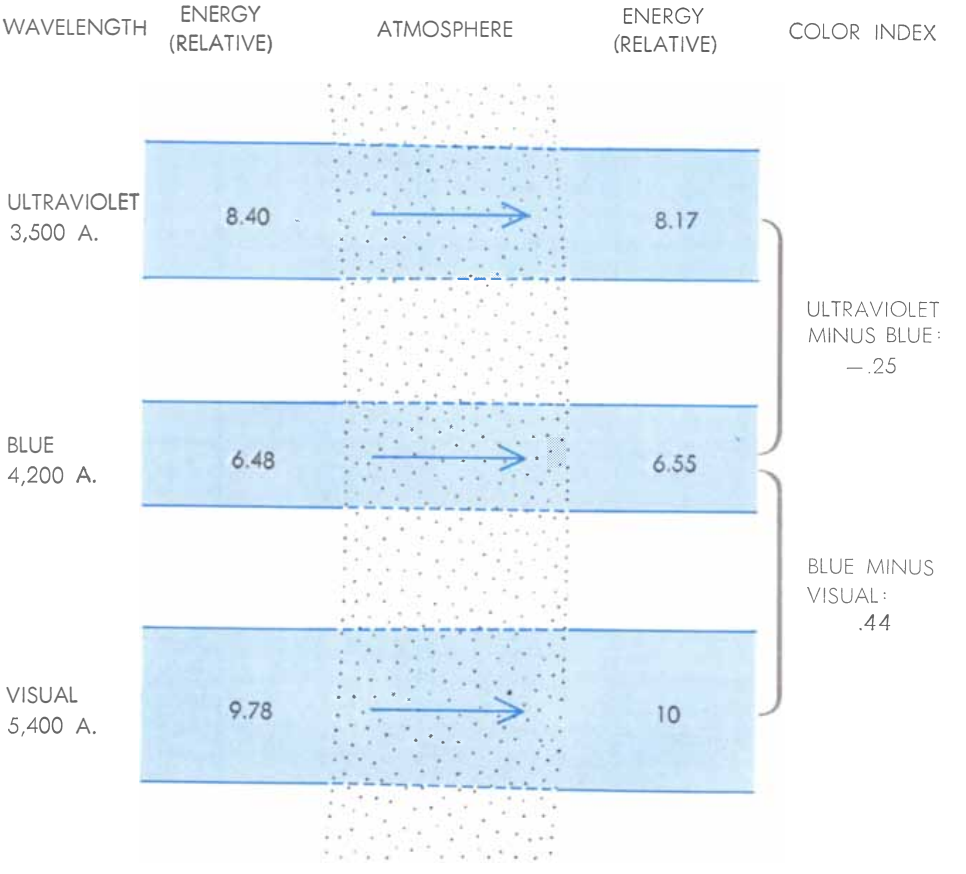
really an artifact. The two sequences would merge if the color-magnitude diagram were plotted according to effective surface temperatures, which are more meaningful than temperatures inferred from color indexes. This was originally pointed out by Olin J. Eggen of the Royal Greenwich Observatory and Allan R. Sandage of the Mount Wilson and Palomar Observatories. Further support came from detailed spectrophotometric measurements of HD 19445 and a normal star by Sandage and ourselves, and subsequent study of HD 19445 and another subdwarf by W. G. Melbourne, a student at the California Institute of Technology.

There is, moreover, theoretical support for merging the subdwarfs into the main sequence. Calculations recently made by Fred Hoyle and C. B. Haselgrove at the University of Cambridge, and Pierre Demarque, a Canadian astrophysicist now at the University of Illinois, suggest that even though stars may deviate considerably in composition they will not shift very far off the main sequence. These three theorists have computed surface temperatures and energy output (total magnitude) for sunlike stars and for stars having a tenth and a hundredth the heavy-element content of the sun. They have further assumed, from the theory of the formation of elements in the stars, that stars low in metals will also be low in helium. It turns out from their computations that a low helium content and a low metal content act in opposite directions and so tend to cancel each other. The result is that a computed "main sequence" of stars of rather differing composition produces a band of stars that is relatively narrow, very much like the one actually observed [*see illustration on page 119*].

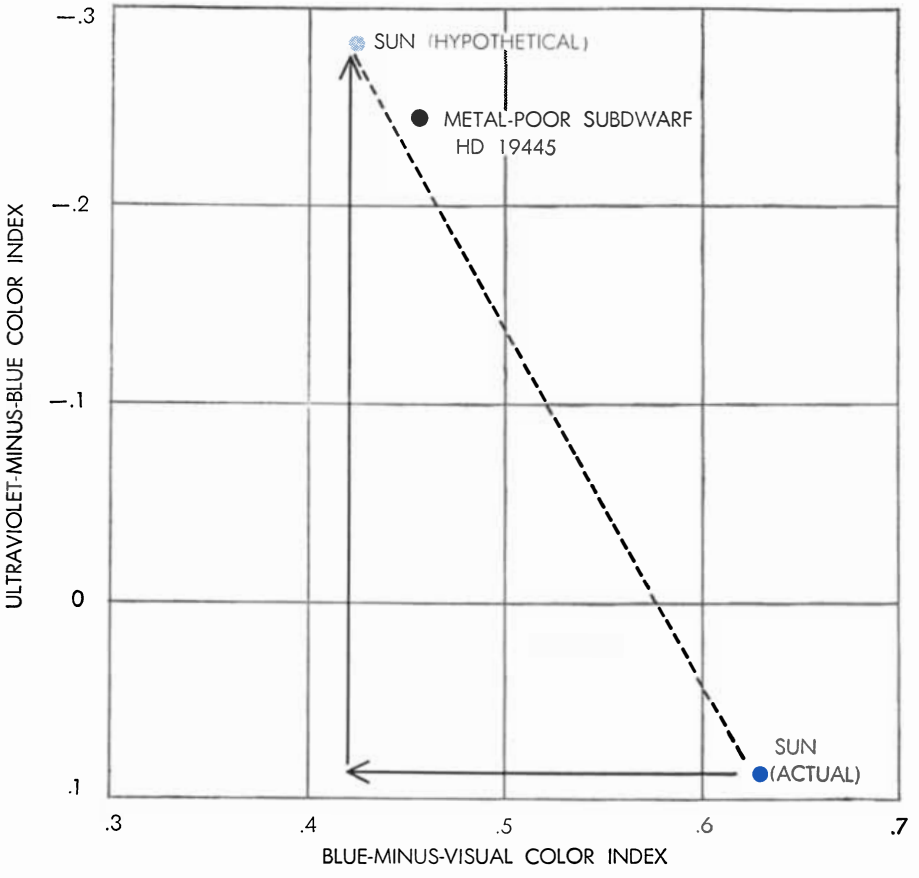
Since astronomical inferences constitute a tightly woven web of observation and theory, the re-examination of the subdwarf category has had an impact beyond mere classification. It has led, for example, to a readjustment in the color-magnitude diagrams drawn for distant globular clusters. These are spherical star groups, each of which contains tens of thousands, or even hundreds of thousands, of stars that were all formed at approximately the same time [*see illustration on page 111*]. Clusters generally lie well off the main plane of our galaxy, and their spectra reveal that most of them have a low metal content. Sandage and his Mount Wilson and Palomar colleague Halton C. Arp have concluded, after readjusting the color-magnitude diagrams of clusters, that the clusters are on the order of 20 billion



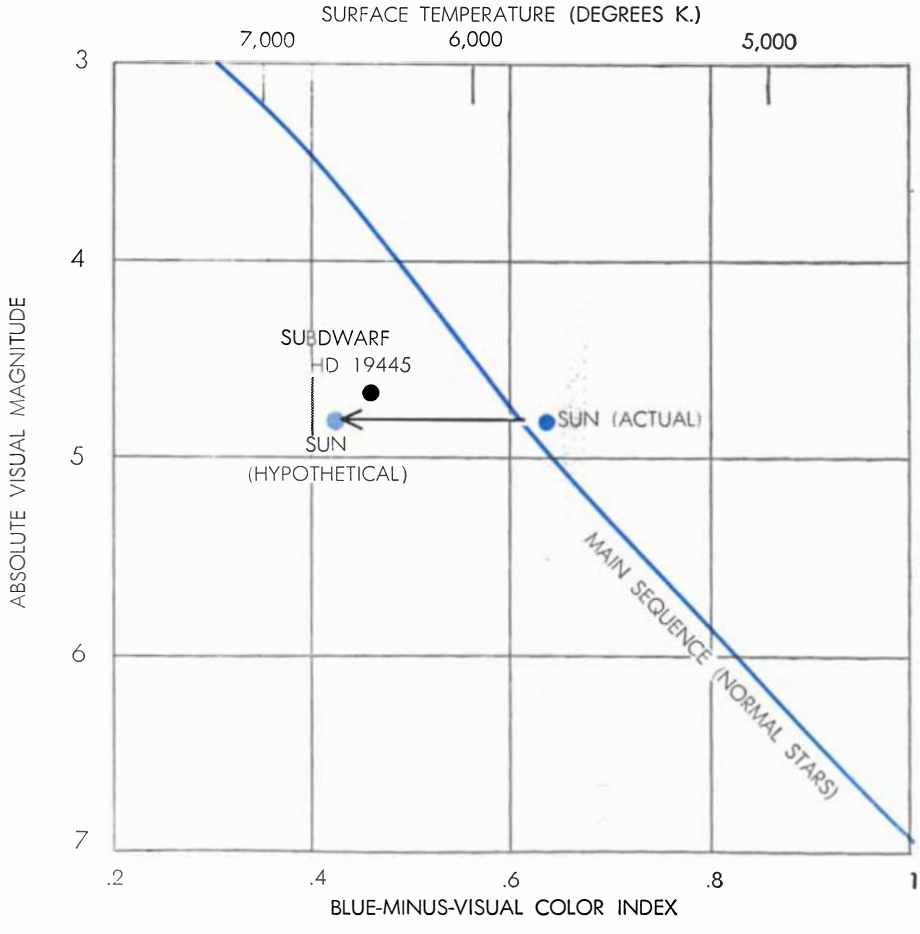
METAL-RICH SOLAR ATMOSPHERE absorbs a fair part of the ultraviolet and blue light leaving the sun's surface (*left*). The specific wavelengths absorbed by metal atoms and ions are largely thrown back into the sun and tend to emerge between the absorption lines. Color indexes are determined by reference to the light output of selected "standard" stars.



METAL-POOR SUBDWARF ATMOSPHERE, having only .01 the metal content of the sun, allows most of the ultraviolet to pass. The small amount turned back into the star slightly raises the observable output in the blue and visual regions. A decrease in color-index value indicates a relative increase in output of the first member of the color pair.



COLOR INDEXES OF SUN (*hypothetical position*) would almost match observed indexes of a typical metal-poor subdwarf if the solar spectrum lacked absorption lines due to metals.



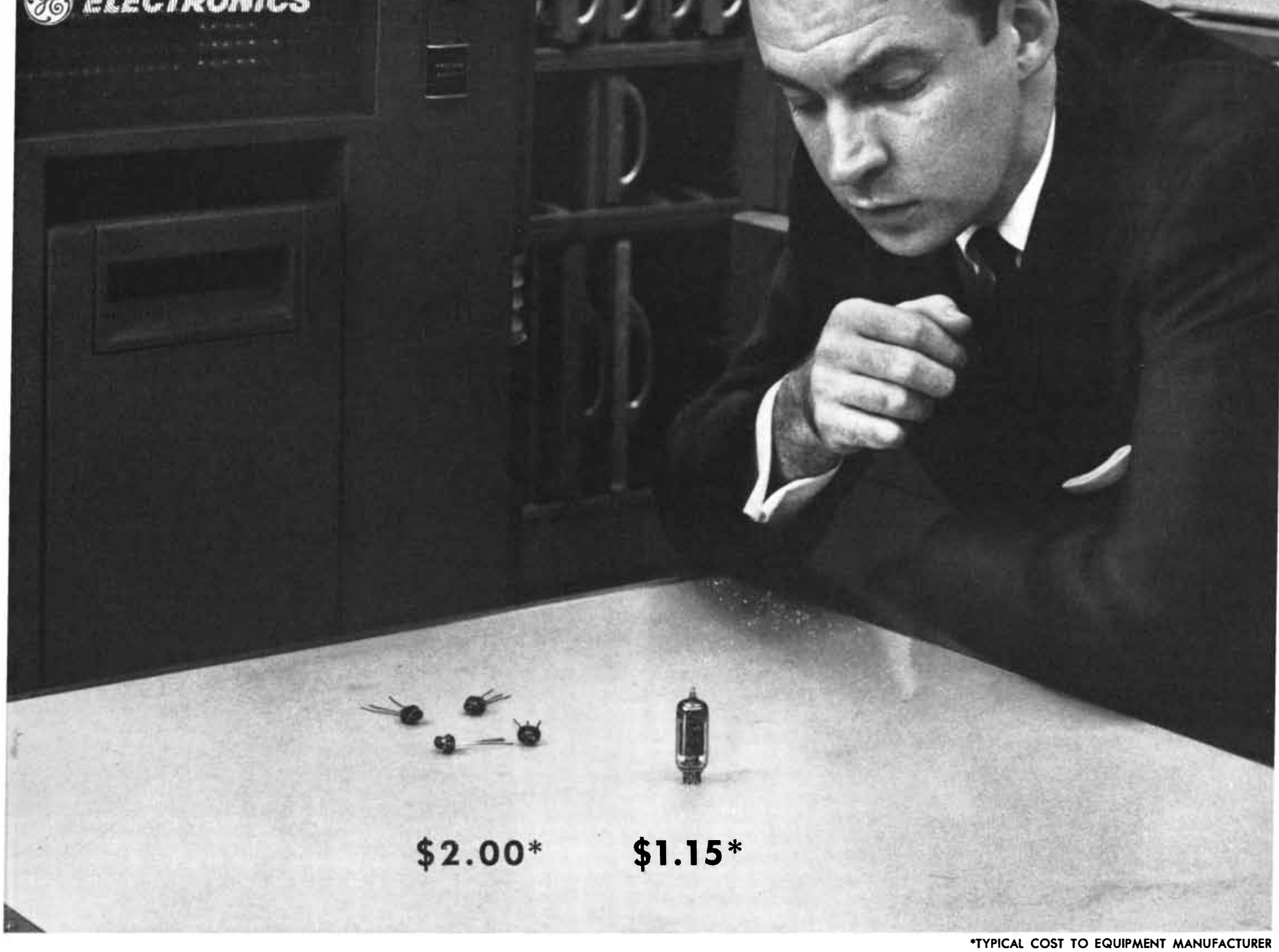
REVISED COLOR-MAGNITUDE PLOT would show the sun and other main-sequence stars shifted into the subdwarf region if their spectra contained no metal absorption lines.

years old instead of six billion. The readjustment also indicates that the so-called RR Lyrae variable stars, which serve as objects of standard brightness for estimating distances of globular clusters and nearby galaxies, are somewhat less bright than they were previously thought to be. As a consequence an important astronomical yardstick has been shortened about 25 per cent.

Yet there are loose ends that do not fit. Arthur Code, director of the Washburn Observatory of the University of Wisconsin, reasoned that if he measured colors other than U, B and V, being careful to select color pairs that should be almost unaffected by blanketing and therefore good indicators of effective temperature, the subdwarf sequence should vanish. He chose for such a color pair the difference between infrared radiation (where there are few spectral lines) and green light (where there are some lines but much fewer than in the blue). The main sequence plotted in this way still shows some subdwarfs, although they lie closer to the main sequence than when B—V is plotted. Code's results have yet to be explained.

Another untidy finding has been reported by Harold Johnson, now at the University of Texas. He found that in a color-magnitude diagram of stars that all seem to be members of the Hyades cluster, many stars appear to fall below the main sequence in a subdwarf sequence. Since all stars in a cluster should be about the same age and the same chemical composition, it is hard to see why the main sequence should be divided into two parts. Perhaps the Hyades subdwarfs do not belong to the Hyades cluster at all but to some more distant cluster that happens to lie directly in the same line of sight.

It is our view, in any case, that the name "subdwarf" is inappropriate for the majority of stars now so designated that fall below and parallel to the main sequence. It is still true, of course, that these stars are nontypical, both in their low metal content and in their high velocity relative to the sun—an observation that was noted previously. They belong to other parts of our galaxy and just chance to be passing through the solar neighborhood. They are not traveling with the sun in its giant orbit around the hub of our galaxy, and consequently they are moving with high speeds relative to the sun and in one general direction—that opposite to the direction in which galactic rotation is carrying the sun. Such properties place them in the category of stars known as Population II.



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His problem:

How to bring NBS accuracy to production line measurements

Name of this scientific American:

Paul C. Ellis
Primary Standards Laboratory
Hughes Aircraft Company

■ In one sense, the problem of high accuracy measurement is a matter of nudging the decimal point to the left, and making certain that the last digit does not stray. Or the problem may take the form of launching an airborne rocket with such precision that it will hit a target whose relative speed is 40 miles per minute. In either case, success or failure may hinge on a vital behind-the-scenes facility . . . the standardizing laboratory. Basically, it is here that the battle for accurate results is won or lost.

Paul Ellis is one of the men who has developed and applied the science of basic measurements to a level which will support seemingly fantastic requirements. As head of the D-C Electrical Section, Primary Standards Laboratory of Hughes Aircraft, Culver City, California, Ellis and his group maintain performance standards of as many as 2000 instruments per year.

Briefly, Ellis' problem is to insure that Hughes' electrical measurements in the production areas are made with an accuracy which approaches that of the National Bureau of Standards. He has succeeded in making Hughes' Primary Standards Laboratory one of the nation's best by virtue of his ability to develop techniques which are as precise as the equipment itself. Over a ten year period, he has trained his personnel in the use of new procedures . . . refining existing ones . . . and developing specialized equipment to meet Hughes' unique requirements.

Today . . . a new order of accuracy

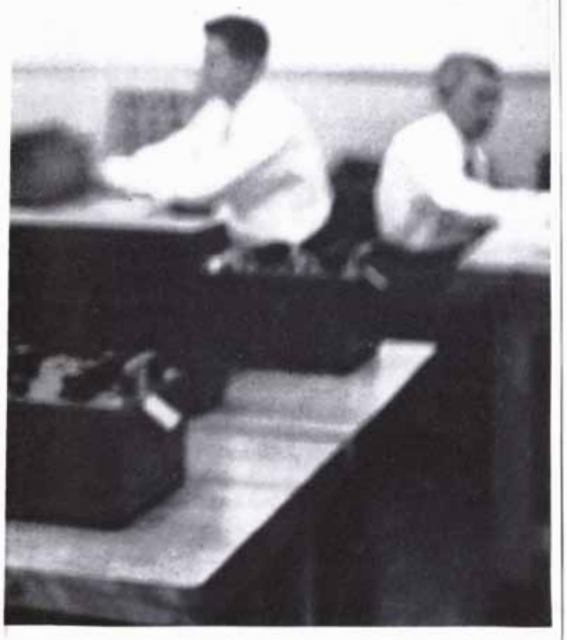
Hughes Aircraft armament control systems are manufactured to tolerances which, until recently, were possible only in the research laboratory. For example, prior to the Korean War, some electrical measurements to an accuracy of 0.01% were considered satisfactory. Today, these same measurements are being made to an accuracy of 0.001% . . . and even 0.0001%. Using NBS certified standards, Ellis and his men can ascertain the value of Hughes' primary standard cells to within one microvolt, and the resistance of a Thomas one-ohm basic standard to within one micro-ohm.

Extending laboratory accuracy into the plant

To further assure that instrument accuracy is maintained, there are secondary calibration laboratories in the various divisions of the Hughes organization. The equipment in these laboratories includes L&N K-3 and Wenner Potentiometers, Mueller and Kelvin Bridges, Voltage Dividers . . . every type of instrument required for high-accuracy d-c measurements.

A specific example is the current production testing of servo mechanisms with Leeds & Northrup voltage dividers. Calibrated in 100,000 equal parts, these instruments provide a ratio indication as small as 1:100,000. Their accuracy of adjustment is such that any ratio number reading from 1 to 100,000 is correct to within ±1 part, or 0.001% of the total.

The transfer of these electrical units to calibration laboratories and



secondary standards demands the best in personnel, techniques and equipment.

Specifically, the voltage range must be extended from the basic standard cell of, say, 1.018222 volts to measurements ranging from one millionth of a volt, to 1000 volts, or more. And, starting with the basic Thomas one-ohm standard, resistance measurements must be made down to 0.0001 ohm, and up to 100,000 ohms on standard resistors —and from fractions of a micro-ohm to mega-megohms for measurements at reduced accuracy.

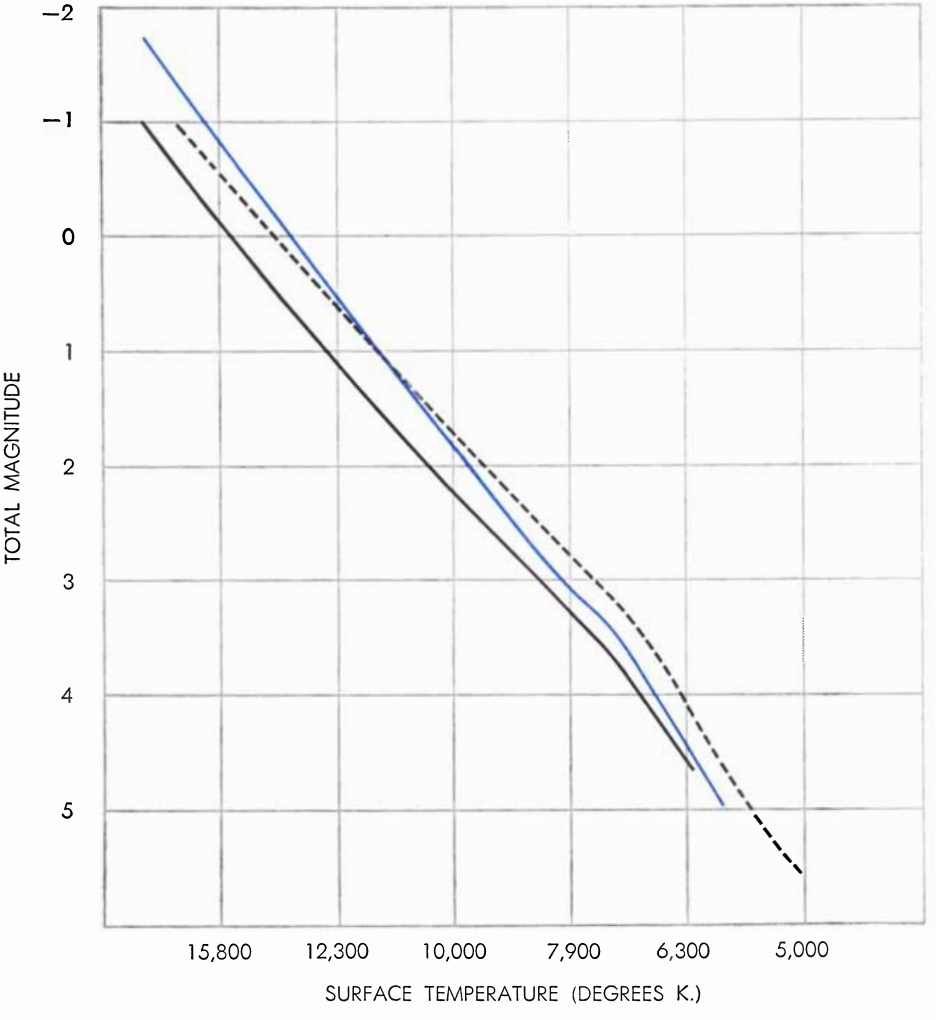
To get results . . .

Leeds & Northrup d-c laboratory instruments are used at Hughes—and wherever the highest accuracies are required. Close examination of L&N instrumentation in the research field—or in any industrial field—shows the kind of *quality* which scientifically-minded leaders respect. Get the facts from your nearby L&N Field Engineer, or write to 4935 Stenton Avenue, Philadelphia 44, Pa.

These stars were formed early in the history of the galaxy [see "Stellar Populations," by Margaret and Geoffrey Burbidge; November, 1958]. The more massive and hotter ones have already come to the end of their lives and are now white dwarfs. The so-called subdwarfs that we still see near (or, as we would say, on) the main sequence are Population II stars whose masses must be close to that of the sun, or slightly greater.

We will conclude with a brief discussion of the second main class of subdwarfs, the much hotter subdwarfs, whose classification is not in question. These stars indeed lie below the main sequence in the color-magnitude diagram. Nearing the end of their lives, nuclear fuel almost spent, they are on the way to becoming white dwarfs. The final white dwarf stage, in which the star is simply radiating its remaining heat energy, is surprisingly long, lasting perhaps billions of years. It is doubtful whether any star in our galaxy is old enough to have cooled so much that it gives off no visible radiation. The subdwarfs that are approaching the white dwarf era vary widely in mass, temperature and composition. The explanation for this diversity is that all stars, whatever their original position on the main sequence, must eventually pass through the subdwarf region, unless they explode as supernovae and disintegrate.

An interesting group of subdwarfs is the one containing stars that become novae or that have been novae in the past. (After a star becomes a nova it is possible to re-examine photographic records made of the star before its flare-up in order to determine its characteristics.) These stars are all very small and hot. Merle F. Walker of the Lick Observatory has found that many of them vary slightly and rapidly in brightness, with a time



THEORETICAL MAIN-SEQUENCE CHART confirms that stars of the type of the sun and subdwarfs should have similar temperatures for a given magnitude. Colored curve shows computed temperatures and magnitudes covering a range of masses for solar-type stars composed of 75 per cent hydrogen, 24 per cent helium and 1 per cent heavier elements. Other two curves depict temperature-magnitude relationships for metal-poor types containing only .1 per cent heavier elements and either 99 per cent hydrogen and .9 per cent helium (*broken line*) or 75 per cent hydrogen and 24.9 per cent helium (*solid black line*).

scale of minutes, so that they seem almost to flicker. Those that become novae often flare up to a brightness 100,000 times that of the sun and remain bright for a week or so before fading rapidly. During the outburst a nova will lose only about a millionth of its mass, so it does not disintegrate and could explode again. Several recurrent novae have been identified. (By contrast, a star that explodes as a supernova is often destroyed; during its brief spectacular life it may shine as brightly as a billion suns.) Some subdwarfs, called SS Cygni stars after their prototype, flare up less brightly than novae at intervals ranging from a few weeks to a year, and smaller variations can be observed every few minutes. They all seem to be members of double-star pairs.

In the great majority of subdwarfs the normal nuclear fuel, hydrogen, has almost certainly been exhausted in the center of the star. They evidently derive their energy by converting nuclei of the isotope helium 4 (He^4) first into beryllium 8 (Be^8) and then into carbon 12 (C^{12}) according to the following reaction:

$$He^4 + He^4 \rightarrow Be^8$$

$$Be^8 + He^4 \rightarrow C^{12}$$

Theoretical stellar models based on these reactions have recently been worked out by E. E. Salpeter and his collaborators at Cornell University. The models seem to give luminosities and surface temperatures characteristic of the general region in which hot subdwarfs appear in the color-magnitude diagram.

It is obvious that nothing has been lost in giving up the name "subdwarf" for the metal-poor and still unevolved Population II stars that have provided our principal theme. If, however, further work shows unambiguously that some of these stars actually lie significantly below the main sequence in a true temperature-luminosity diagram, a satisfying explanation will have to be provided. Presumably the explanation will require stellar models with compositions rather different from any that have been proposed so far. Such model building could provide a means for determining the spectroscopically unobservable helium content in very old stars. This could be done by first determining the abundance of the heavier elements directly from the spectra. Then models can be formulated that combine this abundance with various ratios of helium to hydrogen until a model is found that fits the correct position in the temperature-luminosity diagram.

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Univac LARC does it in 36 microseconds

The second of the two largest, fastest, most powerful computers now operating —the Univac LARC—recently completed its acceptance tests at the Navy's David Taylor Model Basin, Carderock, Md. The first of the LARC series has been successfully operating for the past year at the Lawrence Radiation Laboratory for the AEC.

6,334,943,675
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In the Department of Inconceivable Statistics, here are some facts about LARC. It can store more than 73 million digits. It can perform 125,000 multiplications or 250,000 additions per second. Switching time of the logic circuitry is faster than the time it takes for light to travel the length of the machine.

Problems previously considered too time-consuming can now be programmed for the LARC. For instance, three-dimensional mathematical models of nuclear reactors will be constructed on LARC programs. Atomic fallout patterns, ocean-wave spectrum analysis, propeller cavitation, magnetic field analysis for mine sweeping operations are also contemplated for future programming.

LARC is another "first" the Univac Division has contributed to the data processing industry. Producer of a complete line of computers and punched card systems, Univac Division has its headquarters at 315 Park Avenue South, New York City, and Engineering Centers at St. Paul, Minnesota; Philadelphia, Pennsylvania; and Norwalk, Connecticut.

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EXCAVATIONS AT SARDIS

The capital of King Croesus of Lydia in the sixth century B.C., this city in Asia Minor was successively conquered by the Persians, the Greeks, the Romans and the Byzantines

by George M. A. Hanfmann

Large ruins are scattered in the vineyards and wheat fields on both sides of the modern highway that runs down the fertile valley of the Hermus River, some 70 miles inland from the Aegean coast of Turkey. Brick walls and water pipes of terra cotta are to be seen, and on the heights above the valley, amid bizarre peaks of conglomerate exposed by centuries of erosion, rise the broken towers of a citadel. Legend, history and now the spade of the archaeologist agree that this is the site of "Golden Sardis"—for 3,000 years a center of urban civilization, the seat of the Lydian Empire in the seventh century B.C. and successively a prize of Persian, Greek, Roman and Byzantine conquest. The last city at the site was obliterated by the Mongol conqueror Tamerlane in A.D. 1402; the great name of Sardis survives only in two villages: Sart-Mustafa, which occupies a corner of the site in the side valley of the Pactolus River; and Sart-Mahmut, just outside the city limits to the north.

European antiquaries who visited the site in the 19th century were forced to conclude that the Sardis of the Lydian Empire had disappeared from the face of the earth. Each civilization had destroyed the works of its predecessor and built anew on the ruins. Over the centuries earthquakes had toppled fortifications and started landslides from the citadel heights. The heavy seasonal rains had turned mountain torrents into flash floods that had deposited quantities of stones and sand on the lowlands. The ruins that were visible obviously belonged to much later times. Archaeologists of the romantic period were sorely disappointed; they knew from Herodotus and other Greek writers of classical times that a gold strike in the Tmolus Range—the long wooded mountain chain that runs east and west just south of the Hermus—had brought untold riches to Sardis at about the middle of the seventh century B.C. The Pactolus was said to have carried gold dust into the city itself. Herodotus reports that "the Lydians were the first nation to introduce the use of gold and silver coin, and the first who sold goods by retail." The kings of Lydia stamped their royal device—a lion and a bull—on coins of electrum, an alloy of gold and silver. Struck with punches into dies, the coins were irregular in shape but remarkably uniform in weight. Later the Lydians established the first bimetallic currency by issuing gold coins and silver coins. From 650 until 547 B.C., when Croesus, last and richest of the Lydian kings, was defeated by Cyrus the Great of Persia, Sardis was a veritable El Dorado and a capital of fashion in the eyes of its neighbors.

Modern archaeology has brought to light evidence of the Lydian civilization, but today no one expects to find royal treasure at Sardis. The site is of interest not only for its eminence in Lydian times but also for the long history of habitation recorded in its ruins.

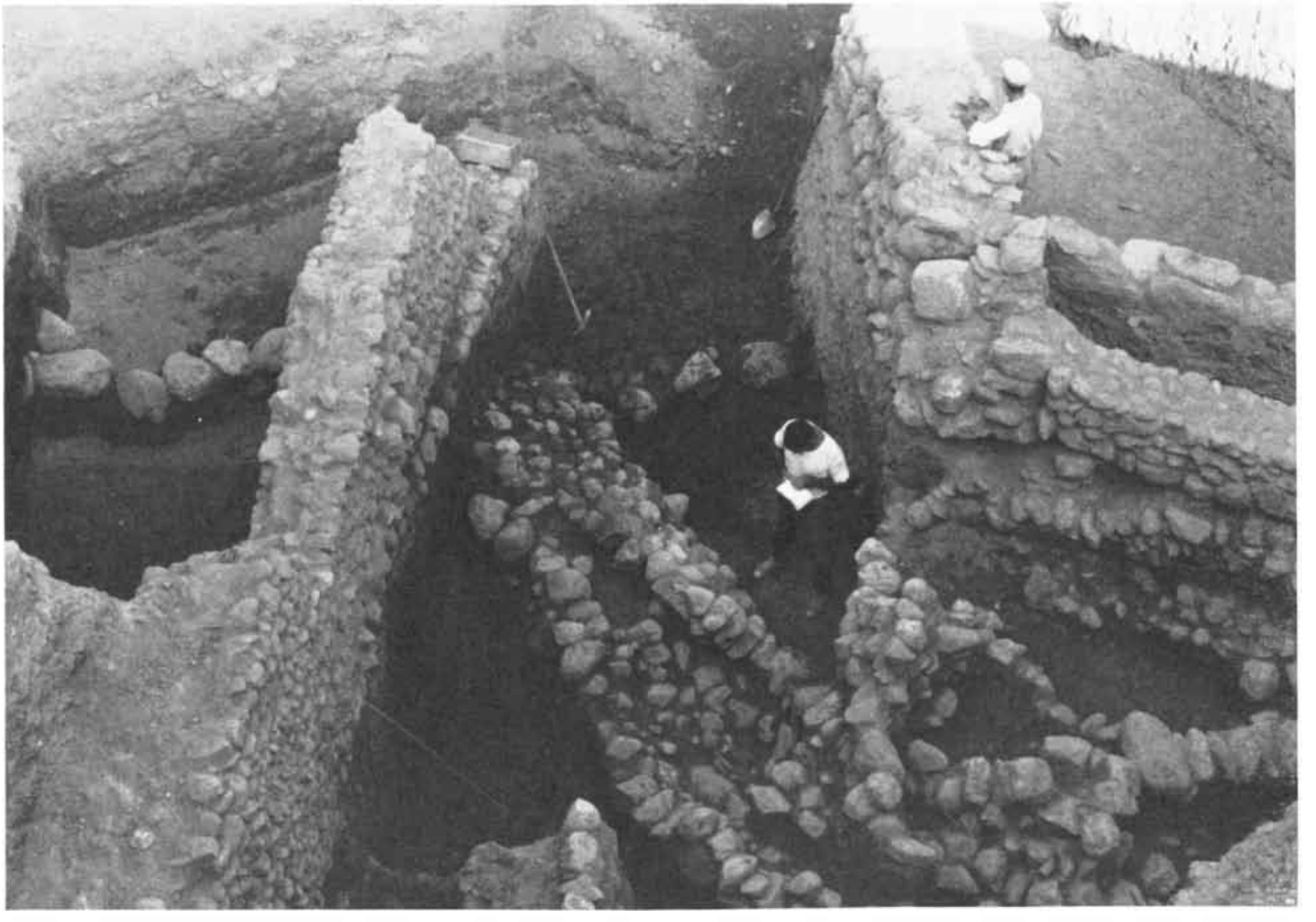
Howard Crosby Butler of Princeton University carried out the first scientific excavation at Sardis in five seasons from 1910 through 1914. In the valley east of the Pactolus two mighty columns still rose above the ground. Here Butler and his 300 workmen uncovered a large marble temple dedicated, according to its inscriptions, to the goddess Artemis. It had been built in the time of Alexander the Great and his successors (late fourth century to early second century B.C.). Around the temple and in the sepulchers on a hill opposite the great citadel Butler found marble slabs with inscriptions in the lost Lydian language. Two burials of the Persian era gave substance to the splendor attributed to Sardis: the dead wore gold bracelets and earrings and garments decorated with small gold plaques. But grave robbers of ancient, medieval and modern times had looted all the other 1,100 graves opened by the first Sardis expedition. The chances of finding treasure are thus on the order of one in 500.

World War I put an end to excavations in 1914, and the Greco-Turkish War halted their brief resumption in 1922. In 1958 a joint Harvard-Cornell expedition took the field under the sponsorship of the American Schools of Oriental Research. The work of the two universities continues from summer to summer with the aid of the Bollingen Foundation. Our objective is to survey the life span of the city from the prehistoric epoch when the earliest farmers settled on the fertile plain to the troubled times when the citadel became a key position in the struggle between Byzantine emperors and Seljuk Turks. We hope to uncover entire quarters of the ancient city and to reconstruct the evolution of this urban community in relation to its environment.

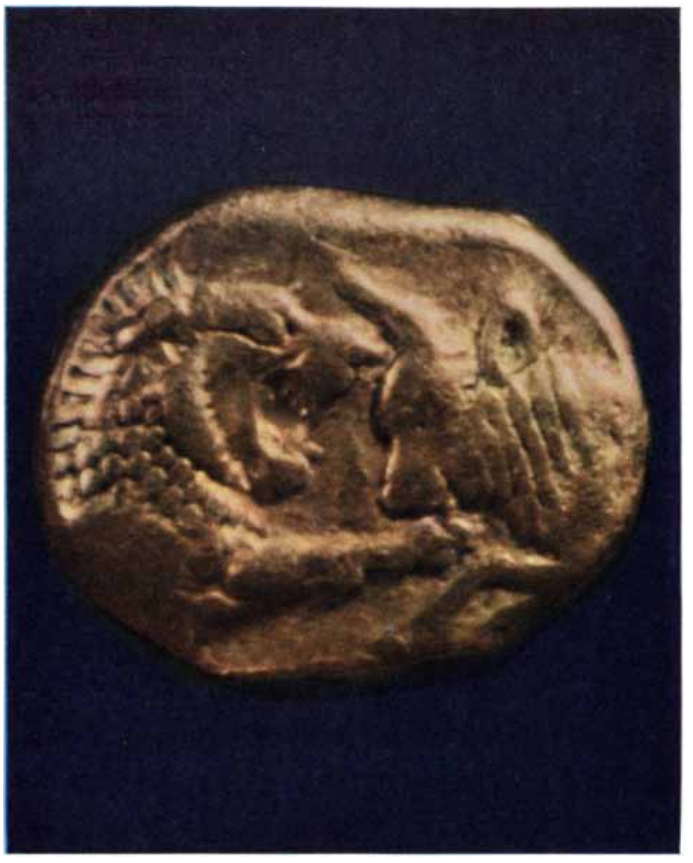
This is a formidable task, horizontally as well as vertically. At its most extensive, including the citadel and outlying habitations, the city probably covered almost two square miles. The city wall of Byzantine times enclosed about 450 acres; the most rigorous calculation, including only the inner core of the city, still yields an area of 280 acres.

We decided first to test Butler's theory that a sanctuary of Croesus' time still lies under the Greek temple of Artemis. Careful digging turned up objects from earlier epochs but no evidence of an earlier building. At the same time we initiated the study of the urban development of Sardis in the large ruins still visible at the eastern and western bound-

RUINS FROM THREE EPOCHS were excavated at this site. House of Bronzes (*center foreground*) was an important early Byzantine residence. It was found under a melon patch. Lydian shops of seventh and sixth centuries B.C., containing pottery and lamps, are in left foreground. To the north, across the highway, the walls of the large Roman gymnasium complex rise to impressive height.



LYDIAN RUINS from four periods were found under Roman and Hellenistic graves in Pactolus Cliff sector. Walls at left and right are parts of large buildings of the third Lydian level. Stones in center are probably a street. The six stones at left and the three in the center at man's right are in fourth and lowest level. The four levels span about five centuries (1000 to 500 B.C.).



GOLD COIN was issued by Croesus. It is 3/4 inch across and bears royal lion-and-bull design. It was not found in present excavations but is in the collection of Arthur Stone Dewing of Newton, Mass.

SILVER COIN of sixth century B.C. was found in the area of the Lydian shops near the House of Bronzes. Of Greek origin, it is approximately 1/2 inch across and bears the design of a flower.

FRAGMENTS OF GREEK "MERRYTHOUGHT" CUP were found at the citadel of Sardis. The cup features a battle scene (*left*) and a legendary boar hunt (*right*). The inscription barely visible at upper right says: "Rejoice and drink well." The cup probably belonged to a Lydian warrior who defended the citadel against the Persians in 547 B.C., when Cyrus the Great defeated Croesus.

aries of the city in the Hermus Valley [*see illustration on page 130*].

At the outset we were able to confirm another piece of intelligence from Herodotus. From an ancient river bed crossed by one of our trenches south of the Artemis temple came a die made of terra cotta. Herodotus credits the Lydians not only with the invention of coinage but also with the invention of dice; the die, from the ninth or eighth century B.C., suggests that he had grounds for this statement.

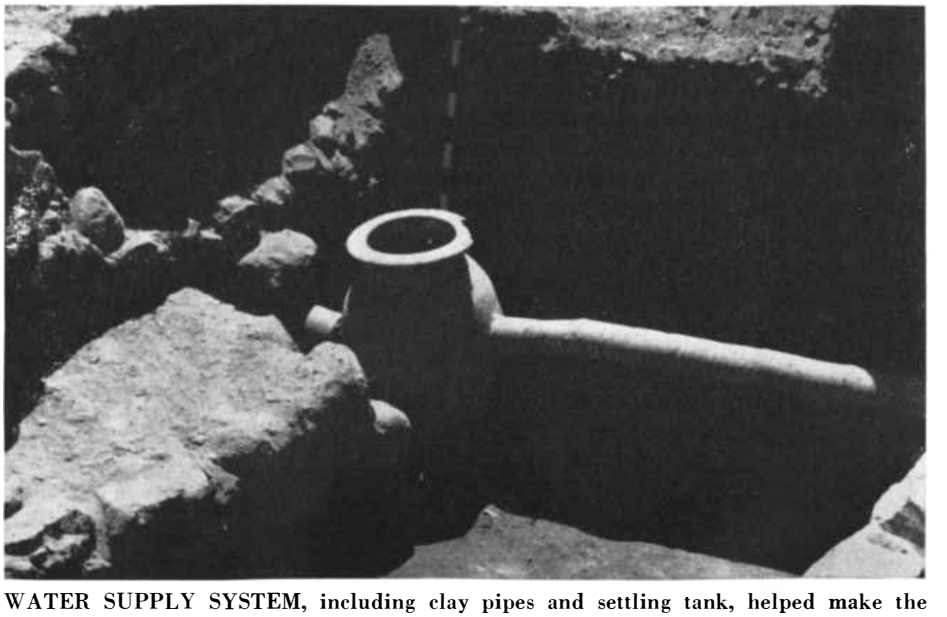
Significant results came dramatically in the last days of the summer campaign of 1958. We were making our last trial sounding of the season alongside the highway. Less than a foot below the surface of a melon patch we found the large walls of a residence dating from early in the Byzantine period of the city's history; its vaulted basements yielded an important array of early Christian bronzes. At the north side of this "House of Bronzes," seeking to penetrate deeper, we jumped across 1,000 years with only three feet of excavation. Here, on a charred earth floor, we came upon the workshop of a Lydian potter who was making and mending his wares at the time of King Alyattes in the seventh century B.C. Large, gaily painted jars, water jugs, stands, stemmed bowls and the characteristic unguent or perfume bottles known as lydions were piled on the floor in heaps, abandoned when the workshop fell victim to a sudden catastrophe. We had located structures that definitely belong to the city of the Lydian kings.

Further search in 1959, undertaken in delicate operations between the foundations of later buildings, yielded only one other Lydian room and fragments of walls. But to the south and west of the House of Bronzes we found in 1960 an area that had not been built over by Romans and Byzantines. More Lydian shops, more pottery and a pile of lamps, as yet unsold at the time of destruction, make it likely that the entire sector was part of a bazaar—the market place of ancient Sardis.

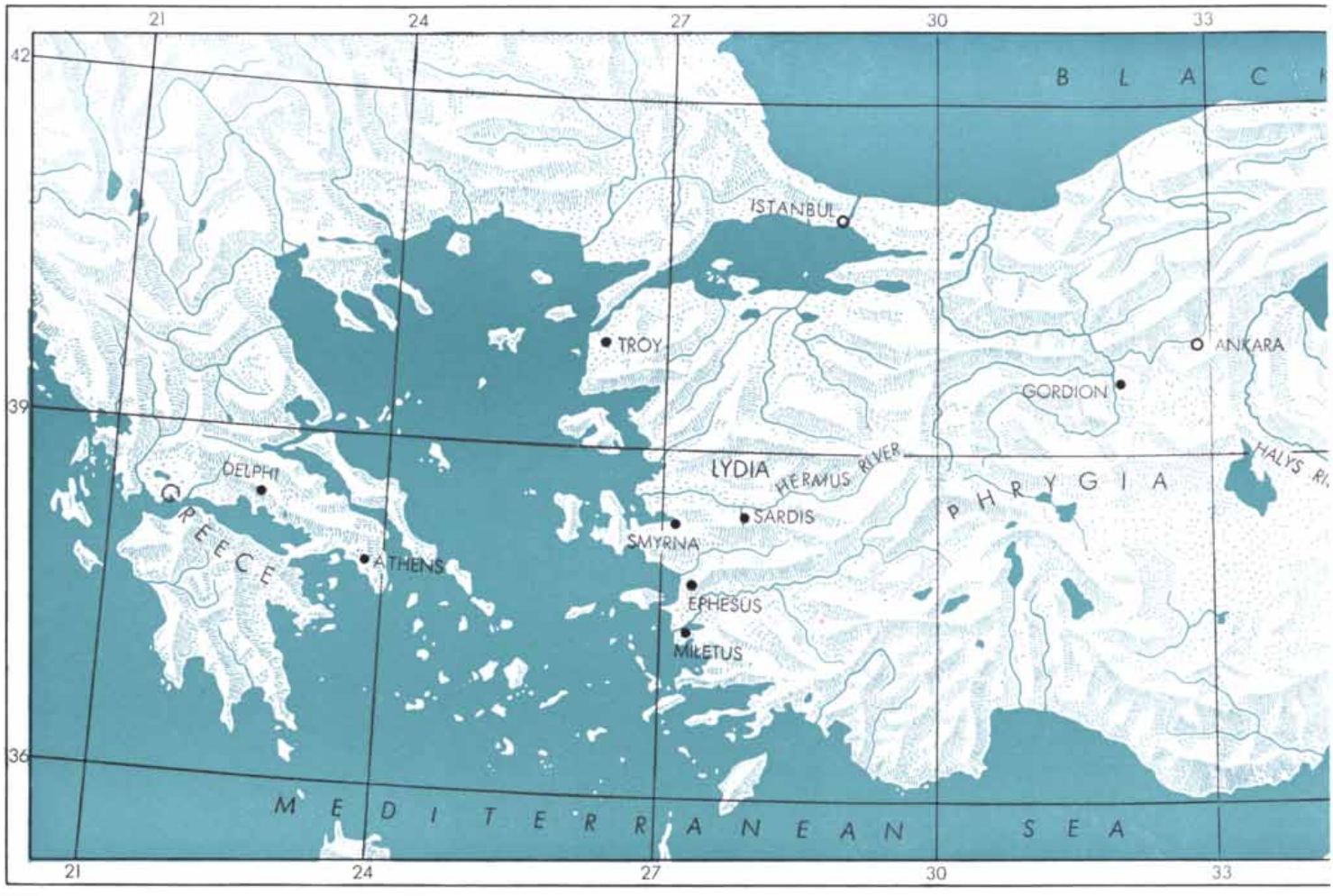
Profiting by the elbow room that a large new trench afforded, we drove a sounding to 35 feet below the surface. Thus we learned that the area had twice been devastated by fire. The later traces of fire correspond to the early seventh century B.C., when the city was sacked by the Cimmerians, the same nomadic warriors from the Crimea who ravaged the kingdom of Phrygia and its capital, Gordion [see "The City of Midas," by

LYDIAN LAMPS of the sixth century B.C. are seen lying where they were found on the floor of a Lydian shop. The Lydian bazaar was excavated near the House of Bronzes.

HEADLESS ROMAN STATUES of husband and wife were buried at House of Bronzes. Heads for such statues were made separately and could be changed to suit the occasion.



WATER SUPPLY SYSTEM, including clay pipes and settling tank, helped make the House of Bronzes a comfortable residence during Byzantine times (seventh century A.D.).

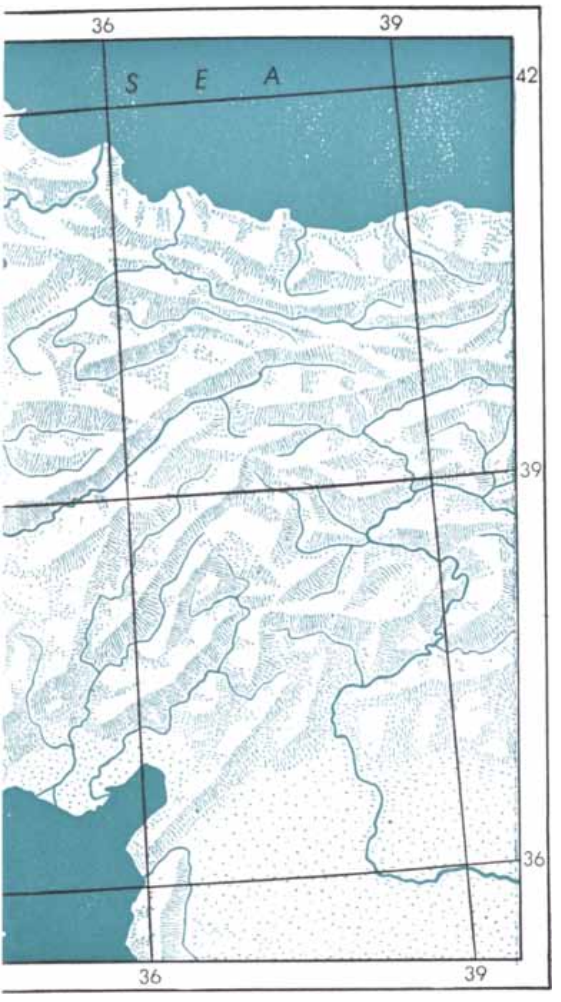


THE SITE OF SARDIS is some 70 miles from the western coast of Turkey, just south of the Hermus River. It was the capital of the ancient Lydian Empire and remained an important city for nearly 2,000 years after the fall of Lydia. Other important ancient

Machteld J. Mellink; SCIENTIFIC AMERICAN, July, 1959]. The lower layer of ashes dates from the late Bronze Age, six centuries earlier. The area was also flooded time and again, but people always returned to trade. This evidence of continuous occupation not only takes Sardis back to about 1300 B.C. but also makes it the only place in western Asia Minor in which there is evidence of habitation through the period from 1200 to 800 B.C., a period known as a "dark age" to students of the region. Bits of Mycenaean pottery, imported from Bronze Age Greece, raise the possibility that Greeks returning from Troy were the Bronze Age destroyers of the town. But Hittite annals speak of an invasion by a Hittite king, and more excavation is needed before we can decide.

In 1959 we located Lydian buildings

ARTIFACTS OF FIVE CULTURES found at Sardis include (*left to right*) a portrait of a Lydian dandy on terra cotta; a piece of a Lydian plate with a painting of a boar; a water jug that was being repaired by a Lydian potter (*note holes drilled for lead clamps*);



sites include Gordion (the capital of Phrygia), Troy, Ephesus, Athens and Delphi.

under Greek and Roman graves along the banks of the Pactolus. As a rule the ancient Greeks and Romans buried their dead outside the city limits; the Lydian houses under the later cemetery indicate that the Lydian city extended farther to the west than the populous city of Greek and Roman times. A heavy layer of charred wood above the Lydian remains bespeaks the fiery destruction that rebellious Greeks wreaked upon Sardis in 499 B.C., when they rose against their Persian overlords and started the great Greco-Persian Wars.

In the sector we call Pactolus Cliff we have uncovered parts of large Lydian buildings quite different from the modest small rooms of the Lydian bazaar near the House of Bronzes. These may have been sanctuaries, but unfortunately the trench is so close to the houses of the modern village that we cannot expand our excavation sufficiently to see the complete layout.

Downstream from this site we are recovering the first monumental building from the time when mighty satraps made Sardis the center of Persian power and intrigue against the west (547 to 334 B.C.). Preserved because they were reused as foundations by the Greeks and Romans, the walls still stand up to six feet high. Two halls with a hairpin-shaped floor plan can be traced; they continue under Roman buildings to the west. This structure may have been a fort that guarded the crossing over the Pactolus or an important residence.

It must now be confessed that we are still moved by the hope that we may uncover the grander temples and public buildings of the city of the Lydian kings, particularly the palace where Croesus lived and the mint where the first coins were struck. Nothing is known about the location of the mint, but ancient authors mention the palace. In 334 B.C. Alexander the Great stood in the citadel of Sardis, which the Persian commander had surrendered without battle. As he marveled at the natural strength of the fortress a tremendous thunderstorm broke, and a bolt of lightning struck the Palace of Croesus. Alexander had planned to crown the citadel with a temple to Zeus, protector of kings, but the lightning revealed to him that the God of the Skies wished his temple to be built next to the palace. Thus we know that the palace was not on the citadel. Another curious allusion to the palace is made by the Roman architect Vitruvius, a contemporary of the Emperor Augustus. He states that according to the Roman building code structures of mud brick were assessed at initial cost if the wall stood plumb; as an example of the durability of mud brick he cites the Palace of Croesus, "still used as the Hall of the City Senate." From Greek inscriptions found at Sardis it appears that the city senate building stood next to a "Gymnasium of Elders." The problem now is to discover such a gymnasium.

Although Alexander allowed the inhabitants to keep their ancient Lydian laws, under his successors Sardis rapidly became Hellenized in speech, customs and constitution. The descendants of Alexander's general Seleucus, who ruled over an empire stretching from Greece into central Asia, kept Sardis as the capital of their dominions in Asia Minor. The gold deposits were running out but the royal mint still struck silver coins. The textile industry, specializing in purple rugs and garments made of gold threads, continued to prosper; new industries came into being, including the mass production of brilliant red pottery. The great marble temple of Artemis

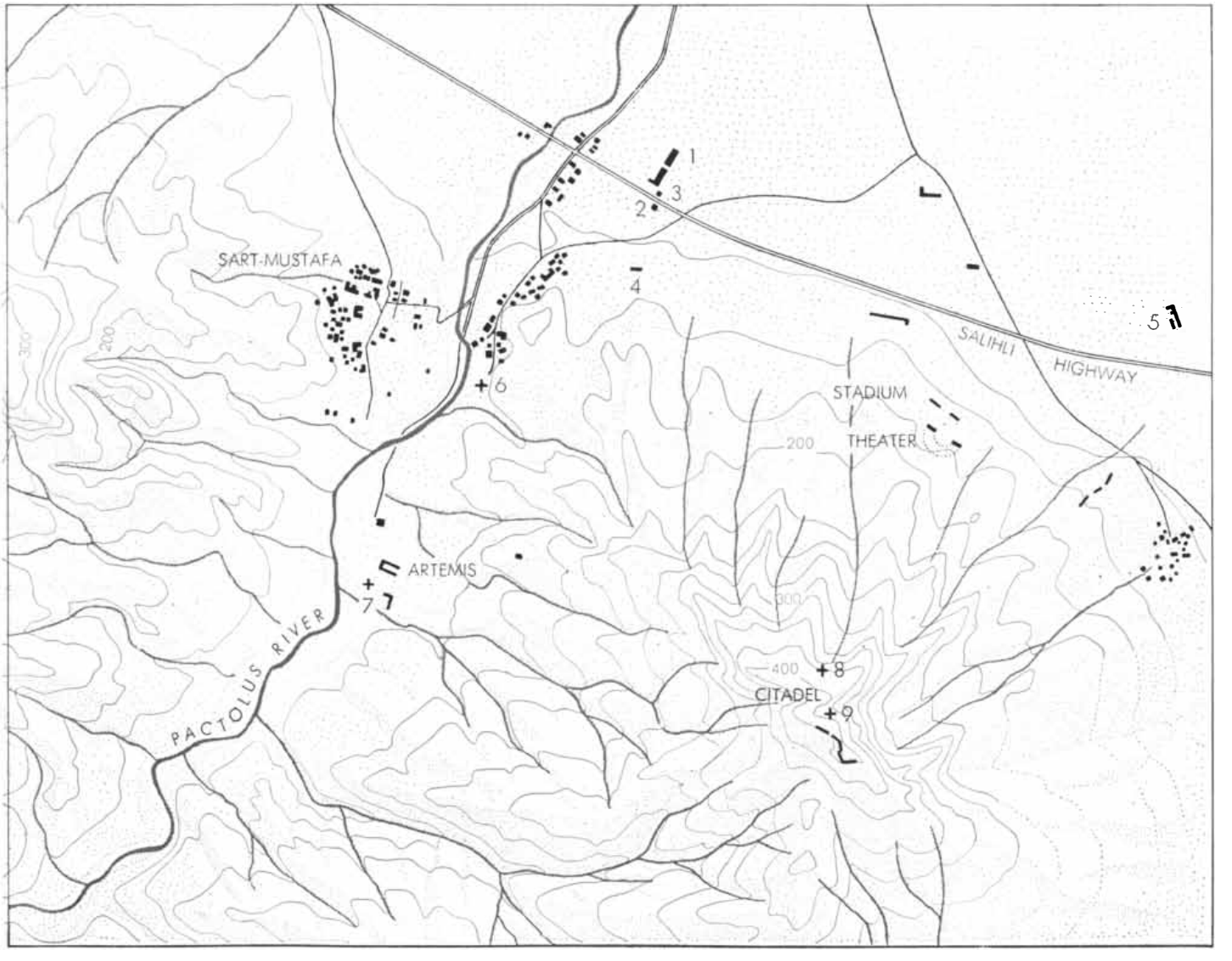
a bronze Persian arrowhead; a fine sixth-century B.C. Greek bronze casting of a boar; a third-century A.D. Roman priest wearing a diadem of the 12 Olympian gods; and a small bronze Byzantine shovel with a Christian cross. Objects are not in same scale.

proves that marble-quarrying had now been undertaken on a larger scale. Inscriptions from the period are in Greek; the Lydian tongue died out quickly.

The descendants of Seleucus and the kings of the neighboring state of Pergamon struggled for Sardis. A marble tower found on the citadel in 1960 revealed that the Seleucid king Antiochus the Great (242 to 187 B.C.) modernized the fortress. Eventually the Pergamenes defeated the Seleucids, only to leave their kingdom to the Romans. This meant no drastic change. Sardis joined a number of other important cities in a league to promote the worship of Roman emperors, but her life and institutions remained Greek. Peace and prosperity within the vast organization of the Roman Empire brought great benefits to the rich province of Asia (the Roman name for their first province east of the Aegean).

The new excavations have considerably increased our knowledge of Roman Sardis. One of our first objectives north of the modern highway was a huge brick building, some 400 feet long and deeply buried by rubble that must once have been its domes and vaults. Early travelers had called it everything from the Palace of Croesus to a Byzantine church. After clearing the southern end we came upon a window through which we sought entry, only to find the way blocked by a large marble pedestal. Further excavation disclosed a majestic inscription carved in monumental letters. It commemorates the Roman Emperor Lucius Verus, who ruled from A.D. 161 to 169, and states that the donor of the statue, one Claudius Antonius Lepidus, "from the beginning took care of the administration of the gymnasium." Unfortunately it does not appear to be the Gymnasium of the Elders that might help to locate the site of Croesus' palace. Traces of gorgeous marble floors and wall facings vie with the most luxurious buildings of Rome. Once the building was abandoned, however, operators of lime kilns moved in to burn the marble to lime. Its former splendor must be reconstructed from fragments that are only a fraction of the original decoration.

To the east and west of the central building are large rectangular areas belonging to the gymnasium complex. That on the east featured a large colonnaded court from which a smaller marble court and a triple gate gave access to the central hall of the gymnasium. The smaller court boasted marble façades with elaborately carved ornaments. An inscription on top of the façade commemorated the Roman emperors Caracalla and Geta (who ruled jointly) and their mother, Julia Domna. Geta settled in Asia Minor but was lured to Rome



AREA OF EXCAVATIONS at Sardis lies on both sides of the Salihli Highway and along Pactolus River. Sart-Mustafa is a modern village on the site. Some of the important excavations are (1) the Roman gymnasium complex, (2) the House of Bronzes, (3) a Byzantine bazaar, (4) "Upper Terrace" area with late Roman ruins, (5) large Roman-Byzantine baths, (6) "Pactolus Cliff" sector, (7) site where Lydian die was found, (8 *and* 9) the 1960 excavations on the citadel. "Artemis" labels temple dedicated to that goddess.

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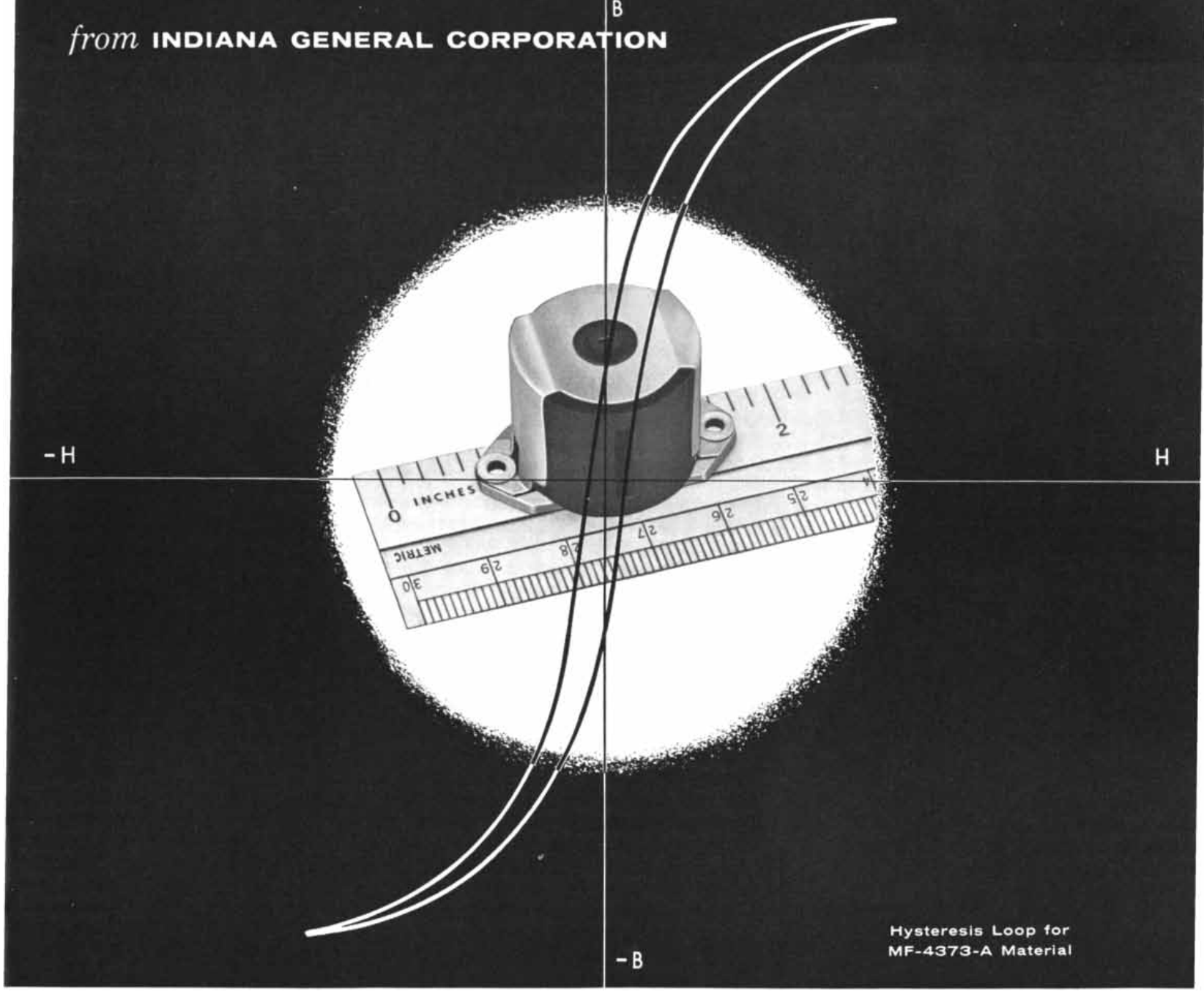

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CITADEL OF SARDIS, viewed from the west, occupied the rugged peak at far right. The highway, built in 1952, follows the same route as the royal road of the Persian kings, which connected Iran to the Mediterranean. The north-south line of trees marks the present course of the Pactolus. Ruins lie along both sides of the highway, on the slopes of the citadel and beside the Pactolus.

and put to death by his brother in A.D. 212. This fratricidal episode is mirrored in the inscription—Geta's name is erased.

Excavating such large public buildings, buried to depths ranging from seven to 20 feet, entails considerable labor. To free the entire complex we would need to excavate an area of about five acres. In our first two campaigns we employed an average of 40 workmen and five horse carts for about 100 working days to clear the southern part of the building and narrow strips in the east and south totaling about a quarter of an acre. At times our workers had only primitive levers with which to move fallen blocks weighing more than two tons. Specialized construction and earth-moving equipment could greatly speed up the work; in 1959, as a result of a generous donation, we were able to use a powerful truck, lifting and hauling equipment and a crane. We have also

EXCAVATIONS ON THE CITADEL have revealed these Persian and Hellenistic fortifications. They lie on the precipitous north slope, some 1,000 feet above the plain of the Hermus River. Croesus, Cyrus, Xerxes and Alexander all mustered armies here.

had the use of machinery on a "lend-lease" basis. In the excavation of a large masonry structure at the eastern edge of the city, for example, we encountered a situation that could not be dealt with by unaided human hands. Two parallel walls rising out of the earth had given the impression of a gate—a city gate, we hopefully assumed. Stone blocks weighing up to a ton and a half had tumbled at various times from the top of the structure and effectively barred our effort to penetrate the loose riverine deposits surrounding the building. Then the Turkish ministry of waterworks lent us a 25-ton crane from the Demir Köprü Dam project; in one day it disposed of obstacles that had stopped us for weeks.

The purpose of the original building, remarkable for its bold use of cut masonry in arches and half domes, remains enigmatic. But in excavating down to about 20 feet below the modern surface, we ascertained that Roman builders had utilized the structure as the central part of a huge bathing establishment. In one of the major arches we discovered a Roman furnace room for a heating system that circulated hot air into the various units of the baths.

Neither Roman nor Byzantine chronicles have much to say about Sardis in the thousand years between the triumph of Christianity and the final destruction by Tamerlane. Our excavations have begun to illuminate this hazy period. Next to the Roman gymnasium we have discovered a long row of shops constituting a regular shopping center. Crockery, glassware and coins lay on the floors. Some of the establishments were restaurants, as indicated by heavy layers of charcoal, animal bones and shells. Fragments of windowpanes show that glass windows were coming into general use. A public toilet, provided for the shoppers, had long rows of marble seats and an efficient flushing and drainage system. From the number of coins it would appear that one had to pay for the use of this convenience. The haul of coins from the entire shopping center is impressive, amounting to several hundred, the great majority from the period A.D. 400 to 600. None is later than the rule of the Byzantine emperor Heraclios, in whose reign sudden destruction befell the shops. It is known that between 615 and 617 the Sassanid king Khosrau II overran most of Asia Minor, and we surmise that his warriors sacked and burned Sardis.

The same fate befell the impressive Christian residence that we call the House of Bronzes. Located across the highway from the Byzantine shops, this palatial house is built in the split-level

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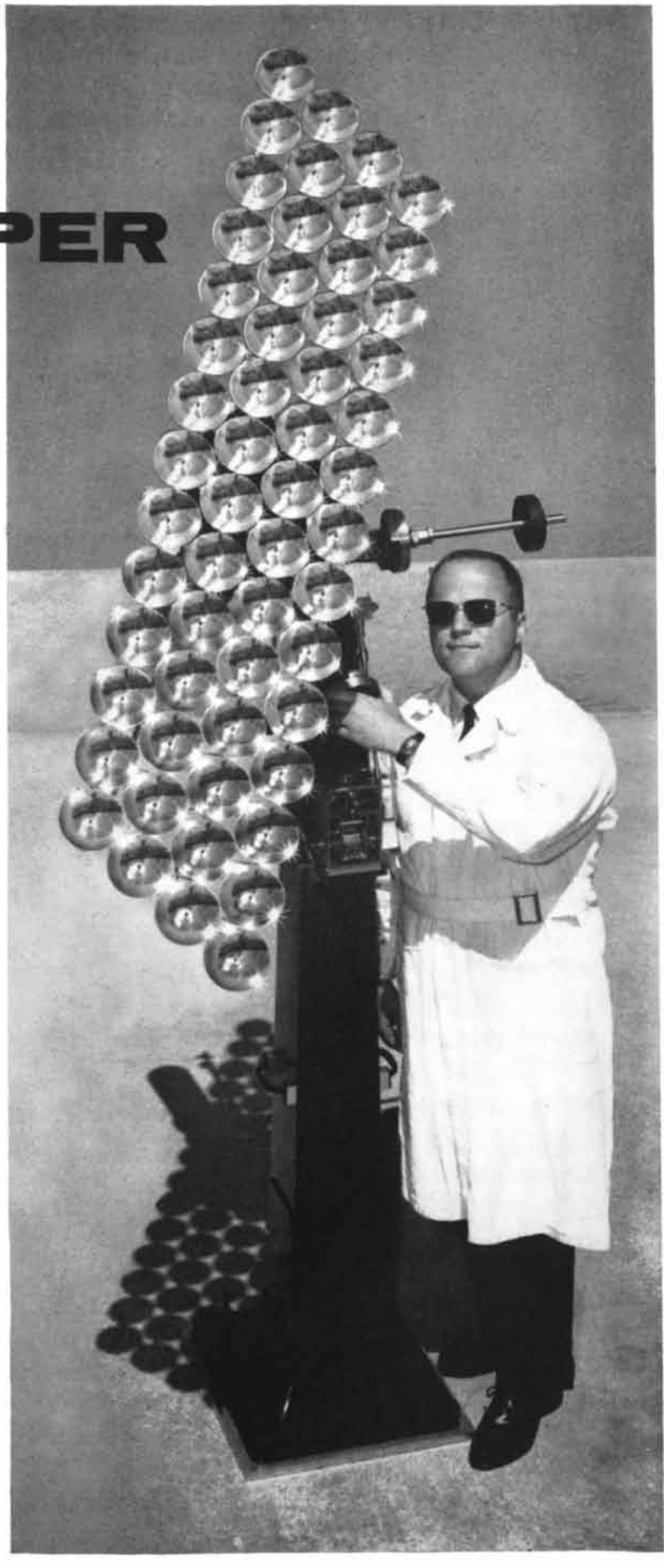


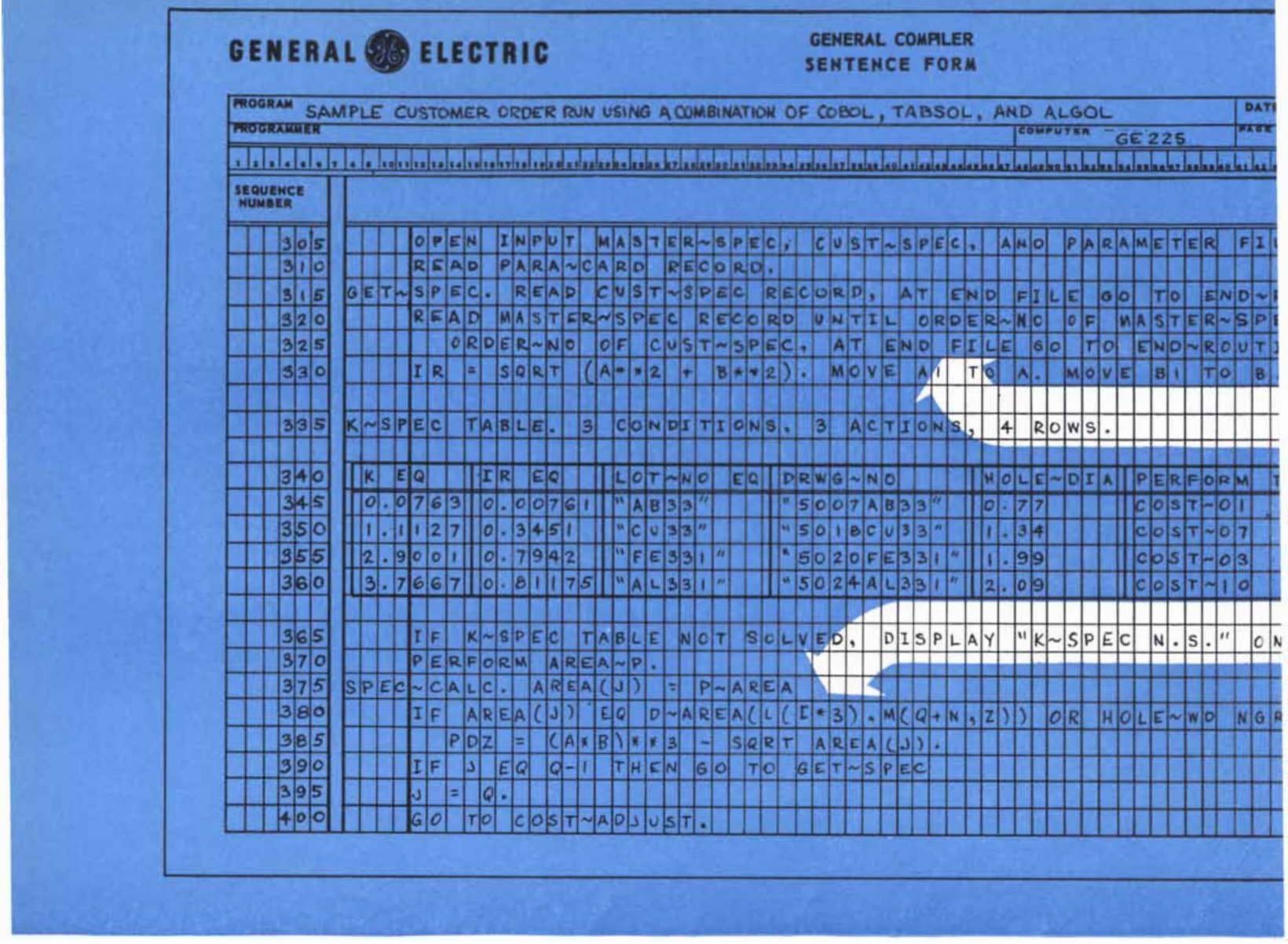
BYZANTINE MARBLE TANK, possibly a baptismal font, was made of used slabs. Wreaths indicate that slab at left once honored a citizen of Sardis. Large inscription shows it was also once a gravestone. The cross was carved later. Upside-down inscription on the other slab is Roman and mentions a temple dedicated to the Emperor Hadrian (A.D. 76 to 138).

style. Storage rooms and workshops flank the entrance. Remarkable bronze implements of the kind used in early Christian churches—two censers and a shovel surmounted by a cross—were lying helter-skelter in a small vault. The shovel may have been used for scooping up embers on which incense was thrown. Magnificent bronze chandeliers and wine jugs suggest more mundane interests of the inhabitants. Two bronze pitchers are interesting forerunners of Russian samovars: inside them is a tube to warm the liquid in the outer shell. The economy of this important household included both domestic and industrial activities. In one of the workrooms we found two large marble basins full of sulfur, perhaps for bleaching wool; corn was ground in stone mortars found piled up in a corner. Running water was supplied by a water main with a settling tank, which we uncovered in one of the back rooms. A statue of the pagan god of wine stood unmolested in a corner of the same room. Did the slaves of the Christian owner cherish the protector of grapes, or was the statue already considered a museum piece?

Beyond the working quarters the visitor entered an open court luxuriously paved with polychrome patterns of cut marble. One of them carries the letters *IE* (an abbreviation for Iesus, or Jesus), another proof of the religious affiliation of the owner. A large marble table along the wall was propped up on pieces salvaged from earlier Roman buildings—a table leg in the shape of a lion and a block cut down from an inscription to the pagan moon god. An exquisite beaker and bowl of blue glass stood in a little wall closet, reminders that the production of glass was a major industry of Sardis. Experts at the Corning Museum of Glass in Corning, N.Y., are now making analytical studies of this material. The owner sought to guard his treasures well; a heavy iron lock lay on the threshold.

Even at the present early stage our excavations have begun to clarify three major periods in the history of Sardis: the Lydian, the Roman and the early Byzantine. With luck and perseverance we may fill in the gaps with the stories of the Hellenistic kings, the Persian satraps and the Hittites and carry the history back to the prehistoric villagers who first brought civilization to this strategic region. The royal cemetery of the "Thousand Mounds" north of the city promises to reveal much about the early history of the Lydians. Perhaps we shall even find the palace of the Lydian kings, with archives that may tell us about the time when coinage was invented.

LYDIAN DIE, made of terra cotta, dates from the ninth or the eighth century B.C.



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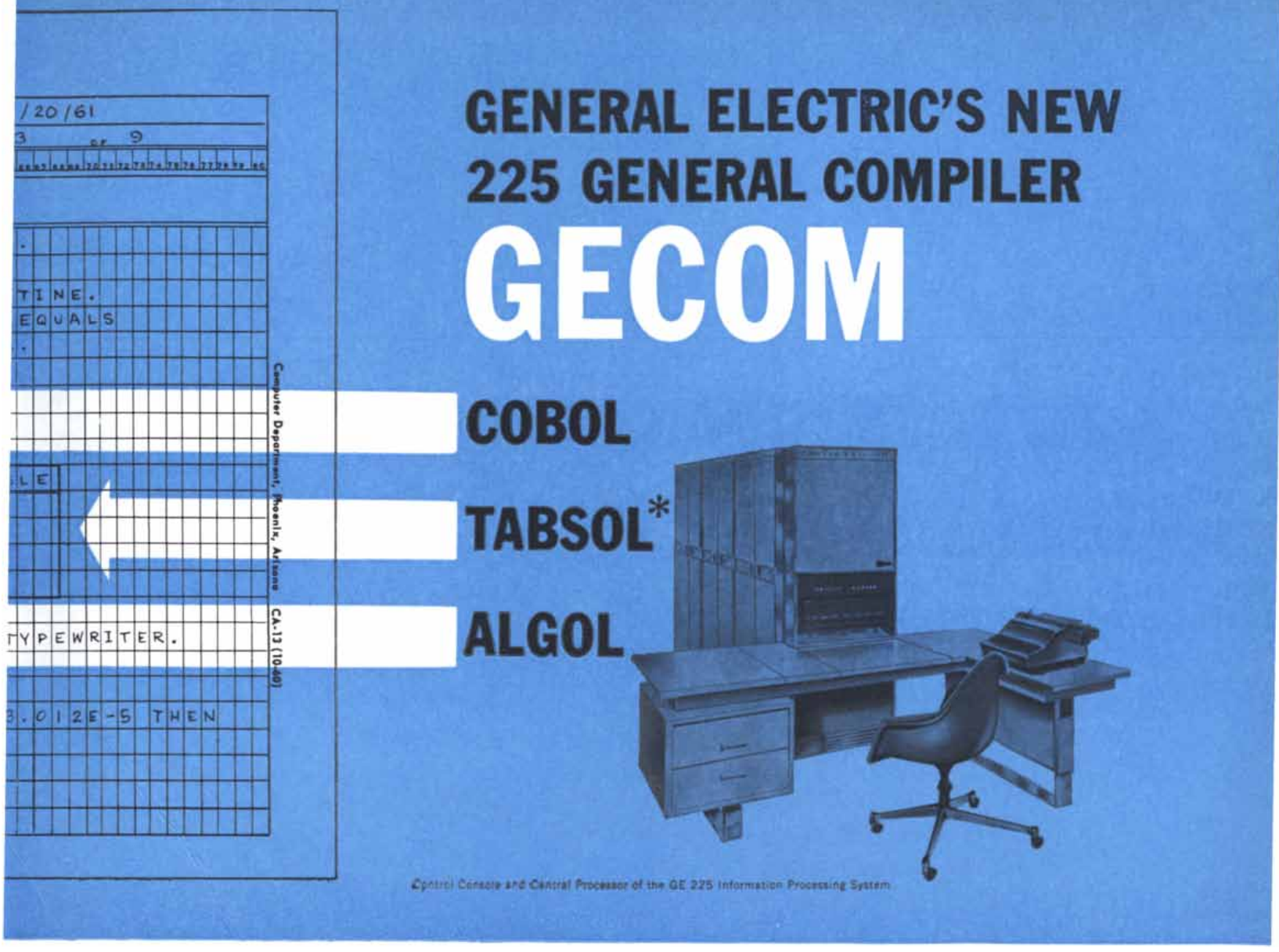

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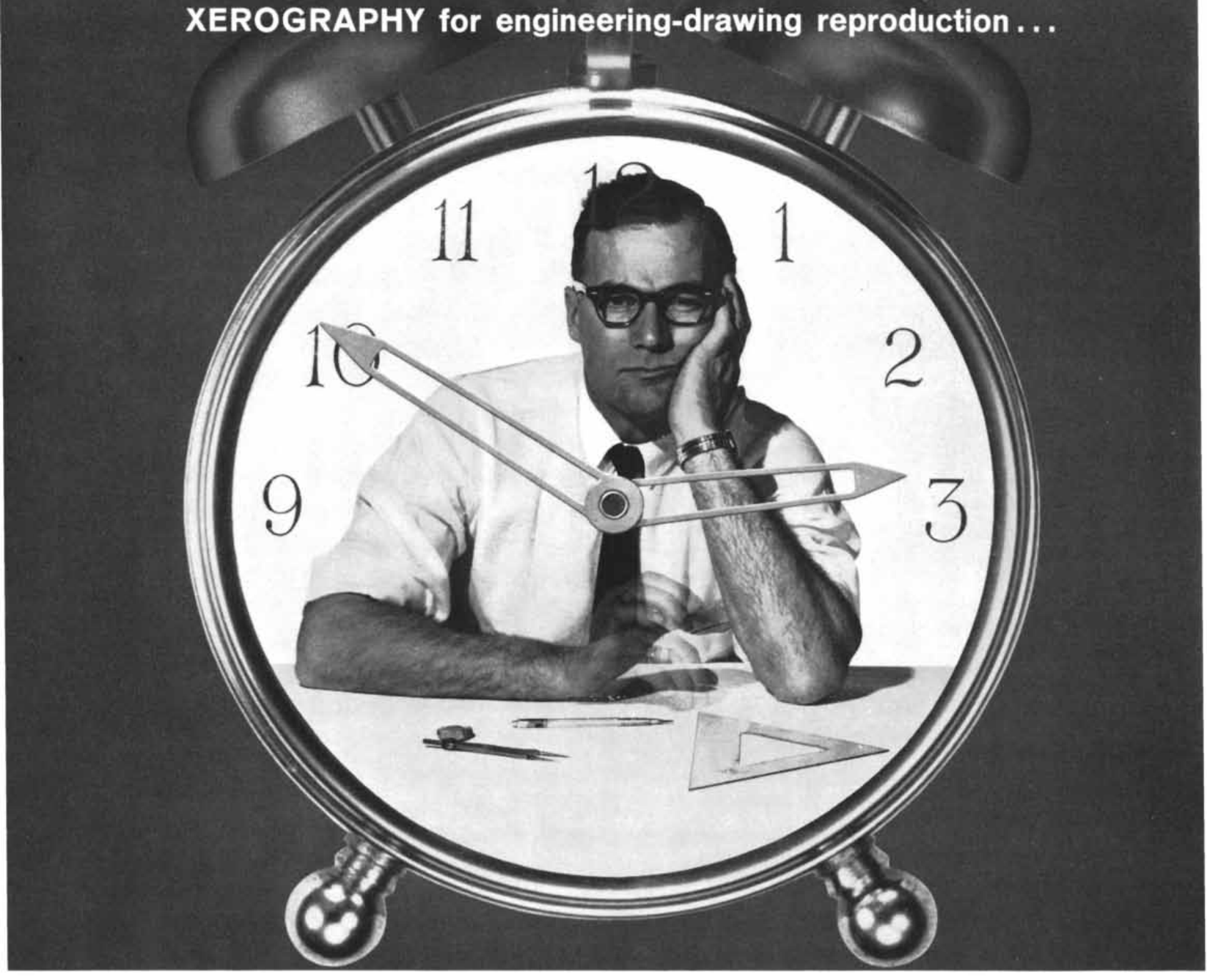

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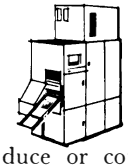

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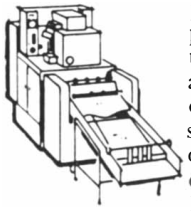

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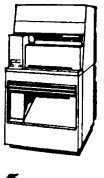

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BIOTIN

This little known but remarkably potent member of the family of B vitamins has been a biochemical puzzle for three decades. The details of its functions are only now beginning to emerge

by John D. Woodward

Hardly anyone who is not a biologist or a biochemist will have heard of biotin. The name of this vitamin does not appear on the labels of tonics and vitamin pills; dietitians do not compile lists of foods that contain it. Perhaps there has never been a case of natural biotin deficiency. Yet anyone deprived of the minute traces of the substance that are required by probably every cell of the body would surely die.

The requirement is extremely small, and biotin is widely distributed. From the point of view of nutrition it can safely be ignored. Nevertheless the amazingly potent vitamin has fascinated biochemists for many years. Since the turn of the century different workers have "discovered" it at least three times and given it half a dozen names. About 20 years ago the diverse lines of research were finally brought together, and the names were shown to apply to a single substance. The chemical structure of biotin was worked out soon afterward. But the job of discovering its essential function, or functions, in the chemistry of living cells has barely begun.

The story goes back to 1901 and some experiments of the Belgian microbiologist E. Wildiers on the culture of yeast cells. His simple medium contained all the nutrients then thought to be essential, but the cells often grew poorly. He found he could obtain normal growth by adding small amounts of brewer's wort (an extract of ground malt) or extracts of dead yeast cells. The extracts evidently contained an unknown nutrient; Wildiers named it "Bios."

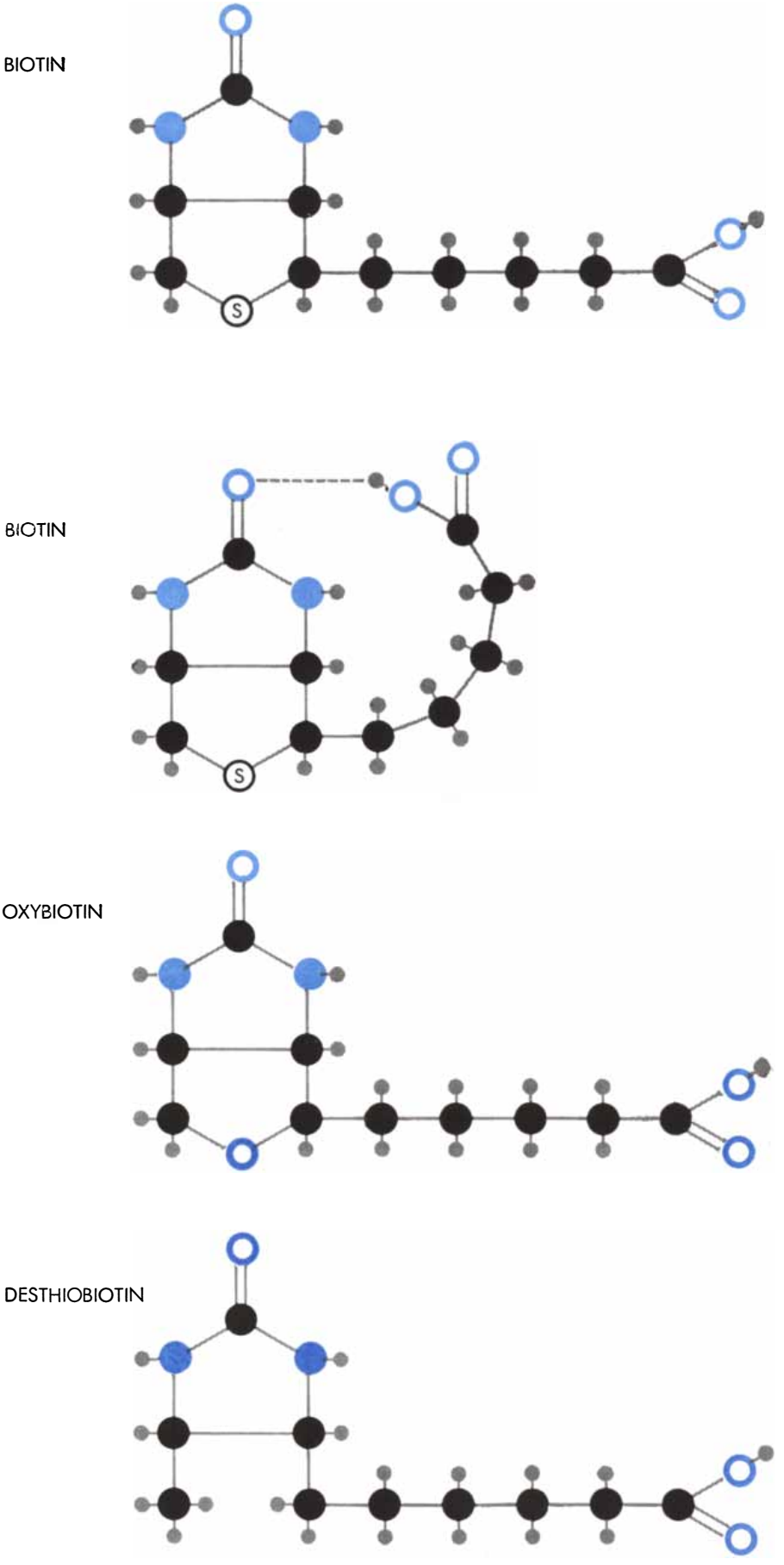
It was many years before Wildiers's observations gained general acceptance. Eventually it became clear that his hypothetical material represented not one but a number of distinct growth factors—water-soluble B vitamins including the now familiar thiamin (B_1), riboflavin (B_2), pyridoxine (B_6) and nicotinic acid (pellagra-preventive factor). One of the Bios fractions, unlike the others, was readily adsorbed by charcoal and so could be separated, at least partially, from the rest of the complex.

In the early 1930's this fraction, designated II*b*, attracted the attention of Fritz Kögl, an organic chemist at the University of Utrecht. Up to that time all the known sources of Bios II*b* contained it in exceedingly tiny amounts, so Kögl began by looking for a richer raw material. Egg yolk was one of the best sources he could find. By 1936 Kögl and B. Tönnis succeeded in isolating about a milligram (less than .00004 ounce) of "beautiful crystals" that strongly promoted the growth of yeast. This scarcely visible quantity they had extracted, in a series of 16 different and tedious steps, from 550 pounds of dried duck-egg yolks. With so small a sample they could do little more than determine the melting point of the crystals. The great biological activity of the substance in yeast cultures, however, convinced the chemists that they had found the active principle of Bios II*b*. They called the elusive compound biotin.

At about the time that Kögl was beginning his research, Franklin E. Allison and his colleagues in the Bureau of Chemistry and Soils of the U. S. Department of Agriculture embarked on a study of another microorganism, the nitrogen-fixing bacterium *Rhizobium trifolii*. They found that the growth and respiration of this organism were stimulated by extracts from various organic sources. Because they believed that an unknown factor in the extracts acted in conjunction with an enzyme, they called the factor coenzyme R (for "respiration"). Philip M. West and P. W. Wilson at the University of Wisconsin noted a similarity between the growth-promoting effects of coenzyme R and of biotin. This suggested that they might be the same substance hiding behind different names. By then Kögl had improved his extraction methods and had a larger supply of crystalline biotin. A test of the material on a culture of *Rhizobium* was made by R. Nilsson, G. Bjälfe and D. Burström of the University of Uppsala in Sweden; they found it to have exactly the same stimulating effects as coenzyme R. In this respect, at least, the two were identical.

The next chapter of the story is drawn from the field of animal nutrition. It opens with a flashback to 1916, when W. G. Bateman of Yale University made the casual observation that raw egg white in the diet of animals had a toxic effect. Nothing came of this until 11 years later, when Margaret A. Boas at the Lister Institute of Preventive Medicine in London happened on the same phenomenon. She was using raw egg white as a source of protein in the diet of rats. After a few weeks the animals developed dermatitis and hemorrhages of the skin; their hair fell out; their limbs became paralyzed; they lost considerable weight and eventually they died. Only raw or cold-dried egg white produced the symptoms. Cooking made it harmless. Subsequent investigation showed that the effects of raw egg white could be alleviated or prevented by any one of a variety of foodstuffs. The action was thought to be due to a substance, common to all these foods, that was dubbed protective factor X.

The search for the protective factor was taken up by Paul György, originally at the University of Heidelberg and later at the University of Cambridge and



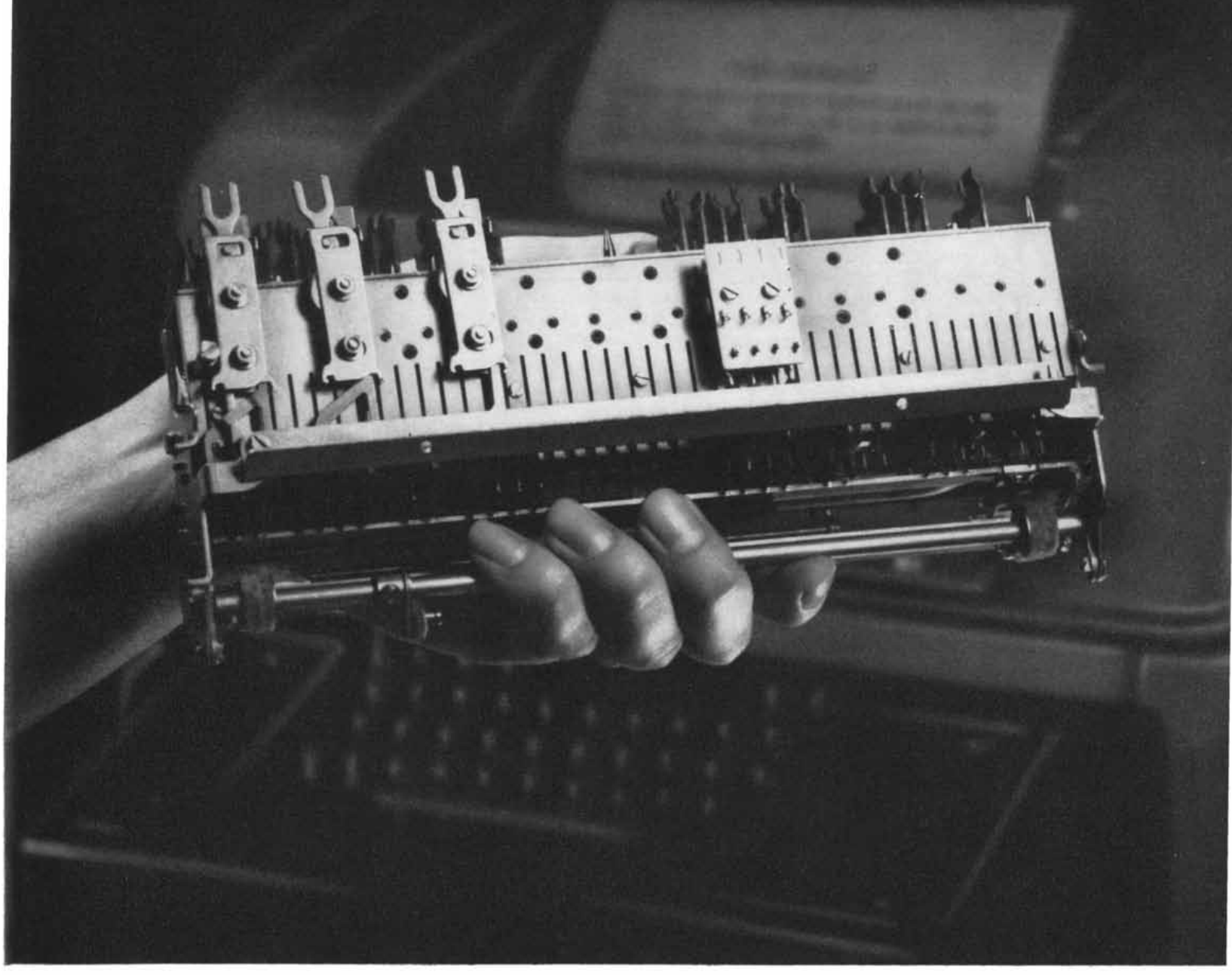
Western Reserve University. He learned that liver is a good source of the protective factor, which he had named "vitamin H." Concentrates prepared from liver had more than 3,000 times the power of liver itself to protect rats on an egg-white diet.

By that time preliminary work on the chemical and physical properties of biotin had turned up some provocative similarities between biotin and concentrates of vitamin H. On the other hand, it should be remembered that there was no evidence of a physiological connection between the two. Biotin was a growth factor for microorganisms; vitamin H prevented egg-white injury in animals. György now suspected a connection, however, and asked Kögl for a sample of his crystalline biotin. Tested on animals, it showed the same protective action against egg-white injury that vitamin H did. In fact, the pure biotin was immensely more potent than the rather crude liver extracts of vitamin H. Would vitamin H concentrates in turn support the growth of biotin-requiring microorganisms? They did. Moreover, the addition of raw egg white to an otherwise adequate culture medium prevented the growth of these organisms. More biotin or vitamin H overcame the toxic effect and growth resumed.

In 1940 György and Vincent du Vigneaud and his colleagues at the Cornell University Medical College independently isolated crystalline vitamin H from highly active liver concentrates and showed that it matched Kögl's biotin in physiological and physical properties. It also yielded the same breakdown products on chemical analysis. There was no longer any doubt that the two compounds were one and the same.

Shortly afterward, biotin was isolated from milk. With so plentiful a source it was now possible to accumulate enough

BIOTIN AND RELATED COMPOUNDS are depicted in these structural diagrams. The second biotin molecule is hypothetical; it shows side chain twisted so that a hydrogen bond (*broken line*) forms between oxygen and hydrogen. This might change the configuration of the molecule and thus activate the nitrogen atoms. Oxybiotin resembles biotin in biological activity; its molecule contains an oxygen atom instead of a sulfur atom. Desthiobiotin lacks the sulfur atom; it is probably the immediate precursor of biotin.



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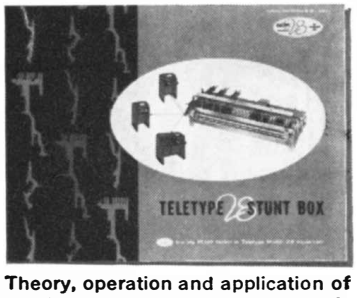

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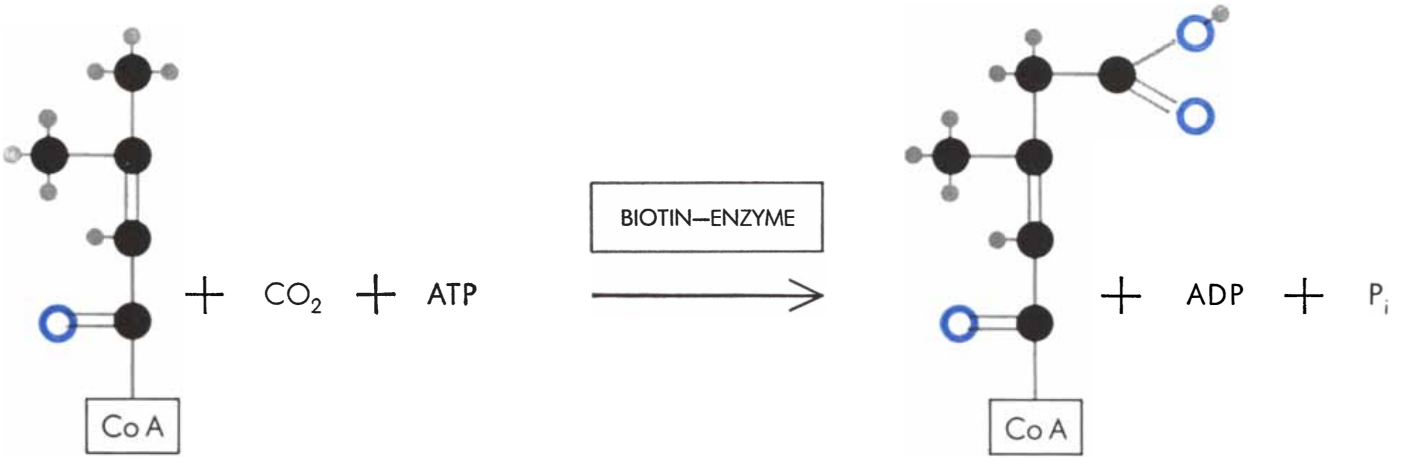
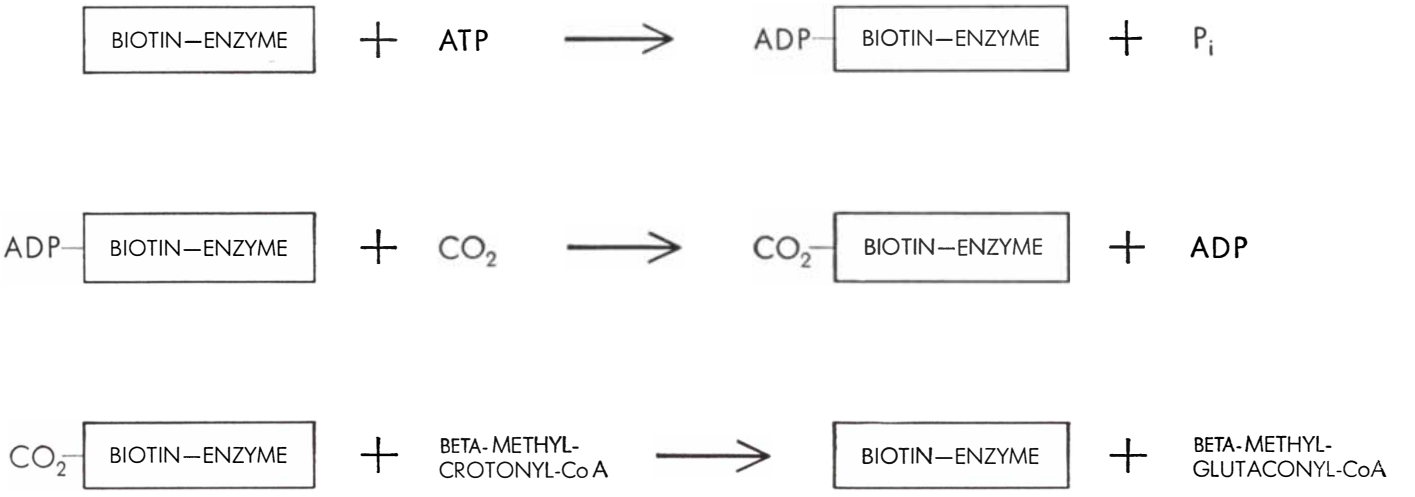


BETA-METHYL-CROTONYL-CoA

BETA-METHYL-GLUTACONYL-CoA

CARBON DIOXIDE TRANSFER is effected by an enzyme that contains biotin. Adenosine triphosphate (ATP) supplies energy for many cellular reactions. The biotin-enzyme directs the union of carbon dioxide and beta-methyl-crotonyl-CoA to give beta-methyl-glutaconyl-CoA, adenosine diphosphate (ADP) and inorganic phosphate (P_i). Proposed details of this reaction are shown below.



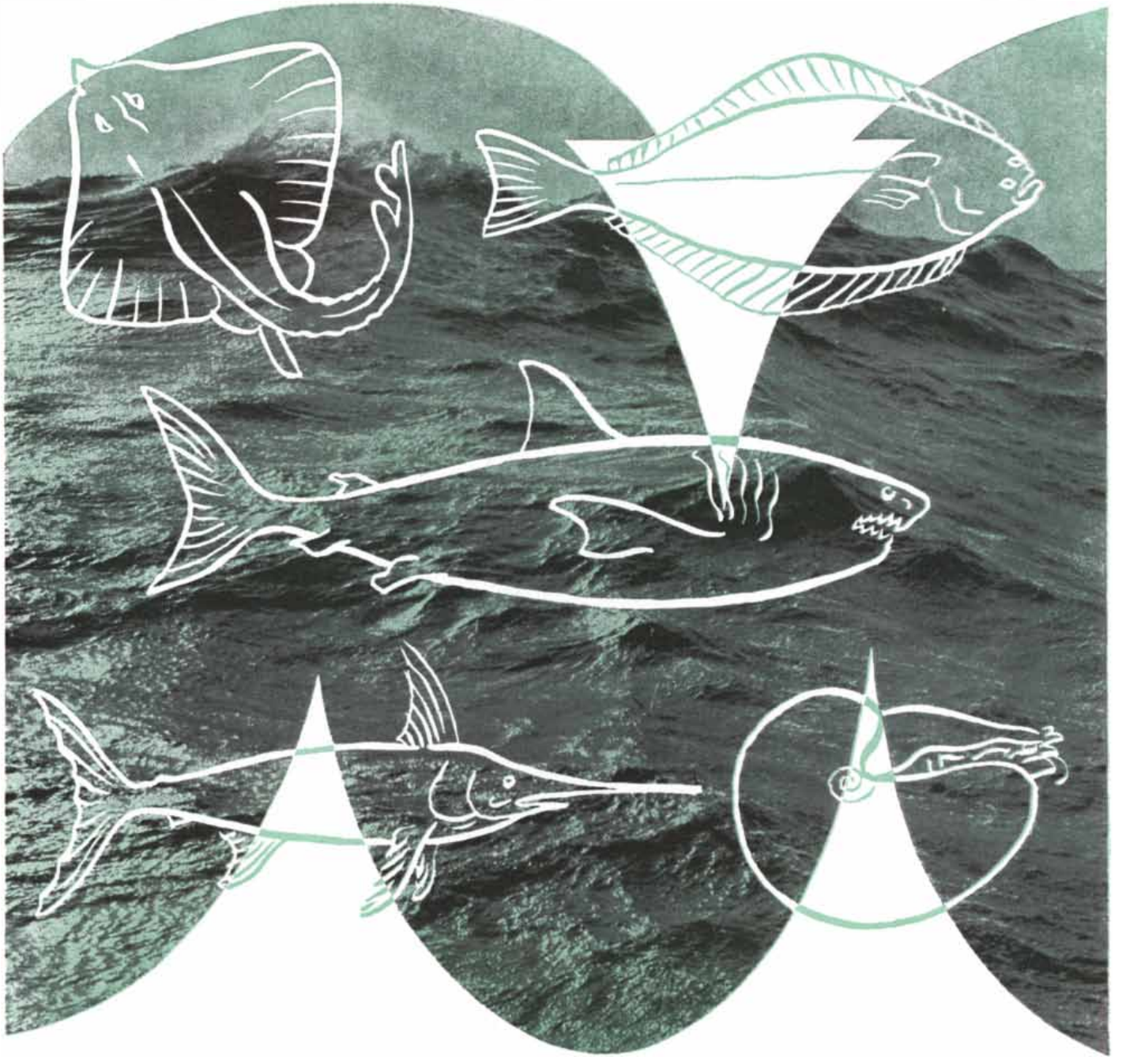
PROPOSED SEQUENCE OF REACTIONS to account for the transfer of carbon dioxide is diagramed. In the first step ATP reacts with the biotin-enzyme. In the second step carbon dioxide combines with the biotin-enzyme. The carbon dioxide is transferred to beta-methyl-crotonyl-CoA in the third step, producing beta-methyl-glutaconyl-CoA. CoA is an abbreviation for coenzyme A.

of the vitamin for a concerted attack on its chemical structure. Du Vigneaud and others proceeded to dissect the molecule and by 1942 were able to write its complete structural formula [*see illustration on page 140*]. The next year Stanton A. Harris and his colleagues at the research laboratory of Merck & Co., Inc., clinched this part of the problem when they synthesized a substance with the proposed structure. It was identical with natural biotin, both chemically and in its physiological action.

So closed a most satisfying chapter in biological research. Bios II*b*, coenzyme R, protective factor X, vitamin H and biotin had been shown to be the same substance—an essential preliminary to any attempt to understand its biochemical function.

Today biotin is known to be very widely distributed. In fact, it is probably an essential constituent of all living cells, both plant and animal. Yet its potency is so great that no cell contains more than a trace of it. Liver, one of the richest sources, contains less than one part of biotin per million. Kögl spent five years accumulating 70 milligrams of the crystalline material. He estimated that he would have needed 360 tons of yeast or about $175,000 worth of eggs (1937 prices) to extract one gram.

Kögl's refined material was not free biotin but its methyl ester, in which the final hydroxyl (OH) of the carboxyl group (COOH) is replaced by a methyl group (CH_3). In tissues biotin is also often found in combination with other compounds rather than free. Proteins are a common partner, and the compounds the two substances form have been named bioto-proteins. The toxic material in egg white is the protein avidin. It combines with biotin in a complex that the digestive enzymes of higher animals cannot split apart and that is



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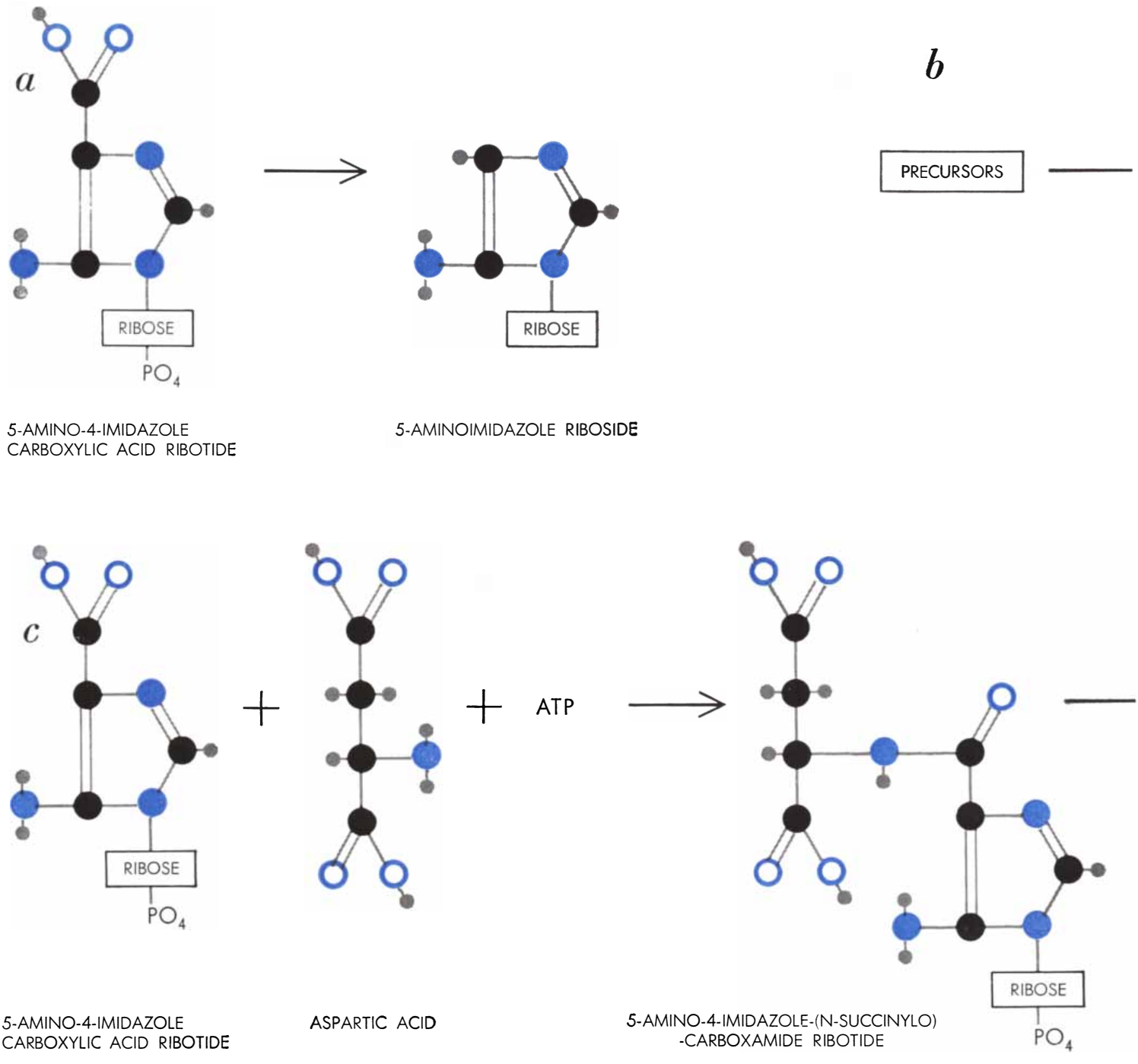
not absorbed from the alimentary canal. Thus raw egg white exerts its toxic action by inducing a deficiency of biotin. Cooking or any heat treatment denatures avidin, destroying its power to combine with biotin. Moreover, the avidin-biotin complex readily breaks down when it is heated.

Under normal circumstances human beings and other mammals do not suffer biotin deficiency even when the vitamin is eliminated from the diet. The intestines contain bacteria that synthesize biotin for themselves and incidentally for their host. Therefore the deficiency can be induced in test animals only by feeding them avidin or by eliminating the intestinal flora with antibacterial drugs. Using these techniques various workers have studied biotin deficiency in many species of higher animal, including rats, mice, hamsters, dogs, cattle, pigs, monkeys and even man. A biotin-free diet alone can induce deficiency symptoms in chickens, presumably because of the low bacterial content of their alimentary tract.

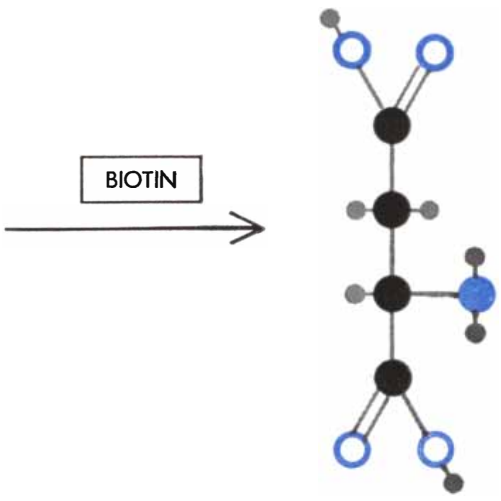
The precise symptoms of biotin deficiency vary from species to species, but skin lesions, dermatitis, loss of hair and nervous disorders usually characterize the disease. Human volunteers at the University of Georgia School of Medicine, put on a diet containing about half a pound of dried egg white a day, developed a scaling dermatitis and a peculiar

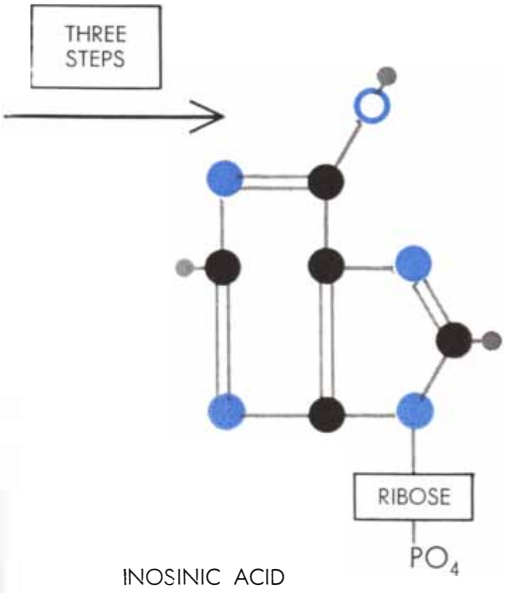


SYNTHESIS OF PURINES depends on biotin. When yeast is deprived of biotin, the synthesis stops with the intermediate shown at left in *a*. This, in turn, breaks down spontaneously to 5-aminoimidazole riboside, which accumulates in the culture medium. The stoppage is caused by a lack of aspartic acid, which is made with the aid of biotin (*b*). When biotin, or aspartic acid, is fed to

gray pallor. Lassitude, mental depression and muscle pains accompanied these symptoms. Administration of biotin promptly relieved the condition.

Of course, the observation of such gross effects cannot by itself elucidate the biochemical role of biotin. Experiments now under way in many laboratories, on a wide variety of cells and tissues, are directed at two fundamental problems: the precise function of biotin in the cell and the way in which it is





INOSINIC ACID

the yeast, the assembly line resumes. Inosinic acid, which is one of the purines, is the end product of this particular process.

synthesized by the organisms that manufacture it.

One difficulty in understanding how biotin works is that it seems to play a number of different roles. Almost all the other B vitamins, which are "cousins" of biotin, have been shown to have unique and specific functions at the cellular level. Biotin participates in many different biochemical reactions and transformations: it helps convert carbon dioxide to carbohydrates; it acts in removing amino (NH_2) groups from certain amino acids and the carboxyl group from certain other organic acids that are key intermediates in the breakdown of carbohydrates; it plays an essential part in the synthesis of aspartic acid and of fatty acids; there is evidence that it is involved in glucose oxidation and the metabolism of pyruvic acid. The list shows that biotin participates in the metabolism of the three principal constituents of living organisms: carbohydrates, fats and proteins. This apparent diversity of function suggests that biochemists have been unable to see the forest for the trees. The role of biotin may be more subtle than has been supposed. Perhaps the vitamin acts to synthesize specific enzymes rather than to assist in their chemical function, serving as a toolmaker rather than as a tool.

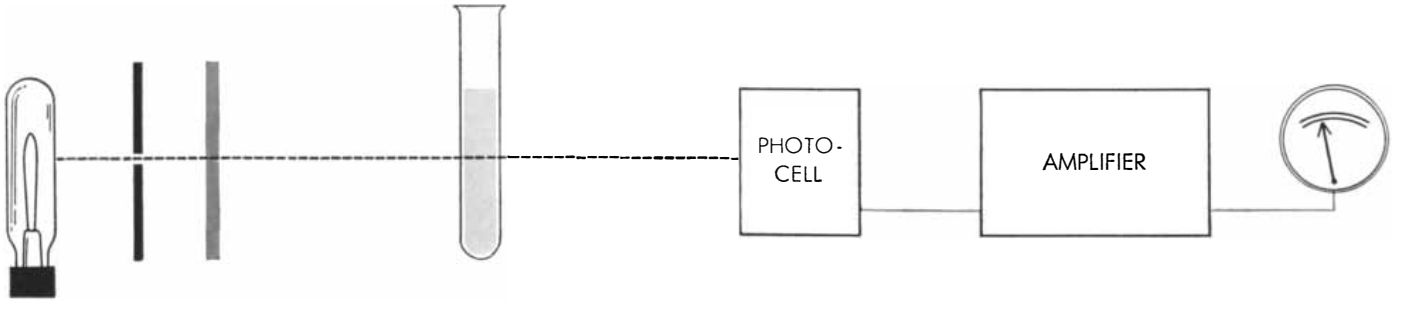
Some evidence for a fundamental role of this sort has come out of experiments in our laboratory at the University of Birmingham in England. In the course of investigation of biotin deficiency in yeast D. Peter Lones, Cyril Rainbow and I found an unexpected compound accumulating in the culture medium. It was a material now known to be an intermediate in the synthesis of purines by cells. The purines, essential components of nucleic acids and other cell constituents, are compounds having a common double-ring framework of carbon and nitrogen atoms [*see illustration on preceding two pages*]. Largely through the elegant studies of John M. Buchanan at the Massachusetts Institute of Technology and G. Robert Greenberg, then at Western Reserve University, each step in the biosynthesis of purines has been delineated.

About halfway along this cellular assembly line aspartic acid is incorporated into the growing framework of the molecule. Biotin-deficient yeast is unable to manufacture enough aspartic acid to keep pace with the purine assembly process. This results in a pile-up of the unfinished purine intermediate, which eventually spills out of the cells into the surrounding medium. If aspartic acid itself is included in the medium, the bottleneck is broken, the assembly line starts moving again and the intermediate compound no longer accumulates. Other recent work indicates that biotin can also function as a coenzyme, as Allison originally supposed. Whereas some of the enzymes for which biotin was once thought to be a cofactor have now been shown to be active without it, Salih J. Wakil at the University of Wisconsin has obtained an enzyme, involved in the synthesis of fatty acids, that does require the vitamin. The activity of the enzyme preparation is proportional to its biotin content. Moreover, the activity disappears with the addition of avidin and reappears when more biotin is added. A similar biotin-containing enzyme has been described by Feodor Lynen of the Max Planck Institute for Cell Chemistry in Munich. Both this enzyme and Wakil's seem to effect the uptake of carbon dioxide through the intermediate formation of an active "carboxylated" biotin. Lynen has provisionally identified such an intermediate, in which carbon dioxide is attached at one of the nitrogen atoms of the biotin molecule. He suggests that there are many biotin-containing enzymes that transfer carbon dioxide in different reactions.

W. Traub of the University of London has suggested a mechanism by which the nitrogen atoms in the biotin molecule may be enabled to participate in these reactions. Examining the spatial arrangement of the molecule, he found that under certain conditions the keto (C-O) oxygen of the ring and one oxygen of the carboxyl group in the side chain may come close enough to each other for a special kind of intramolecular bond—the hydrogen bond—to form between them. This would distort the molecule in such a way that it would increase the chemical reactivity of the nitrogen atoms in the ring.

As for the synthesis of biotin by living cells, the process has not yet been traced very far. The immediate precursor of the vitamin is probably desthiobiotin, which lacks only the sulfur atom of the biotin molecule [*see illustration on page 140*]. Part of the carbon skeleton is thought to be supplied by pimelic acid, a seven-carbon compound. In fact, pimelic acid acts like biotin in certain microorganisms and stimulates the production of biotin in others.

Here matters stand as these lines are written. The story, which nicely illustrates the trend in modern biology, began with the recognition of an undefined principle in brewer's wort and it closes with the consideration of individual atoms in a precisely known molecular structure. There is still a lot to learn, and biotin is very much a "hot" topic today. By the time this article is published the chances are that someone will have made a further important contribution to the understanding of this unfamiliar but vital substance.



MICROBIOLOGICAL ASSAY OF BIOTIN employs cultures of yeast cells. It can detect a biotin concentration of only one part in 500,000 million. More yeast cells appear in a culture as the concentration of biotin rises, making the suspension more turbid. A light (*left*) shines through a diaphragm, a filter and the culture in the test tube until it hits a photocell, which detects changes in light intensity. The amount of light transmitted by the culture registers on the ammeter at right, giving the measure of the concentration of biotin. With a compound as active as biotin such a method of quantative measurement is essential to the understanding of its functions.

AUTOMATIC SKY FIGHTER. Supersonic Boeing BOMARC is U.S. Air Force's push-button defense weapon against airborne missiles and attacking bombers. New "B" models have scored test intercepts up to 446 miles from base at altitudes of more than 100,000 feet, establishing new surface-to-air defense missile records for range and altitude. BOMARC A models are now operational at five U.S. Air Defense Command bases. B models will be installed at six bases in the United States and two in Canada.

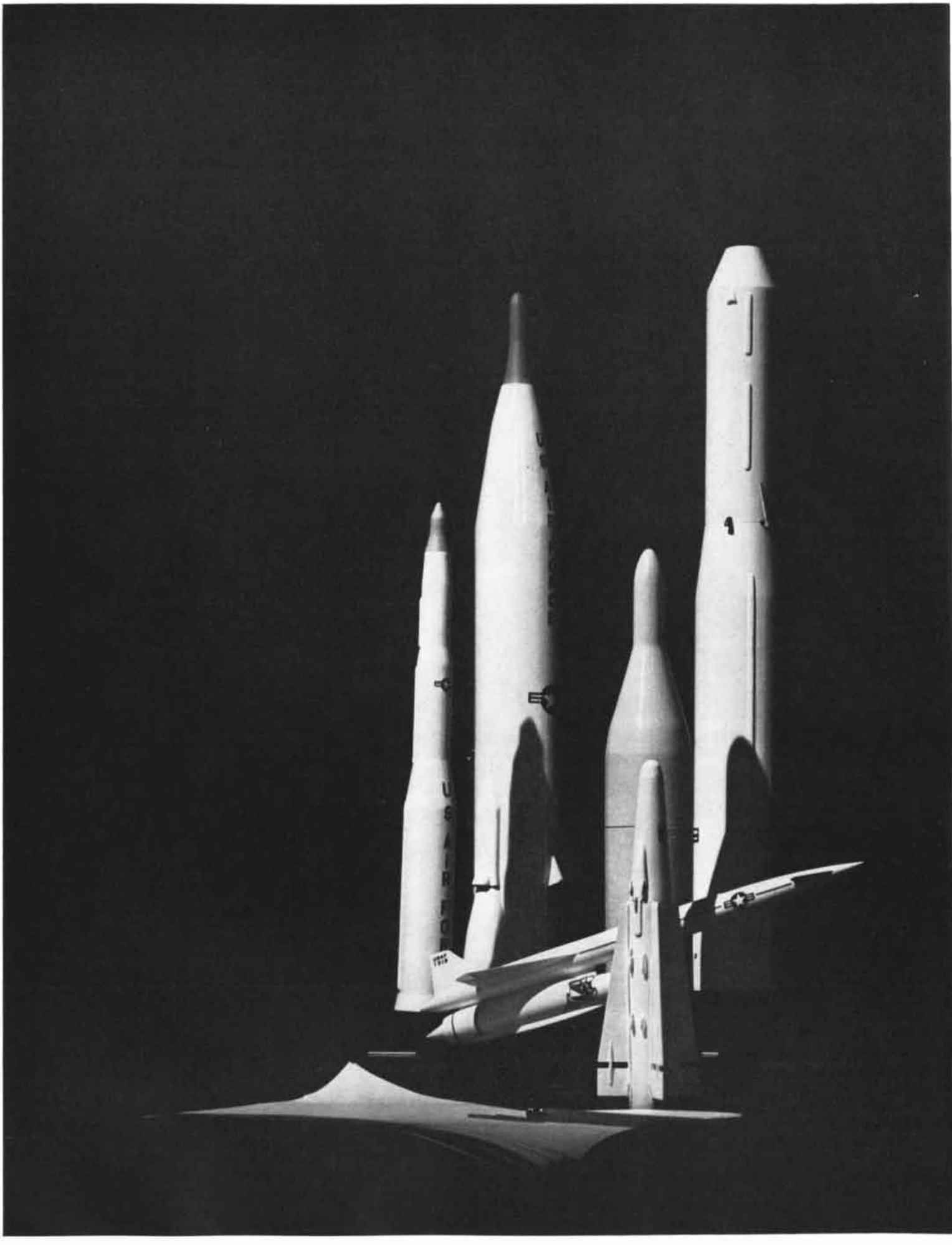
Capability has many faces at Boeing

WIND SONDE, developed by Boeing subsidiary, Allied Research Associates, will measure wind direction and velocity at wide range of altitudes, telemetering data back for instant use at missile launch ranges, other weather stations.

SPACEMAN'S BLAST-OFF. Boeing Space Medicine researcher prepares for simulated blast-off, wearing belt of Boeing-developed miniature electronic instruments which measure reactions to stresses imposed by take-off of space vehicles.

JET-PROPELLED TEST BOAT, now being built for Boeing, will be used to test experimental surface and subsurface marine vehicle designs at speeds up to 100 knots. Test models will be suspended between two forward hulls. Test boat will supplement Boeing tow-tank research in advancing knowledge in area of hydrodynamics.

BOEING



Where does Hughes fit in the missile picture?

The modern missile ranks as one of man's most ambitious achievements. To design and build an efficient missile requires a wide range of skills — many of which did not even exist a few years ago.

Today, many firms are pooling their special abilities to speed the development of more effective missiles.

Hughes is active in a number of these team projects, as well as in the production of complete missile systems. Here are some examples of Hughes' current missile work:

POLARIS—Hughes is a prime contractor for the production of complete guidance systems for the Navy's sub-launched ballistic missile and is a subcontractor for the fire control system.

FALCON—With both radar and infrared guidance systems, the Falcon family of missiles has demonstrated amazing accuracy and reliability. To date Hughes has delivered to the U.S. Air Force over 30,000 of these high performance air-to-air missiles. And Hughes recently began production on a new nuclear Falcon missile.

SIDEWINDER—This Navy air-to-air missile will carry Hughes infrared detector and cryostat systems in its most advanced models.

MAULER—A highly mobile anti-aircraft and anti-missile missile now being developed for the Army, the Mauler will have a Hughes designed guidance system.

TITAN—Hughes is manufacturing portions of the launch control systems for this Air Force giant.

Hughes is also under contract to investigate the application of Versatile Automatic Test Equipment (VATE) for the guidance systems on the *MINUTEMAN*, *SKYBOLT*, *ATLAS*, *TITAN* and *HOUND DOG* missiles.

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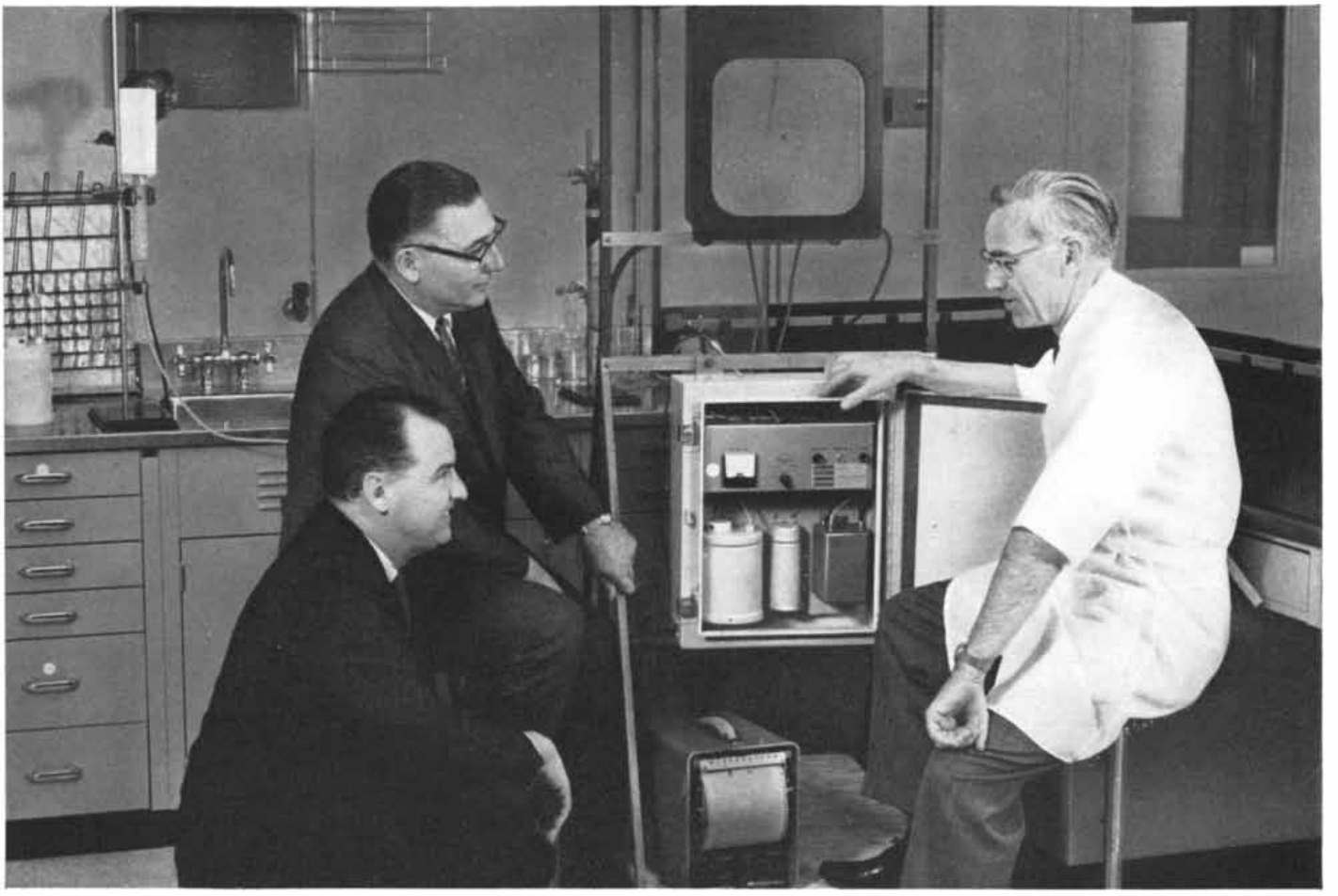

Checking performance of a nitrogen tetroxide OLFACTRON (center unit): Dr. R. R. Austin (right), with Mr. D. S. Barlow, Vice President (left), and Mr. L. M. Ballard (center) of the Instrument Division.

A Report from American Systems Incorporated...

Exotic Propellant Vapor Detection

As a major step in its program of developments for the aerospace field, American Systems Incorporated is introducing a new type of instrument for detection of toxic propellant vapors. Called OLFACTRONS because they act like an electrochemical "nose," quantitatively measuring vapors in amounts too slight to be detected by human senses, these instruments increase safety and effectiveness in handling high-energy propellants.

In the OLFACTRON principle, the vapor sensed produces a proportional electric current, which in turn is indicated on a meter, or recorded. The instruments are fast-acting, and can be integrated easily into electronic warning systems. OLFACTRONS are now available for detection of hydrazine, UDMH, nitrogen tetroxide, and borane. Similar instruments for detection of sulfur, hydrocarbons, and moisture are in production for the natural gas, LP gas, petrochemical, and chemical industries.

Developed by Dr. Robert R. Austin and Myron L. Robinson, in association with the Instrument Division of American Systems, OLFACTRONS illustrate the systems influence in practical instrumentation design. The instruments are adaptable to system networks involving communications, computation, and data processing.

Complementing the work of the Instrument Division, technical programs are under way in six other Divisions:

INFORMATION SCIENCES
Mathematical and statistical research; computer programming, and advanced programming systems; computation services; digital system studies; logical design; advanced systems analysis.

DATA PROCESSING
Data processing subsystems research and development; logic of command and control complexes; optical recognition systems.

ELECTROMAGNETIC SYSTEMS
Electromagnetic physics; electronic and mechanical scanning antenna systems; development and manufacturing of complete sensor systems and special microwave components.

RESEARCH LABORATORIES
Solid state physics and systems; magnetic thin-film research and subsystems; advanced components for information processing.

COMPONENT DEVELOPMENT
Advanced component technology; materials and processes; computer component development; chemical deposition of magnetic surfaces on drums, disks, rods.

AUDIO-VISUAL
Audio-visual (INSTRUCTRON) devices for assembly line and instructional applications; production of work stations designed on human factors principles.

Qualified scientists and engineers who are interested and experienced in these fields of activity are encouraged to investigate career opportunities with American Systems.

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The Airborne Magnetometer

A sensitive instrument that points the way to ore deposits and oil fields by detecting magnetic anomalies from the air has greatly broadened the scope of geophysical exploration

by Homer Jensen

In the past 20 years man has virtually completed the huge task of exploring the earth's surface for evidence of mineral deposits. In all the world only a few outcropping ore bodies can have gone undetected; most of the earth's remaining mineral resources lie beneath the surface. The discovery of raw materials has become to a large extent the job of geophysicists. Geophysics has long been important in the search for petroleum; since the end of World War II it has revolutionized mineral prospecting, helping to keep pace with the exponential rise in the demand for new resources. This revolution in exploration involves a number of methods of detecting buried or hidden deposits, but in the end it rests largely on one instrument—the airborne magnetometer—and related techniques that it has brought into use.

Mineral concentrations are associated to a remarkable extent with magnetic materials; hence significant distortions in the earth's magnetic field mark and identify much of the mineral wealth of the world. These distortions are meas-

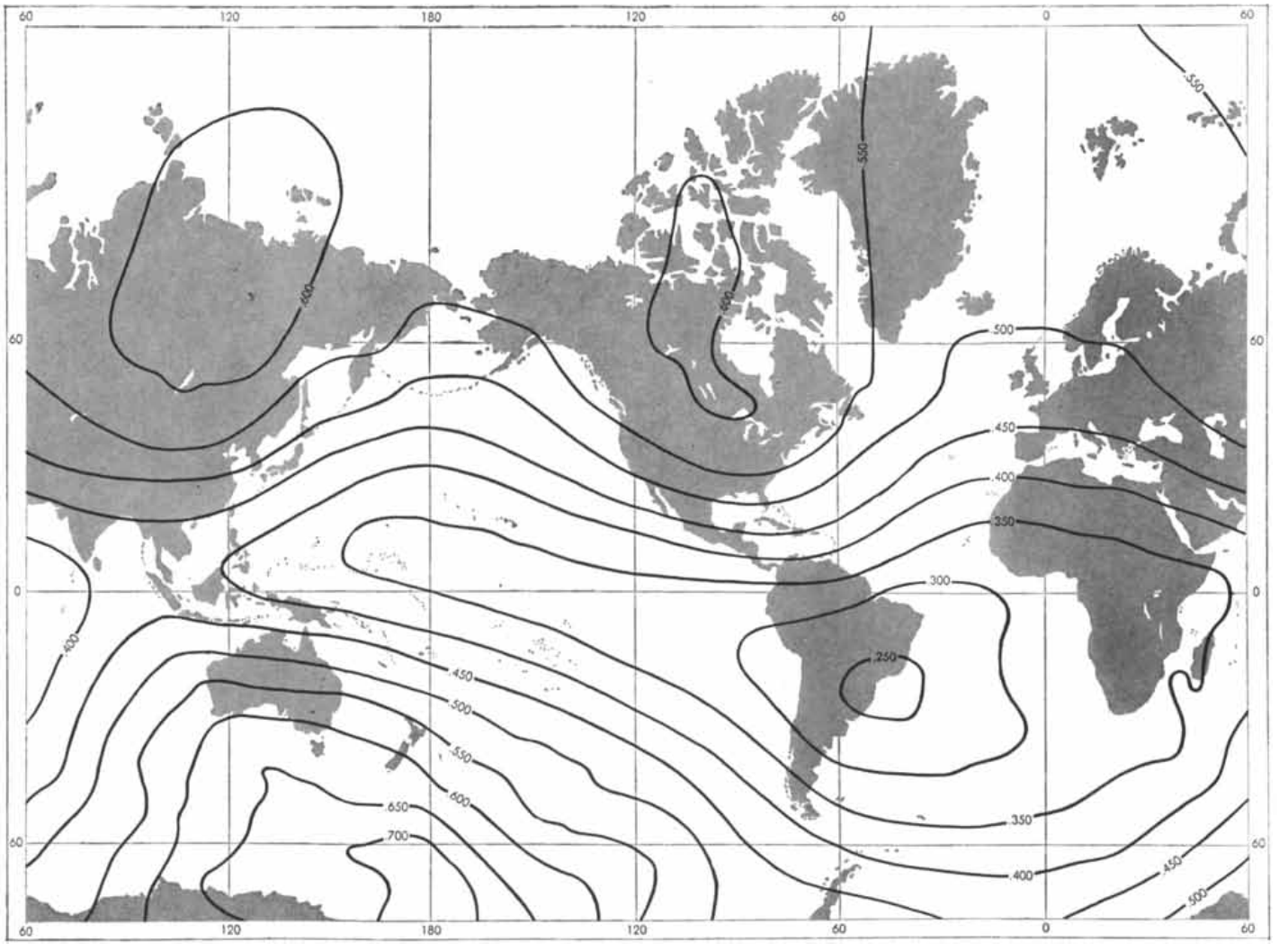
AIRBORNE MAGNETIC SURVEY is conducted over the thick jungle of Surinam in South America. The magnetometer is housed in the protrusion at the plane's tail. Speed, coverage and economy make magnetic surveys ideal for mapping vast undeveloped regions.

urable not only at the surface but thousands of feet in the air. The development of an instrument that can accurately measure variations in the earth's field from a moving airplane opened the way to exploration on a scale previously undreamed of. Surveys of entire geologic provinces and even whole nations are now economically feasible and can be carried out in years rather than decades. By itself the airborne magnetometer has already located deposits of ore worth billions of dollars. And it has delineated likely target areas in which more costly and detailed ground-based techniques have been justified.

Conventional geophysical methods, other than magnetic, have been employed for many years to detect the remote effects of the concentration of a mineral in an ore body. To take one example, massive ore bodies are often heavier than the surrounding rock, and their excessive mass produces anomalously high values of the force of gravity at the earth's surface above them. Very exact measurements of gravity, to an accuracy of at least one part in a million, give evidence of the ore. As a second example, copper, lead or nickel ore bodies conduct electricity more readily than the surrounding materials. Magnetic pulses transmitted downward from the surface induce electric currents in these bodies, and the currents in turn generate detectable magnetic fields. A third example depends on the fact that several metals normally occur in a mixture of isotopes, some of which are radioactive. If these deposits are near enough to the surface, counters pick up the gamma radiation of their radioactive decay. And finally, the acoustical properties of rocks vary with rock type or condition, so something of the shape and composition of buried bodies can be determined from an analysis of the passage of sound waves through the earth. This is the principle behind the seismic method, which is the basic tool in petroleum exploration.

All these geophysical methods are in current use, and their combined power is considerable. But most of them cannot be applied from a moving airplane. For example, the gravity meter cannot distinguish between the effects of motion and those of mass attraction; and when seismic vibrations pass from the ground to the air there is a prohibitive energy loss. The airborne magnetometer is completely free of these limitations. The magnetic field is unaffected by accelerations, and the magnetometer picks up significant signals that have passed through thousands of feet of rock, hundreds of feet of water and 1,000 feet of air. Whereas electromagnetic and radiation measurements are also made from airplanes, neither approaches the magnetic survey in the distance over which it is effective, in its ability to penetrate intervening strata and above all in the wide variety of diagnostic information it conveys.

The magnetic field of the earth is shaped, in the large, as if it were caused by a bar magnet that was about one-



TERRESTRIAL MAGNETISM is very weak, ranging from .25 to .7 oersted. (The field between the poles of a small horseshoe magnet is about 1,000 oersteds.) The earth's field varies from place to place on the surface, as shown by these magnetic contour lines.

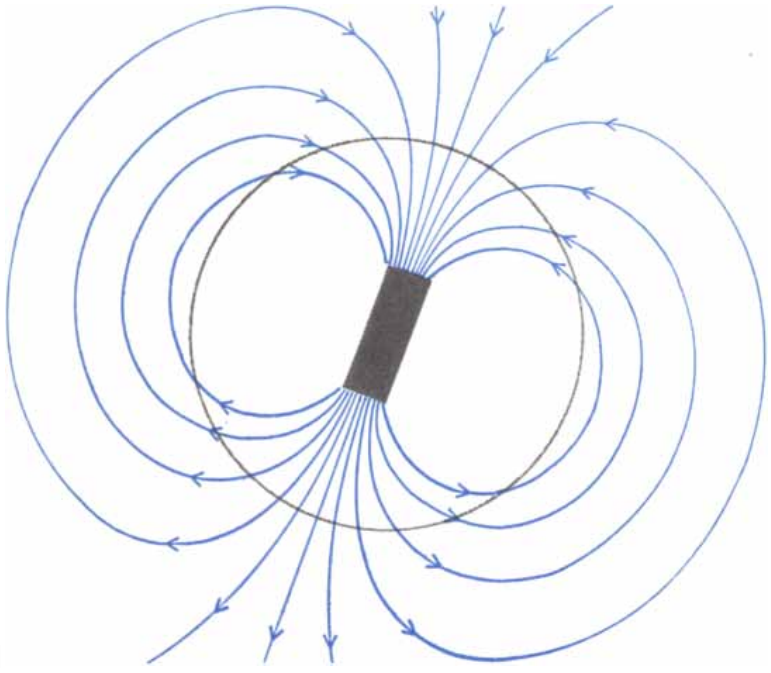
third of the earth's diameter in length, situated near the earth's center and canted about 20 degrees from the earth's spin axis [*see top illustration at right*]. The field is weak, varying from about .7 oersted at the magnetic poles to about .25 oersted at some points on the magnetic equator. (The field between the poles of an ordinary horseshoe magnet can exceed 1,000 oersteds.) In geomagnetic studies it is usually expressed in terms of a much smaller unit: the gamma, which is .00001 oersted, or about a fifty-thousandth of the earth's field in the vicinity of New York City.

Superimposed on this general pattern are regional irregularities caused by variations in the shape and composition of the earth's crust and upper mantle. On a smaller scale are the disturbances resulting from concentrations of magnetic material near the surface. In exploring for minerals these are the disturbances that the surveyor seeks.

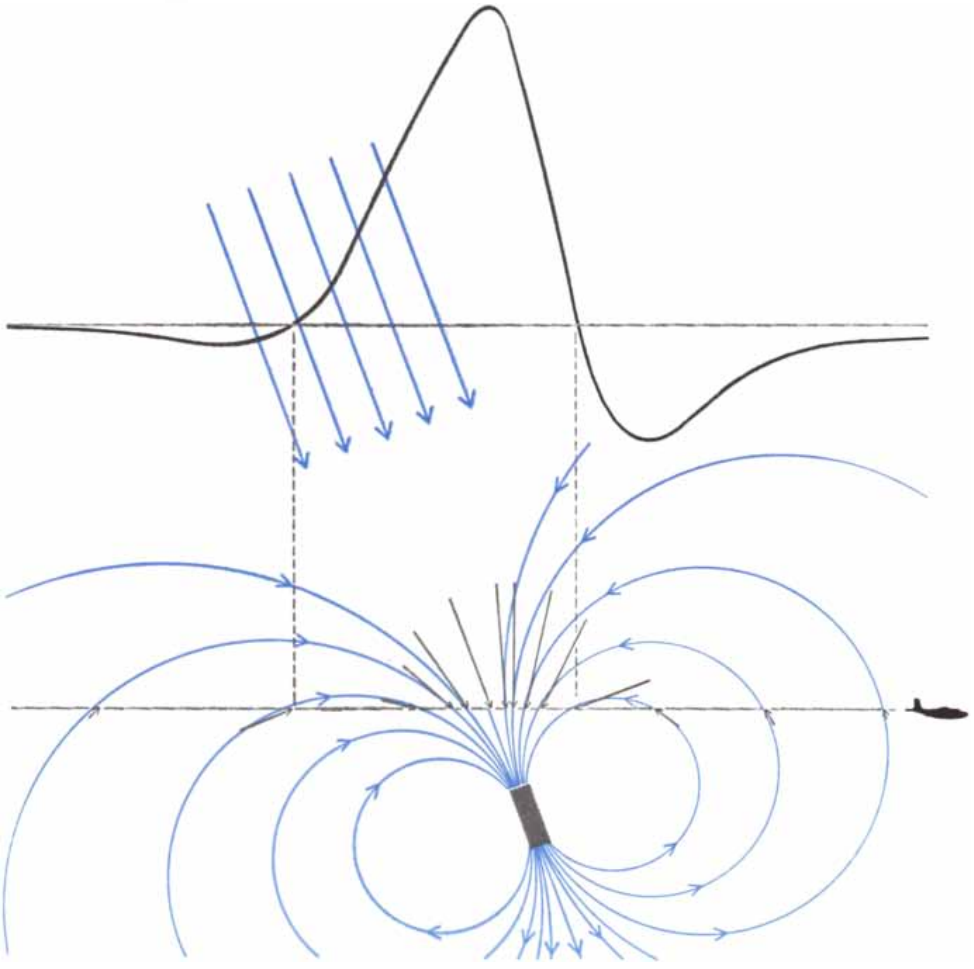
In general, near-surface variations in magnetic intensity are caused only by variations in the amount and condition of magnetite (Fe_3O_4, the ferrous oxide of iron) in the rocks. The magnetic susceptibility of magnetite is very much greater than that of any other naturally occurring substance, and in the earth's field any large amount of it will act like a magnet, seriously distorting the magnetic field [*see bottom illustration at right*].

High concentrations of magnetite, such as those in deposits of iron-ore quality, often produce changes of as much as 10 per cent in the strength of the normal field. Sometimes the anomaly is even larger than the normal geomagnetic field. These changes show as very obvious features on a magnetic map. A striking instance is provided by the Marmora ore body in southern Ontario, which contains perhaps 100 million tons of magnetite lying about 200 feet underground without any visible surface expression. It was discovered in 1949 solely on the evidence in an aeromagnetic map published by the Province of Ontario [*see illustrations on page 162*].

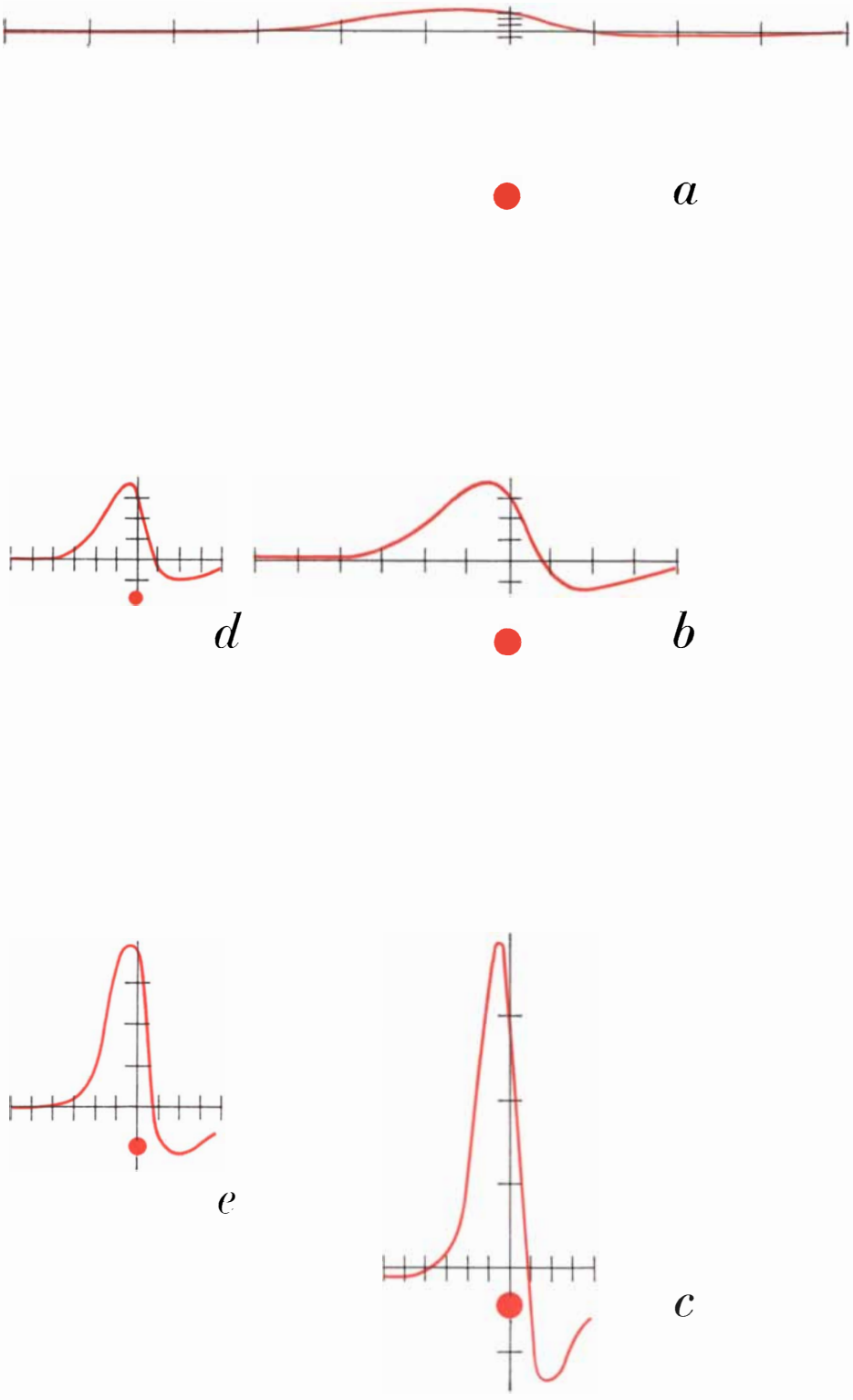
A good deal of iron is found as hematite (Fe_2O_3, or ferric oxide), which is only weakly magnetic. Almost always, however, some rock that is rich in magnetite is found near hematite ore and in a recognizable relationship to it. The great iron deposits of Minnesota's Mesabi Range, now nearly exhausted, consisted chiefly of hematite. But there was enough magnetite in the formations so that compass needles carried over the



EARTH'S FIELD, in the usual model based on measurements of magnetic intensity such as those on the map on the opposite page, is shaped as if it were caused by a bar magnet one-third of the earth's diameter in length and canted somewhat from the earth's spin axis. The lines of force curve from pole to pole through the earth and space. To measure the full field at any point on the surface, an instrument must be parallel to the lines of force there.



MAGNETIC SOURCE such as an ore body acts like a bar magnet buried parallel to the earth's field (*colored arrows*). It has its own lines of force (*colored curves*), the vectors of which (*short black arrows*) add to or subtract from the intensity of the earth's field, depending on their direction. As a result there is an anomalous magnetic field over the buried source, which is recorded as a characteristic curve (*shown in black*) by the magnetometer.



CHARACTERISTIC CURVES of magnetic anomalies are the same shape at a given latitude but vary in dimension with the strength of the source and depth below the magnetometer. For a cylindrical source the horizontal extent of the curve varies directly with the depth; the vertical amplitude, directly with the strength and inversely with the square of the depth. In these examples *a*, *b* and *c* are sources of the same strength buried respectively at depths of four, two and one units. Sources *d* and *e* are buried at the same depth as *c* but are respectively 1/4 and 1/2 as strong. The reasoning from curve to description of source might go like this: The horizontal extent of curve *e* is 1/2 that of *b*. Hence the depth of source *e* must be 1/2 that of *b*. If the strength of the two sources were the same, the amplitude of curve *e* would be four times (the inverse square of the depth factor) that of *b*. But the amplitude of curve *e* is only twice that of *b*, so the strength of source *e* must be 1/2 the strength of *b*. Moreover, while curves *d* and *b* have the same amplitude, the depth of sources *d* and *b* can be differentiated by the horizontal extent of the two curves.

surface of the region acted erratically. As a result the original surveyors of the region established some very peculiar boundary lines. If anyone had had the foresight to buy land in Minnesota's "crooked townships," he would have owned most of the Mesabi Range.

Because of the relationships between magnetite and the less magnetic iron ores, the magnetometer has almost universal applicability in iron exploration. Magnetite also adjoins many other types of deposit and in high concentration it is recognized as a broad-spectrum symptom of mineralization. Among the substances to which it can frequently lead the way are asbestos, sulfur, lead, nickel, copper, gold, titanium and chromium.

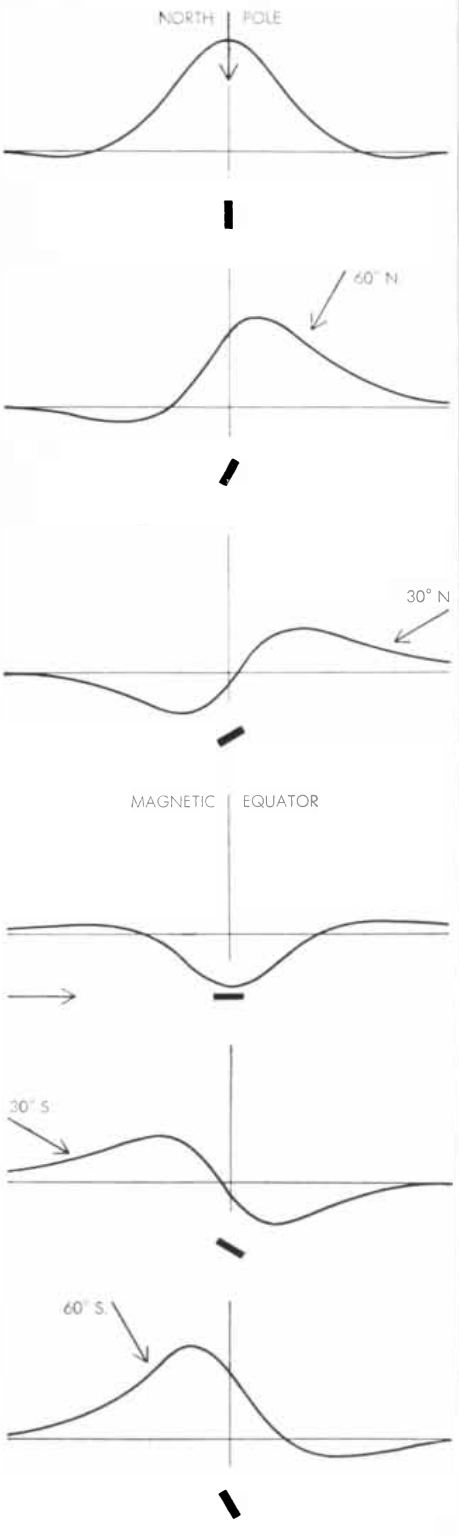
Even in the absence of large deposits the geomagnetic field varies from place to place with the composition and structure of the uppermost igneous or metamorphic rocks. The magnetite present in low concentration in these rocks serves as an indicator of subsurface geological formations. Where sediments overlie the magnetic basement rock, the sedimentary layers contribute little or nothing to the magnetic fluctuations, since they generally lack magnetite. Thus when the sediments are thicker, the magnetic surface is lower and the magnetic variations are weaker. The breadth and flatness of the magnetic record indicates the distance down to basement rock—in other words, the thickness of the sedimentary layers. The detailed shape of the fluctuations provides evidence of faulting and other geological features.

Oil is found only in sedimentary layers, and it is usually associated with specific sedimentary structures that can be inferred from knowledge of the underlying basement. As a result magnetic surveys pick out formations that are likely to contain oil. With the search for petroleum extending more and more into jungle, desert and the ocean floor, the airborne magnetometer—although it cannot sense the presence of oil directly—has served as a fundamental tool in oil exploration for the past 15 years.

Sensitive and accurate magnetometers have existed for a longer time but not in a form suited to operation in an airplane. In the type of magnetometer most commonly employed for ground surveys the force that the earth's field exerts on a magnet is precisely offset by a sliding weight on a balance arm. Obviously such an arrangement would never work if the weight were subjected to forces from random accelerations such as those encountered in an airplane. An-

other device, called the earth inductor, measures the field by the voltage it induces in a rotating coil of wire. Here too the irregular motions of an airplane are a serious problem because the induced voltage changes with different positions of the coil in relation to the field.

In the 1930's C. W. La Pierre of the



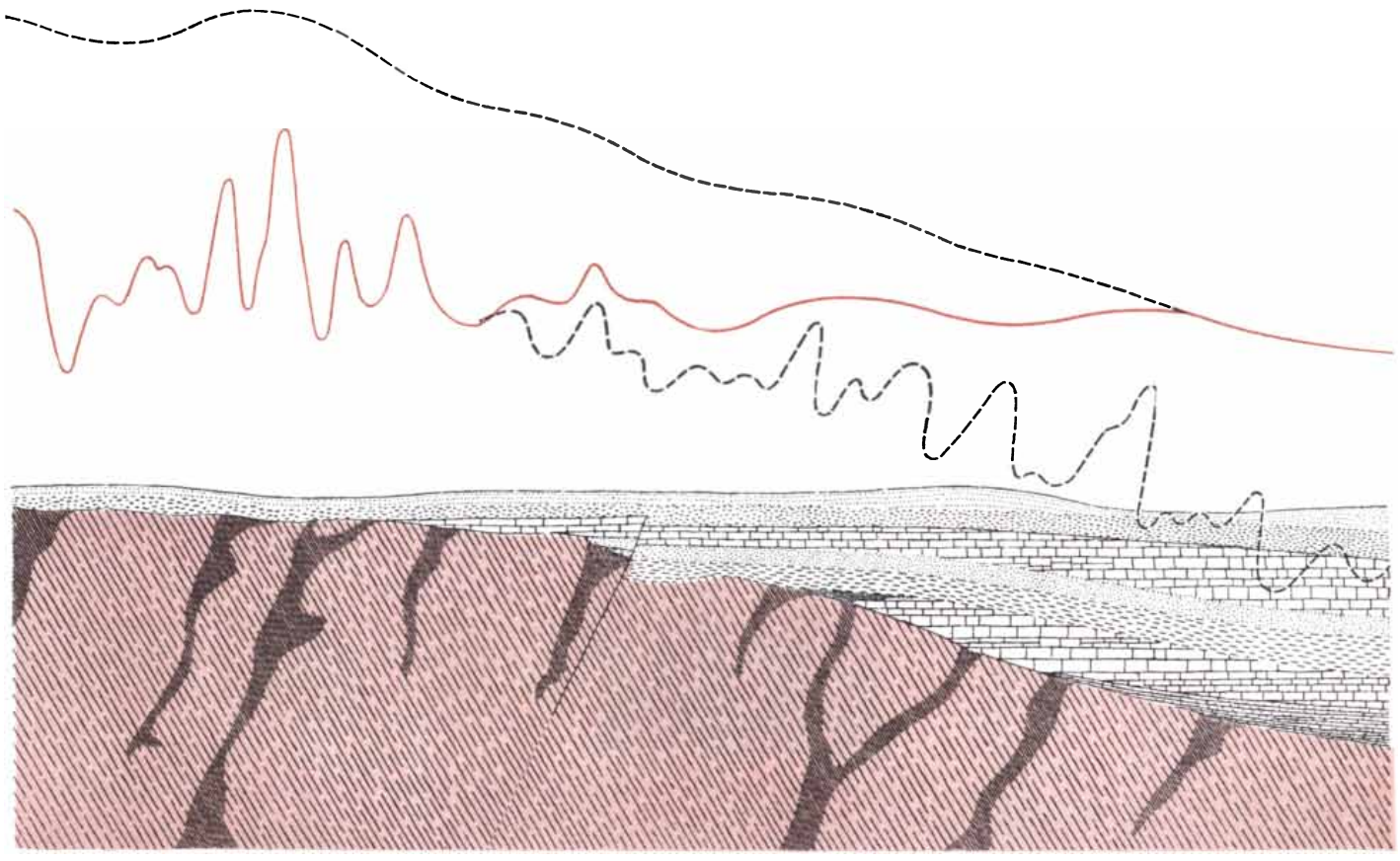
SHAPE of the curve of a magnetic anomaly varies with the direction of the earth's lines of force and therefore with latitude. South Pole curve would match the North Pole's.

General Electric Company, and also some workers in Germany, adapted an electromagnetic circuit known as a flux gate to the accurate measurement of magnetic fields. Shortly before World War II, in the laboratories of the Gulf Research and Development Company, Victor Vacquier, Gary Muffly and R. D. Wyckoff improved the sensitivity of the flux gate and invented a method of stabilizing it against the motions of an aircraft in flight. Foreseeing that an airborne magnetometer could be used to locate submarines, they informed the Government of their work and under contract built a prototype magnetometer for submarine detection. Further development at the Airborne Instruments Laboratory of Columbia University produced a successful submarine detector, the ASQ-1. Working at the Bell Telephone Laboratories under another Government contract, E. P. Felch, W. J. Means and T. Slonczewski produced a second successful instrument, which was modified at the request of the U. S. Geological Survey for geophysical operations. With this equipment J. R. Balsley of the Geological Survey, pilot Ed Canfield of the Aero Service Corporation and the author made (in April, 1944, near Boyertown, Pa.) what we believe to be the first high-sensitivity airborne geophysical survey. The results were promising; they narrowly missed being sensational. If we had flown 10 miles farther we would have found at Morgantown, Pa., what is now known to be one of the biggest iron deposits in the U. S. This deposit was discovered by an aeromagnetic survey made five years later.

The flux gate, the sensing element of the magnetometer, consists essentially of a pair of parallel coils so arranged that they produce a voltage when they are placed in a magnetic field that has a component along their axes [*see middle illustration on page 160*]. In a given field the voltage varies from a maximum when the axis of the flux gate and the field are parallel to zero when they are perpendicular. In geomagnetic measurements, therefore, the device must be accurately aligned with the earth's field to ensure measurement of the total field.

To accomplish this in a moving airplane the modern magnetometer uses the field itself as a reference. Three flux gates with mutually perpendicular axes are mounted on a platform that is free to swivel in any direction. Two of them maintain themselves perpendicularly to the field, thus keeping the third one aligned parallel to it. The instrument has no independent means of sensing its own position, so it measures only the strength and not the direction of the field.

Each of the first two flux gates is connected to a servomotor. Any voltage from the element causes its motor to turn it in a direction that decreases the voltage. Hence it is held in the position of zero output, perpendicular to the field. In the third, or measuring, element a solenoid surrounds the sensing coils. A servomechanism controls the current through this additional winding, holding it at a value that brings the output of the flux gate to zero. This means that the magnetic field of the solenoid exactly cancels the earth's field. The nulling cur-



BASEMENT-ROCK PROFILE is delineated by the magnetometer record. Igneous and metamorphic basement rock (*colored area*) is magnetic in varying degrees, so it produces a fluctuating signal. The fluctuations are flattened out by distance even if sedimentary layers (*gray layers*) intervene, because sediments are nonmagnetic. A flight following the basement rock at a high altitude would produce a flat curve (*broken line at top*). A record made by an instrument following the basement lower down would fluctuate all the way (*left-hand portion of colored line as extended by lower broken line*). The actual record (*colored line*) made in level flight varies in flatness with the basement's depth below the surface. Analysis of the actual record determines the thickness of the sediments.

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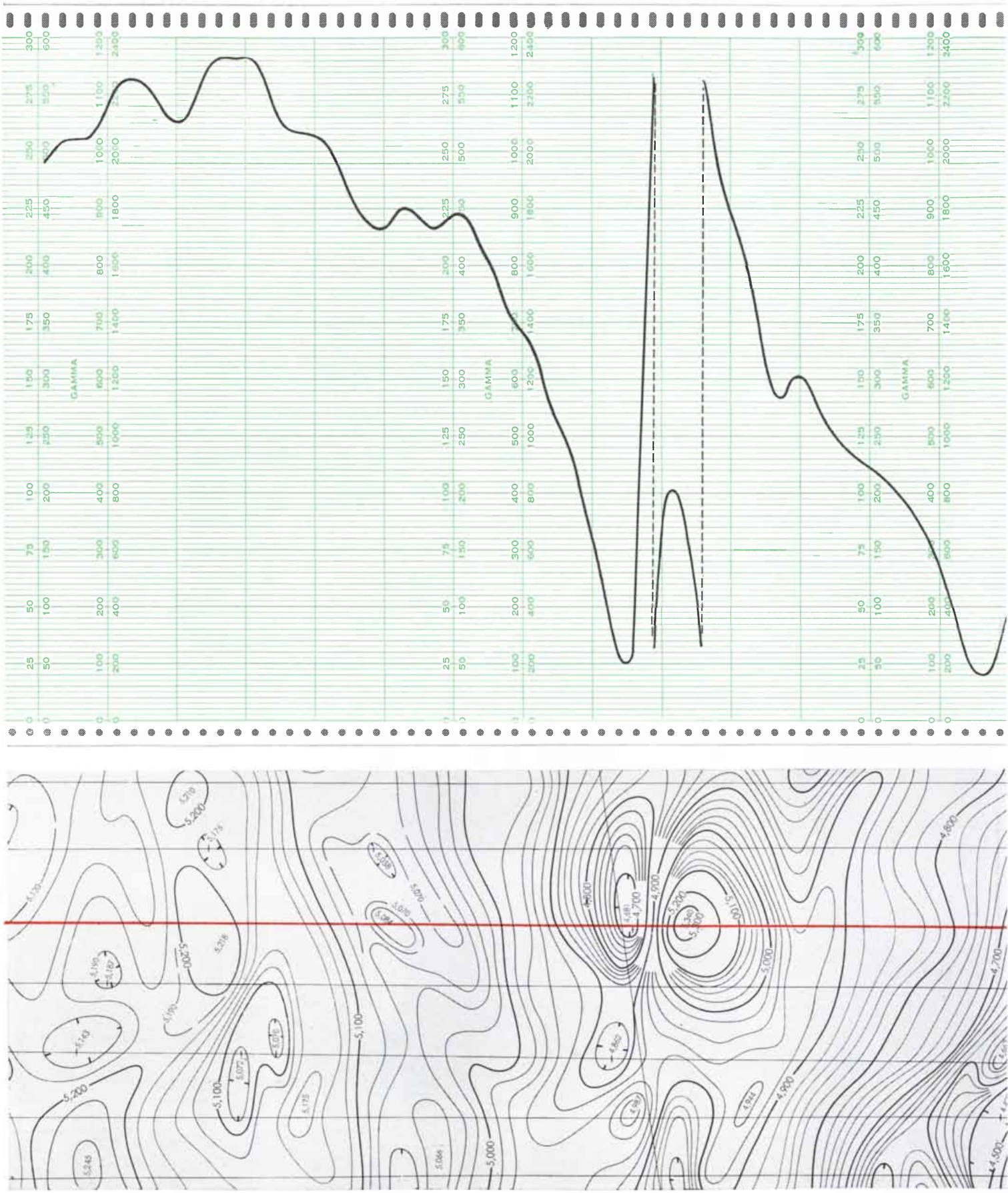
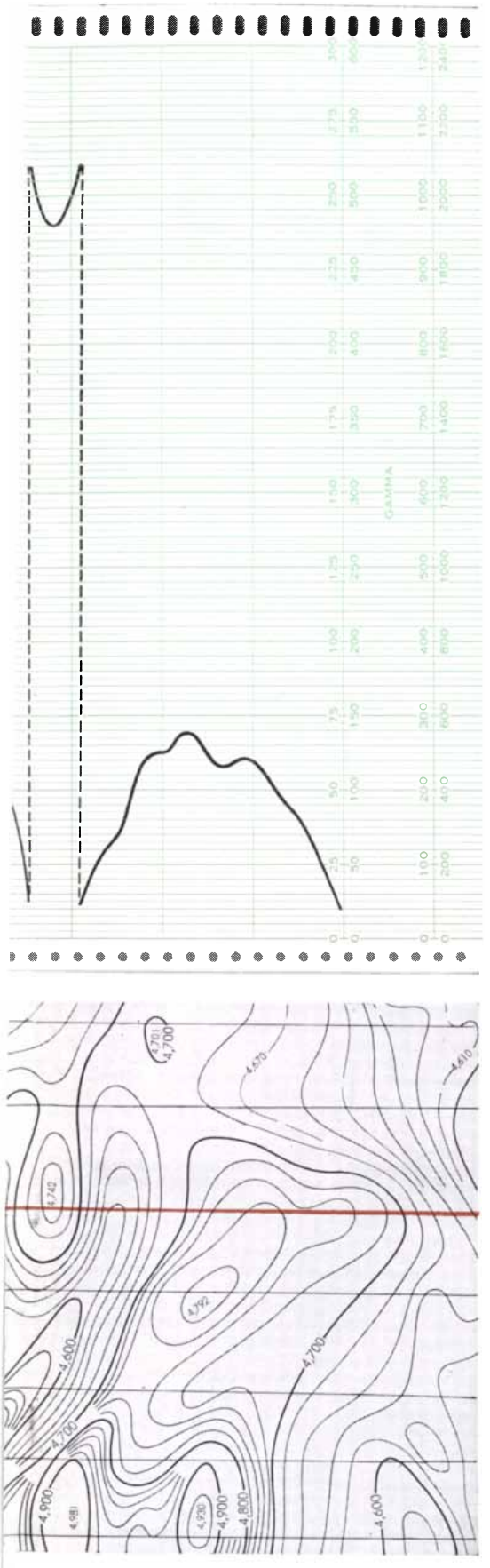


MAGNETOMETER RECORD (*top*) is shown here together with the contour map made from it. The record is in the form of a continuous curve drawn by a pen on a moving sheet of chart paper. The vertical scale on the chart is in gammas. (One gamma is .00001 oersted.) The operator selects and sets on the recorder the scale he wants to use, in this case the one in which 600 gammas is the top value. When the magnetometer records a particularly large peak or depression, automatic offsets (*broken lines*) are introduced to keep the curve on the chart. The magnetometer chart is correlated with aerial photographs so each point on the chart can be identified with a point on the ground. To make a contour map, segments of the record corresponding to particular flight lines laid



out on the map are identified. This one is for the flight line shown in red. Then the values indicated on the chart are transferred to the corresponding points on the map. The peaks and depressions of the record show up as magnetic "hills" and "valleys" on the map.

rent therefore measures the earth's field, which is recorded directly in gammas. Present versions of the flux-gate magnetometer are sensitive to variations of half a gamma to two gammas. (The nails in a shoe produce a one-gamma signal at five feet.)

In the past few years magnetometers have been developed that are more sensitive than the flux-gate device and require no mechanical stabilization. One is the proton-precession magnetometer, in which the sensing elements are spinning hydrogen nuclei, or protons, which precess, or wobble, around lines of force in the earth's magnetic field. The frequency of precession depends on the strength of the field, and the frequency can be measured. Although nuclear instruments of this and other types now find some application in magnetic surveying, the flux gate seems likely to remain in wide use for some years. Its performance is well matched to the limitations imposed by unavoidable "noise" in the measurements, arising from daily changes in the earth's field, uncertainties in the position of the airplane and so on. The newer instruments are nonetheless accurate, well adapted to telemetering their information and capable of operating in very small fields, and they do not require precise orientation. These advantages have led to their extensive use in satellites and space probes for the measurement of magnetic fields.

Putting a magnetometer of any sort in an airplane poses a special problem: avoiding interference by the magnetic fields of the airplane itself. In the early days the instrument was simply placed out of reach of the fields. It was towed about 100 feet behind the plane in a bomb-shaped housing, or "bird." This led to as many problems as it solved, however, and now the magnetometer is usually mounted at the wing tip or just behind the tail.

Compensating for the stray fields caused by various parts of the plane calls for a high order of ingenuity. Magnets strategically placed in the instrument housing cancel the effect of every piece of metal in the plane that is permanently magnetized. The earth's field induces magnetism in other iron parts; this is offset by Permalloy strips, in which the earth's field induces an equal and opposite effect for every orientation of the airplane. Finally, the earth's field induces electric currents in the airplane's aluminum skin when the plane turns, and these give rise to still further magnetic disturbances. They are compensated by arrays of nonmagnetic conducting sheets.

In aerial surveying the magnetometer is flown back and forth at a fixed altitude along a series of predetermined flight lines. These are generally chosen to run at right angles to the main trend of geological features, and they are parallel to each other at intervals of a quarter of a mile to a mile. As the survey progresses, the base value of the magnetometer may drift and the earth's field changes in strength. Accordingly the surveyor also flies a number of control lines across the pattern, rapidly obtaining a set of second readings at the intersections with the flight lines. These values are used to correct for drift in the instrument and the field.

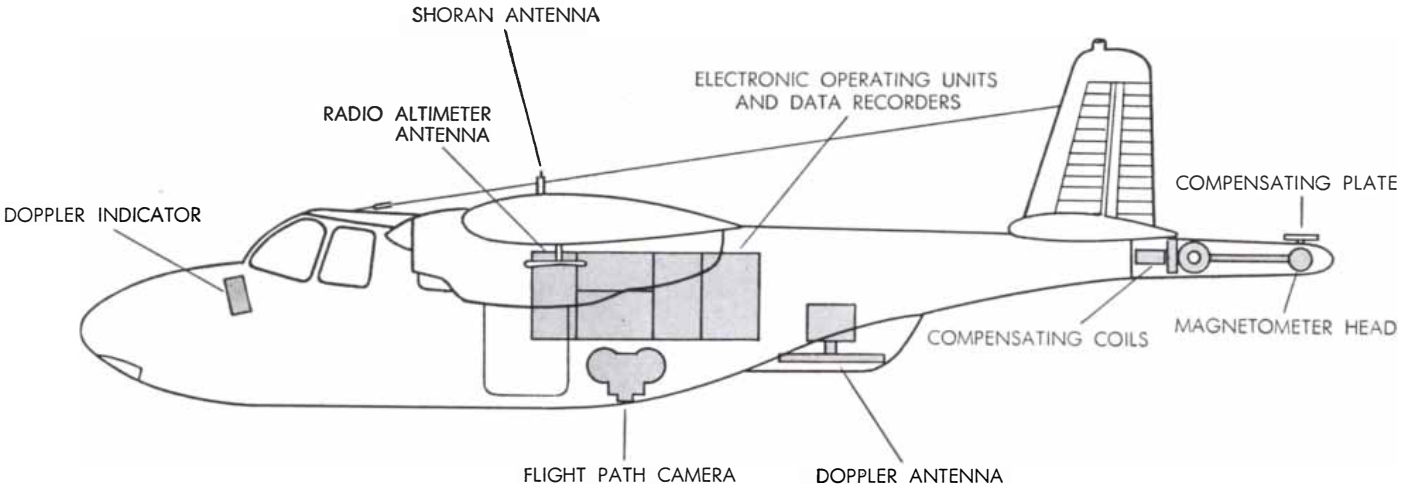
In some localities, particularly those in the auroral zones and over mountains near the Equator, the earth's magnetism often varies so frequently and erratically as to limit the times when surveys can be made. The field may change by 1 per cent, or several hundred gammas, in a minute. But the quietest areas experience occasional magnetic storms, and the worst have occasional quiet periods when surveys can be made. Systematic observations make it possible to predict when these periods are likely to come. In all surveys a second magnetometer is operated at the base station to guard against flying during an excessive disturbance.

When a survey area has varied surface features, the pilot guides his plane by reference to detailed maps or photographs on which the flight lines have been marked. In the course of the flight a 35-millimeter camera makes a continuous picture or series of pictures of the ground. Identical serial numbers printed simultaneously on the film and the magnetometer record tie together the corresponding points on each.

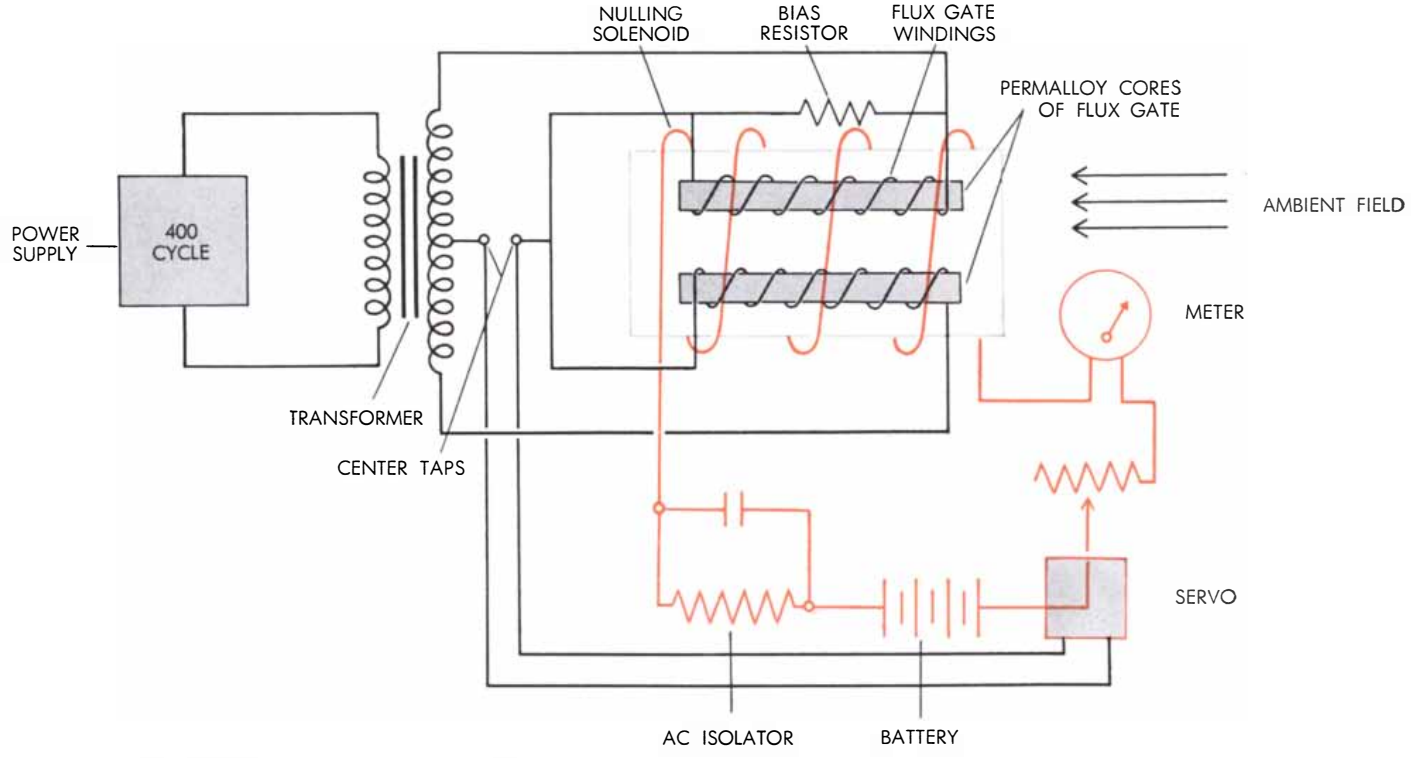
Some flights present more of a problem. Oil exploration is being pressed over largely featureless terrain, where maps and photographs are inadequate for the exact navigation required in magnetic surveys. Here flights must be guided by other means.

Surveys over water generally depend on radio navigation aids such as Shoran. In this system the position of the airplane is fixed by determining the distance to it from each of two ground stations. A unit aboard the plane sends out interrogating pulses that trigger answering pulses from the ground installations. The time between interrogation and the receipt of the reply is translated into range, and triangulation determines the position.

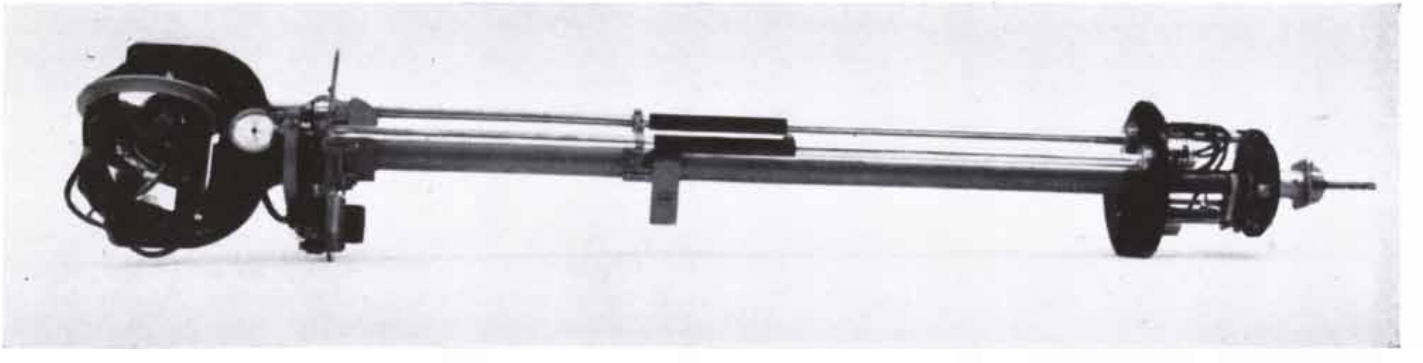
In desert and jungle territory ground



TYPICAL INSTALLATION of the equipment for a magnetic survey is shown in an Aero Commander plane. The compensating devices near the magnetometer head are to cancel the fields of the plane's magnetic parts. The normal crew for a flight is three men.



FLUX-GATE ELEMENT, the heart of the magnetometer, includes two coils wound so that their polarity is opposed. In the absence of an external field they are balanced and no voltage appears at the center taps. The earth's field reinforces one coil as it detracts from the field of the other; this unbalances the circuit to produce a voltage, proportional to the ambient field, at the center taps. This voltage provides information to servo circuits. In the case of the measuring flux gate shown here, a servo-controlled current (*colored circuit*) creates a field in the solenoid that cancels the earth's field, and the servo current is therefore a measure of that field. In the case of two other flux gates, the center-tap voltage controls servomotors that keep the measuring flux gate oriented.



MAGNETOMETER HEAD includes the detecting flux gates on a gimbaled platform (*left*), the orienting servomotors (*right*) and drive shafts by which they turn the gimbal mount. The instrument, 38 inches long, is housed at the tail of the plane or at a wing tip.

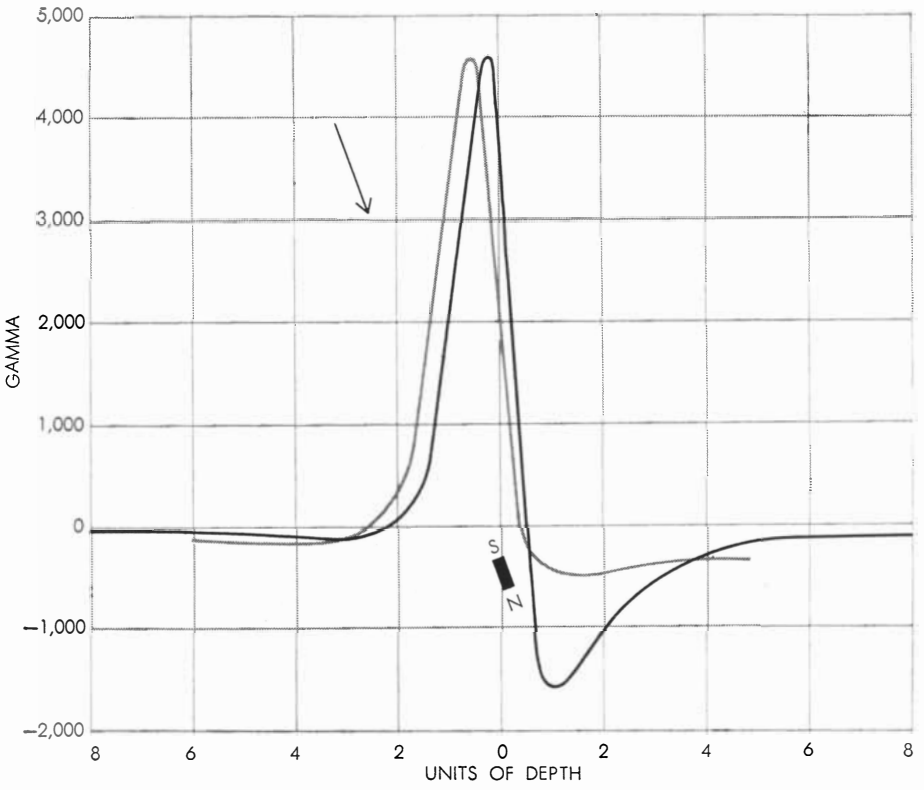
stations are expensive to build and inconvenient to maintain. Therefore Shoran has been largely replaced in these regions by a new self-contained airborne system: the radar Doppler navigator. Radar beams directed at the ground fore and aft of the airplane are partially reflected back to the ship. As a result of the Doppler effect and the forward motion of the plane, the frequency of the returning forward beam is increased and that of the backward beam decreased. The instrument continuously converts the frequency shift into ground speed. Combining the speed with directional information from a precise compass, the device then computes the true flight path, which is correlated with the magnetometer readings.

The magnetometer supplies records in the form of continuous profiles of magnetic intensity along the flight lines. After adjustment to bring them into agreement with the control-line data, the variations of magnetic intensity are plotted as contour lines on a map [*see illustration on pages 158 and 159*].

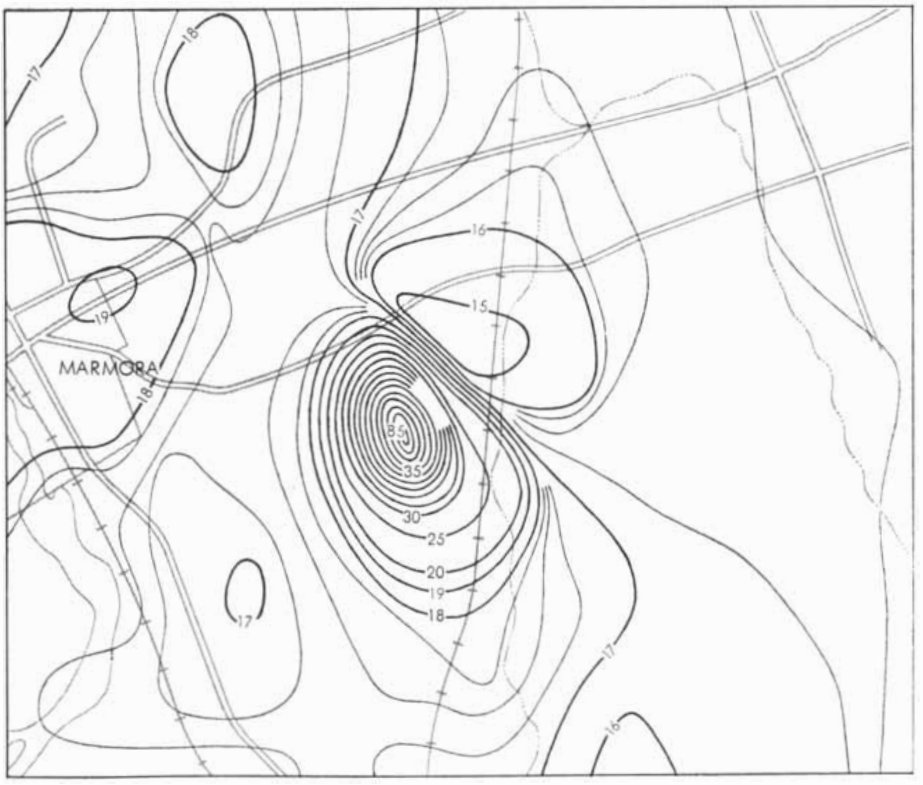
The impact of this simple technique has been explosive. The U. S. Geological Survey has already completed magnetic studies of a tenth of the entire area of the U. S. The Canadian Government is embarking on a 12-year program to explore all the potential mineral-bearing regions of the country. Big as they are, these projects represent a minor part of the work done with the airborne magnetometer. Since 1946 no fewer than five and often as many as 20 airplanes carrying magnetometers built by Gulf and operated by private companies have seen almost continuous service over much of the world. The mining industry now spends more on magnetic surveys than it spent on all geophysical prospecting before the war. And, as indicated previously, the techniques of airborne surveying have been extended to include radiation and electromagnetic measurements. Scintillation counters are usually carried on flights along with the magnetometer; the electromagnetic detector is more often brought into play in follow-up flights to examine magnetic anomalies for further evidence based on the deposits' conductivity.

Aerial surveying offers a tremendous boost to underdeveloped nations trying to hasten their industrial revolution. The program in Surinam (formerly Dutch Guiana) provides a striking example. In six months beginning in July, 1959, a DC-3 airplane equipped with magnetometer, scintillation counter and

Doppler navigator completely explored a jungle area covering 80 per cent of the country's 55,000 square miles. Maps prepared from the data have been made available to mining companies interested in developing new resources. Ghana, Chile, Bolivia, Angola, Mozambique, the United Arab Republic, Venezuela and Turkey are now planning or have already begun similar comprehensive surveys. The airborne magnetometer will play a major role in the struggle to bring the benefits of 20th-century technology to all the people of the earth.



LARGE ORE BODY at Marmora, Ontario, created a strong anomalous signal (*gray curve*) during a magnetometer survey. It is a remarkably close fit to the "pure" theoretical curve (*shown in black*) for a spherical magnetic body located at the latitude of Marmora.



MARMORA ANOMALY, when rendered in contour lines, produced a distinctive magnetic "mountain" (*center*) on a map. Steel company experts noticed it and staked a claim.

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MATHEMATICAL GAMES

A new collection of "brain teasers"

by Martin Gardner

As regular readers of this department are aware, every once in a while it is entirely devoted to brief problems of special interest. The current collection of "brain teasers" follows. The answers will be given here next month.

1.

H. S. Percival, of Garden City, N.Y., called my attention to this frustrating little problem with three pennies and two dimes. Arrange the five coins in a row on the table, alternating the pennies and dimes as shown at the top of the illustration below. The problem is to change their positions to those shown at the bottom of the illustration in the shortest possible number of moves.

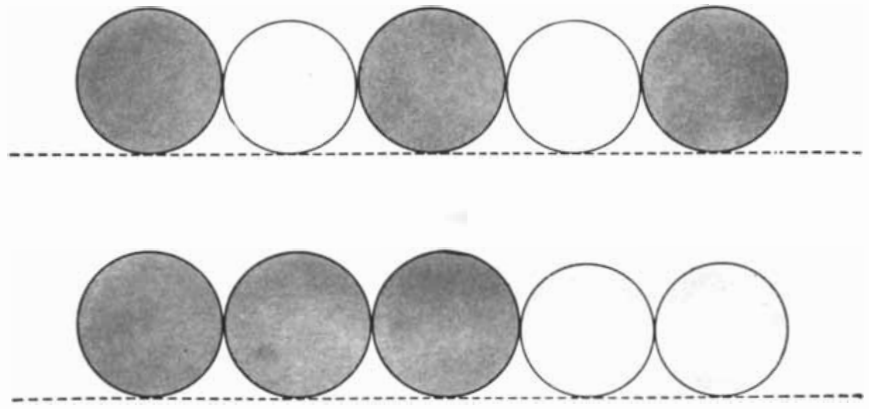
A move consists of placing the tips of the first and second fingers on any two touching coins, *one of which must be a penny and the other a dime,* then sliding the pair to another spot along the imaginary line shown in the illustration. The two coins in the pair must touch at all times. The coin at left in the pair must remain at left; the coin at right must remain at right. Gaps in the chain are allowed at the end of any move except the final one. After the last move the coins need not be at the same spot on the imaginary line that they occupied at the start.

If it were permissible to shift two coins of the same kind, the puzzle could be solved easily in three moves: slide 1, 2 to left, fill the gap with 4,5, then move 5,3 from right to left end. But with the proviso that each shifted pair must include a dime and penny it is a baffling and pretty problem.

2.

Even the simplest of household tasks can present complicated problems in operational research. Consider the preparation of three slices of hot buttered toast. The toaster is the old-fashioned type, with hinged doors on its two sides. It holds two pieces of bread at once but toasts each of them on one side only. To toast both sides it is necessary to open the doors and reverse the slices.

It takes three seconds to put a slice of bread into the toaster, three seconds to take it out and three seconds to reverse a slice without removing it. Both hands are required for each of these operations, which means that it is not possible to put in, take out or turn two slices simultaneously. The toasting time for one side of



The pennies and dimes puzzle

What can a skipping stone teach us about re-entry from space?

One promising approach to the problem of atmosphere re-entry is called the skip-glide path. The spaceship would follow an undulating trajectory, glancing off the atmosphere to lose its speed, much as a stone skips across the water. The necessary lift might be provided by a deployable pneumatic wing which would inflate on entering the atmosphere.

This and other approaches to aerospace deceleration are now being studied and evaluated at Northrop's Radioplane Division as part of its comprehensive program in landing and recovery systems. Long recognized as the leader in all aspects of paradynamics, Radioplane is fast becoming the industry's standard for space and aerospace landing systems. Active programs now include lunar soft landing studies, aerospace decelerators, and re-entry drag devices as well as recovery and landing systems for *all manned space vehicles actively scheduled by the U.S.*

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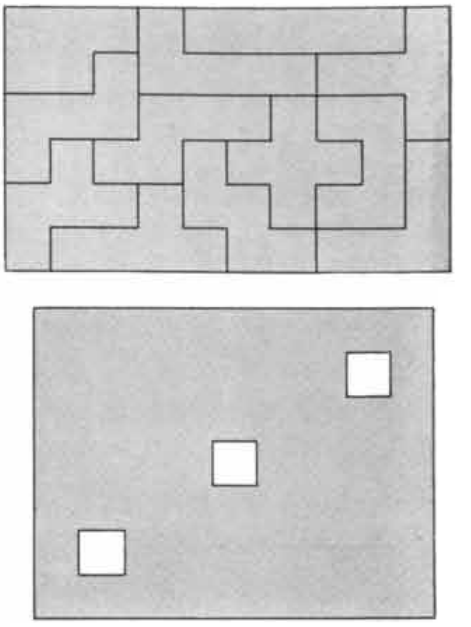


A pentomino problem

a piece of bread is 30 seconds. It takes 12 seconds to butter a slice.

Each slice is buttered on one side only. No side may be buttered until it has been toasted. A slice toasted and buttered on one side may be returned to the toaster for toasting on its other side. The toaster is warmed up at the start. In how short a time can three slices of bread be toasted on both sides and buttered?

3.

For pentomino buffs, here are two recently discovered problems, the first one easy and the second difficult.

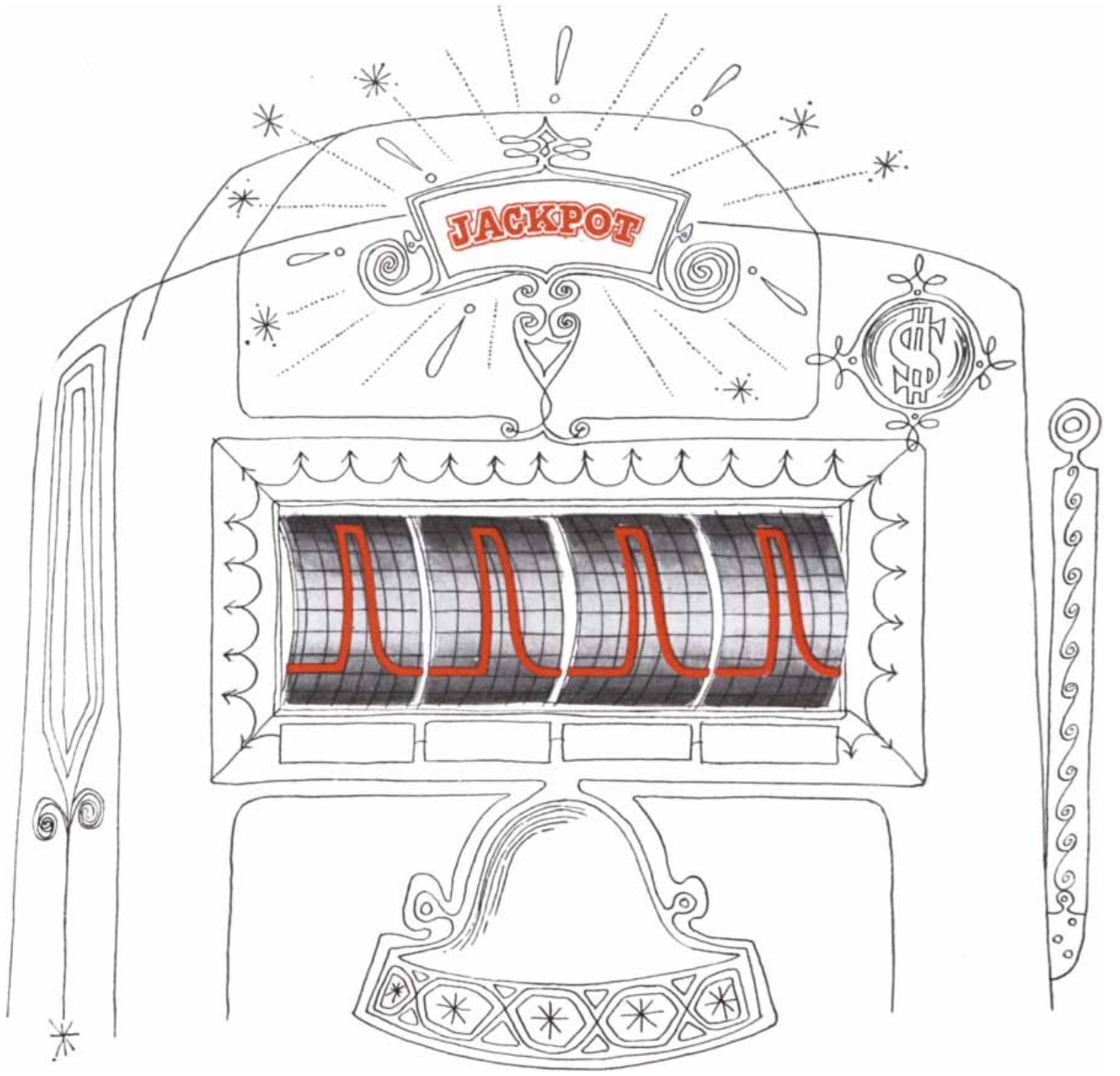
A. At the top of the illustration on this page the 12 pentominoes are arranged to form a 6-by-10 rectangle. Divide the rectangle, along the black lines only, into two parts that can be fitted together again to make the three-holed pattern at the bottom of the illustration.

B. Arrange the 12 pentominoes to form a 6-by-10 rectangle but in such a way that each pentomino touches the border of the rectangle. Of several thousand fundamentally different ways of making the 6-by-10 rectangle (rotations and reflections are not considered different), only two are known to meet the condition of this problem.

4.

One morning, exactly at sunrise, a Buddhist monk began to climb a tall mountain. The narrow path, no more than a foot or two wide, spiraled around the mountain to a glittering temple at the summit.

The monk ascended the path at vary-



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ing rates of speed, stopping many times along the way to rest and to eat the dried fruit he carried with him. He reached the temple shortly before sunset. After several days of fasting and meditation he began his journey back along the same path, starting at sunrise and again walking at variable speeds with many pauses along the way. His average speed descending was, of course, greater than his average climbing speed.

Prove that there is a spot along the path that the monk will occupy on both trips at precisely the same time of day.

5.

The following two problems seem to call for a digital computer so that hundreds of combinations of digits can be tested in a reasonable length of time. But if approached properly and with the aid of a clever dodge or two, both problems can be solved with very little pencil and paper work. It is by such short cuts that a skillful programmer often can save his company valuable computer time and in some cases even eliminate a need for the computer.

A. *The Square Root of Wonderful* was the name of a recent play on Broadway. If each letter in WONDERFUL stands for a different digit (zero excluded) and if OODDF, using the same code, represents the square root, then what *is* the square root of wonderful?

B. There are many ways in which the nine digits (not counting zero) can be arranged in square formation to represent a sum. In the example shown at left in the illustration on this page, 318 plus 654 equals 972. There are also many ways to place the digits on a square matrix so that, taken in serial order, they form a rookwise connected chain. An example is at right in the illustration. You can start at 1, then, moving like a chess rook, one square per move, you can advance to 2, 3, 4 and so on to 9.

The problem is to combine both features in the same square. In other words, place the digits on a 3-by-3 matrix so that they form a rookwise connected chain, from 1 to 9, and also in such a way that the bottom row is the sum of the first two rows. The answer is unique.

6.

It is said that Immanuel Kant was a bachelor of such regular habits that the good people of Königsberg would adjust their clocks when they saw him stroll past certain landmarks.

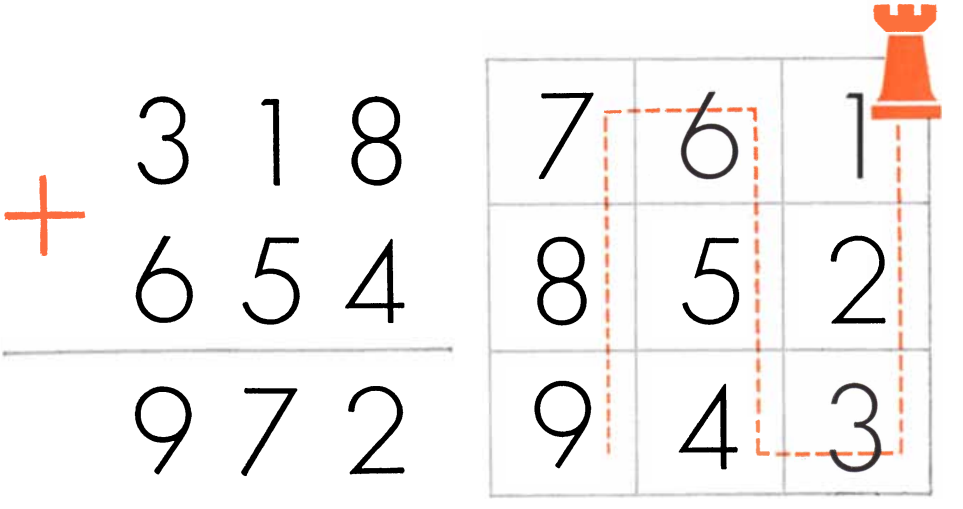
One evening Kant was dismayed to discover that his clock had run down. Evidently his manservant, who had taken the day off, had forgotten to wind it. The great philosopher did not reset the hands because his watch was being repaired and he had no way of knowing the correct time. He walked to the home of his friend Schmidt, a merchant who lived a mile or so away, glancing at the clock in Schmidt's hallway as he entered the house.

After visiting Schmidt for several hours Kant left and walked home along the route by which he came. As always, he walked with a slow, steady gait that had not varied in 20 years. He had no notion of how long this return trip took. (Schmidt had recently moved into the area and Kant had not yet timed himself on this walk.) Nevertheless, when Kant entered his house, he immediately set his clock correctly.

How did Kant know the correct time?

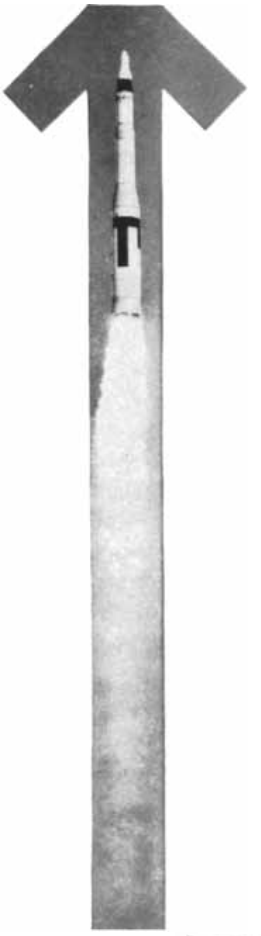
7.

In the well-known game Twenty Questions one person thinks of an object, such as President Kennedy's rocking



Can features of both squares be combined?

Join the Minutemen of Space Technology Leadership



MINUTEMAN

In 1957, the Air Force Ballistic Missile Division, now the Ballistic Systems Division, awarded Space Technology Laboratories, Inc. a contract to study the feasibility of a solid propellant, multi-stage Intercontinental Ballistic Missile. When that study demonstrated that such a missile system was technically feasible, STL was awarded a contract to provide systems engineering and technical direction for the program to bring the system into being.

Design criteria for the system and its subsystems were prepared by STL as a member of the industry team which, under the leadership of the former Air Force Ballistic Missile Division, set about the task of creating the Minuteman system. Guided by the principle of concurrency and spurred on by the same appreciation of urgency which marked the development of those other Air Force weapon systems in which STL performed systems engineering and technical direction — Atlas, Thor and Titan — this industry team met the rigorous time schedule established for the program. The first captive test of the missile was made on 15 September 1959, the exact date scheduled eighteen months earlier. The dramatically successful first flight test at Cape Canaveral on 1 February 1961 occurred within weeks of the programmed date.

The Minutemen of STL are proud of their role in the development of the Minuteman system, and of their association in that program with: Boeing Airplane Co. (assembly and test); Autonetics Division of North American Aviation (guidance and control); Thiokol Chemical Corp., Aerojet General, and Hercules Powder Co. (propulsion); and Avco Corp. (re-entry vehicle).

Minuteman has passed its first research and development flight test. Ahead lies the work of completing the ground system and missile development, and of bringing the system to operational readiness. These tasks require qualified engineers and scientists to augment STL's Minuteman team in both Southern California and Cape Canaveral. Those capable of contributing to this important program in Space Technology Leadership are invited to write Dr. R. C. Potter, Manager of Professional Placement and Development, at either location.

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chair or Lawrence Welk's left little toe, and another person tries to guess the object by asking no more than 20 questions, each answerable by yes or no. The best questions are usually those that divide the set of possible objects into two subsets as nearly equal in number as possible. Thus if a person has chosen as his "object" a number from 1 through 9, it can be guessed by this procedure in no more than four questions—possibly less. In 20 questions one can guess any number from 1 through 2^{20} (or 1,048,576).

Suppose that each of the possible objects can be given a different value to represent the probability that it will be chosen. To cite a specific example, suppose that an unmarried mathematician playing the game is anxious to learn the age of a certain young woman. She declares that her age in years, to her nearest birthday, is more than 20 and less than 30, and she agrees to answer truthfully any yes or no question about her age, provided she receives a ten-dollar gift for each answer. The mathematician has sound reasons for thinking that she is more likely 29 than any of the other possible ages, and that the probability decreases as her age lowers. Since he wishes to spend as little money as possible in acquiring this vital information, what is his best guessing strategy?

This problem was recently solved, for any set of objects for which the probability of choosing each is known, by Seth Zimmerman, a mathematician at Dartmouth College. His general solution will be given next month.

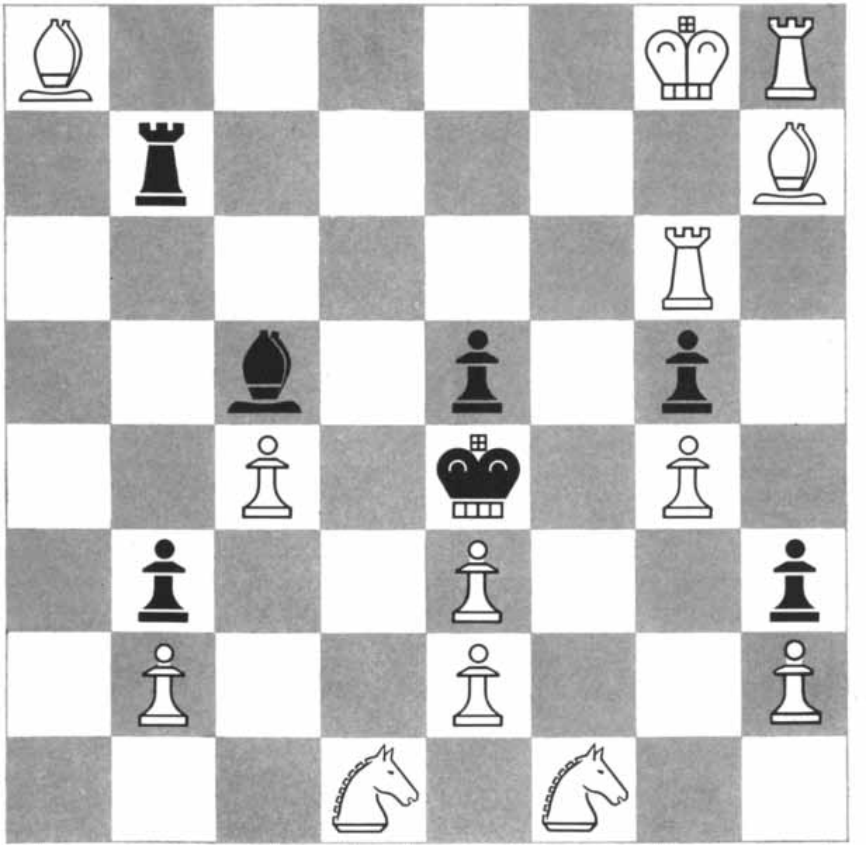
8.

Karl Fabel, a German chess problemist, is responsible for the outrageous problem depicted in the illustration on this page. It appeared recently in Mel Stover's delightful column of offbeat chess puzzles, currently running in *Canadian Chess Chat* magazine.

You are asked to find a move for white that will *not* result in an immediate checkmate of the black king.

9.

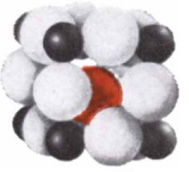
A polyhedron is a solid bounded by plane polygons known as the faces of the solid. The simplest polyhedron is the tetrahedron, consisting of four faces, each a triangle. A tetrahedron can have an endless variety of shapes, but if we regard its network of edges as a topological invariant (that is, we may alter the length of any edge and the angles at which edges meet but we must preserve the structure of the network), then there is only one basic type of tetrahedron. It is not possible, in other words, for a



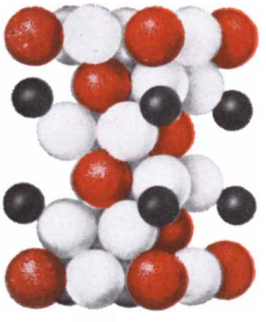
White to move and not *checkmate*

FROM RESEARCH . . .

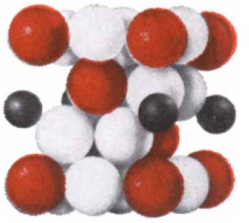
Interesting new compounds



Perovskite



Five layers



Three layers

A number of new oxide compounds with the perovskite structure have been developed by one of our research groups. Investigations of related three-layered and five-layered structures are also in progress. To discover the relationships between crystal structure and physical properties, intensive studies are being carried on to determine ferroelectric, ferromagnetic and dielectric characteristics. From this basic research may come advanced materials superior to any currently available. • Our corporate-sponsored research programs into the fundamental nature of matter offer *unusual opportunity* to any scientist interested in doing *original work*. Inquiries are invited particularly from those with experience in—Solid State Physics • Plasma Physics • Particle Physics • Nuclear Engineering • Gaseous Electronics • Direct Conversion • Surface Chemistry.

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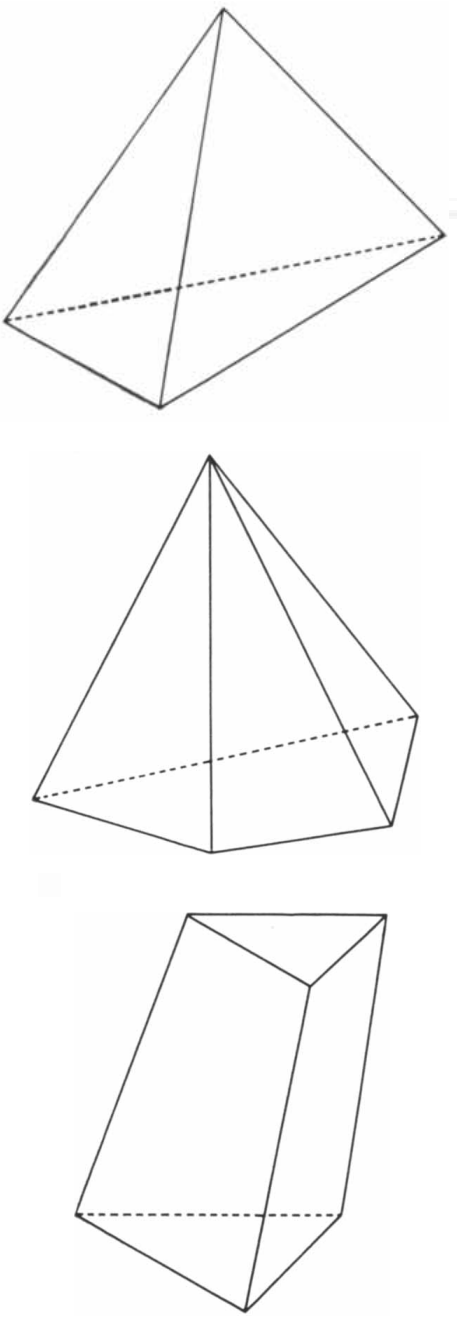
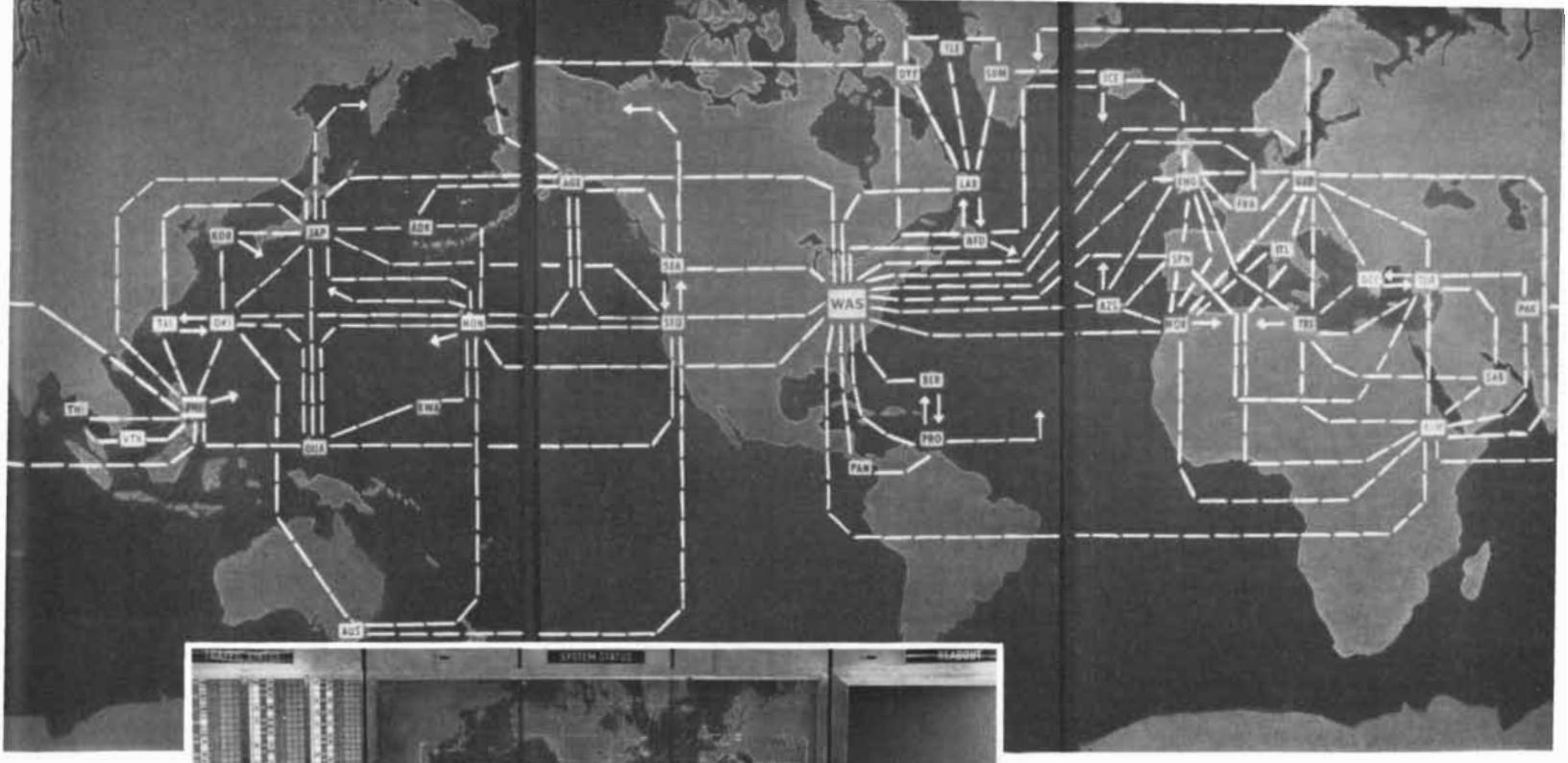
tetrahedron to have sides that are anything but triangles.

The five-sided polyhedron has two basic varieties. One is represented by the Great Pyramid of Egypt (four triangles on a quadrilateral base). The other is represented by a tetrahedron with one corner sliced off; three of its faces are quadrilaterals, two are triangles.

John McClellan, an artist in Woodstock, N.Y., poses this interesting question: How many basic varieties of hexahedron, or six-sided solid, are there altogether? The cube is, of course, the most familiar example. Readers will find it a pleasant challenge to sketch their networks. There are less than 10 but it is not easy to find all of them, and if you do,



Three types of polyhedron



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Keeping U. S. Armed Forces communications traffic flowing rapidly and efficiently is an enormous task. The Defense National Communications Control Center was designed, fabricated and installed by Philco for the Defense Communications Agency to provide the means to monitor and control this gigantic traffic load.

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it is still harder to prove that there are no others.

If you search for hexahedrons by chopping corners from simpler solids, you must be careful to avoid duplication. For example, the Great Pyramid, with its apex sliced off, is equivalent to the cube. Be careful also to avoid models that cannot exist without warped faces.

The paradox of the tiles, demonstrated last month by P. Bertrand Apollinax, is explained as follows. When all 17 tiles are formed into a square, the sides of the square are not absolutely straight but convex by an imperceptible amount. When one cube is removed and the 16 tiles re-formed into a square, the sides of the square are concave by the same imperceptible amount. This accounts for the apparent change in area. To dramatize the paradox, Apollinax performed a bit of sleight of hand by palming the fifth cube as he rearranged the pattern of the tiles.

In his prediction bet the event that Apollinax described on the file card was: "You will place in your left trouser pocket a card on which you have written the word 'No.'" The simplest presentation of the same paradox is to ask someone to predict, by saying yes or no, whether the next word that he utters will be no. Karl R. Popper's reasons for thinking that part of the future is in principle unpredictable are not based on this paradox, which is simply a version of the old liar paradox, but on much deeper considerations. These considerations are given in Popper's "Indeterminism in Quantum Physics and in Classical Physics," in *The British Journal for the Philosophy of Science*, Vol. 1, No. 2 and 3, 1950, and will be discussed more fully in his forthcoming book *Postscript: After Twenty Years*. A prediction paradox essentially the same as Apollinax', except that it involves a computer and electric fan instead of a person and card, is discussed in Chapter 11 of John G. Kemeny's *A Philosopher Looks at Science*, published by D. Van Nostrand in 1959.

The paradox of the infinite series of fours, alternately added and subtracted, is explained by the fact that the sum of this series does not converge but oscillates back and forth between the values of zero and four. To explain the rotation paradoxes would require too deep a plunge into relativity theory. For a stimulating presentation of a modern approach to these classic difficulties, Dennis Sciama's recent book, *The Unity of the Universe*, published by Doubleday & Company, Inc., is recommended.

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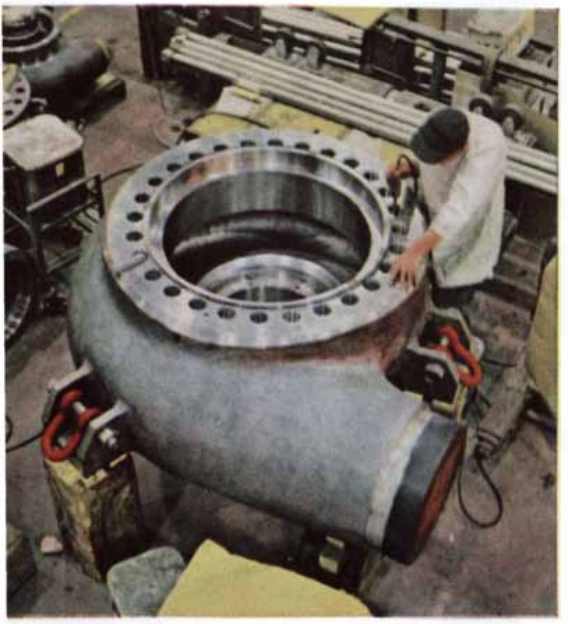
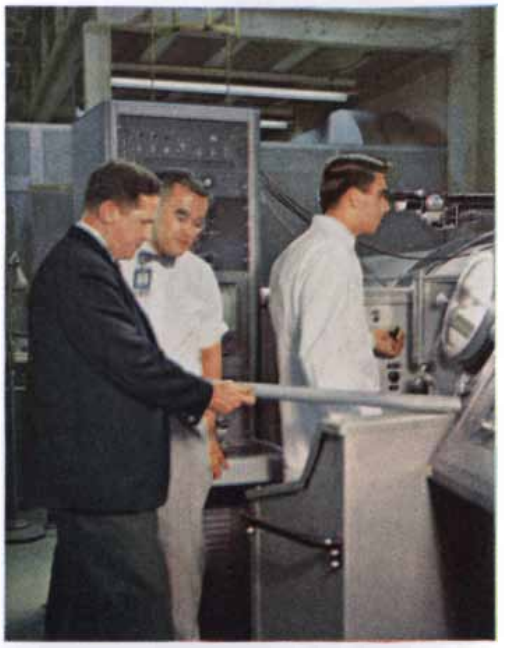
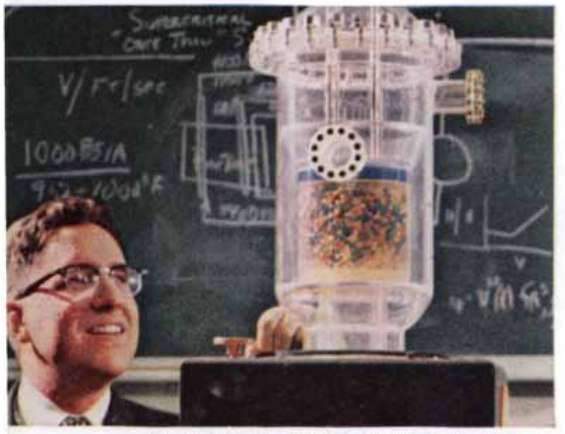


Westinghouse Quality Control inspector is working on a nine ton stainless steel pump casing at the Atomic Equipment Department in Cheswick, Pa. Department produces canned motor pumps, valves and control rod mechanisms.



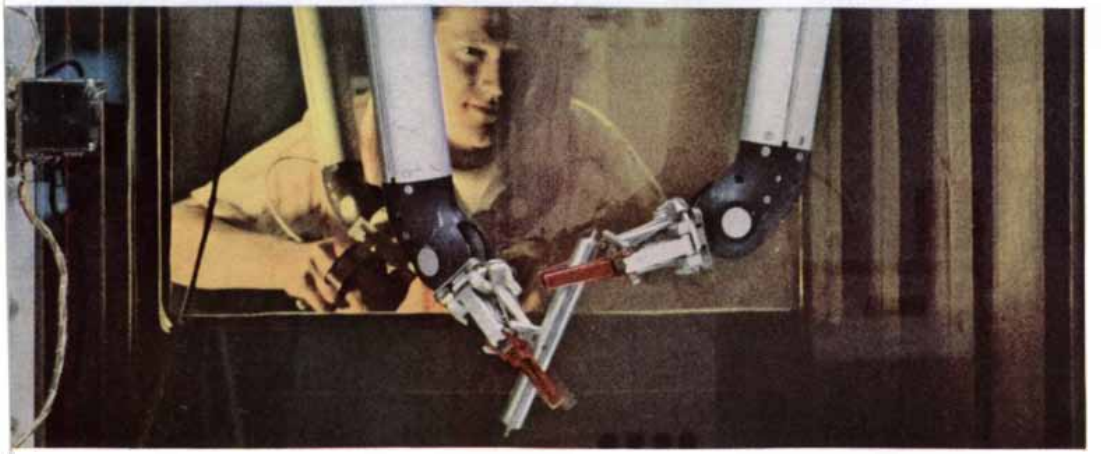
Electron Beam Welding of core components is one of the many special skills employed at the Atomic Fuel Department, Cheswick, Pa. Standard products of the department are reactor cores and their components.



Dr. James H. Wright, shown here with an organic moderated fluidized bed reactor model, is also doing important development work on the concept of an integral boiling and superheat reactor (IBSHR).

Westinghouse Engineers, after design, follow through on construction of reactor plants such as this 5,000 kilowatt plant being built at Saxton, Pa., for the Saxton Experimental Corporation. This new reactor will be used with an existing turbine generator at the Pennsylvania Electric Company site.

Critical Experiment Station at Testing Reactor. This technician is working in the low power test facility used to confirm physics calculations by experiments before exposure in the reactor.

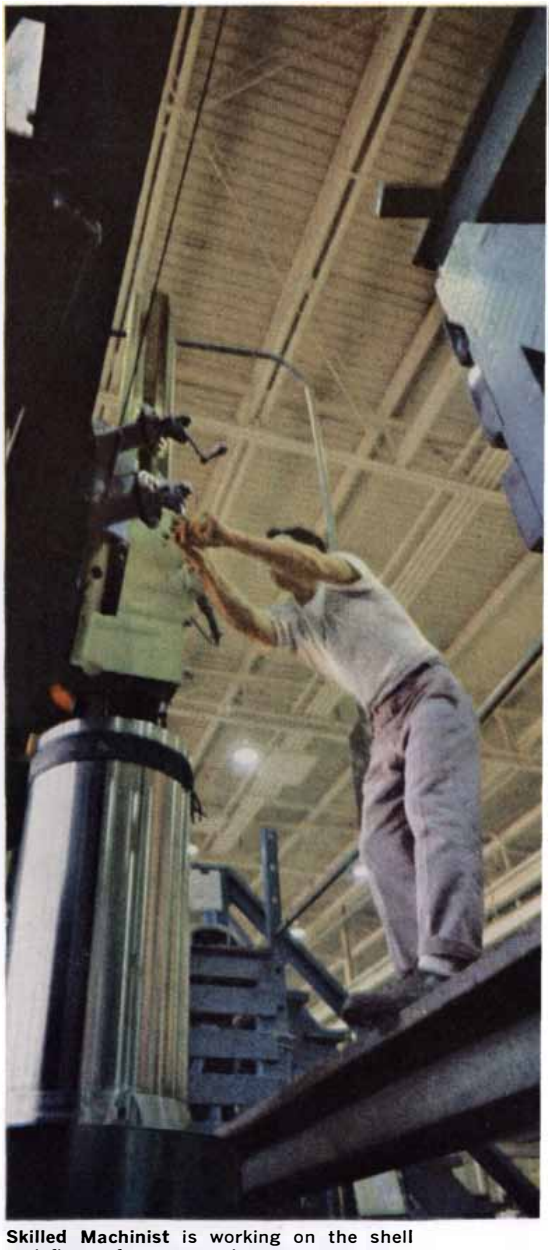


Westinghouse Testing Reactor facility includes hot cells and metallographic cells for post-irradiation examination of samples. Nuclear fuels and other materials can be tested inside cylindrical fuel elements of reactor core. Chemical, analytical and counting laboratories are used for post-irradiation tests.

J-59503

Westinghouse Mathematicians are working out the solution to a nuclear fuel problem at this computer installation in the Atomic Power Department at Forest Hills, Pa.

Dr. W. E. Shoupp, Technical Director of the Atomic Power Department, plays vital role in developing atomic fueled plants to the point where they will be economically competitive with fossil fueled plants in the generation of electric power.



Skilled Machinist is working on the shell and flange for a canned motor pump on a 120″ vertical boring mill at the Atomic Equipment Department.

Dr. Joseph C. Danko heads up promising advanced research of the thermoelectric reactor, a potential means of generating electricity directly from fission heat without a turbine-generator unit.

Fuel Assembly Operation at the Atomic Power Department, where facilities are maintained for development of advanced fuel concepts. Technician is working on cage of a fuel assembly.

Dr. Sidney Krasik, Technical Director of Astronuclear Laboratory, works on applications of atomic power in outer space, such as nuclear power propulsion, the nuclear ram jet and auxiliary power plants for space vehicles.

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...a hand in things to come

THE AMATEUR SCIENTIST

An amateur's improved design for a homemade quartz crystal clock

Conducted by C. L. Stong

Almost everyone admires a good watch or clock and would enjoy owning one of split-second accuracy. But until recent years the best clocks were cumbersome, cost thousands of dollars and for the most part were confined to astronomical observatories. In 1930, however, a method was developed for driving synchronous motors of the type used in electric clocks with alternating current derived from a vibrating quartz crystal. The natural period of the quartz vibration turned out to be more constant than the period of the earth's rotation—the interval to which observatory clocks are referred. The accuracy of the quartz crystal clock bettered that of the most precise pendulum clock by a full order of magnitude and outstripped that of the best chronometer by three orders. Moreover, the quartz crystal clock was rugged, simple to build and inexpensive. Its construction demands none of the clockmaker's skills, and even at today's prices it can be assembled for less than $100. Several such clocks have been built by amateurs.

The heart of the instrument is a thin wafer cut from a natural crystal of quartz. Two basic properties of the wafers account for their attractiveness as timekeepers. First, they are so elastic that when they are struck a sharp blow they vibrate as much as five million times before the amplitude of vibration falls to half its initial value. In contrast, the swing of a good pendulum in a vacuum falls to half its initial value after 100,000 oscillations. Since the rate of oscillation of any resonant system is disturbed by the application of an external force, this characteristic of the quartz wafer gives it a clear advantage over the pendulum: the vibration of the quartz can be sustained with less energy. Second, quartz crystals can be driven electrically, without mechanical linkage, and can also be used as generators of alternating current. An electric field distorts the crystal physically: it becomes longer in one dimension and shorter in the transverse dimension. Conversely, when the crystal is distorted by a mechanical force applied to either of these dimensions, electric charges of opposite sign appear on the facets at right angles to the plane of the applied force.

As a vibrating element for measuring time the crystal has still other inherent advantages. Its performance is independent of gravity; accordingly its rate of oscillation is not altered by changes in altitude and latitude or by tidal effects. It can be supported at the node of its vibration and is therefore free from the class of errors introduced by the suspension of a pendulum. The rate at which the crystal vibrates is virtually independent of the amplitude of vibration. Finally, the crystal is small, durable and self-contained.

Like the swing of a pendulum, the rate of vibration of a quartz wafer is influenced by changes in temperature and atmospheric pressure. The rate is also disturbed by certain effects associated with the aging of the crystal. These can be minimized, however, by appropriate expedients. It turns out that wafers cut from a larger crystal in a certain direction (called the *X* axis) have a negative temperature coefficient of frequency: the rate of vibration falls with increased temperature. Wafers cut at right angles to the *X* axis (the *Y* axis) exhibit the opposite effect: the frequency increases with temperature. It is possible to cut wafers at an intermediate (*G-T*) angle between the *X* and *Y* axes so that the rate of vibration remains constant through a limited range of temperatures. Even these wafers show some variation in rate during intervals when the temperature is changing, but the vibration returns to its former rate when all parts of the wafer have reached the same temperature. The frequency of *X*-cut crystals falls 30 parts per million per degree centigrade of temperature change; the frequency of *Y* cuts increases about 100 parts per million per degree. In contrast, the rate of intermediate cuts remains constant within one part per million per degree, depending on the operating temperature. A *G-T* wafer designed for operation at 30 degrees C. will vibrate precisely at the frequency for which it is ground at any temperature between about 20 and 40 degrees, after all parts of the wafer reach that temperature.

Like a swinging pendulum, a vibrating crystal gives up energy to the surrounding air at a rate depending on the atmospheric pressure. Changes in air pressure are therefore reflected by the rate of vibration. This source of error is minimized by mounting the wafer in a housing from which air can be evacuated. The frequency is also affected by surface contamination. A film of oil from the fingers, for example, can increase the effective mass of the wafer enough to reduce its frequency one part per million. The best crystals are equipped with supporting lead-in wires, are scrupulously cleaned and are immediately enclosed in glass or metal envelopes from which the air is pumped.

Certain other factors, not all of them well understood, affect the rate. One appears to arise from stresses set up in the surfaces of the wafer during the grinding operation. Such stresses are relieved spontaneously during the life of the wafer and therefore induce long-term changes in rate. The defect can be minimized by grinding the wafer slowly, giving the wafer a final etch with hydrofluoric acid and aging it artificially by heating.

Anyone who has figured and ground a telescope mirror should be able to make a satisfactory crystal. Radio amateurs used to cut their own to control the frequency of short-wave transmitters. Today, however, homemade crystals are rare. Excellent crystals ground to specified frequencies can be bought new from $5 to $25, depending on the cut and the method of mounting. Temperature-compensated *G-T* cuts are generally priced higher than *X* cuts.

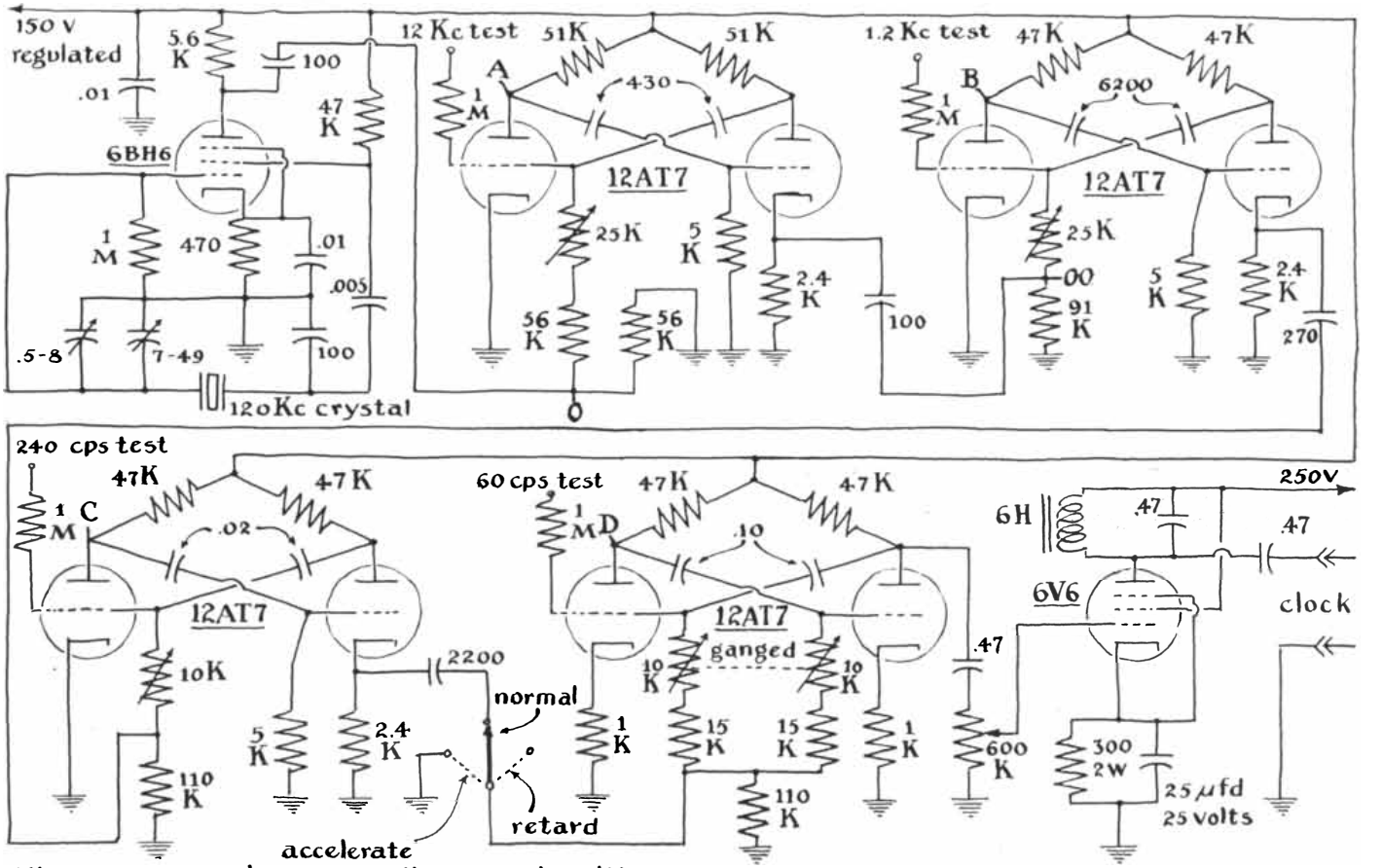
For maximum performance crystals

should be enclosed in a constant-temperature oven and operated in an oscillator circuit of the bridge type. An adequate oven can be made of wood or plastic lined with glass wool and controlled by a heater and thermostat of the kind used in home aquariums. A variety of suitable oscillator circuits will be found in reference texts prepared for radio amateurs. If one wishes, the crystal, oscillator and oven can be bought as a unit from a crystal manufacturer.

Crystals operate at frequencies ranging from about 16 kilocycles per second to a few megacycles. Clock motors operate from sources of low frequency, ordinarily a 60-cycle power line. This means that the crystal frequency must be divided to a value appropriate for the clock motor. Several electronic devices can perform this division, but the so-called free-running multivibrator seems best for amateur purposes. This device utilizes a pair of triode vacuum tubes so connected that the output of each tube feeds energy to the input of the other. The circuit is violently unstable. In effect each tube functions as a sequential trigger for its companion, so that the tubes conduct current alternately. The rate at which conduction alternates is largely determined by the rate at which the capacitors linking the grids of the tubes to the plates of their opposite numbers can charge and discharge through resistors included in the circuits. By choosing appropriate values for the grid capacitors and companion resistors, multivibrators can be designed to operate at any frequency from a small fraction of a cycle per second to many megacycles.

Normally multivibrators oscillate at a reasonably constant rate. But their action can be momentarily speeded up by introducing a voltage pulse from an external source into the grid circuit of either tube. The external pulse causes the tubes to switch conduction early. Thus if a multivibrator is designed to oscillate at the rate of 55 cycles per second, and if a source of voltage that alternates at 240 cycles is connected to the grid of either tube, the multivibrator will lock into step with the submultiple of 240 cycles that is nearest to 55 cycles, *i.e.*, 60 cycles. The multivibrator performs reliably up to 10-fold divisions. Divisions greater than 10 are accomplished by interconnecting two or more multivibrators in cascade. A quartz crystal of any frequency can therefore be used to drive a clock motor if the selected crystal frequency is a multiple of the frequency at which the motor is designed to operate. Most electric clocks run on 60-cycle current. Crystals ground to vibrate at 120 kilocycles, the 2,000th harmonic of 60 cycles, are commercially available and have been used by amateur clockmakers.

Jim Phillips of Phoenix, Ariz., recently joined the ranks of these enthusiasts. "For years," he writes, "I have been consumed with the desire to know what time it is down to the smallest fraction of a second that can be read on a dial. This led me to buy several pocket watches of the type used by railway employees. Good as they were, the best of these watches gained or lost several seconds per month. Last year, while casting about for a project required for completing a course in electrical engineering, I ran across a reference to an article in *Scientific American* that explained how to build a quartz crystal clock [see "The Amateur Scientist"; September, 1957]. This struck me as the ideal project—one



Circuit diagram of a quartz crystal clock

Bendix-Pacific Electronic "Anchor" Stabilizes Platform

For Off-Shore Exploration of Inner Space

How to maintain a barge in an exact position at sea, so that it can be used as a stable platform from which to drill into the earth several miles below the surface.

That's the problem posed by Project Mohole—the scientific probe of inner space calling for the deepest off-shore drilling ever attempted.

To solve this problem, Bendix-Pacific engineers have devised an electronic "anchor"—a combined sonar and radar position-fixing system which pinpoints the barge so that the record-length drill pipe won't break.

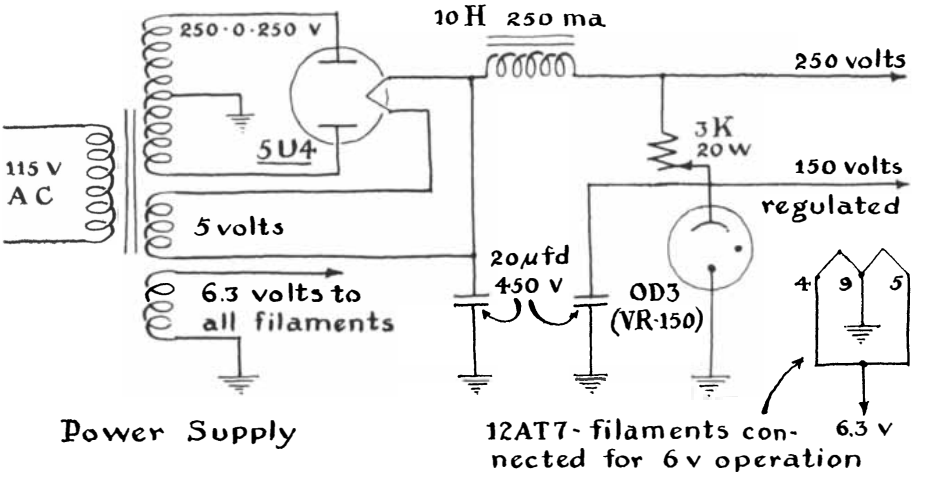
Dual Signalling

The "anchor" includes a Bendix Marine Underwater Scanner and a Bendix Marine Radar. The scanner picks up signals bounced back from four transponders anchored underwater around the barge, while the radar receives signals from reflectors floating on the surface above the transponders. Comparing the two sets of signals, the operator can determine when to move the barge... how far, and in which direction. Outboard motors then maneuver it into position.

The Bendix position fixing system has wide application in the petroleum industry, for off-shore drilling in much deeper water than was previously possible. Similarly, the scanner is finding wide application among commercial fishermen in locating their catch.

Diverse Capability

The electronic "anchor" devised for Project Mohole is one more example of the ingenuity and capability of Bendix-Pacific – leader in Marine Electronics, Airborne Radar, Data Handling, Electro-Mechanics, Guidance Systems, Hydraulics /Pneumatics, Military Navigation, Sonar, and Telemetry. For information on how Bendix-Pacific can help you in any of these fields, write.



Circuit diagram for the power supply of the clock

that should satisfy my desire for a really accurate timepiece as well as meet the course requirement.

"The clock had been developed by W. W. Withrow, Jr., of Teague, Tex. Withrow is to be congratulated on a fine design. Anyone considering the construction of a similar clock should make a point of reading his description. I decided to modify the design in some respects, chiefly to facilitate duplication of the circuit, allow the interchange of components such as vacuum tubes and simplify the required adjustments and synchronization of the clock with time signals broadcast by WWV, the radio station maintained by the National Bureau of Standards.

"The crystal oscillator of my clock was made by the International Crystal Manufacturing Company of Oklahoma City. It comes complete in the form of a printed circuit, with provision for plugging in a 6BH6 oscillator tube and the 120 kilocycle F-13 crystal shown at upper left in the accompanying diagram [*page 182*]. I modified the unit to the extent of adding a 50-microfarad trimmer capacitor between one terminal of the crystal and ground. This serves as vernier adjustment for varying the crystal frequency through a narrow range.

"A major difference between my circuit and that of Withrow is the design and arrangement of the multivibrators. His units reduced the frequency of the 120-kilocycle crystal to 60 cycles by successive divisions of 20, 5, 5 and 4 that respectively give frequency steps of 6,000, 1,200, 240 and 60 cycles. He had difficulty adjusting the first multivibrator, mainly because the unit was required to divide by a larger number than multivibrators can handle reliably. I distributed the successive divisions in steps of 10, 10, 5 and 4. This also enabled me to eliminate the preamplifier that Withrow inserted between the output of the crystal oscillator and the first multivibrator. In addition, I used asymmetrical multivibrators in all but the 60-cycle stage. The grid capacitor and associated resistor of one tube in each pair was made substantially smaller than the value required for establishing the free-running frequency of the stage. This

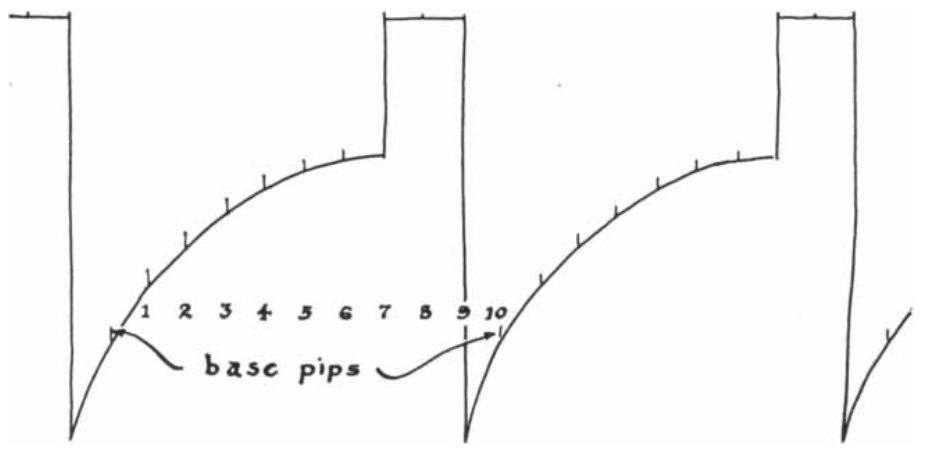


Diagram of oscilloscope pattern showing grid voltage of multivibrator

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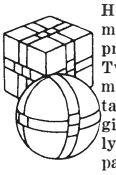

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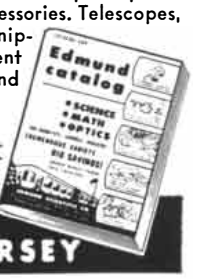

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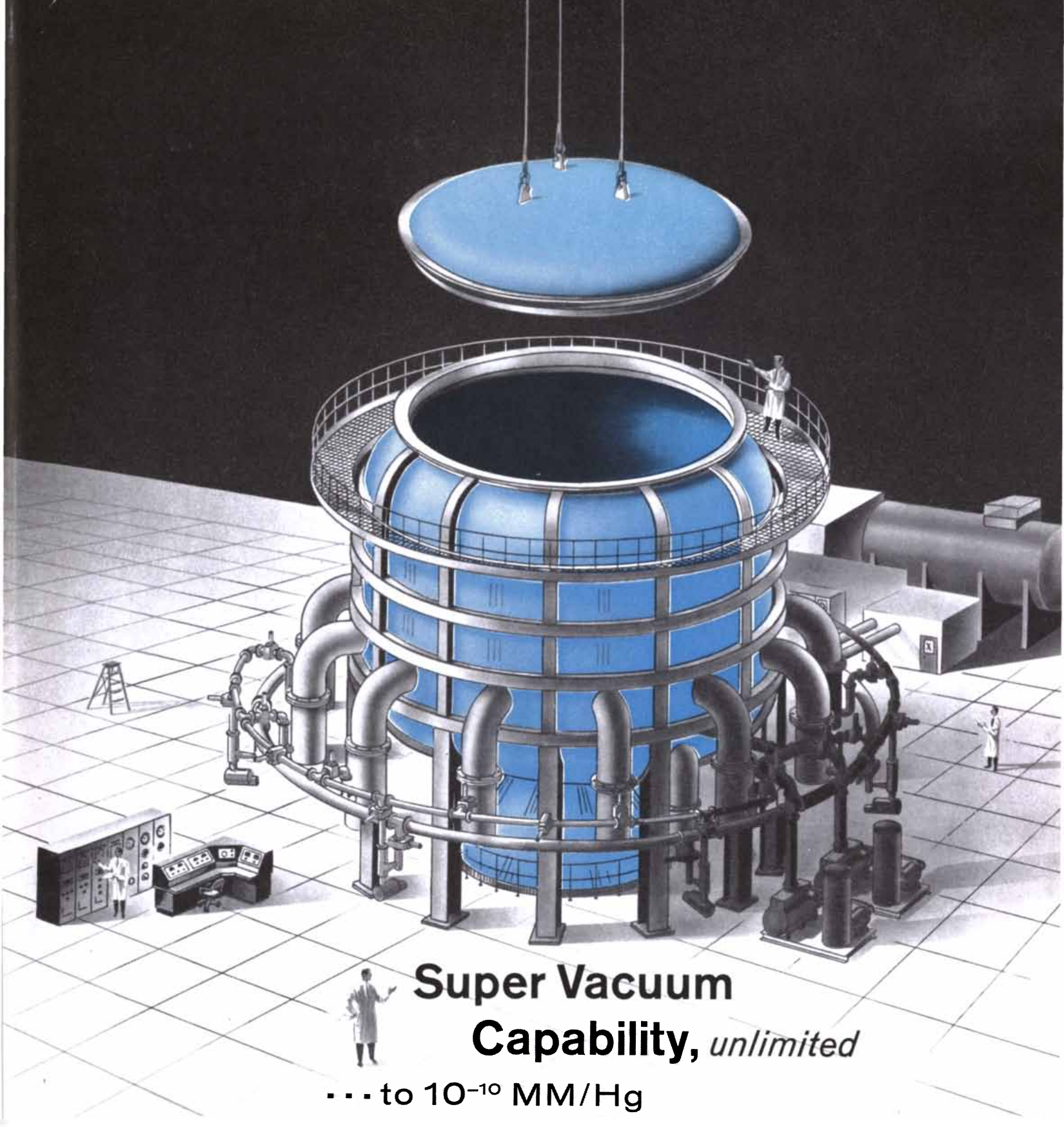
tube would therefore react more quickly than its companion. The rate of oscillation was fixed by the other tube of the pair. This tube was in the conducting state most of the time, whereas the quick-acting tube conducted just long enough to initiate a new cycle. The asymmetry increases the time available for injecting the incoming signal into the tube of shortest conduction time and simplifies the adjustment of the stage in addition to increasing its reliability.

"The 60-cycle multivibrator must operate symmetrically because the clock is designed to run from alternating current in the form of a sine wave. The frequency division of this stage is low, but it is not loaded heavily and symmetrical operation was easily achieved by feeding the input signal to the grids of both tubes simultaneously. As an operating convenience the grid circuits of all tubes concerned with frequency control were equipped with adjustable resistors.

"I must acknowledge that the power amplifier for supplying the clock is a strange-looking duck, the result of 'cut and try' design. But it works well in the several clocks I have made and does not overload the 60-cycle multivibrator. It was possible, therefore, to eliminate the voltage amplifier that Withrow used between the final multivibrator and power amplifier of his clock. The value given for the inductor in the plate circuit of the power amplifier is approximate. (It was a gift and bore no value markings.) Any inductor in the range of 4 to 10 henrys should work if the parallel capacitor is selected to produce both satisfactory voltage and a reasonable wave form at the clock terminals when the clock is plugged in. As a first approximation the size of the capacitor in microfarads can be taken as approximately equal to four divided by the inductance in henrys. Fortunately clock motors are easy to please both in respect to voltage and wave form.

"The power supply is conventional except that oversize components were used, as shown in the accompanying diagram [*top of page 184*]. The fact that the unit is intended for continuous operation should be kept in mind when substitutions are made for the parts recommended.

"A feature of the circuit that may be novel, and which certainly is a convenience, is the three-point switch that connects the output of the 240-cycle multivibrator to the input of the 60-cycle one. It is used for synchronizing the clock with the time signals broadcast by WWV. The switch is spring-loaded so that it centers automatically and



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closes the circuit between the cathode of the second tube of the 240-cycle multivibrator and the input of the 60-cycle multivibrator. Holding the switch to the right opens the circuit and allows the 60-cycle multivibrator to run free at about 55 cycles. This slows the clock. Holding the switch to the left short-circuits the 110 K resistor in the grid circuit of both tubes, which allows the unit to run free at approximately 65 cycles per second and so speeds up the clock.

"These are the circuits. Gather up the parts and assemble them on a chassis that measures approximately 17 inches long, 12 inches wide and 3 inches deep. Routine care should be exercised in layout and construction. Anyone who does not know what that means should call on a radio amateur for advice. When all the connections have been inspected for workmanship, plug *new* tubes into the sockets, set the voltage-regulator rheostat of the power supply at about 2,800 ohms, the multivibrator potentiometers to midrange, turn the 600 K potentiometer that feeds input to the power amplifier all the way down, plug in a clock that draws no more than three watts, turn on the juice—and stand back! The voltage-regulator tube should fire within a few seconds. When it does, advance the 600 K potentiometer that feeds the power amplifier until the clock motor starts. Then adjust the 60-cycle multivibrator so that the clock runs at a reasonable rate.

"The multivibrators are next adjusted for correct frequency division. This procedure requires a cathode-ray oscilloscope. If the builder does not own one, doubtless a radio amateur or television serviceman can be induced to co-operate in the venture. Two types of display are possible. The one suggested by Withrow produces a Lissajous figure on the scope that resembles a crown viewed sideways. The number of spikes that appear on the crown represents the division ratio. In other words, if the crown displays 10 spikes and does not rotate when the scope is connected between the crystal oscillator and the first multivibrator stage, the division is 10-fold and the multivibrator is locked to the frequency of 12,000 cycles.

"To make scope connections twist one lead of a 1-megohm resistor to each probe of the scope. Half-watt resistors are adequate. Thereafter use the free leads of the resistors as test probes. Starting with the 12-kilocycle multivibrator, connect the probe for the horizontal amplifier of the scope to test point *A* and the vertical probe to point *O*, the output of the oscillator. After the amplifiers of

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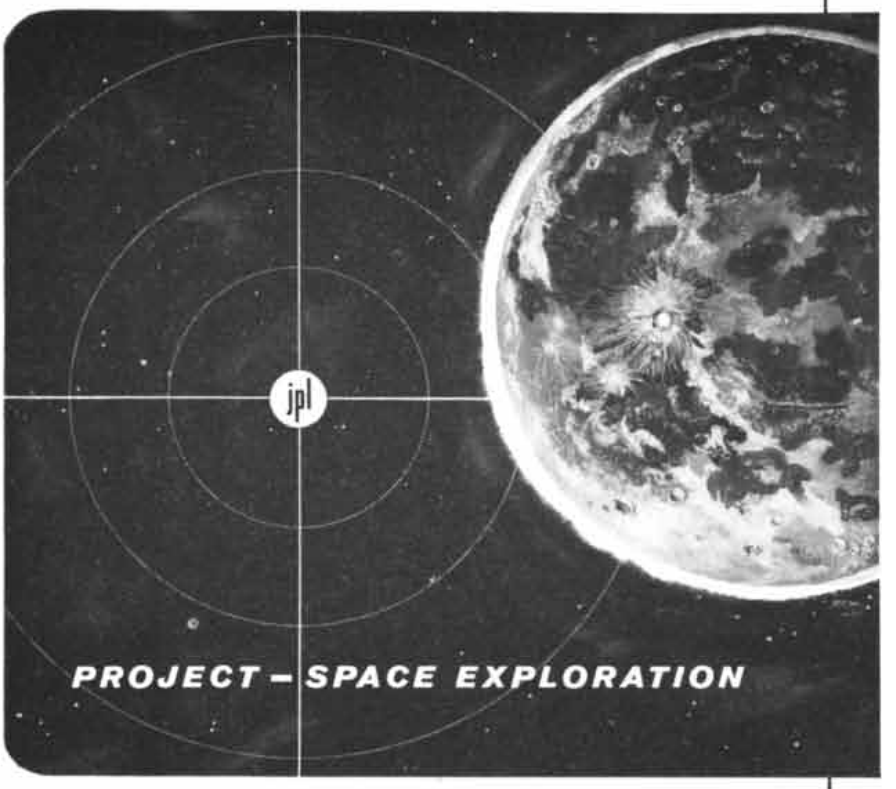
the scope have been adjusted for a figure of reasonable proportions, the crown described above should appear. If it fails to appear, adjust the multivibrator until the 10 spikes are counted. Next, shift the vertical probe to test point *OO* (the output of the 12-kilocycle multivibrator) and the horizontal probe to test point *B*. Adjust the 1.2-kilocycle multivibrator for another 10-spiked crown. The 240-cycle and 60-cycle multivibrators are easiest to adjust with the horizontal input probe connected to the ungrounded side of the filament supply. The vertical probe is connected to test points *C* and *D* respectively, and each of the multivibrators is adjusted until the scope displays a crown with four spikes and one spike respectively. The clock motor is now locked to the 2,000th submultiple of the crystal frequency.

"An alternate scope display, and the one that I prefer, permits you to observe what is really going on. In this scheme the vertical probe of the scope is connected to the grid test points of the first tube of each multivibrator pair. Horizontal deflection is provided by the internal sweep oscillator of the scope. The scope is adjusted for a pattern similar to the one shown in the accompanying illustration [*bottom of page 184*]. The base pips in the illustration represent the signal that is being divided. The remainder of the pattern reflects the irregular rise and fall of grid voltage of the first multivibrator tube. The ratio of the input to output frequencies is determined by counting the pips. Counting is facilitated by equipping the scope with a conventional screen of crossed lines. The scan frequency and horizontal gain of the scope should be set so that pips appearing on the exponential rise of the voltage display coincide with any convenient vertical lines on the screen. The number of pips per cycle can be determined by counting the number of vertical lines from base pip to base pip.

"One final adjustment remains to be made before the oscillator is tuned. The operating range of the OD3 voltage-regulator tube of the power supply extends from about 5 to 45 milliamperes. The 3K rheostat should be set to limit the current through the OD3 to about 25 milliamperes. Connect an appropriate milliammeter in the circuit temporarily and make the adjustment. The same result can be had by connecting a 100-ohm resistor in the circuit and adjusting the rheostat until 2.5 volts appear across the resistor.

"To tune the oscillator, set the vernier capacitor (.5 to 8 picofarads, or micromicrofarads) to midrange. Synchronize



In the next decade, the United States is committed to an extensive program of space exploration. The Jet Propulsion Laboratory has been assigned, by the National Aeronautics and Space Administration, a responsibility for lunar, planetary and interplanetary un-manned exploration programs.

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By 1970, sufficient scientific data is to be acquired demonstrating the feasibility of spacecraft capable of orbiting and landing on Mars and Venus. In addition, programs will be initiated for probing Mercury and Jupiter and for further penetration into space.

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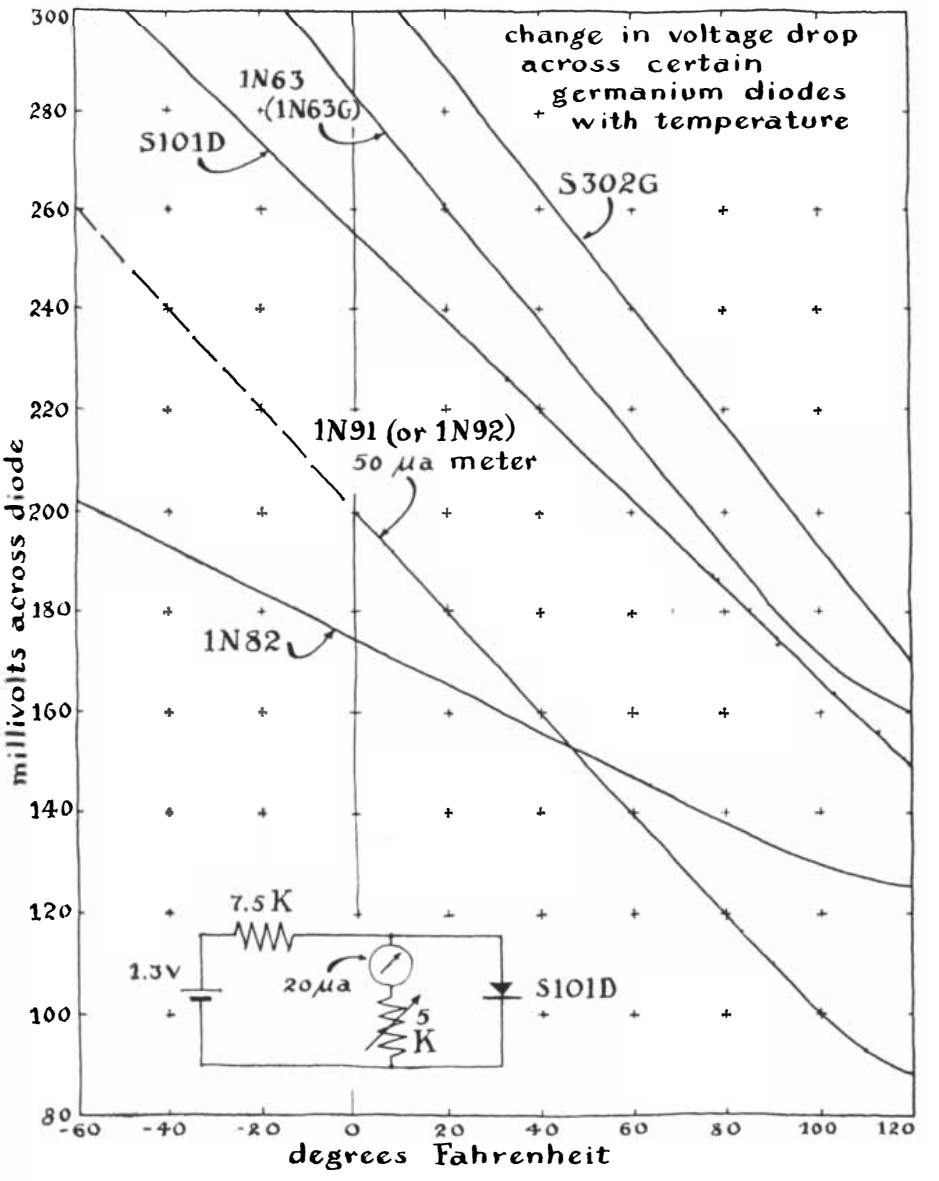
the second hand of the clock as closely as possible with the seconds signals broadcast by WWV by operating the spring-centered rate switch in the input of the 60-cycle multivibrator. Then adjust the rough frequency control (the 7–49 variable capacitor of the oscillator) by observing deviations from WWV. Finally, bring the crystal into step with WWV by adjusting the vernier."

Herbert Harris of Mount Wilson, Calif., proposes a somewhat less ambitious project in electronics for those interested in electric thermometers. "A number of the solid-state diodes now available on both the regular and the surplus market have excellent negative temperature coefficients of resistivity," he writes. "They appear to be more plentiful than thermistors and much less costly. I decided to build one into a circuit for indicating the outdoor temperature at our local hotel and am gratified by the results. The relative performance of several diodes, together with the circuit used during this series of experiments, is shown by the accompanying graph [*below*]. With this circuit the scale of my meter reads backward and about a third of it is unused. Other circuits, including bridges and semibridges, can be improvised for meters of other types. The experimenter should not overlook the fact that losses occur in diodes; the current should be kept low if accuracy is desired. The leads between the diode and meter can be extended to any reasonable length but must be included in the circuit when the instrument is calibrated. A comparison thermometer is used for calibration. Three calibration points can be established by successively placing the sensing elements in a refrigerator, in boiling water and exposing them to room temperature."



Concerning a thermometer made with solid-state diodes

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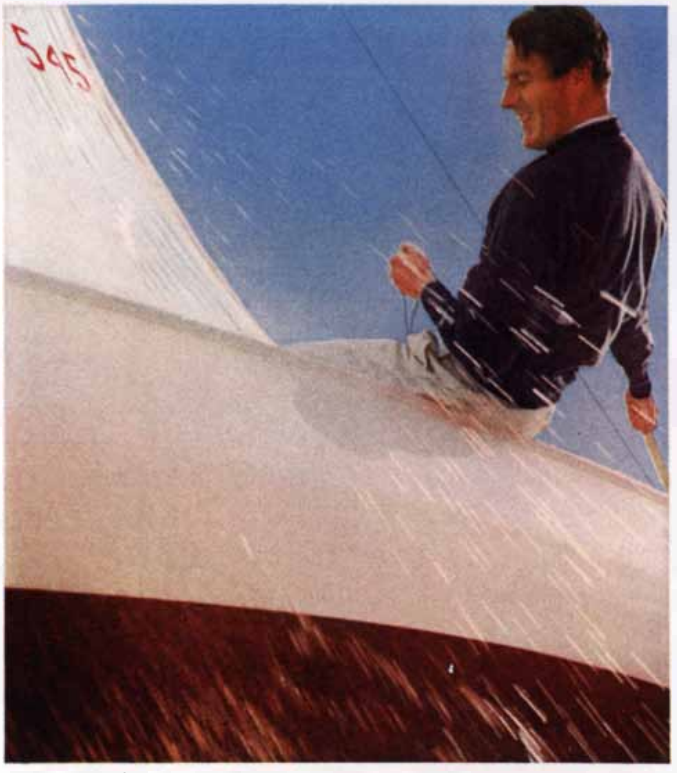

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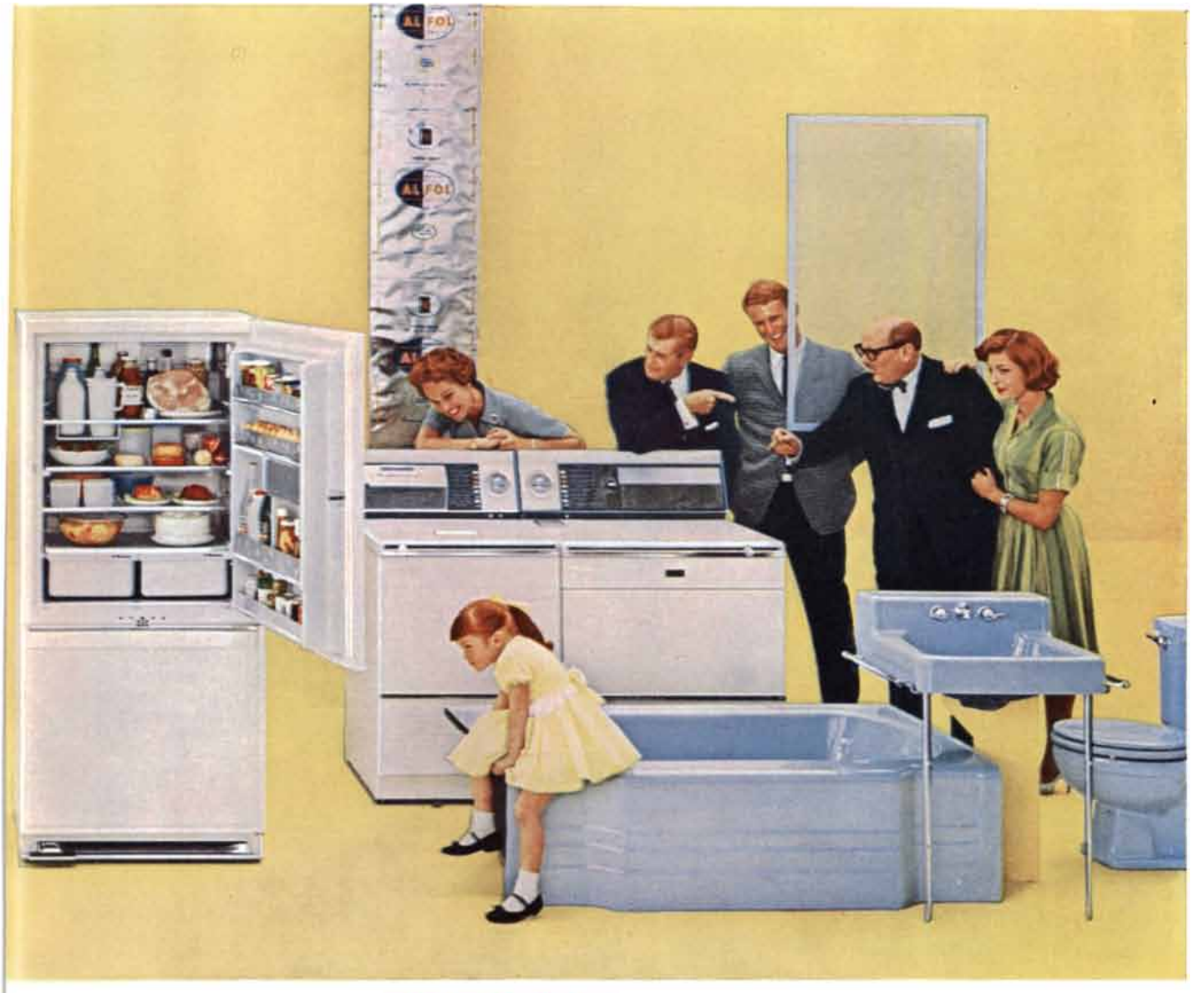

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Divisions and subsidiary companies of Borg-Warner contribute vitally to seven areas of activity, as symbolized by the *7 Hats of Borg-Warner.* They are: (top) national defense; oil, steel and chemicals; (middle row) agriculture; industrial machinery; aviation; (bottom) automotive industry; home equipment.

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BOOKS

A new work on the bases of scientific explanation

by A. J. Ayer

THE STRUCTURE OF SCIENCE, by Ernest Nagel. Harcourt, Brace & World, Inc. ($10).

I cannot think of anyone who is better qualified than Ernest Nagel to write a major work on the philosophy of science. There are eminent scientists who have a gift for popularization, but their philosophical outlook tends to be naïve. Philosophers, who have the logical equipment, are usually deficient in their knowledge of the scientific facts. In some cases, though they have the requisite knowledge, they are so governed by their preconceived ideas of what scientific procedures ought to be that they give a distorted account of what they actually are. Nagel is free from all these defects. He is a master of the technique of logical analysis; his knowledge both of the physical and the social sciences is detailed and extensive; and his approach to his subject is entirely open-minded. He has his philosophical position, which can be broadly described as a liberal empiricism, but one of its salient features is a meticulous respect for fact.

Up to now Nagel's work has been mainly critical. He has been a relentless enemy of philosophical *Schwärmerei,* and has proved himself an adept at puncturing pretentious theories, both in the philosophy of science and in other fields. Occasionally one had the feeling that these targets were hardly worthy of the skill and labor he devoted to destroying them. In contrast, the present book is not at all polemical. Its analyses display his critical powers but its character is almost wholly expository. The aim is to exhibit the logic of scientific explanation as it is actually developed throughout the whole range of science. Philosophical questions about the status of scientific concepts and about the justification of scientific theories, with such difficult topics as the analysis of probability and the problem of induction, are reserved for a second volume. Though the scope of the inquiry is wide, it is not pursued at too high a level of generality. One of the great merits of the book is the profusion and variety of its examples and the care and lucidity with which they are set out. Many of these examples are highly technical, but they are presented with only slight recourse to advanced mathematics and without too forbidding an array of technical terms. In an effort to make his book intelligible to the layman, Nagel has also avoided the symbolism of formal logic. The book is not popular in the sense of minimizing the difficulty or complexity of the questions with which it deals, but it is written in a good, plain, sober style and the argument is developed in an orderly, straightforward fashion. It should therefore have the wide appeal for which its author hopes.

The book, which is more than 600 pages long, is divided into 15 chapters. Of these the first six, which together occupy about a quarter of the work, are devoted to general questions about the forms of explanation, the character of scientific laws and the distinction between more abstract scientific theories and experimental laws and facts. The results of this investigation are then applied to the special case of physics, in a discussion that occupies the next quarter of the book. Of the four chapters that make up this section, two are concerned respectively with classical mechanics and with the question of causality and indeterminism, especially as it is raised by the quantum theory; the other two, with the set of problems that have regard to the nature of geometry and its application to physics and to physical space.

There follows an account of what may be meant by saying that one scientific theory is reducible to another, the main purpose of which is to lay the groundwork for examining the relations between physics and biology. The idea that biology differs essentially from physics because it is concerned with organic wholes, as opposed to merely mechanical aggregations, is critically discussed. From biology Nagel passes to the social sciences, assigning one chapter to their methodological problems and another to an analysis of the types of explanation they can furnish. The last chapter in the book is devoted to the topic of history. The main question it raises is whether historical inquiry has a logic peculiar to itself.

At the outset Nagel distinguishes four types or patterns of scientific explanation; he calls them deductive explanations, probabilistic explanations, functional or teleological explanations, and genetic explanations. Of these he clearly regards deductive explanations as the most important; indeed, one of his purposes is to show that the explanations he characterizes as functional or genetic are themselves only variants of deductive or probabilistic explanations; and probabilistic explanations, though weaker than deductive explanations in the strict sense of the term, are still deductive in pattern.

The requisites for a deductive explanation are first that the proposition that states what is to be explained should appear as the conclusion of a valid logical argument; second, that this argument should have more than one premise and that these premises, while entailing the conclusion, should not also be entailed by it; and third, that, independently of the conclusion, there should be good reason for believing the premises to be true. A further condition, of minor importance, is that none of the premises should be superfluous, in the sense that the argument would still be logically valid if one or more of them were dropped. It has also been suggested as a further requirement that at least one of the premises should be more general than the conclusion, but, as Nagel points out, the notion of greater generality is not at all easy to define. Whether one proposition is more general than another would appear to depend on the way in which they are expressed. He does, however, succeed in formulating a set of rather elaborate conditions under which comparisons of generality would have a

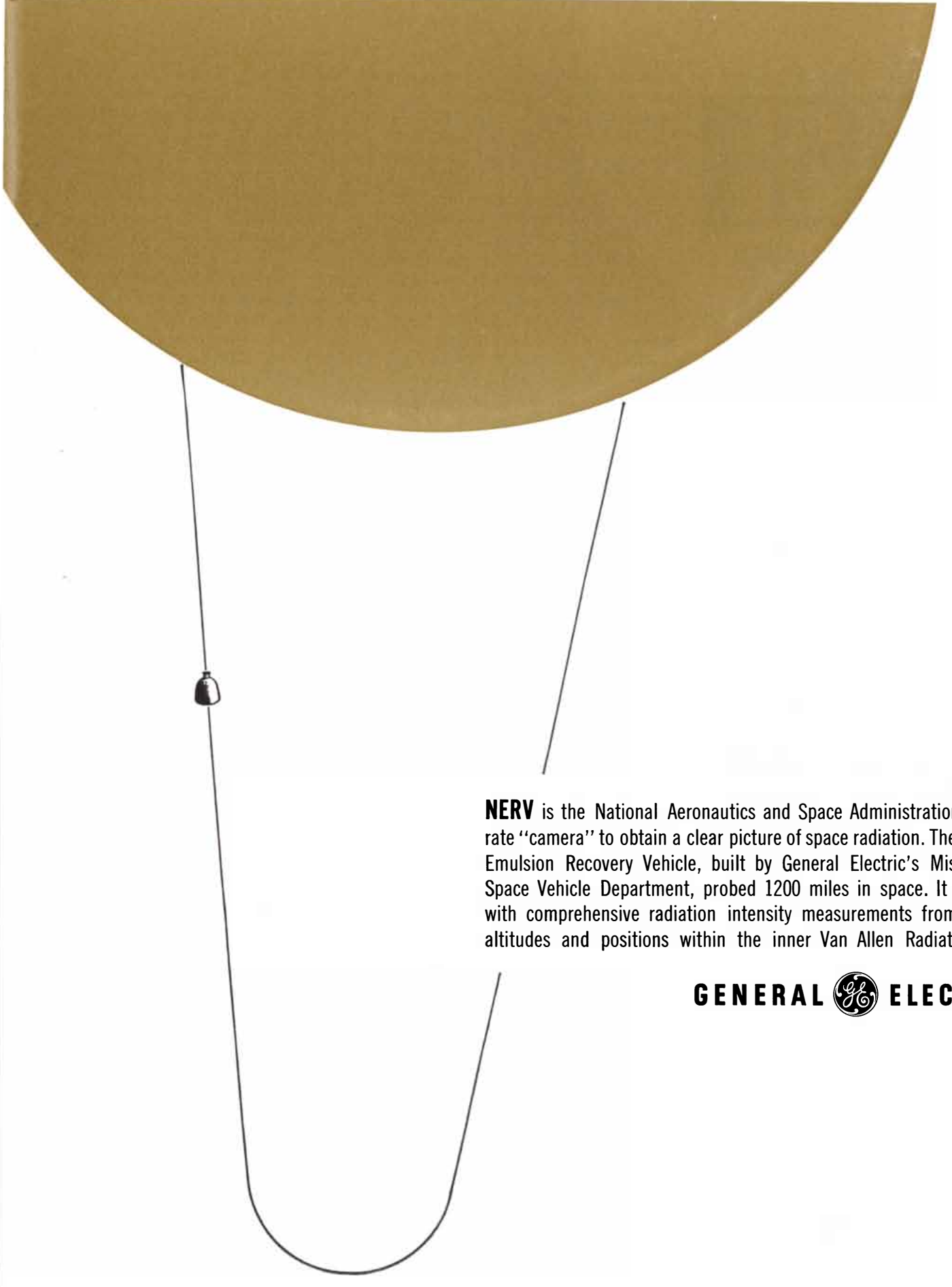
more precise meaning, and he argues that these conditions are quite commonly satisfied.

In the case where what has to be explained is the occurrence of some particular event, the premises must contain one or more propositions that refer to particular events. These propositions describe the so-called initial conditions, which are linked to the event they help to explain by some statement of natural law. In the case where the thing to be explained is itself a law of nature the same must be true of all the premises from which it is deduced. It is important to note that in neither case is it sufficient for one or more of the premises to be a true universal statement, if it falls short of being a natural law. For example, the proposition that this coin is made of silver is logically deducible from the true premises that this coin is in my pocket and that all the coins in my pocket are made of silver, but no one would say that in making this deduction I had given an explanation of the fact that this coin is made of silver. The reason for this is that the universal proposition that all the coins in my pocket are made of silver, though it happens to be true, is not the expression of a law of nature.

But what makes a universal proposition the expression of a law of nature? How do such statements of law differ from merely accidental generalizations such as the proposition that all the coins in my pocket are made of silver? Nagel tries to answer this question, but I do not think that his treatment of it is altogether satisfactory. Following Hume, he rejects the idea that propositions that express laws of nature are statements of logical necessity, and he holds that the idea that they state nonlogical necessities would be of no service, even if it were intelligible. On these points I am sure he is right. But if the connection between the predicates associated by a law of nature is purely *de facto,* it is hard to see what can be meant by saying that it is a law. It has been suggested that the difference between a statement of law and a generalization of fact is that the statement of law makes no specific reference to any individual, but, as Nagel points out, this is not always so. For example, the first of Kepler's three laws of planetary motion—that the planets move on elliptical orbits with the sun at one focus of each ellipse—explicitly refers to the sun. How then, to use Nagel's own example, does a statement of this kind differ from the statement that all the screws in Smith's current car are rusty, which he takes as his "paradigm of accidental universality"?

Nagel's answer is that the statement about Smith's car is restricted in a way that the statement of Kepler's law is not. It is restricted in that it marks out the objects to which it applies as falling within a specific spatiotemporal region. Nagel argues that this would remain true even if one disguised it by coining the word "scarscrew," meaning "screw in Smith's car during period *a*," and changing the statement to "All scarscrews are rusty." The objection to this is that it will always be possible to find a genuinely qualitative predicate that will serve to identify any such collection as the sets of screws that are now in Smith's car. It is only necessary to find some object that happens to be unlike any other in appearance and some event that happens to be unique in character, and then characterize the members of the set as those that satisfy the predicate of being in such and such spatial and temporal relations to an object or an event of that kind. It will be a contingent fact that this predicate does apply uniquely to the things in question, but this does not matter to the argument. On the contrary, if the generalization is to be unrestricted, the things to which it applies must not be identified by a predicate that it is logically necessary only they could satisfy.

Nagel also suggests that an accidental generalization can be distinguished from a statement of natural law by the fact that it "can be construed as a compendious way of asserting a finite conjunction of statements," whereas a statement of law cannot. Thus he maintains that "All the screws in Smith's current car are rusty" is equivalent to "If s_1 is a screw in Smith's car during period *a,* then s_1 is rusty during *a,* and if s_2 is a screw, etc., up to s_n, where *n* is some finite number." This is surely a mistake. These two statements are not only not equivalent; neither of them entails the other. From the fact that screws s_1 to s_n are rusty it does not follow that all the screws in Smith's car are rusty, because it does not follow that there are not more than this number of screws in Smith's car. Conversely, from the fact that all the screws in Smith's car are rusty it does not follow that all or even any of the screws s_1 to s_n are rusty, because it does not follow either that these are the screws in question or that there is just this number of them. It is true that the number of screws in the car will in fact be finite, but the number of the things to which a law of nature applies—for example, the planets—may also be finite. It is also true that the way in which we commonly establish an accidental generalization is by inspecting all the instances, whereas this



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is not the way in which we establish a generalization of law. I suppose that a generalization of law could be established in this way, if its instances were finite. In any case, as Nagel admits, this is not the only way of establishing a statement of accidental generality.

There is, nevertheless, something in this point. One feels that even finding that all the actual instances were favorable would not conclusively establish a mere generalization of fact. The reason for this is that the statement of law is supposed to cover not only all the actual instances but all possible instances as well. One way to make this distinction is to say that statements of law entail subjunctive conditionals and that generalizations of fact do not. It is implied by Kepler's law that if anything were a planet it would move on an elliptical orbit, whereas in the other example it is not implied that if a different set of screws were in Smith's car they also would be rusty. But then the question arises: How are subjunctive conditionals to be interpreted?

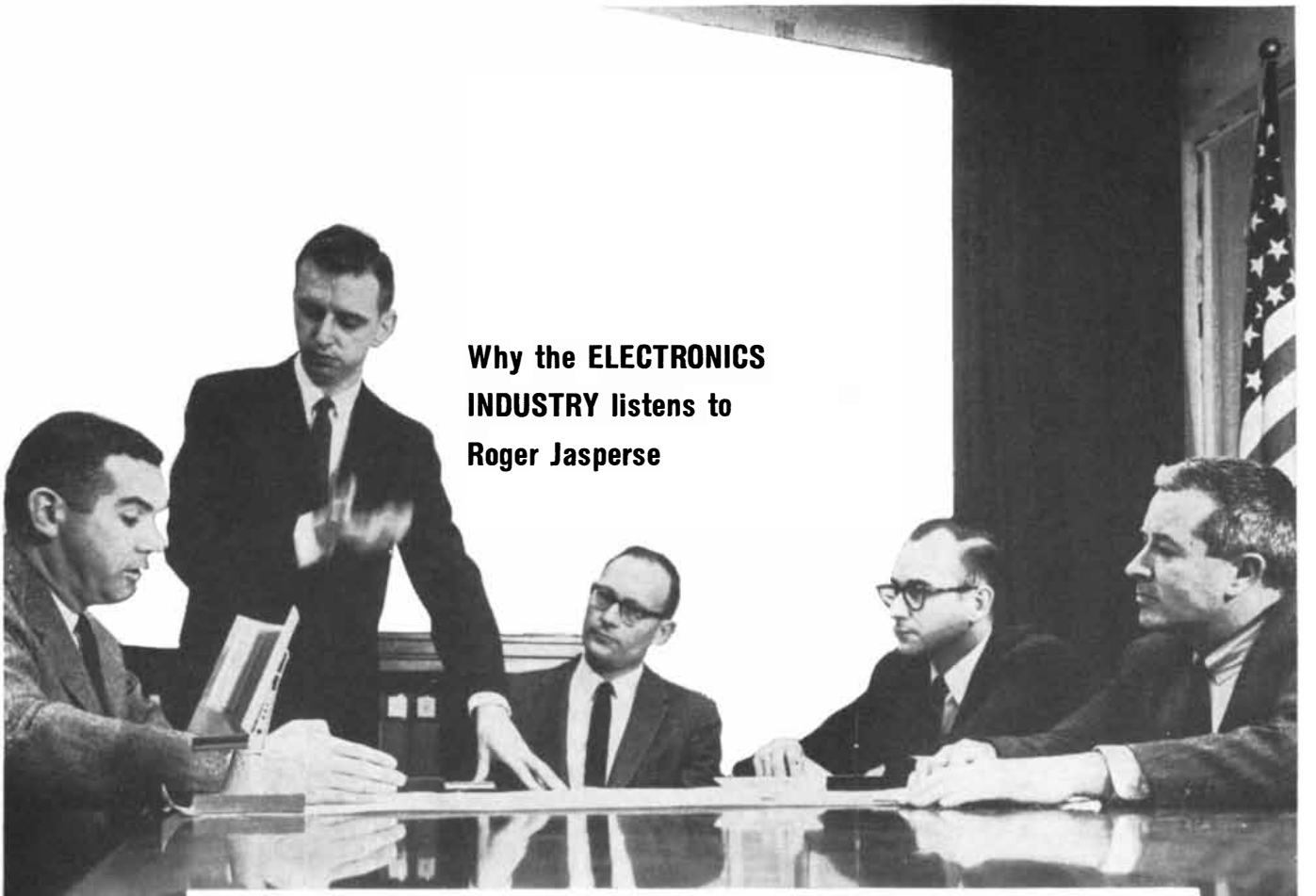
Nagel considers this question, though in outline rather than in detail. His suggestion is that counterfactuals, as he calls them, are statements about statements. In his view, to say that if a were P, then b would be Q, where both the antecedent and the consequent are known to be false, is to say that the statement "a is P and b is Q" follows from a statement of law together with some appropriate specification of initial conditions. But, apart from other difficulties, this merely reinstates the problem of characterizing statements of law. Moreover, while it may be that the only reason for accepting a counterfactual hypothesis is that it can be backed by a statement of law, this is not the same as saying that the statement of law is actually part of the content of the hypothesis; indeed, there are many examples in which this seems most implausible.

My own view is that the difference between generalizations of law and generalizations of fact is not so much a difference in their content as a difference in our attitude toward them. It is partly a question of the different roles that these generalizations play in explanatory systems, partly that the evidence that might lead us to abandon a statement of one or other type is differently weighted. Nagel makes some remarks that suggest he might be sympathetic to a theory of this kind but he does not develop them. In so far as the problem can be reduced to a question of the value of evidence, Nagel will no doubt be returning to it in his second volume.

Nagel already deals to some extent with questions of evidence in the chapters that he devotes to the status of scientific theories. He recognizes that the distinction between abstract theories and experimental laws is not sharp but he thinks that it can be given a sufficiently clear meaning. In his view there are three components in a scientific theory that it is useful to distinguish: first, an abstract calculus that "implicitly defines the basic notions of the system"; second, a set of rules that relate the abstract calculus "to the concrete materials of observation and experiment"; and third, "an interpretant or model for the abstract calculus . . . in terms of more or less familiar conceptual or visualizable materials." The second component is essential because without it the theory would have no material content. It is not necessary, however, for every term in the theory to be linked with observations; it is enough if the connection can be made at certain points. Neither is it necessary for the linkage to take the form of explicit definitions on the basis of terms that stand for what can be observed; the correlations may be not logical but factual. Nagel therefore rejects the classical thesis of phenomenalism, that theoretical statements can be simply translated into observational ones. The question then arises whether these theoretical statements can be said to be true in the sense that they state facts about real physical entities, or whether, as some hold, they are merely instruments that serve to correlate and systematize the facts that are revealed by observation. After examining the question in some detail he concludes that it is mainly verbal. It depends on the criteria we choose to adopt for deciding what is to count as a real physical entity.

On the subject of geometry and physics Nagel's views are not novel, but they are sensible and convincing. He allows that there is a sense in which a geometry may be regarded merely as a set of conventions, which serve to fix the usage of such terms as "plane" and "straight line"; he also allows that since Euclidean and non-Euclidean geometries are intertranslatable, experience cannot decide between them. Nevertheless it is an empirical question whether or not a given set of physical objects conforms to some physical theory of which a particular geometry is a component, and experience can show that one or another form of spatial analysis is better adapted in a given domain to serve as a basis for a successful physical theory.

To my mind the most impressive section of Nagel's book is the one in which



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he deals with the question of causality and indeterminism. He first gives a clear account of the sense in which classical mechanics was deterministic. If we define the "mechanical state" of a point mass at a given time as being its position and momentum at that time, then the assumption of classical mechanics is that "given the force-function for a physical system, the mechanical state of the system at any time is completely and uniquely determined by the mechanical state at some arbitrary initial time." There are, however, two points to be noted about this that are often overlooked. First, allowing the assumption to be true, it establishes determinism only with respect to the mechanical properties of a physical system; second, the mechanical states that are determined are theoretical states: they are defined in terms of instantaneous positions and velocities, but these are not the states that are actually measured.

We are often told that determinism breaks down when it comes to quantum physics; but the ground for saying this is just that there is no place in quantum physics for the classical notion of a mechanical state, since quantum physics does not allow us to assign any values to the exact position and momentum of a particle at a given instant. In quantum physics such expressions as "the instantaneous momentum and position of an electron" are not assigned any empirical meaning. The reason for this, as Nagel points out, is that such terms as "position" and "momentum" do not have the same sense here as they have in classical mechanics; they are defined by means of quantum equations, which include the so-called relations of uncertainty. Thus the impossibility of precisely measuring the position and velocity of an electron at a given instant is not just an empirical fact on which the uncertainty relations are grounded; it is a consequence of the theory.

The point, then, about quantum mechanics is that it has its own special form of state description, which is different from that of classical physics. Nagel argues that with respect to its own form of state description, which is defined by Erwin Schrödinger's celebrated psi function, quantum mechanics is deterministic, because one state can be calculated in terms of another. The system gets its empirical meaning through the fact that "the square of the absolute value of psi is interpreted as the *probability* that the elementary constituents of the system for which it is defined (*e.g.*, the system consisting of the nucleus and the single electron of a hydro-

gen atom) are at various points in space"; these probabilities are associated with other probabilities that are co-ordinated with empirical concepts. Thus the laws connecting micro-states are statistical, but Nagel argues that it does not follow from this that the laws that connect macro-states must be statistical also.

The conditions Nagel lays down for the successful reduction of one theory to another are that the basic terms of the secondary theory should be analyzable into those of the primary theory; that the laws of the secondary theory should be logically deducible from those of the primary; that the premises of the primary theory should be supported by empirical evidence; that the reduction should integrate into one theory laws that were previously independent; and that it should lead to the discovery of new laws. In the case of biology and physics it is an open empirical question whether or not these conditions can be satisfied. We must not, however, assume that biology cannot be reduced to physics merely because its pattern of explanation is likely to be teleological. Explanations of this kind are also to be found in physics, and in any case, Nagel maintains, an explanation that is teleological in form can always be recast in a form that is not teleological. Neither is there any fundamental distinction between teleological and nonteleological statements with respect to the evidence that supports them.

I have left myself no room in which to give a detailed account of Nagel's treatment of history and the social sciences. His main contention is that the patterns of explanation that are employed in these fields are not essentially different from those he attributes to the physical sciences. He makes out a strong case for this view and supports it as usual with a careful analysis of fundamental concepts and a generous provision of examples.

Altogether I regard this book as a most important contribution toward the essential task of building a bridge between philosophy and science. I have learned a great deal from reading it and hope that its sequel will not be long delayed.

Short Reviews

BIOLOGY AND COMPARATIVE PHYSIOLOGY OF BIRDS: VOL. I, edited by A. J. Marshall. Academic Press Inc. ($14). The editor of this co-operative survey, an Australian biologist, remarks that its genesis lay in personal necessity. "I had become extremely bored," he writes,

"with the frequent need to go back into the Victorian or Edwardian literature, or to translate from another language, whenever I wanted a relatively simple piece of information about a muscle, bone, the blood, gut or sense organs of birds." Moreover, no single volume gave "even moderately comprehensive accounts of the many—and often exciting—ornithological discoveries made during the past thirty years." In this volume, the first of two, specialists discuss the origin of birds, adaptive radiation, classification and distribution, development, the integumentary system, skeleton, musculature, vascular system, respiratory system, digestion, excretion. The topics of the promised second volume range from the nervous system through bird flight, long-distance orientation, behavior and bird populations. Illustrations and bibliographies.

SMOKING: ITS INFLUENCE ON THE INDIVIDUAL AND ITS ROLE IN SOCIAL MEDICINE, by C. van Proosdij. Elsevier Publishing Company ($11). Shah Abas the Great—the story is told by the chevalier Chardin, who visited Persia in the 17th century—abominated smoking and decided to make sport of those addicted to the filthy habit. He had the hookahs of several distinguished personages who were dining with him filled with horse droppings instead of tobacco. From time to time he asked his guests what they thought of his tobacco; they invariably replied that it was excellent. Admittedly it would have been imprudent to cross the Shah; still, smokers are a determined lot and when they will smoke they will smoke. Yet if they were as hospitable to reason as they are to almost any fumes they can inhale without instant suffocation, they would be much chastened by this excellent book. The author, a Dutch physician, has made a careful review of the huge literature on the tobacco habit. He summarizes present knowledge on a wide range of topics: pharmacology, methods of investigating the effects of smoking, the damage tobacco does to the human organism, tobacco as a sociopsychological phenomenon. His commentary is no less valuable than his précis; he is always fair, clear and reasonable and as free from preconceptions as one could wish. The evidence is overwhelming that smoking, except in true moderation, is harmful. Cigarettes are of course the worst form of the habit and by far the most widely practiced. (Is smoking 10 cigarettes a day "moderate"? Van Proosdij offers a disconcerting statistic: Anyone smoking 10 cigarettes a day

from the age of 20 to 60, spending eight minutes on every cigarette, has been occupied in smoking for nearly two years and a half.) The author makes no bones about his position on the serious dangers of smoking. At the same time he recognizes the charms and lures of tobacco, its soothing effects, the door of escape it offers from the pressures, the tensions and the tedium of daily life. If that door is shut, others even more dangerous may be opened. He makes a number of suggestions, among them changes in smoking habits, making people more fully aware of the harmful effects of smoking and especially educating and supporting the younger people who have not yet become addicts. Puffing away nervously while preparing this note, your reviewer is in a position to recommend this book highly to those who need the weed, to those who have forsworn it but fear they will slide back, to those who mean either to cut down or to stop entirely tomorrow and even to those who have never been seduced. You will not light up with quite the same alacrity for at least a day after this sobering experience.

EAST ANGLIA, by R. Rainbird Clarke; THE ANGLO-SAXONS, by D. M. Wilson; BRITTANY, by P. R. Giot; THE CELTS, by T. G. E. Powell; THE SCYTHIANS, by Tamara Talbot Rice; WESSEX, by J. F. S. Stone. Frederick A. Praeger, Inc. ($6.50 each). These are further volumes in the series "Ancient Peoples and Places," edited by the British archeologist Glyn Daniel. Each fulfills the editor's aim of providing clear introductions to the early history of important regions and peoples, summaries of what archeologists have found in their digging: the remnants and fragments, the graves and urns and caskets, the tools, weapons, household articles, jewels, statues, monuments, coins and eoliths—the many rude or sophisticated or exquisitely beautiful objects by which the past is brought alive. All the authors have experience in the field and write with enthusiasm about their subject and with a sure sense of how much detail the nonspecialist reader is prepared to consume. Admirable plates and drawings as well as useful maps and charts appear in each volume, and each is an attractive example of book design. Altogether a delightful set.

PIONEERS OF SCIENCE, by Sir Oliver Lodge. Dover Publications, Inc. ($1.50). This is a famous elementary history of science, based on lectures which Lodge gave at the University of

Liverpool in 1887. The subjects include the life and work of Copernicus, Tycho Brahe, Kepler, Galileo, Descartes, Newton, Ole Roemer and James Bradley, Lagrange and Laplace, William Herschel, F. W. Bessel. Modern researches in the history of science have left this book behind in some respects, but it is lucid, attractively written and well illustrated. One cannot find a history better suited to the tastes and needs of the student and general reader.

THE LOWER ANIMALS, LIVING INVERTEBRATES OF THE WORLD, by Ralph Buchsbaum and Lorus J. Milne, in collaboration with Mildred Buchsbaum and Margery Milne. Doubleday & Company, Inc. ($12.50). This recent volume in the "World of Nature Series" is a rather ambitious natural history of animals without backbones. Insects are not covered in this volume; nevertheless its range is very large and the authors have had the task of covering a wider field than is dealt with in other books of the series. The text is authoritative, agreeably discursive and filled with striking facts that charm the common reader. A large collection of illustrations (315, including 144 in color) helps make this an excellent introductory guide to sponges, sea anemones, comb jellies, beard worms, lamp shells, jellyfishes, mollusks, arthropods, echinoderms and all their weird and enchanting relatives.

MEDICAL AND BIOLOGICAL RESEARCH IN ISRAEL, edited by Moshe Prywes. Grune & Stratton, Inc. ($8). An impressive survey of the medical and biological research done in Israel. The volume contains about 2,000 references, selected from some 5,000 publications. It deals with institutions, medical and higher education, regional and applied research in public health, social medicine, plant sciences, animal husbandry, and research of a general nature in experimental biology, medical disciplines, botany and zoology. Photographs.

THE SEARCH FOR THE TASSILI FRESCOES, by Henri Lhote. E. P. Dutton & Co., Inc. ($6.95). An absorbing account of the author's adventures in an expedition to discover the prehistoric rock engravings and paintings of the Sahara. This is an exciting story and the record of a major archaeological achievement; the rock paintings are among the most charming and remarkable examples of prehistoric art. Indeed, the pictures are so extraordinary that one is at first disinclined to believe in their authen-

ticity. This, however, has now been acknowledged by leading specialists.

ECONOMIC ATLAS OF THE SOVIET UNION, by George Kish. University of Michigan Press ($10). Five general maps portray physical features, vegetation zones, administrative divisions, air transportation, population distribution; 60 regional maps deal with agriculture, minerals, industrial location, rail transportation and cities. A useful and accurate guide, affording a synoptic view of the economic structure of the U.S.S.R.

A MANUAL OF COMMON BEETLES OF EASTERN NORTH AMERICA, by Elizabeth S. Dillon and Lawrence S. Dillon. Row, Peterson & Company ($9.25). Among the million species of insect known, the beetles form the largest group, possibly more than 600,000 having already been described. This volume deals with all aspects of those members of this numerous family living in eastern North America. It will serve the casual naturalist as well as the professional in need of a handy reference book.

ANTARCTICA, by Emil Schulthess. Simon and Schuster, Inc. ($15). A handsome and interesting oblong picture book by a Swiss photographer who took part in Operation Deep Freeze IV, a U. S. undertaking during the International Geophysical Year. Schulthess got fine shots in black-and-white and color of camps, planes, tractors, icebreakers, the incredible landscape, crevasses, icebergs, sunsets and of course penguins. Somehow there can never be too many photographs of these birds, and Schulthess has some beauties.

CRETE AND MYCENAE, by Spyridon Marinatos; photographs by Max Hirmer. Harry N. Abrams, Inc. ($25). A leading Greek scholar presents a lavishly illustrated account, historical and descriptive, of the archaeological discoveries and researches which uncovered the art of Crete and Mycenae. This is a splendid book for the general reader who wants an authoritative summary of these two great cultures. There are 421 illustrations, including 52 in color.

THE INTERNATIONAL DICTIONARY OF APPLIED MATHEMATICS, edited by W. F. Freiberger and others. D. Van Nostrand Company, Inc. ($25). A technical handbook covering mathematical terms and concepts in acoustics, aerodynamics, hydrodynamics, astronomy,

chemistry, atomic structure, mechanics, electromagnetic theory, probability, quantum mechanics, relativity, solid state physics, spectroscopy, thermodynamics, vector analysis, tensors and other subjects. Multilingual indices in German, Russian, French and Spanish.

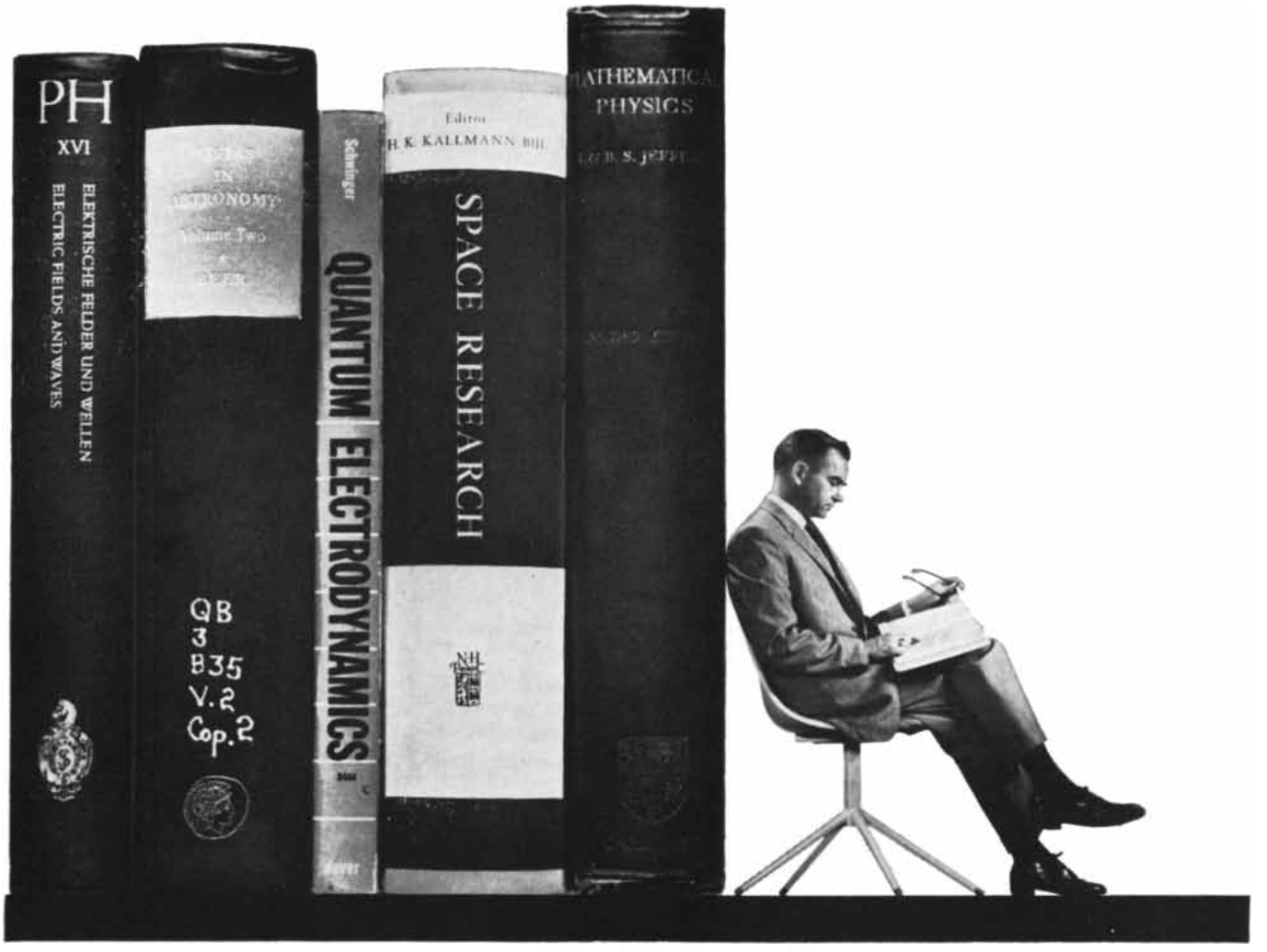
COMPUTER LOGIC, by Ivan Flores. Prentice-Hall, Inc. ($12). The merit of this book is that it describes plainly, with the help of diagrams, how a computer is put together, how it works and how it is used. The account begins at the most elementary level and proceeds through the more advanced aspects of design and function. A glossary adds to the usefulness of the volume for students, practitioners and the ordinary reader who wants to understand these industrious engines.

A BIBLIOGRAPHY OF DR. ROBERT HOOKE, by Geoffrey Keynes. Oxford University Press ($8). This attractively made book gives a biographical sketch of Robert Hooke and a scholarly, illustrated rundown of his writings. Hooke had a finger in every Royal Society pie and his nose in everyone's business—especially Isaac Newton's—but he was a man of extraordinary qualities, an inventive genius and richly imaginative, as may be seen from the range of his writings.

RUSSIAN SCIENCE IN THE 21ST CENTURY, by Sergei Gouschev and Mikhail Vassiliev. McGraw-Hill Book Company, Inc. ($4.95). What leading Russian scientists are doing and planning in physics, biology, astronomy, medicine and technology. The authors are Soviet journalists and they palpitate in exactly the same way as some American journalists. This makes for a mildly interesting but not always convincing story. Photographs.

LEGACY OF SUPPRESSION, by Leonard W. Levy. Harvard University Press ($6.50). A balanced history of the background and original meaning of the First Amendment's clause on freedom of speech and the press. This is a revisionist work which dispels some sacred national myths.

THE LOST CITIES OF AFRICA, by Basil Davidson. Little, Brown & Co. ($6.50). A lively and intelligent account of the evolution of African civilization based both on a study of the best sources—historical, archaeological and anthropological—and personal acquaintance with the land and its people. This



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is a strongly pro-African book but it is none the worse for its prejudices. Maps and photographs.

LIFE AND DEATH IN THE BRONZE AGE, by Sir Cyril Fox. Humanities Press ($8.50). A fascinating survey by a pioneer of modern archaeology of the yield of patient and prolonged field work in Bronze Age barrow excavations. From bits and pieces, with great skill and imagination, it has been possible to reconstruct many of the ceremonial, cultural, structural, technical and economic aspects of Britain from 1700 B.C. to 700 B.C. It is from the ceremonies surrounding burial of the dead that much has been learned about the ways of the living. Many fine photographs, maps, plans and the like.

Notes

MAMMALS OF WISCONSIN, by Hartley H. T. Jackson. University of Wisconsin Press ($12). A comprehensive reference work dealing with the more than 6,300 specimens of mammals in Wisconsin: descriptions, distribution data, information on habitat, status and habits. Photographs, diagrams and maps.

STARS AND STELLAR SYSTEMS: TELESCOPES. Gerard P. Kuiper, general editor; Barbara M. Middlehurst, associate general editor. University of Chicago Press ($8.50). This volume, the first of nine in a new compendium of astronomy and astrophysics, contains articles which describe in some detail the different telescopes in use at optical and radio wavelengths.

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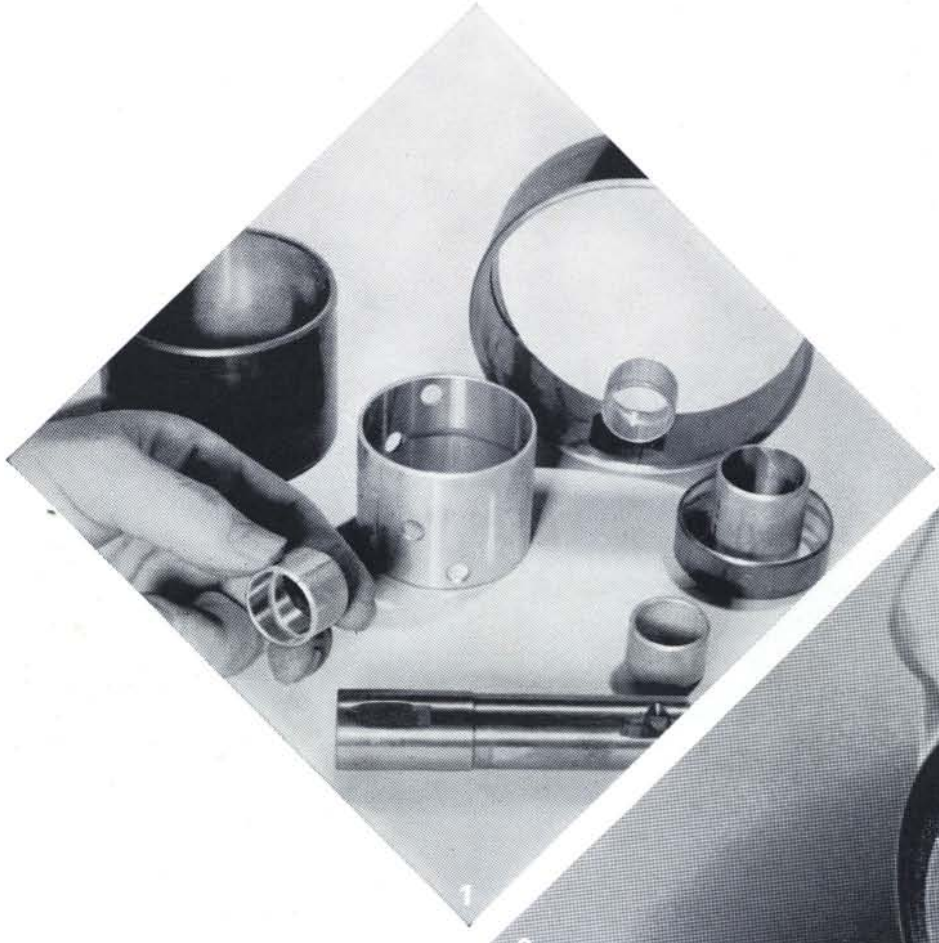

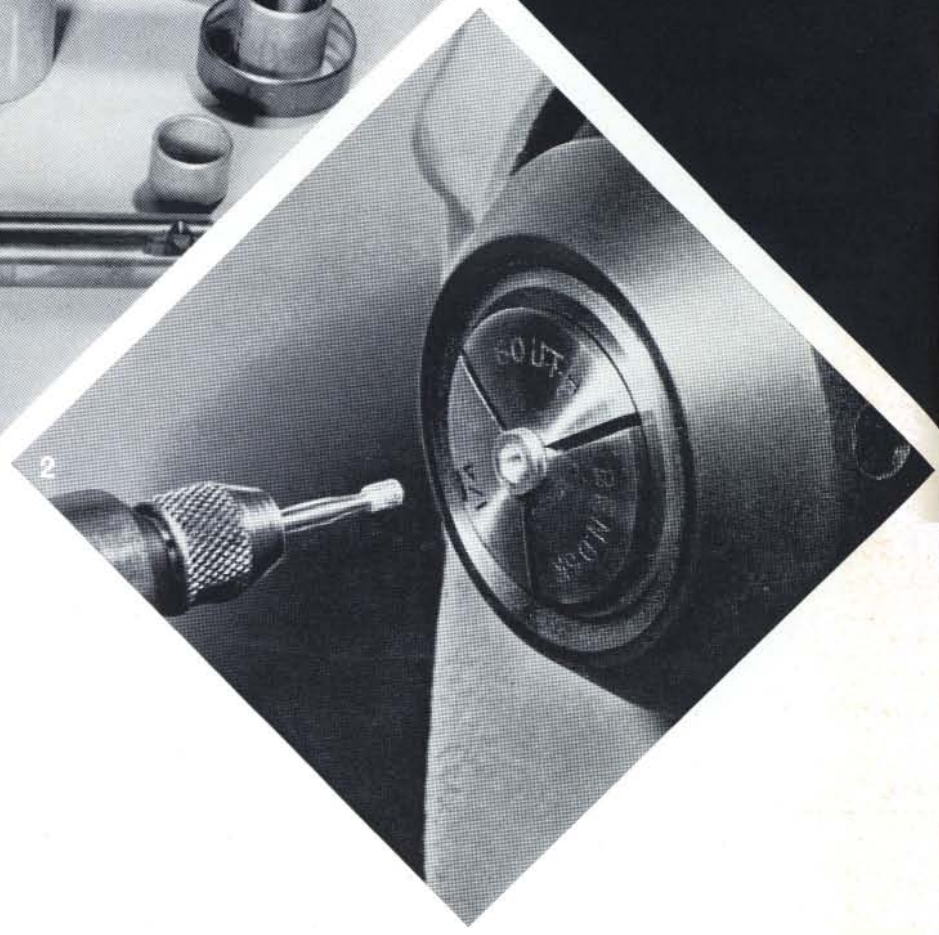

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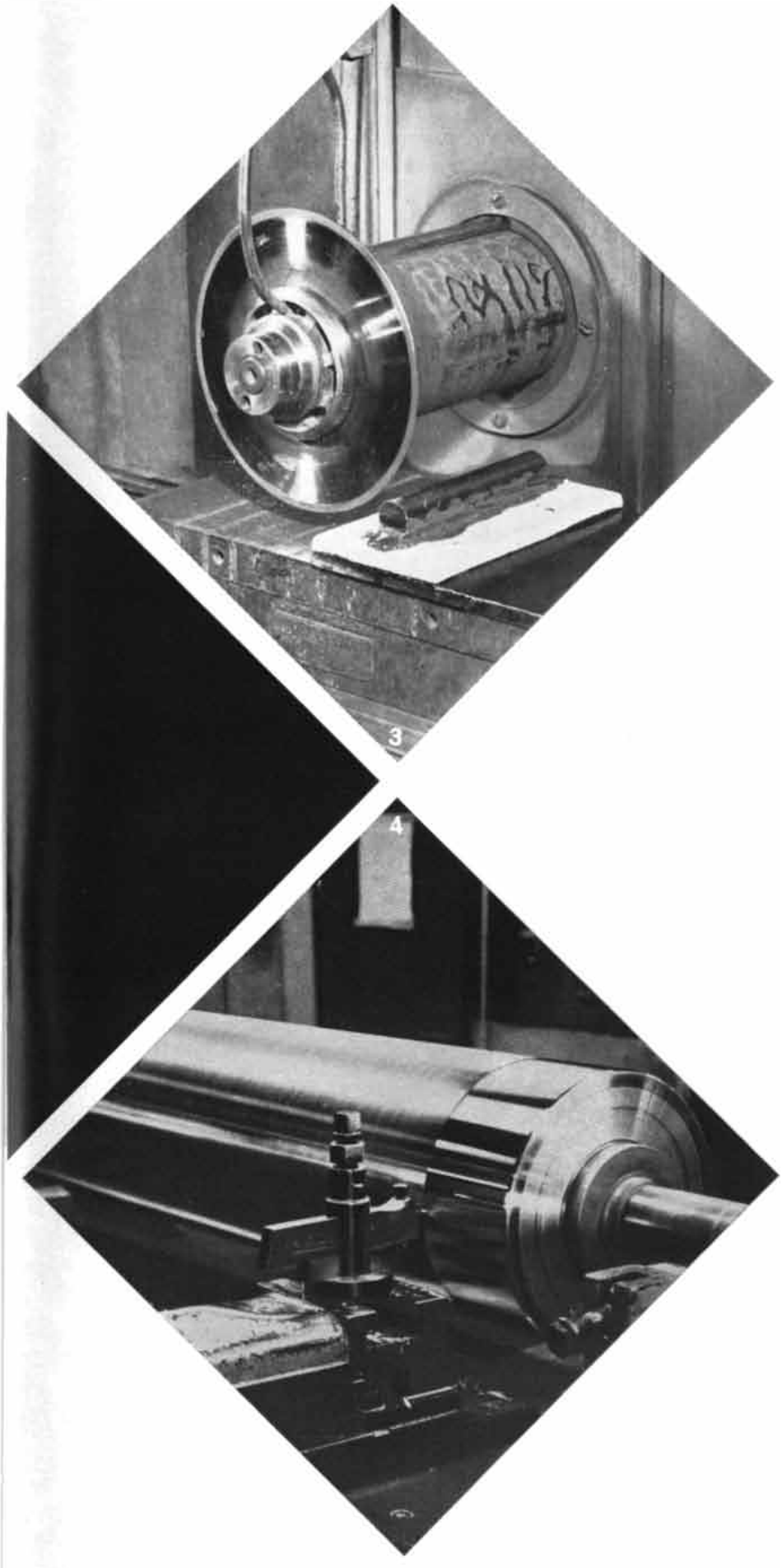

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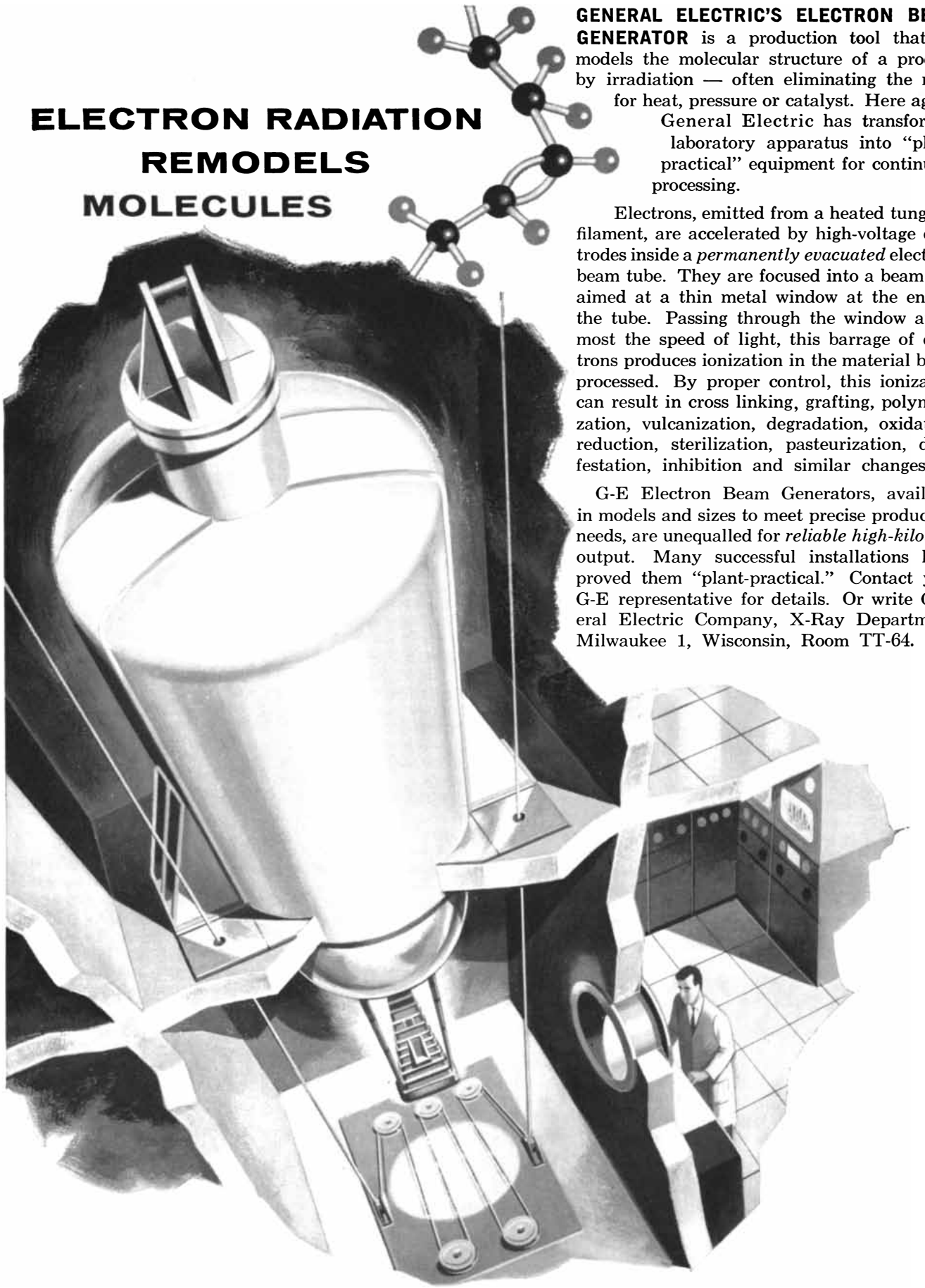

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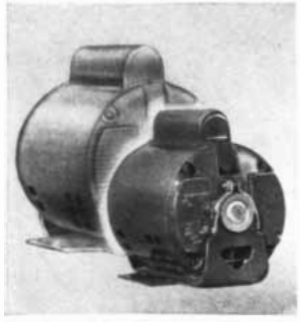

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