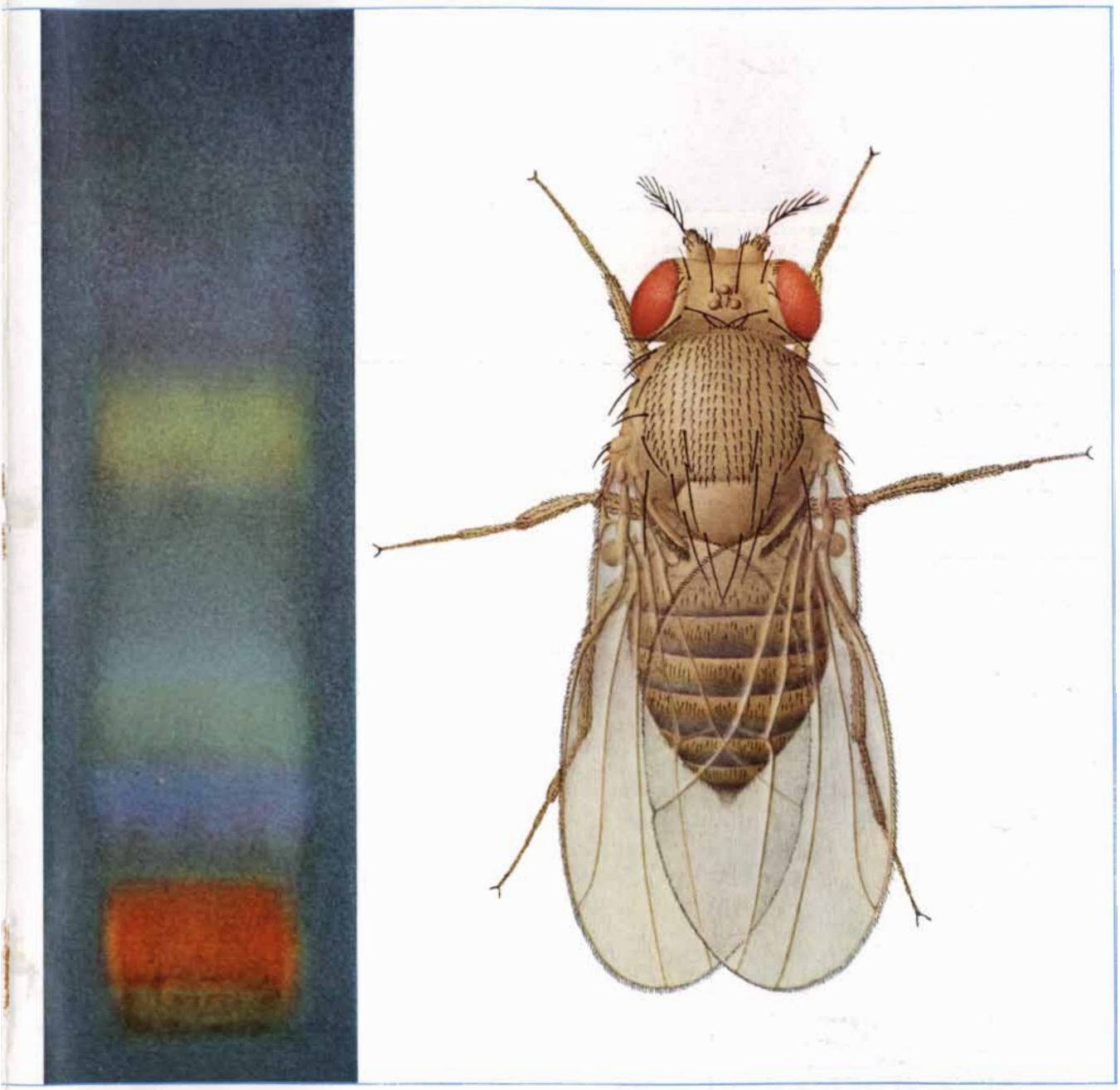
SCIENTIFIC AMERICAN



FRACTIONATED FRUIT FLY

FIFTY CENTS

April 1962

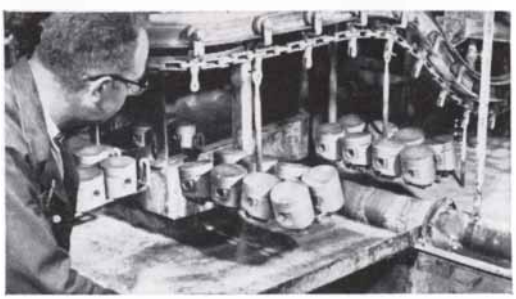
LOOKS BEST – GETS STILL BETTER: Just a few millionths of an inch of chromium—and automotive brightwork stays beautiful. Plating it a little thicker (over a nickel base) greatly increases corrosion resistance. In developing SRHS® Chromium, a self-regulating high speed process, M&T simplified plating this thicker chromium, dramatically increased its outdoor durability.

Metals meet Chemistry at M&T

Though M&T's activities are diverse, there is a solid base of imaginative chemistry underlying all. Such a union of chemistry and metals means scientific progress and better products.

OVER 1000 TONS – OVER 1000 FEET: At Cape Girardeau, Mo., the world's tallest structure rises 1676 feet. This TV tower is a tribute to modern welding which leans on science as well as skill. Not only is the chemistry of the electrode compatible with the structural metal but electrodes are also coated with metals and chemicals to promote weld integrity. M&T satisfies the specifications with "Murex" electrodes—mines titanium mineral used in many electrodes.

QUICK BATH SLOWS ENGINE WEAR: The auto factory does more to "break in" aluminum pistons properly than careful new car drivers. A quick bath in a solution containing M&T potassium stannate puts on a thin, soft, lubricating layer of tin. Surfaces then wear-in without galling or scoring. M&T is the country's leading supplier of stannates.



Metal & Thermit Corporation

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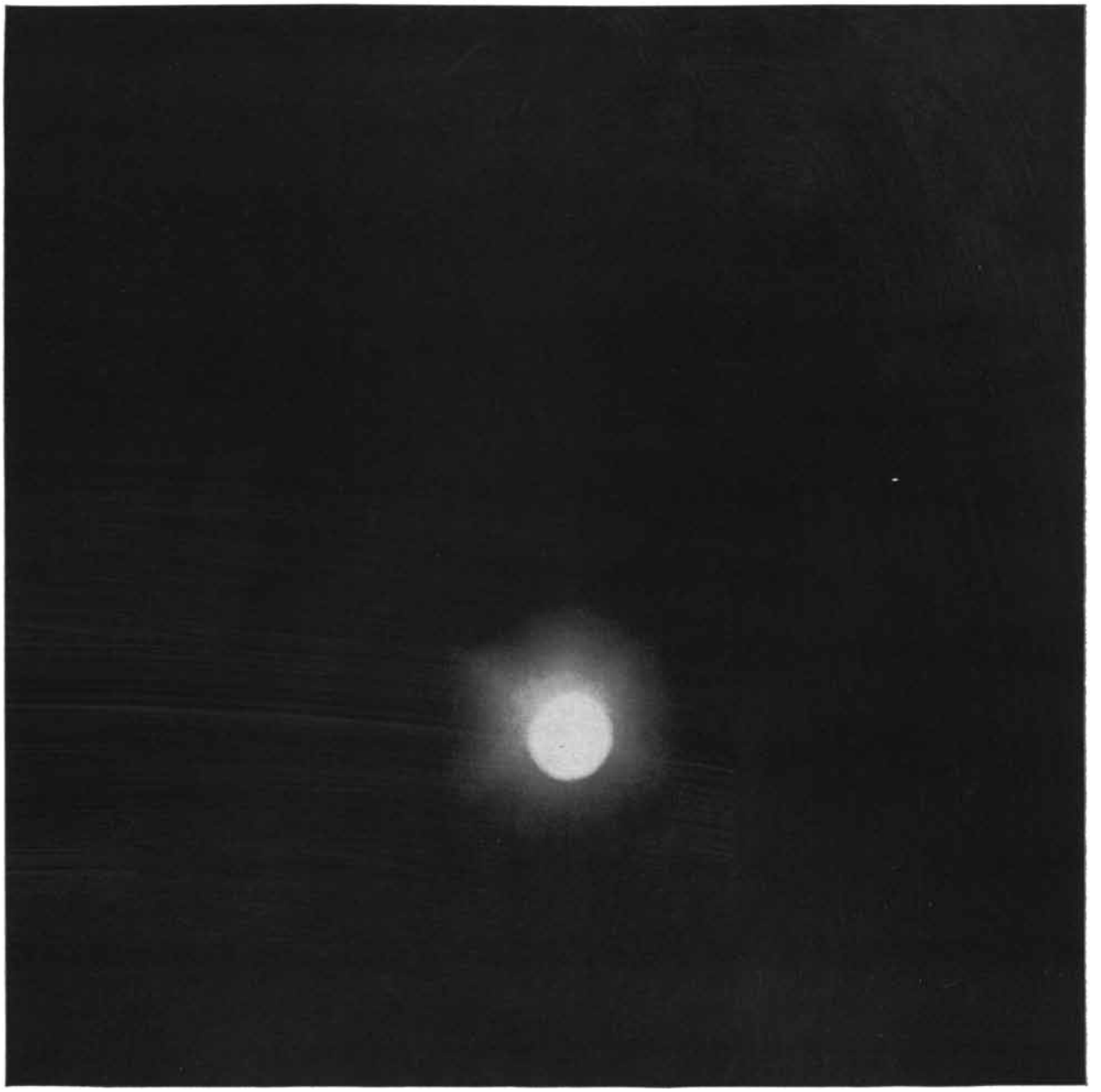
M&T



material in search of an inventor

DOW EPOXY RESINS

Can inventors and designers do without Dow epoxy resins? It's not likely.

We know of great numbers of jobs best done by epoxy resins. Beyond doubt other new applications virtually beg for the toughness, chemical inertness, moisture resistance, and dielectric superiority of Dow epoxy resins. Then there's the extremely high adhesion and low shrinkage, plus resistance to mechanical and thermal shock. Why Dow? Because we make every ingredient that goes into our resins . . . which means we can offer unusual purity. We can also offer resins with unusual properties. A Dow epoxy novolac, for example, with unusual high temperature stability (up to 500° F.). Or a flame retardant epoxy which provides top physical and electrical properties. Not to mention formulations which are almost colorless. And so on.

When you have the problems, we have the epoxies . . . many types. Chances are one is just right for your job. Samples available. Write Coatings Sales Dept. 1640EQ4.

THE DOW CHEMICAL COMPANY DOW Midland, Michigan

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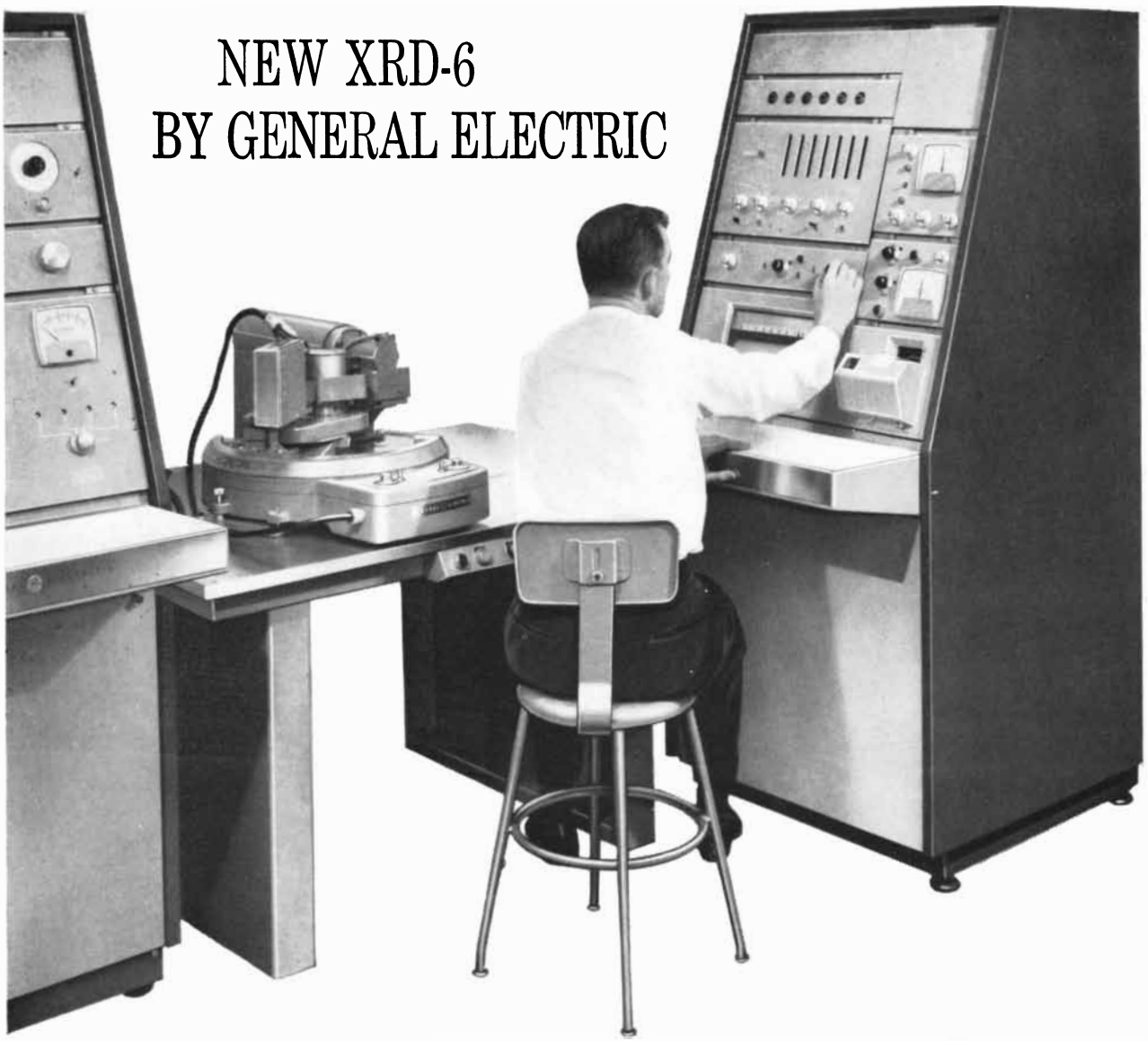
BY GENERAL ELECTRIC



New power... new flexibility... new functional efficiency

X-ray analysis makes a major advance with the introduction of this new XRD-6 diffraction and emission equipment — designed and developed by General Electric. Everything new about the XRD-6 can be translated into terms of new capabilities and greater utilization for the laboratory and the production line.

XRD-6 DEVELOPS MORE POWER. With a maximum total output of 75 kvp at 50 ma, or 37½ kvp at 100 ma, you can expect greater versatility in the kind of materials you can analyze and in the kind of analyses you can perform.

XRD-6 PRODUCES GREATER FLEXIBILITY. A higher intensity of x-rays gives you a correspondingly high speed of measurement, shorter studies over a broad operating range and with greater efficiency. The spectrogoniometer provides a stable, accurate base for holding and measuring a wide variety of samples. Angles are measured with a precision of .002°. Sample holders, spectrometers, and cameras match this accuracy and add a versatility that accommodates a broad range of applications.

XRD-6 GIVES YOU TRUE FUNCTIONAL EFFICIENCY. This system features a functional design that puts precise information conveniently at your fingertips. Physical design and human engineering result in maximum comfort at the controls, as well as easy internal access and a new, high degree of utilization for any application.

Contact your General Electric representative for more information on XRD-6. Or, for your copy of the new catalog on diffraction and emission, write directly, to X-Ray Department Room TT-44, General Electric Company, Milwaukee 1, Wisconsin. Ask for Pub. 7A-3912.

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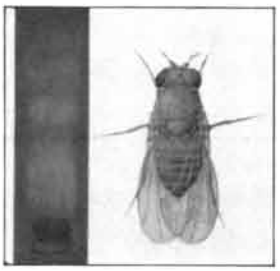
GENERAL ELECTRIC

Established 1845 **SCIENTIFIC AMERICAN** April 1962 Volume 206 Number 4

ARTICLES

DEPARTMENTS

PUBLISHED MONTHLY BY SCIENTIFIC AMERICAN, INC., 415 MADISON AVENUE, NEW YORK 17, N.Y. SECOND-CLASS POSTAGE PAID AT NEW YORK, N.Y., AND AT ADDITIONAL MAILING OFFICES. SUBSCRIPTION RATE: $6 PER YEAR.



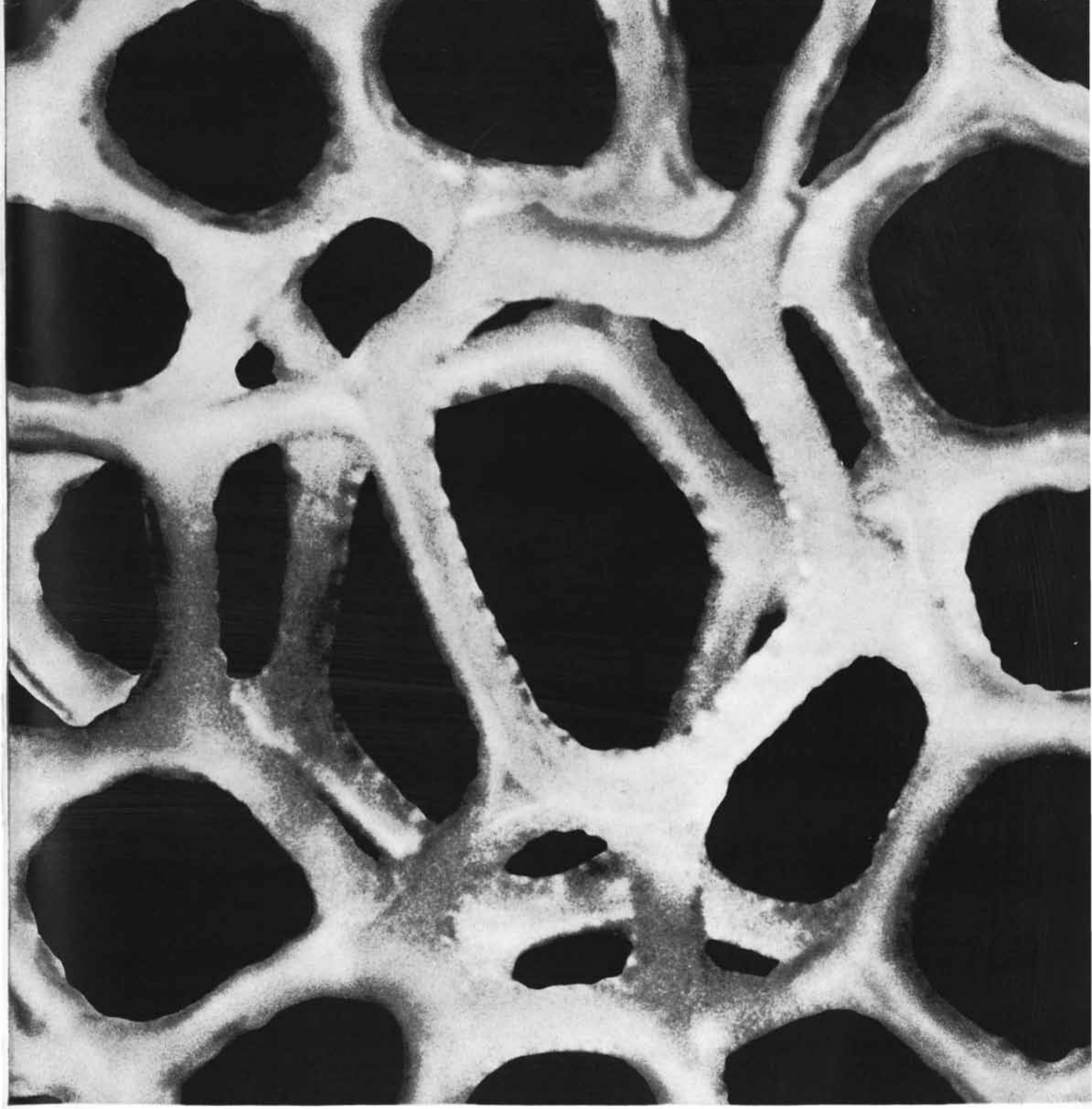
THE COVER

At right in the illustration on the cover is a normal, or "wild type," female fruit fly of the species *Drosophila melanogaster*. The fly is enlarged some 50 diameters. At left in the illustration is a paper chromatogram made by crushing the fly at the bottom of a piece of filter paper and then allowing a solvent to travel up the paper by capillary attraction. As the solvent moves upward it carries with it various pigments of the crushed fly at various rates. When the paper is viewed under an ultraviolet source, the pigments appear as luminous bands of color. Other varieties of the same species of fly give rise to different assortments of pigments and different chromatograms (see "Fractionating the Fruit Fly," page 100). By the use of this technique Ernst Hadorn and his colleagues at the Federal Institute of Technology in Switzerland are able to study the hidden chemical effects of various genes.

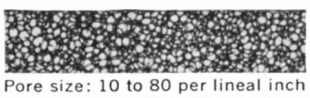
THE ILLUSTRATIONS

Cover photograph (*left*) by the Department of Photography, Federal Institute of Technology, Zurich; cover painting (*right*) by John Langley Howard

Page	Source
46–51	Bunji Tagawa
52	Patra McElwee
55	William C. Miller, Mount Wilson and Palomar Observatories
56	Walter Baade, Mount Wilson and Palomar Observatories
57	Harvard College Observatory (*top*), Yerkes Observatory (*middle*), Mount Wilson and Palomar Observatories (*bottom*)
59–62	James Egleson
63	Robert P. Kraft, Mount Wilson and Palomar Observatories
64	J. David Robertson, Harvard Medical School
66–67	Thomas Prentiss (*top and bottom right*); J. David Robertson, Harvard Medical School (*bottom left*)
68–69	J. David Robertson, Harvard Medical School
70–71	J. David Robertson, Harvard Medical School (*top*); Thomas Prentiss (*bottom*)
72	Thomas Prentiss
85–94	Stefan Martin
100	John Langley Howard
	(*left and right*), Department of Photography, Federal Institute of Technology, Zurich (*center*)
102	John Langley Howard
103	Hatti Sauer
104–107	John Langley Howard
108	Hatti Sauer
110	John Langley Howard
114–115	David Linton
116	Ramsey & Muspratt (*top*), Dan Todd (*bottom*)
118	Dan Todd
120	Aero Research Ltd.
122	Norman A. de Bruyne, Techne Limited
124	Dan Todd
130–134	Rudolf Freund
136	Allan W. Cruikshank, National Audubon Society (*top*); David Linton (*bottom*)
138	Rudolf Freund
144–147	Bunji Tagawa
148	H. K. Dunn, Bell Telephone Laboratories
151	Bunji Tagawa
154–164	James Egleson
168	Roger Hayward
170	Joan Starwood
172–174	Roger Hayward



This versatile product may have a place in your design. Scott Industrial Foam, a unique "open pore" urethane, comes in a wide variety of pore sizes, some of which are shown at right. It can be readily cut to any shape. Easy to clean, strong, resilient. Has 97% void volume. Already in wide use for demisting, liquid detraining, coalescing, and even powder puffs. It revolutionized the air filtration industry. Can it revolutionize yours? Write Ed Mack, Manager Industrial Sales, Foam Division, Scott Paper Co., Chester, Pa., for free bulletin giving complete technical details.



Pore size: 10 to 80 per lineal inch

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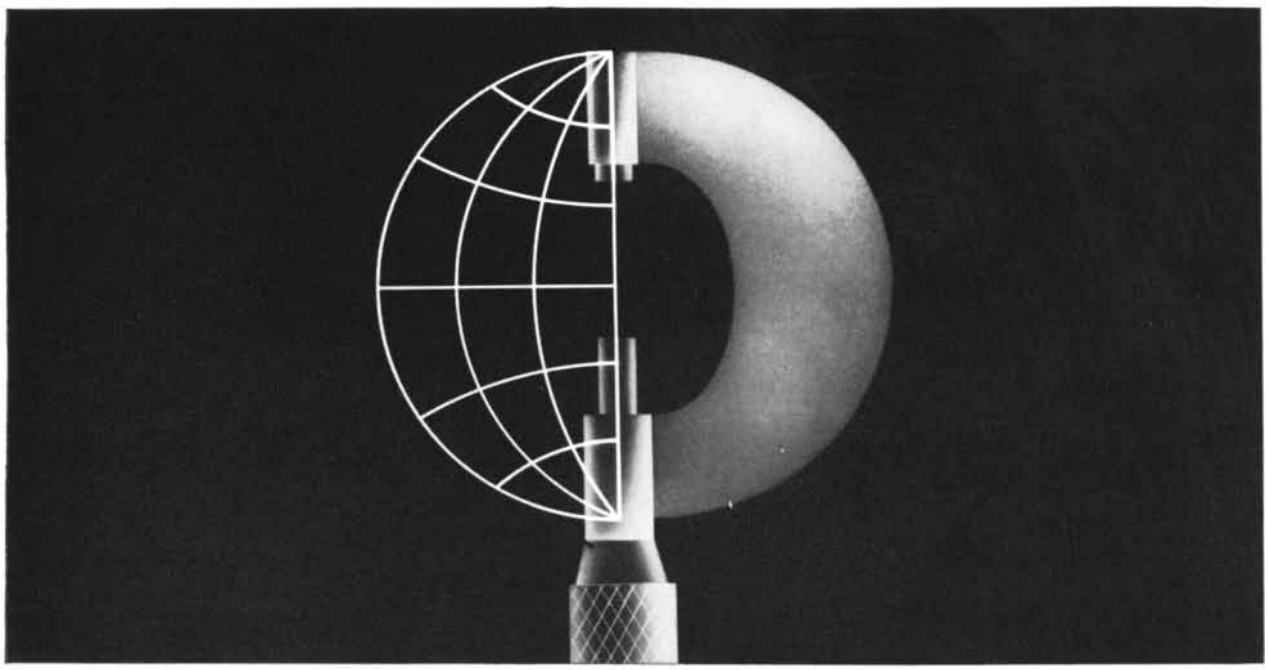


NEW METAL-REPLACEMENT PLASTIC MAPS A CAREER HERE AND ABROAD

Celanese has developed an important new high strength plastic designed to replace metals in a wide range of uses. One of the newest and most advanced of the "engineered" plastics, Celcon, an acetal copolymer, is extremely tough, fatigue and temperature resistant and resilient. It is easily molded into dimension-holding shapes that resist abrasion and chemical attack.

These properties enable Celcon to replace diecast zinc and aluminum, brass, copper and steel in many applications with these advantages: lower initial costs; greater design versatility; lighter weight; and the elimination of costly finishing and assembly procedures.

To date, there are more than a hundred different industrial parts and products already being produced in Celcon. They include: carburetor components, cams and gears, business machine and pump housings, and spring clips for automobile trim. In addition, Celcon is under evaluation in over six hundred applications, where its unique properties promise new design freedom and manufacturing economies.

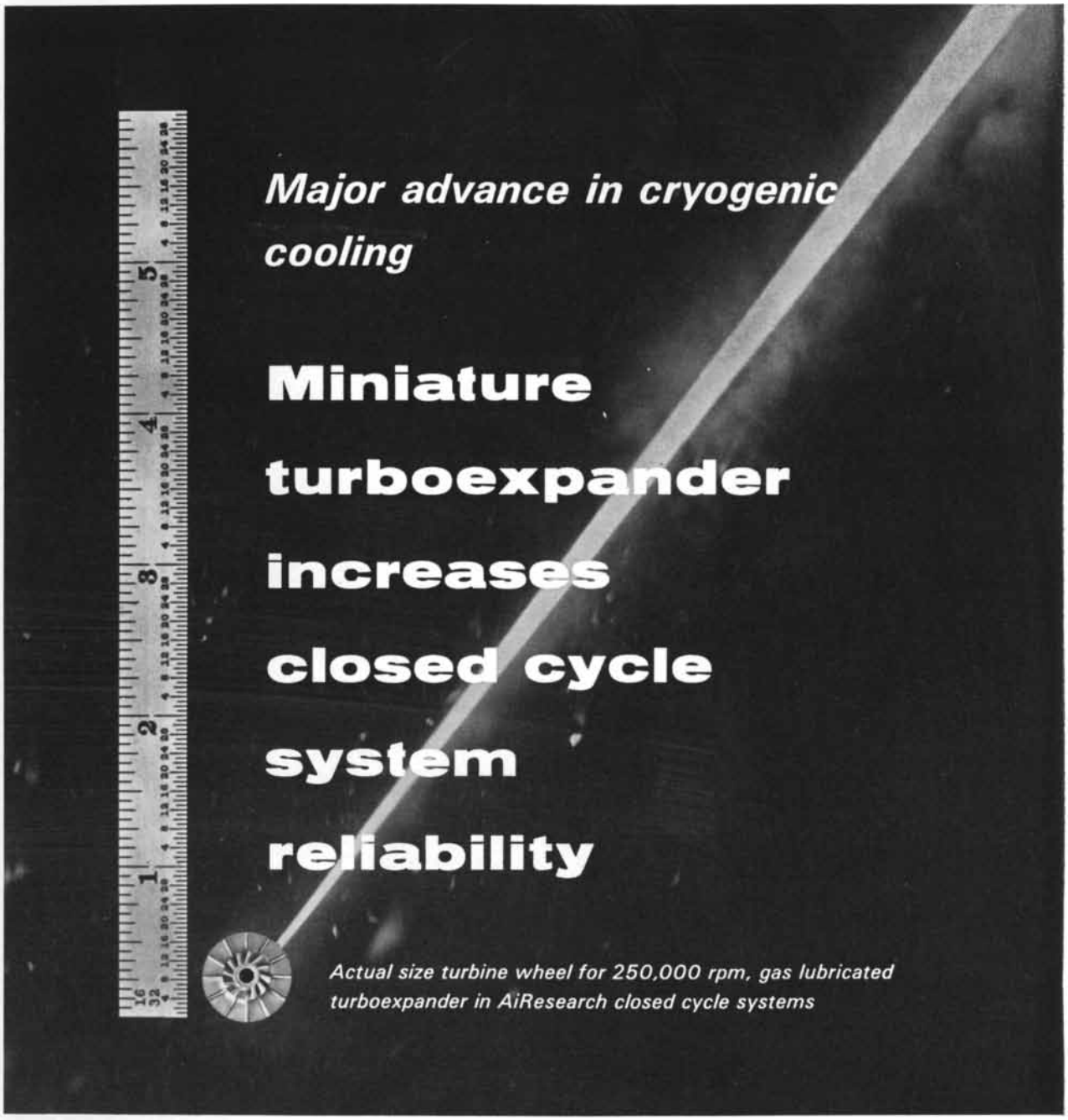
A new plant for the volume production of Celcon is now in operation at Bishop, Texas. It is designed for ultimate capacity of over 30 million pounds annually. A foreign affiliate of Celanese has recently entered into a joint venture with Farbwerke Hoechst A. G. to produce Celcon in Germany. Until this plant is completed, the European market will be supplied from U. S. domestic production. Further plans to widen the availability of Celcon in world markets are under consideration.

The development of Celcon is another example of Celanese basic policy of integrating research, raw materials, production and marketing into a unified program that can be projected into a worldwide operation.

Celanese market research first disclosed the enormous potential open to a metal-replacement plastic. Chemical research found the answer in the copolymerization of trioxane—a derivative of formaldehyde. And, as one of the world's largest producers of formaldehyde, Celanese is in an excellent position to supply this essential ingredient economically. Celanese Corporation of America, 522 Fifth Avenue, New York 36, N. Y. Celanese® Celcon®

Celanese

CHEMISTRY FOR THE MARKETS OF THE WORLD



Garrett-AiResearch is completing development work on closed cycle nitrogen, helium and neon systems using a tiny turboexpander in place of a piston expander.

This promises to dramatically increase system reliability and service life because all wearing surfaces, valves and troublesome reciprocating loads have been eliminated.

These compact, lightweight systems for masers, parametric amplifiers, IR cell cooling and computer components are ideally suited to commercial applications as well as military ground and aerospace uses.

AiResearch was first in production with an open cycle IR cooling system, and has already produced a closed cycle nitrogen system. The company is now working on military programs for 30°K and 4.2°K closed cycle systems.

Utilizing its experience as a world leader in lightweight turbomachinery and cryogenic cooling, AiResearch is also developing an all-turbomachinery closed cycle system incorporating a turbocompressor as well as turboexpander.

Your inquiries are invited.

GARRETT

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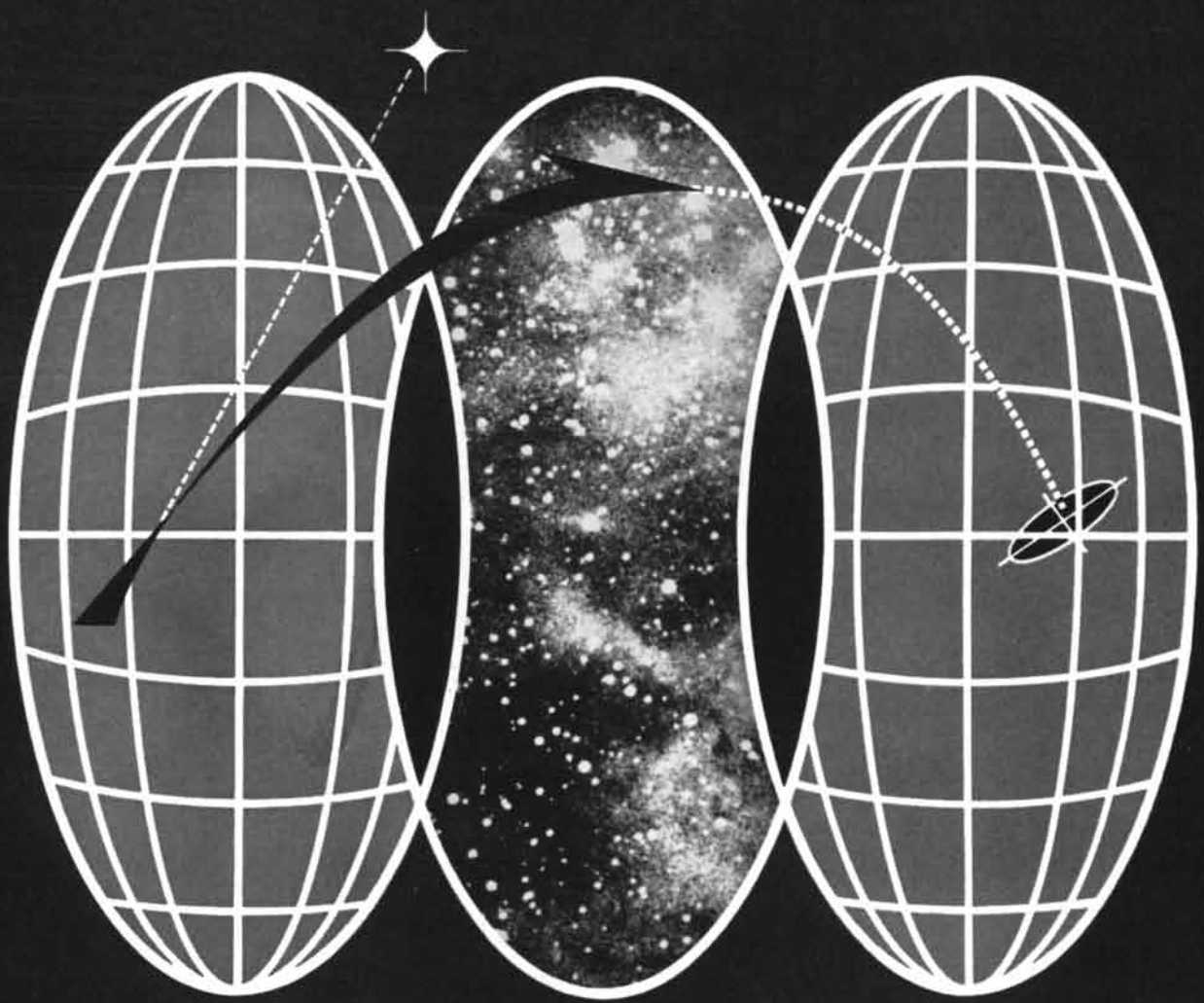
Systems and Components for:

Aircraft, Missile, Spacecraft, Electronic, Nuclear and Industrial Applications

GENERAL PRECISION & STELLAR INERTIAL GUIDANCE SYSTEMS

A contract for production and testing of a Stellar Inertial Guidance System for ballistic missiles has recently been awarded to General Precision by the United States Air Force. Using the stars as reference points, this highly advanced missile-borne system employs a General Precision celestial sensor integrated with a miniature inertial guidance system to deliver the missile to its target.

This is only one in a succession of missile programs for which General Precision's capabilities have been evaluated and found acceptable. Other areas where General Precision has demonstrated competence include Space Vehicle Guidance and Control, Manned Aircraft Systems and Sub-Systems, Air Traffic Control and Industrial Control. General Precision, Inc., Tarrytown, New York, the principal operating subsidiary of General Precision Equipment Corporation.



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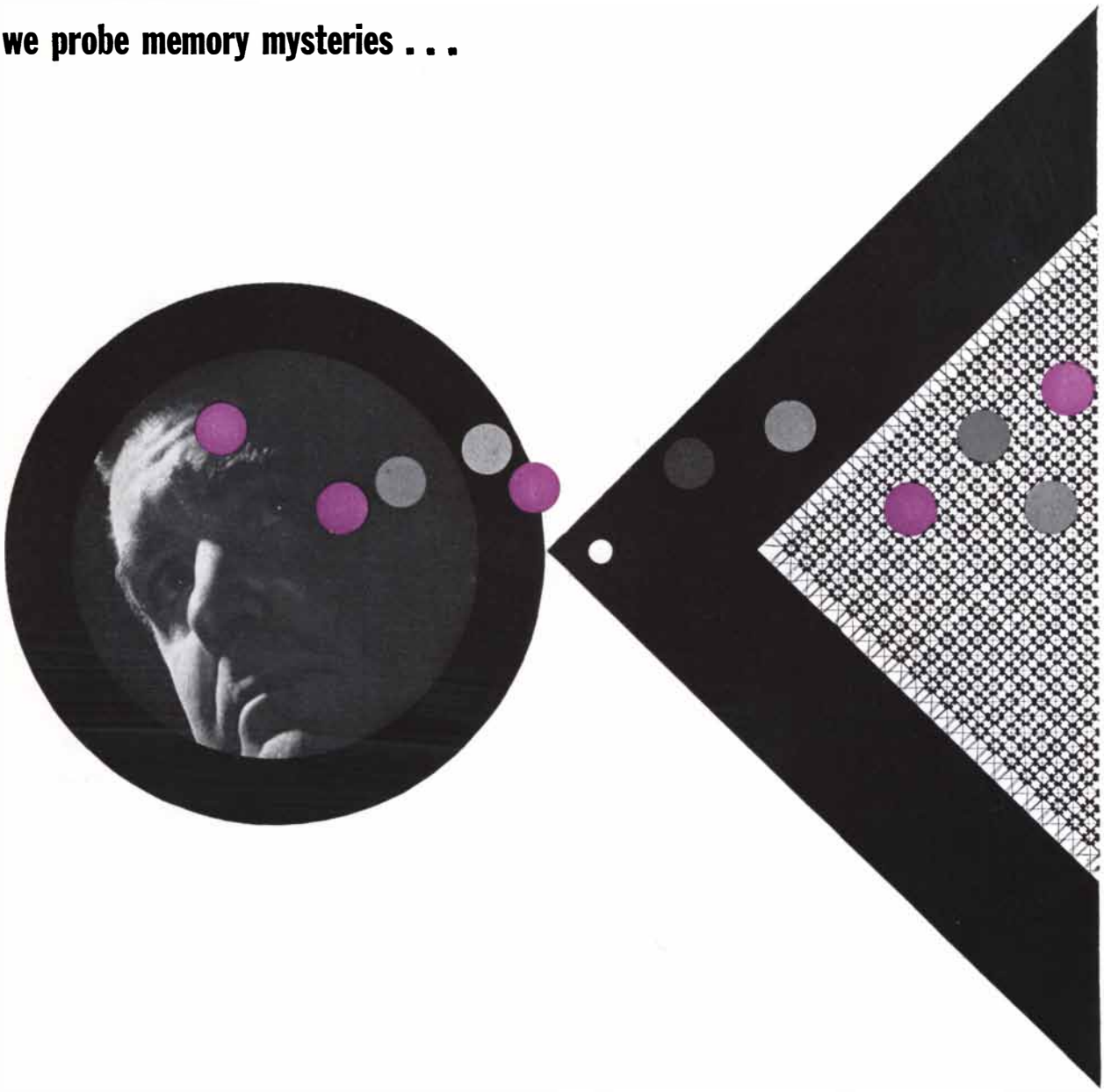
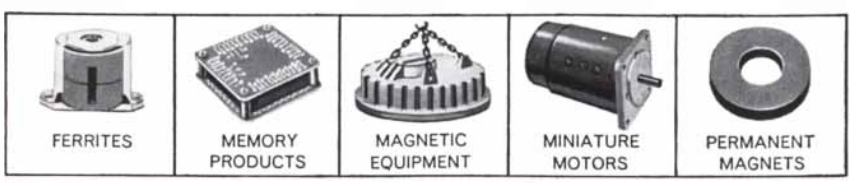
GP GENERAL PRECISION

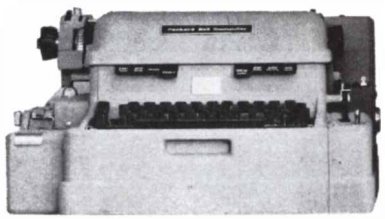
we probe memory mysteries . . .

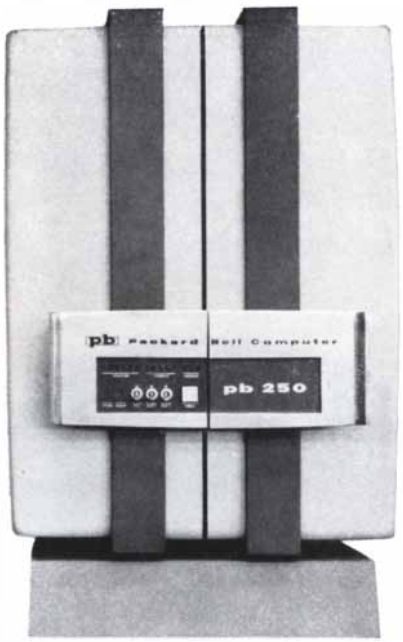


. . . because magnetism is our business. Just as with ferrites, permanent magnets and industrial magnetic equipment, our basic research continues to probe potential advances in memory products. Objectives: to speed up switching times, extend operating temperature ranges; reduce size and weight, lower costs, build resistance to environmental conditions; shock, heat, vibration and corrosion. ■ Years ago, our research discovered the first square loop ferrite memory core. We pioneered the application of this basic scientific breakthrough into our modern cores, planes, stacks and complete memory systems. This experience sharpens our research — separates the practical from the possible and puts maximum dependability into our memory products with every passing day. ■ We offer you a highly competent team of research, development and application engineers — backed by the finest production facilities in this industry. For faster, smoother solutions to your memory mysteries, profit from our experience and capabilities. **Write for "This is Indiana General"** to Indiana General, Valparaiso, Indiana.

INDIANA GENERAL







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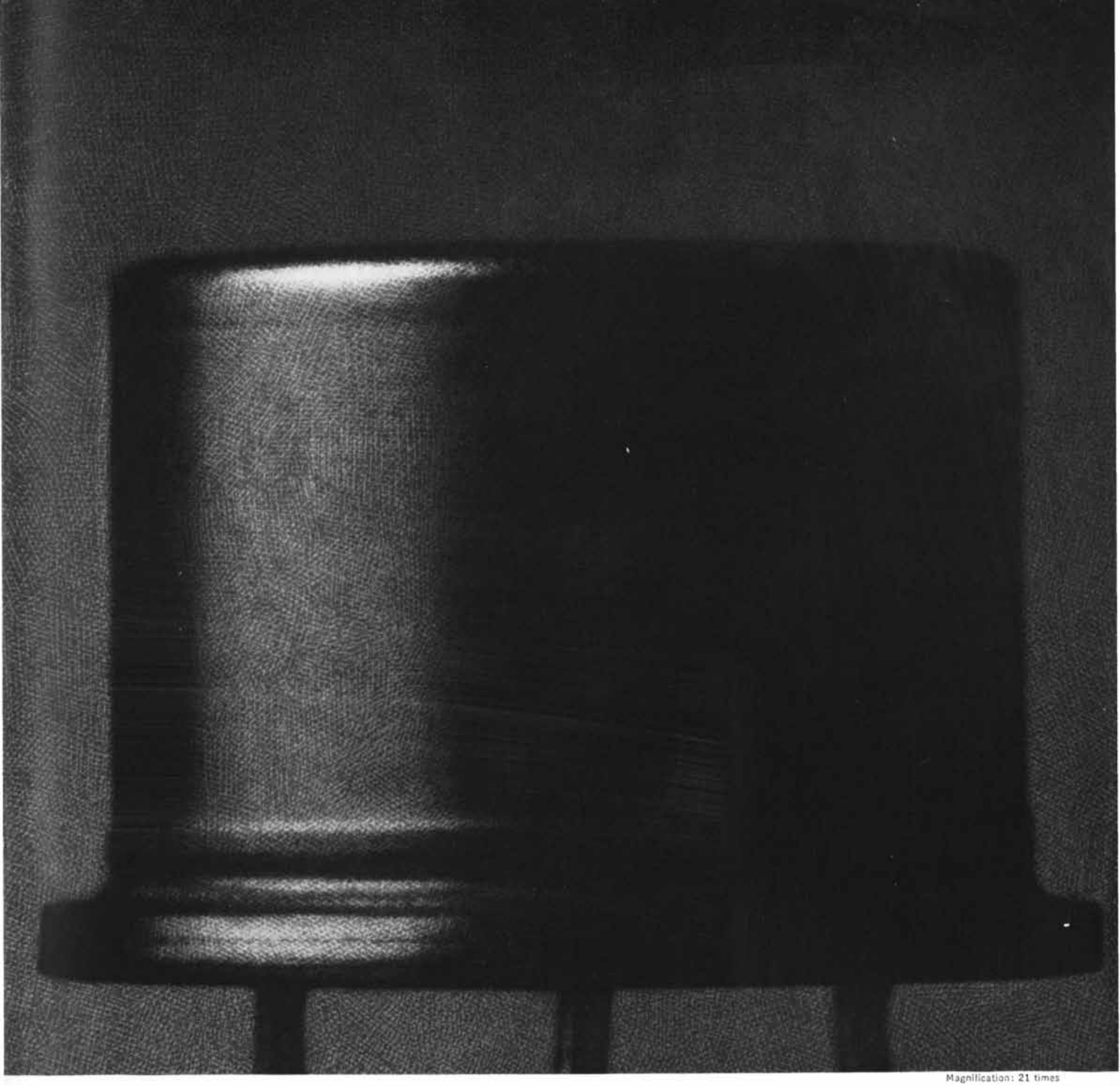

Magnification: 21 times

Old hat

Six months ago this Fairchild transistor was the newest thing on the market. Now there's a better one. Made by Fairchild. Meeting the challenge of your own products is a criterion of leadership in this fast-moving, fast-changing industry. That's why the search to make it (1) work better, (2) do more and (3) cost less—goes on 24-hours a day at Fairchild.

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SEMICONDUCTOR

LETTERS

Sirs:

We were pleased to see our work discussed in your department "Science and the Citizen" under the heading "Breaking the Code" [SCIENTIFIC AMERICAN, February] but we would like to call your attention to a misstatement in it. It was said that our results are to be published in the February issue of the *Proceedings of the National Academy of Sciences.* We would like to state that, following the discovery by workers at the National Institutes of Health that polyuridylic acid (poly U) contains the code letters for phenylalanine, we were the first to use copolynucleotides (e.g., poly UC, poly UA, poly UAC) of such composition that incorporation into protein of amino acids other than phenylalanine was promoted. We were the first to propose, as a result of these experiments, triplet code letters for all of 20 amino acids.

The successful use of copolynucleotides was disclosed October 23 at Roswell Park Memorial Institute and at the University of Buffalo, and November 9 at the New York Academy of Medicine; code letters for 11 amino acids were presented. Our first two publications assigning code letters to 14 amino acids appeared in the December 1961 and January 1962 issues of the *Proceedings of the National Academy of Sciences.* Two more publications in this series follow in the February and March num-

Scientific American, April, 1962; Vol. 206, No. 4. Published monthly by Scientific American, Inc., 415 Madison Avenue, New York 17, N.Y.; Gerard Piel, president; Dennis Flanagan, vice-president; Donald H. Miller, Jr., vice-president and treasurer.

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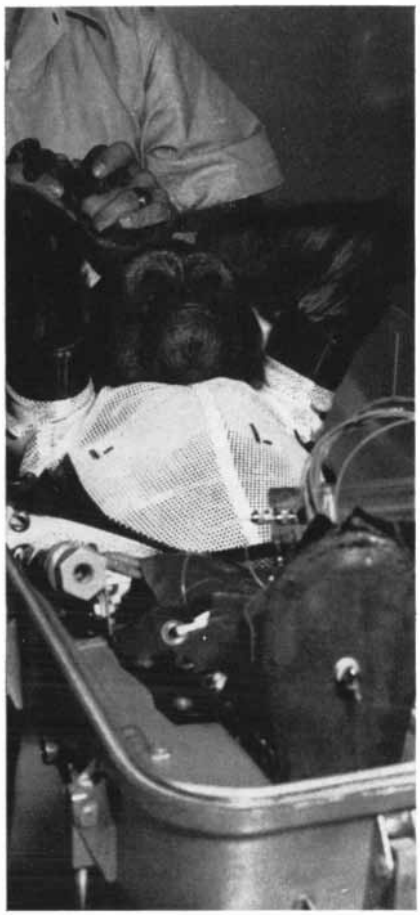
Vitro has the imagination . . . the experience . . . the organization



Enos, the orbiting chimp, didn't tell Col. Glenn much about his flight. Tapes of data received over Vitro telemetry equipment did. Instead of being rewarded for proper procedure, poor Enos was shocked.

to hear what shocked Enos . . .

That's an indication of the complexity of the Polaris missile system. Vitro, as the US Navy's systems engineering coordinator, integrates the talents of the many companies involved to insure that the systems work perfectly, as designed.

to keep 18,400 switches open . . .

Is it profitable to process millions of tons of sugar beets at Drayton, N.D.? To find the answer, Red River Valley Sugar Co. had Vitro prepare preliminary design, engineering, cost, feasibility and marketing studies.

to size up a dead beet . . .

Vitro means imaginative application of scientific knowledge in electronics, chemistry, advanced R&D and engineering. Find out today how Vitro's creative ingenuity can help solve your problems.

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bers of the same journal. The February publication assigns the code letters for all 20 amino acids.

CARLOS BASILIO
PETER LENGYEL
SEVERO OCHOA
JOSEPH F. SPEYER

Department of Biochemistry
New York University Medical Center
New York University School of Medicine
New York, N.Y.

Sirs:

In his article "Wear" [SCIENTIFIC AMERICAN, February] Ernest Rabinowicz cites a rabbit's incisor as a natural example of a self-sharpening tool. The outer lining of enamel wears slower than the inner dentine. As the softer dentine wears away, particles of the unsupported enamel break away to keep a sharp edge. He underestimates human ingenuity, however, when he states "no man-made tool employing this principle of self-sharpening through differential hardness has been devised."

I haven't seen it recently, but a couple of years ago the Robeson Cutlery Co. of Perry, N.Y., advertised a knife with one side coated with a carbide compound. In use the uncoated side was expected to wear more rapidly, thus keeping the edge perpetually thin and sharp.

BERNARD ABOSH

Brooklyn, N.Y.

Sirs:

Ernest Rabinowicz' article "Wear" states that no man-made tool employing the principle of self-sharpening through differential hardness has been devised. I submit, as an exception, the roller bits used in rotary drilling of rock.

These commonly consist of two or three conical rollers so arranged that they lie on the bottom of the hole being drilled, their vertices on or close to the axis of the hole. The rollers are studded with teeth, which do the cutting as the bit turns. Some of these bits are made with a hard facing on one side of each tooth and are self-sharpening in the same manner as the rabbit's tooth described in the article.

CARL A. RAMBOW

Division of Industrial Research
Washington State University
Pullman, Wash.

حياة طويلة

This Arabic script means "Long Life." For people who deal with complex microwave problems, "long life" means Varian klystrons—pulse, CW, reflex.

Simplicity of design, ruggedness, and precision manufacture make possible these histories: On Spruce Mountain, Nevada, a VA-220 reflex oscillator klystron was installed in 1956 in a TV transmission system. It has been operating unattended for more than 33,000 hours. Near the Arctic Circle, VA-842 super-power klystrons were installed in 1956 in a classified radar network. Eight tubes had reached 10,000 hours operation by December, 1961. In Norway, VA-800C CW amplifier klystrons were installed in 1958 in HOTLINE, a link in a NATO troposcatter system. Six tubes are still going after 10,000 hours; one has reached 20,000 hours. If your microwave system design calls for tubes that *last,* contact Tube Division.

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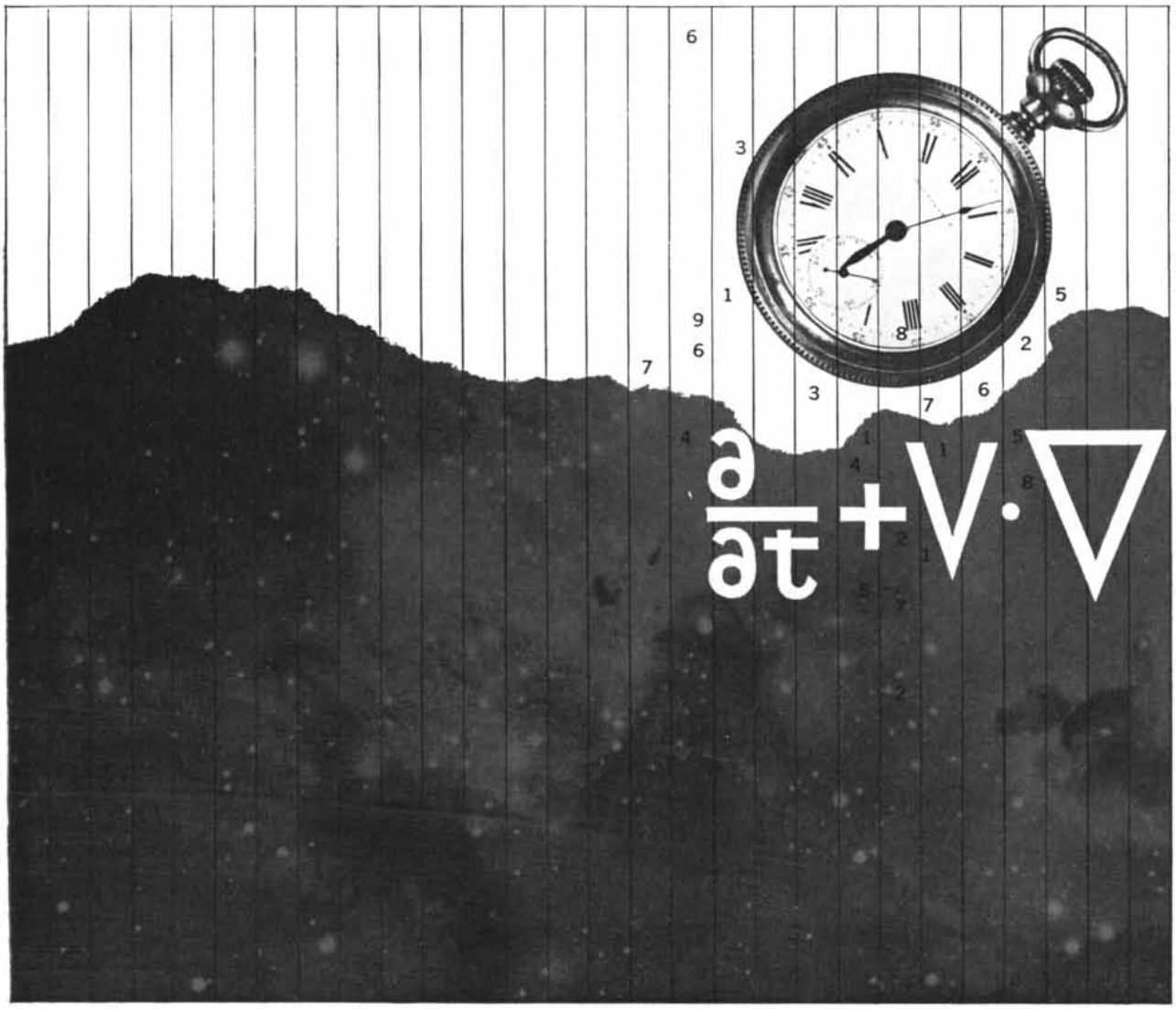

purposeful imagination....in time

The men of Aerospace apply the full resources of modern science and technology in a timely manner to achieve the continued advances in ballistic missile and space systems basic to national security. Their mission includes stimulating the flow of the most advanced scientific information and objectively planning the technical management programs necessary to generate superior systems in the shortest possible time. □ Chartered exclusively to serve the United States Government in this effort and acting in partnership with the Air Force-science-industry team, the men of Aerospace contribute: advanced systems analysis and planning; theoretical and experimental research; general systems engineering and corresponding technical direction of programs. □ To aid in reducing the timetable of advanced systems, from concept through completed mission, more men with advanced degrees are needed at Aerospace Corporation, an equal opportunity employer. Dedicated interdisciplinary scientists and engineers who can contribute effectively are invited to contact Mr. George Herndon, Room 120, Aerospace Corporation, P. O. Box 95081, Los Angeles 45, California. □ Organized in the public interest and dedicated to providing objective leadership in the advancement and application of science and technology for the United States Government.

AEROSPACE CORPORATION

Relay by Babcock Relays Division of the Babcock Electronics Corp.

THE INSIDE STORY: making a tiny coil fit a tight spec

In this versatile subminiature relay, the coil form is molded of Du Pont TEFLON FEP-fluorocarbon resin. Because FEP resin is melt-processible, the coil form is rapidly and economically produced by injection molding. These coil forms require insulation resistance of 10,000 megohms minimum at temperatures from 65°C to 150°C. The manufacturer found that Du Pont TEFLON FEP resin was the only practical material offering the necessary insulating characteristics over this range of temperatures. The new relay meets the rigid MIL specifications for virtually all aircraft and missile applications.

The molding of the coil form of a TEFLON FEP resin also made possible miniaturization of the relay —only 1.3″ high and slightly over one ounce in weight. And the stability of TEFLON at high temperatures eliminates the major problem of contact contamination by outgassing. The superior electrical properties of TEFLON are also utilized in tape and in lead wire in this relay.

This is another example of improved design made possible by the new melt-processible FEP resins, which make TEFLON available in the form of easily molded components and in long, continuous lengths of extruded wire insulation. For more information, write: E. I. du Pont de Nemours & Co. (Inc.), Dept. SA-4, Room 2526T Nemours Building, Wilmington 98, Delaware.

In Canada: Du Pont of Canada Limited, P. O. Box 660, Montreal, Quebec.

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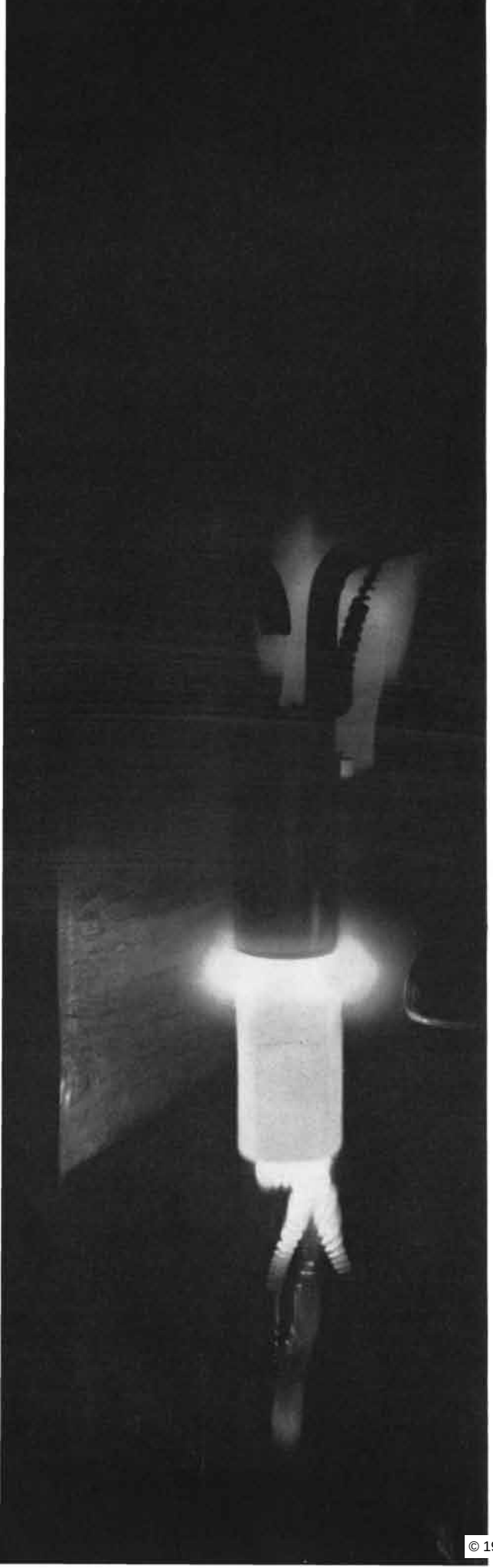
TEFLON is Du Pont's registered trademark for its family of fluorocarbon resins, fibers and film, including TFE (tetrafluoroethylene) resins and FEP (fluorinated ethylene propylene) resins.



One of a series

An Unperturbed Picture of Plasma

Plasma . . . a hot ionized gas, the bright stuff in a neon sign, a welding arc, a lightning flash. And now being put to use by scientists around the world in research on thermionic energy conversion, thermonuclear power, and magnetohydrodynamics.

Fundamental to these studies is knowledge of the plasma's physical properties.

How hot are its electrons, ions, and smattering of atoms? (Often the temperatures are different.)

How many particles?

How distributed?

To find out, physicists at the GM Research Laboratories have blended spectroscopic methods with the latest theories of how plasma particles shape the spectral lines (both Stark and Doppler broadening). As a result they've been able to measure all ion, electron, and atom temperatures and number densities in a cesium plasma *without perturbing it.* And the variety of techniques developed (3 for electron density alone) has yielded a pleasing picture of self-consistent values.* Another new technique, time-resolved spectroscopy, is supplying the microsecond history of plasma parameters in a spark.

These developments in plasma diagnostics are not only forwarding our research on thermionic converters . . . but are also refining our understanding of such workaday applications as electrical discharge machining and spectrochemical analysis. *Enriching the Science . . . Advancing the Technology of Tomorrow.*

General Motors Research Laboratories

Warren, Michigan

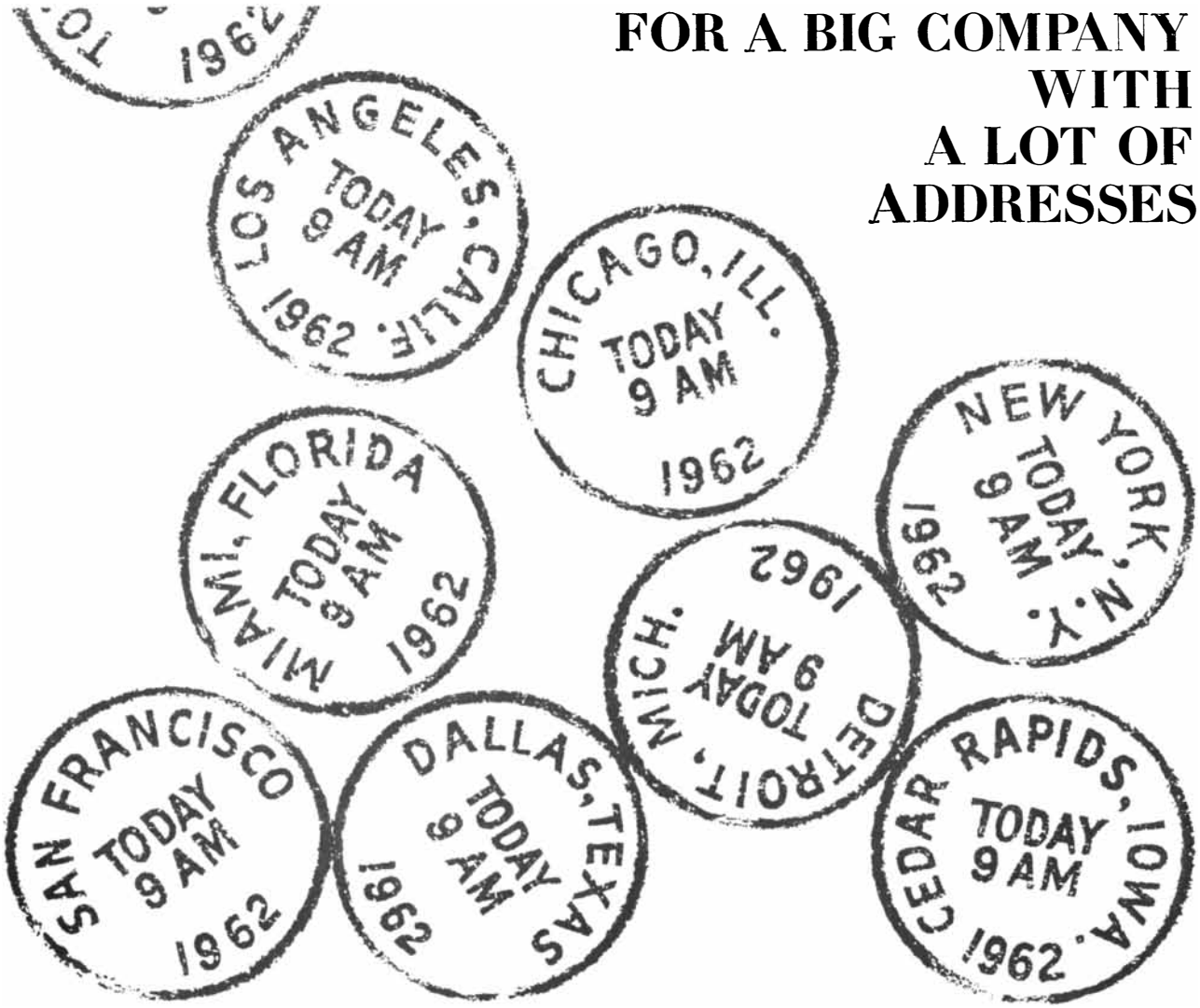
In a Cesium Diode:

Type of Measurement	*Electron Number Density*
Continuum	3.6×10^{15} cm^{-3}
Stark Broadening	1.6×10^{15} cm^{-3}
Series Limit	2.1×10^{15} cm^{-3}

From a recent paper, "Spectroscopic Measurements of Temperatures and Densities in a Cesium Plasma." Available on request.

A noble gas plasma in a pulsed discharge thermionic converter.

FOR A BIG COMPANY WITH A LOT OF ADDRESSES



THE SHORTEST DISTANCE BETWEEN PLANTS IS KINEPLEX®

Today, some of the nation's most widely scattered organizations have the fastest reactions. They gather facts and transmit reports from coast to coast as quickly as most companies communicate from office to office in the same plant. Even outlying locations have instant access to the most powerful computers. ☐ *Kineplex makes it possible.* ☐ This patented data transmission technique from Collins is the speediest way to move information over a telephone line. Kineplex terminals handle digital data at rates up to 13,500 words a minute. Using wireline or radio, they form a fast, reliable information network that can span thousands of miles to link a company's plants and computers. ☐ The speed, dependability and adaptability of Kineplex has established Collins as a leading source of equipment for the new age of data communication. **COLLINS RADIO COMPANY,** Communication and Data Systems Division, Dallas, Texas.

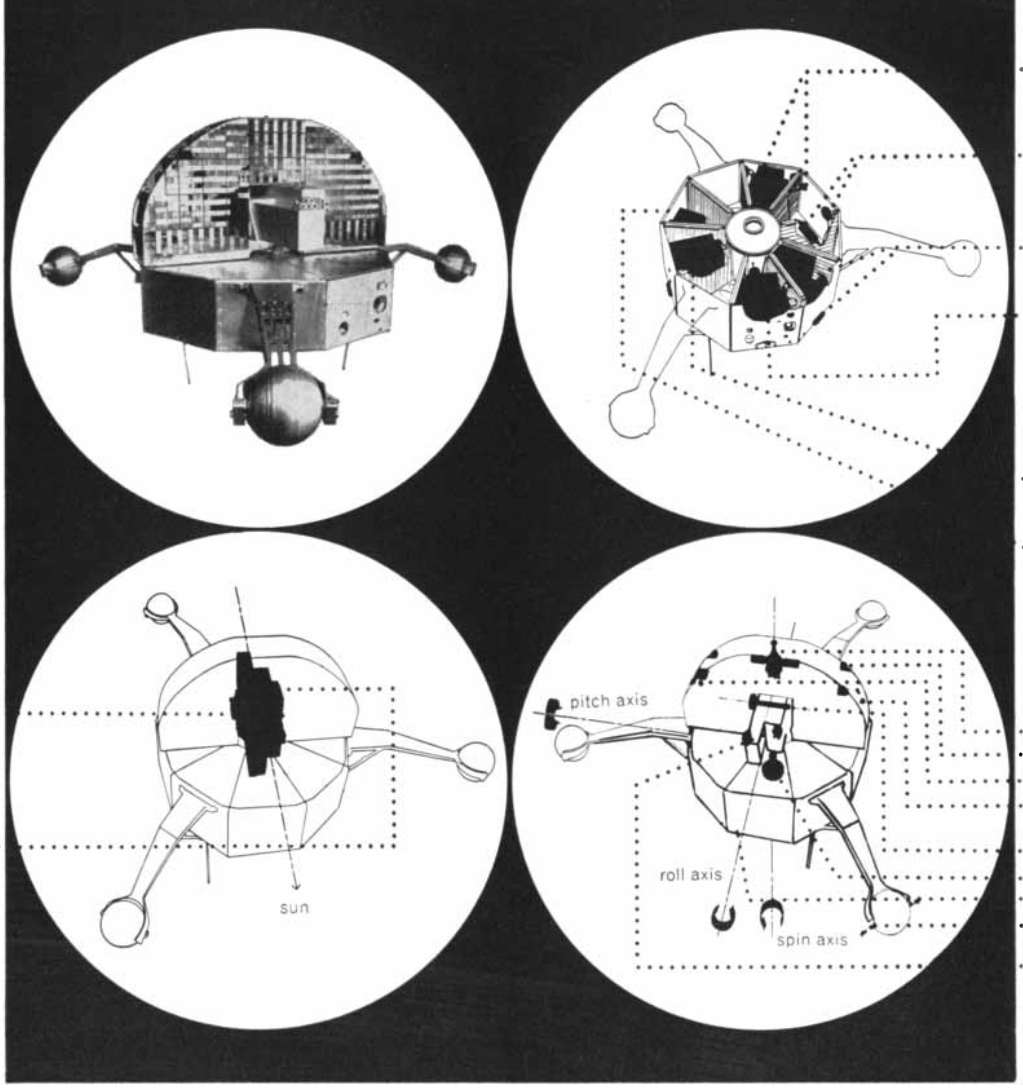
COLLINS

sun tracker

oriented experiments

goddard space flight center
x-ray spectrometer (10-400Å)

goddard space flight center
x-ray and gamma ray monitoring dust particle experiment



wheel experiments

- univ. of minnesota
  intensity and angular distribution of gamma rays (0.1-5 mev)
- ames research center
  surface erosion studies
- univ. of rochester
  high energy gamma rays (above 100 mev)
- goddard space flight center
  solar radiation (4080-4800Å)
  gamma ray energies (0.2-1.5 mev)
  solar ultraviolet and x-ray (1100-1250Å)
- univ. of california
  neutron flux measurement
- univ. of california
  proton flux analyzer (E_p 2 mev)
  electron flux analyzer (E_e 60 kev)

control systems

- nutation damper
- coarse eyes (azimuth)
- pitch control eyes
- jet thrust for pitch control
- elevation servo motor
- azimuth servo motor
- turn-on eyes
- jet thrust for spin control
- fine eyes (azimuth and elevation)

Designed . . . Developed . . . Constructed by Ball Brothers Research Corp. for NASA's Goddard Space Flight Center. **Scientists and engineers are urged to work with us on subsequent models of a new generation of scientific satellites.**

The recently launched Orbiting Solar Observatory is the first of a series of satellites to intensively study the electromagnetic spectrum from visible light through energetic gamma. From these investigations knowledge of the Sun's composition, Earth-Sun relationships and celestial phenomena will be greatly extended.

As prime contractor on the OSO-1, Ball Brothers Research Laboratories designed and built the spacecraft structure, the major spacecraft systems, and integrated the thirteen scientific instruments aboard the satellite. In so doing, several outstanding technological advancements were made: a unique biaxial control system requiring only 4 watts of power; a high scientific instrument-to-total-weight ratio (173 lbs. to 450 lbs.); several low-power, high-efficiency electronic components; and a thin film lubricant which permits motor brushes, bearings and slip rings to work for extended periods in a space environment.

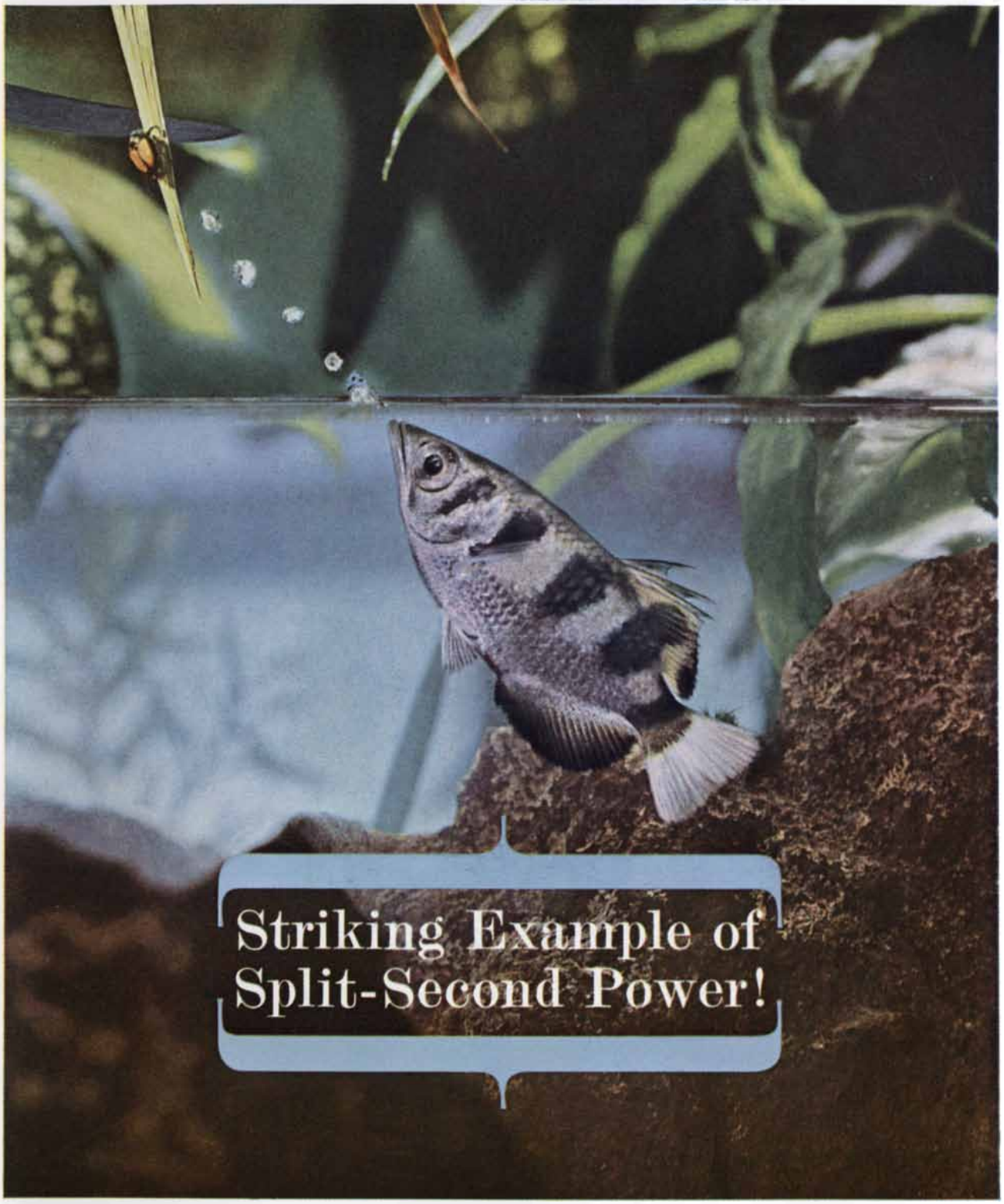
Ball Brothers Research Corporation is a company with broad scientific and engineering interests. Our technical staff works in an informal atmosphere that permits easy exchange of ideas and stimulates the creative processes. To meet our expanding spacecraft programs, select opportunities exist for applied physicists with advanced degrees, electronic engineers experienced in circuit design and spacecraft and digital television systems, mechanical engineers with experience in servo mechanisms, spacecraft systems engineering and electronic packaging. EE's and ME's must have at least five years professional experience.

If you are seeking creative work with a growing company, we invite you to make your qualifications known to Dr. David Stacey, Technical Director.

BALL BROTHERS RESEARCH CORP.

INDUSTRIAL PARK, BOULDER, COLORADO / *a division of Ball Brothers Company, Incorporated*

AN EQUAL OPPORTUNITY EMPLOYER



This archer fish, shooting a jet of water at its prey, aptly illustrates the value of sudden, swift, long-range attack. Giving our military missiles the same kinds of capabilities calls for extraordinary materials and methods. For example, Phelps Dodge has developed a special ceramic magnet wire to withstand the vacuum of space, hard solar radiation and the searing heat encountered when re-entering the earth's atmosphere. In applied electronics, in power transmission, in communications, in so many areas vital to America's progress, Phelps Dodge is playing a basic role.

P MINE TO MARKET D

Deep in the process of shaping the future!

PHELPS DODGE COPPER PRODUCTS

CORPORATION • 300 Park Avenue, New York 22, New York

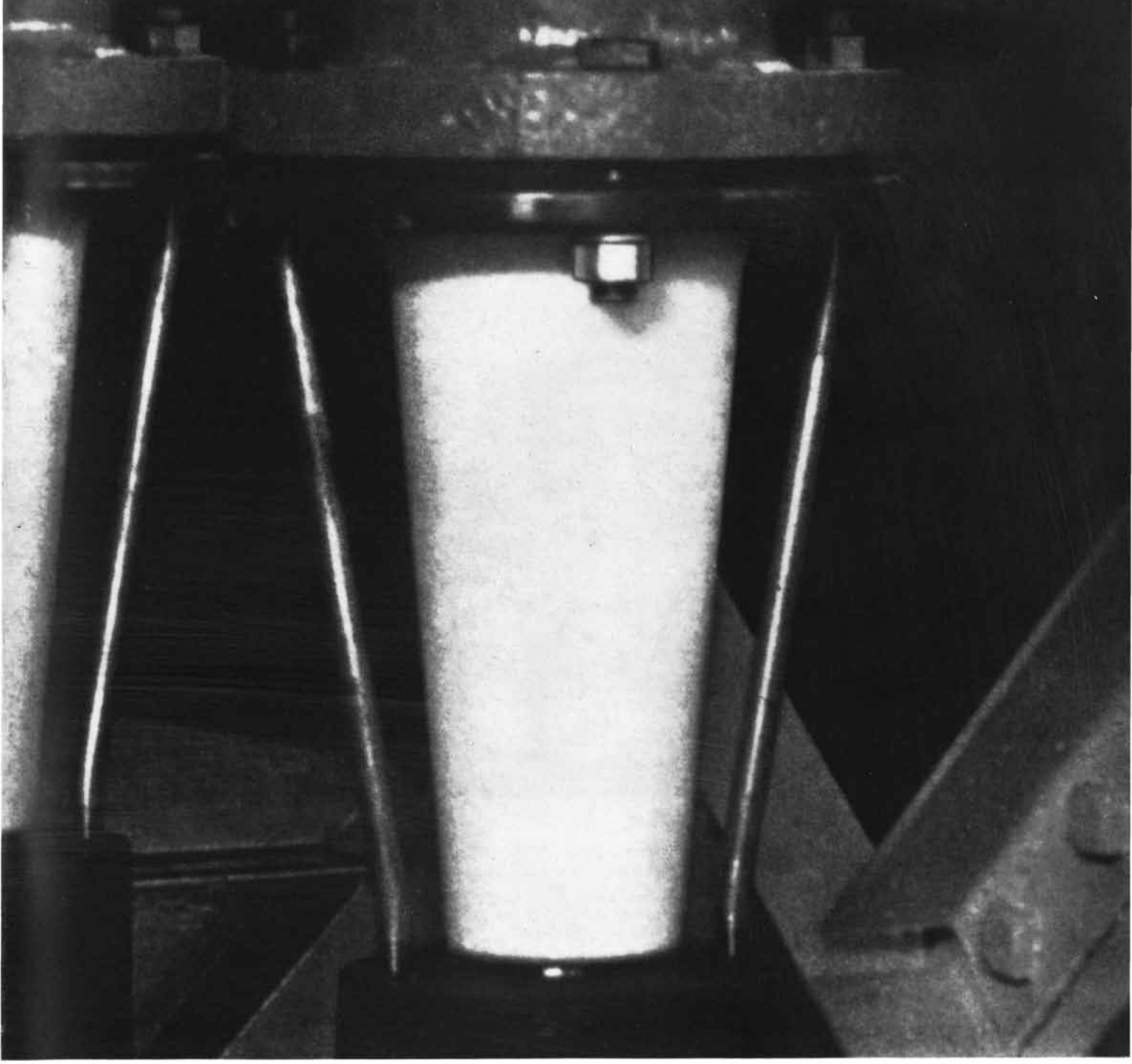
THE GATEWAY TO THE WEST has become the Gateway to Space. The spirit of St. Louis first turned pioneers westward in a struggle that unlocked half a continent. It nourished the practical dreams of Charles Lindbergh and he opened an ocean and an era. The spirit of St. Louis has now spread through all America, charting the course for a great new American enterprise. Mercury Spacecraft, designed and built in St. Louis, have carried Astronauts Shepard, Grissom and Glenn on their history-making flights. As this new national enterprise reaches toward the moon, it deserves the enthusiasm and support of every American. For the historic achievements of nations are but reflections of the courage of individual citizens who rise to meet great challenges.

MCDONNELL

Designers and builders of Project Mercury Spacecraft for the

NATIONAL AERONAUTICS and SPACE ADMINISTRATION

Engineers and Scientists: Employment opportunities exist at McDonnell, prime contractor on projects in the national interest such as MERCURY, ASSET, GEMINI, and PHANTOM II. Equal Opportunity Employer. For information, write: Professional Placement, McDonnell, Dept. SA, Box 516, St. Louis 66, Mo.



Ceramic engineers at Coors mix imagination with Alcoa Aluminas to produce ceramics withstanding 7,000 times the force of gravity

High-strength ceramic cones are used in pulp cleaners built by The Bauer Bros. Co. of Springfield, Ohio.

The cleaning units extract grit, sand, dirt and bark specks while paper is still in pulp form.

In one Bauer cleaner, centrifugal force hits a peak 7,000 times that of gravity.

It is commonplace for high-alumina ceramics to withstand stresses of such magnitude.

Ceramic technology, skill and Alcoa® Aluminas produce material which will withstand these high stress and erosion forces for many months without wear.

Try Alcoa Aluminas in *your* next ceramic project.

Meanwhile, write for our booklet, *Ceramics-Unlimited Horizons*.

Aluminum Company of America, Chemicals Division, 965-D Alcoa Building, Pittsburgh 19, Pa.

Entertainment at Its Best
ALCOA PREMIERE with Fred Astaire as Host
Tuesday Evenings, **ABC-TV**

ALCOA CHEMICALS
ALUMINUM COMPANY OF AMERICA

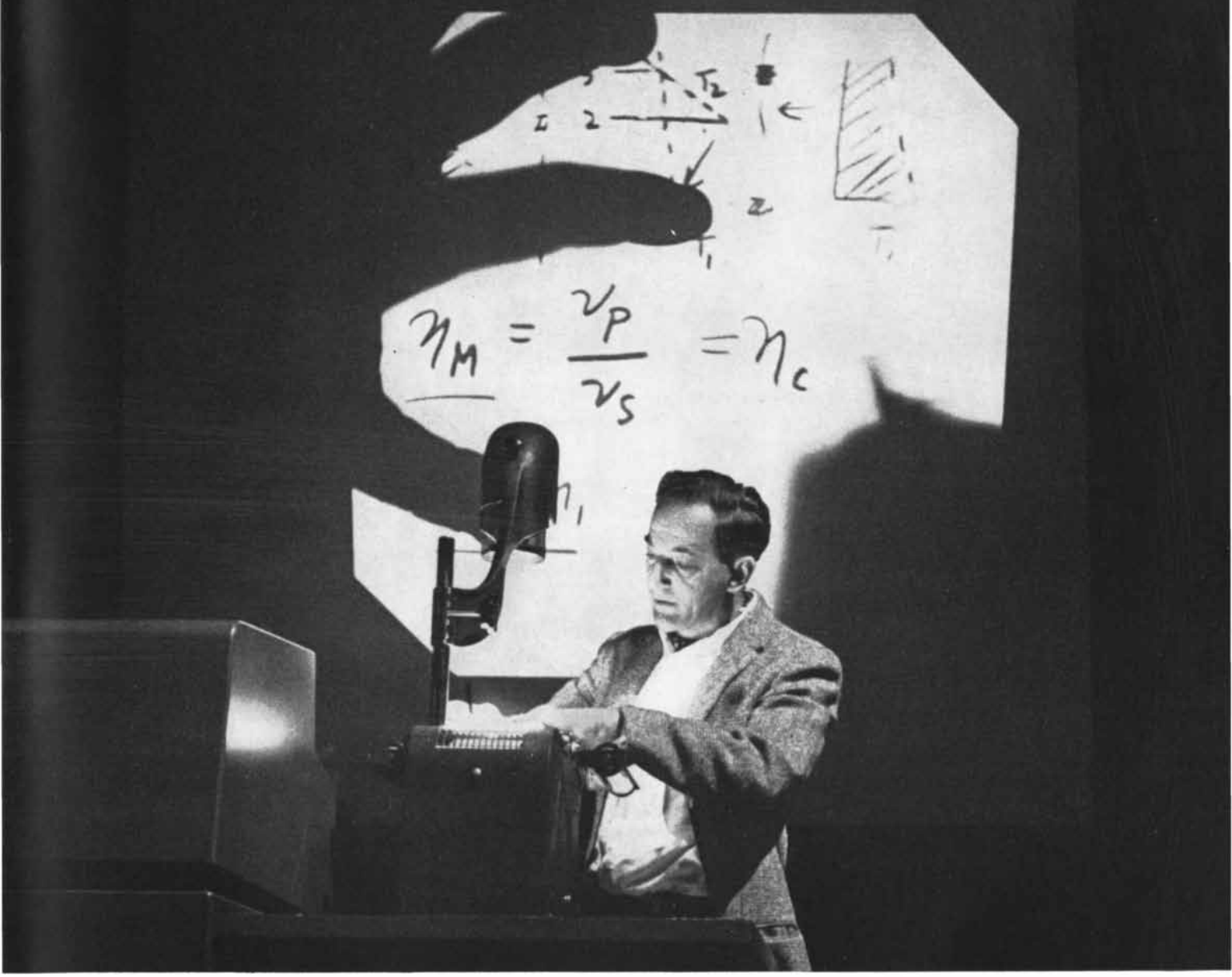
50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

APRIL, 1912: "On Sunday, April 14, the largest and supposedly the safest steamship afloat, while steaming on her proper course, on a clear, starlit night, struck an iceberg and within a few hours sank, carrying down with her more than 1,600 souls. The loss of the *Titanic* has brought home to the public at large the fact that, in spite of the improvements in ship design and construction, there is not a vessel afloat that is unsinkable by one or other of the accidents to which ocean travel is liable. And this is not to say that a great advance toward the unsinkable ship has not been made. If, then, the modern ocean liner is not unsinkable, dictates of common prudence and humanity demand that it should carry a sufficient number of lifeboats to accommodate every soul on board. Under an international agreement our government accepts the certificate of inspection of foreign countries; and if the Board of Supervising Inspectors finds that the foreign ship carries the number of boats called for by the certificate, she is permitted to sail. Had the *Titanic* carried the American flag, she would have had to provide space in her lifeboats for 2,412 passengers and crew. As it was, the maximum provision in the lifeboats that the *Titanic* carried was about 1,000! In the presence of this stupefying disaster, we enter a plea for the exercise by Congress of a calm and judicial spirit in all legislative action that may be taken. Evidently the matter is one for joint international action."

"The German and English expeditions contrast strongly with Amundsen's impromptu assault upon the South Pole. Lieut. Filchner's undertaking has been conducted with true German deliberateness. The gratifying news that has just come from Scott indicates that he has carried out his plans so far in the same spirit. He may or may not have reached the pole during the past winter. Probably he did. The fact remains that the English expedition has thus far made a more substantial contribution to the world's knowledge of Antarctica than any of its

What sets the stage for scientific discovery?



H. E. D. Scovil, pioneer developer of the solid state microwave maser, explains a point at a symposium at Bell Telephone Laboratories.

There is no one answer. But surely discovery is more likely when people are stimulated to think in new ways. And nothing more powerfully stimulates scientists and engineers than up-to-the-minute discussion of the latest developments.

Bell Laboratories scientists and engineers make a point of exchanging information on their latest advances not only among themselves but with the great world-wide professional community to which they belong. Last year, for example, Bell Laboratories specialists delivered over 1200 talks to technical societies and universities. The stimulating exchange of new ideas plays an indispensable role at the world center of communications research and development.

Bell Telephone Laboratories

competitors. Enough material has already been gathered to make up a report comparable to the splendid series of volumes that constitutes an imperishable monument to Scott's previous explorations of 1901–1904. No Englishman of science will have reason to feel chagrined at the comparative results of Scott's and Amundsen's undertakings—even if Scott never gets nearer to the pole than he was when last heard from."

"It is very difficult to determine the cause of most aeroplane accidents, but during the investigation that followed the fatal accident to Lieut. Sevelle recently in France an important discovery is said to have been made by eyewitnesses. This was that the wing of his Blériot broke downward instead of upward, indicating that there was an extreme downward pressure as he started to volplane. Experiments lately made in France are said to have confirmed this, and it is now believed to be necessary to guy the wings as substantially above as below."

"King George IV has appointed Sir J. J. Thomson to the Order of Merit. The distinction has been conferred also in the past upon Lord Rayleigh, Dr. Alfred Russel Wallace and Sir William Crookes."

Scientific American.

APRIL, 1862: "The greatest battle of the war, and the greatest ever fought on this continent, took place on Sunday and Monday, April 6 and 7, at Pittsburgh Landing, in Tennessee, on the Tennessee River. It has been known for some time that the enemy were concentrating large forces at Corinth, in Mississippi. Our forces, under Generals Grant and Buell, were advancing to the attack, and Gen. Grant's army, some 40,000 strong, had landed at Pittsburgh Landing, about 18 miles northeast of Corinth, when Generals Johnston and Beauregard marched from Corinth and attacked them. The fight raged all Sunday with doubtful and wavering chances, our side losing many prisoners. Toward night Gen. Grant was re-enforced by portions of Gen. Buell's army, and on Monday morning the bloody and doubtful struggle was renewed. At about 4 o'clock in the afternoon a brilliant charge by Gen. Grant, at the head of some fresh regiments, decided the fate of the day, which ended in a complete rout of the

ANACONDA COMMENTS...

new facts about copper—man's oldest metal

SPECIAL SPRING ISSUE — NUMBER 5 OF A SERIES

NEW RESEARCH CENTER PROBES MODULUS OF ELASTICITY IMPORTANT ADVANTAGE OF COPPER ALLOYS FOR SPRINGS

INTRODUCTION—When a metal is stressed by service loads, the amount of stress it can withstand and still recover its original position upon release is determined by its proportional limit—a strength property which can be varied considerably by working and annealing. However, the deflection of a metal in response to stress from applied loads is determined by its MODULUS OF ELASTICITY (ratio of stress to strain); this property is a fundamental characteristic of the metal and can be varied only slightly by treatment.

INVESTIGATION—At Anaconda's new Research and Technical Center, studies now under way are helping scientists to better understand the role of modulus of elasticity in making copper metals among the most useful spring materials known to man and to predict spring performance at various ambient temperatures.

Although the modulus of elasticity can be determined by very precise physical testing in tension or compression, Anaconda finds that a "dynamic" method is easier to perform and just as accurate. This method capitalizes on the mathematical relationship between the natural frequency of vibration of a properly supported rod or bar and the modulus of elasticity of its material.

Dynamic test apparatus is shown in the schematic diagram. In use, a carefully machined bar of known mass and dimensions is suspended at the quarter points, as indicated. An oscillator slowly changes the frequency supplied to a transducer until the bar suddenly begins to vibrate; these vibrations are shown on an oscilloscope. From this natural frequency, which is accurately measured by special instrumentation, the "dynamic" modulus can be computed. Measurements may be taken over a wide range of controlled temperatures by suspending the bar in a furnace.

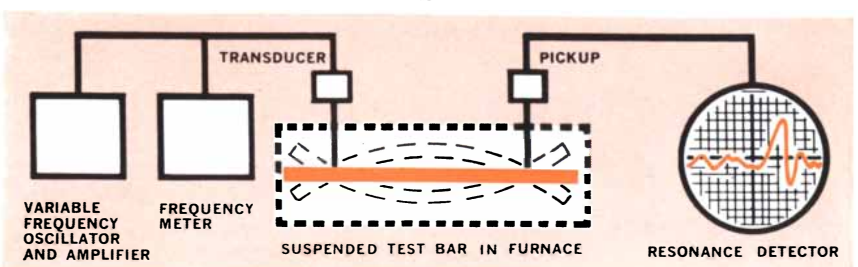
RESULTS—The modulus of elasticity of copper alloys at room temperature ranges from about 14 million psi for high tin phosphor bronzes to 22 million psi for 30% cupro nickel. The modulus of copper itself is approximately 18 million psi, while that of yellow brass is about 15 million psi. Steel, on the other hand, has an average modulus of elasticity of approximately 30 million psi.

The modulus of elasticity of these metals will decrease at elevated temperatures. For copper-base metals, the rate of decrease is in the range of 2000 to 7000 psi per degree Centigrade, varying with alloy and temper.

SUMMARY—The significantly lower modulus of elasticity for copper, as compared with steel, is of prime commercial importance to designers of spring devices. It means that at the same level of stress, copper alloy components will deflect or extend almost twice as far as similar components made of steel.

Thus, in some applications, copper alloys can be used to advantage because their greater deflection makes control devices more sensitive. In others, copper metals can be specified to provide "softer" action in the absorption of energy. Since in many environments the allowable working stress (usually determined by endurance strength) of copper alloys is at least equal to that of steel, the advantages of greater sensitivity and "softness" are usually obtained with no sacrifice of maximum stress. And, of course, the excellent corrosion resistance and conductivity of copper alloys are bonus factors which add to their desirability in applications determined primarily by modulus considerations.

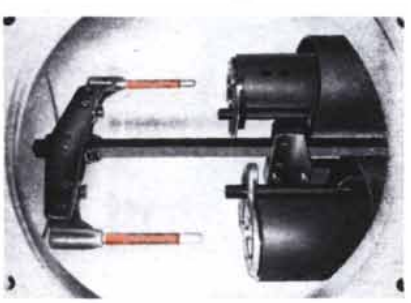
Probing the modulus of elasticity is only one of the Company-sponsored research activities now in progress at the new Research and Technical Center. When more of the facts about properties that make copper unique among metals are known and understood, designers and manufacturers will be able to count on even greater product improvements . . . and even lower product costs. A question about how Anaconda can go to work for your company? Write: Anaconda American Brass Company, Waterbury 20, Connecticut. In Canada: Anaconda American Brass Ltd., New Toronto, Ontario.



IMPROVED MILL PRACTICES PRODUCE EVEN BETTER CHROMIUM COPPER-999

Intensive experimental work at Anaconda American Brass has led to improvements in several key mill practices for Chromium Copper-999. Result: greater uniformity and higher quality than ever before.

This heat-treatable alloy is available as strip, plate, wire, rod, die-pressed forgings, and tube. It has an established record of high performance in numerous applications. In electrical equipment, Chromium Copper-999 is specified for such switchgear uses as switch blades, circuit breakers, conductors, and contact points. Chromium copper tubes are used as sliding conductors. In resistance welding, Chromium Copper-999 rod provides disk, wheel, or rod electrodes; die-pressed forgings are used as electrode-holder jaws and spot welding tips; wire is used for grid supports in vacuum tubes.



View of circuit breaker through manhole shows interrupting devices—fabricated with Chromium Copper-999—with contacts in open position.

PROPERTIES—Chromium Copper-999 offers excellent mechanical properties and relatively high electrical and thermal conductivities, both in cold-worked and heat-treated conditions.

In strip, rod, and tube forms, the following values are consistently reported:

Tensile strength . . . . . 65,000 psi
Yield strength . . . . . 55,000 psi
Electrical conductivity . . . 75% IACS

Strength is retained to a remarkable degree at temperatures as high as 750°F.

For complete information about Chromium Copper-999, and technical assistance pointing out ways in which it can serve you best, write Anaconda American Brass Company, Waterbury 20, Connecticut.

61-1965

ANACONDA®
AMERICAN BRASS COMPANY

rebels. It is positively asserted that the able rebel general, A. Sidney Johnston, is among the killed. Gen. Grant, who won this great and important victory, is the same who captured Fort Donelson."

"The annual report of the Vaccine Committee was read at a recent meeting of the French Academy, in which the question of early vaccination was fully discussed. M. Depaul, the reporter, states that in spite of the opposition raised to the vaccination of newborn children, the researches of the committee tend to show that this operation is not more dangerous in very early life than at the second or third month."

"Professor Thomson, of Glasgow, celebrated for his great knowledge respecting the operations of electricity, states that he usually finds the atmospheric electricity within doors negative to that of the earth. The air outdoors is generally positive."

"The insurance companies in London, like those in New York, have become alarmed at the large quantity of well oil at present stored in the British metropolis. These companies have laid their grievances before the Mayor, and they assert that this oil is of a most inflammable and dangerous character, being liable to spontaneous combustion. It is said that there are about half a million gallons of such oils now stored on the wharves in London. As crude petroleum is more dangerous than the refined quantities, and as the cost for carriage to market is just the same for both, it would be well to refine all petroleum in the vicinity of the oil wells."

"M. Niepce de Saint-Victor, in continuing his researches upon heliochromy, has succeeded in giving greater permanence to the colors obtained, chiefly by the employment of a bath of chloride of lead and dextrine. In diffused light the colored images obtained will remain ten or twelve hours. This is certainly a step in advance toward the solution of this very interesting problem; and, as M. Niepce remarks, if it be not yet completely solved, there is hope that it may be ere long."

"Uriah A. Boyden, Esq., of Boston, Mass., has deposited with the Franklin Institute the sum of $1,000, to be awarded as a premium to 'any resident of North America who shall determine by experiment whether all rays of light, and other physical rays, are or are not transmitted with the same velocity.' "

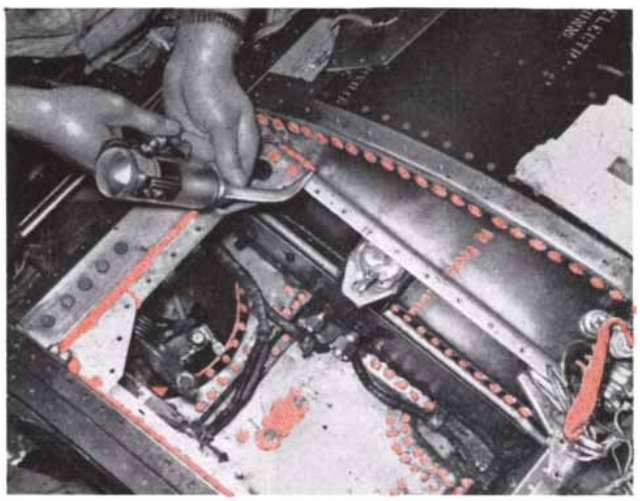
Leonardo da Vinci described how faraway ships were detected by a listening tube placed in the sea. From this crude beginning has evolved passive and active sonar. But the full impact of sonics and ultrasonics was not realized until electronics with its high-power components made possible refined equipment of infinite precision and reliability.

The Tung-Sol line of energy-producing active components for electronics is one of the most extensive in the industry—high-power gas-filled and vacuum tubes, receiving-type tubes, transistors and diodes. They are found in military and space equipment, computers and similarly sophisticated industrial control and test devices, as well as entertainment sets. Because Tung-Sol specializes in components, the accumulated applications experience is especially valuable to equipment manufacturers. Designers find it most helpful while equipment is being prototyped. Tung-Sol Electric Inc., Newark 4, New Jersey.

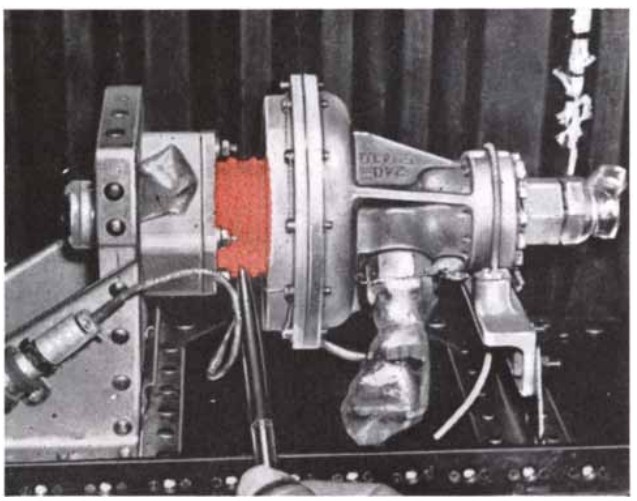
TUNG-SOL®

ELECTRON TUBES AND SEMICONDUCTORS — LAMPS FOR INSTRUMENTATION

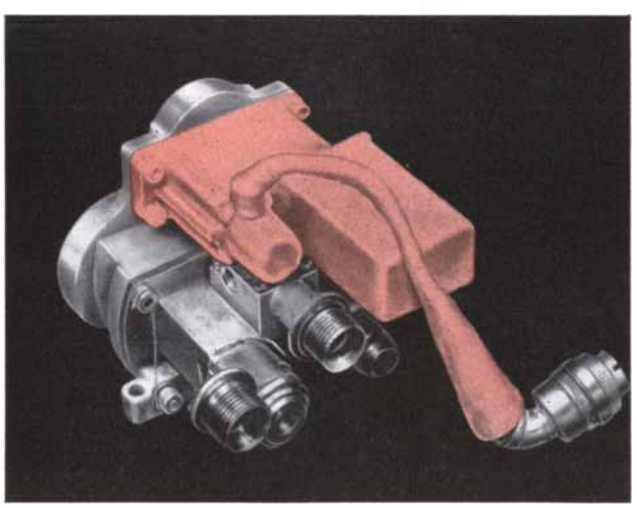
GENERAL ELECTRIC RTV SILICONE RUBBER KEEPS THE PRESSURE IN THE X-15!



Critical pressurized areas of the X-15, designed and built by North American Aviation through a joint NASA-Air Force-Navy research project, are sealed with General Electric RTV (room temperature vulcanizing) silicone rubber. After a thorough analysis of all high temperature sealants, RTV was selected to seal the aft bulkhead behind the cockpit, instrumentation compartment and shelving near the ship's mid-section.



RTV adhesive seals heating blanket for helium pressure regulator. RTV rubber forms tenacious bonds to most materials provided surfaces are properly primed. It is easily removed from unprimed surfaces. It can be applied by dipping, pouring, spraying or buttering—cures in place at room temperature to form a tough, flexible seal. Cure times can be varied from minutes to hours depending on catalyst used and heat, if applied.



Protection against hydrogen peroxide spillage is provided by RTV silicone rubber coating on this three position actuator. RTV is commonly used to protect against moisture and many chemicals. It's used in almost all U.S. missiles and space vehicles, not only for sealing, but for electronic potting and encapsulating, and as thermal insulation. It combines excellent electrical properties with physical protection.

If you would like a free sample for evaluation, write on your letterhead, describing your application. Section U466, Silicone Products Department, General Electric Co., Waterford, N. Y.

TYPICAL PROPERTIES OF RTV SILICONE RUBBER

	RTV-11	RTV-20	RTV-40	RTV-60	RTV-77	RTV-88	RTV-90
Viscosity, Poises	120	300	450	550	8,000	10,000	12,000
Color	White	Pink	White	Red	White	Red	Red
Consistency	Easily Pourable	Pourable			Spreadable Thixotropic Paste		Stiff Paste
Temperature Resistance	FROM −90°F TO +600°F FOR EXTENDED PERIODS TO 9,000°F FOR LIMITED TIME AS THERMAL INSULATION						
Specific Gravity	1.18	1.35	1.37	1.47	1.33	1.47	1.47
Radiation Resistance	10^9 ergs/gram						
Tensile Strength, psi	350	450	550	650	500	750	750
Shrinkage, %	0.4	0.2	0.2	0.2	0.3	0.3	0.2
Durometer, Shore A	45	50	55	60	50	65	60
Volume Resistivity, ohm-cm	$6x10^{14}$	$5x10^{13}$	$1x10^{14}$	$2x10^{14}$	$1x10^{15}$	$1x10^{14}$	$2x10^{14}$
Solids Content, %	100	100	100	100	100	100	100
Elongation, %	180	140	120	110	220	110	190

A wide range of RTV compounds meet a variety of application requirements. Low viscosity RTV-11 (or transparent LTV-602) is used for potting electronic assemblies and coil impregnation. RTV-77, 88 and 90 are mainly used for high-temperature sealing and for thermal insulating and ablative applications. Intermediate viscosities meet other insulating and sealing requirements, are also used as flexible mold materials.

GENERAL ELECTRIC

HOW

■ *can multi-processing make all components of your computer system work full time for you?*

■ *can your jobs run simultaneously in any combination even though your programs are written to run by themselves?*

■ *can you feed new jobs into the system any time without interfering with programs in process?*

■ *can you add a second central processor to the system and thus get true parallel processing without reprogramming?*

■ *can you have automatic scheduling, memory allocation, error checking, and routine control functions without the inefficiencies of conventional operating systems?*

A Burroughs B 5000 is your answer to all these questions. Take multiple processing. We define it as "priority processing on a time-sharing basis." This is the way the B 5000 is normally used. When you want to feed in another job, the B 5000 does not need additional instructions for sequencing and scheduling. It has its own master control program that does scheduling automatically. The programmer doesn't even have to specify the components to be used. He just feeds in the new program. Any time. Usually while other jobs are processing. The master control will integrate it into the work load and see that the components operate at maximum efficiency. The human error factor in scheduling is virtually eliminated.

And your work load can't outgrow the B 5000. It's the only computer on the market that can accommodate a second central processor. A new processor can be linked in any time—*without* costly reprogramming. Thus equipped, the B 5000 can solve several problems absolutely simultaneously; this is *true* parallel processing.

You see our master control program wasn't patched up to fit the computer. We designed the computer to fit a carefully thought-out master control. This is the secret of the built-in operating system's unmatched flexibility and efficiency. It does all the things we mentioned in our 5th question and also permits the addition of new equipment and programs.

Another thing: The B 5000 can process programs written in COBOL or ALGOL—but that's a story in itself. If you would like the details on *all* the advantages of this remarkable computer, just write Burroughs and ask for a copy of *The B 5000 Concept*, Burroughs Corporation, Detroit 32, Mich.

Burroughs—TM

Burroughs Corporation

New asynchronous* message printer combines reliability, quietness and high speed

**Start-Stop operation under the command of input data.*

The S-C 3070 message printer utilizes an electrostatic process to produce highly legible, permanent copy. The printer is designed to operate at speeds up to 3000 words per minute using standard computer or communications codes over telephone, telegraph and microwave links. ■ Compact dimensions and quiet operation make the S-C 3070 ideal for offices and communications or command centers. Multiple copies of S-C 3070 printer output can be easily obtained by using the original as a litho offset master or by standard office copying methods. ■ Reliable, unattended operation in the S-C 3070 results from the unit's non-impact printing concept and field proven electronic circuitry. Ease of maintenance is assured through modular design and readily replaceable printed circuit boards. Replacement paper rolls can be loaded into the S-C 3070 without interrupting operation or interfering with message transmission. The S-C 3070 has many applications in military, government, and commercial communications systems—and in the data processing field. ■ For additional information on the S-C 3070, write to Department C-26, General Dynamics | Electronics, Post Office Box 2449, San Diego 12, California.

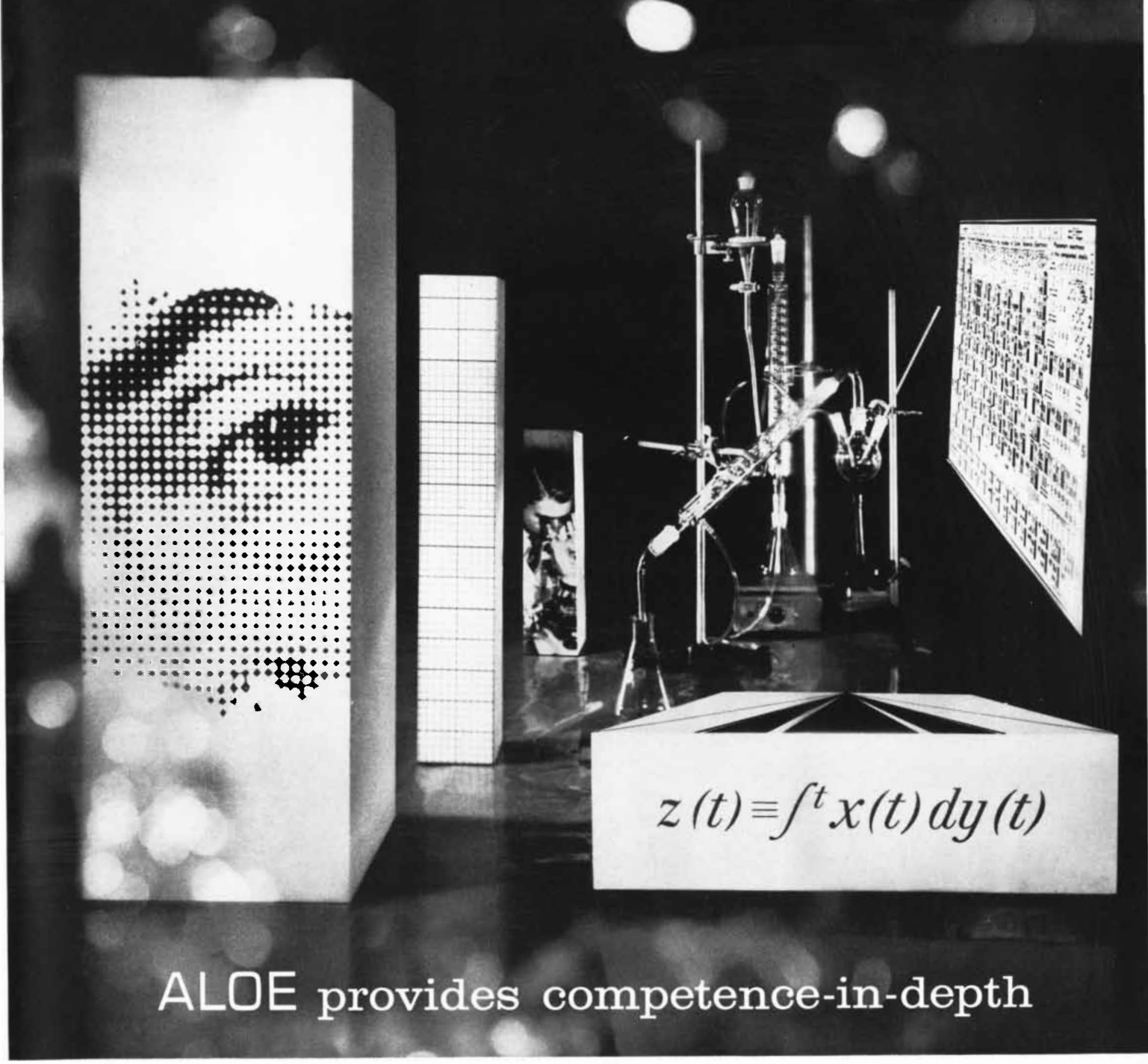
GENERAL DYNAMICS | ELECTRONICS GD SAN DIEGO

THE AUTHORS

P. M. S. BLACKETT ("Steps toward Disarmament"), professor of physics at the Imperial College of Science and Technology of the University of London since 1953, is distinguished both as a physicist and as an adviser to the British Government on military and scientific policy. A graduate of the University of Cambridge and a Fellow of the Royal Society, he won the Nobel prize in physics in 1948. He went into physics from the Royal Navy, a graduate of the Royal Naval College at Dartmouth and a veteran of the Battle of Jutland. From 1934 to the beginning of World War II Blackett served on the Aeronautical Research Committee chaired by Sir Henry Tizard, which developed Britain's radar defense system; his work during the war was instrumental in defeating the German submarine campaign. Since the war he has played a leading role in public discussion of military questions; his writings include *Atomic Weapons and East-West Relations*, published by Cambridge University Press in 1956. Portions of the present article appeared in the *New Statesman* for March 2.

ROBERT P. KRAFT ("Exploding Stars") is a staff member of the Mount Wilson and Palomar Observatories. Kraft received his B.S. and M.S. in mathematics from the University of Washington in 1947 and 1949 respectively. After joining the faculty of Whittier College in California he became interested in the philosophy of the physical sciences. This led him to abandon pure mathematics for astronomy, which he describes as "a truly empirical science, in which theory really meets the test of experience." Kraft acquired a Ph.D. in astronomy at the University of California in 1955 and taught at the University of Indiana and the University of Chicago before going to Mount Wilson and Palomar. This is Kraft's second article for SCIENTIFIC AMERICAN. The first was "Pulsating Stars and Cosmic Distances" (July, 1959).

J. DAVID ROBERTSON ("The Membrane of the Living Cell") is assistant professor of neuropathology at the Harvard Medical School and associate biophysicist at McLean Hospital in Belmont, Mass. A graduate of the University of Alabama, Robertson took his M.D. at Harvard in 1945, interned at Boston City Hospital and in 1948 went to the Massachusetts Institute of Tech-



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nology. After receiving a Ph.D. in biochemistry from M.I.T. in 1952 he taught for three years at the University of Kansas. From 1955 to 1960, when he went to Harvard, Robertson was research associate in anatomy at University College London.

W. V. QUINE ("Paradox") is Edgar Pierce Professor of Philosophy at Harvard University. He was graduated *summa cum laude* from Oberlin College, where he had majored in mathematics and done honors reading in mathematical logic. Two years later, in 1932, he obtained his Ph.D. from Harvard University, having written his dissertation in logic under Alfred North Whitehead. A year of informal study at the universities of Vienna, Prague and Warsaw was followed by Quine's election to Harvard's Society of Fellows. He began teaching at Harvard in 1936 and in 1948 became professor of philosophy and a Senior Fellow of the Society of Fellows. Since then Quine has also lectured and studied at the University of Oxford, the Institute for Advanced Study in Princeton, N.J., and the Center for Advanced Study in the Behavioral Sciences in Palo Alto, Calif. In the summer of 1959 he lectured in Japan and Australia. Of the seven books he has written, the latest, *Word and Object*, appeared in 1960.

ERNST HADORN ("Fractionating the Fruit Fly") is director of the Institute of Zoology and Comparative Anatomy of the University of Zurich. He was trained as a biologist at the universities of Bern and Munich, receiving his Ph.D. degree from the former in 1931. After lecturing at Bern for several years Hadorn spent a year on a Rockefeller fellowship at Harvard University and the University of Rochester and in 1939 became professor at the University of Zurich. Hadorn began his career as an experimental embryologist working on the interactions between the nucleus and cytoplasm of cells in amphibians. He later discovered the role of the "ring gland" as the center of hormone production in insects. Since then he has done research chiefly in developmental and biochemical genetics, investigating problems of mutating pattern formation and the action of lethal factors in the fruit fly. Hadorn's book *Developmental Genetics and Lethal Factors* appeared recently in English translation.

NORMAN A. DE BRUYNE ("The Action of Adhesives") is chairman and research director of Techne Limited, an English instrument-manufacturing firm

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he founded in 1948. De Bruyne was born at Punta Arenas in Chile in 1904. He studied physics at the University of Cambridge, where he took first-class honors in 1923 and was elected to a fellowship at Trinity College for research done at the Cavendish Laboratory under Ernest Rutherford. Having already begun to design, build and fly airplanes embodying structural concepts new at the time, De Bruyne in 1934 founded the firm Aero Research Ltd., acquired in 1947 by the Ciba Corporation. He was awarded the gold medal of the Royal Aeronautical Society in 1937 and later invented honeycomb construction and metal-metal bonding for aircraft structures.

CLARENCE D. CONE, JR. ("The Soaring Flight of Birds"), is a research aerodynamicist in the General Aerodynamics Branch of the National Aeronautics and Space Administration's Langley Research Center in Virginia. Cone attended Armstrong College in Savannah, Ga., receiving a degree in chemistry in 1952, and the Georgia Institute of Technology, where he acquired a degree in chemical engineering two years later. Until 1957 Cone was a staff member of the Herty Foundation in Savannah. There he specialized in basic and applied research on pine barks and other plant products. Since taking his present job in 1957 Cone has been engaged primarily in research in subsonic aerodynamics. He obtained an M.A. in aeronautical engineering from the University of Virginia in 1959 and is currently working toward a Ph.D. in aerophysics at that institution.

DONALD E. BROADBENT ("Attention and the Perception of Speech") is director of the Applied Psychology Research Unit of the Medical Research Council in Cambridge, England. His original intention was to be a physical scientist, but while serving with the Royal Air Force he became interested in the problem of how the arrangement of controls on instrument panels might make some aircraft more difficult to fly than others. Subsequently he took a degree in psychology at the University of Cambridge in 1949, going to work in the Applied Psychology Research Unit immediately thereafter. Broadbent became director of the Applied Psychology Research Unit in 1958.

MAX BLACK, who in this issue reviews G. J. Whitrow's *The Natural Philosophy of Time,* is Susan Linn Sage Professor of Philosophy at Cornell University.

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The Study of Surface States on Clean Semiconductor Surfaces

The electrical properties of a semiconductor are drastically modified by effects that occur on the surface. A new cleavage method enables scientists to measure true properties on perfectly clean surfaces.

The effects of the surface on the electrical characteristics of a semiconductor are well known. While the proper semiconductor materials can be prepared to produce the desired characteristics in the bulk material the surface effects can drastically alter these desired characteristics. Desired surface effects are now obtained through empirical means, although at present it is not understood why these empirical approaches work.

The problem then becomes to theoretically define what surface characteristics are desired and in turn manufacture the surface so as to be simple and reproducible.

There are states at the surface of a semiconductor that can both attract electrons from the bulk material and give up electrons to the material. One type of state, associated with the material itself, derives from the fact that absolutely clean surfaces have surface states available. Some scientists associate this with dangling valence bonds while others, solving the equations of the crystal, assume extra states are available.

A second type of state occurs because adsorbed atoms on the surface can pick up or donate electrons to the material.

The change in charge density at the surface resulting from the surface states causes three important electrical effects:

Conductance changes because charges coming from the material are trapped at the surface leaving fewer carriers or electrons in the material.

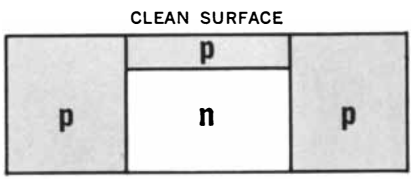
Work function, the measure of the energy required for an electron to move out of the material into free space, changes because the charges placed on the surface set up an electrical field at the surface.

The lifetime of the material, the time for an excited electron to return to its normal bound position in a crystal lattice, changes due to the same electrical field and because it extends into the bulk material.

In the past a large amount of work has been done on surface states where the surfaces were chemically etched. This procedure produced most of the fundamental results presently used but has the inherent limitation of making it impossible to determine the nature of the types of atomic species on the surface.

More recently scientists have worked with sputtering techniques where the surface is cleaned by a bombardment of atoms under an inert gas. The atoms remove the impurities but also disturb some layers of the material under study thereby changing the conductivity of the semiconductor. Also there is a question of whether the surface is actually atomically clean or whether there is a small number of foreign atoms remaining.

Honeywell scientists were the first to prepare a fresh surface by cleaving a piece of semiconductor material under an ultra-high vacuum in such a way that electrical measurements can be made.



pnp CONFIGURATION
FOR SURFACE STUDY

In germanium the surface states are such that the material nearest the clean surface is p type or a type of material that conducts by holes or vacancies. In a pnp configuration (see diagram) there is a conducting path between the p type regions. (The n type conducts by electrons.) The p type layer is entirely controlled by surface states. Therefore any changes in the characteristics of the layer can be associated with changes in surface states.

By applying a voltage across the two p regions the conductivity through the layer, or channel can be measured easily. This conductivity, or hole density of the channel, can be plotted as a function of the voltage between the n region and the channel. By analysis the energy and density of the surface states can be determined. With the density of the surface states for the particular material determined oxygen is introduced and the number of surface states resulting from both inherent and adsorptive surface states can be measured.

With the ability to determine the surface states, both inherent and adsorptive, it is possible to more clearly understand what occurs at the surface. This is an important step towards the ability to define what surface states are produced by different gases and different semiconductor materials. With further analysis it is possible to determine what arrays or types of surface states are desired for good transistor characteristics.

Further research should eventually lead to methods for controlling surface states and laying down surface states at will in the same way that impurities are introduced into basic semiconductor materials to produce desired characteristics.

For the chemist, information on the nature of surface states and their control will be an important step in defining the reactivity of adsorbed species on the surface. This will in turn be significant in understanding catalytic phenomena.

If you are engaged in scientific work involving surface states and wish to know more about Honeywell's research in this area, you are invited to correspond with Dr. S. Roy Morrison, Honeywell Research Center, Hopkins, Minnesota.

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

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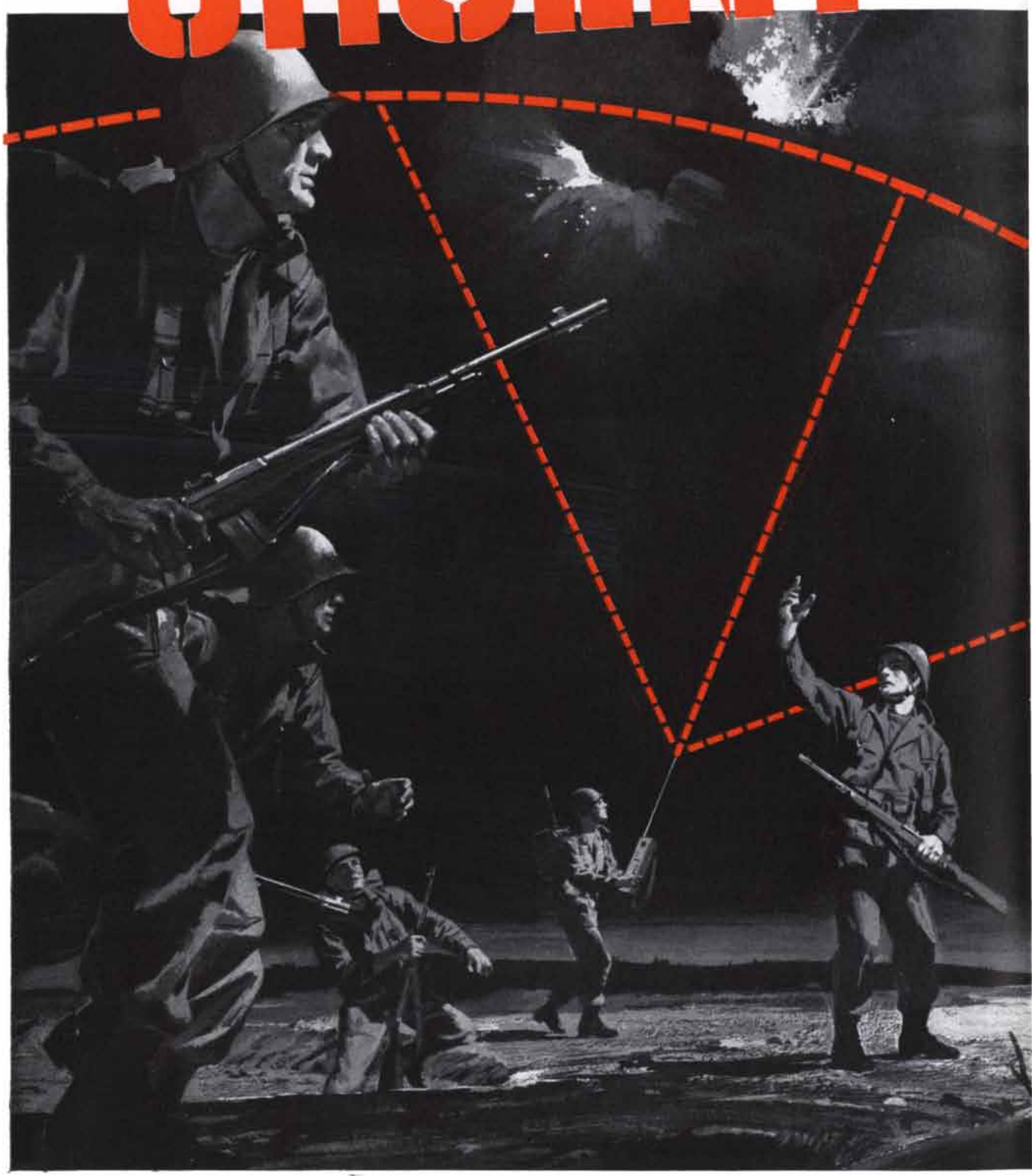

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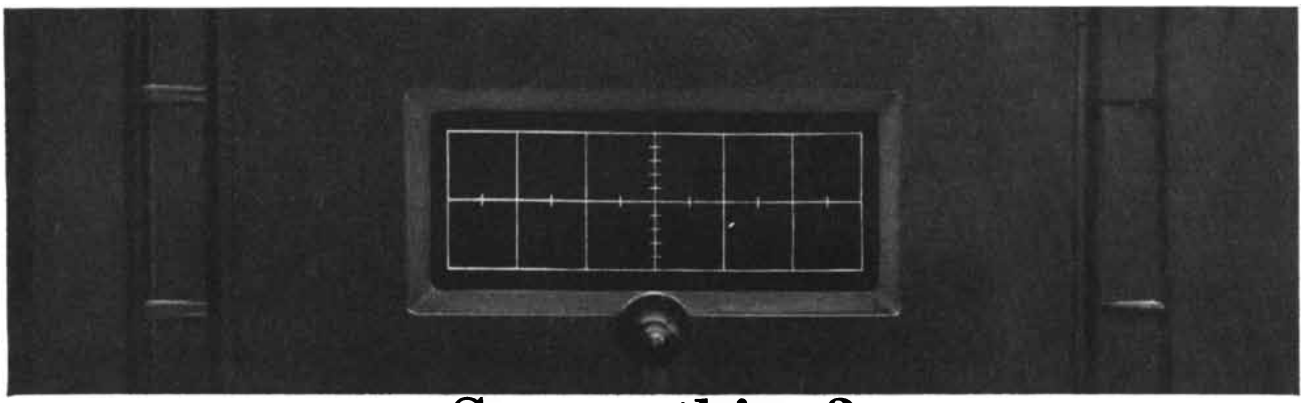
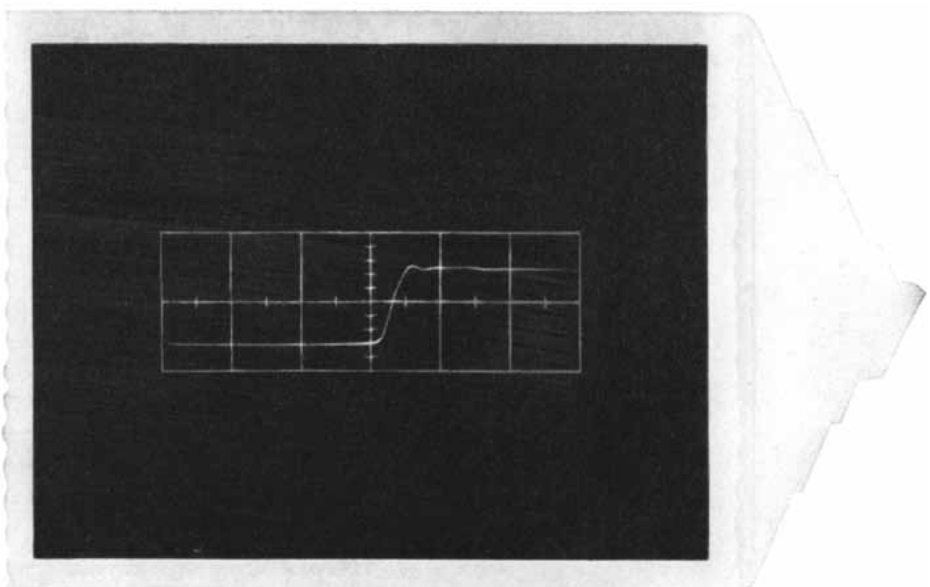


See anything?



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Steps toward Disarmament

A British physicist and World War II military operations analyst discusses the problems that underlie the present disarmament negotiations

by P. M. S. Blackett

The representatives of 17 nations—the two main nuclear powers, seven nations allied with one or the other of them, and eight uncommitted nations—have convened at Geneva for the third formal, full-dress attempt since the end of World War II to negotiate disarmament. It must be conceded that the circumstances are not entirely favorable to agreement. During 1961 the U.S. and the U.S.S.R. reversed the trend of nearly a decade and increased their military expenditures by something on the order of 25 per cent. The three-year moratorium on the testing of nuclear weapons was terminated by the series of Soviet tests in the fall; on the eve of the Geneva meeting the U.S. announced its intention to move its present series of underground tests into the atmosphere if the U.S.S.R. did not immediately agree to a test ban.

On the other hand, both the Soviet and the Western bloc are committed by categorical public statements to the objective of complete and general disarmament under strict inspection and control. What is more, practical military considerations, arising from the nature of nuclear weapons, commend substantial reduction in armaments to the great powers as a measure that will increase their security in the first step toward disarmament.

In considering possible first steps that would lead to increased security for both sides, partisans of each side should try to understand how the present military situation must look to the other. A military commander, in planning a campaign or a battle, attempts to do this as a matter of course. He has first to find out all he can about the material facts of his opponent's military deployment and secondly to assess the probable intentions of his opponent for its use. This is the process that has been described as "guessing what is happening on the other side of the hill." A similar obligation rests on those who plan a disarmament negotiation. A military planner, it is true, can much more easily put himself mentally in the position of his military opponent than a statesman can think himself into the position of his opposite number, because a statesman must enter imaginatively into the political as well as the military thought processes of his opponent. This is hard to do at a time of acute ideological struggle. It is nonetheless essential that the military and political leaders of both sides do just this. No small part of the present crisis, concerning armaments in general and nuclear weapons in particular, has been due to a tendency in the West to attribute to ideological motives actions by the U.S.S.R. that seem to have been motivated mainly by military considerations. Conversely, much of the West's defense policy appears to have been influenced by political and economic factors.

It may be useful to start by describing the most important elements in the military capabilities of the Soviet bloc and the Western alliance. In recent months there have been significant disclosures about the nuclear weapons and their means of delivery possessed by both sides. On November 12 of last year Robert S. McNamara, Secretary of Defense of the U.S., said that the U.S. nuclear-strike force consists of 1,700 intercontinental bombers, including 630 B-52's, 55 B-58's and 1,000 B-47's. He said that the U.S. possesses in addition several dozen operational intercontinental ballistic missiles (ICBM's), some 80 Polaris missiles in nuclear-powered submarines, about the same number of Thor and Jupiter intermediate-range missiles, some 300 carrier-borne aircraft armed with megaton war heads and nearly 1,000 supersonic land-based fighters with nuclear war heads. According to his deputy, Roswell L. Gilpatric, "the total number of our nuclear delivery vehicles, tactical as well as strategic, is in the tens of thousands, and of course we have more than one war head for each vehicle.... We have a second-strike capability that is at least as extensive as what the Soviets can deliver by striking first, therefore we can be confident that the Soviets will not provoke a major conflict." The U.S. stockpile of nuclear weapons is most often estimated as around 30,000 megatons, that is, enough for some 30,000 one-megaton bombs.

Naturally no such precise figures for Soviet strength are available. I have seen no reliable estimates of the U.S.S.R.'s nuclear stockpile, nor of its possible nu-

clear-armed submarine strength, nor of its nuclear-armed fighter-bomber strength (the last, of course, would not have sufficient range to contribute to the Soviet strike power against the U.S.). But recent semiofficial estimates from Washington give the U.S.S.R. some 50 ICBM's, some 150 intercontinental bombers and some 400 medium-range missiles (the last able to cover Europe but not the U.S.). The same sources indicate that the U.S. may have a small lead over the U.S.S.R. in the number of ICBM's. That such estimates should issue from Washington may seem surprising in view of the role that an alleged "missile gap" played in the 1960 presidential election campaign. That the estimates are realistic, however, is indicated by the statement of Senator Stuart Symington that the U.S. intelligence estimate of the missile force available to the U.S.S.R. at the middle of 1961 was only 3.5 per cent of the number predicted a few years ago. The corresponding estimate of Soviet bomber strength, he revealed, was 19 per cent of the number predicted in 1956 [*see illustrations on page 52*]. Mr. Symington explained that the new figures are predicated on intelligence about Soviet "intentions" as well as "capability" and expressed his own disquiet at "the tentativeness at best of our intelligence estimates." It is one of the purposes of this article to attempt to elucidate some of these Soviet intentions.

At first sight there appears to be a contradiction between Washington's claim of a marked over-all nuclear superiority and the recent statement by Marshal Rodion Y. Malinovsky, the Soviet Minister of Defense, that the U.S.S.R. has the power to destroy all the important industrial, administrative and political centers of the U.S. and "whole countries that have provided their territories for the siting of American war bases." The explanation may be as follows. To carry out such destruction would require not more than 1,000 megatons of nuclear destructive power, say five megatons for each of 100 key targets in the U.S. and another 500 megatons for Western Europe and U.S. bases overseas. At only 100,000 dead per megaton such an attack would kill 100 million people. The U.S. stockpile, estimated at 30,000 megatons, is 30 times greater than the U.S.S.R. would need to carry out the retaliatory blow described by Malinovsky.

There is, of course, the possibility that the new U.S. estimates of Soviet nuclear strength are too low. After all, firm information about Soviet military preparations is notoriously hard to come by. It seems certain, however, that the U.S. Department of Defense must believe the estimates to be roughly correct. It would be politically disastrous for the Administration to be found guilty of underestimating Soviet nuclear strength. But even assuming that the estimates of the relative strength of the two sides are only approximately correct, they show that the possibility of a rationally planned surprise nuclear attack by the U.S.S.R. on the nuclear delivery system of the West must be quite negligible. The question of why the U.S.S.R. has built such a small nuclear delivery system should perhaps be replaced by the question of why the U.S. has built such an enormous striking capacity.

In order to understand the possible motives behind Soviet defense policy, it is necessary to consider the history of the growth of nuclear-weapon power. During the period of U.S. atomic monopoly or overwhelming numerical superiority, say from 1947 to 1954, the role of the U.S. Strategic Air Command was to attack and destroy Soviet cities in case of war. This countercity policy, like most traditional military doctrines, had both an offensive and a defensive aspect. From the Western viewpoint, under the doctrine of "massive retaliation," this nuclear striking power was seen to be both a deterrent to the possibility of attack by Soviet land forces and, in the extreme "roll back," or "liberation," statement of the doctrine, an offensive weapon to obtain political concessions by threat of its use. By 1954 the threat was implemented by more than 1,000 intercontinental B-47 bombers, plus larger numbers of shorter range vehicles deployed around the U.S.S.R.

From the U.S.S.R.'s point of view, its land forces were the only available counter to the Western nuclear monopoly during this period. The answer to the threat of nuclear attack was the threat of taking over Europe on the ground. In retrospect the military reaction of the U.S.S.R. seems understandable. It started a crash program to produce its own nuclear weapons. It also embarked on a huge air defense program; by 1953 it was credited with an operational fighter strength of some 10,000 aircraft. As Western nuclear strength grew, the U.S.S.R. gradually built up its land forces so as to be able to invade Europe, even after a U.S. nuclear attack. At the political level the U.S.S.R. consolidated its forward military line by the political coup in 1948 in Czechoslovakia and integrated the other satellite countries more closely into the Soviet defense system. Since the main military threat then to the U.S.S.R. was from manned nuclear bombers, the greatest possible depth for air defense was vital. During World War II it was found that the efficacy of a fighter defense system increased steeply with the depth of the defense zone. Finally, the U.S.S.R. maintained strict geographical secrecy over its land area so as to deny target information to the U.S. Strategic Air Command.

The doctrine of massive retaliation became less and less plausible as the

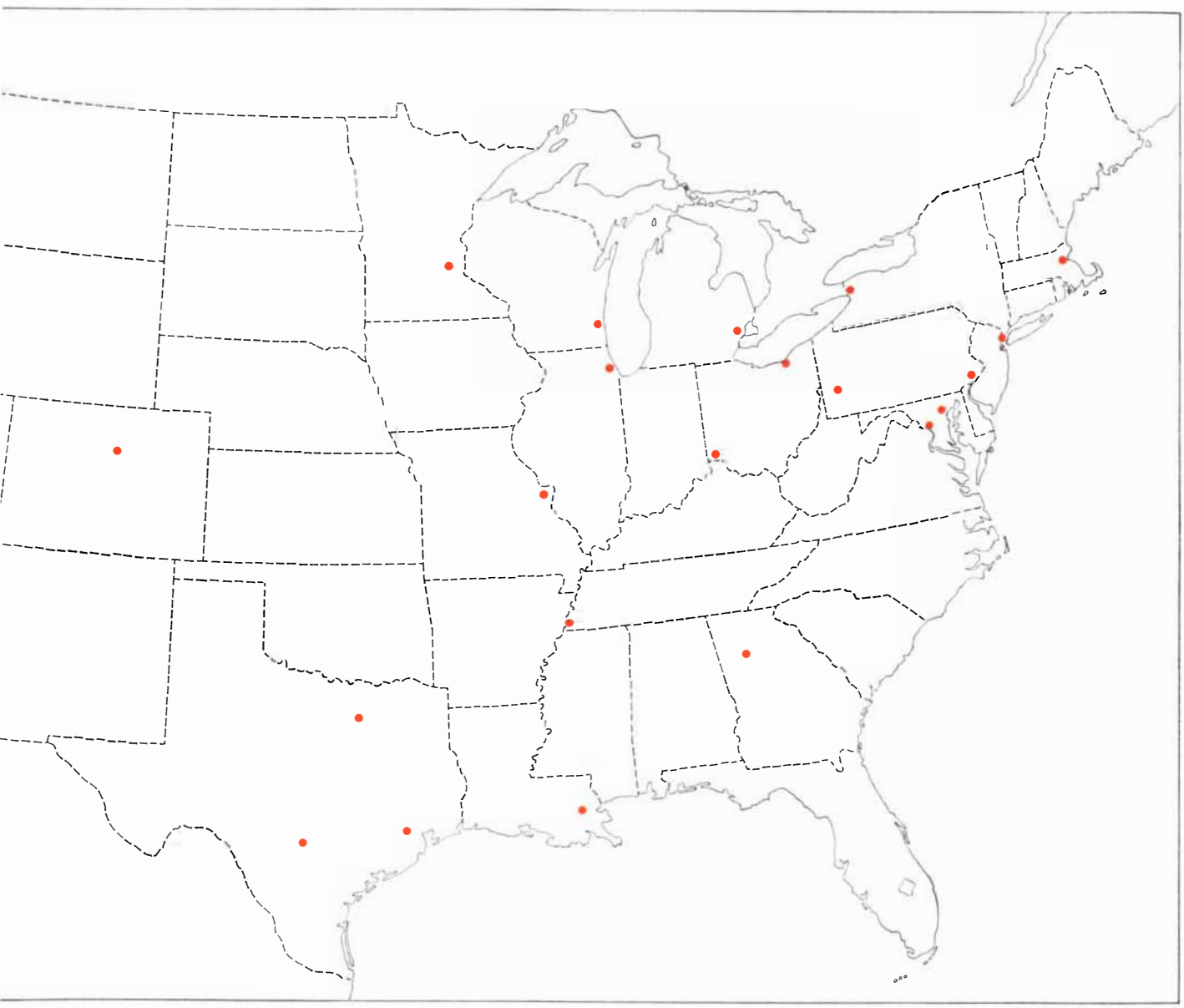
MINIMUM DETERRENT strategy of a nuclear opponent of the U.S. could logically

Soviet nuclear stockpile grew. It had to be abandoned after 1954, when hydrogen bombs became available to both East and West. When the U.S.S.R. proceeded to build up a fleet of long-range bombers to deliver its hydrogen bombs, the U.S. became vulnerable to nuclear counterattack. Some form of nuclear stalemate by balance of terror seemed to have arrived.

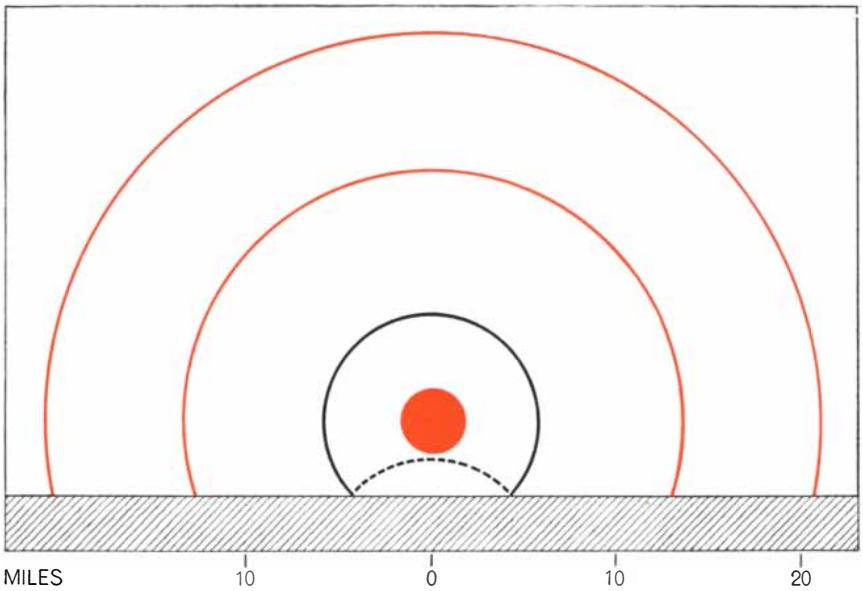
This balance seemed still further strengthened about 1957, when rapid progress in the technology of nuclear weapons and missiles made it possible to carry multimegaton hydrogen bombs in ICBM's. Because such missiles are most difficult, if not impossible, to destroy in flight, a nuclear aggressor would have to leave no enemy missiles undestroyed if it wanted to keep its own major cities from being wiped out by a retaliatory attack. The advent of long-range missiles therefore made the balance of terror more stable.

Two contrasting systems of military theory evolved in response to this new situation. The first led off from the premise that a rather stable kind of military balance had been reached, in which neither side could make use of its strategic nuclear power without ensuring its own destruction. In other words, the balance of terror was likely to be rather stable against rational action, even though the actual nuclear strengths of the two sides were markedly different, as indeed they were in the middle 1950's, when the U.S. was already vastly stronger in over-all deployed nuclear strength. This view rested on the assumption that neither side could hope to knock out the other's nuclear system entirely. Since some power to retaliate would survive attack, a rational government would be nearly as much, if not just as much, deterred from a first strike by the expectation that it would suffer, say, 10 million deaths as it would be if the expectation were 100 million.

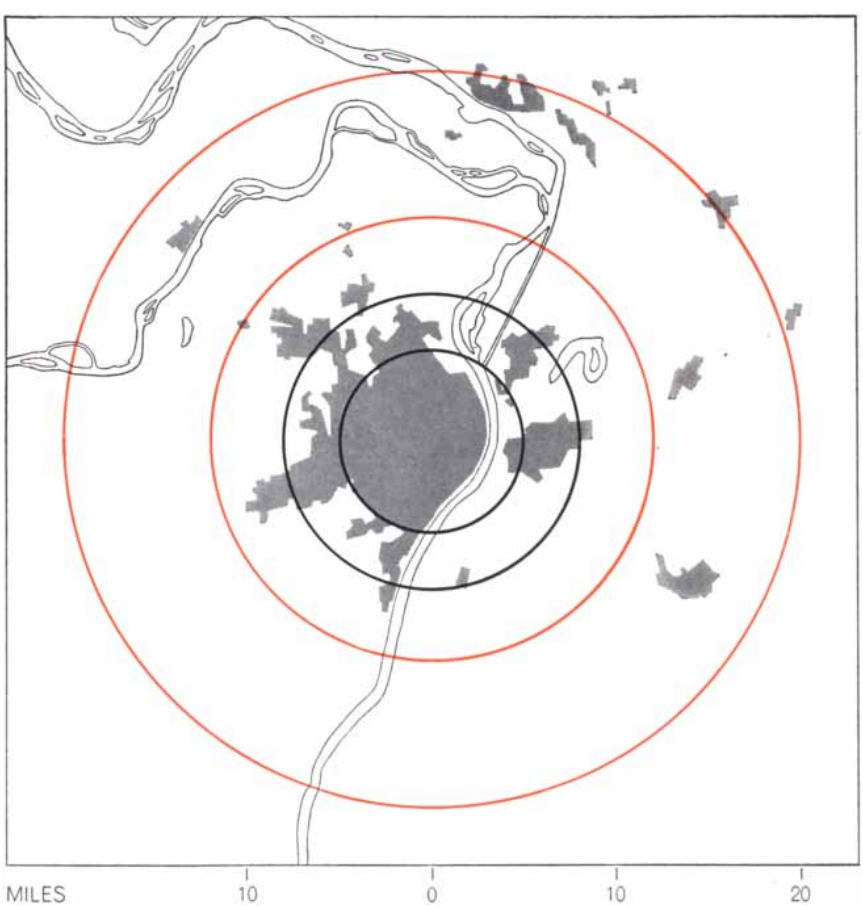
This view led to the practical conclu-



be based on an attack on the U.S. population rather than on U.S. airfields and missile bases. The colored dots on this map represent the 25 largest U.S. cities. In the 1960 census the combined population of the metropolitan areas of these cities was 60.8 million.



AIR BURST of a nuclear bomb would maximize its effects on a city, the most widespread of which would be due to heat. This drawing outlines the effects of a 10-megaton bomb set off at 20,000 feet. At 12 miles (*inner colored circle*) from "ground zero" the fireball, 3.4 miles in diameter, would deliver 30 calories per square centimeter at a rate sufficient to ignite virtually all flammable building materials. At 20 miles (*outer colored circle*) from ground zero the heat would be 12 calories per square centimeter, enough to cause third-degree burns and start many fires. Arc extending upward from ground below the burst is a reflected shock wave that would amplify blast effects of the explosion (*see drawing below*).



RADII OF EFFECTS of a 10-megaton air burst are superimposed on a map of St. Louis and the surrounding area. The two colored circles correspond to the colored circles in the drawing at the top of the page. The black circles concern effects due to blast. At a distance of five miles (*inner black circle*) from ground zero virtually all buildings would be destroyed. At eight miles (*outer black circle*) virtually all wooden buildings would be destroyed.

sion that "enough is enough." In today's jargon this is the policy of the minimum deterrent—that is, the possession of a nuclear force adequate only for a retaliatory attack on enemy cities but incapable of successful attack on the enemy's nuclear delivery system. It is clear that only a small nuclear delivery system is necessary for a minimum deterrent. One big hydrogen bomb dropped on a big city could kill several millions. The small delivery system must, however, be highly invulnerable. Otherwise the enemy might think it possible to bring off a successful "counterforce" first strike, aimed at the destruction of the system. Little operational intelligence is needed for such a minimum deterrent policy because this involves attack on cities, whose locations are known, and does not involve surprise attack on nuclear bases, whose locations therefore do not need to be known.

On the political plane, it was thought, the resulting period of relative stability would be favorable for a serious attempt to negotiate a substantial measure of disarmament, both nuclear and conventional. Far-reaching disarmament was seen to be highly desirable, if only because such a balance of terror is stable solely against rational acts of responsible governments. It is not stable against irresponsible actions of individuals or dissident groups or technical accidents. A few suitably placed individuals—a missile crew or the crew of a nuclear bomber on a routine flight—could kill a few million enemy city dwellers on their own initiative. The best way to reduce this danger is to reduce drastically the number of nuclear weapons on both sides.

The second and quite different doctrine was that the balance of terror was not even stable against rational acts of responsible governments. This was based on the view that a determined nuclear power might be able to launch a surprise counterforce attack on the enemy's nuclear delivery system of such strength that the enemy would not be able to retaliate. The aggressor, without suffering unacceptable casualties, would then have the enemy at its mercy. The practical consequence of this doctrine is to strive for maximum superiority in number of weapons, maximum invulnerability of one's own nuclear delivery system and maximum intelligence about the enemy's nuclear system.

Plainly a successful counterforce attack would require knowledge of the location of all the enemy's nuclear missile and air bases and the power to dispatch

several weapons against each, so as to ensure that at least one reached its target. A counterforce strategy thus implies the necessity for a many-fold nuclear superiority over the enemy. Moreover, to have the slightest chance of success such an attack must come as a complete surprise to the enemy: it must be a first strike. This policy has various pseudonyms: maximum deterrent posture, first-counterforce-strike capability, or, in plain English, preparation for nuclear aggression.

Since the possession of nuclear armament raises the possibility that either side could adopt either one of these strategies, both of them must have been discussed in military circles in Moscow and Washington during the years after the explosion of the first hydrogen bombs in 1954. Let us try to find out how the discussions went by studying what shape the nuclear-defense policies of the U.S.S.R. and the U.S. took in the subsequent years.

If the Washington figures for Soviet nuclear strength are valid, it is clear that the U.S.S.R. has planned for a purely retaliatory nuclear role and has definitely not planned for a surprise attack on the U.S. delivery system. As long ago as 1956 the U.S.S.R. was believed to have the capability of making 25 long-range bombers a month. It appears today to have only some 150, compared with the 1,700 U.S. long-range bombers able to reach the U.S.S.R. Even though Soviet medium-range bombers could reach the U.S. on a one-way flight, this is much more than counterbalanced by the 1,500 or so Western fighter bombers, carrier-borne aircraft and medium-range missiles able to reach the U.S.S.R. It is also probable that the U.S.S.R. could have made many more than the 50 or so ICBM's with which it is now credited, since its space program indicates substantial industrial resources for making missiles. The evidence is that the U.S.S.R. has based its safety on the retaliatory power of a small number of missiles and aircraft operating from bases whose exact locations are kept as secret as possible. The deterrent value of its missiles is certainly enhanced by the prestige of its space program.

That the U.S.S.R. believed the danger of a major war, intentionally initiated, had been reduced by the advent of hydrogen bombs seems indicated by the fact that it reduced the total number of men in its armed forces from 5.8 million in 1955 to 3.6 million in 1959. In January, 1960, Premier Khrushchev announced the U.S.S.R.'s intention to reduce this to 2.4 million by the end of 1961. The U.S.S.R. needed fewer troops because it no longer had to rely on a retaliatory land blow in Europe to counter a Western nuclear attack. Its concern about the danger of accidental, irresponsible or escalated war is probably one of the reasons for its strong espousal in 1955 of a drastic measure of comprehensive and general disarmament.

Turning to the history of U.S. defense policy over this period, it is to be noted that the total service manpower fell slowly from 2.9 million in 1955 to 2.6 million in 1960. The development of improved nuclear weapons, missiles and aircraft continued, but not at a great rate, even after the Soviet launching of an artificial satellite in 1957 and much boasting by the U.S.S.R. of its missile prowess. Although subjected to considerable public pressure to engage in a crash program to close the alleged missile gap, President Eisenhower maintained that the existing program was adequate for the safety of the nation. In his last State of the Union Message in January, 1961, he declared: "The 'bomber gap' of several years ago was always a fiction and the 'missile gap' shows every sign of being the same."

As 1954 was the year of the hydrogen bomb, so 1961 was for both sides in the cold war the year of the Great Rearmament. In the U.S.S.R. the decrease of total armed forces to 2.4 million projected for 1961 was deferred and the arms budget was markedly increased. In July the Soviet Government went on the diplomatic offensive to bring about changes in the status of Berlin and to get the division of Germany recognized. In August it began testing nuclear weapons again, in spite of a promise in January, 1960, by Premier Khrushchev that the U.S.S.R. would not be the first to do so. No doubt there were some political motives behind these drastic moves. Possibly heavy pressure was put on Khrushchev from China and from the opposition elements in the U.S.S.R. to admit that his policy of coexistence had not produced political gains commensurate with its possible military risks. But such drastic changes, with the inevitable adverse reaction of much of world opinion, would hardly have been made unless there were strong military reasons for them. To get at these reasons it is necessary to recall in more detail the circumstances in which the changes took place.

In the first place the flights of the U.S. reconnaissance U-2 aircraft must have had decisive importance in shaping the attitudes of Soviet military leaders. Although the over-all nuclear strength of the U.S. is now, and was then, much greater than that of the U.S.S.R., Soviet leaders could reckon that one vital factor would make a U.S. nuclear attack on the U.S.S.R. exceedingly risky: the secrecy as to the location of the Soviet nuclear bases. Obviously one of the main objectives of the U-2 flights was to locate those nuclear bases. The Soviet command knew that the U-2 flights had been going on for some years before the first aircraft was shot down in the spring of 1960; presumably they reacted by greater dispersal and camouflage. What must have disturbed the Soviet military staff was President Eisenhower's justification of the flights as essential for U.S. security. This implied that U.S. security could only be maintained if the U.S. had sufficient information as to the location of Soviet nuclear sites to make possible a successful surprise attack on the Soviet retaliatory force.

If these were the Soviet fears, the rejection by the U.S.S.R. early in 1961 of the British-American draft of a treaty to ban the testing of nuclear weapons finds explanation in the same jealous military concern to protect the country's geographical security. A detailed study of this document makes it clear that the elaborate international inspection system proposed for the prevention of underground tests could conceivably have served to reveal the location of at least some of the Soviet missile sites. It would be hard to convince a military staff officer of any nationality that this possibility was negligible. If the West had been content to monitor only the atmosphere against test violations, a much less comprehensive inspection system would have sufficed and a test-ban treaty might well have been signed. The Soviet fear of inspection may have been the more acute because there was so little in the U.S.S.R. to inspect.

The resumption of testing by the U.S.S.R. in September, 1961, would seem to fall into the same pattern of motivation. Although its timing may have been influenced by the Berlin crisis, which Khrushchev himself brought to a head, the testing of war heads with an explosive force of up to 60 megatons and the simultaneous well-publicized success of putting seven ICBM's on their target in the Pacific at a range of some 7,000 miles was an effective way of reestablishing the U.S.S.R.'s confidence in the few deployed ICBM's that formed its main retaliatory force. Soviet spokesmen

were at pains to promote the credibility of the U.S.S.R.'s deterrent by emphasizing to the U.S. the accuracy of its missiles and the possible power of the war heads demonstrated in these tests.

In the redirection of Soviet military policy considerable weight must also have been carried by the fear that if the NATO rearmament continued, the time could not be far distant when West Germany would get *de facto* control of its own nuclear weapons. In Soviet eyes the refusal of the West to take disarmament seriously at the "Committee of Ten" conference in 1960 was evidently decisive. As early as November, 1960, the Russians stated that if the West continued to temporize on disarmament, the U.S.S.R. would be forced into massive rearmament.

Sometime in the latter half of 1960 or early in 1961 it seems probable that the Soviet military staff began to have doubts as to the adequacy of the minimum deterrent posture in relation to the near-maximum deterrent posture of the U.S. It must have been later than January of 1960, for in that month Khrushchev announced a drastic cutback of both long-range bombers and conventional forces. Since the effectiveness of the Soviet minimum deterrent rested so heavily on geographical secrecy, the U.S.S.R. command may have feared that the U.S., by further air or satellite reconnaissance, or by espionage or defections, would ultimately acquire the intelligence necessary to make a successful nuclear attack on Soviet nuclear bases. Probably the main fear of the Soviet Government was that circumstances might arise in which the U.S. Government would be pushed by irresponsible or fanatical groups into reckless action. The Russians certainly noted the doctrine of some civilian analysts that it would be quite rational to make a "preemptive first strike" even at the cost of 10 million deaths to the attacking side, and the doctrine of others that the U.S. should prepare itself mentally and materially to suffer such casualties.

In the U.S. the program for the Great Rearmament was projected as early as 1959 by the Democratic National Committee. In preparation for the impending presidential election the party leadership published a detailed study of defense problems and recommended a $7 billion increase (16 per cent) in the $43 billion defense budget proposed by President Eisenhower. The funds were to go partly for increased conventional forces and partly to increase the strength and reduce the vulnerability of the U.S. nuclear striking power. In January, 1961, almost immediately after taking office, the Administration authorized an increase of $3 billion and later in the year another $4 billion, thus carrying out the program in full. The present plans include the provision of up to 800 ICBM's of the solid-fuel Minuteman type in underground "hardened" bases by 1965.

The Democratic Party's campaign for increased nuclear armaments was closely linked with the theoretical doctrine of the instability of the balance of terror, derived from the alleged overwhelming advantage accruing to the nuclear aggressor. This was ably argued by civilian analysts closely associated with the U.S. Air Force. The U.S.S.R. was said to have both the capability and the intention to launch a surprise nuclear attack on the U.S. In retrospect, it would seem that these "looking-glass strategists" endowed the U.S.S.R. with a capability that it did not have and that the U.S. had once had and had now lost.

That the Soviet military staff had reason to take this element in U.S. opinion seriously may be judged by the fact that President Kennedy himself found it necessary to launch in the fall of 1961 a vigorous campaign against all those in the U.S. who urge "total war and total victory over communism... who seek to find an American solution for all problems"—against those who were living in the long-past era of the U.S. nuclear monopoly. In this campaign President Kennedy has been vigorously supported by ex-President Eisenhower. Very possibly the U.S.S.R. may have overestimated the potential influence of the proponents of aggressive nuclear strategy and the ultra-right-wing groups that yearn "to get it over with." Nonetheless, the fact that both Kennedy and Eisenhower have felt it necessary to combat them must also imply that the Soviet military planners could not afford to ignore their existence.

The Kennedy Administration's recent vigorous emphasis on the overwhelming nuclear superiority of the U.S. over the U.S.S.R., and the assertion that the U.S. possesses a second strike that is as strong as the Soviet first strike might perhaps be held in the U.S.S.R. to suggest a move by the U.S. Administration toward a preventive war posture. Undoubtedly the exact reverse is the case. The Administration's statements are designed to bury officially the fear of a Soviet first strike, sedulously propagated by those who believe that the U.S.S.R. has planned for, and in fact now has, a first-counterforce capability, and so at a time of crisis might use it. If this were in truth the situation, the argument that the U.S. must forestall the Soviet blow might seem strong. The Kennedy Administration evidently foresaw this danger arising and effectively removed it by denying that the U.S.S.R. has ever had an effective first-strike capacity; thus there would be no reason for a forestalling blow in a crisis. The President, by emphasizing U.S. nuclear superiority over the U.S.S.R., has forestalled the potential forestallers, or, in the current jargon, has pre-empted the potential pre-empters. At the same time he has refuted many of the arguments on which the Democratic Party based much of its election campaign, and indeed many of the arguments for his own present rearmament program.

It is, for instance, hard to see the military justification for the program of up to 800 Minuteman ICBM's in the next few years. If these are, as claimed, reasonably invulnerable, this number is at least 10 times larger than is necessary for an effective retaliatory force to attack Soviet cities.

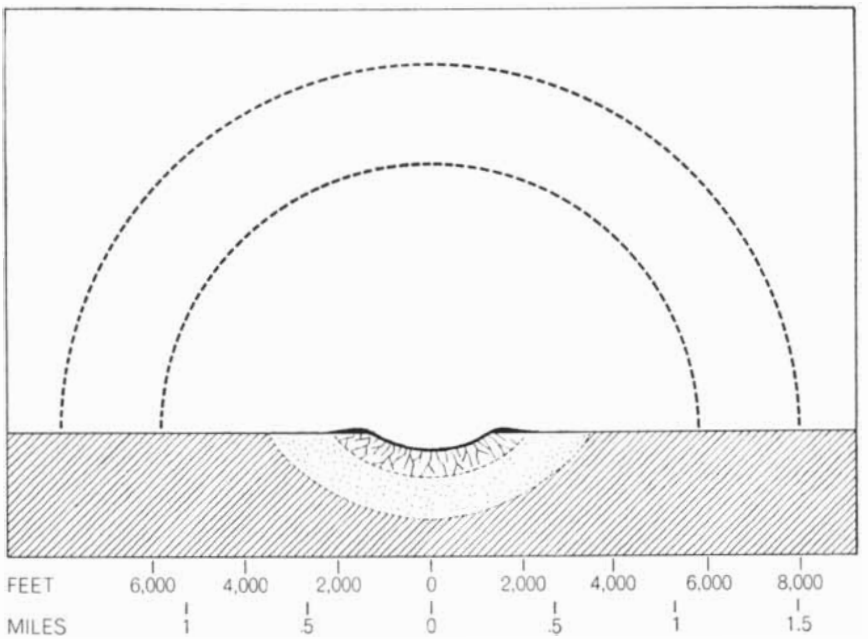
The only military circumstance that could justify such a continuous build-up of nuclear striking force would be that the other party could adequately protect its cities or succeed in perfecting an antimissile defense system. Recently Soviet generals have boasted that "the complex and important problems of destroying enemy rockets in flight have been solved." This must refer to the scientific and technical problems; these have also been solved in the U.S. A complete antimissile defense system that is of any operational significance certainly does not exist today and, in my view, will not exist in the foreseeable future. Suppose, however, that I am wrong and that a system can eventually be constructed capable of destroying, say, 50 per cent of a retaliatory missile attack by 50 ICBM's, so reducing the number reaching the target to 25. Even this reduced blow would kill tens of millions of people. Moreover, it would only be necessary to increase the strength of the retaliatory force from 50 to 100 missiles to cancel out the antimissile missile. This illustrates the general conclusion that since a purely retaliatory nuclear force can be quite small, any possible defense system, either active or passive, can be canceled out by a small number of additional missiles. The fact that a purely retaliatory posture is little affected by technological innovation, whereas a

counterforce posture is very much affected, may prove a vital factor in disarmament negotiations.

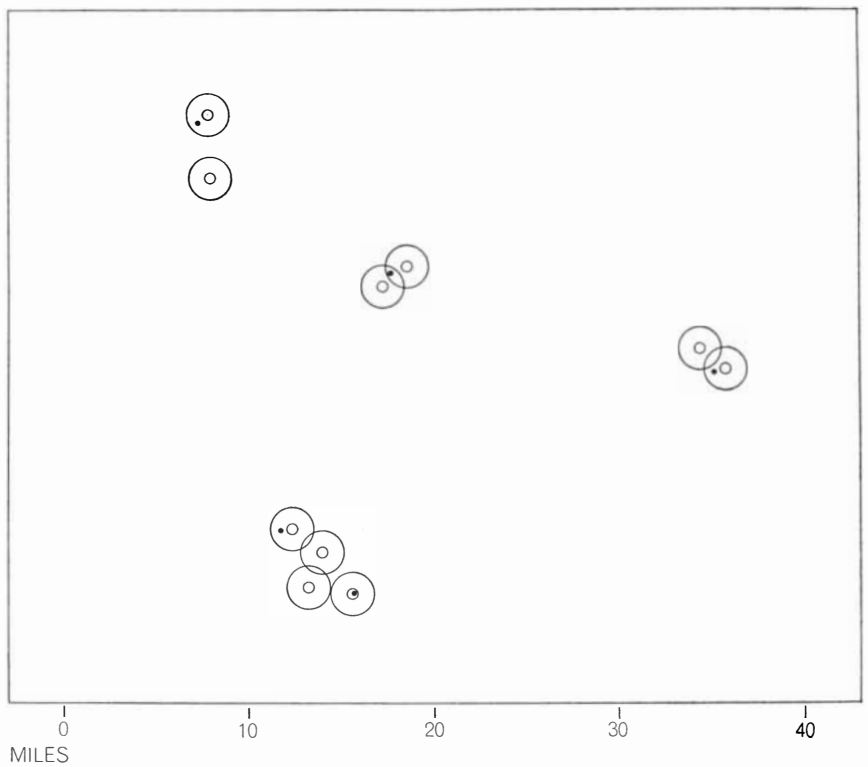
It cannot be seriously believed now that the U.S.S.R. has either the capability or the intention of making an all-out attack on U.S. missile sites and bomber bases. Much genuine alarm in the West might have been allayed if the U.S.S.R. had been more successful in making clearer its disbelief in the military possibility of a successful first-counterforce strike and its intention not to plan for such a possibility. After the brutality of Soviet action in Hungary in 1956 and the technological triumph of the artificial satellite the following year, there may have been legitimate grounds in the West for fearing that the U.S.S.R. might adopt the Western policy of massive retaliation, which, against a nuclear power, requires a counterforce capability. In January, 1960, however, Khrushchev explicitly declared the Soviet commitment to a purely retaliatory strategy. The Soviet second-strike force was strong enough, he said, "to wipe the country or countries which attack us off the face of the earth." To his own rhetorical question, "Will they not, possibly, show perfidy and attack us first... and thus have an advantage to achieve victory?" he replied: "No. Contemporary means of waging war do not give any country such advantages." In addition to freeing resources for capital development, the Soviet minimum-deterrent strategy has avoided the greatest military danger: that the U.S. might attack the U.S.S.R. because of a belief that the U.S.S.R. was about to attack the U.S.

If the analysis given here is approximately correct, what are the prospects of progress toward disarmament at the present meeting in Geneva? Both blocs are fully committed by official pronouncements to the goal of complete and general disarmament under strict control and inspection—notably by the British Commonwealth Prime Ministers' statement in the spring of 1961, by President Kennedy's speech to the General Assembly of the United Nations and by the Soviet-American Joint Statement of Principles, both in September of 1961. Moreover, both sides are committed to attempting to work out first steps of the disarmament process that do not impair the present strategic balance.

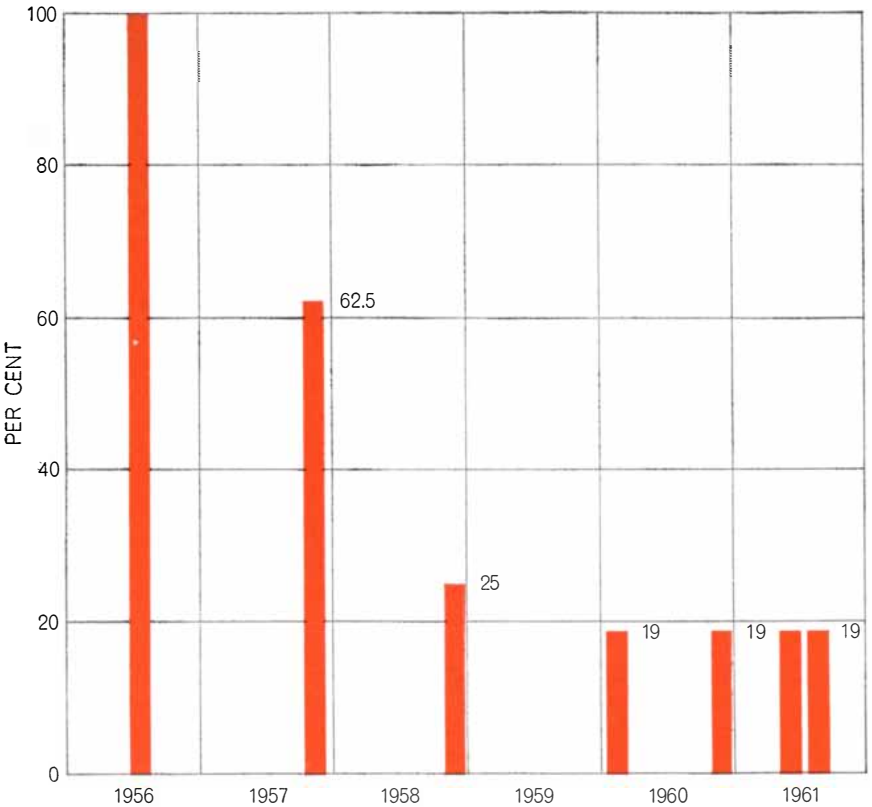
Clearly, conventional and nuclear disarmament must go in parallel. The fear of the West of Soviet superiority in trained and deployed land forces must be met by a drastic reduction during the



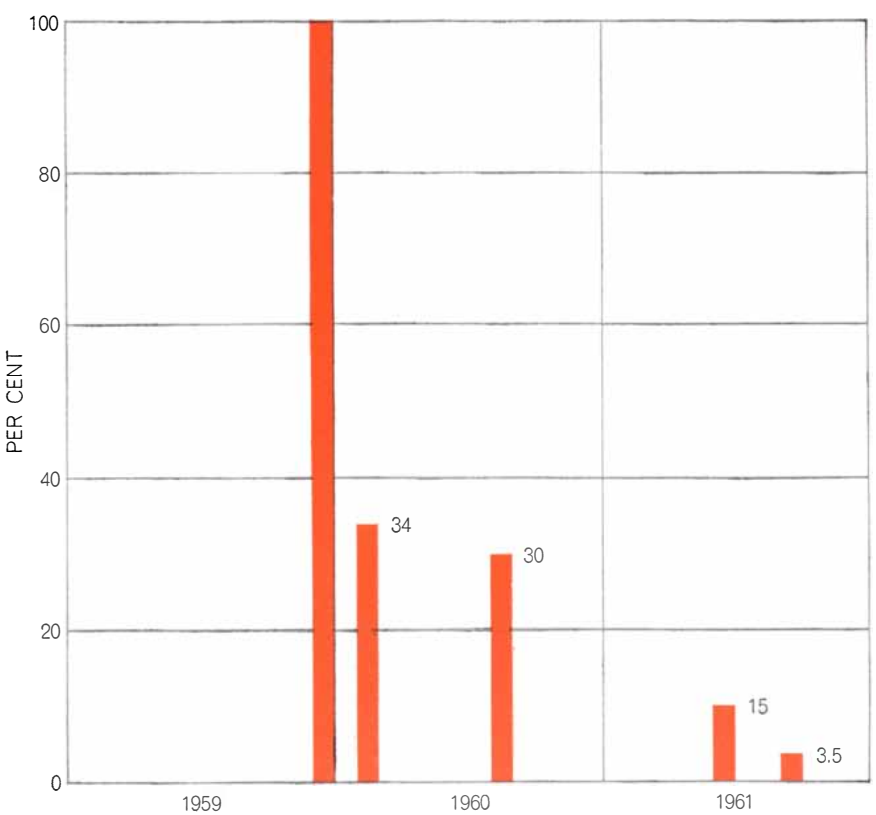
GROUND BURST of a nuclear bomb would be required to neutralize a "hardened" (i.e., buried) missile site. Diameter of the crater dug by a 10-megaton ground burst in dry soil would be 2,600 feet; the depth of the crater would be 250 feet. Radius of the underground "plastic zone" (*outer line below ground*) would be 3,250 feet; the radius of the "rupture zone" (*inner line below ground*) would be 2,000 feet. At a distance of 1.1 miles from ground zero the blast would exert an air pressure of some 300 pounds per square inch (*inner circle above ground*); at a distance of 1.5 miles (*outer circle above ground*), 100 pounds per square inch.



PATTERN OF GROUND BURSTS would be required to neutralize a dispersed group of hardened missile sites. In this schematic drawing a "circle of probable error" of one mile is assumed for each of the attacking missiles; this implies that at least two missiles would be directed at each of the sites. There are five sites, represented by dots. The smaller of each of the 10 pairs of concentric circles represents the 2,600-foot diameter of a 10-megaton bomb crater; the larger of the circles, the 1.1-mile radius at which the air pressure is 300 pounds per square inch. The total weight of the attack on the five bases is 100 megatons. The scale of the drawing is the same as that of the map of St. Louis at the bottom of page 48.



U.S. ESTIMATE OF SOVIET HEAVY-BOMBER STRENGTH by the middle of 1961, according to an article by Senator Stuart Symington in *The Reporter*, decreased by 81 per cent between August, 1956 (*bar at left*), and August, 1961 (*right*). Senator Symington's figures were given in percentages, rather than absolute numbers, for security reasons.



U.S. ESTIMATE OF SOVIET OPERATIONAL ICBM STRENGTH similarly decreased, according to Senator Symington, by 96.5 per cent between December, 1959, and September, 1961.

first stage to low levels such as those suggested by the Anglo-French memorandum of 1954: one million or at most 1.5 million men each for the U.S., the U.S.S.R. and China. When the correspondingly limited contributions to the land forces of NATO from Great Britain, France and West Germany are taken into account, the armies of the Soviet bloc would not have the capability of overrunning Europe in a surprise land attack.

The number of nuclear weapons in existence on both sides, their explosive power and the diversity of the delivery systems are so overwhelming that no small step in nuclear disarmament can have much significance. In a situation in which the U.S. has 10,000 delivery vehicles and a stockpile of 30,000 megatons of explosive (which is said to be increasing at the fastest rate in its history), a first disarmament step involving only a small percentage reduction is not worth negotiating. To justify the labor of negotiating any agreed reduction, and to offset the undoubted strains and disputes that will inevitably arise from the operation of any inspection and control system, the negotiated reduction must be a major one; in fact, of such magnitude as to change qualitatively the nature of the relative nuclear postures of the two giant powers.

The simplest big first step, and the one most consistent with realistic military considerations, is that both giant powers should reduce their nuclear forces to a very low and purely retaliatory role. That is, each should retain only enough invulnerable long-range vehicles to attack the other's cities if it is itself attacked, say less than 100 ICBM's with one-megaton war heads. This is still an enormous force, capable of killing tens of millions of people. A reduction to a level of 20 ICBM's or less would be much preferable. Such a reduction would at once prevent nuclear weapons from being used by sane governments as weapons of aggression or coercion. It would not, of course, prevent them from being used by irresponsible groups who do not calculate the cost. It is only at a later stage in disarmament, when nuclear weapons are completely destroyed, that this danger will be excluded. It has always been clear that the ever present danger of accidental or irresponsible war is a cogent reason for big and rapid steps in the disarmament process.

Detailed studies are needed of possible ways in which both the U.S.S.R. and the U.S. could take such an impor-

tant first step without upsetting the present strategic balance. A major problem is how to phase the building up of a system of general inspection while at the same time making a drastic reduction in nuclear delivery systems by their actual destruction under international verification. Taking military considerations only into account, I believe that a procedure acceptable to both blocs could be devised.

The difference hitherto between the proposed Western and Soviet first steps in relation to nuclear weapons has been often simplified to the statement that the U.S.S.R. wants disarmament without control and the West wants control without disarmament. It would be more accurate to say that the clash is on the phasing of the stages of disarmament and the stages of control.

In its 1960 proposals the U.S.S.R. suggested that, in the first step, international teams should be dispatched to inspect the destruction of all rocket weapons, military aircraft and other carriers of nuclear weapons. It did not propose the inspection or control of those that remain waiting to be destroyed. Full inspection of a country was to be undertaken only when all weapons had been destroyed. It is clear that the U.S.S.R.'s first steps of disarmament are consistent with its presumed military policy of relying for its safety from nuclear attack on a relatively small force of purely retaliatory nuclear weapons in secret sites.

On the other hand, the U.S. proposals in 1960 envisaged widespread inspection in the first stages and no actual disarmament until the second stage. This proposal might make military sense if put by a weak nuclear power to a much stronger one. But when put by a strong power to a weaker one, rejection must have been expected. If the U.S.S.R. had accepted the proposal, the geographical secrecy of its nuclear sites would have been lost and it would have been vulnerable to nuclear attack from the much stronger West.

Any realistic first stage must start from the fact that the present nuclear balance, such as it is, has a highly asymmetric character: the West's much greater nuclear power is balanced by Soviet geographical secrecy. Since the military balance is asymmetric, so must be any mutually acceptable first step. Concessions must be made by both sides and these must be based on the realities of the military postures of the two blocs.

The U.S.S.R. should accept general inspection not, as in their proposals hitherto, when disarmament is complete but at some intermediate stage on the road to disarmament. Reciprocally, the West should not demand widespread inspection before any disarmament has taken place, as it has done hitherto, but only after substantial destruction of nuclear armaments has taken place under international verification.

In the first stage, therefore, all parties might supply to one another a list of nuclear weapons and their delivery systems, together with research and production facilities. The exact location of sites would not be included at this stage. An agreed number of weapons would then be destroyed and their destruction would be verified by on-site inspection by the international control organization. When this destruction has been verified, a general inspection, using some sampling technique, would begin. The object would then be to verify the correctness of the original declared inventories by checking the numbers remaining after the agreed reductions had been verified, and to proceed to the elimination of the armament remaining.

A word must be said about the place of a test-ban agreement in the stages of a disarmament plan. If this agreement did not involve a type of inspection that might reveal the Soviet nuclear sites, it would be advantageous for it to be included in the first stage, or preferably agreed to at once. If, however, it involved widespread inspection that might reveal these sites, Soviet military planners would certainly advise its rejection. It would then have to wait for the second stage of disarmament, when general inspection starts after the destruction of agreed numbers of nuclear weapons in the first stage.

Some such compromise between Western and Soviet proposals would seem to meet many of the reciprocal criticisms made by the two parties of their respective 1960 proposals without compromising the military security of either. The problem becomes more difficult, however, when nonmilitary considerations are taken into account. Since nonmilitary considerations have played a major role in shaping the defense policies of the great powers, they must inevitably also affect their disarmament policies. For example, if it is difficult to find legitimate military reasons for the vast number of U.S. nuclear weapons and delivery vehicles, it is clear that military arguments alone are not likely to be dominant in U.S. discussion of a possible drastic first step toward nuclear disarmament. This is widely admitted in the U.S., where the impediments to disarmament are being seen more and more as economic, political and emotional in origin rather than as based on operational military considerations. A vital aspect of the problem for the U.S. is the effect that drastic disarmament steps would have not only on the economy as a whole but also on those special sections of high-grade, science-based and highly localized industries that are now so overwhelmingly involved in defense work. A valuable step would be for both the U.S. and Soviet governments to produce and publish detailed and politically realistic economic plans for the transition to a purely retaliatory capacity.

It is fair to conclude that a realistic military basis for an agreed drastic first step in disarmament may not be impossible to find. The urgency of the situation was declared with eloquence by President Kennedy in his speech to the United Nations in September:

"Today, every inhabitant of this planet must contemplate the day when this planet may no longer be habitable. Every man, woman and child lives under a nuclear sword of Damocles, hanging by the slenderest of threads, capable of being cut at any moment by accident or miscalculation or by madness.... The risks inherent in disarmament pale in comparison to the risks inherent in an unlimited arms race."

This great goal of disarmament will be achieved only if the real nature of the arguments against disarmament are clearly identified and frankly faced. The problems of disarmament must not be obscured, as they sometimes have been in the past, by ingenious but fallacious military doctrine applied to false intelligence estimates.

The growing power of China, and the evidence of an ideological rift between it and Russia, provide an added reason for urgency in the drive for disarmament. The U.S.S.R. and the U.S. will be wise to limit drastically their nuclear arms before China becomes a major nuclear power. It is to be observed that whatever influence China may now be exerting on the U.S.S.R. to adopt a harder policy with the West certainly arises in part from the failure of Premier Khrushchev's campaign for disarmament. This failure greatly weakens Khrushchev's argument for the feasibility of peaceful coexistence of the Soviet and the Western worlds. It would seem urgently necessary to attempt to bring China into the disarmament negotiations as soon as possible.

EXPLODING STARS

They are of three main types: dwarf novae, novae and supernovae. Recent studies indicate that the typical nova or dwarf nova is the volatile member of an unusual and closely coupled star pair

by Robert P. Kraft

The explosion of a star is an awesome event. The most violent of these cataclysms, which produce supernovae, probably destroys a star completely. Within our galaxy of roughly 100 billion stars the last supernova was observed in 1604. Much smaller explosions, however, occur quite frequently, giving rise to what astronomers call novae and dwarf novae. On the order of 25 novae occur in our galaxy every year, but only two or three are near enough to be observed. About 100 dwarf novae are known altogether. If the exploding star is in a nearby part of the galaxy, it may create a "new star" that was not previously visible to the naked eye. The last new star of this sort that could be observed clearly from the Northern Hemisphere appeared in 1946. In these smaller explosions the star loses only a minute fraction of its mass and survives to explode again.

Astrophysicists are fairly well satisfied that they can account for the explosion of supernovae. The novae and dwarf novae have presented more of a puzzle. I shall describe recent investigations that have provided important new information about these two classes of exploding star. The picture that emerges is quite astonishing. It appears that every dwarf nova—and perhaps every nova—is a member of a pair of stars. The two stars are so close together that they revolve around a point that lies barely outside the surface of the larger star. As a result their period of rotation is usually only a few hours, and their velocities range upward to within a two-hundredth the speed of light.

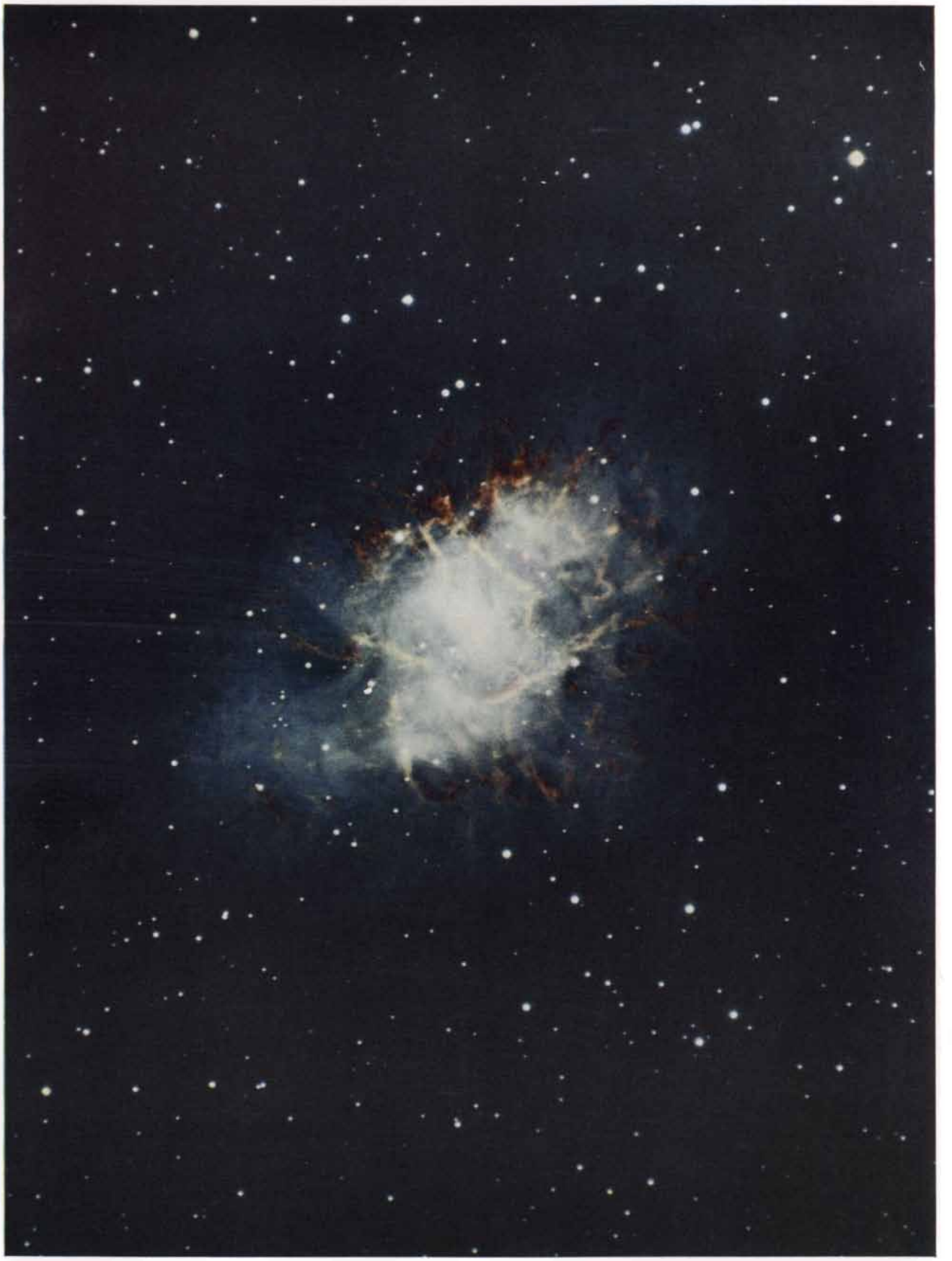
Astronomers use the term "cataclysmic variable" to embrace the three general classes of exploding star: dwarf novae, novae and supernovae. A cataclysmic variable is defined as a star that suddenly and unpredictably increases in brightness by a factor of at least 10. Dwarf novae are stars that increase in brightness by a factor of 10 to 100 within a period of several hours and decline to their former brightness in two or three days [*see top illustration on page 59*]. In this period they emit some 10^{38} to 10^{39} ergs of energy. At maximum brilliance a dwarf nova shines about as intensely as our sun; previously it had been only about a hundredth as bright. The number of outbursts ranges anywhere from three to 30 a year, but for any one star the intervals have a fairly constant value. Moreover, the maximum brightness from outburst to outburst is the same within a factor of two for a given star. The dwarf novae are often referred to, after their prototypes, as U Geminorum or SS Cygni stars. (The stars of each constellation are designated by letters or numbers.) A subgroup of dwarf novae, called Z Camelopardalis stars, do not always descend to minimum brightness between outbursts but may stay at some intermediate level for several months.

Novae are stars that increase in brightness from 5,000 to 100,000 times during an outburst. The total energy emitted during an outburst is about a million times greater than that of the dwarf novae, and the rise in brightness usually takes a day or two. Recent prominent novae are Nova DQ Herculis, which flared up in 1934, Nova CP Puppis (1942) and Nova T Coronae Borealis (1946). For a few days these three novae respectively appeared to the unaided eye as bright as the prominent stars Deneb, Rigel and Polaris. Novae are classified as "fast" or "slow" depending on the rate of their decline from peak brightness, which may require from a month or so to a few years. The overwhelming majority of novae—the "ordinary" variety—flare up only once. "Recurrent" novae, on the other hand, flare up periodically at intervals lying roughly between 10 and 100 years. The best known of the recurrent novae are Nova T Coronae Borealis (1866 and 1946), Nova RS Ophiuchi (1898, 1933 and 1958) and Nova T Pyxidis (1890, 1902, 1920 and 1944).

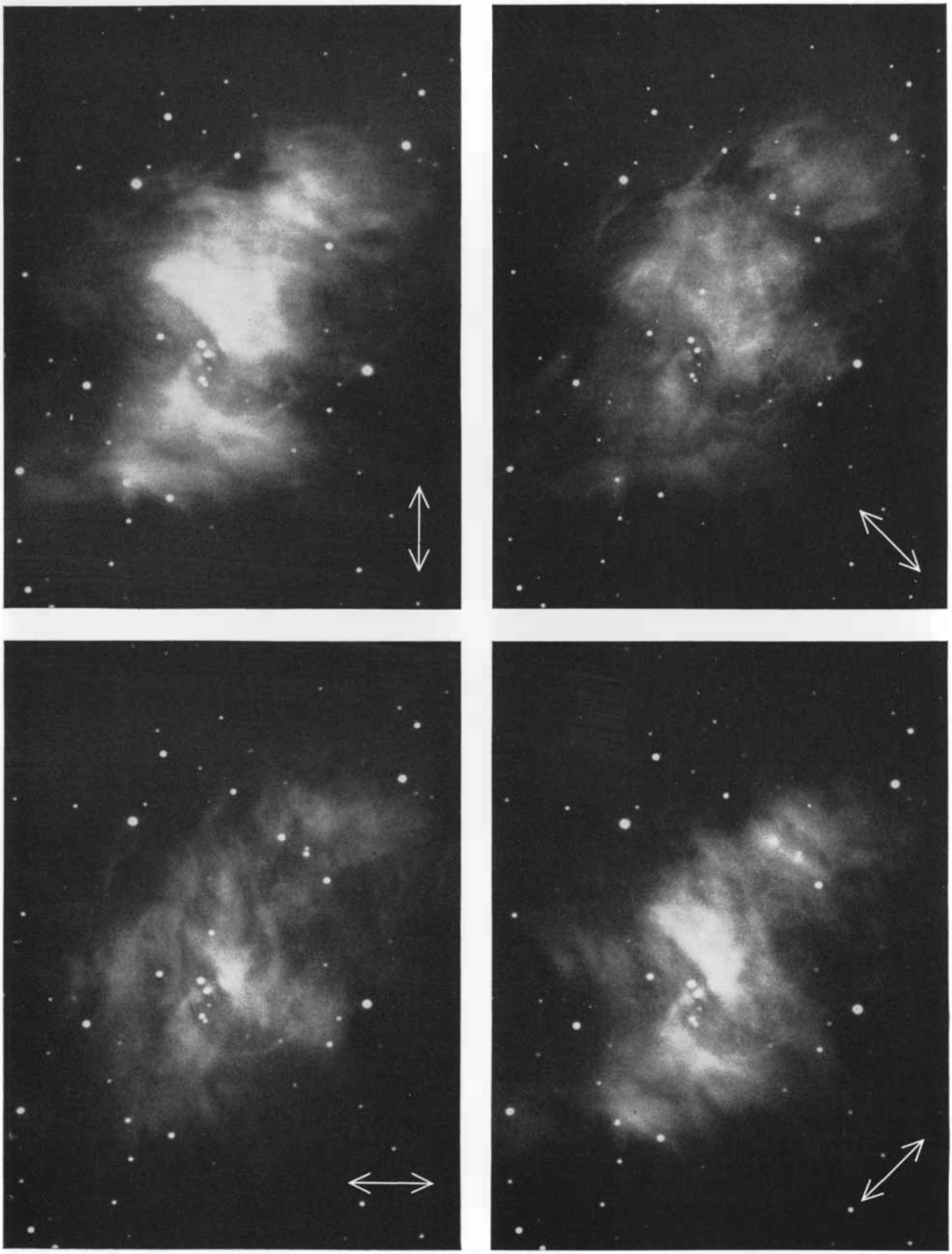
Supernovae are 100 million times brighter than the sun; they release as much as 10^{51} ergs of energy, which is roughly equivalent to all the energy contained in a star. Obviously no recurrence is possible. Supernovae known as Type I release from 10 to 100 times more energy than those classified as Type II. Type I supernovae seem to develop from relatively old stars with about as much mass as the sun. Type II supernovae develop from massive young stars, recently formed in the arms of a spiral galaxy.

Only two supernovae have been recorded within our galaxy by Western astronomers, the first by Tycho Brahe in 1572 and the second by Johannes Kepler only 32 years later. At its peak Tycho's new star was five or 10 times brighter than Venus and could be seen even in the daytime. Kepler's supernova was as bright as Jupiter. Chinese astronomers had earlier recorded at least four other supernovae, including one in A.D. 1054, the remains of which are now recognized as the Crab nebula. With modern telescopes supernovae are regularly found in other galaxies. In some cases the supernova may exceed the rest of the galaxy in brightness.

Information about the various kinds of nova is obtained chiefly from photography, spectroscopy and photometry carried out with large reflecting telescopes. Because most of the novae are intrinsically faint objects when they are



CRAB NEBULA is the remnant of a supernova recorded in A.D. 1054 by Chinese astronomers. This color photograph was made with the 200-inch Palomar telescope by William C. Miller. The Crab nebula is 3,500 light-years away. Its shell of hot gas, still expanding at some 1,000 kilometers a second, measures about five light-years across. See the next page for other views of the nebula.



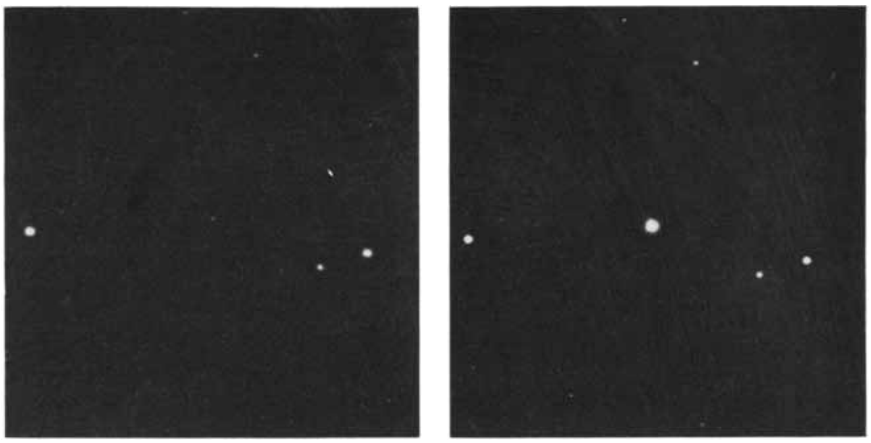
POLARIZATION OF LIGHT emitted by the Crab nebula is shown in this series of photographs made with the 200-inch telescope by Walter Baade. Arrows in the lower right-hand corners show the plane of polarization of light recorded in each picture. Polarization indicates that the light is "synchrotron radiation," produced when high-speed electrons orbit around magnetic lines of force.

in the quiescent state, only a few dozen of them are within range of even the largest reflector, the 200-inch instrument on Palomar Mountain. To be spectroscopically observable between outbursts, dwarf novae must be closer than about 400 light-years, and ordinary novae within about 4,000 light-years. For astronomy these are extremely small distances.

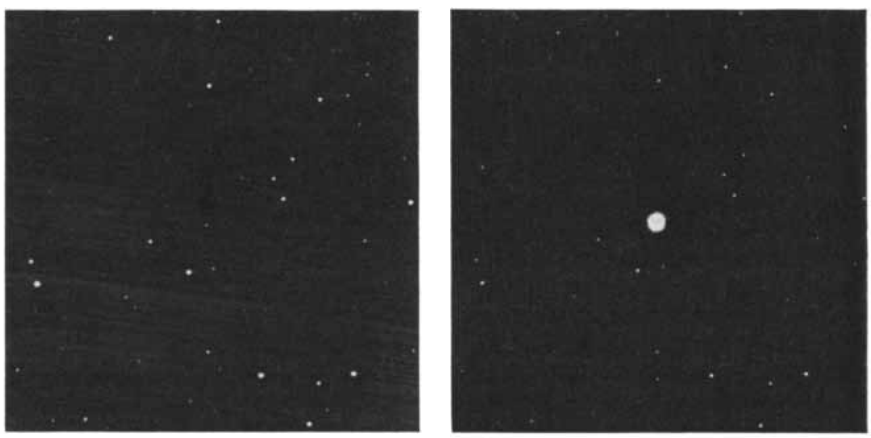
Supernovae can of course be observed out to distances of tens of millions of light-years. For examining the debris of relatively nearby supernovae radio astronomy has become an important adjunct to optical astronomy. The discovery of radio emission from the Crab nebula, and its subsequent interpretation, has influenced ideas in both physics and astronomy.

The Crab nebula is an irregular but roughly elliptical mass of glowing gas, 3,500 light-years away, that is still expanding at the rate of some 1,000 kilometers a second. It was only about 40 years ago that astronomers identified the Crab nebula as the gaseous remnant of the supernova of 1054. The Crab nebula is also an extremely powerful source of radio waves, being the fourth brightest object in the radio sky. Its immense radio output is evidently due to the motion of very-high-speed electrons spiraling around magnetic lines of force, a process that leads to an electromagnetic emission known as synchrotron radiation [see "Radio Galaxies," by D. S. Heeschen; SCIENTIFIC AMERICAN, March]. The suggestion that synchrotron radiation is the source of the Crab nebula's radio emission, and much of its optical emission as well, was made in 1953 by the Soviet astrophysicist I. S. Shklovsky. An important characteristic of such radiation is its strong polarization. That the light from the Crab nebula is indeed highly polarized was first confirmed by Soviet and Dutch astronomers. Photographs showing polarization, made with the 200-inch telescope by Walter Baade, appear on the facing page.

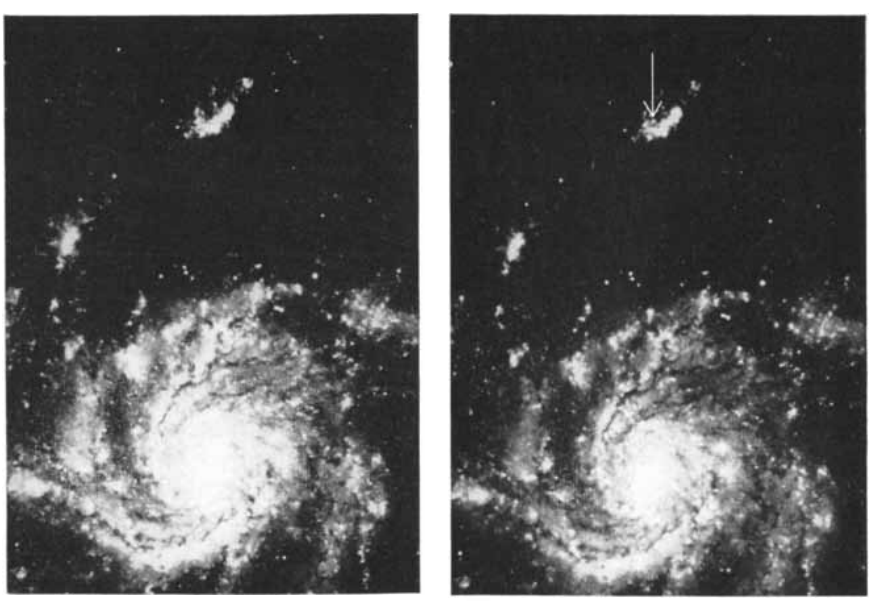
For the astronomer the Crab nebula provides direct observational evidence that magnetic fields on a large scale may exert a decisive influence on certain kinds of astrophysical phenomena. Consequently theories of the evolution of the universe must now provide for electromagnetic as well as gravitational and thermodynamic processes. For the physicist the Crab nebula indicates that supernovae are a likely source of high-energy cosmic rays. The high-speed electrons involved in synchrotron radiation imply



OUTBURST OF DWARF NOVA SS CYGNI (*right*) **was recorded in September, 1946, by the Harvard College Observatory; its visual magnitude was 8.2. Before the outburst** (*center of picture, left*) **its magnitude was 12. Outbursts of SS Cygni occur about every 50 days.**



OUTBURST OF NOVA DQ HERCULIS (*right*) **was photographed in 1934 at the Yerkes Observatory when its visual magnitude reached 1.0. Before the outburst** (*center of picture, left*) **its magnitude was 15. This is an increase of 400,000 times in brightness.**



NOVA IN NEARBY GALAXY, M 101, is identified by the arrow in the photograph at right, made in February, 1951, on Palomar Mountain. In the picture at left, made in June, 1950, the nova cannot be seen. M 101 is a spiral galaxy about eight million light-years away.

the presence of equally energetic protons, presumably released in the supernova explosion. The particles gradually leak out of the magnetic field left by the supernova and are eventually picked up by the magnetic field of the arms of the galaxy, whence, as cosmic rays, some of the particles reach the earth.

The sequence of events following the outburst of ordinary novae has been observed many times and is known in more detail than the events following a supernova explosion. Well before the nova has reached maximum brightness its spectrum indicates that it is a fairly hot star ejecting material at a velocity of about 1,000 kilometers a second. Just after maximum brightness the nova is surrounded by an expanding shell of ejected material that is perhaps 100 times the diameter of the sun. At first the shell is opaque but later the expansion of its material reveals a hot central star. Analysis of the intensity of spectral lines indicates that the mass of material ejected is from a thousandth to a ten-thousandth the mass of the sun. Since the typical nova probably has a mass roughly equal to that of the sun, the material lost through ejection has only a small effect on the basic properties of the star.

In contrast, the spectra of dwarf novae at maximum brightness are not very informative. For example, no expanding shell of gas has been detected. Consequently there is no direct evidence to show that dwarf novae eject matter during their outbursts.

Until recently little was known of the spectra of novae and dwarf novae at minimum light because of their apparent faintness. Novae at their minima have luminosities ranging from a little brighter than the sun to a fiftieth the brightness of the sun. Dwarf novae are dimmer by another factor of two or three.

According to concepts of stellar evolution current only a few years ago it seemed that all stars pass through much the same cycle. Briefly stated, a star is born from a condensation of gas, mostly hydrogen, that heats up as it is compressed by gravitational forces. In due course the hydrogen is heated to a few hundred million degrees centigrade, at which point thermonuclear reactions begin. At first the star is not particularly bright and its cool surface is reddish. Gradually it becomes hotter, bluer and brighter and resembles the sun. At the same stage of evolution stars more massive than the sun are brighter and bluer; stars less massive are dimmer and redder. When the absolute luminosity of the stars in this vigorous "adult" stage is plotted against their color, the stars are distributed on a curve called the main sequence. With the further passage of time, when a star has burned up about 10 per cent of its hydrogen, it swiftly becomes brighter and redder and moves off the main sequence on its way to becoming a red giant. Now the star, having consumed most of its remaining hydrogen at a rapid rate, begins to contract rapidly until it becomes a white dwarf. On the color-luminosity diagram white dwarfs fall below and to the left of the main sequence. It is evident from the observed masses of white dwarfs that somewhere along the way they must have thrown out into space about half or more of their original mass. It was generally believed that this ejection of mass was accomplished by the outbursts that take place in novae. In other words, it was believed that essentially all stars were potential novae. The supernovae were presumably exceptional cases, which posed a separate problem.

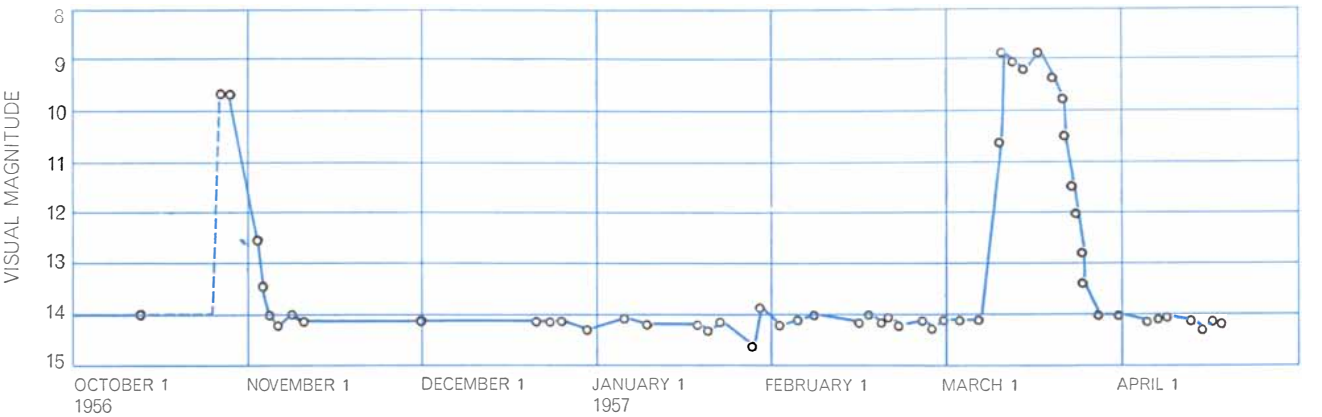
A major advance in the understanding of dwarf novae came with Alfred H. Joy's discovery, made in 1943 at the Mount Wilson Observatory, that the dwarf nova SS Cygni is not one star but a pair of stars that revolve around each other in the remarkably brief period of six hours 38 minutes. This implied that the two stars are extremely close together. Typical eclipsing binaries have periods of two or three days, which means that in relation to their size even they are proportionately much closer to each other than the earth is to the moon. An eclipsing binary can be observed because the plane of the orbit of the two stars lies nearly edgewise to the earth, so that the two stars mutually eclipse twice in the course of each revolution. The two stars are so close together that in photographs they appear as a single star; the periodic variation in their light produced by the eclipses is usually measured with a photoelectric device.

Photometry had revealed nothing unusual about SS Cygni. Spectrographic plates, however, revealed two superimposed but distinguishable sets of spectra. One spectrum was that of a hot dwarf star, located below the main sequence, and the other was that of a main-sequence star somewhat less luminous, and therefore redder, than the sun. By relating luminosity and period of rotation Joy reached the surprising conclusion that the radius of the red star was almost the same as the radius of its orbit around the center of mass of the two stars.

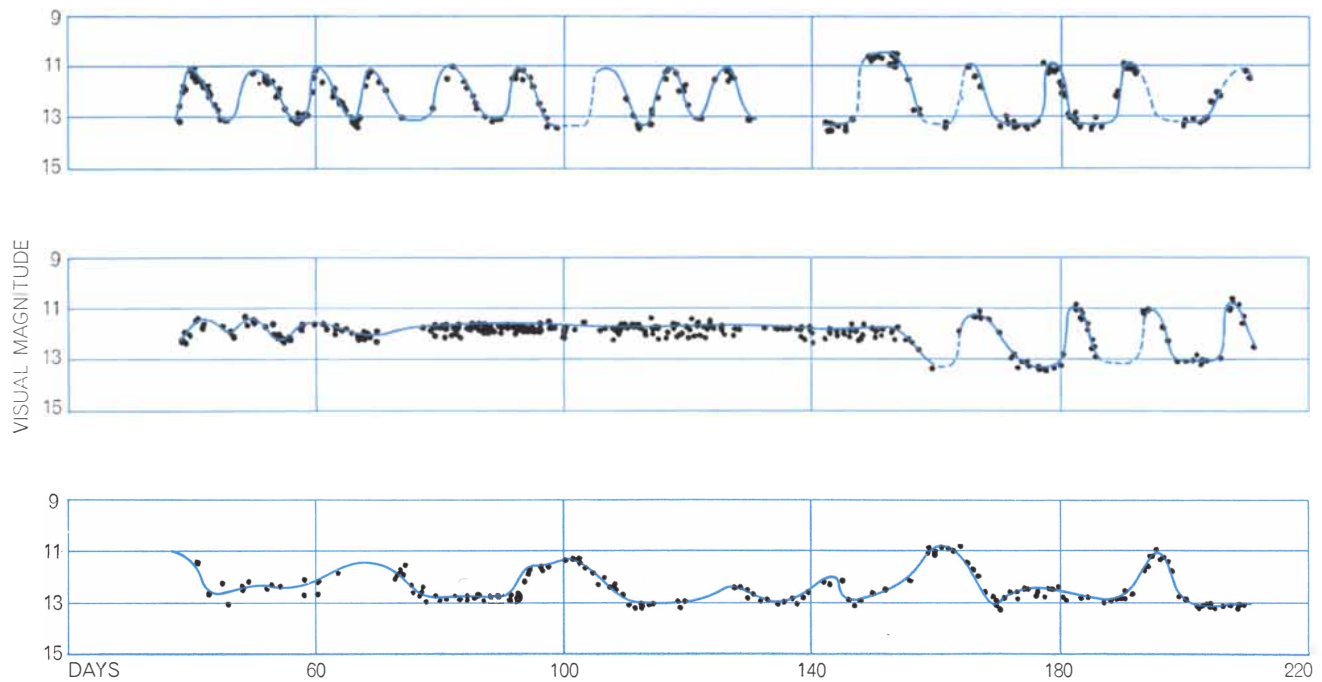
Not long thereafter Roscoe F. Sanford of the Mount Wilson and Palomar Observatories, who had been examining the spectral changes in Nova T Coronae Borealis during its 1946 outburst, concluded that it too is a double star. He saw that certain absorption lines, which appeared after the star had returned to normal, reflected a velocity shift with a period of about 230 days. Certain lines alternately shift first toward the violet end of the spectrum and then toward the red end. A shift toward the violet means that stellar material is moving toward the observer; a shift toward the red means it is moving away. Evidently in T Coronae Borealis the shifting absorption lines are associated with a giant red star.

In 1955 and 1956 I made spectrograms of T Coronae Borealis with the 100-inch reflecting telescope on Mount Wilson and was able to detect a velocity shift of the hydrogen emission lines comparable to that shown by the absorption lines but 180 degrees out of phase. Sanford had not detected this motion in 1947 because it was masked by the emission from the still expanding shell of the 1946 outburst. The hydrogen lines presumably originate in the smaller and hotter—but slightly dimmer—member of the binary pair. There is now no question that T Coronae Borealis consists of a hot dwarf star and a very large red star whose radius is approximately equal to the radius of its orbit about the center of gravity of the binary system.

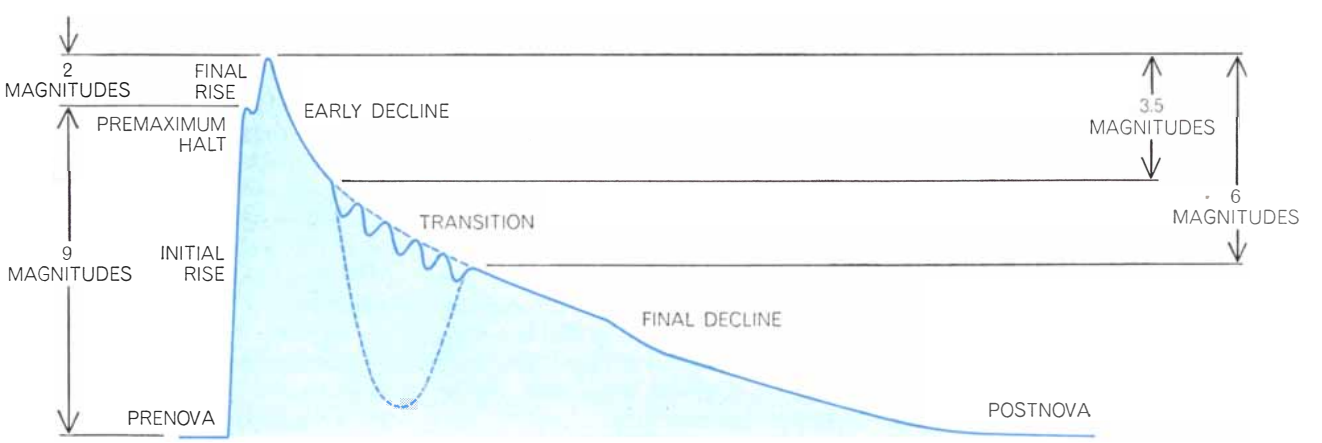
In 1954 Merle F. Walker, then a Carnegie Fellow at Mount Wilson and Palomar, discovered by photoelectric photometry that Nova DQ Herculis (1934) is an eclipsing binary with a period of about 4.6 hours [*see illustration on page 60*]. Subsequently I used the 100-inch telescope to make spectrograms of the nova and found that the radial velocity of the helium lines changes with a period that exactly matches that of the eclipse cycle. The spectrum is peculiar in that it consists solely of emission lines [*see illustration on page 63*]. Normally some of the lines emitted from a hot stellar surface are absorbed in passing through a cooler atmosphere. In interpreting the unusual spectrum of DQ Herculis I have had the benefit of collaborating with Jesse L. Greenstein of Mount Wilson and Palomar, who obtained a number of excellent spectrograms of DQ Herculis with the 200-inch telescope. Our conclusion is that the spectrum is produced by emission from a low-density shell or ring surrounding the nova and not by the nova itself; the ring moves with the nova



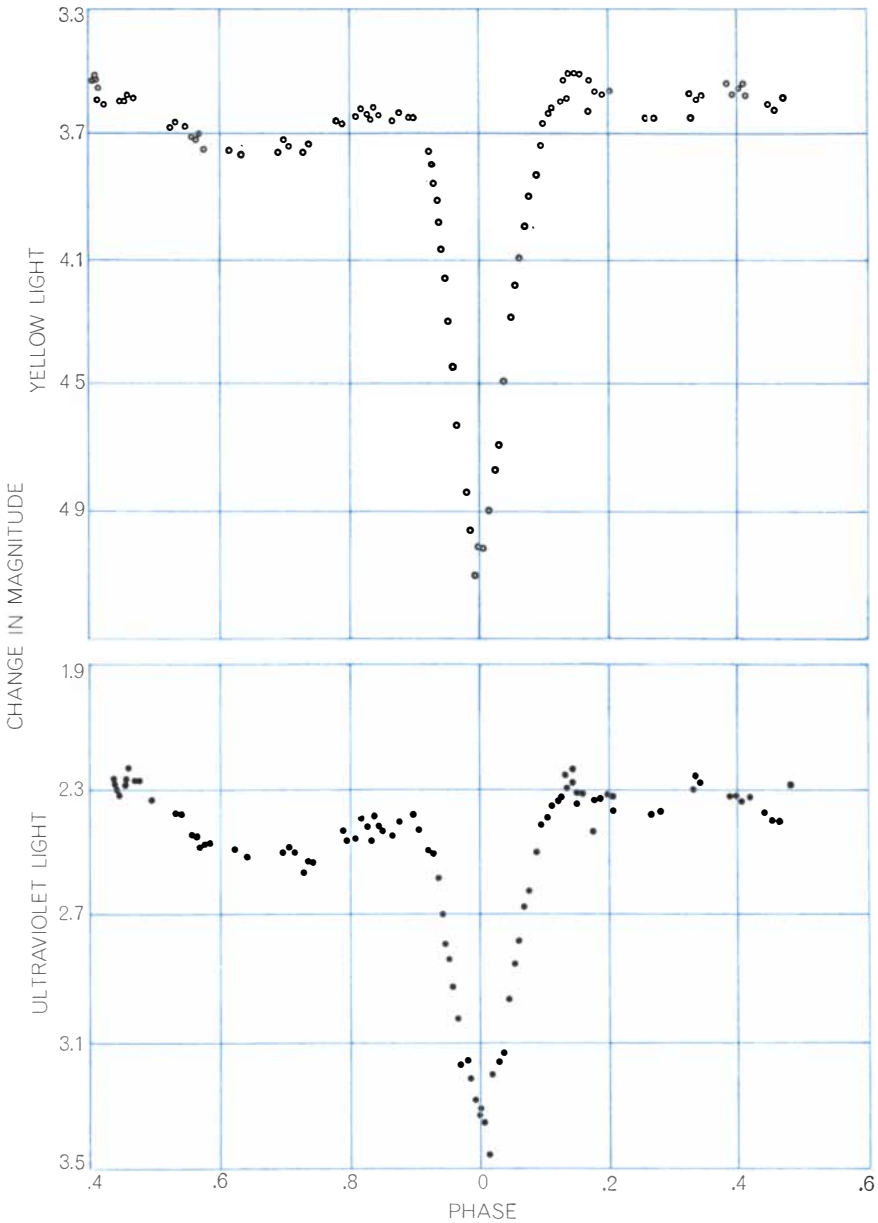
OUTBURSTS OF U GEMINORUM are characteristic of a certain type of dwarf nova. A change of five magnitudes represents a 100-fold increase in brightness. The dots are daily means estimated by the American Association of Variable Star Observers.



OUTBURSTS OF RX ANDROMEDAE are typical of dwarf novae of the Z Camelopardalis subgroup. The top outburst is normal; the middle shows a "still stand" at mean light; the bottom is erratic. The data are from Luigi Jacchia of Harvard College Observatory.



LIGHT OUTPUT OF TYPICAL NOVA may show an increase of 5,000 to 100,000 times over prenova level. Eleven magnitudes signifies an increase of 25,000-fold. (Each magnitude is a factor of 2.5 in brightness.) The time scale of the first half of this curve is expanded with respect to the second half. The curve was drawn by Dean B. McLaughlin of the University of Michigan.



ECLIPSE CYCLE OF NOVA DQ HERCULIS is shown in photometric observations made by Merle F. Walker at the Mount Wilson Observatory. The nova actually consists of two stars revolving with a period of four hours 39 minutes. Phases are counted from mid-eclipse.

in its orbit around the center of mass of the system.

The DQ Herculis system is unusual in other respects. The spectrum of the larger but fainter star cannot be recorded even when it is eclipsing the bright shell or ring. More remarkable still, the luminosity of the nova waxes and wanes with a perfectly regular period of 71 seconds, except, of course, when it is in eclipse and cannot be seen. Walker has suggested that the rapid light variation is due to radial pulsations, and I have used this concept as a basis for estimating the mass of the nova. (A theory is available to show how any stellar pulsation is related to period, radius and mass.) The pulsation is a fortunate key to the mass problem; the normal method for calculating the masses of stars in a binary system requires the spectra of both stars, and for DQ Herculis we have only one. The present estimate indicates that the nova is a typical white dwarf with about a fourth the mass of the sun and only about a hundredth the diameter. Its companion is probably a dim red star, also about a fourth the mass of the sun but with a diameter 100 or more times greater.

Walker's work on DQ Herculis profoundly altered our thinking about novae in much the same way that Joy's work on SS Cygni had changed our ideas about dwarf novae. Their findings raised the possibility that membership in a certain kind of binary system is a necessary condition for a star to become a nova. This implies in turn that all single stars—and this means the great majority—can reach the ultimate white-dwarf stage only by some other process of losing mass.

There are, in fact, other arguments to show that nova outbursts are too rare to be a typical stage in stellar evolution. Edwin E. Salpeter of Cornell University has estimated that some 50 billion stars in our galaxy, or about half of the total population, have already evolved into white dwarfs. Studies of the nearby galaxy in Andromeda by Halton C. Arp of Mount Wilson and Palomar indicate that there are, on the average, only about 25 nova outbursts a year in a galaxy comparable in size to ours. This implies that only 50 billion outbursts have occurred in the last two billion years, or, on the average, about one outburst for each white dwarf. Since each outburst involves the ejection of only a ten-thousandth of the mass of the star, there is clearly no way to account for a loss of several tenths or more of a star's mass.

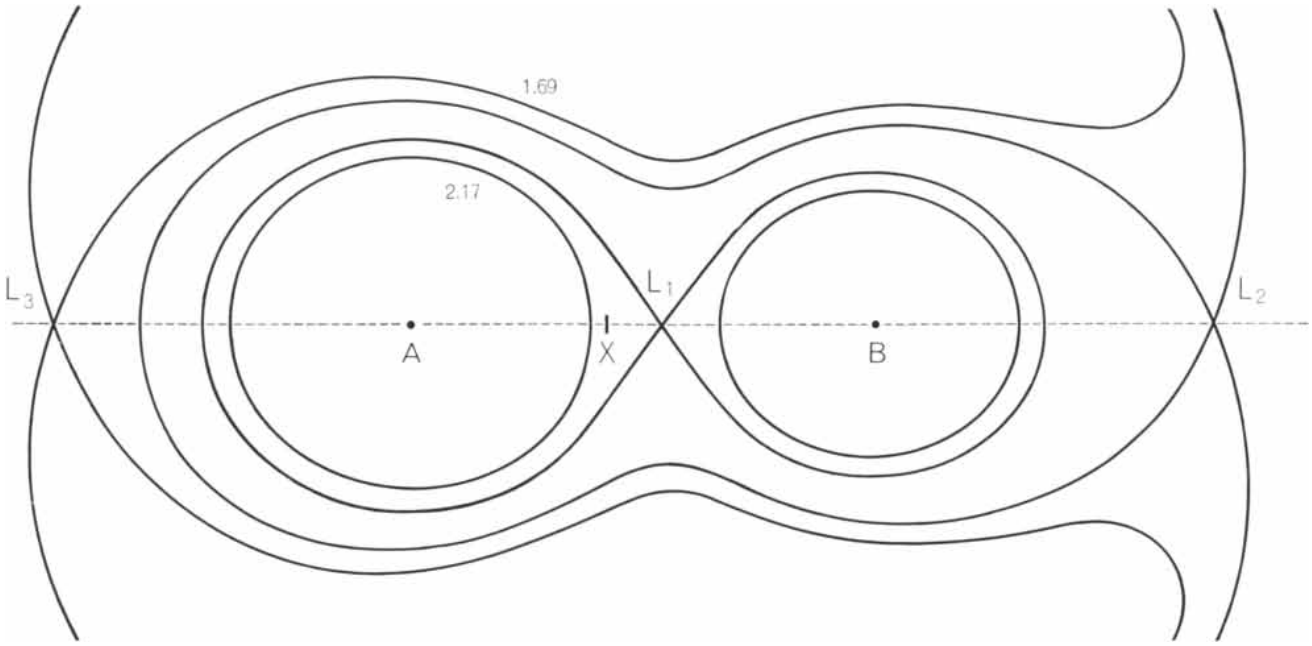
The solution to this puzzle may be supplied by the discovery of Armin J. Deutsch of Mount Wilson and Palomar that red giants slowly eject mass into space over a period of millions of years. Since all stars go through a red-giant stage before becoming white dwarfs, the loss of mass can probably be accounted for in this way.

Let us now examine the dynamic relationship that may exist between the stars in a closely linked binary system in which one star is a nova. If the dark component of DQ Herculis is in fact a cool red star, then it would seem to be a system much like T Coronae Borealis and SS Cygni. In all three the two stars of the binary pair have roughly the same mass, and the radius of the red star is nearly the same as the radius of its orbit around the center of gravity. Under these conditions centrifugal force enables atoms to leave the surface of the red star and pass into the gravitational field of the smaller star, the nova.

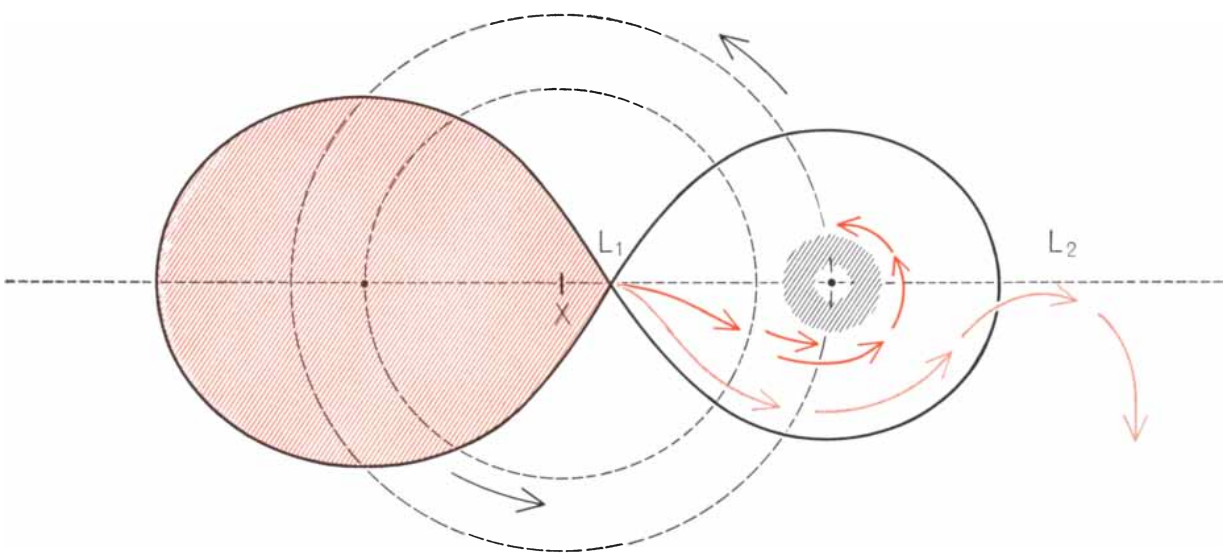
This conclusion is reached by analyzing the forces acting on a tiny third body —say an atom of gas—in the presence of two massive bodies rotating around a common center of gravity. This is a case of the famous three-body problem, one for which certain limiting solutions but no unique solution can be obtained. The limiting solutions depend on the choice of a certain value of the con-

stant of integration, C, which appears in the differential equations of motion of the small particle. For any given value of C the equations of motion define a surface, called the zero-relative-velocity surface, which divides space into two regions, one accessible to and the other inaccessible to the particle. If a particle having zero initial velocity lies on one side of this surface, it cannot pass to the other side. Some of these surfaces are depicted in the upper illustration below.

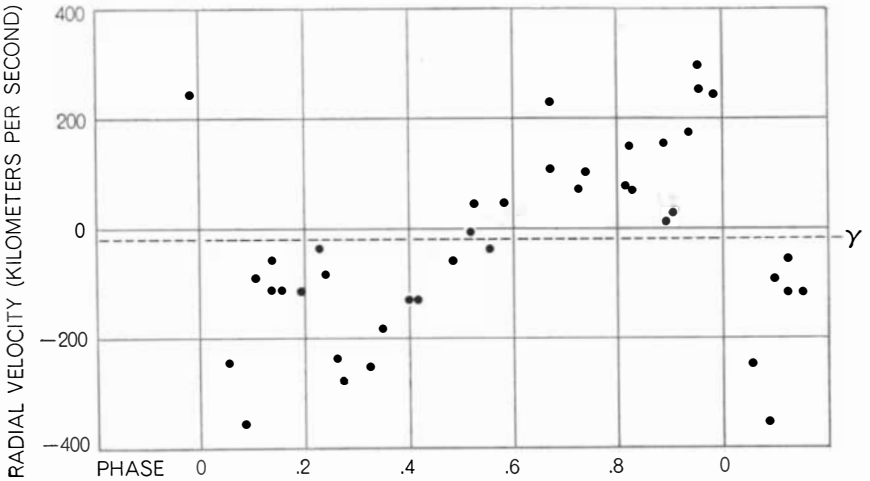
It can be seen that when C is large, the surface consists of two separate lobes, one surrounding each mass. As C decreases, the lobes touch, forming a double point (or singular point) at L_1. Further decrease in C leads to a further spreading out of the surface, a second double point at L_2 and finally a third at L_3. Particles with zero velocity are sub-



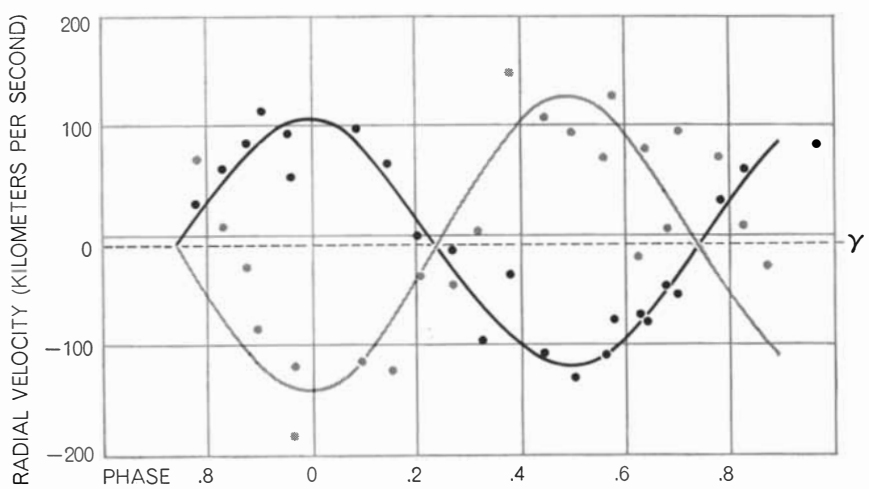
SURFACES OF ZERO VELOCITY provide a mathematical model for gravitational forces acting in the neighborhood of a binary star system, viewed here pole on. The surfaces divide space into two regions, one accessible to and one inaccessible to a particle of zero velocity acted on by two bodies of different mass, A and B, rotating around a point X. The location and geometry of the zero-velocity surface change with values assigned to a "constant of integration." When this value is high, for example 2.17, the surface has two lobes. As the value falls, the lobes join. At the double points L_1, L_2 and L_3 a particle is not subjected to gravity.



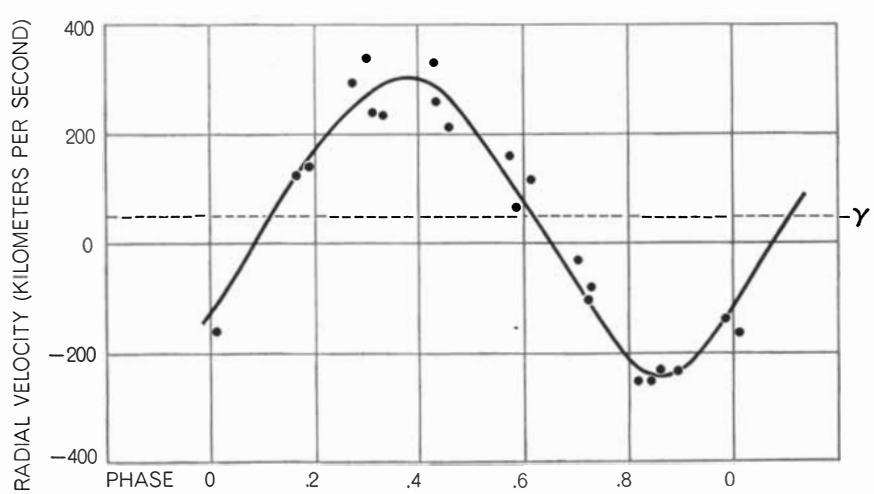
MODEL OF NOVA shows approximate size and relationship of a two-star system containing a typical nova or dwarf nova. The entire left lobe of the horizontal figure eight is occupied by the large red member of the pair of stars. Its outer surface coincides roughly with the point (X) around which both stars revolve. The two lobes of the eight join at the double point L_1 (*see upper illustration*). It seems probable that material flows from the red star through L_1 into the lobe surrounding the blue star, which is actually the nova, and takes up an orbit around it. Some material may also escape into space at another double point at the extreme right.



RADIAL VELOCITY of the binary system comprising Nova DQ Herculis is deduced from the velocity variation shown in the emission line of ionized helium, plotted here. The helium seems to be in a small rotating ring surrounding the nova. The helium is receding at about 150 kilometers per second (*phase .7*) shortly before the nova is eclipsed by its larger (and invisible) partner. As the eclipse begins (*phase .93*) the dark star covers the approaching side of the ring, revealing only the side receding at a velocity that reaches about 300 kilometers per second. The opposite effect occurs immediately at end of the eclipse (*phase .05*).



VELOCITY OF BINARY RU PEGASI can be cleanly plotted from the shift in spectral emission lines. The black curve refers to the cool red component, the gray curve to the hot blue star, a dwarf nova. Period of revolution of system is eight hours 54 minutes.



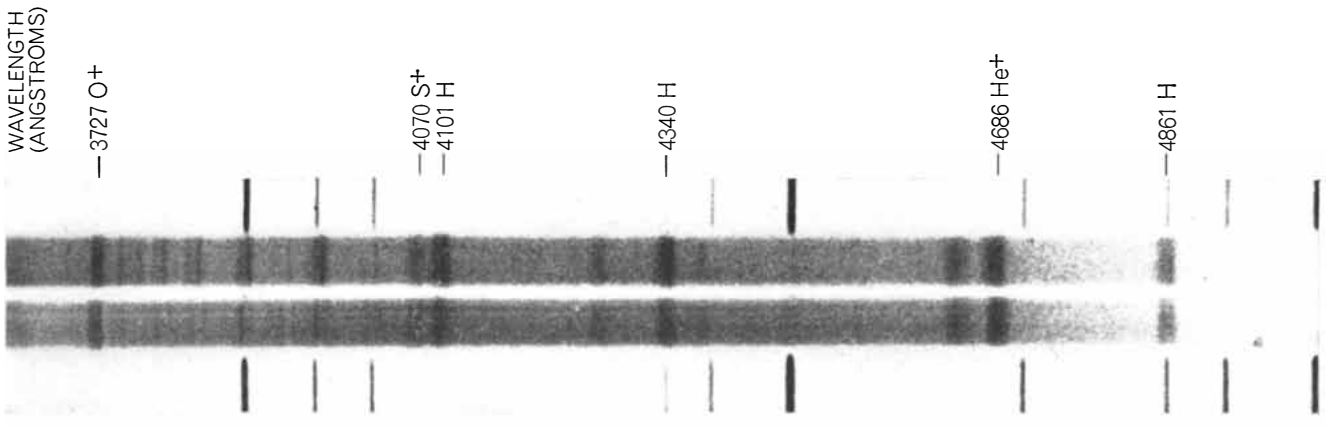
VELOCITY OF U GEMINORUM, another dwarf nova, can be deduced from a spectrum that shows only the hot member of a binary pair. The orbital period is four hours 11 minutes.

jected to no gravitational force if they are located at these singular points. So located, they respond to the slightest push from any source. If a group of particles with a random velocity distribution should be placed at L_1, for example, they could migrate into either lobe.

In the actual binary systems we have been discussing it appears that the large red stars fill one entire lobe of the zero-relative-velocity surface that forms a figure eight. As a result atoms in the atmosphere of the red star escape at L_1 and go into orbit around the much smaller blue star [*see lower illustration on preceding page*]. These orbiting particles, continuously being fed in from the red star, presumably account for the luminous ring that we observe in DQ Herculis. Some of the orbiting material may spiral in to the surface of the blue star, providing a net transfer of mass from the red star to the blue. It is likely that some of the material also escapes into space by way of the outer double point L_3.

I shall briefly summarize the first results of examining other novae and dwarf novae in a search for binary systems. Of 19 dwarf novae that can be observed from Palomar Mountain, eight have now been studied and all have turned out to be binaries. I have no doubt that the others will prove to be binaries also. The orbital periods range from 3.5 to almost nine hours, with a mean value of about six hours. In every case it appears that the red star supplies material for a ring surrounding the blue star. Meanwhile W. Krzeminski, working at the Lowell Observatory in Flagstaff, Ariz., has found that U Geminorum, the prototype dwarf nova, is also an eclipsing binary [*see bottom illustration at left*].

The search for binaries among ordinary novae has just begun, but early results strongly suggest that the binary hypothesis holds for them as well. In addition to T Coronae Borealis and DQ Herculis, 15 other novae are within range of the 200-inch Palomar reflector. Four of the 15 have now been examined. Two are certainly binaries: Nova Persei (1901) and Nova WZ Sagittae (1913 and 1946). According to Greenstein, Nova Aquilae (1918) shows velocity variations and may be a binary. A few months ago Walker reported that Nova Aurigae (1891) is an eclipsing binary with a period of 4.9 hours. The total is therefore five definite binaries and one suspect out of 17 novae available for study. WZ Sagittae is the most remarkable observed so far. Spectra I have made show that it has a period of only 81.5 minutes and a radial velocity rang-



SPECTRUM OF DQ HERCULIS discloses a velocity shift only for emission line of ionized helium (He^+) and for hydrogen lines with a wavelength of 4,101 angstrom units or less. In upper strip, made at maximum approach velocity, helium line shifts to the left, or violet, end of the spectrum. In lower strip, at maximum recession, shift is to the right, or red, end. Other lines, such as ionized oxygen (O^+) and sulfur (S^+), do not shift, presumably because they arise in a nebular envelope surrounding both stars.

ing between 1,200 and 1,400 kilometers per second. Krzeminski finds that WZ Sagittae is also an eclipsing binary.

What is the evolutionary history of these curious systems? In the case of dwarf novae, at least, we can imagine that such a system consists originally of two main-sequence stars, one a little more massive and more luminous than the sun, the other less massive and considerably less luminous than the sun. The original period is perhaps 12 hours. At first neither star fills its lobe of the critical zero-velocity surface. The more massive component is the first to burn 10 per cent of its hydrogen, whereupon it expands, encounters the critical surface and begins losing mass rapidly, either to the other star or to space or both. Since hydrogen-rich material is lost, the evolution of the more massive star is greatly speeded up, and the material collected by the secondary star causes its evolution to be slowed down. Eventually the more massive component becomes a white dwarf and stops losing mass. Later the component that was originally less massive evolves into a red giant and begins losing matter to the white dwarf. This is the state of the dwarf novae we observe. An idea of this kind originally was advanced by John A. Crawford of the University of California to explain the subgiant components of certain eclipsing binary systems, and has been dubbed by the University of Cambridge astronomer Fred Hoyle the "dog eat dog" hypothesis.

Unfortunately the hypothesis throws no direct light on the source of the outbursts. For supernovae, however, which are almost certainly not part of binary systems, a rather satisfactory explosion mechanism has been developed jointly by Margaret and Geoffrey Burbidge of the Yerkes Observatory, William A. Fowler of the California Institute of Technology and Hoyle. They suggest that in the case of the massive Type II supernovae before the star explodes the temperature deep in its interior rises to more than seven billion degrees C. This comes about when hydrogen, helium and heavier elements have been consumed as fuels and the core shrinks by gravitational contraction, becoming hotter as it shrinks. Above seven billion degrees iron is rapidly converted into helium by a nuclear process that absorbs energy. In meeting the sudden demand for energy the core cools off rapidly and shrinks catastrophically. The core implodes in a matter of seconds and the outer envelope crashes in after it. As the lighter elements of the envelope are heated by the implosion they burn so rapidly that the envelope is blasted out into space.

The explanation for Type I supernovae, proposed by Hoyle and Fowler, rests on the unusual properties of matter in the "degenerate" state. This term describes the behavior of a gas under the tremendous pressures found in white-dwarf stars, where matter weighs more than 15 tons per cubic inch [see "Dying Stars," by Jesse L. Greenstein; SCIENTIFIC AMERICAN, January, 1959]. Most of the electrons in such a star behave as if they were frozen: they are not free to move because their positions and momenta are rigidly prescribed. Only a few electrons and the nuclear particles are free to move at random. Hoyle and Fowler propose that a Type I supernova explosion results if some process increases the temperature slightly. Unlike ordinary matter, degenerate matter does not expand with temperature and therefore the temperature rise is not offset by expansion cooling. Hence the temperature rise increases the rate of thermonuclear reactions, which in turn raises the temperature, and so on. The result is a catastrophic explosion.

For ordinary novae and dwarf novae, however, there is no reason to suppose that the explosion results from thermonuclear activity deep in the core of the star. Indeed, observations of some novae suggest that "cones" of material, rather than spherical shells, are ejected. Evry Schatzman of the Institut d'Astrophysique in Paris has proposed that forced oscillations of the blue star, produced by its circling companion, may trigger the outburst. According to the view presented here, however, the blue star may gain material from the shell supplied by the red star. The increased pressure of the new material should force unburned hydrogen-rich material on the surface of the blue star to move downward into the outer part of its degenerate core. If conditions are right, the result would be a limited explosion on the model proposed by Hoyle and Fowler for Type I supernovae. The explosion need not be deep-seated, because the degenerate cores of old stars with the mass of the sun are large and lie not far beneath the surface. Whatever the reason for outbursts of novae and dwarf novae, it must be intimately related to the presence of a large but dim companion.

The Membrane of the Living Cell

The electron microscope reveals the structure of this gossamer layer, which not only constitutes the exterior of the cell but also folds inward to make up much of its internal architecture

by J. David Robertson

Almost everyone who has looked at a cell through a microscope has assumed that it is surrounded by a membrane. Some sort of coating seems necessary to maintain the integrity of the soft, yet far from shapeless, bit of protoplasm in its liquid environment and to control the constant exchange of material between inside and outside. But the nature of the membrane—its thickness and composition—was until quite recently a matter of conjecture. The membrane is far too thin to be visible under the most powerful light microscope.

Now, with the help of the electron microscope, the membrane has been seen. Its thickness has been measured. By combining the new direct evidence with the results of older studies, the general features of its molecular structure have been deduced and a fundamental constant pattern of organization common to all cells has been defined. Moreover, the cell membrane has proved to be much more than an outer coat: in most cells it forms an essential part of the internal structure. The present understanding is the culmination of a fascinating search, extending over many years and following several pathways that have at last converged.

UNIT MEMBRANE surrounds a Schwann cell protecting the axon of mouse sciatic nerve. Axon (*lower left*) is encased in its membrane and in a myelin sheath, composed of layers of Schwann cell membrane. Round object at top center is a growth spiral, where new membrane may be produced. Mitochondria, seen as oblong object at upper right and larger round objects throughout cell, are composed in part of paired unit membranes. Other membranous forms are endoplasmic reticulum. Micrograph enlarges structures 75,000 diameters.

The indirect evidence for a definite cell membrane structure has long been highly persuasive, if not conclusive. Studies of the traffic between the interior of the cell and its surroundings show molecules of various kinds passing back and forth in an orderly sequence. Often they move against strong concentration barriers that can be overcome only by expenditure of energy [see "How Things Get into Cells," by Heinz Holter; SCIENTIFIC AMERICAN, September, 1961]. For example, sodium ions are continuously pumped out of the cell while a high concentration of potassium ions (with respect to the surrounding liquid) is maintained within the cell. In nerve fibers this activity is related to an electric potential difference between inside and outside, which forms the basis for the transmission of nerve impulses. It is possible to imagine how such electrochemical processes could be carried out without a membrane, but they are much more readily understood by supposing that there is a separate, specialized structure at the boundary, capable of converting and expending energy.

However strongly biologists may have believed in the cell membrane, they could not hope to see it directly in the light microscope. At best this instrument has a resolving power of about a thousandth of a millimeter. Assuming, as seemed likely, that the membrane is only a few molecules thick, it would be expected to measure less than a hundred-thousandth of a millimeter across. Nevertheless, light microscopists had fallen into the habit of talking about a cell membrane, by which they meant the thinnest dense line they could see next to the cytoplasm (the part of the cell that lies between the membrane and the nucleus). But there was little assurance that this line represented any particular constant structure. After all, structures radically different from one another could look the same.

With the advent of the electron microscope the nature of the problem changed completely. Now the microscopist has a device with about 1,000 times more resolving power. The thinnest dense line seen in the light microscope stands out as a complex structure containing several denser and lighter layers. How many of them constitute the membrane proper? The former stratagem of defining it as the thinnest dense line will not do. Present-day electron microscopes are quite capable of resolving a layer one protein molecule thick, and so this approach would lead to the definition of the cell membrane as a monomolecular layer. From the physiological point of view, however, it seems unlikely that a layer one molecule thick could carry out the functions of cell membranes.

The solution to the problem of defining the limits of the membrane has come chiefly from studies of long nerve fibers, or axons. These are threads of protoplasm, extending from nerve cells located mainly in the spinal cord or brain, that carry messages to and from the central nervous system. In human beings axons are commonly a few thousandths of a millimeter in diameter and up to several feet long. They are accompanied along their entire length by a succession of specialized satellite cells, named Schwann cells after Theodor Schwann, one of the great 19th-century cell biologists.

Under the light microscope two different types of nerve fiber could be made out. One is enclosed in a thick sheath of fatty material called myelin; the other is not. Whether the myelin is part of the axon or of the Schwann cells was not clear. It could be seen, however, that the sheath is broken up into seg-

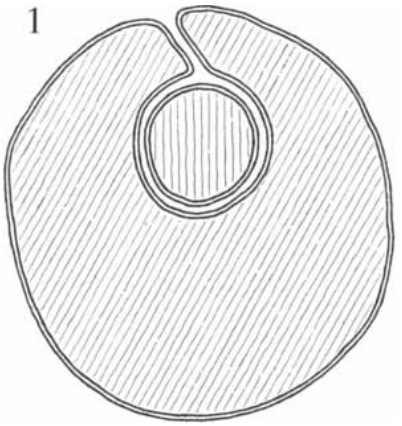
ments, one for every Schwann cell. Almost always each axon in myelinated fibers has its own set of Schwann cells. In unmyelinated fibers several axons usually share one set. It appeared to light microscopists that the unmyelinated fibers were completely surrounded by the substance of their Schwann cells.

The first views of nerve fibers in the electron microscope, obtained by H. Fernandez-Moran in Venezuela and Fritiof Sjöstrand in Sweden, told a different story. In the first place the myelin sheath proved to be part of the Schwann cell, not the axon. Seen in cross section, the sheath turned out to consist of many repeating layers, each 110 to 140 angstrom units thick (an angstrom unit is a ten-millionth of a millimeter). In each repeating stratum there is a "major dense line" about 30 angstroms thick followed by a lighter zone 80 to 110 angstroms across. This zone is bisected by another dense layer, called an intraperiod line [*see illustrations at bottom of these two pages*].

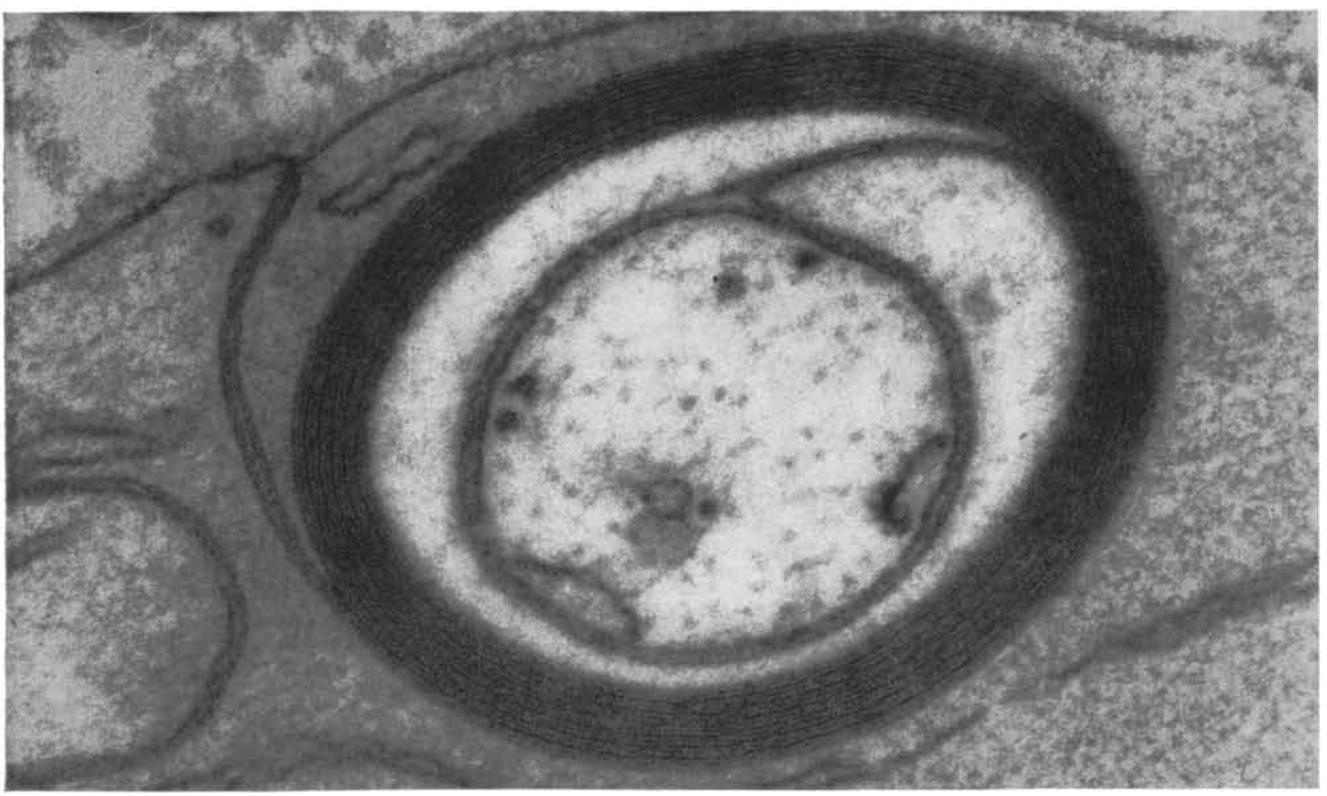
The stratified myelin structure held the key not only to delimiting the cell membrane but also to determining its molecular organization. These problems were solved by combining the results of two lines of investigation: (1) older biochemical and biophysical studies of myelin, which I shall discuss shortly, and (2) electron microscope studies that showed how the myelin sheath is formed. The latter investigation began early in the 1950's, when Herbert S. Gasser of the Rockefeller Institute first examined unmyelinated nerve fibers by electron microscopy. He soon discovered that, contrary to what had been thought, the fibers are not completely enclosed within the cytoplasm of the Schwann cells. Instead they lie close to each satellite cell or are sometimes embedded in its surface. No matter how deep the intrusion is, the overhanging lips of Schwann cytoplasm do not quite touch. They are always separated by a gap 100 to 150 angstroms wide. Topologically the fiber is outside the Schwann cell. Gasser named the almost closed pair of lips a mesaxon.

Shortly afterward Betty Ben Geren-Uzman of the Harvard Medical School began to study the development of the myelin sheath in embryonic chick nerves. She found some unmyelinated fibers arranged like those Gasser had described but with only one axon per Schwann cell, like myelinated fibers. She noted that some of these fibers had long mesaxons drawn loosely into a simple spiral running around the axon in several loops. It occurred to her that the myelin sheath might be nothing more than a mesaxon, greatly drawn out and wound around the axon in a tightly packed spiral.

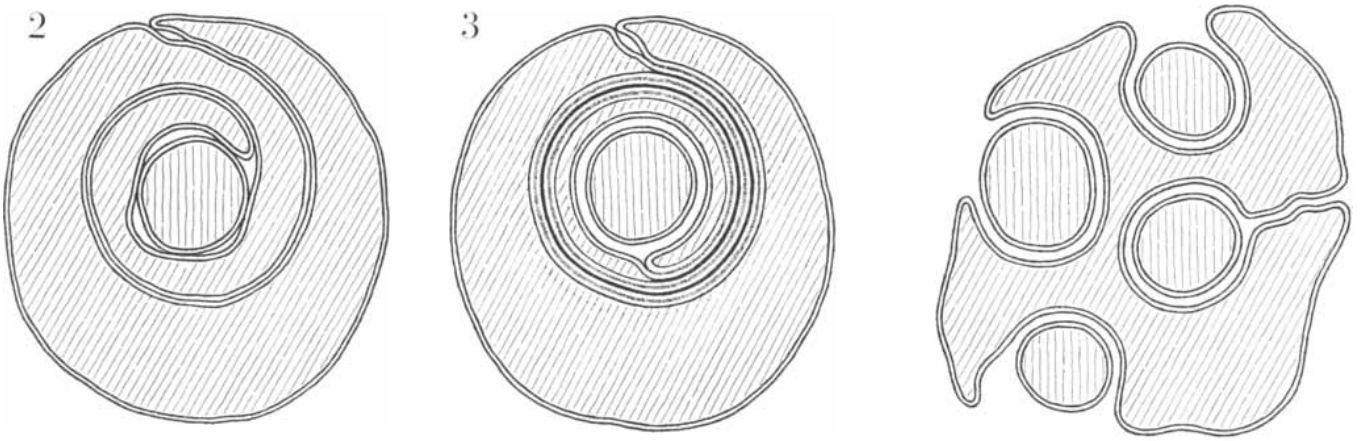
In 1955 I published an electron micrograph of an adult myelin sheath that confirmed Mrs. Uzman's conjecture [*see illustration on page 68*]. Although technically inferior to present-day micrographs, the picture displayed for the first time the outer and inner end of the postulated mesaxon loop. Further-



FORMATION OF MYELIN SHEATH from Schwann cell membrane is depicted. The axon, shown as the circle with vertical



MYELIN SHEATH is enlarged 160,000 diameters in this micrograph. The dark lines represent the inner sides of the membranes that come together to form the sheath. The fainter lines are the outer sides of these membranes. The two membranes composing the sheath can be distinguished clearly. The diagram on the opposite page shows the left-hand section of the sheath schematically.



hatching, is surrounded by its own membrane and embedded in a Schwann cell (*1*). The myelin sheath is produced when membranes separating overhanging lips of Schwann cell cytoplasm come together and elongate (*2*) to form a tightly packed spiral around the axon (*3*).

UNMYELINATED AXONS are also embedded in Schwann cells. But the membranes remain separated and do not elongate.

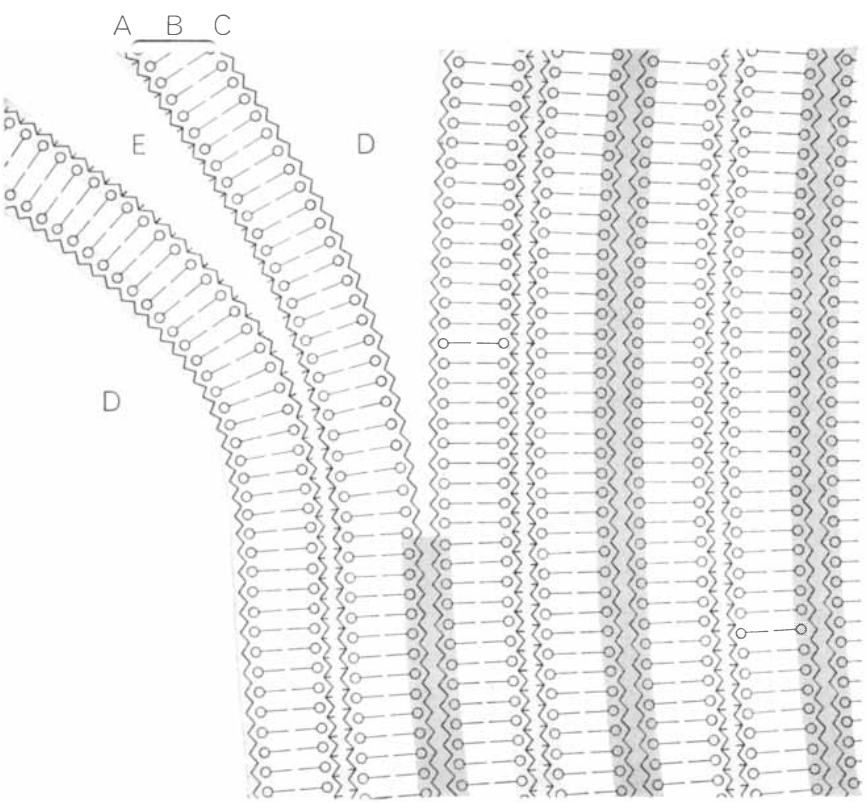
more, it was clear enough to suggest, although not to prove, that the turns of the spiral are tightly packed, with neither additional material from the Schwann cytoplasm nor any extracellular material between them. In other words, it appeared that the myelin sheath might be nothing but a winding of a double layer of the Schwann cell membrane, just as Mrs. Uzman had postulated. The idea was exciting because a great deal was already known about the molecular structure of myelin, and it now seemed possible to apply this knowledge directly to the cell membrane.

Research on myelin goes back to the latter part of the 19th century. At that time it had already been learned that a large part of the myelin sheath is dissolved away by fat solvents. This fact, plus the staining characteristics of intact myelin, made it clear that it contains a large proportion of fatty substances, or lipids. In addition, it was soon realized that the material remaining after the lipids are dissolved consists largely of protein.

The next major advance came in the 1930's through studies of myelin with the polarizing microscope, particularly by the noted German biophysicist W. J. Schmidt. With this instrument it is possible to discover something about the internal molecular architecture of a translucent material. If it is composed of long, thin molecules with their long axes parallel to one another and a beam of plane-polarized light is sent through the material, the direction of polarization of the emerging beam is rotated. From the amount and direction of the rotation the orientation of the molecules can be deduced.

A myelinated nerve fiber, examined in the polarizing microscope, alters the polarized beam in such a way as to indicate that the sheath contains long molecules lined up radially with respect to the axis of the fiber. Moreover, pure lipid extracted from myelin can be shown to produce a similar effect under the same optical conditions. Therefore it seems reasonable to suppose that it is the lipid molecules in myelin that have the radial orientation. As has been mentioned, the residue remaining after the extraction of lipid from myelin consists largely of protein. This residual material also alters polarized light, but in a way opposite to that caused by intact myelin. The protein molecules, then, must be aligned at right angles to the lipid molecules; they lie parallel to the fiber axis. Schmidt therefore concluded that myelin consists of alternating layers of lipid and protein molecules stacked at right angles to each other.

As for the lipid fraction, it had also



MOLECULAR STRUCTURE of unit membranes forming myelin sheath is diagramed. *A* is a layer of protein and carbohydrate on outer side of membrane. *B* is its lipid core. *C* is the protein layer of the inner side. *D* is Schwann cell cytoplasm, *E* extracellular matter.

been studied intensively by itself and a good deal was known about it. The phospholipid molecules found in myelin consist of two parts: a long, straight chain of carbon and hydrogen atoms attached to a more complicated structure containing atoms of carbon, hydrogen, oxygen, nitrogen and phosphorus. The two portions can be split apart and examined separately. The hydrocarbon chains are soluble in organic solvents such as ether and chloroform but are not soluble in water; the more complex end of the molecule, containing phosphorus and nitrogen, is not soluble in these substances but dissolves readily in water. The difference in solubility is explained by the electrical characteristics of the two fractions. In the water-soluble material the negatively charged electron clouds in the atoms are slightly displaced with respect to the positive nuclei, so the group as a whole is electrically polarized: one end is positive and the other negative. Water molecules are also strongly polarized, so the substances attract each other. In the hydrocarbon chain, on the other hand, the centers of negative and positive charge are symmetrically disposed, and there is no such electrical polarization.

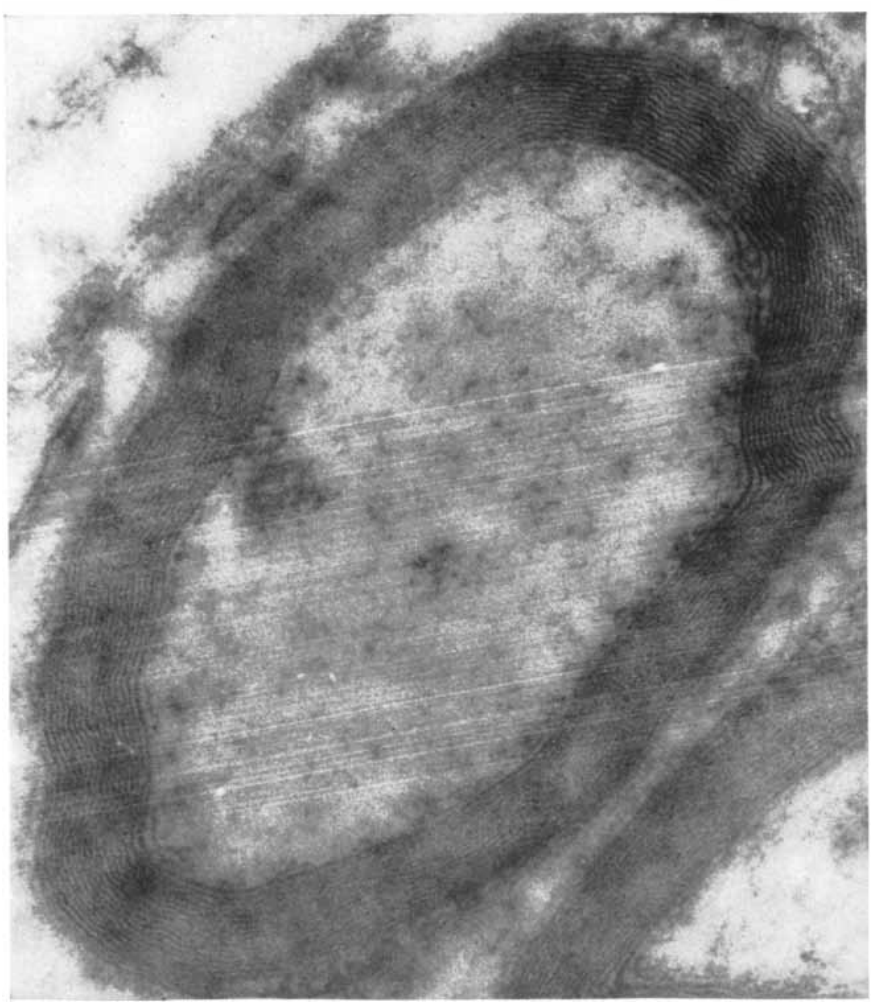
Intact phospholipid molecules, then, have a "hydrophilic" end, which is attracted to water, and a "hydrophobic" end, which is not. Under certain conditions pure phospholipids take on an orderly arrangement in which the molecules lie side by side in sheets, the hydrophilic ends at one surface and the hydrophobic ends at the other. The sheets themselves pair up, with the hydrophobic, or nonpolar surfaces, facing each other. Such a pair is known as a bimolecular leaflet. The over-all ordered structure is a stack of many leaflets.

Like any other regular molecular array, a stack of bimolecular leaflets will diffract a beam of X rays in a meaningful pattern. Long before the electron microscope became available, X-ray diffraction techniques had revealed a good deal about the architecture of ordered lipids. From the angle through which the rays were bent, each bimolecular leaflet, containing mixed lipids of the kind readily extracted from nerve fibers, was computed to be about 65 angstroms thick.

X-ray diffraction was also applied to whole myelin, particularly by Francis O. Schmitt, Richard S. Bear and G. L. Clark, then at Washington University in St. Louis. They found a repeating unit 170 to 185 angstroms thick in the radial direction. Since the material consists of protein as well as lipid, the repeating interval could obviously contain no more than two bimolecular leaflets. It would also have room for a few layers of protein molecules with their long axes perpendicular to the radial direction. In this position they would be only about 15 angstroms thick. Schmitt's group concluded that myelin is made up of bimolecular leaflets alternating with protein layers.

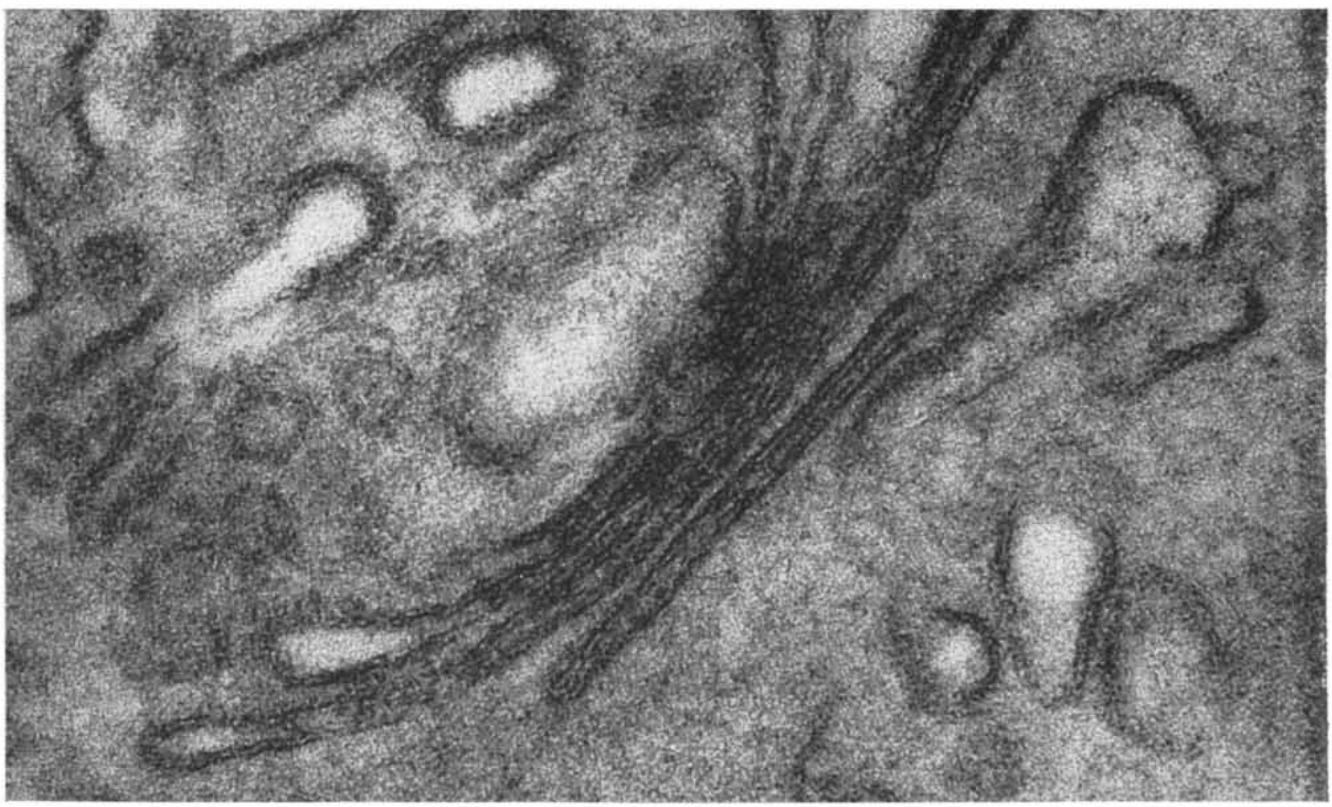
Here matters rested until the development of the electron microscope. Now the structures of pure phospholipid and of myelin, which had been inferred from X-ray analysis, could be examined directly. The first electron micrograph of ordered phospholipids, made by Schmitt and Mrs. Uzman, displayed a series of alternating dense and light strata. Each of the strata was narrower than the known length of the phospholipid molecule, and so it was concluded that each dense layer must represent one part of the molecule and each light layer the other part. Then the question arose: Is the dense layer the hydrophilic or the hydrophobic part of the molecule? To find out I studied samples of phospholipid treated with water. When water penetrates the material, it runs between the polar surfaces of the individual molecular sheets but not between the nonpolar, or hydrophobic, surfaces. In the electron microscope it could be seen that the water had split each dense stratum into two layers and had left the light strata unchanged. Therefore the dense material represents the polar surfaces of the bimolecular leaflets and the lighter regions the hydrophobic carbon chains. This conception has recently received support from the work of Walther Stoeckenius of the Rockefeller Institute.

The appearance of whole myelin under the electron microscope was described earlier in this article. To recapitulate, it is made up of alternating major dense lines and light zones, the pattern repeating in an interval of 110 to 140 angstroms. Bisecting the light

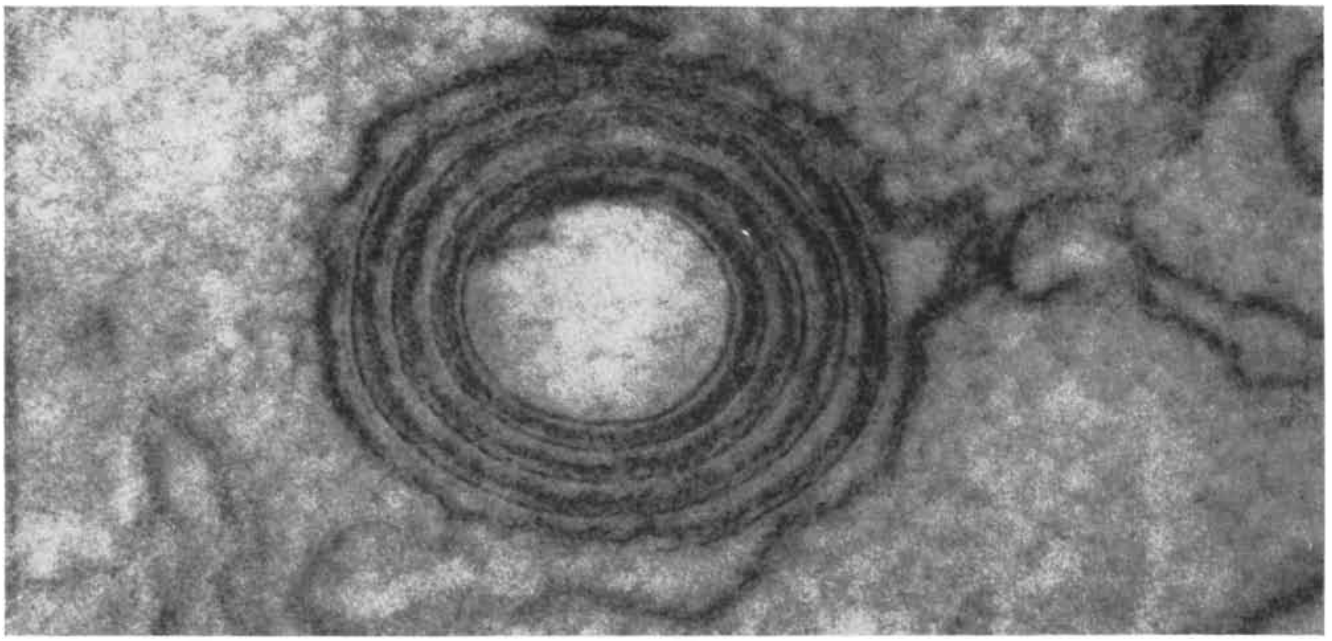


ELECTRON MICROGRAPH published by the author in 1955 showed that myelin is made of layers of Schwann cell membrane. Both outer and inner ends of myelin sheath can be seen in upper right-hand section of micrograph, which enlarges the structure 81,250 diameters.

MITOCHONDRIA in frog muscle are seen here connected by a narrow tubular neck. Mitochondria, which usually appear separate from one another, are composed of a pair of unit membranes. In some electron micrographs the outer membrane is connected with the endoplasmic reticulum. As such micrographs and this one suggest, mitochondria may be formed when cytoplasm fills a cavity of the endoplasmic reticulum, which then pinches off to produce discrete organelles. The structures are enlarged 77,500 diameters.



GOLGI BODY is found in nearly all cells. Its function is still unknown but its structure can be seen clearly. Like the endoplasmic reticulum, of which it is a part, it is composed of a pair of unit membranes. In this micrograph it is enlarged 240,000 diameters.



GROWTH SPIRAL is an elongated, cigar-shaped structure formed of a flattened sac bounded by a pair of unit membranes wrapped up in a spiral. It is often found in developing Schwann cells. The shape of the growth spiral may indicate that its outer membrane is the seat of new membrane synthesis for the growing cell. This micrograph shows the growth spiral in the sciatic nerve of a young mouse at an enlargement of 265,000 diameters. Like all the other micrographs accompanying the article, it was made by the author.

zones is a darker intraperiod line, which in the early micrographs was broken into short segments or dots.

In trying to correlate this picture with the earlier results, one must take into account the method used to prepare materials for electron microscopy. First they are "fixed" by treatment with certain chemicals; then they are embedded in a block of plastic and cut into very thin slices. J. B. Finean in England and Fernandez-Moran considered the effects of fixing and embedding on the myelin structure. They showed that the material shrinks just enough to reduce the size of the repeating interval from the value deduced from X-ray diffraction (170 to 185 angstroms) to the width seen in electron micrographs (110 to 140 angstroms).

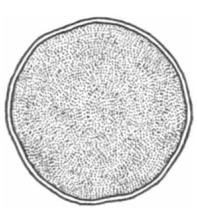
As was pointed out above, the polar groups in lipid bimolecular leaflets were found to produce dense areas in an electron micrograph. (They do so because they combine readily with the fixing chemical, which contains heavy metal atoms that strongly scatter electrons.) Moreover, it was known that pure protein also forms dense lines or spots on fixation. Therefore the dense lines in the electron micrographs of myelin were interpreted as representing combined protein monolayers and lipid polar surfaces.

Much of this had been learned by about 1955. Considering what was also known about the origin of myelin from the Schwann cell, it was tempting to trace the laminated structure of myelin directly to the Schwann cell membrane. The evidence was not yet quite good enough, however. The main trouble was that the membrane itself could not be seen clearly.

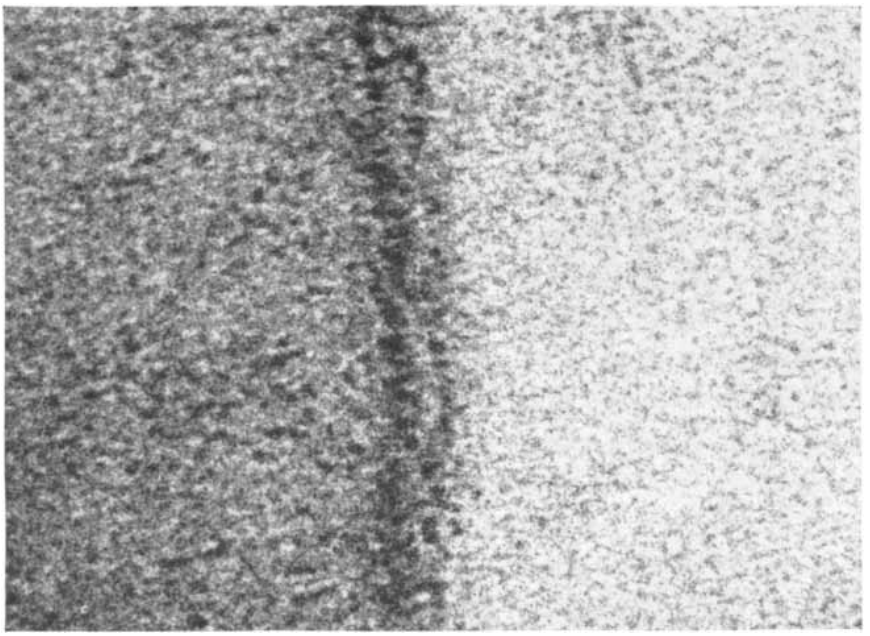
Then in 1956 John H. Luft at the Rockefeller Institute introduced a new fixing technique using potassium permanganate instead of osmium tetroxide, which had been the only effective agent up to that time. When the method was tried on preparations of axons and Schwann cells, the hazy line that had bounded their cell bodies in earlier micrographs stood out clearly as a layered structure containing three distinct strata. Next to the cytoplasm is a thin dense line measuring about 20 angstroms in thickness. This borders a light central zone about 35 angstroms thick that is in turn bounded externally by another thin dense line about 20 angstroms thick. The whole structure measures about 75 angstroms across and is called a unit membrane.

Micrographs of developing myelin sheaths fixed with potassium permanganate show clearly that they consist simply of a double layer of Schwann cell unit membranes wound into a spiral. The major dense lines represent the intimate apposition of the inside, or cytoplasmic, surfaces of the membrane. The intraperiod lines are formed by the outside layers coming together as each layer wraps around the previous one. Since the new micrographs also demonstrate the absence of any material other than the unit membrane, the structure of myelin layers can now be related directly to that of the membrane. The membrane must consist of a core containing a single bimolecular leaflet of lipid, its polar surfaces pointing outward and covered by monomolecular films of nonlipid.

Until the introduction of the potassium permanganate technique the nonlipid material was assumed to be almost all protein. This turns out not to be so. Osmium tetroxide produces a dense line at the inside surface of the membrane but usually does not produce such a line



EVOLUTION OF CELL may have followed the pattern diagramed here. First drawing shows matrix material bounded by a unit



MEMBRANE of human red blood cell is seen as a double line separating the cell body (*at left*) from extracellular matter. The red blood cell is composed only of cytoplasm bounded by a unit membrane. Although it originates from a more complex cell, its simplicity suggests the form the earliest cells may have taken. Micrograph enlarges the cell 925,000 diameters.

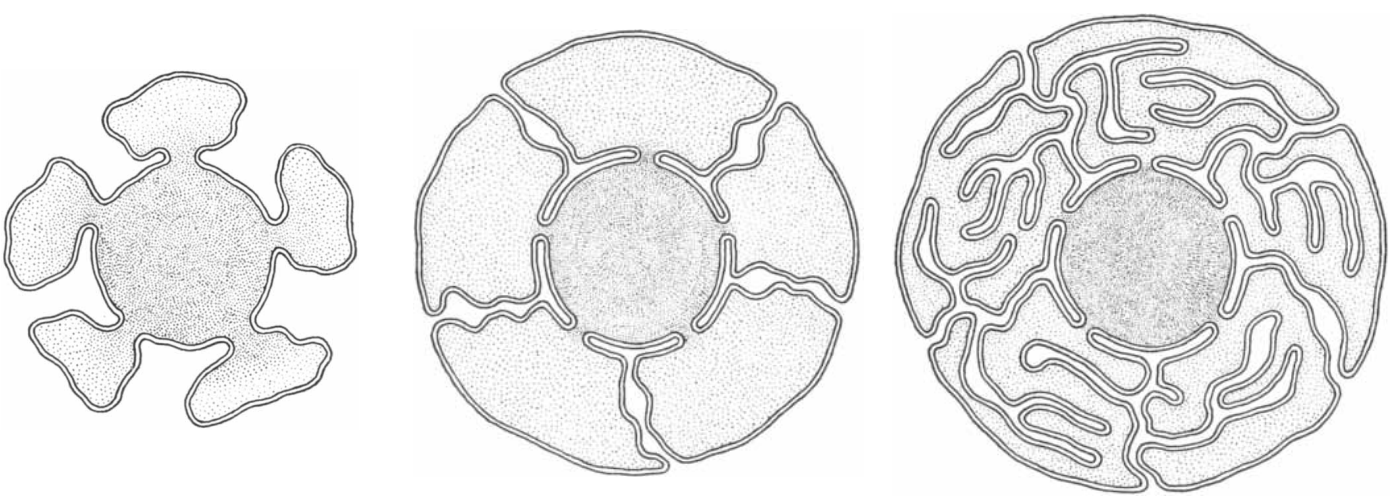
at the outside. Potassium permanganate, on the other hand, gives a density at both surfaces. Obviously the inner layer must differ chemically from the outer layer. The difference also carries over to myelin. Treated with osmium tetroxide, the substance displays a heavy major dense line (formed by the inside surfaces of the membrane), but the intraperiod line (representing the outside surfaces) is broken into irregular dots or granules. In contrast potassium permanganate yields a solid intraperiod line as thick but not quite as dense as the major dense line.

Evidently osmium tetroxide does not fix the outer half of the Schwann cell membrane as well as potassium permanganate does. Recently it has been found that osmium tetroxide reacts poorly with many sugars and more complex carbohydrates. It therefore seems likely that the outer surface of the membrane is mainly carbohydrate in nature and the inside mainly protein.

The same kind of 75-angstrom unit membrane found at the surface of the Schwann cell can apparently be demonstrated at the surfaces of all cells. A survey of a great many different kinds of animal cell, plant cell and bacterium has failed to turn up a single case where the structure was lacking. It would appear to be a biological constant common to the surfaces of all kinds of cell.

In the past 10 years electron microscopists have found that practically all cells are filled with numerous membranes folded in complicated ways. Keith R. Porter, George E. Palade and Sanford L. Palay at the Rockefeller Institute and Sjöstrand have studied the arrangement of the internal membranes and have produced strong evidence that many of them are linked together. One reason for thinking so is that the membranes always appear in pairs, forming the lining of extensive cavities, sinuses and canals that run throughout the cell. This extensive system is known as the endoplasmic reticulum. Michael L. Watson of the University of Rochester has shown that the nuclear membrane is in fact simply a system of sacs of the endoplasmic reticulum arranged around a spherical bit of cytoplasm containing the principal genetic material. There is direct continuity between nuclear and cytoplasmic matrix maintained by openings in the nuclear membrane. Many workers have discovered continuities between the sacs of the endoplasmic reticulum and the surface membrane of the cell. Therefore it seems reasonable to think of the cell as essentially a three-phase system. First, there is a cytoplasmic phase. Second, there is a phase made up of contents of the cavities in the endoplasmic reticulum. Third, there is a membrane phase separating the first and second phases.

This concept implies that the material



membrane. In second, matrix material has pushed out to form pseudopodia. In third, evaginated membranes have folded back to make paired nuclear membranes and a primitive endoplasmic reticulum. Fourth drawing shows further development of endoplasmic reticulum. Now material that was at first completely outside cell is included in its volume, although remaining outside topologically.

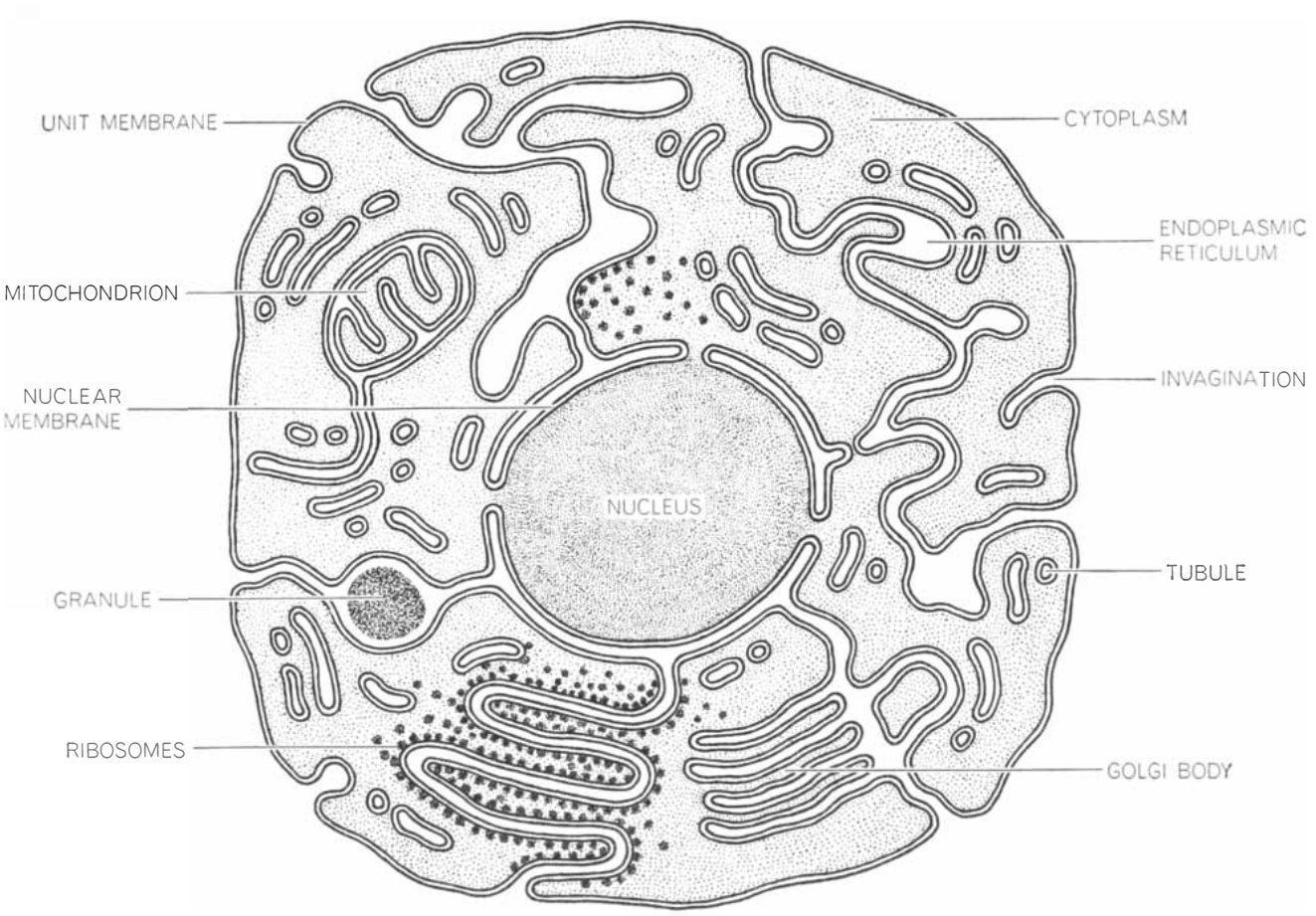
of the second phase is in a sense outside the cell. It also implies that the membranes of the endoplasmic reticulum are an extension of the surface membrane. Recent electron micrographs clearly demonstrate that the unit membrane structure does appear in various parts of the endoplasmic reticulum. Although for technical reasons the structure cannot always be seen, there seems good reason to suppose that it occurs throughout the system of interior membranes.

If the three-phase idea is literally true, it must also accommodate the various membranous bodies, or organelles, inside the cell. They are surrounded by membranes but seem to be distinct from the endoplasmic reticulum. Mitochondria are the most abundant of these organelles. Electron micrographs of mitochondria show that their membranes too exhibit the familiar unit structure. In fact, it now seems that mitochondria are formed when cytoplasm pushes into a cavity bounded by an internal membrane, which then pinches off and separates from the continuous system.

Recently I have found a new membranous organelle, about the size of mitochondria, in developing Schwann cells. This long, cigar-shaped body also consists of unit membranes, which are rolled up in a tight helix around a core of cytoplasmic matrix filled by the small particles known as ribosomes. The coiled arrangement could result if one membrane were growing faster than another. In my opinion this is just what is happening. I have named the body a growth spiral and visualize it as a structure actively spinning off new membranes of the endoplasmic reticulum.

The three-phase view implies that the simplest possible cell might consist of cytoplasm bounded by a purely surface membrane. In that case the second phase would be completely outside the cell. An example of such an organism is the human red blood cell, which has a surface membrane but no organelles. If the simple primordial cells were of this type, more complex cells could have evolved by the invagination, or drawing inward, of the surface membrane. Conversely, they could have evolved by the evagination, or pushing outward, of sections of the cytoplasmic matrix together with its membrane. The hypothesis means that any piece of membrane in the cell must have come from pre-existent membranes; it was not formed normally *de novo* in the cytoplasm or elsewhere. Membranes make membranes.

If this rule is true, one is led to ask: "Where did the first membranes come from?" In speculation about the origin of life the emphasis has been on protein and nucleic acid. There has so far been little interest in the origin of lipids. Actually the production of lipid molecules may have been crucial to the origin of life. This is so because lipids in a watery medium tend to aggregate into thin continuous sheets. The primitive membrane would have served both as a container for the various large molecules and as a surface on which they could be anchored and arranged in the integrated patterns that are as essential to life as the existence of the large molecules themselves. It seems highly probable that only after membranes appeared could the first living things be organized from the soup brewing in the ancient seas.



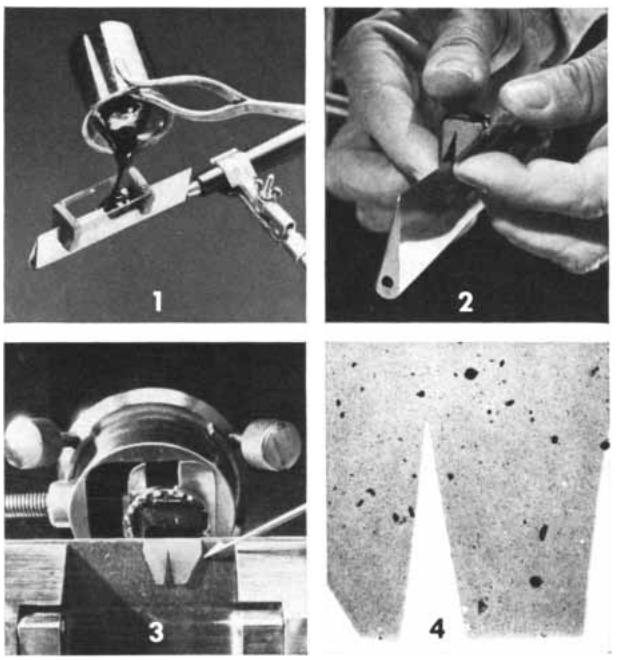
SCHEMATIC DIAGRAM, based on the author's concept of cell structure, shows the extensive distribution of membrane within the cell and some of the many membranous organelles so far identified. Since the membranes within cells always have the unit membrane pattern, it may be that most of these organelles are formed from the unit membrane structure bounding all cells.

Kodak reports on:

resin salesmen for free . . . a contribution from the axoplasm of squid nerves . . . progress for ascetics

Faithful but flexible

A microbiologist of ours who sometimes minds other people's business has come up with a stunt. Watch what he does:



Do not be confused. Because the old microtome comes readily to hand in his lab, it not only appears in his demonstration as a tool but also provides one of its spare knives to illustrate a genre of objects possessing profile sections that might require microscopic study at chosen points.

Aside from a desire to be generally helpful, we wish to make propaganda about the casting material, which is *Epolene C-10* polyethylene resin. Although we offer a large variety of *Epolene* resins for a multitude of uses and although numerous other casting compounds, including dental impression waxes, have been tried in this application, nothing seems to come even close to the *Epolene C-10* material. Chemically inert, applied at only 100 C, it follows profile details as small as 0.00009-in. radius. Four percent carbon black can be added by the user to make the resin black for contrast in photomicrography.

Fine, but what about deformation when you try to unpeel it from shapes more complex than that of a microtome knife?

Rarely a problem. The little casting is so flexible at room temperature and "remembers" its shape so accurately that you can step on it, then slice out a 40μ-thick section and depend on measurements of the section profile. (Under less dramatic conditions, reproducibility to $\pm$ 0.00001 inch seems not too much to expect.) Then, if overheating is avoided, you can remelt and reuse the resin for more castings!

A postcard addressed to "Department BLB," Eastman Chemical Products, Inc., Kingsport, Tenn. (Subsidiary of Eastman Kodak Company) and containing nothing more than your name and address will inform us that you are interested in this subject. Even if we fail to clear many dollars from the profile-sectioners themselves, we think they are influential people to have demonstrating the peculiar virtues of Epolene C-10 *low-melting polyethylene for us.*

An ion for the élite

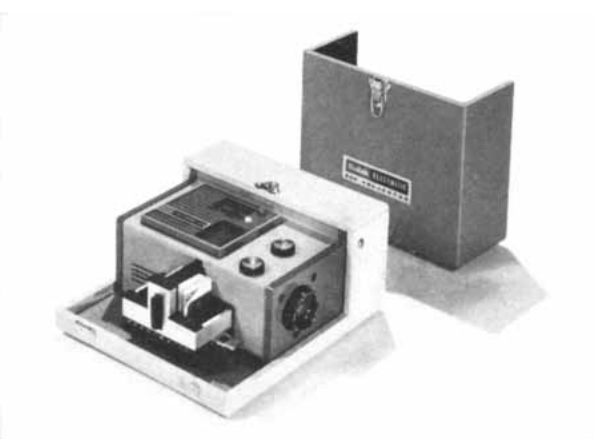
Research seems at times more fashion-prone than millinery. It is not for us to judge whether this is good or bad. Rather it is up to us to keep fashionable merchandise on hand.

We have been advised by volunteers scouting for us in the fashionable circles of physiology that the thing to do this season is to substitute bulky anions for Cl^- in physiological salt solutions. The smart set recognizes, for example, that since frog muscle cell membranes are highly permeable to chloride ions, not just Na^+ and K^+, one can't count on measurements of currents carried through the cell membranes of muscles by the cations without allowing for the chloride conductance of the membrane. This they avoid by replacing Cl^- with some anion that is too big to get through, has a sodium salt soluble enough to permit at least 0.15M solutions, doesn't complex with Ca^{++} or Mg^{++}, and is stable and non-toxic at pH 7 to 8.

Many of them use the methylsulfate ion for the purpose, and we are now in a position to supply them with *Methylsulfuric Acid Sodium Salt* (Eastman P809) if they want it. Our scouts, who are very smart, point out, however, that even Beilstein, way back in Volume 1, is gloomy about the stability of organic sulfate esters. They have reported to us that the really clever ones are going to the isethionate ion $(HOCH_2CH_2SO_3)^-$, which is a normal constituent of the axoplasm of squid nerves.

We hope we are not spoiling it for anybody by making this anion readily available as Isethionic Acid Sodium Salt (Eastman 8541). $3.30 buys 100 grams from Distillation Products Industries, Rochester 3, N. Y. (Division of Eastman Kodak Company).

It projects slides!

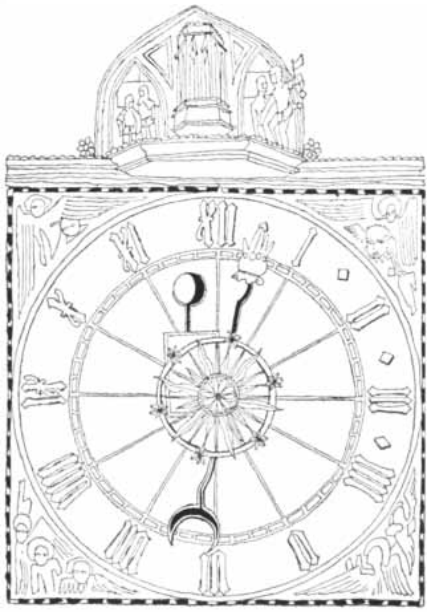


Though this simple device *is* our latest in slide projectors, owners may find it difficult to convince their friends of that fact. Those who prefer to talk of other things and want to pay less than $70 for a 500-watt 2x2 projector, complete with case and 4-inch lens, from a manufacturer of wide reputation who claims only that the low price sacrifices neither optical performance nor ease of slide-changing nor ruggedness of construction—those ascetics will ask to see a *Kodak Readymatic 500* projector at a camera shop.

Prices subject to change without notice.

Kodak
TRADE MARK

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



SCIENCE AND

One Space

The success of Project Mercury's first manned orbital flight on February 20 may have set the stage for international co-operation in the exploration of space, as well as demonstrating through the performance of the astronaut, John H. Glenn, Jr., that men have a useful function in space vehicles.

In his congratulatory message to President Kennedy, Premier Khrushchev wrote: "If our countries pooled their efforts—scientific, technical and material—to explore outer space, this would be very beneficial to the advance of science." The President replied: "I welcome your statement that our countries should co-operate in the exploration of space.... I am instructing the appropriate officers of this Government to prepare new and concrete proposals for immediate projects of common action, and I hope that at a very early date our representatives may meet." At a news conference Kennedy said: "We will be prepared to discuss this matter ... at the United Nations or bilaterally, or any other way." A possible forum for such a discussion would be the United Nations Committee on the Peaceful Uses of Outer Space. Established in 1958, the committee has been largely inactive as a result of an intermittent Soviet boycott and procedural disagreements.

Last December the General Assembly of the UN passed a resolution on space originally sponsored by the U.S. and concurred in by the U.S.S.R. It held that international law and the UN charter apply "to outer space and celestial bodies," and that these are "free for exploration and use by all states." The resolution also established a "public registry" for space-flight information. U.S. officials said that information on "orbital and transit characteristics" of the Glenn flight would be submitted to the registry.

In contrast with the two earlier manned-satellite experiments of the U.S.S.R., much of the data on the Mercury flight became public property even as the capsule was circling the earth. Such information as was released by the U.S.S.R. on the 17-orbit flight of Gherman Titov last August did not make it clear to just what extent the "cosmonaut" controlled his spaceship. Glenn, on the other hand, demonstrated that he could "fly" the capsule, controlling its pitch, yaw and roll after malfunctions in the automatic system developed early in the flight. At one point he swiveled the vehicle completely around to investigate mysterious glowing particles he saw at dawn on each orbit. Glenn later said his experience indicated "that a man can take over control of the various systems." In fact, he suggested, "we probably can go on some future flights with considerably less automation and less complexity."

Human Cancer Virus?

A British surgeon in East Africa has uncovered a human cancer with a startling resemblance to polyoma, the virus cancer of mice, and a geographic distribution suggesting that it is spread by mosquitoes. The cancer occurs in children living in tropical Africa and was originally thought to attack only the jaw. Five years ago, however, Denis Burkitt of the Makerere College Medical School in Uganda noted that affected children also had tumors in the thyroid gland, kidneys, stomach, ovaries, testes and other organs and that the disease constituted a distinct and previously unrecognized variety of generalized cancer. Subsequent studies showed that the cancer, which grows with great rapidity and usually causes death in a few months, spares only the lymph glands, spleen and lungs—organs that are largely immune to the attack of polyoma [see "The Polyoma Virus," by Sarah E.

Stewart; SCIENTIFIC AMERICAN, November, 1960]. Moreover, the tumors do not spread from a single location in the body but appear to spring from independent foci, as though caused by an infectious agent.

In discussing the disease (which he had named malignant African lymphoma before he realized it does not attack the lymph glands) with a South African physician, Burkitt learned that it is not found at all in South Africa. This led Burkitt to explore its geography. He has uncovered more than 400 cases so far, including several among children of Asian and European ancestry, thus proving that the cancer is a disease of Africa, not of Africans. The largest number of cases have been found around East Africa's great lakes and in low-lying coastal areas such as Mozambique. No case has turned up in the highlands or other areas where the temperature drops below 60 degrees Fahrenheit at any time during the year or where the annual rainfall is less than 20 inches. Such a distribution is characteristic of mosquito-borne diseases. In fact, a map of Burkitt's cases proved indistinguishable from maps showing the distribution of African yellow fever.

Because of the strong evidence that African lymphoma is a mosquito-spread virus disease, investigators see in it a unique opportunity to isolate the first human cancer virus. British and U.S. research teams in East Africa are already at work on the problem.

Observatory in Space

An orbiting solar observatory, called OSO for short, was successfully launched by the National Aeronautics and Space Administration last month. The satellite, weighing 460 pounds overall and containing 173 pounds of instruments, is the first member of a "second generation" of U.S. space probes projected for the next 10 years. From its position above the atmosphere (its height varies between 340 and 370 miles on each orbit) the observatory can continuously monitor parts of the solar spectrum that do not reach the ground.

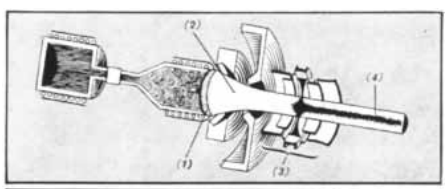
The OSO vehicle is designed to accommodate any of a number of standardized instrument packages for differ-

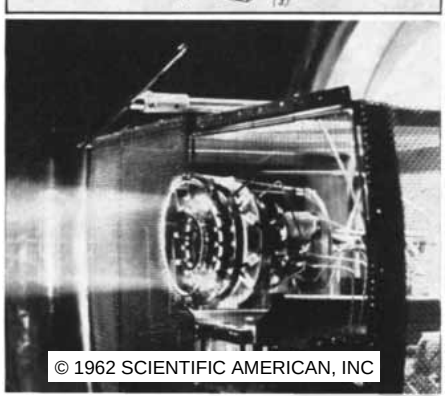
expect more from Hughes in space

Will ion engines take men to Mars?

This tiny Hughes ion engine produces much less than 1/100 of a pound of thrust. Yet this prototype will lead to larger engines which may be the practical solution to the problem of transporting men to distant planets.

An ion engine is actually an *electrical* propulsion engine. Instead of burning chemicals, the ion engine develops thrust by expelling ionized particles. In "weightless" space the constant "push" of only three or four pounds of thrust produced by a cluster of ion engines could propel a vehicle weighing more than 50 tons on interplanetary trips. Eventually, ion engines could send a manned spacecraft to Mars at a speed of two million miles a day. Trips to Pluto, the farthest planet, 3½ billion miles away, may be practical only with this type of engine.





The new Hughes ion engine (1) converts cesium atoms into ions—charged particles. (2) These ions form a beam which is put through a system of electrodes where voltage is applied, accelerating the ions to a high velocity. (3) The charged ions are then neutralized to prevent them from being attracted to the space vehicle. (4) Finally, the beam emerges at a high velocity—producing thrust.

This ion engine is under actual test in a special vacuum chamber designed for space environment simulation. It demonstrates the principle described as the "ultimate" in propulsion devices.

NASA will test a Hughes ion engine in space late this year. A number of such flight tests will be essential before the complete ion propulsion system, including a nuclear-electric power supply, can be tested in 1965.

Hughes scientists, with company support

Creating a new world with electronics

HUGHES

HUGHES AIRCRAFT COMPANY

and under contract to NASA, already have made important gains—in developing more precise control of ions, in methods for increasing engine life, and in devising unique methods of neutralizing the charge of the expelled ions.

Expect more from Hughes. Imaginative pioneering at Hughes is speeding man's progress in a host of new ways—with the SYNCOM communications satellite, with the SURVEYOR moon vehicle, with 3-dimensional radar systems. Today, Hughes is one of the world's most important producers of space age systems and products.

ent experiments. Among those carried on the first flight are units to measure gamma rays, two parts of the X-ray band, a portion of the ultraviolet spectrum containing the important Lyman-alpha radiation and a section of the short-wave visible light. In addition OSO is recording the neutrons, ions and dust particles it encounters. All the instruments, and the telemetering system that relays their readings to the ground, are functioning properly.

A system of photocells, gyroscopes, servomotors and jets of compressed nitrogen holds the satellite stable and keeps its radiation detectors and solar batteries pointing toward the sun. The supply of nitrogen gas will limit the useful life of the OSO to about six months.

First Inducer

For the first time a substance that specifically induces the formation of a specialized tissue has been found in developing embryos. Investigators at the University of Pennsylvania and the University of Nijmegen in the Netherlands have isolated from a limited region of the chick embryo spinal cord a material that causes cartilage to form in surrounding tissues. The extract has not yet been fully analyzed, but it contains nucleotide bases (the components of nucleic acids) and amino acids; it may well be a nucleoprotein of low molecular weight.

Over the past several decades embryologists have been looking in vain for just such specific differentiation inducers. Nonspecific "organizers" that trigger some development in very early embryos have been found by the score, but no agent that could be connected with a particular step in embryonic development. Two years ago, however, Howard Holtzer and James W. Lash of the University of Pennsylvania found that the ventral half of the embryonic chick spinal cord produces an agent that stimulates the formation of vertebral cartilage. Lash and a University of Nijmegen group—Frits A. Hommes, F. Zilliken and G. Van Leeuwen—have now extracted the agent in purified form. It induces the formation of cartilage both in whole chick embryos and in tissue culture of somatic cells from the embryos.

Space Tracer

A method of making visible the outer reaches of the earth's magnetic field and the stream of particles from the sun that constitutes the solar wind has been proposed in both England and Germany. The idea is to release an alkaline earth such as barium in gaseous form at high altitude. Alkaline earths readily lose a single electron and, when in the singly ionized state, are strong scatterers of visible light. Thus the movements of a cloud of barium ions should be visible at great distances from the earth.

The magnetic field experiment is the proposal of E. R. Harrison of the Atomic Energy Research Establishment at Harwell in England. Writing in *Nature,* Harrison notes that space probes have yet to determine the shape of the outer regions of the earth's magnetic field, now known to extend to about 10 earth radii, and whether or not the distant portion of the field rotates with the earth. He calculates that as little as 10 kilograms of gaseous barium, released at an altitude of five to 10 earth radii and ionized by solar radiation, would suffice to answer both questions.

The solar wind experiment has been put forward by Ludwig Biermann of the Max Planck Institute for Astrophysics in Munich. In *Zeitschrift für Astrophysik* he suggests releasing just one kilogram of barium gas at a distance of 15 earth radii—beyond the effective range of the geomagnetic field—which would provide enough light-scattering ions to allow direct observation of the solar wind through telescopes.

Isolating a Gene

A chemical method sensitive enough to pick out the material produced by a single gene has been developed by E. K. F. Bautz and Benjamin D. Hall of the University of Illinois. The product they have isolated is a part of "messenger RNA," a form of ribonucleic acid that is believed to convey information from the genetic material, deoxyribonucleic acid (DNA), to sites in the living cell where protein is synthesized in accordance with the genetic code [see "Messenger RNA," by Jerard Hurwitz and J. J. Furth; SCIENTIFIC AMERICAN, February].

The Illinois biochemists, who reported their experiments at a meeting of the Biophysical Society in Washington, D.C., worked on colon bacteria infected with the virus designated T4. The genetic mechanism of these cells is taken over by the viral DNA, and they produce messenger RNA appropriate to viral rather than bacterial protein. Last year Bautz and another colleague, Sol Spiegelman, found that messenger RNA produced by a given type of DNA has a strong tendency to unite with it, forming a hybrid DNA-RNA molecule, provided that the two-stranded DNA mole-

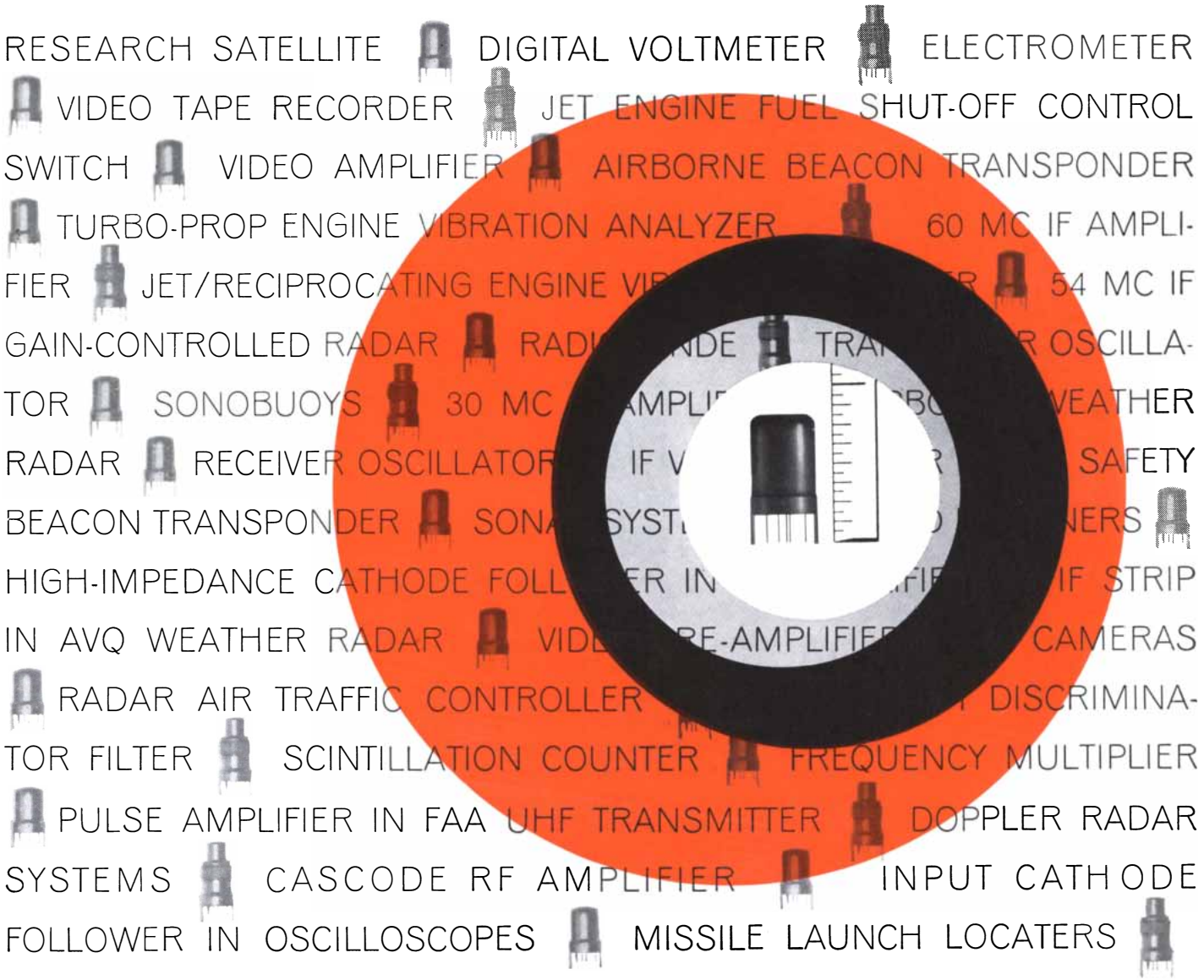
cules are "denatured" into single strands. Bautz and Hall put denatured DNA from the T4 virus into a cellulose-packed column and then poured in a crude mixture of RNA extracted from infected cells. The messenger RNA created by T4 combined with the T4 DNA and remained in the column, whereas all other forms of RNA passed through. The experimenters then gently uncoupled the hybrid and recovered the viral RNA in pure form.

To isolate the fraction formed by a single gene, they used two columns. The first contained denatured DNA from a wild-type (normal) strain of T4, the second contained the DNA from a mutant virus in which a gene known as *r*II is missing. By means of the first column they obtained a pure sample of RNA produced by the wild-type virus. They then poured this material into the second column. The stretch of RNA corresponding to the *r*II gene had no DNA with which to hybridize, so it passed through the column and was recovered. By analyzing this RNA fragment, representing the code transcription of a single gene, it may be possible to establish for the first time the chemical structure of a gene.

Ultrasilent Owls

The deadly quiet of the owl's flight extends into the ultrasonic region, beyond the frequency limits of human hearing. The fact, which is lucky for owls and too bad for field mice, was reported recently in *Nature* by W. H. Thorpe of the University of Cambridge and Donald R. Griffin of Harvard University.

In the course of studying the sound spectrum of bird songs the two ornithologists had been surprised to learn that the wing beats of small birds make a great deal of ultrasonic noise. This made them curious about the owl. If its wings were similarly noisy, the supposed adaptive advantage of its silent flight would disappear, since the small mammals on which it preys can hear ultrasonic tones. Directing their detector on free-flying owls, Thorpe and Griffin found that the birds are ultrasonically quiet. Small and medium-sized owls are completely silent, whereas large species make a little ultrasonic noise in taking off. The wings of all these birds have a downy upper surface and fringes of feathers on the leading and trailing edges, which evidently act as silencers by reducing the turbulence of air flow. The Asiatic fishing owl, which feeds on fish and crustaceans, does not possess these features. A check of the bird's wing beat showed that it is



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Almost daily, it seems, equipment manufacturers come up with new applications for the amazing RCA nuvistor tube. Small wonder! This radically new type of electron tube packs unexcelled performance capabilities into a package of extremely small size and light weight. Witness these nuvistor advantages to designers and manufacturers:

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Nuvistorization has been the answer to many critical circuit design problems; it may well be the answer to yours. For additional information, write to Commercial Engineering, RCA Electron Tube Division, Section D-95-DE, Harrison, N.J.

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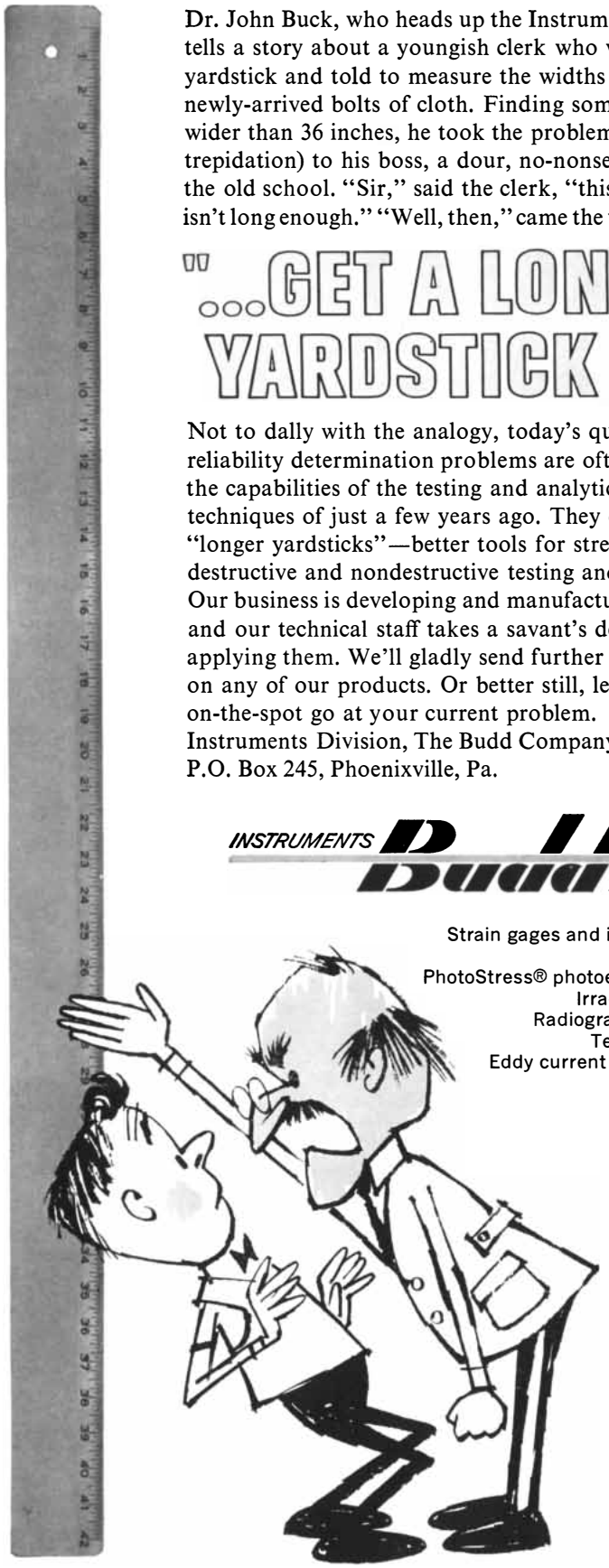

noisy at all frequencies but not noisy enough to scare a fish or a shrimp.

Blocked Viruses

Two ophthalmologists, working independently, have used substances that block the formation of nucleic acid to interfere with the multiplication of a virus and obtain the first cures of a true virus disease. The disease is herpetic kerato-conjunctivitis, an eye inflammation due to the "cold sore" virus *Herpes simplex.* It has resisted other forms of treatment and has caused many cases of blindness by scarring the cornea.

In a series of 46 patients Herbert E. Kaufman of the Massachusetts Eye and Ear Infirmary found that hourly treatment with drops containing 5-iodo-2′-deoxyuridine halted mild herpetic eye infections in an average of three days, and more severe infections in four days. Depending on the severity of the attack, scarring of the cornea was minimized or prevented altogether. Favorable results have been obtained in a smaller number of patients by Sidney Lerman of the University of Rochester School of Medicine and Dentistry with a related substance: 5-fluoro-2′-deoxyuridine. Lerman has also demonstrated interference with virus multiplication by fluoro-deoxyuridine in chick-tissue cultures of the virus.

Both substances are analogues of one of the constituents of deoxyribonucleic acid (DNA), the genetic material of the virus. Presumably they work by entering into the cellular metabolic machinery that the virus has taken over for the synthesis of its DNA; at some later stage they block the synthesis. They are effective in controlling infection of the cornea by *Herpes simplex,* both investigators agree, only because such an infection is superficial; the virus is therefore unusually accessible to them.

Pots across the Sea

Archaeologists working in Ecuador have dug up samples of pottery suggesting that men from Asia crossed the Pacific to South America 4,500 years ago. At the lowest level of the so-called Valdivia site on the Ecuadorean coast they have found vessels dating back to the third millennium B.C. and resembling, in shape and in many decorative details, pottery of the same period from Japan and East Asia. The archaeologists—Emilio Estrada of the Museo Víctor Emilio Estrada in Ecuador and Betty J. Meggers and Clifford Evans of the Smithsonian Institution—consider it un-

SIGNIFICANT FIGURES: remember the big difference between 0.001 and 0.0010? As a production tolerance, it can be the difference between achieving a research dream and failure. Luckily, there's a skilled watchdog over these significant affairs: the quality control engineer. □ A passion for quality is one of General Cable's secrets, too. Tough-minded quality control teams make sure our products are uniform, and meet or exceed every requirement. Research, production, quality control—a balanced group producing the finest wires and cables for any application—that's General Cable Corporation, 730 Third Avenue, N.Y. 17.

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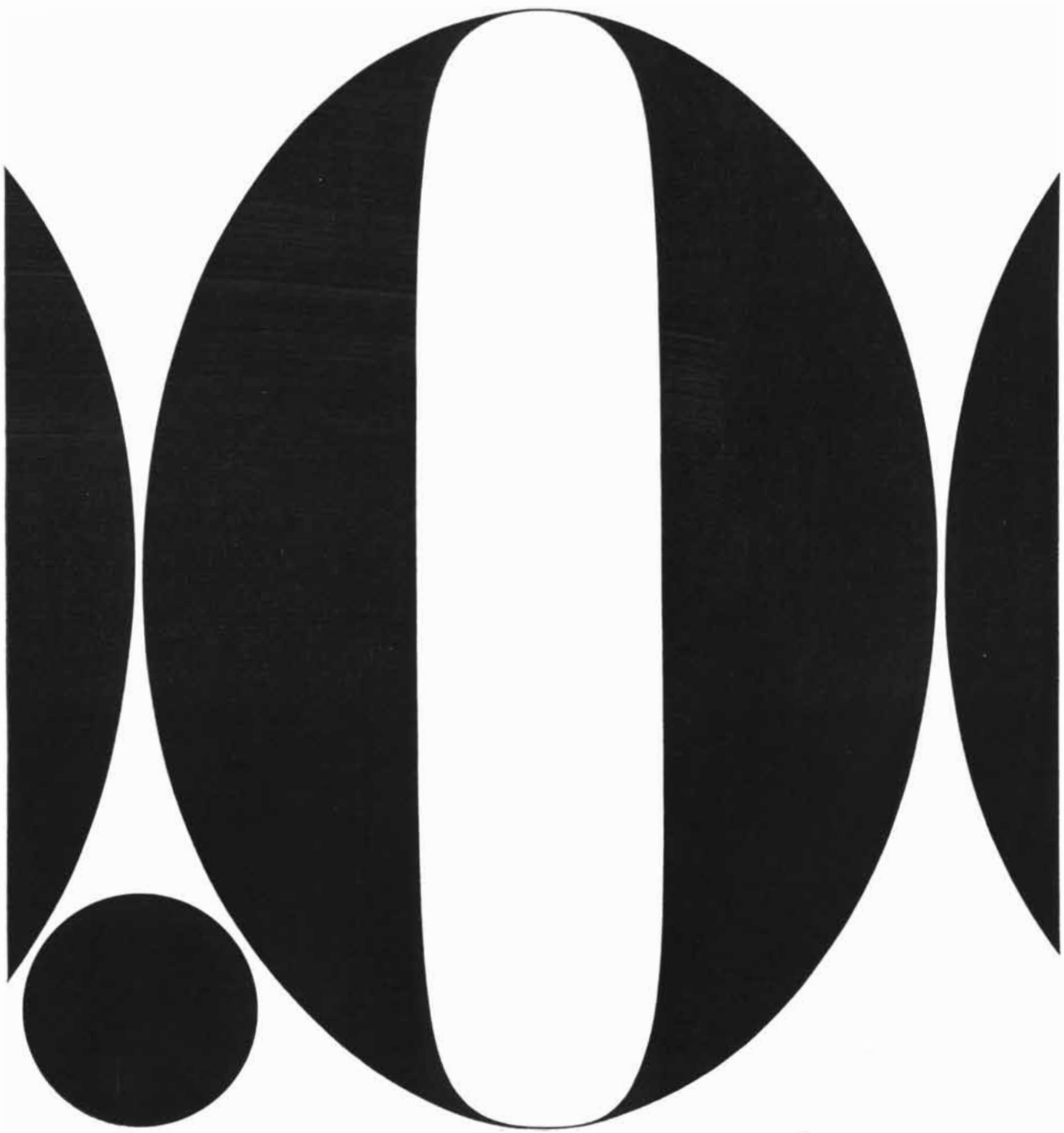


likely that the style could have had an independent local origin because of the high technical level of the pieces they have found and the absence of more primitive forms either at Valdivia or other South American sites.

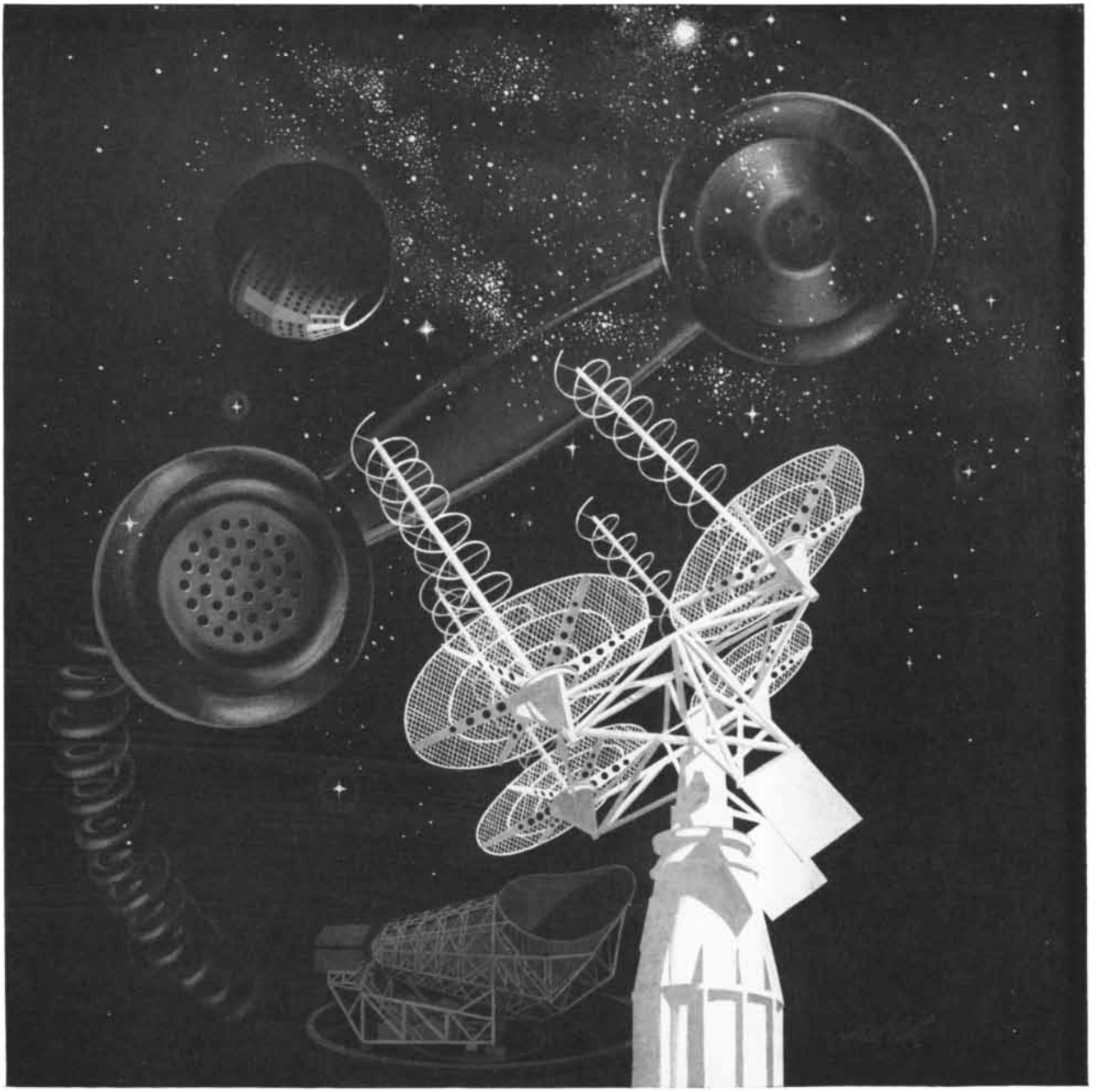
Transpacific contact has been suggested in the past as an explanation for several features of American Indian culture, particularly in Central America and along the west coast of South America. On the other hand, most authorities have doubted the ability of primitive man to cross the Pacific Ocean. Writing in *Science*, Estrada and his colleagues point out that the coast of Ecuador is washed by currents that could, during appropriate seasons of the year, bring a raft from across the Pacific.

Immunity and the Thymus

The long-standing mystery of the physiological role of the thymus gland may have been solved. At a meeting of the New York Academy of Sciences, Jacques F. A. P. Miller of the Chester Beatty Research Institute in London presented evidence that the gland is the source of the body's first antibody-producing cells. Once they have been produced the cells evidently migrate to the lymph nodes and other sites where they multiply and produce antibodies as needed. Meanwhile the thymus gland itself, its initiating function completed, gradually diminishes in size and finally all but disappears.

Miller carried out his study on mice, removing the thymus glands from one group of animals on the day they were born and from other groups at one or more weeks after birth. The mice in the first group stayed apparently healthy for three or four months, but then about 70 per cent of them rapidly wasted away and died. This seldom happened to mice that kept their glands for one to three weeks, and never to those operated on after the third week.

Investigation disclosed a severe immunological deficit in the animals operated on at birth. The number of antibody-forming white cells in their blood was greatly reduced; their spleen weighed less than half of normal; their lymph nodes were minute and poorly developed. These animals readily accepted skin grafts, not only from other strains of mice but also from albino rats. The immune response could be restored by grafts of thymus gland from other mice. When the glands came from foreign strains, the mice became tolerant to grafts of other tissue from the donors.



AT RADIATION, CHALLENGE IS OPPORTUNITY

Example: Bell System's TELSTAR

Bell Telephone Laboratories is now taking an important step toward commercial utilization of space. Bell's experimental Project Telstar satellite and its ground stations point the way toward a new kind of communications network—one that ultimately can link all the telephones on one continent with those on every other.

Radiation Incorporated was chosen by Bell Laboratories to play a vital role in this venture. The challenge of an environment where service is not yet possible called for a satellite PCM telemetry system of extremely long life and highest possible reliability. Radiation engineers met the challenge, and designed the system to Bell's rigid specifications.

In addition, Radiation produced an antenna which will help pinpoint the satellite during its brief passes, and will enable a precision tracker to acquire the satellite and bring a 340-ton horn-reflector onto the tiny target.

Radiation scientists and engineers are also at work on many other challenging projects. More able people like them are needed. If your imagination and resourcefulness match high technical proficiency, here is full range for your talents. Send your resume or write for additional information to Personnel Director, Dept. SA-42, Radiation Incorporated, Melbourne, Florida. *Radiation is an equal opportunity employer.*

RADIATION
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PARADOX

Some self-contradictory statements are amusing; others are profoundly puzzling. A few paradoxes have called for major reconstructions of the foundations of logic and mathematics

by W. V. Quine

Frederic, the young protagonist of *The Pirates of Penzance*, has reached the age of 21 after passing only five birthdays. Several circumstances conspire to make this possible. Age is reckoned in elapsed time, whereas a birthday has to match the date of birth; and February 29 comes less frequently than once a year.

Granted that Frederic's situation is possible, wherein is it paradoxical? Merely in its initial air of absurdity. The likelihood that a man will be more than n years old on his nth birthday is as little as one to 1,460, or slightly better if we allow for seasonal trends; and this likelihood is so slight that we easily forget its existence.

May we say in general, then, that a paradox is just any conclusion that at first sounds absurd but that has an argument to sustain it? In the end I think this account stands up pretty well. But it leaves much unsaid. The argument that sustains a paradox may expose the absurdity of a buried premise or of some preconception previously reckoned as central to physical theory, to mathematics or to the thinking process. Catastrophe may lurk, therefore, in the most innocent-seeming paradox. More than once in history the discovery of paradox has been the occasion for major reconstruction at the foundations of thought. For some decades, indeed, studies of the foundation of mathematics have been confounded and greatly stimulated by confrontation with two paradoxes, one propounded by Bertrand Russell in 1901 and the other by Kurt Gödel in 1931.

As a first step onto this dangerous ground, let us consider another paradox: that of the village barber. This is not Russell's great paradox of 1901, to which we shall come, but a lesser one that Russell attributed to an unnamed source in 1918. In a certain village there is a man, so the paradox runs, who is a barber; this barber shaves all and only those men in the village who do not shave themselves. Query: Does the barber shave himself?

Any man in this village is shaved by the barber if and only if he is not shaved by himself. Therefore in particular the barber shaves himself if and only if he does not. We are in trouble if we say the barber shaves himself and we are in trouble if we say he does not.

Now compare the two paradoxes. Frederic's situation seemed absurd at first, but a simple argument sufficed to make us acquiesce in it for good. In the case of the barber, on the other hand, the conclusion is too absurd to acquiesce in at any time.

What are we to say to the argument that goes to prove this unacceptable conclusion? Happily it rests on assumptions. We are asked to swallow a story about a village and a man in it who shaves all and only those men in the village who do not shave themselves. This is the source of our trouble; grant this and we end up saying, absurdly, that the barber shaves himself if and only if he does not. The proper conclusion to draw is just that there is no such barber. We are confronted with nothing more mysterious than what logicians have been referring to for a couple of thousand years as a *reductio ad absurdum*. We disprove the barber by assuming him and deducing the absurdity that he shaves himself if and only if he does not. The paradox is simply a proof that no village can contain a man who shaves all and only those men in it who do not shave themselves. This sweeping denial at first sounds absurd; why should there not be such a man in a village? But the argument shows why not, and so we acquiesce in the sweeping denial just as we acquiesced in the possibility, absurd on first exposure, of Frederic's being so much more than five years old on his fifth birthday.

Both paradoxes are alike, after all, in sustaining prima facie absurdities by conclusive argument. What is strange but true in the one paradox is that one can be $4n$ years old on one's nth birthday; what is strange but true in the other paradox is that no village can contain a man who shaves all and only those men in the village who do not shave themselves.

Still, I would not limit the word "paradox" to cases where what is purportedly established is true. I shall call these, more particularly, veridical, or truth-telling, paradoxes. For the name of paradox is suited equally to falsidical ones. (This word is not so barbarous as it sounds; *falsidicus* occurs twice in Plautus and twice in earlier writers.)

The Frederic paradox is a veridical one if we take its proposition not as something about Frederic but as the abstract truth that a man can be $4n$ years old on his nth birthday. Similarly, the barber paradox is a veridical one if we take its proposition as being that no village contains such a barber. A falsidical paradox, on the other hand, is one whose proposition not only seems at first absurd but also is false, there being a fallacy in the purported proof. Typical falsidical paradoxes are the comic misproofs that $2=1$. Most of us have heard one or another such. Here is the version offered by the 19th-century English mathematician Augustus De Morgan: Let $x=1$. Then $x^2=x$. So $x^2-1=x-1$. Dividing both sides by $x-1$, we conclude that $x+1=1$; that is, since $x=1$, $2=1$. The fallacy comes in the division by $x-1$, which is 0.

Instead of "falsidical paradox" could I say simply "fallacy"? Not quite. Fallacies can lead to true conclusions as well as false ones, and to unsurprising conclusions as well as surprising ones. In a falsidical paradox there is always a fallacy in the argument, but the proposition purportedly established has furthermore to seem absurd and to be indeed false.

Some of the ancient paradoxes of Zeno belong under the head of falsidical paradoxes. Take the one about Achilles and the tortoise. Generalized beyond these two fictitious characters, what the paradox purports to establish is the absurd proposition that so long as a runner keeps running, however slowly, another runner can never overtake him. The argument is that each time the pursuer reaches a spot where the pursued has been, the pursued has moved a bit beyond. When we try to make this argument more explicit, the fallacy that emerges is the mistaken notion that any infinite succession of intervals of time has to add up to all eternity. Actually when an infinite succession of intervals of time is so chosen that the succeeding intervals become shorter and shorter, the whole succession may take either a finite or an infinite time. It is a question of a convergent series.

Grelling's Paradox

The realm of paradox is not clearly exhausted even by the veridical and falsidical paradoxes together. The most startling of all paradoxes are not clearly assignable to either of these domains. Consider the paradox, devised by the German mathematician Kurt Grelling in 1908, concerning the heterological, or nonself-descriptive, adjectives.

To explain this paradox requires first a definition of the autological, or self-descriptive, adjective. The adjective "short" is short; the adjective "English" is English; the adjective "adjectival" is adjectival; the adjective "polysyllabic" is polysyllabic. Each of these adjectives is, in Grelling's terminology, autological: each is true of itself. Other adjectives are heterological; thus "long," which is not a long adjective; "German," which is not a German adjective; "monosyllabic," which is not a monosyllabic one.

Grelling's paradox arises from the query: Is the adjective "heterological" an autological or a heterological one? We are as badly off here as we were with the barber. If we decide that "heterological" is autological, then the adjective is true of itself. But that makes it heterological rather than autological, since whatever the adjective "heterological" is true of is heterological. If we therefore decide that the adjective "heterological" is heterological, then it is true of itself, and that makes it autological.

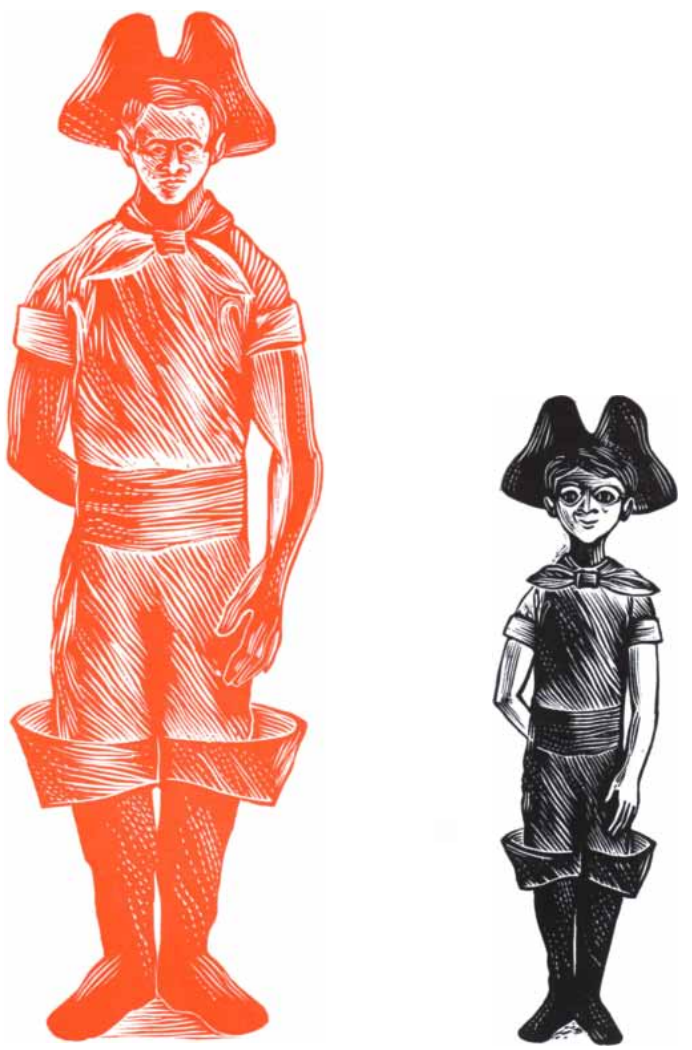
Our recourse in a comparable quandary over the village barber was to declare a *reductio ad absurdum* and conclude that there was no such barber. Here, however, there is no interim premise to disavow. We merely defined the adjective "heterological" and asked if it was heterological. In fact, we can get the paradox just as well without the adjective and its definition. "Heterological" was defined as meaning "not true of self"; we can therefore ask if the adjectival phrase "not true of self" is true of itself. We find that it is if and only if it is not, hence that it is and it is not; and so we have our paradox.

Thus viewed, Grelling's paradox seems unequivocally falsidical. Its proposition is a self-contradictory compound proposition to the effect that our adjective is and is not true of itself. But this paradox contrasts strangely with the falsidical paradoxes of Zeno, or of $2=1$, in that we are at a loss to spot the fallacy in the argument. It may for this reason be best seen as representing a third class of paradoxes, separate from the veridical and falsidical ones.

Antinomies

The paradoxes of this class are called antinomies, and it is they that bring on the crises in thought. An antinomy produces a self-contradiction by accepted ways of reasoning. It establishes that some tacit and trusted pattern of reasoning must be made explicit and henceforward be avoided or revised.

Take Grelling's paradox, in the form in which it shows the adjective phrase



"MOST INGENIOUS PARADOX" of *The Pirates of Penzance* involves Frederic, who was born on a February 29. He is 21, but going by birthdays "only five and a little bit over."

"not true of self" to be both true and false of itself. What tacit principles of reasoning does the argument depend on? Notably this one: the adjective "red" is true of a thing if and only if the thing is red; the adjective "big" is true of a thing if and only if the thing is big; the adjective "not true of self" is true of a thing if and only if the thing is not true of itself; and so on. This last case of the principle is the case that issues directly in the paradox.

There is no denying that this principle is constantly used, tacitly, when we speak of adjectives as true of things: the adjective "red" is true of a thing if and only if the thing is red, and correspondingly for all adjectives. This principle simply reflects what we mean in saying that adjectives are true of things. It is a hard principle to distrust, and yet it is obviously the principle that is to blame for our antinomy. The antinomy is directly a case of this principle. Take the adjective in the principle as the adjectival phrase "not true of self" instead of the adjective "red," and take the "thing" in the principle, of which the adjective is to be true, as that adjective over again; thereupon the principle says outright that "not true of self" is true of itself if and only if it is not true of itself. So the principle must be abandoned or at least somehow restricted.

Yet so faithfully does the principle reflect what we mean in calling adjectives true of things that we cannot abandon it without abjuring the very expression "true of" as pernicious nonsense. We could still go on using the adjectives themselves that had been said to be true of things; we could go on attributing them to things as usual; what we would be cutting out in "true of" is merely a special locution for talking about the attribution of the adjectives to the things.

This special locution, however, has its conveniences, and it would be missed. In fact, we do not have to do without it altogether. After all, to speak of adjectives as true or not true of things makes trouble only in a special case, involving one special adjective, namely the phrase "not true of self," in attribution to one special thing, namely that same phrase over again. If we forswear the use of the locution "true of" in connection with this particular phrase in relation to itself as object, we thereby silence our antinomy and may go on blithely using the locution "true of" in other cases as always, pending the discovery of further antinomies.

Actually related antinomies are still forthcoming. To inactivate the lot we have to cut a little deeper than our one case; we have to forswear the use of "true of" not only in connection with "not true of self" but also in connection with various other phrases relating to truth; and in such connections we have to forswear the use not only of "true of" but also of various other truth locutions. First let us look at some of the antinomies that would otherwise threaten.

The Paradox of Epimenides

There is the ancient paradox of Epimenides the Cretan, who said that all Cretans were liars. If he spoke the truth, he was a liar. It seems that this paradox may have reached the ears of St. Paul and that he missed the point of it. He warned, in his epistle to Titus: "One of themselves, even a prophet of their own, said, The Cretans are always liars."

Actually the paradox of Epimenides is untidy; there are loopholes. Perhaps some Cretans were liars, notably Epimenides, and others were not; perhaps Epimenides was a liar who occasionally told the truth; either way it turns out that the contradiction vanishes. Something of paradox can be salvaged with a little tinkering; but we do better to switch to a different and simpler rendering, also ancient, of the same idea. This is the *pseudomenon*, which runs simply: "I am lying." We can even drop the indirectness of a personal reference and speak directly of the sentence: "This sentence

BARBER PARADOX assumes that in a certain village there is a barber who shaves all and only those men who do not shave themselves. The question is whether this barber shaves himself. The paradox is that he does shave himself only if he does not.

is false." Here we seem to have the irreducible essence of antinomy: a sentence that is true if and only if it is false.

In an effort to clear up this antinomy it has been protested that the phrase "This sentence," so used, refers to nothing. This is claimed on the ground that you cannot get rid of the phrase by supplying a sentence that is referred to. For what sentence does the phrase refer to? The sentence "This sentence is false." If, accordingly, we supplant the phrase "This sentence" by a quotation of the sentence referred to, we get: " 'This sentence is false' is false." But the whole outside sentence here attributes falsity no longer to itself but merely to something other than itself, thereby engendering no paradox.

If, however, in our perversity we are still bent on constructing a sentence that does attribute falsity unequivocally to itself, we can do so thus: " 'Yields a falsehood when appended to its own quotation' yields a falsehood when appended to its own quotation." This sentence specifies a string of nine words and says of this string that if you put it down twice, with quotation marks around the first of the two occurrences, the result is false. But that result is the very sentence that is doing the telling. The sentence is true if and only if it is false, and we have our antinomy.

This is a genuine antinomy, on a par with the one about "heterological," or "false of self," or "not true of self," being true of itself. But whereas that earlier one turned on "true of," through the construct "not true of self," this new one turns merely on "true," through the construct "falsehood," or "statement not true." We can avoid both antinomies, and others related to them, by ceasing to use "true of" and "true" and their equivalents and derivatives, or at any rate ceasing to apply such truth locutions to adjectives or sentences that themselves contain such truth locutions.

This restriction can be relaxed somewhat by admitting a hierarchy of truth locutions, as suggested by the work of Bertrand Russell and the Polish mathematician Alfred Tarski, who is now at the University of California. The expressions "true," "true of," "false" and related ones can be used with numerical subscripts "0," "1," "2," and so on always attached or imagined; thus "true_0," "true_1," "true_2," "false_0" and so on. Then we can avoid the antinomies by taking care, when a truth locution (T) is applied to a sentence or other expression (S), that the subscript on T is higher than any subscript inside S. Violations of this restriction would be treated as

meaningless, or ungrammatical, rather than as true or false sentences. For instance, we could meaningfully ask whether the adjectives "long" and "short" are true_0 of themselves; the answers are respectively no and yes. But we could not meaningfully speak of the phrase "not true_0 of self" as true_0 or false_0 of itself; we would have to ask whether it is true_1 or false_1 of itself, and this is a question that leads to no antinomy. Either way the question can be answered with a simple and unpenalized negative.

This point deserves to be restated: Whereas "long" and "short" are adjectives that can meaningfully be applied to themselves, falsely in the one case and truly in the other, on the other hand "true_0 of self" and "not true_0 of self" are adjectival phrases that cannot be applied to themselves meaningfully at all, truly or falsely. Therefore to the question "Is 'true_0 of self' true_1 of itself?" the answer is no; the adjectival phrase "true_0 of itself" is meaningless of itself rather than true_1 of itself.

Next let us consider, in terms of subscripts, the most perverse version of the *pseudomenon*. We have now, for meaningfulness, to insert subscripts on the two occurrences of the word "falsehood," and in ascending order, thus: " 'Yields a falsehood_0 when appended to its own quotation' yields a falsehood_1 when appended to its own quotation." Thereupon paradox vanishes. This sentence is unequivocally false. What it tells us is that a certain described form of words is false_1, namely the form of words: " 'Yields a falsehood_0 when appended to its own quotation' yields a falsehood_0 when appended to its own quotation." But in fact this form of words is not false_1; it is meaningless. So the preceding sentence, which said that this form of words was false_1, is false. It is false_2.

This may seem an extravagant way of eliminating antinomies. But it would be much more costly to drop the word "true," and related locutions, once and for all. At an intermediate cost one could merely leave off applying such locutions to expressions containing such locutions. Either method is less economical than this method of subscripts. The subscripts do enable us to apply truth locutions to expressions containing such locutions, although in a manner disconcertingly at variance with custom. Each resort is desperate; each is an artificial departure from natural and established usage. Such is the way of antinomies.

A veridical paradox packs a surprise, but the surprise quickly dissipates itself as we ponder the proof. A falsidical paradox packs a surprise, but it is seen as a false alarm when we solve the underlying fallacy. An antinomy, however, packs a surprise that can be accommodated by nothing less than a repudiation of part of our conceptual heritage.

Revision of a conceptual scheme is not unprecedented. It happens in a small way with each advance in science, and it

EPIMENIDES THE CRETAN made the statement that all Cretans were liars. Such a statement can be simplified to "I am lying" or "This sentence is false." One can seemingly prove of such paradoxes, called antinomies, that they are true if and only if they are false.

happens in a big way with the big advances, such as the Copernican revolution and the shift from Newtonian mechanics to Einstein's theory of relativity. We can hope in time even to get used to the biggest such changes and to find the new schemes natural. There was a time when the doctrine that the earth revolves around the sun was called the Copernican paradox, even by the men who accepted it. And perhaps a time will come when truth locutions without implicit subscripts, or like safeguards, will really sound as nonsensical as the antinomies show them to be.

Conversely, the falsidical paradoxes of Zeno must have been, in his day, genuine antinomies. We in our latter-day smugness point to a fallacy: the notion that an infinite succession of intervals must add up to an infinite interval. But surely this was part and parcel of the conceptual scheme of Zeno's day. Our recognition of convergent series, in which an infinite number of segments add up to a finite segment, is from Zeno's vantage point an artificiality comparable to our new subscripts on truth locutions. Perhaps these subscripts will seem as natural to our descendants of A.D. 4000, granted the tenuous hypothesis of there being any, as the convergent series does to us. One man's antinomy is another man's falsidical paradox, give or take a couple of thousand years.

I have not, by the way, exhausted the store of latter-day antinomies. Another good one is attributed by Russell to a librarian named Berry. Here the theme is numbers and syllables. Ten has a one-syllable name. Seventy-seven has a five-syllable name. The seventh power of seven hundred seventy-seven has a name that, if we were to work it out, might run to 100 syllables or so; but this number can also be specified more briefly in other terms. I have just specified it in 15 syllables. We can be sure, however, that there are no end of numbers that resist all specification, by name or description, under 19 syllables. There is only a finite stock of syllables altogether, and hence only a finite number of names or phrases of less than 19 syllables, whereas there are an infinite number of positive integers. Very well, then; of those numbers not specifiable in less than 19 syllables, there must be a least. And here is our antinomy: the least number not specifiable in less than nineteen syllables is specifiable in 18 syllables. I have just so specified it.

This antinomy belongs to the same family as the antinomies that have gone before. For the key word of this antinomy, "specifiable," is interdefinable with

ZENO'S PARADOX of Achilles and the tortoise proposes an absurdity: that so long as the tortoise continues to move, however slowly, the fleet Achilles can never overtake him. The paradox is called falsidical, there being a fallacy in its purported proof.

"true of." It is one more of the truth locutions that would take on subscripts under the Russell-Tarski plan. The least number not specifiable$_0$ in less than nineteen syllables is indeed specifiable$_1$ in 18 syllables, but it is not specifiable$_0$ in less than 19 syllables; for all I know it is not specifiable$_0$ in less than 23. This resolution of Berry's antinomy is the one that would come through automatically if we paraphrase "specifiable" in terms of "true of" and then subject "true of" to the subscript treatment.

Russell's Antinomy

Not all antinomies belong to this family. The most celebrated of all antinomies, discovered by Russell in 1901, belongs outside this family. It has to do with self-membership of classes. Some classes are members of themselves; some are not. For example, the class of all classes that have more than five members clearly has more than five classes as members; therefore the class is a member of itself. On the other hand, the class of all men is not a member of itself, not being a man. What of the class of all classes that are not members of themselves? Since its members are the nonself-members, it qualifies as a member of itself if and only if it is not. It is and it is not: antinomy's by now familiar face.

Russell's antinomy bears a conspicuous analogy to Grelling's antinomy of "not true of self," which it long antedates. But Russell's antinomy does not belong to the same family as the Epimenides antinomy and those of Berry and Grelling. By this I mean that Russell's antinomy cannot be blamed on any of the truth locutions, nor is it resolved by subjecting those locutions to subscripts. The crucial words in Russell's antinomy are "class" and "member," and neither of these is definable in terms of "true," "true of" or the like.

I said earlier that an antinomy establishes that some tacit and trusted pattern of reasoning must be made explicit and be henceforward avoided or revised. In the case of Russell's antinomy, the tacit and trusted pattern of reasoning that is found wanting is this: for any condition you can formulate, there is a class whose members are the things meeting the condition.

This principle is not easily given up. The almost invariable way of specifying a class is by stating a necessary and sufficient condition for belonging to it. When we have stated such a condition, we feel that we have "given" the class and can scarcely make sense of there not being such a class. The class may be empty, yes; but how could there not be such a class at all? What substance can be asked for it that the membership condition does not provide? Yet such exhortations avail us nothing in the face of the antinomy, which simply proves the principle untenable. It is a simple point of logic, once we look at it, that there is no class, empty or otherwise, that has as members precisely the classes that are not members of themselves. It would have to have itself as member if and only if it did not.

Russell's antinomy came as a shock to Gottlob Frege, the German mathematician who founded mathematical logic. In his *Grundgesetze der Arithmetik* Frege thought that he had secured the foundations of mathematics in the self-consistent laws of logic. He received a letter from Russell as the second volume of this work was on its way to press. "Arithmetic totters," Frege is said to have written in answer. An appendix that he added to the volume opens with the words: "A scientist can hardly encounter anything more undesirable than to have the foundation collapse just as the work is finished. I was put in this position by a letter from Bertrand Russell . . ."

In Russell's antinomy there is more than a hint of the paradox of the barber. The parallel is, in truth, exact. It was a simple point of logic that there was in no village a man who shaved all and only those men in the village who did not shave themselves; he would shave himself if and only if he did not. The barber paradox was a veridical paradox showing that there is no such barber. Why is Russell's antinomy then not a veridical paradox showing that there is

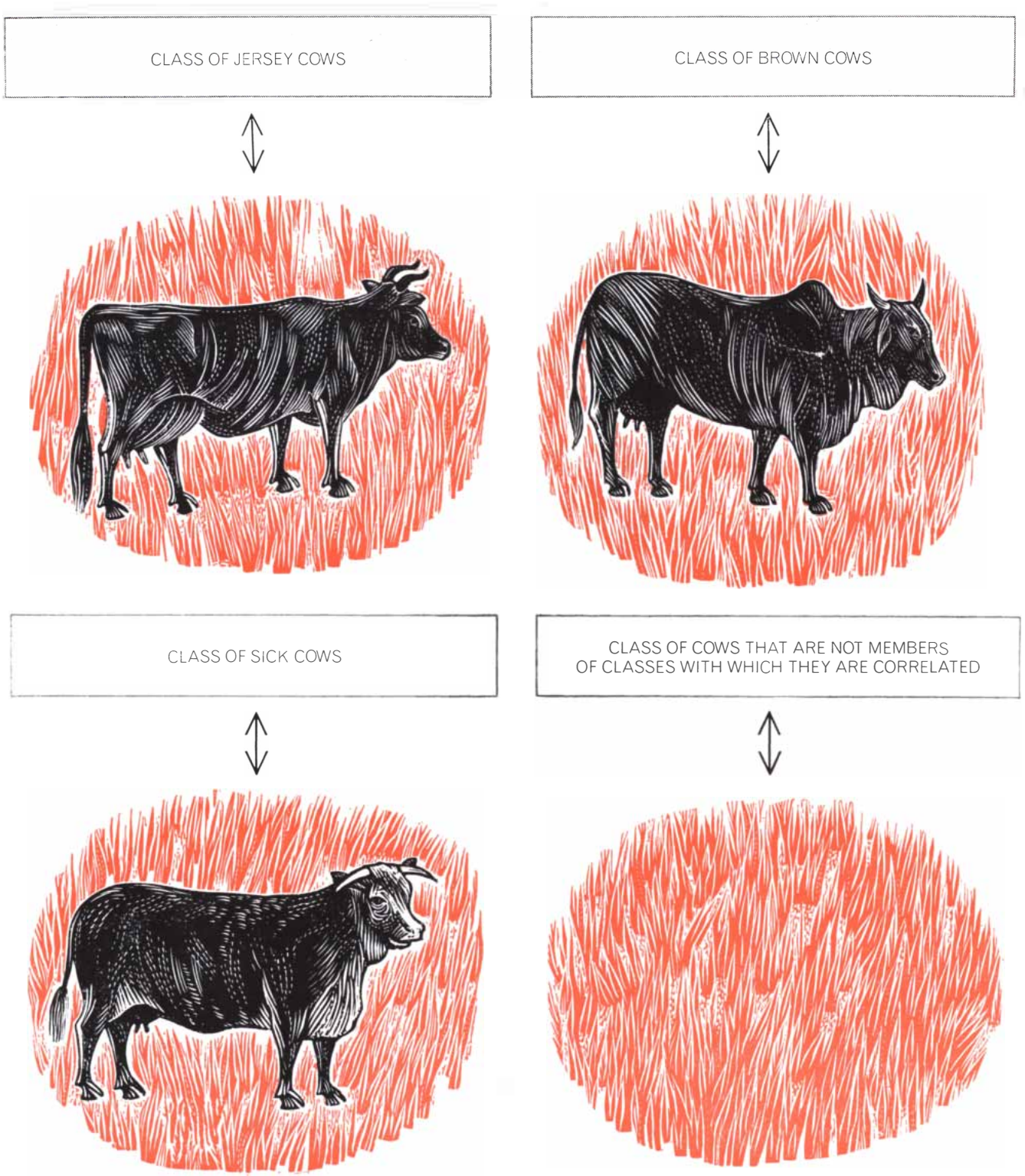
no class whose members are all and only the nonself-members? Why does it count as an antinomy and the barber paradox not? The reason is that there has been in our habits of thought an overwhelming presumption of there being such a class but no presumption of there being such a barber. The barber paradox barely qualifies as paradox in that we are mildly surprised at being able to exclude the barber on purely logical grounds by reducing him to absurdity. Even this surprise ebbs as we review the argument; and anyway we had never positively believed in such a barber. Russell's paradox is a genuine antinomy because of the fundamental nature of the principle of class existence that it compels us to give up. When in a future century the absurdity of that principle has become a commonplace, and some substitute principle has enjoyed long enough tenure to take on somewhat the air of common sense, perhaps we can begin to see Russell's paradox as no more than a veridical paradox, showing that there is no such class as that of the nonself-members. One man's antinomy can be another man's veridical paradox, and one man's veridical paradox can be another man's platitude.

Russell's antinomy made for a more serious crisis still than did Grelling's and Berry's and the one about Epimenides. For these strike at the semantics of truth and denotation, but Russell's strikes at the mathematics of classes. Classes are appealed to in an auxiliary way in most branches of mathematics, and increasingly so as passages of mathematical reasoning are made more explicit. The basic principle of classes that is tacitly used, at virtually every turn where classes are involved at all, is precisely the class-existence principle that is discredited by Russell's antinomy.

I spoke of Grelling's antinomy and Berry's and the Epimenides as all in a family, to which Russell's antinomy does not belong. For its part, Russell's antinomy has family connections of its own. In fact, it is the first of an infinite series of antinomies, as follows. Russell's antinomy shows that there is no class whose members are precisely the classes that are not members of themselves. Now there is a parallel antinomy that shows there is no class whose members are precisely the classes that are not members of members of themselves. Further, there is an antinomy that shows there is no class whose members are precisely the classes that are not members of members of members of themselves. And so on ad infinitum.

All these antinomies, and other related

ones, can be inactivated by limiting the guilty principle of class existence in a very simple way. The principle is that for any membership condition you can formulate there is a class whose members are solely the things meeting the condition. We get Russell's antinomy and all the others of its series by taking the condition as nonmembership in self, or nonmembership in members of self, or the like. Each time the trouble comes of taking a membership condition that itself talks in turn of membership and nonmembership. If we withhold our principle of class existence from cases where the membership condition mentions membership, Russell's antinomy and related ones are no longer forthcoming. This restriction on class existence is parallel to a restriction on the truth locutions that we contemplated for a while,



CANTOR'S PROOF is important in set theory. He showed that there are always more classes of things of a kind than there are things of that kind. Take cows, for example, and classes of cows (*indicated here by rectangles*). If every cow is arbitrarily correlated with a class (of which it may or may not be a member), there will remain a class that is not correlated with any cow.

before bringing in the subscripts; namely, not to apply the truth locutions to expressions containing any of the truth locutions.

Happily we can indeed withhold the principle of class existence from cases where the membership condition mentions membership, without unsettling those branches of mathematics that make only incidental use of classes. This is why it has been possible for most branches of mathematics to go on blithely using classes as auxiliary apparatus in spite of Russell's and related antinomies.

The Mathematics of Classes

There is a particular branch of mathematics in which the central concern is with classes: general set theory. In this domain one deals expressly with classes of classes, classes of classes of classes, and so on, in ways that would be paralyzed by the restriction just now contemplated: withholding the principle of class existence from cases where the membership condition mentions membership. So one tries in general set theory to manage with milder restrictions.

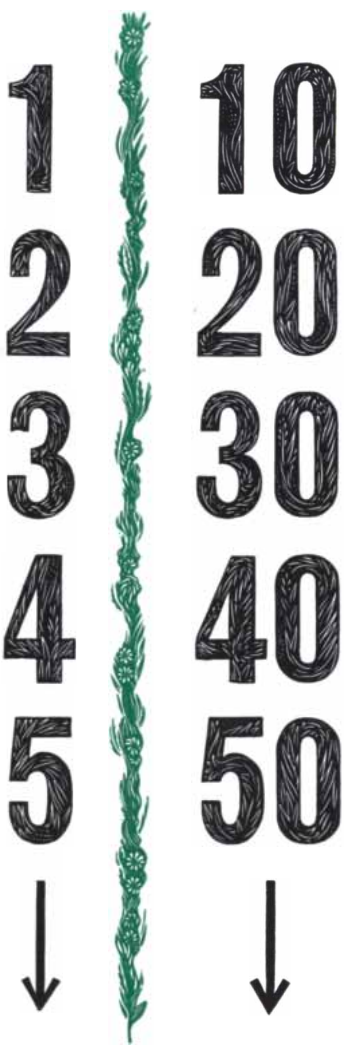
General set theory is rich in paradox. Even the endless series of antinomies that I mentioned above, of which Russell's was the first, by no means exhausts this vein of paradox. General set theory is primarily occupied with infinity—infinite classes, infinite numbers—and so is involved in paradoxes of the infinite. A rather tame old paradox under this head is that you can exhaust the members of a whole class by correlating them with the members of a mere part of the class. For instance, you can correlate all the positive integers with the multiples of 10, thus: 1 with 10, 2 with 20, 3 with 30 and so on. Every positive integer gets disposed of; there are as many multiples of 10 as integers altogether. This is no antinomy but a veridical paradox. Among adepts in the field it even loses the air of paradox altogether, as is indeed the way of veridical paradox.

Georg Cantor, the 19th-century pioneer in general set theory and infinite arithmetic, proved that there are always more classes of things of a given kind than there are things of that kind; more classes of cows than cows. A distinct air of paradox suffuses his proof of this.

First note the definition of "more." What it means when one says there are more things of one kind than another is that every correlation of things of the one kind to things of the other fails to exhaust the things of the one kind. So what Cantor is proving is that no correlation of cow classes to cows accommodates all

the cow classes. The proof is as follows. Suppose a correlation of cow classes to cows. It can be any arbitrary correlation; a cow may or may not belong to the class correlated with it. Now consider the cows, if any, that do not belong to the classes correlated with them. These cows themselves form a cow class, empty or not. And it is a cow class that is not correlated with any cow. If the class were so correlated, that cow would have to belong to the class if and only if it did not.

This argument is typical of the arguments in general set theory that would be sacrificed if we were to withhold the principle of class existence from cases where the membership condition mentions membership. The recalcitrant cow class that clinched the proof was specified by a membership condition that mentioned membership. The condition was nonmembership in the correlated cow class.



POSITIVE INTEGERS can all be correlated with multiples of 10 even though the latter are only part of the class of integers.

But what I am more concerned to bring out, regarding the cow-class argument, is its air of paradox. The argument makes its negative point in much the same way that the veridical barber paradox showed there to be no such barber, and in much the same way that Russell's antinomy showed there to be no class of nonself-members. So in Cantor's theorem —a theorem not only about cows and their classes but also about things of any sort and their classes—we see paradox, or something like it, seriously at work in the advancement of theory. His theorem establishes that for every class, even every infinite class, there is a larger class: the class of its subclasses.

So far, no antinomy. But now it is a short step to one. If for every class there is a larger class, what of the class of everything? Such is Cantor's antinomy. If you review the proof of Cantor's theorem in application directly to this disastrous example—speaking therefore not of cows but of everything—you will quickly see that Cantor's antinomy boils down, after all, to Russell's.

So the central problem in laying the foundations of general set theory is to inactivate Russell's antinomy and its suite. If such theorems as Cantor's are to be kept, the antinomies must be inactivated by milder restrictions than the total withholding of the principle of class existence from cases where the membership condition mentions membership. One tempting line is a scheme of subscripts analogous to the scheme used in avoiding the antinomies of truth and denotation. Something like this line was taken by Russell himself in 1908, under the name of the theory of logical types. A very different line was proposed in the same year by the German mathematician Ernst Zermelo, and further variations have been advanced in subsequent years.

All such foundations for general set theory have as their point of departure the counsel of the antinomies; namely, that a given condition, advanced as a necessary and sufficient condition of membership in some class, may or may not really have a class corresponding to it. So the various alternative foundations for general set theory differ from one another with respect to the membership conditions to which they do and do not guarantee corresponding classes. Nonself-membership is of course a condition to which none of the theories accord corresponding classes. The same holds true for the condition of not being a member of any own member; and for the conditions that give all the further antinomies of the series that began with Russell's; and for any membership condition that would give rise to any other antinomy, if we can spot it.

But we cannot simply withhold each antinomy-producing membership condition and assume classes corresponding to the rest. The trouble is that there are membership conditions corresponding to each of which, by itself, we can innocuously assume a class, and yet these classes together can yield a contradiction. We are driven to seeking optimum consistent combinations of existence assumptions, and consequently there is a great variety of proposals for the foundations of general set theory. Each proposed scheme is unnatural, because the natural scheme is the unrestricted one that the antinomies discredit; and each has advantages, in power or simplicity or in attractive consequences in special directions, that each of its rivals lacks.

I remarked earlier that the discovery of antinomy is a crisis in the evolution of thought. In general set theory the crisis began 60 years ago and is not yet over.

Gödel's Proof

Up to now the heroes or villains of this piece have been the antinomies. Other paradoxes have paled in comparison. Other paradoxes have been less startling to us, anyway, and more readily adjusted to. Other paradoxes have not precipitated 60-year crises, at least not in our time. When any of them did in the past precipitate crises that durable (and surely the falsidical paradoxes of Zeno did), they themselves qualified as antinomies.

Let me, in closing, touch on a latter-day paradox that is by no means an antinomy but is strictly a veridical paradox, and yet is comparable to the antinomies in the pattern of its proof, in the surprisingness of the result and even in its capacity to precipitate a crisis. This is Gödel's proof of the incompletability of number theory.

What Kurt Gödel proved, in that great paper of 1931, was that no deductive system, with axioms however arbitrary, is capable of embracing among its theorems all the truths of the elementary arithmetic of positive integers unless it discredits itself by letting slip some of the falsehoods too [see "Gödel's Proof," by Ernest Nagel and James R. Newman; SCIENTIFIC AMERICAN, June, 1956]. Gödel showed how, for any given deductive system, he could construct a sentence of elementary number theory that would be true if and only if not provable in that system. Every such system is

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therefore either incomplete, in that it misses a relevant truth, or else bankrupt, in that it proves a falsehood.

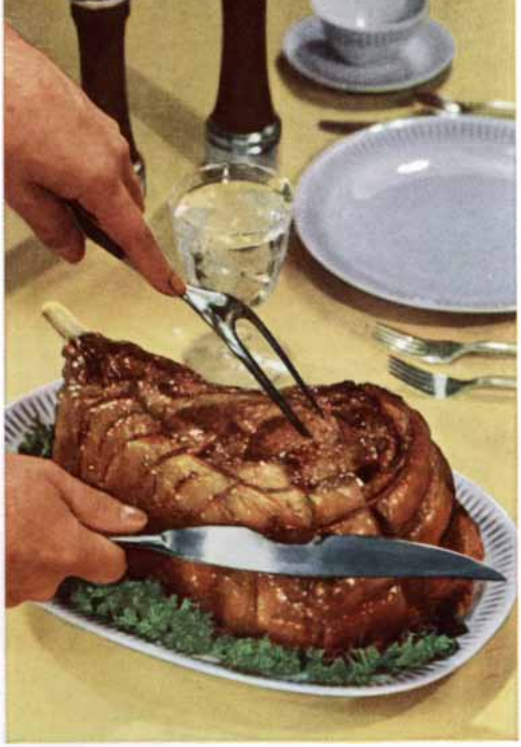
Gödel's proof may conveniently be related to the Epimenides paradox or the *pseudomenon* in the "yields a falsehood" version. For "falsehood" read "nontheorem," thus: " 'Yields a nontheorem when appended to its own quotation' yields a nontheorem when appended to its own quotation."

This statement no longer presents an antinomy, because it no longer says of itself that it is false. What it does say of itself is that it is not a theorem (of some deductive theory that I have not yet specified). If it is true, here is one truth that that deductive theory, whatever it is, fails to include as a theorem. If the statement is false, it is a theorem, in which event that deductive theory has a false theorem and so is discredited.

What Gödel proceeds to do, in getting his proof of the incompletability of number theory, is the following. He shows how the sort of talk that occurs in the above statement—talk of nontheoremhood and of appending things to quotations—can be mirrored systematically in arithmetical talk of integers. In this way, with much ingenuity, he gets a sentence purely in the arithmetical vocabulary of number theory that inherits that crucial property of being true if and only if not a theorem of number theory. And Gödel's trick works for any deductive system we may choose as defining "theorem of number theory."

Gödel's discovery is not an antinomy but a veridical paradox. That there can be no sound and complete deductive systematization of elementary number theory, much less of pure mathematics generally, is true. It is decidedly paradoxical, in the sense that it upsets crucial preconceptions. We used to think that mathematical truth consisted in provability.

Like any veridical paradox, this is one we can get used to, thereby gradually sapping its quality of paradox. But this one takes some sapping. And mathematical logicians are at it, most assiduously. Gödel's result started a trend of research that has grown in 30 years to the proportions of a big and busy branch of mathematics sometimes called proof theory, having to do with recursive functions and related matters, and embracing indeed a general abstract theory of machine computation. Of all the ways of paradoxes, perhaps the quaintest is their capacity on occasion to turn out to be so very much less frivolous than they look.



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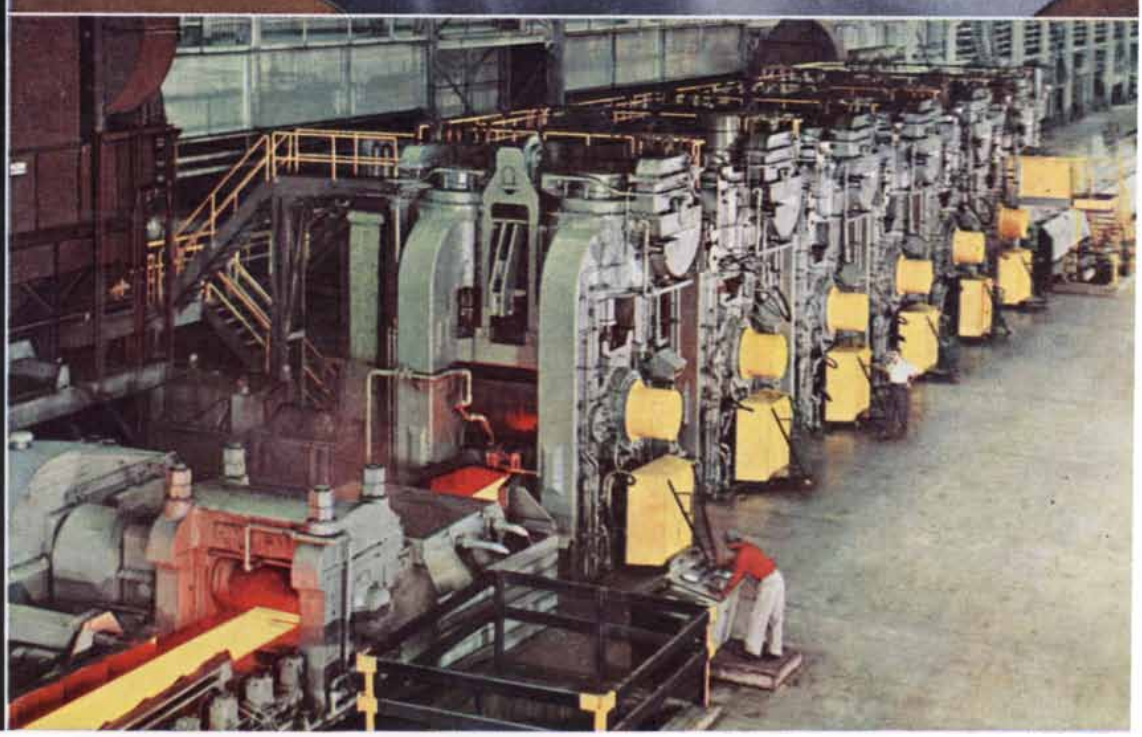

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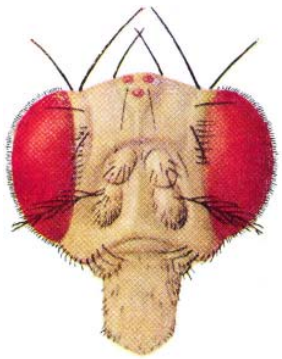
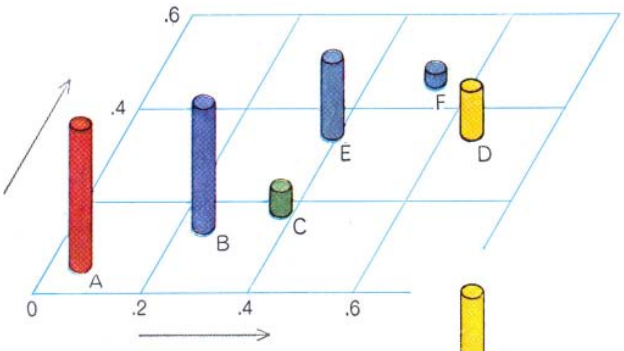
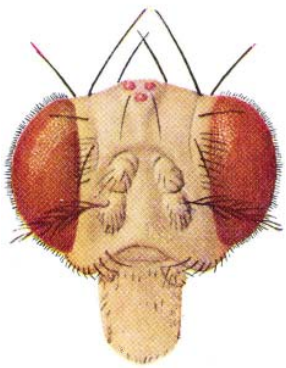
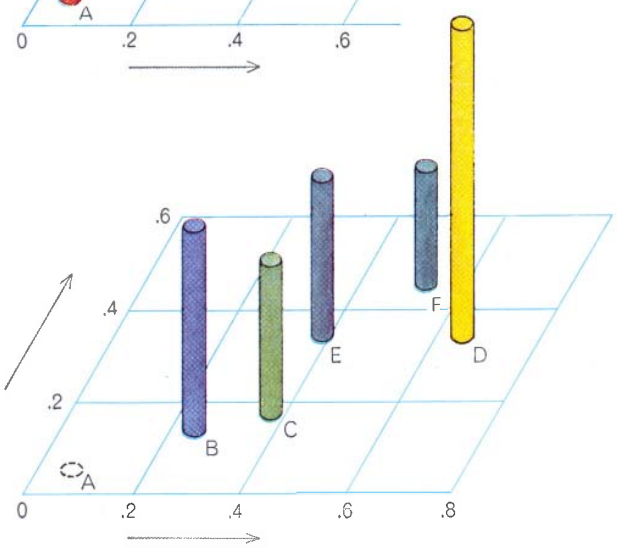


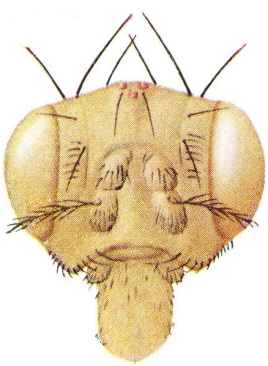
WILD-TYPE MALE



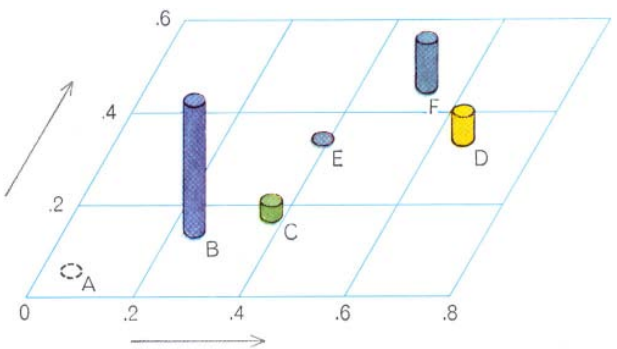


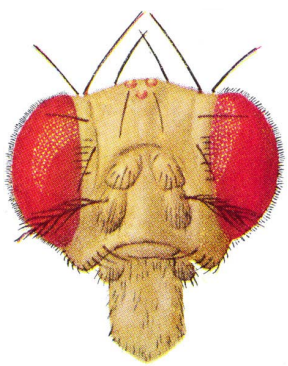
SEPIA MALE



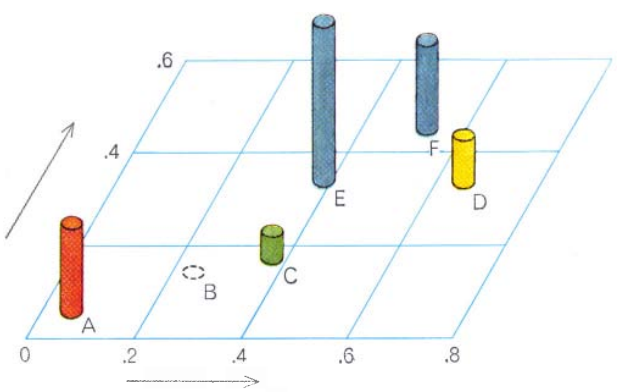


LOZENGE-CLAWLESS MALE





ROSY MALE



Fractionating the Fruit Fly

A simple technique reveals that genes controlling eye color in flies also control the production of a whole family of unusual substances. The study has importance for understanding hereditary disorders

by Ernst Hadorn

Two decades ago George W. Beadle and Edward L. Tatum found experimental support for the concept that the genes control the chemistry of the cell by controlling the production of the chemical catalysts called enzymes. This concept became known as the one-gene-one-enzyme hypothesis. The main support for the hypothesis rests on studies of microorganisms, such as molds and bacteria. In larger organisms, such as fruit flies, investigators have found it harder to associate genes and enzymes. It is easy enough to show that a change in a gene—a mutation—leads to a change in eye color or to a bent wing, but it is difficult to establish *how* the color is changed or the wing bent. Geneticists have also been puzzled by the observation that a single mutation will usually lead to changes in various characteristics of the organism. This effect is termed pleiotropy. In the fruit fly, for example, certain genes that affect eye color also affect the shape of the spermatheca, the organ in which the female stores the sperm deposited by the male. Pleiotropy puts the one-gene-one-enzyme hypothesis to an interesting test.

I shall describe a method of investigation that sheds light on mutation-induced chemical changes in the fruit fly and on the phenomenon of pleiotropy. The method was first developed in 1951 at the California Institute of Technology by Herschel K. Mitchell and me, and has since been extended with the help of others at Cal Tech and at the University of Zurich, with which I am associated.

Our objective has been to learn something about the chemical composition of the fruit fly *Drosophila melanogaster* and to see if this composition differs from one strain, or genotype, to another. We have found that the chemical fractionation of flies can be carried out quite simply by the method of paper chromatography. On a rectangular sheet of filter paper we draw a pencil line parallel to, and about 1.5 centimeters in from, one edge. Then with a glass rod we crush individual flies along this line, creating a series of spots. We form the filter paper into a cylinder, with the samples near the base, and place it in a glass jar that contains a shallow layer of a mixture of solvents such as water, propanol and ammonia [*see illustration on next page*].

The solvent is drawn up into the paper by capillary action and in a few hours reaches a "front line" near the top edge of the cylinder. In the process the solvent passes through the spots where the bodies of fruit flies have been crushed. Substances that are soluble in the solvent move upward with the fluid. The distance that a particular substance is carried toward the front line is called its ratio-to-front value, or Rf value. The Rf value for any given substance is determined by its chemical nature. Consequently different compounds are distributed between the starting spots and the front line. Only certain kinds of compound, notably pigments, show up directly. Others, such as amino acids and sugars, become visible only if the chromatographic paper is chemically treated. Still a third group consists of compounds that fluoresce and emit light of a characteristic color when struck by ultraviolet radiation.

Our first look at chromatograms under an ultraviolet lamp was a delightful surprise. There, on what had appeared to be blank paper, we saw a series of beautifully colored spots. All these fluorescent substances had been hidden within the fruit flies' bodies. Immediately we detected differences between males and females and between various genotypes. Some of these findings, which raised a host of fascinating questions, are illustrated on the opposite page.

What questions had to be answered first? Obviously we wanted to learn the chemical nature of these compounds. We wanted to know where within the body these substances are located, when they first appear during the fly's development and whether they change during its adult life. Furthermore, it soon became clear that each fluorescent pattern was intimately related to the fundamental genetic make-up of each fly, and this gave us an opportunity to learn something new about the action of genes.

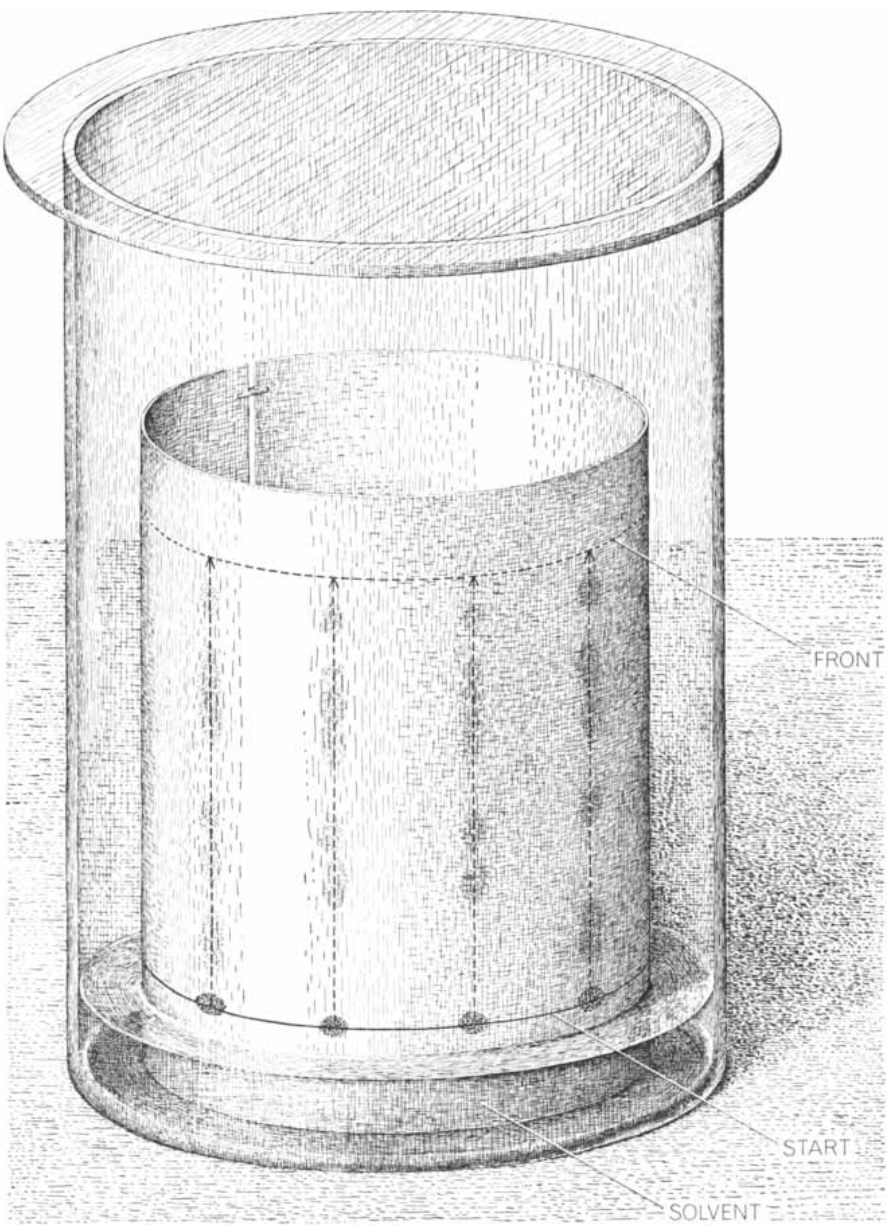
The identification of the various fluorescent compounds has been a laborious task. This work, which is still in progress, has been shared by a group of biochem-

FRUIT FLY CHROMATOGRAMS show the striking biochemical changes brought about by the mutation of genes that control eye color. The heads of a normal (wild type) fly and three mutants are at far left. The chromatograms (*center column*), characteristic for each type of fly, fluoresce in color under ultraviolet radiation. The color bands reveal the amounts of various substances, called pteridines, extracted when whole flies are crushed on filter paper and exposed to a solvent (in this case propanol-ammonia) that makes the substances migrate. If the filter paper is turned and dipped in a second solvent (collidine), the compounds are further separated and provide the basis for the bar charts shown at the right side of the page. The pteridines are: *A*, drosopterins; *B*, isoxanthopterin; *C*, xanthopterin; *D*, sepiapterin; *E*, 2-amino-4-hydroxypteridine; *F*, biopterin. The chromatograms were photographed by the Department of Photography of the Federal Institute of Technology in Zurich.

ists under Mitchell at Cal Tech, by H. S. Forrest at the University of Texas and by Max Viscontini, Paul Karrer and their associates in the Institute of Chemistry at the University of Zurich. Whereas the material of a single fly is sufficient for detecting the substances on chromatograms, several kilograms of flies are needed for the chemical investigation. Since a fruit fly weighs hardly a milligram, millions have had to be raised to obtain material for chemical analysis.

Most of the fluorescent substances have proved to be pteridines, a term derived from *pteron*, the Greek word for wing. The term was chosen years ago because the first compounds of the family were extracted from wings of butterflies. Recently pteridines have been detected in many different organisms. They occur not only in insects and other invertebrates but also in certain pigment cells of fishes and amphibians.

The inventory of seven pteridines, listed with their chemical structures on the opposite page, is characteristic for the normal "wild type" fruit fly. When we look at a chromatogram made with material from a mutant fly that has an abnormal eye color, we immediately see a pteridine pattern that differs strikingly from that of the wild-type fly. The differences are clearly shown in the four distinctive patterns that appear on page 100. The four patterns are the chromatograms of a wild-type male and of three mutant males identified, mainly on the basis of eye color, as sepia, lozenge-clawless and rosy. (The "lozenge" eye is amber in color and narrower than the normal eye; "clawless" refers to the absence of claws.) The differences in pattern become sharper still if one makes a two-dimensional chromatogram. This is done by turning the filter paper 90 degrees and exposing the samples to a second run using a solvent different from that used in the first run. From such sheets we can cut out each fluorescent spot and measure the intensity of the emitted light, which is proportional to the amount of substance present in each spot. The results of such a quantitative study are illustrated at the right side of page 100.



PAPER CHROMATOGRAPHY provides a simple means for fractionating the complex gene products found in the fruit fly. Each spot on the starting line of the filter-paper cylinder represents a whole crushed fly. As the solvent travels upward through the spots it carries soluble compounds different distances. Pigments are visible directly; other substances fluoresce under ultraviolet radiation; others can be made visible by chemical treatment.

One can see that some of the pteridines are completely missing in the mutants. There are, for instance, no drosopterins (red eye pigments) in the sepia and lozenge-clawless mutants. The rosy mutant lacks isoxanthopterin, a significant fact to which we shall refer later in this article. Other pteridines are present in abnormally large quantities in the mutants compared with the wild type. For example, we observe an increase of 2-amino-4-hydroxypteridine and of biopterin in rosy and sepia mutants. Moreover, the sepia mutant is characterized by a high content of xanthopterin and a large amount of sepiapterin.

There are so many different eye-color mutants in the fruit fly that it is hard to find enough descriptive words to characterize all of them. Eye colors include almost every shade of red, brown, cream and off-white. We have studied many of these mutants by our chromatographic method. All of them show a departure from the normal wild-type pteridine inventory, and each variety of mutant displays a characteristic chromatographic pattern of its own.

By definition a mutation is a genetic event that leads to a change in the organism. The change may be morphological, physiological, biochemical or even behavioral. In any case it must be discernible by some means of observation. In paper chromatography we have a new method for observing mutations, and it has already led to the discovery of one mutation previously hidden.

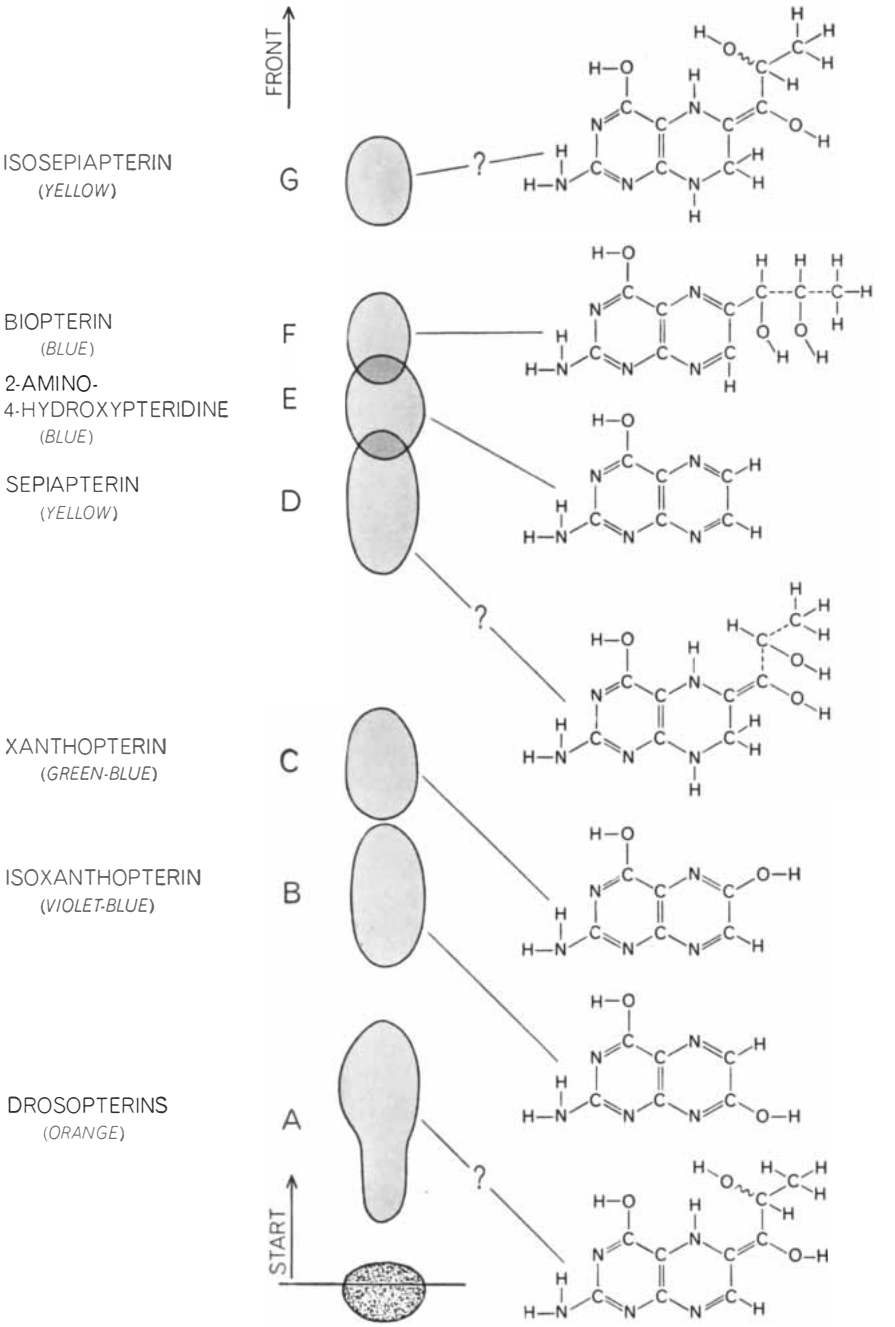
The finding was made in collaboration with A. Kühn of the Max Planck Institute for Biology in Tübingen when we

were studying the meal moth *Ephestia*. On the starting line of a sheet of chromatographic paper we crushed the heads of about 20 moths of the wild type, which we assumed to be of single "pure" stock. When we examined the chromatograms in ultraviolet light, we saw to our great surprise that our pure stock concealed two distinctive and biochemically different types. Most of the heads produced a rich assortment of fluorescent spots, all having the same pattern. A few heads, however, contained only two pteridines, but in very large amounts.

Breeding experiments showed that the aberrant individuals bore a new recessive mutant gene. Since this genotype had been discovered solely by using biochemical methods we gave the underlying gene the name "biochemica." This mutant had been overlooked because, like the wild-type moth, it has black eyes. But after detecting its biochemical peculiarities we re-examined its eyes and found that their color was a shade darker than that of the wild stock. Furthermore, microscopic examination disclosed differences between the biochemica and the wild type in the content and distribution of pigment granules. Thus biochemistry played the leading role in the discovery of a mutation that later was seen to affect the organism in a number of ways. In other words, the mutation was pleiotropic.

Indeed, it is doubtless now apparent to the reader that the various chromatographic patterns associated with the eye-color mutants of the fruit fly must be regarded as evidence of biochemical pleiotropy. A mutation does not simply change the eye color from one hue to another; it changes the concentration of pteridines present in various parts of the fly's body.

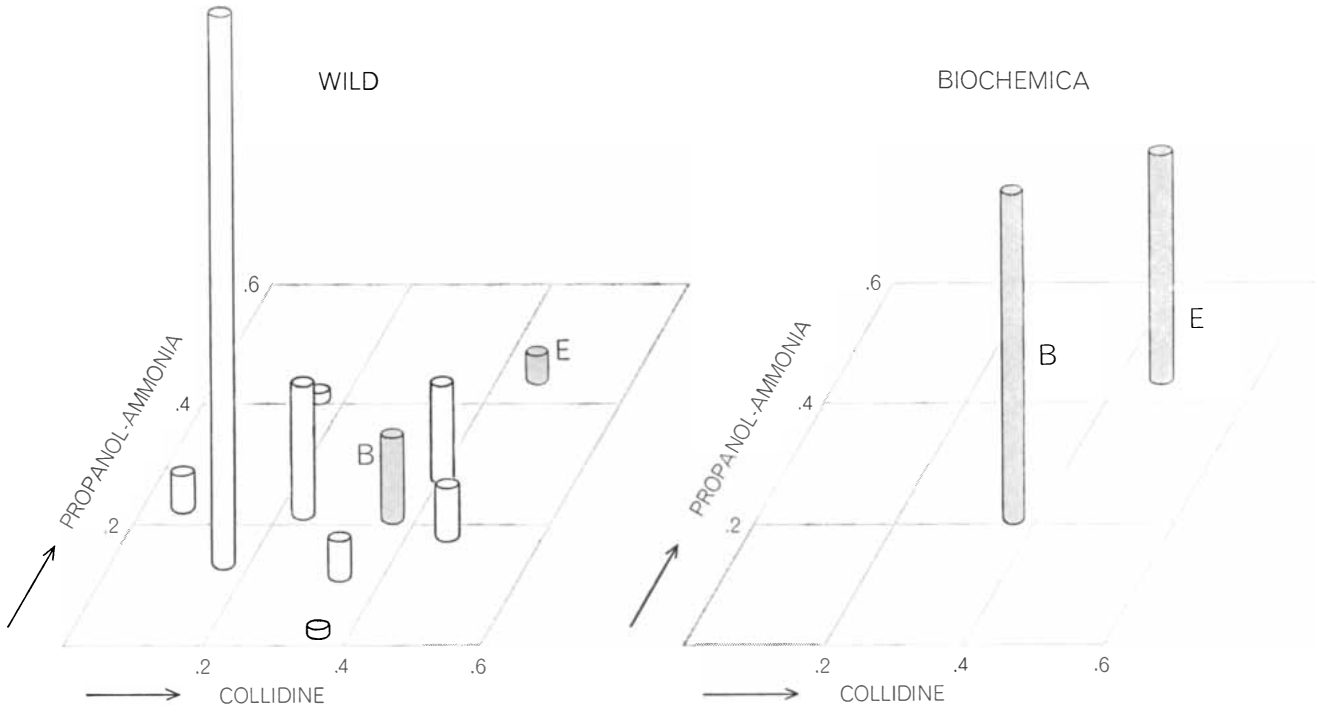
Similarly, we find that genes thought to be recessive because in single dose they produce no outwardly visible effect on the organism may still produce subtle changes in biochemistry. A classic example of a recessive factor is the gene for white eye color in the fruit fly. A fly containing two genes of the wild type will have red eyes. If a fly contains one wild gene and one white-eye gene, the resulting eye color is indistinguishable from that of the fly that has two wild-type genes. Chromatograms, however, tell us a different story. If we look at the pteridine inventory, we see that the white gene is not fully recessive. When the white-eye gene is present, the fruit fly contains fewer drosopterins and less xanthopterin and distinctly more sepiapterin and 2-amino-4-hydroxypteridine



FRUIT FLY PTERIDINES appear in this order when fractionated with propanol-ammonia as a solvent. The pteridines are those of the wild-type fly. Chemical structures were worked out by Max Viscontini of the Institute of Organic Chemistry of the University of Zurich.

than a fly in which the eye-color genes are both wild [*see illustration on page 107*]. Examination of other recessive genes shows that they too alter the chromatographic pattern.

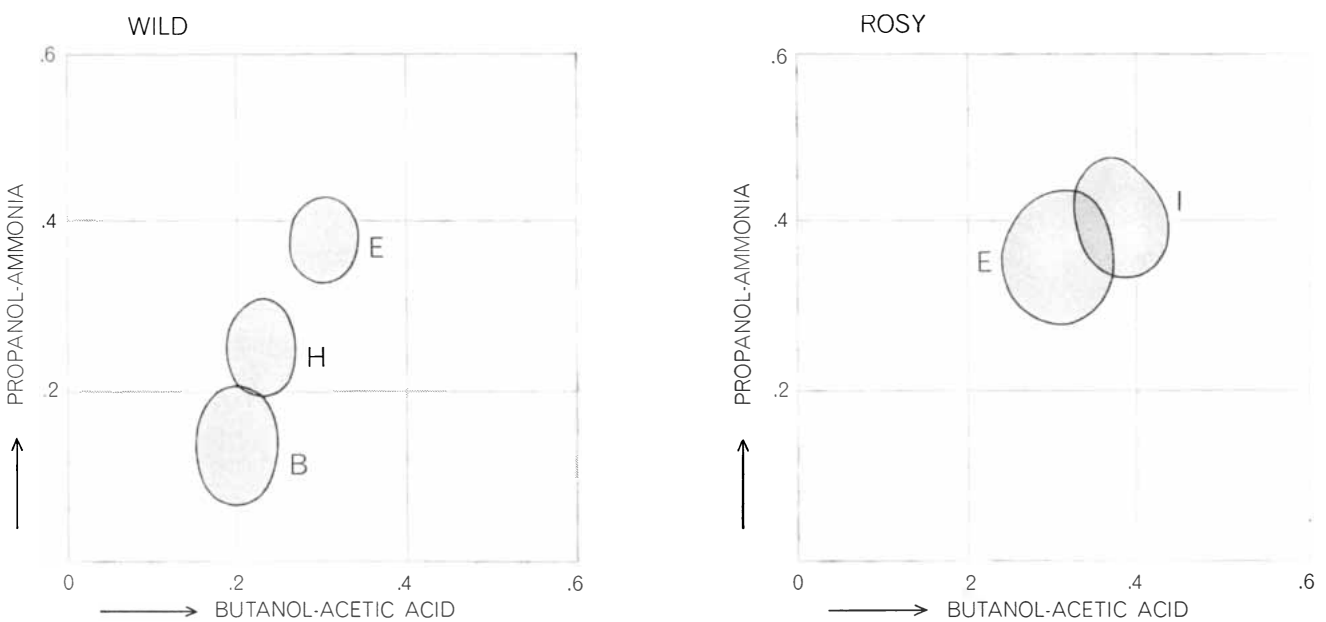
It follows that one must be very cautious before classifying a gene as a completely recessive hereditary unit. If total recessiveness occurs at all, it must be rare. This insight has an important bearing on human heredity. The human population contains many recessive genes that cause a disease only in homozygous individuals—that is, individuals who happen to inherit two recessive genes of a particular type. Many more individuals are heterozygous with respect to these unfavorable hereditary units, which means that they carry only a single harmful gene and hence do not suffer from the disease. But with new biochemical methods it is possible to recognize minute metabolic deviations from normality in the healthy heterozygote who carries one of a number of harmful genes.



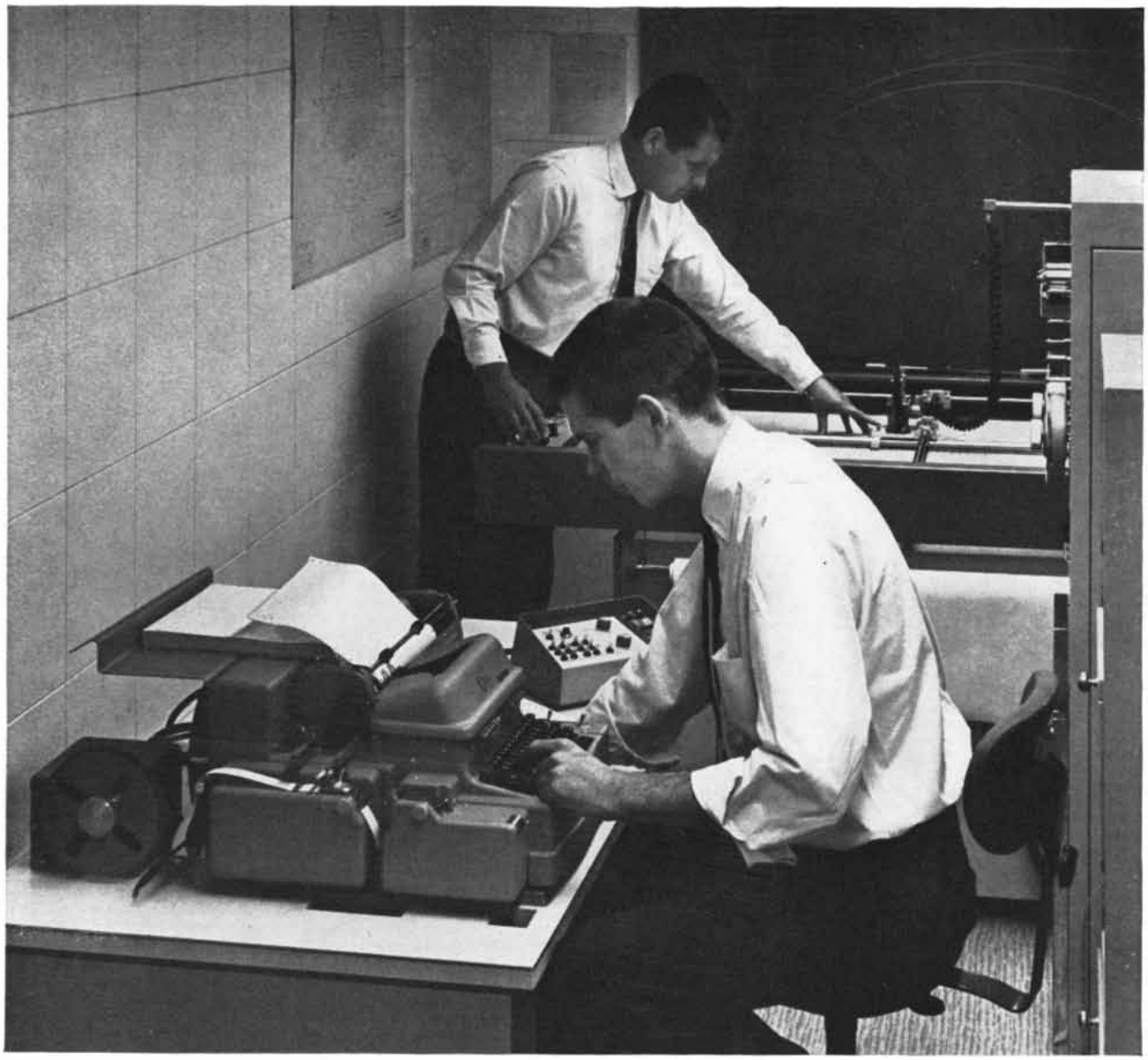
HIDDEN MUTATION in the meal moth *Ephestia* was first revealed by chromatography. Heads of moths thought to be of a pure wild type gave the two chromatograms plotted here. The strain now regarded as truly wild contains many pteridines (*left*). The mutant, named "biochemica," contains only two of the wild-type pteridines, isoxanthopterin (*B*) and 2-amino-4-hydroxypteridine (*E*).

There is, for instance, a nominally recessive gene that causes the disease galactosemia when it is present in double dose. The lives of children who are homozygous for this mutant gene are endangered because they are unable to metabolize properly the sugar galactose, a constituent of milk. Herman M. Kalckar of Johns Hopkins University has found that these children are deficient in the enzyme galactose-1-phosphate-uridyltransferase, which is indispensable for the transformation of galactose to glucose. If the parents of an affected child do not suffer from galactosemia, they must be heterozygous carriers of the mutant gene. It has been shown recently that in these heterozygous individuals the gene causes an apparently harmless but distinct decrease in the activity of the enzyme compared with the standard values measured in homozygous normal individuals.

Such findings are not only of great medical value; they also support the one-gene-one-enzyme hypothesis of Beadle mentioned at the beginning of



EFFECT OF ROSY GENE shows up clearly in chromatograms. Wild-type fruit flies contain isoxanthopterin (*B*), uric acid (*H*), 2-amino-4-hydroxypteridine (*E*). Rosy mutants lack *B* and *H*, have large amounts of *E* and, instead of *H*, contain hypoxanthine (*I*).



Jet Propulsion Laboratory will use Recomp III for processing data from NASA deep space tracking antennas.

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Q. Who has the facts about aligning a tracking antenna to one second* of arc?

* One second of arc on a radius of 250 yards is the width of a needle's eye.

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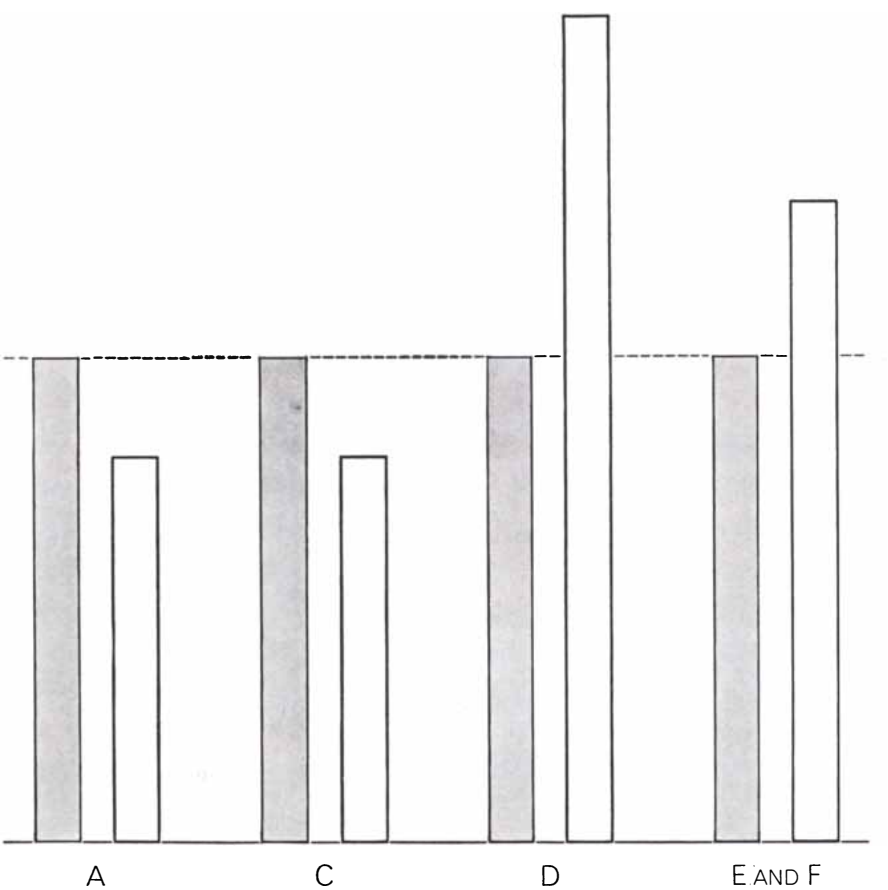
this article. There are now hundreds of examples, involving many kinds of organism, to show that enzymes are gene-conditioned products. To be sure, the hypothesis can hardly cover all cases of gene action on enzyme systems, but we need not be concerned herewith qualifications. The main statement is still valid, and the following discussion is based on it.

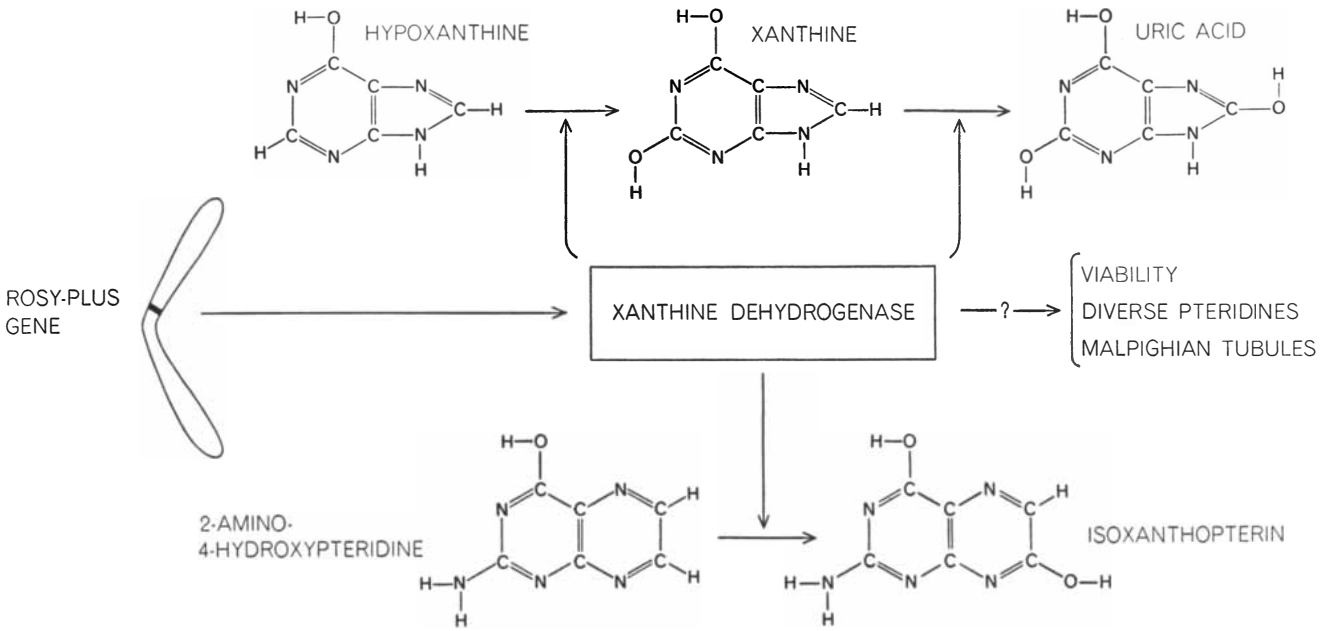
If the role of a gene is confined to the production, modification, inactivation or loss of just one enzyme system, how can one explain that genes determine, as a rule, not only one but a whole set of characteristics, or phenes? Unity of primary genic action must be confronted with pleiotropy of genic manifestation. A discussion of the mutant gene that causes a rosy eye color in the fruit fly will indicate how far one can go in resolving this seeming paradox.

We have already seen that the rosy-eyed mutant lacks the fluorescent compound isoxanthopterin. In addition, the rosy-eyed fly contains an abnormally high content of 2-amino-4-hydroxypteridine and biopterin, and a subnormal amount of the drosopterins, the red eye pigments. The deficiency in red pigments accounts for the difference in eye color between the mutant and the wild type. The chromatograms, viewed by ultraviolet radiation of short wavelength, reveal another important characteristic of rosy-eyed flies [*see bottom illustration on page 104*]. Uric acid, a common excretion product of insects, appears as an ultraviolet-absorbing spot in chromatograms of wild-type flies. In chromatograms of rosy-eyed flies this spot is missing. Instead, farther from the starting line we find another spot, identified as hypoxanthine, which replaces uric acid as a nitrogen-containing excretion product.

These biochemical traits are accompanied by at least one morphological characteristic. In rosy-eyed mutants we find that the Malpighian tubules, which act as the kidney of the fly, are shortened and malformed. Furthermore, clumps of excretory material tend to accumulate inside the tubules. One might guess that these abnormalities would have a harmful effect on the mutant fly. As a matter



EFFECT OF RECESSIVE GENE for white eyes in the fruit fly shows up in the pteridine inventory even though the presence of a wild-type gene for red eyes endows the fly with a normal outward appearance. The pteridine inventory of a homozygous wild-type female, which has two genes for red eyes, is shown by dark bars. One recessive white-eye gene produces the inventory given by open bars. (Letters refer to pteridines shown on page 103.)



PLEIOTROPY, or multiple changes traceable to a single mutant gene, has been partially explained for the changes brought about in the fruit fly when the rosy-plus gene mutates. This gene, located in the third chromosome (*bent shape at left*), evidently carries the code for the production of xanthine dehydrogenase, an enzyme that catalyzes the chemical changes indicated by the structural formulas. The enzyme seems also to have a bearing on viability, the synthesis of pteridines and on development of the Malpighian (excretory) tubules. When the rosy-plus gene mutates, enzyme activity is absent and all the processes shown are affected.

of fact about 50 per cent of the individuals that are homozygous for the rosy-eyed gene fail to emerge from the pupal case. This semilethal effect is manifest, however, only if the cultures are held at 25 degrees centigrade. At 18 degrees practically all rosy-eyed mutants are fully viable.

Many other fruit fly mutants are similar to the rosy-eyed type in showing complex patterns of pleiotropy, which include biochemical, physiological and morphological phenes. But in most cases we know nothing about the underlying genic effect, which must be of a biochemical nature. In contrast, we now know the particular enzyme that is affected in the rosy-eyed mutant. My American colleagues Mitchell, Forrest and Edward Glassman have discovered that the rosy-eyed fly is deficient in the enzyme xanthine dehydrogenase.

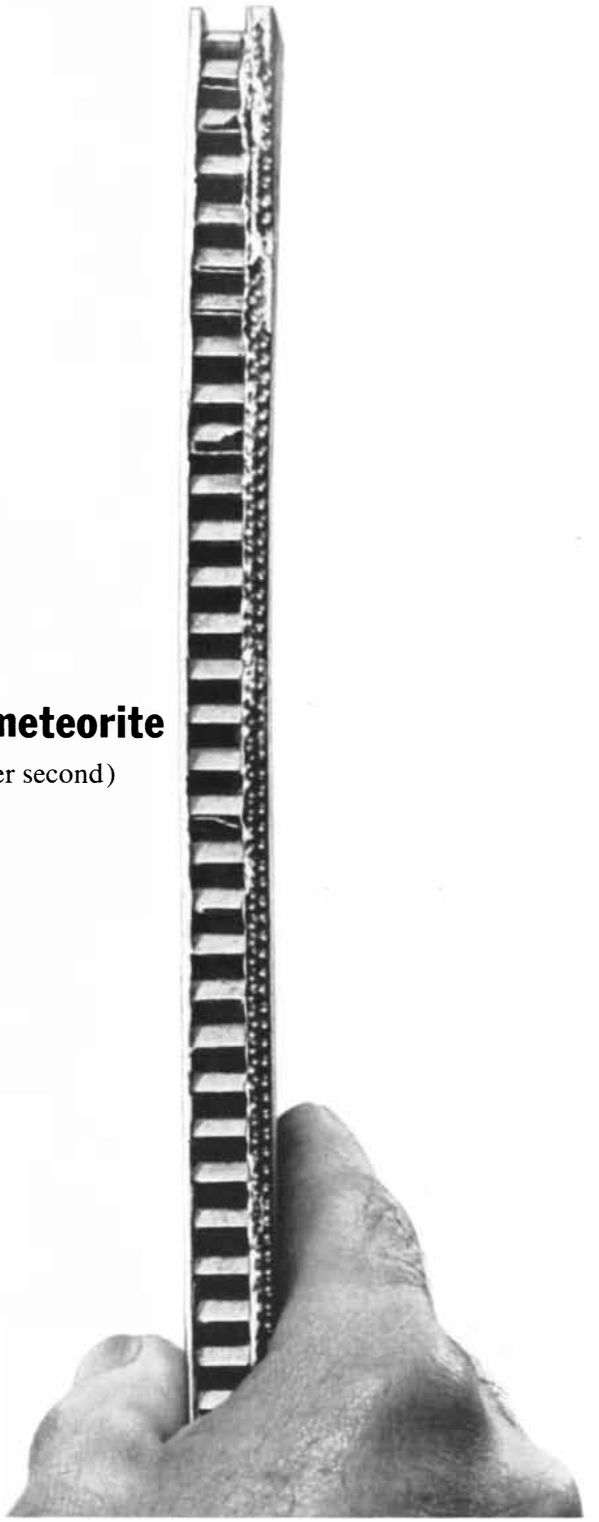
The rosy-eyed fly is a mutant resulting from a change in a normal Mendelian factor that is located in the third chromosome of the fly's cells and that we call the rosy-plus gene. Presumably this normal gene functions as a coding unit that determines the formation and specificity of xanthine dehydrogenase. This enzyme in turn acts on at least two groups of compounds: it catalyzes the formation of isoxanthopterin from 2-amino-4-hydroxypteridine and it mediates the transformation of hypoxanthine to xanthine and xanthine to uric acid [*see illustration above*]. In the rosy-eyed mutant no active xanthine dehydrogenase is formed because of a mutation in the rosy-plus gene. Therefore we find neither isoxanthopterin nor uric acid in flies that are homozygous for the mutant gene. On the other hand, the nonmetabolized precursor substances 2-amino-4-hydroxypteridine and hypoxanthine are accumulated in abnormally high quantities and show up clearly in our chromatograms.

We see that the discovery of the gene-conditioned enzyme defect allows us to understand at least part of the pleiotropic pattern. We have learned how a single gene, although it determines only one enzyme system, can affect diverse compounds. But we cannot yet explain all the phenes of the rosy-eyed fly. We feel sure, however, that with further biochemical information we will learn why the rosy gene causes a decrease in the drosopterins and an increase in biopterin, why the Malpighian tubules become malformed and why viability is reduced under certain conditions.

Pleiotropic patterns of gene action like the rosy-eyed syndrome can be compared with many hereditary diseases in man, which are also based on enzymatic defects. What are the chances of curing such defects? Might it be possible to supply an individual with a missing enzyme? Unfortunately there appear to be serious obstacles to such a procedure. The great majority of all hereditary traits, beneficial as well as harmful, reflect the intrinsic genic constitution of individual cells, which are not easily influenced from the outside. This autonomy of gene action can be demonstrated by transplanting a piece of skin from a newborn albino mouse to a normal littermate of the gray wild type. The transplanted tissues never form pigment and consequently the growing hair remains white, even though the transplanted skin is surrounded and nourished by a genetically normal host organism.

Most of the eye-color mutants of the fruit fly behave in a similar way. A rudiment of an eye usually develops its own genetically determined color when it is implanted into the larval body of a different genotype. There are, however, a few exceptional mutants that behave in a nonautonomous manner. In the 1930's Beadle and Boris Ephrussi discovered that eye rudiments from vermilion and cinnabar mutants developed the normal red color when grown in a wild-type host, and that one can normalize the eye color of vermilion and cinnabar individuals by injecting them with cells from wild-type donors. These findings have had great significance for biochemical and physiological genetics.

We were pleased to find that our rosy mutant also behaves nonautonomously. In one experiment we open a wild-type larva, take a sample of fat-body cells and inject them into a rosy-eyed host larva [*see illustration on page 110*]. When the



This thin panel stopped a meteorite

(man-made, traveling at 21,000 feet per second)

A steel pellet struck this panel at 21,000 feet per second — more than six times the speed of a high powered rifle bullet — but could not pierce it. It disintegrated after puncturing the outer metal skin, and dissipated all its energy without reaching the inner lining.

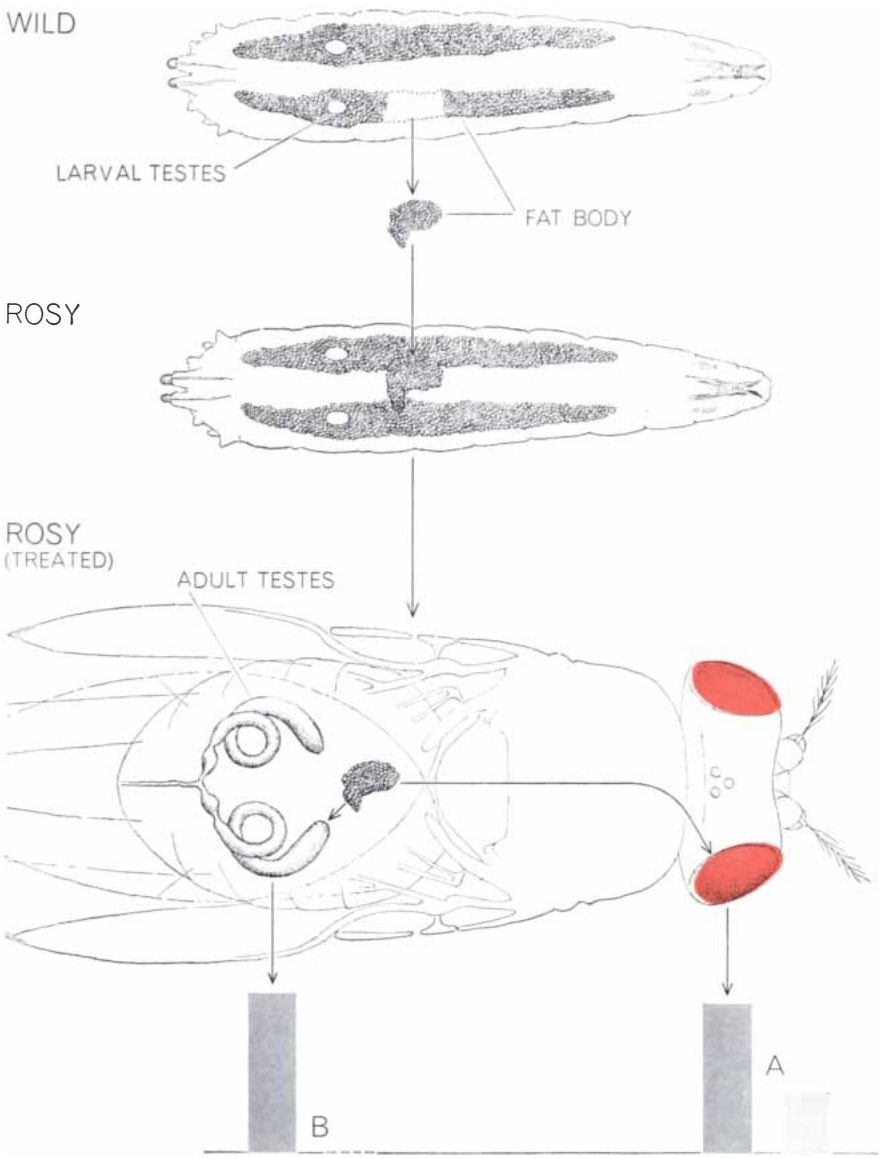
This composite honeycomb panel is one of the techniques Northrop is developing to protect spacecraft against meteorite collisions. The entire lightweight panel is less than half an inch thick, and the honeycomb is filled with sealant to prevent air from escaping in case a particle should ever penetrate.

Though most of the meteorites a spacecraft is likely to encounter will be fine as dust, some may be as large as buckshot, and dense enough to puncture an ordinary metal skin. The search for materials to meet this hazard is another example of Northrop's practical work on the problems of space.

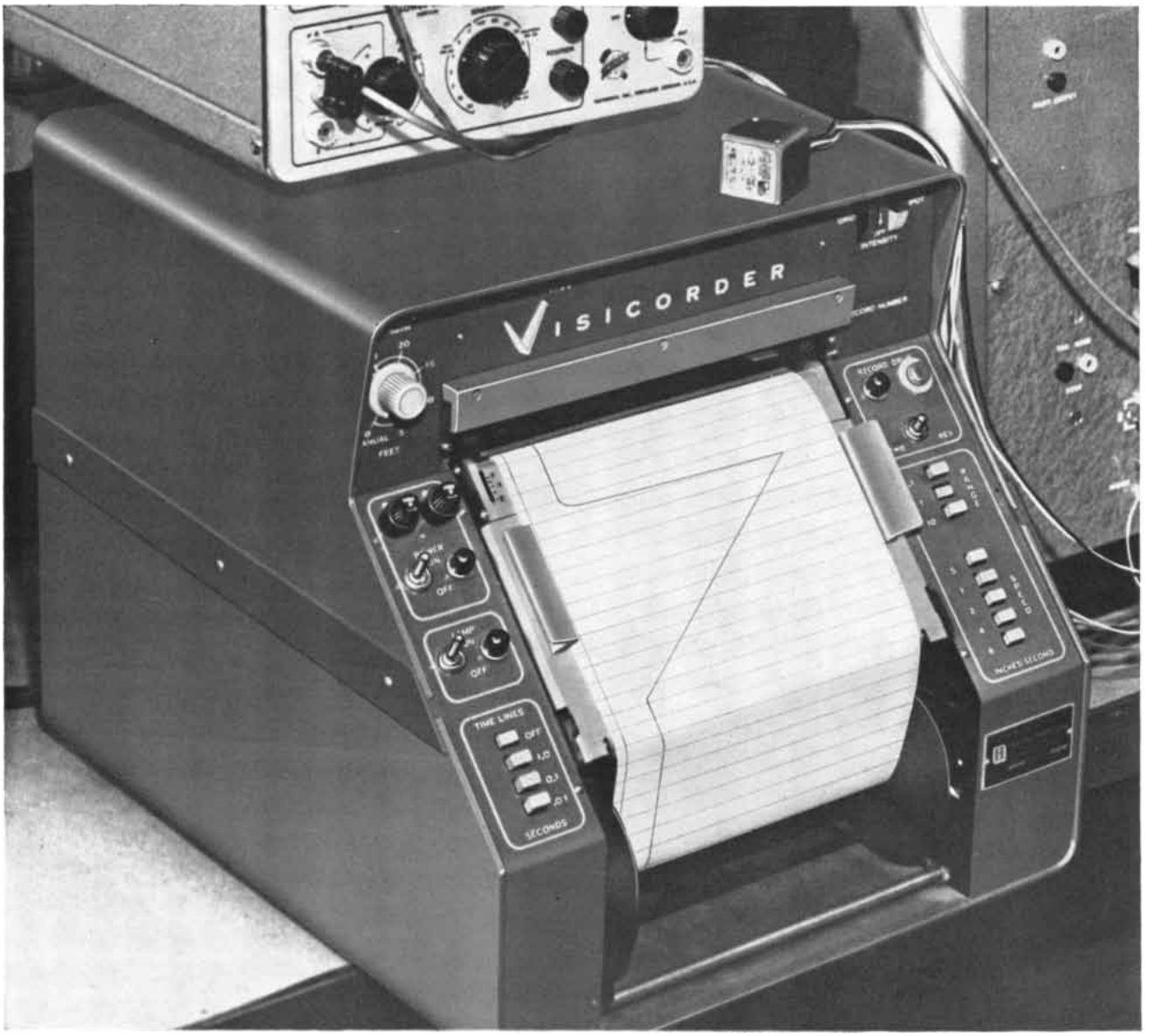
NORTHROP

rosy-eyed host develops, it appears to be "cured" of its inborn hereditary disease. Its eyes contain a normal amount of drosopterins and therefore have the red color of the eyes of the wild-type fly. Moreover, its testes contain an amount of isoxanthopterin comparable to that found in the testes of normal males. (The typical rosy-eyed mutant completely lacks this substance.) Evidently the normal cells injected into the rosy-eyed larva somehow introduce or stimulate the activity of xanthine dehydrogenase, which the rosy-eyed mutant normally lacks. It is possible, although it has not yet been proved, that it is the enzyme molecule itself that leaves the implanted fat-body cells and enters the developing testes, where it becomes fully active.

The case of the rosy mutant is typical of many mutants under investigation. Biochemists are just beginning to uncover the pathways that lead from primary genic actions to the manifold pattern of hereditary characteristics. Ultimately this work should provide ways of helping people who have had the misfortune to inherit those genes that create metabolic deficiencies or disorders.



"CURE" FOR HEREDITARY DEFECTS has been achieved in fruit flies carrying a mutant rosy gene. The cure consists of transplanting fat-body cells from the larva of a normal wild-type donor into a larva of the mutant rosy. When the treated larva develops into an adult fly, the implanted cells lead to an increase in drosopterins (*A*), so that the mutant has a normal red eye, and to the appearance of isoxanthopterin (*B*) in the testes. The bars show the relative amounts of these substances in the treated fly and in an untreated control.



Honeywell Visicorder Oscillograph checks resolution of an event marker

Electro Development Corporation, Seattle, Wash., uses a Model 1108 Honeywell Visicorder Oscillograph to prove the linearity and resolution of signal conditioner-event markers which they supply to the Boeing Company.

A missile telemetering system samples each channel only once every 30 milliseconds, but missile engineers want to know when some events occur to an accuracy of better than one millisecond.

The event marker (the small cube atop the Visicorder) produces a highly-linear ramp output that starts exactly when the marker is triggered by the event in question. This ramp continues for about 100 milliseconds . . . enough time so that the telemeter system can sample the ramp at least three times. A straight line drawn through these points will accurately determine the occurrence of the event.

To check event marker linearity, the ramp is recorded at the very high record speed of 80″/sec. It's this high speed, the .01-second timing lines, the ease of operation, and the wide deflection capabilities of Honeywell galvanometers (approx. 7″ in this application) that caused the Electro Development Corporation to select the Model 1108 Honeywell Visicorder.

For more details about the Model 1108 (24 channels), the 1012 (36 channels) and other Honeywell Visicorders, write Minneapolis-Honeywell, Heiland Division, 4800 E. Dry Creek Road, Denver 10, Colorado. Our DDD phone number is 303-794-4311.

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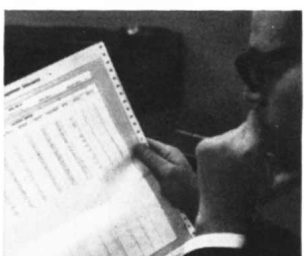

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THE ACTION OF ADHESIVES

Fundamentally they work by being liquid and bringing molecules close together. In the newer adhesives this state of affairs is maintained by minimizing stresses within the adhesive itself

by Norman A. de Bruyne

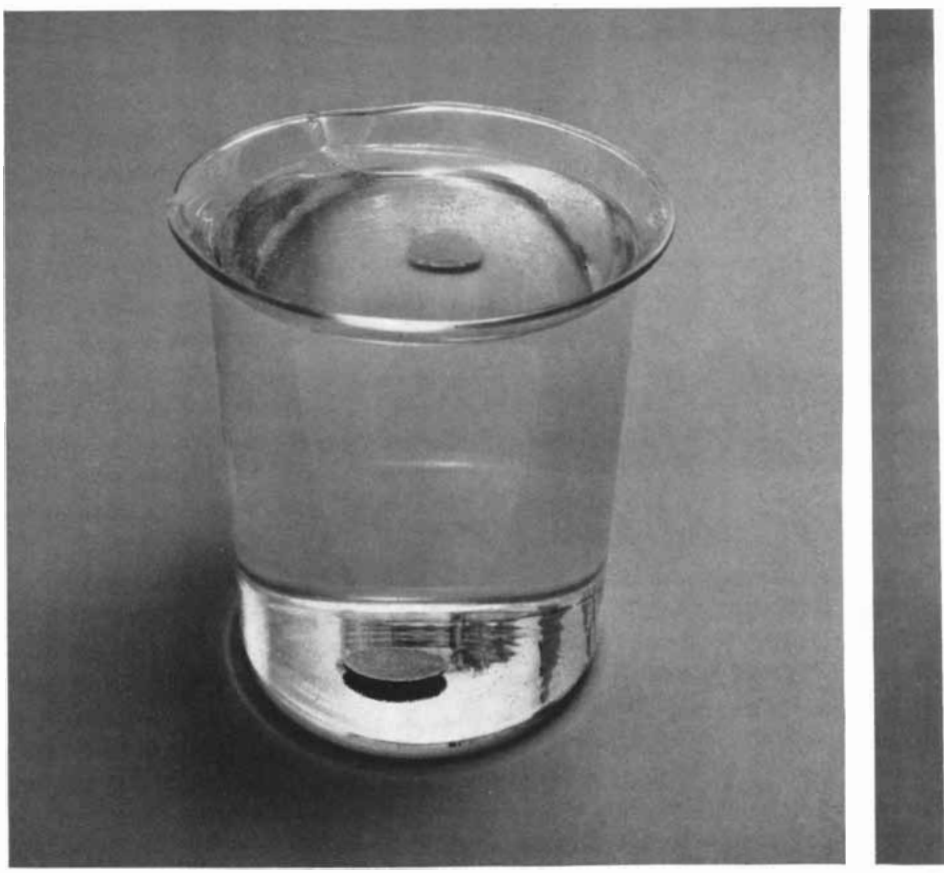
"There are Agents in Nature able to make the Particles of Bodies stick together by very strong Attractions and it is the Business of experimental Philosophy to find them out." So wrote Isaac Newton in his *Opticks* more than 250 years ago. Experimenters—and theoreticians as well—were slow to take up the challenge. They had acquired a thorough knowledge of the forces within the atom, and had even begun to plumb the forces within the nucleus of the atom, well before they could account correctly for the molecular interactions that are responsible for adhesion. Meanwhile the makers of paste and glue had proceeded by trial and error to develop better adhesives.

Finally, in the past 10 years or so, substantial progress has been made in "finding out" Newton's sticky "Agents." H. B. G. Casimir in the Netherlands and E. M. Lifshitz in the U.S.S.R. have explained the attractive force between molecules and predicted its variation with distance of separation. The force turns out to be due to electromagnetic interactions produced by continual fluctuations in the distribution of electrons within the molecules.

Checking the predicted attraction experimentally is extremely difficult—almost at the limit of what is possible. Two bodies must be held at a fixed and measurable distance apart while the attractive force between them is determined. Because the force has an extremely short range, the separation must be minute, on the macroscopic scale. Yet any separation that can be stably maintained is very large on the molecular scale, and so the force of attraction will be tiny. Notwithstanding these problems the molecular attraction between a pair of bodies has recently been measured by B. V. Derjaguin and his colleagues in the U.S.S.R. and by M. J. Sparnaay in the Netherlands. Both experiments confirm the theoretical predictions at "large" separations on the order of a ten-thousandth of a millimeter and more.

At small separations—a few ten-millionths of a millimeter—the theory indicates that the force between molecules will be large. The lesson, so far as adhesion is concerned, is clear. To make two surfaces stick together, bring their molecules very close to each other. If the principle is correct, it should be possible to make solids adhere without using any glue at all. Such is in fact the case. The only trouble is that, on the scale of a few angstrom units (an angstrom unit is one ten-millionth of a millimeter), most solid surfaces are rough and so cannot be brought into really close contact over a substantial area.

The difficulty of bringing solids into



CLOSE CONTACT BETWEEN SOLIDS is difficult to achieve without any intermediating material. As explained in the text, total internal reflection makes it possible to see the

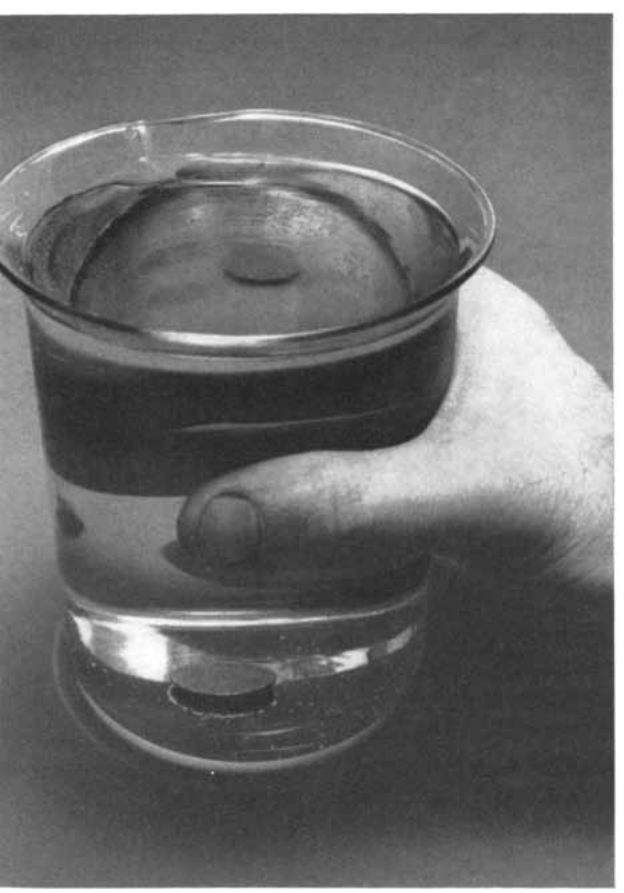
close contact can be demonstrated by means of the phenomenon of total internal reflection. If you look down into a beaker of water, the sides of the beaker have a mirror-like, silvery appearance and reflect objects on the bottom [*see illustration below*]. The reason is that light waves striking the sides at sufficiently oblique angles are totally reflected; they do not pass out of the glass wall into the air, even though the glass is transparent. More accurately, the light travels into the air for a wavelength or two and then turns back into the glass, like a flying fish leaping out of the water for a few feet and then returning.

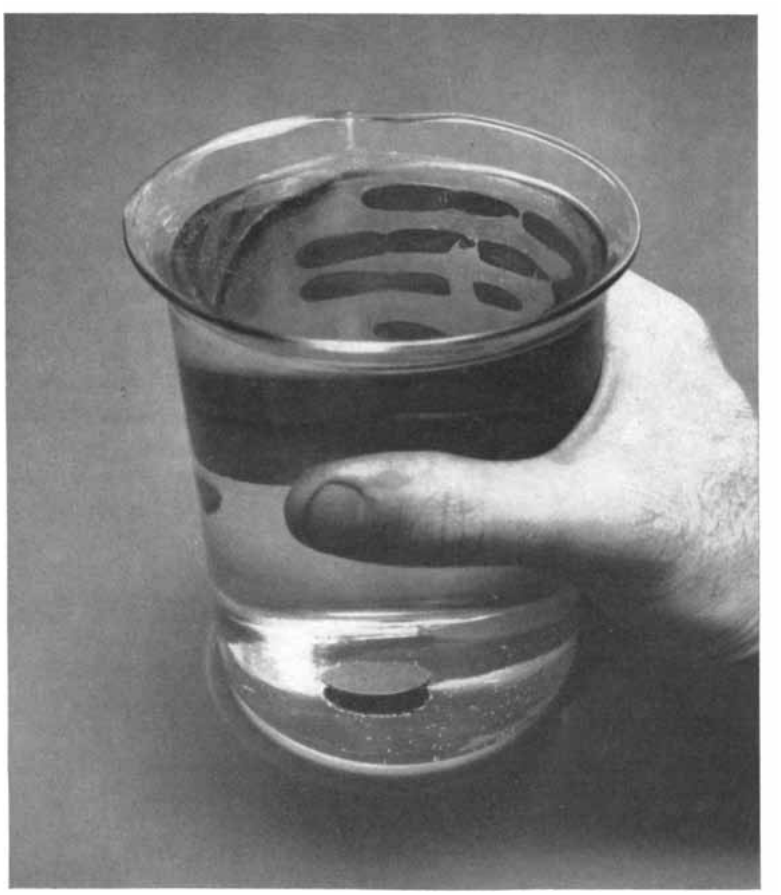
Now, a flying fish could easily jump high enough to land in a rowboat, its re-entry into the water thereby being frustrated. It could scarcely land on the deck of an ocean liner, however. Similarly, emerging light waves can be captured by an object placed close to the glass surface and their total internal reflection frustrated. In performing the experiment with the beaker of water, first make sure that the outside is quite dry, then press a smooth, polished object against it. You will see nothing; the two surfaces are not close enough to catch the light. Now try your thumb; press hard and you will see a few sweat marks breaking through the silvery surface. A rubber ball pushed against the beaker will also appear as a gray patch. But as soon as the pressure is released, the patch disappears. The elastic energy stored up in the flattened ball is enough to disrupt any bonds that were made on the close approach of the rubber and the glass.

The last experiment suggests that if two clean solids could be deformed plastically when pushed together (so that they have no tendency to regain their original shape), they should adhere. There would then be no stored energy to disrupt the bonds. This can actually be done with soft aluminum, as was discovered some years ago. The surfaces are cleaned with a rotary scratch brush, placed quickly together and given a smart blow with a punch. A good joint results. If the cleaned surfaces are touched with the fingers before they are hit with the punch, there is no adhesion, showing that the joint is not the result of any mechanical interlocking caused by the punch.

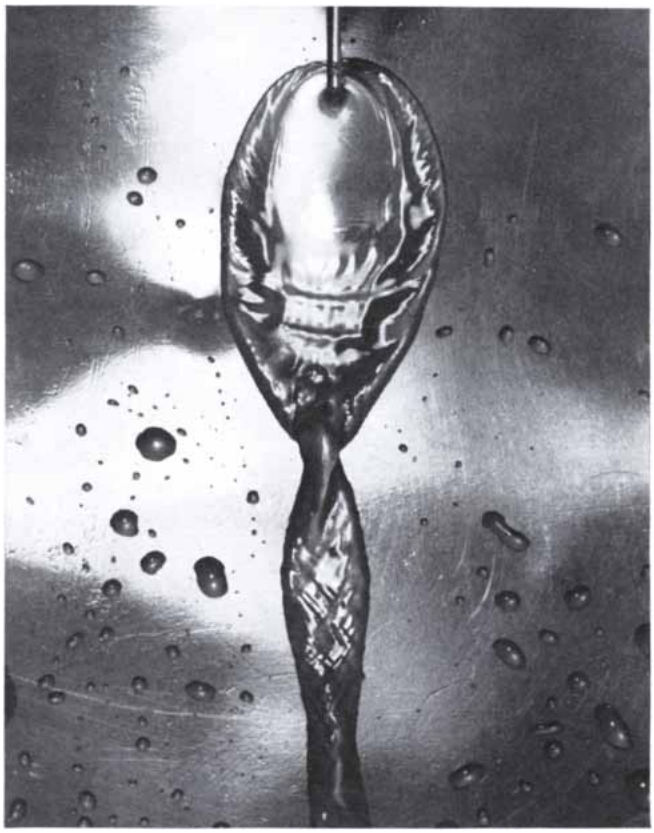
If solid surfaces are naturally smooth on an atomic scale, they will adhere spontaneously without having to be forcibly pushed together. Mica can be split so that it is smooth to a few angstrom units over a visible area, and its adhesion is easily demonstrated in another simple experiment. Take a sheet of mica and separate a pair of its layers, starting the cleavage by working the point of a needle into the edge. (Don't use a drop of water to facilitate the separation, as is frequently done: its high dielectric constant considerably reduces the electric forces that hold the layers together.) Stop the splitting before it has gone entirely through the sheet and quickly bring the surfaces together again. They will adhere tightly, although not with quite the strength of the unseparated layers in the sheet because air and moisture are absorbed on any exposed mica surface.

This experiment has been refined by J. S. Courtney-Pratt and Anita I. Bailey at the University of Cambridge. They took a pair of mica sheets silvered on one side, formed them into arches and placed the unsilvered sides in contact with their axes of curvature at right angles. By observing interference fringes at the

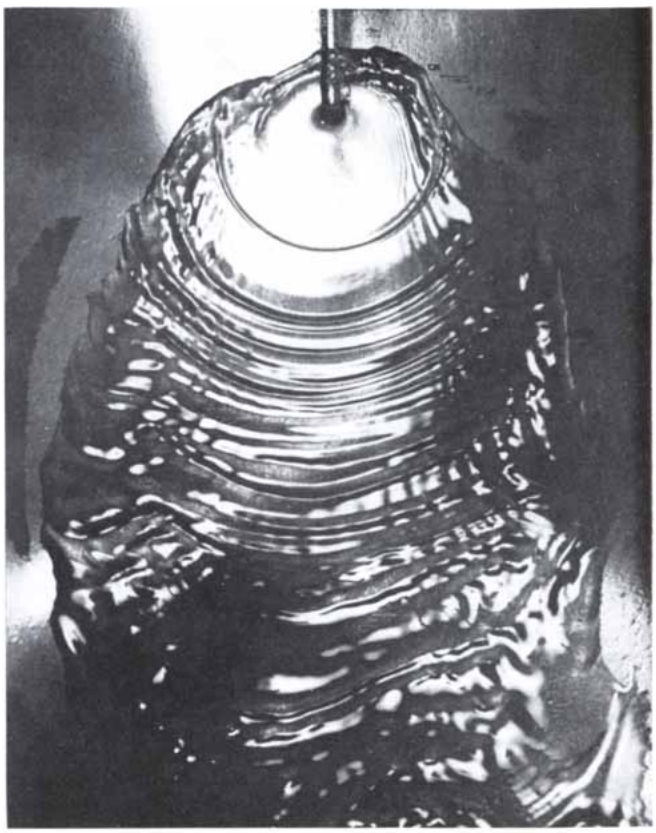




reflected image of a penny in a beaker of water (*left*). Fingers of the hand tightly holding the beaker (*middle*) are barely seen from the top because the two surfaces are not close enough to catch the light. When wet, however, the fingers are clearly visible (*right*).



UNTREATED POLYETHYLENE SURFACE is not wetted by the jet of water seen in this flash photograph; the water is repelled.



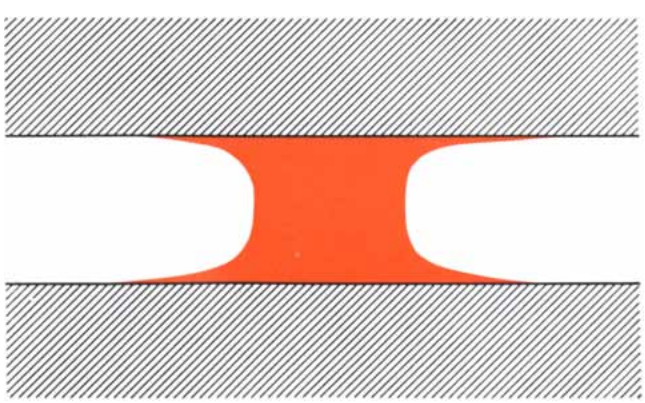
TREATED POLYETHYLENE SURFACE (previously "flamed" with a Bunsen burner) is wetted. Jet of water spreads in a sheet.

point of contact they verified that the area was smooth. Measuring the strength of the tiny joint, they found that it had a shear strength equivalent to 14,000 pounds per square inch—as strong as the mica itself.

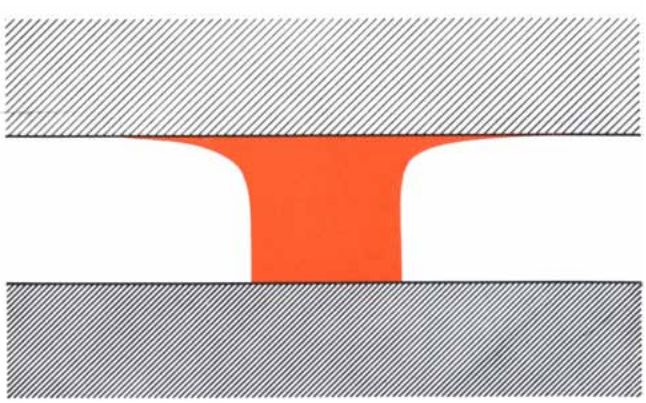
Two pieces of a solid in which the molecules are able to change places (as in glass close to the annealing temperature) or in which the molecules have an appreciable thermal motion (as in rubber and other elastomers) can also be joined by being placed in contact with each other. This, however, is a process more akin to fusion welding than to adhesion by surface forces.

Although solids can be made to stick together without any glue under special circumstances, in practice the extremely small separation necessary for adhesion is almost always achieved by introducing a liquid between the solid surfaces. The function of this liquid, or adhesive, is to adapt itself, in so far as possible, to the irregularities in both surfaces, establishing close contact with each. The effectiveness of a liquid adhesive can again be demonstrated with the beaker of water. A dry finger tip pressed against the glass is barely visible from the top; a wet finger tip completely frustrates total internal reflection and "breaks through" the mirror. After a liquid adhesive has established the necessary contacts it is usually made to solidify.

Not always, however. Some of the most common adhesives in use today are kept permanently liquid in form. These

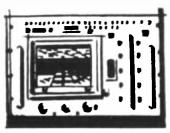


ATTRACTION resulting from capillarity (or surface tension) of a liquid between two plates that it wets pulls the plates together.



REPULSION results when a liquid between two plates fails to wet one or both of the plates. Bottom plate has not been wetted.

How will they see at 50 fathoms



In the shadowy underworld of the sea, U.S. submariners rely on a remarkable underwater eye to watch the course ahead.

The eye is part of a new Norden display system which combines the most advanced techniques of computers and television. At a single control station, the helmsman can watch pitch, roll, heading, speed, surface and bottom positions continually displayed on a 14-inch screen. At 50 fathoms, it charts a pictorial roadway beneath the sea.

The contact analog display was developed by our Norden division for the Navy from concept to hardware in less than 18 months. A similar unit is available for aircraft to guide pilots flying in all weather conditions.

Advanced electronic systems are only one example of the expanding product spectrum at United Aircraft. This pioneering corporation serves industry, commerce, and defense with unmatched research capability and the multiple skills of 60,000 people. United Aircraft is a significant and growing force in power, propulsion, nuclear energy, electronics, vertical flight, navigation, and controls.

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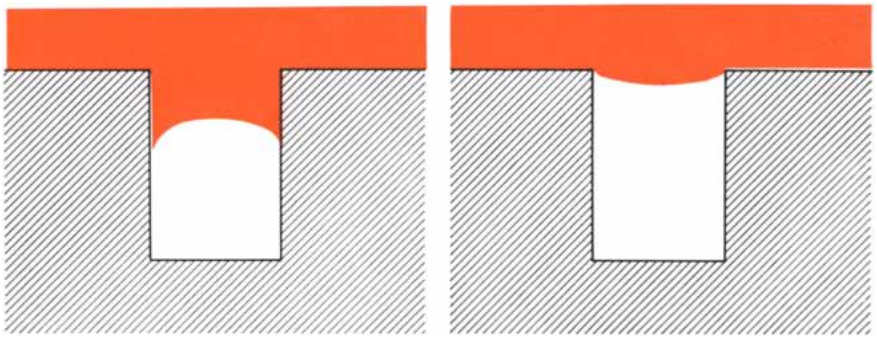
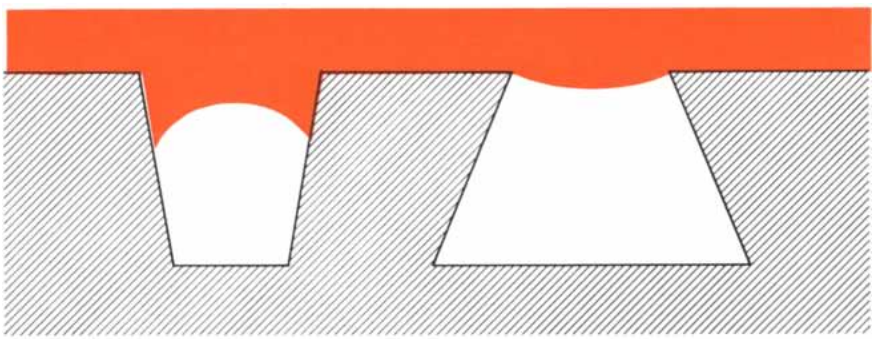
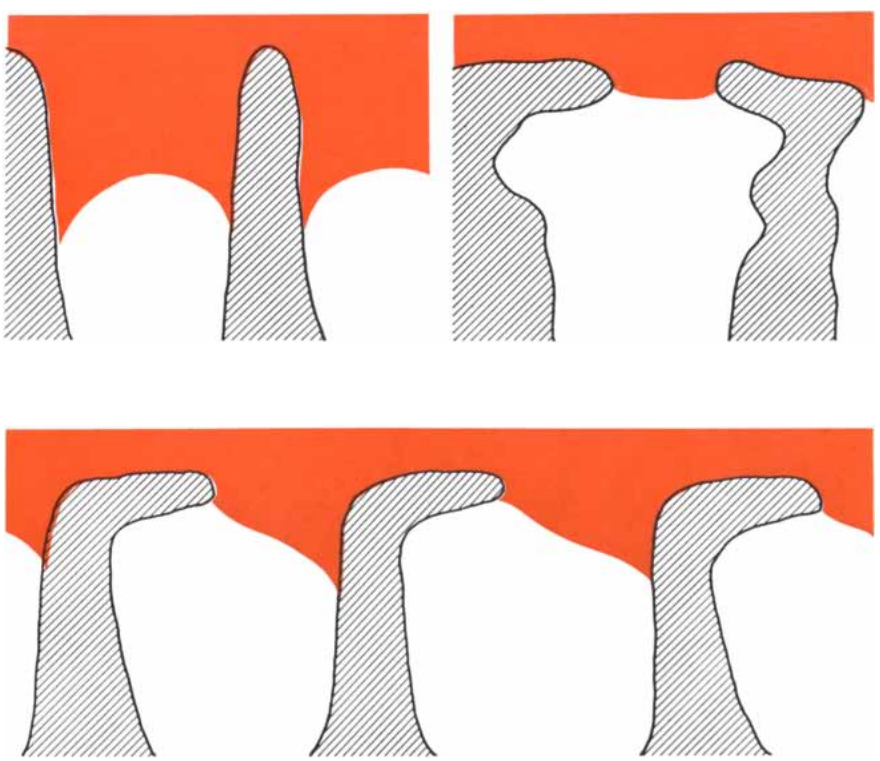


WETTING OR NONWETTING of a solid surface by a glue affects the penetration of the surface and thus the effectiveness of the bond. A glue (*color*) that wets the inside surface of a hole creeps into the hole (*left*), forming a good bond; a nonwetting glue does not (*right*).



"FLOWERPOT" AND "INK BOTTLE" PITS (*left and right respectively*) are depicted in cross section. Glue (*color*) penetrates the flowerpot pit until it is stopped by the pressure of the compressed air trapped in the pit. An ink-bottle pit prevents any effective penetration.



ADHESION OF GLUE AND WOOD is good if the angle between the sides of the wood cells (*hatched areas*) and the surface is roughly 90 degrees (*top left*). Adhesion is poor when this angle is less; i.e., when cells are burred (*top right*) or burred in one direction (*bottom*).

are the pressure-sensitive adhesives. By retaining their mobility they avoid one of the causes of poor adhesion—the locked-in, or residual, stress that is produced by contraction of glue as it solidifies. On the other hand, permanently liquid adhesives are never very strong and they creep under small loads.

Any fluid, even water or air, can act as a pressure-sensitive adhesive. The effect is nicely shown by a pair of flat, smooth objects, such as plate-glass disks, placed one on the other and immersed in water. If the upper plate is lifted, the lower plate will follow. If the lower plate is prevented from moving, a considerable resistance to separation will be experienced until quite suddenly the two surfaces come apart. The resistance to separation is caused by the viscous drag of the water as it creeps in between the surfaces from the edges. The closer the disks are pressed together initially, the longer it will take them to separate under a given force. Hence the name pressure-sensitive adhesives.

Because of their low viscosity and their volatility, simple liquids such as water are not suitable materials for pressure-sensitive adhesives. In practice such adhesives are made from highly viscous materials with complex flow properties. At room temperature they are far too viscous to flow between the surfaces to be joined. This difficulty is overcome by applying them in solution or as a hot melt to a tape backing, to which they adhere firmly. The discovery that one could roll up such a coated tape and then unroll it again was an apparently trivial observation that gave birth to a new industry.

The low mobility of pressure-sensitive adhesives prevents them from getting into good contact with a surface, but they stick tenaciously; when an attempt is made to peel the tape off, it is pulled down onto the surface just before it is torn away. This is because of the stiffness of the tape and probably also because of the movement of the adhesive toward the line of peeling. The effect can be demonstrated by pulling apart two tapes that have been stuck together over a small area. As they come apart, an area of close contact can be seen running ahead of the separation.

The example of the glass plates under water is not typical. Usually objects are glued together in air, and some part of the adhesive is in direct contact with air; the phenomenon of surface tension therefore comes into play. Surface tension is of the nature of a mathematical

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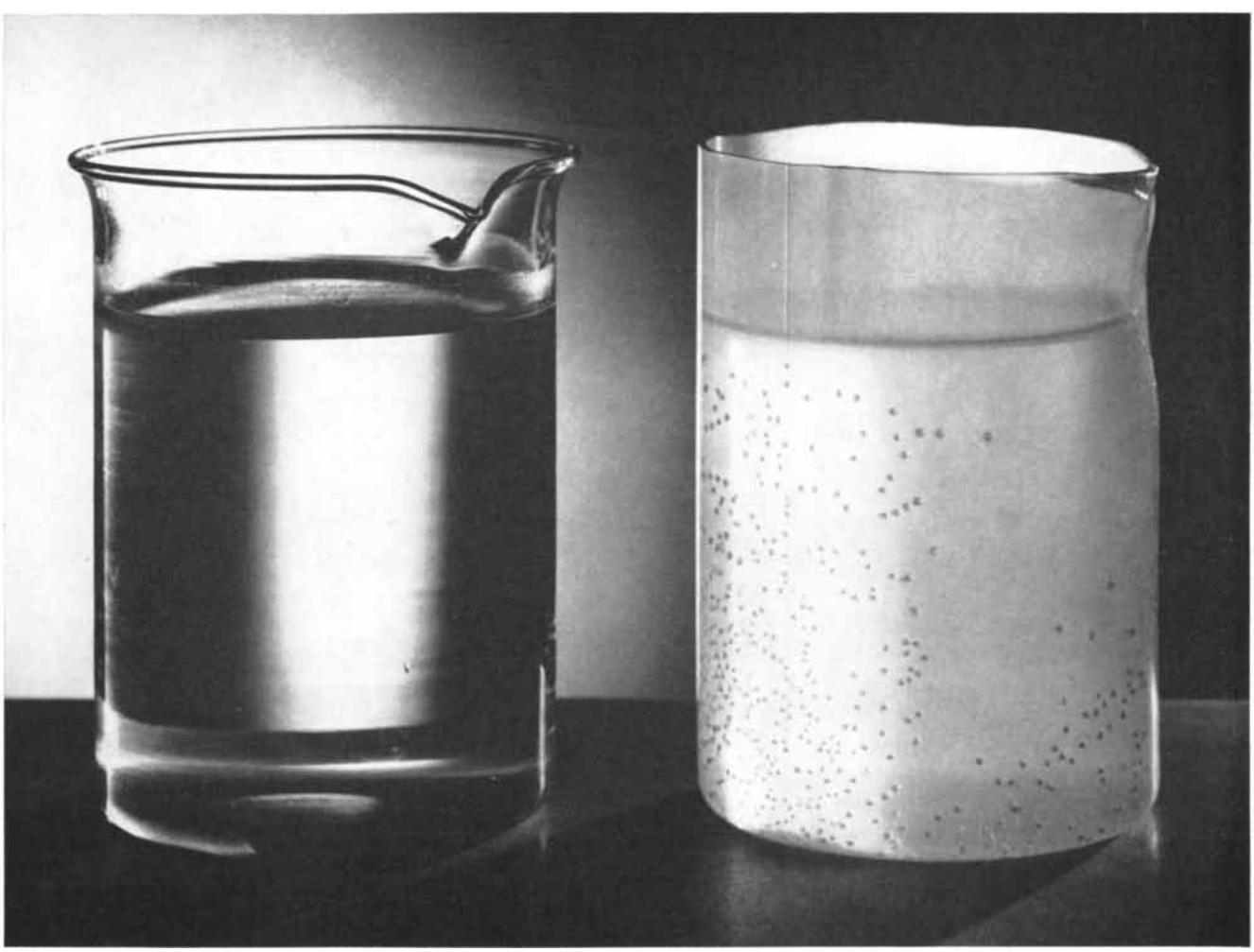
fiction—a convenient way of expressing the fact that each molecule at the surface of a liquid is subject to an unbalanced, inwardly directed force from the molecules inside the liquid. As a result the surface contains as few molecules as possible, tending to contract like a stretched elastic sheet. When a liquid is in contact with both air and a solid, surface tension can produce some interesting situations that are of importance in understanding the behavior of adhesives. Its effects can be decisive, even when the liquid is subsequently solidified. Consider first the effect of surface tension on a liquid of low viscosity between two flat horizontal plates. If the molecules at the interfaces of the liquid and the solid are attracted more strongly by the solid than by the liquid, the liquid wets the surfaces and tends to creep outward along them. Because the curved lateral surface tends to contract under surface tension, it pulls the plates strongly together. For example, a water film one-millionth of a centimeter thick generates a pressure of one ton per square inch. Such gigantic forces are involved even in the simple matter of attaching a postage stamp to an envelope.

On the other hand, surface-tension forces work against adhesion if the liquid does not wet one (or both) of the surfaces. On a nonwetted surface the water molecules are still influenced by their own attraction for one another. As a result the water tends to gather into a hemisphere and the surface will be pushed away [*see illustration below*]. If one attempts to stick a postage stamp to a polyethylene bottle, it soon wrinkles and drops off.

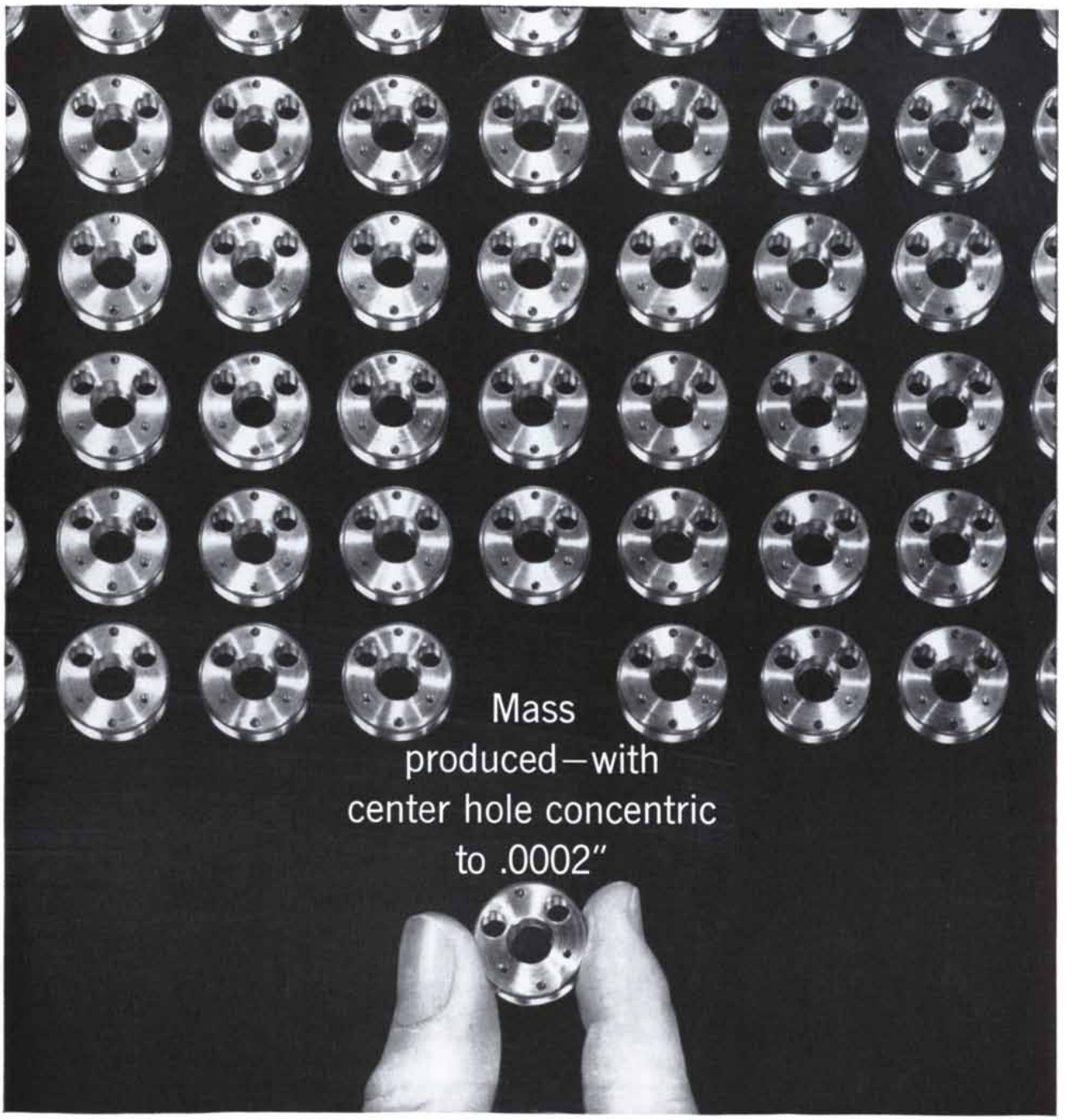
To make a joint strong enough to satisfy an engineer a liquid adhesive must be solidified, and this can be done in various ways. A solid, previously dissolved or dispersed in a liquid, can be allowed to dry out; this is possible only if one or both of the surfaces to be joined are either porous, as are wood and paper, or are themselves soluble in the solvent. To make strong joints between materials such as glass and metal requires a glue free from solvents. One type is a molten solid that refreezes in the joint (this might be called the sealing-wax approach). Another is a liquid in which, after it has been applied to the joint, the molecules can be made to polymerize or to cross-link with each other by the use of catalysts, reactive chemicals or heat.

In order to produce a good joint, the adhesive, while still in the liquid state, must wet the surfaces that are to be joined. Just why this should be necessary in a solidifying glue is rather puzzling. The reason is probably that an adhesive cannot penetrate the valleys of a solid surface unless it meets the surface at a small angle, which it does only if it wets the surface.

Penetration depends not only on contact angle but also on the shape of the pits in the surface. If they are "ink bot-



SURFACE-TENSION FORCES work against adhesion when a liquid does not wet the surface it contacts. Glass and polyethylene beakers seen here contain water several hours old. Part of the latter (*right*) has been exposed to chromic acid. Water wets glass and exposed portion of the polyethylene, "creeping" in behind air bubbles formed on the surfaces and enabling them to escape. The unexposed portion of the polyethylene is not wetted: surface tension acts to push nonwetted surface away and bubbles cannot escape.



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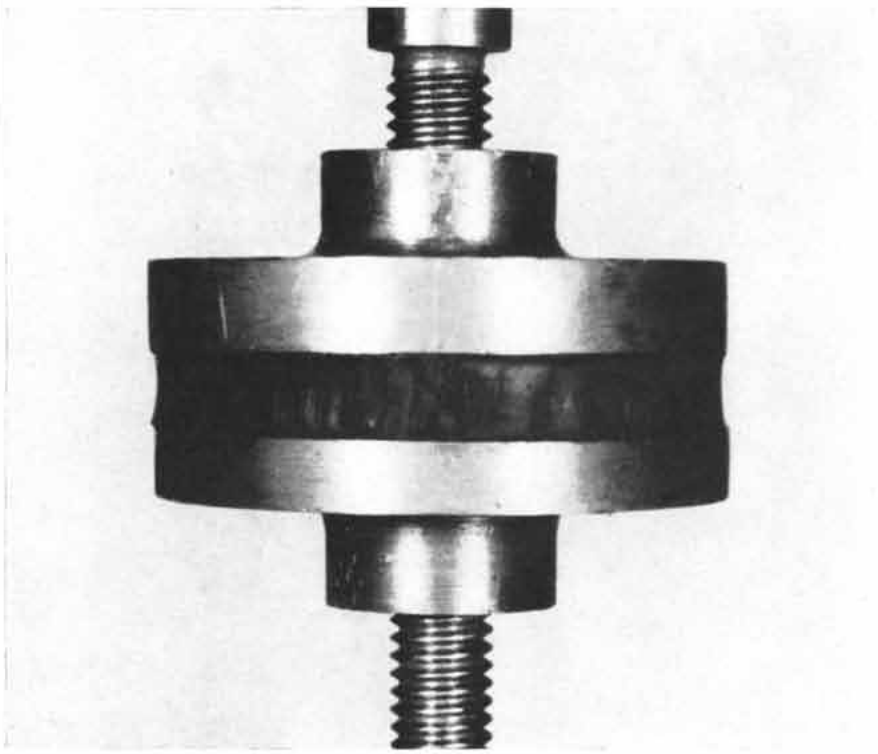
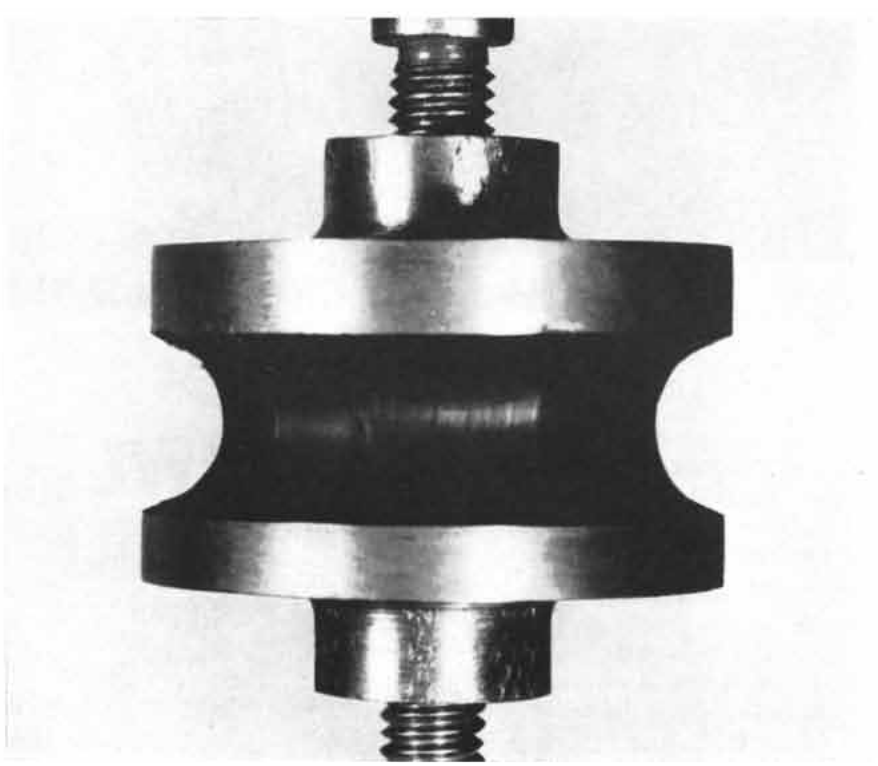
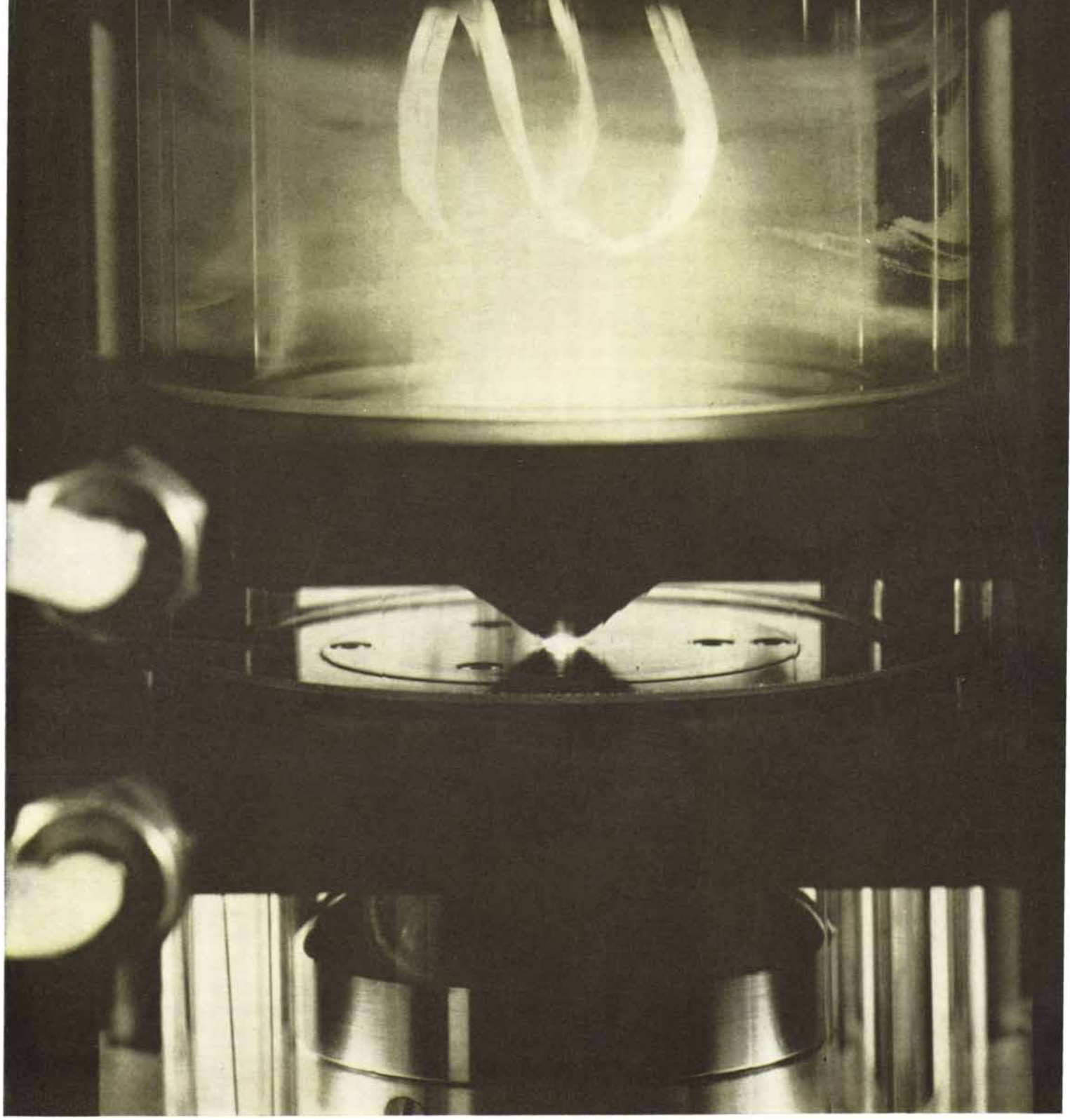
tle" pits—narrower at the top than at the bottom—the adhesive can hardly penetrate [*see second illustration from top on page 118*]. Ink-bottle pits are often produced when the ends of wood cells have been burred over, and a wood surface made up of such cells will produce a joint having practically no resistance to stripping or peeling loads. The only effective remedy is to sand off the burred tops of the cells, as was discovered in England before World War II by C. A. A. Rayner of Aero Research Ltd. After some serious accidents





UNEVEN DISTRIBUTION OF STRESS in a rubber-to-metal joint under an applied load is reflected in the constriction of the circumference of the rubber portion. The photograph above shows the joint before any load has been applied; that below, the effect of the load.



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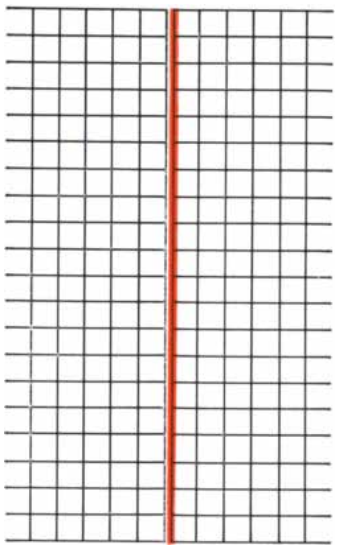
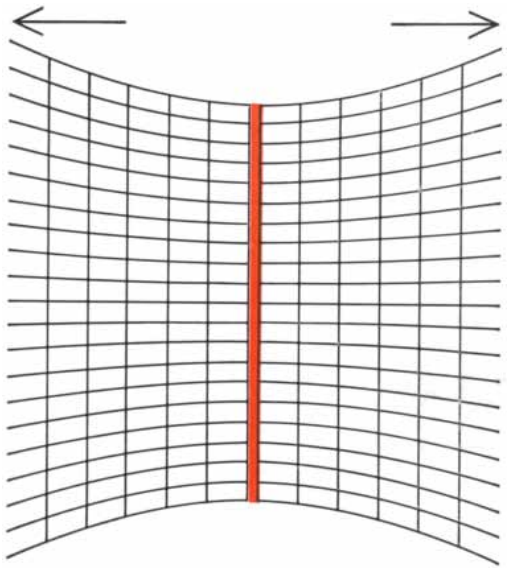
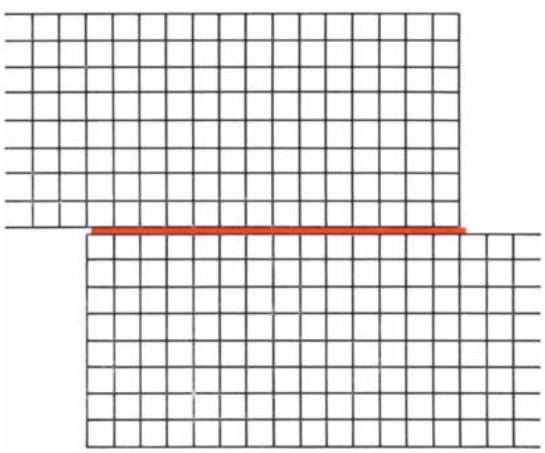


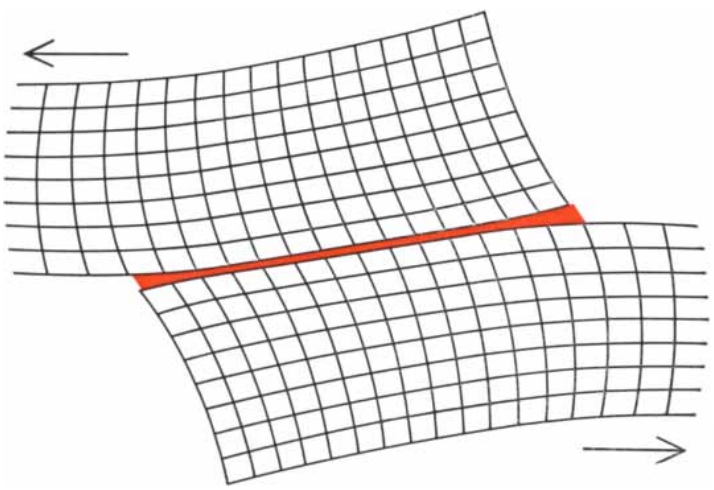
BUTT JOINT is depicted here in two dimensions as it might look before (*left*) and after (*right*) being subjected to an applied load.

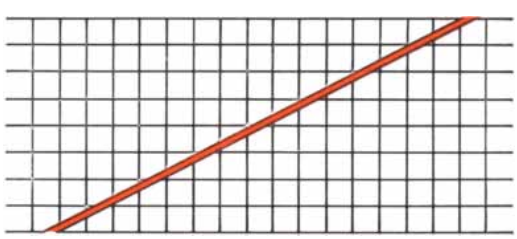


Arrows indicate the directions of stress; the constriction in the center, the nonuniform distribution of stress across the area of the joint.

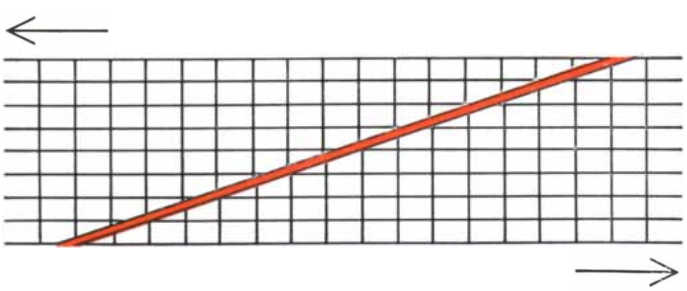


LAP-JOINT ADHESIVE (*color*) under an applied load is strained chiefly at both ends. One component of the stress results in a shearing motion, which tends to slide the two portions of the joint over each other; a second component acts to force the joint open.





SCARF JOINT is far stronger than either a butt joint or a lap joint (*see illustrations above*). This is a type of joint in which the two adherent materials are tapered off so that they stretch uniformly throughout the length of the joint when subjected to an applied load.



during the war the sanding of all aircraft plywood was made mandatory.

If the pit is shaped like a flowerpot rather than an ink bottle, a liquid adhesive will move down into the depression, compressing the air that previously filled the space. Here the limit of penetration is reached when the force of the surface tension pulling the adhesive into the pit is balanced by the pressure of the trapped air bubble.

Good wetting, then, is one of two major requirements for a solidifying glue. The other is that the adhesive must not set up excessive residual stress on solidifying. The process of solidifying always involves some change in volume, which produces a locked-in stress in the joint, tending to weaken it. If the adhesive were free to contract, no stress would be set up as it solidified. But it is not free because it is anchored to the solid surfaces, which keeps the glue in a state of tension and the glued pieces in a state of compression. In a long joint there is inevitably a high shear stress in the interface between the adhesive and the adjacent surfaces at each end of the joint.

In addition to the stress caused by solidification, glued joints are subject to the forces produced by externally applied loads. Differences in the elastic and plastic properties of the adhesive and the pieces it joins usually cause some concentration of stress. A model of the distribution of forces in typical joints under load is provided by large-scale joints cut out of soft plastic sheets [*see illustrations on opposite page*]. The glue itself is represented by a line drawn on the sheet. As the illustrations show, in a lap joint the adhesive is mainly strained at each end, in part by a shearing motion, tending to cause the two portions of the joint to slide over each other, and in part by a tearing force, tending to open up the joint. The result of this lack of uniformity is that while the strength of a lap joint increases with increase in width, it does not rise in proportion to increase in the overlap, and it is influenced by the thickness of both members of the joint. Tension joints also show a nonuniform stress distribution across their area. A scarf joint, in which the two sides are tapered so that they stretch uniformly throughout the length of the joint, is a far stronger arrangement. Uneven concentrations of stress imply that the ultimate breaking strength of a glued joint, even if rupture takes place at the interface, is not in general a measure of the strength of the adhesive bond. For example, lap

joints of copper are usually weaker than those of steel, even though glued with the same material. The disparity is probably due to the greater extensibility of copper rather than to any difference in the intrinsic strength of adhesion.

About five years ago there became available a new class of adhesives with properties far superior to any of the older types for many purposes. These are the epoxy resins. They are formed by mixing together two materials, each composed of small molecules that link together by spontaneous chemical reaction. The resulting long-chain, cross-linked polymer is a strong, hard solid rather like bakelite, containing side groups that promote electrical attraction to other molecules. Before polymerization the liquid mixture has a low viscosity, so that it flows easily between the surfaces to be joined; moreover, it is a good wetting agent and therefore penetrates pits in the surfaces. The process of solidification depends neither on evaporation nor on oxidation; hence it can take place throughout a joint between two large pieces of metal or other nonporous material. No gas is evolved, which means that no bubbles weaken the solidified adhesive. Finally, there is very little shrinkage and therefore a minimum of locked-in stress.

Because epoxy resins polymerize spontaneously, their components must be stored separately and mixed shortly before use. Once applied, they set slower than many other types of glue. This is advantageous in some applications but undesirable in others. The setting time can, however, be shortened with heating.

Epoxy resins provide the engineer with entirely new possibilities of construction. In thin gauges glued metal joints can be far stronger than riveted or spot-welded joints. More important, they have much greater resistance to fatigue. (As a corollary, riveted joints can be reinforced by gluing laminated sections across them.)

The ability to glue metals is a particular boon to the airplane builder, who has acquired a new weapon against fatigue failure and a new freedom in design. He can now thicken a structure by lamination without the expense of machining from the solid. And lamination prevents the rapid propagation of cracks to which one-piece structures are subject. Glued metal parts are to be found in many modern aircraft.

The list of applications is large and still growing. Newton's prevision has been amply confirmed.

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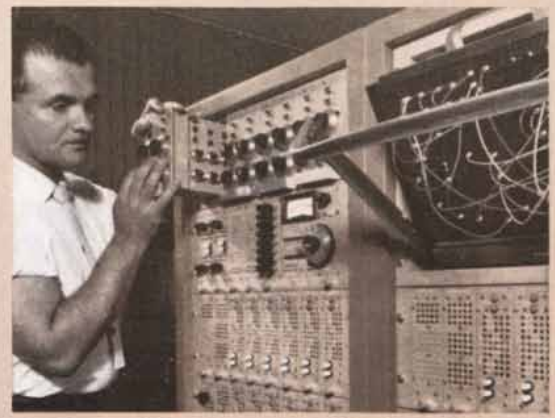

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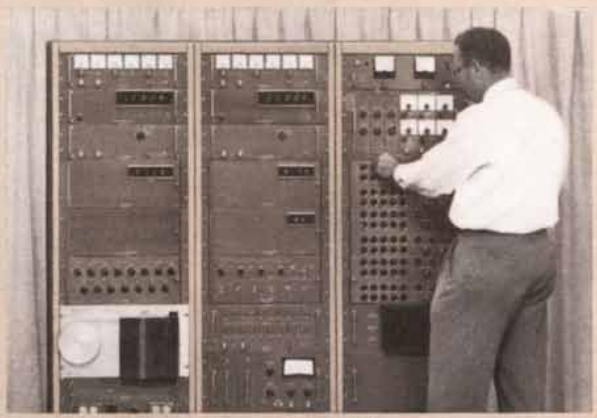

This digital data acquisition system built for North American Aviation is an example of Systron systems capability. It measures up to 140 temperatures and 60 strain or motion inputs every few seconds and records them for computer analysis on perforated tape. A built-in design feature is the system's ability to trouble-shoot its own faults.

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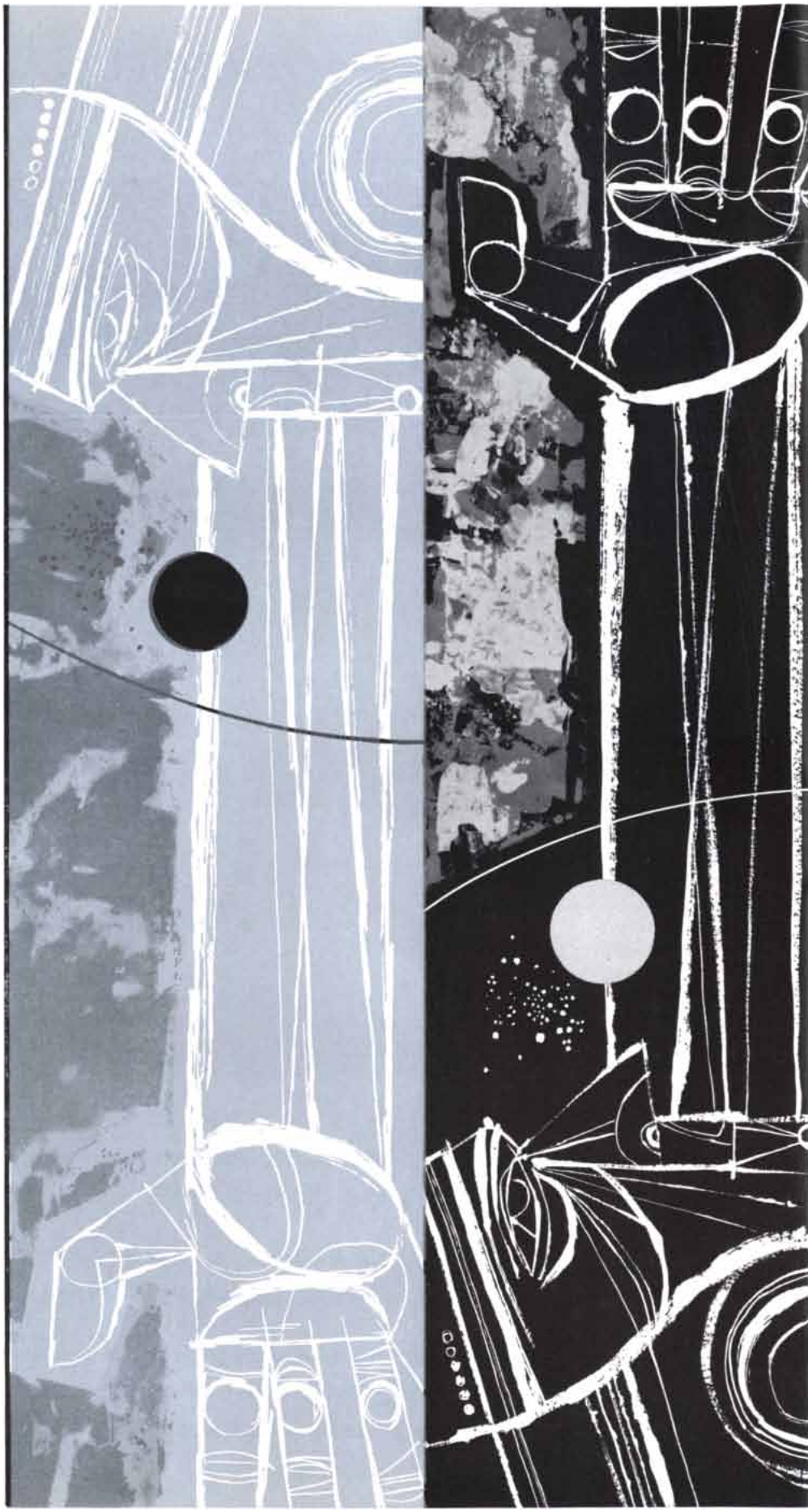
MIRROR

NO. 3 IN A SERIES OF SCIENCE-FICTION ORIGINALS CREATED EXPRESSLY FOR HOFFMAN ELECTRONICS CORPORATION

by FRITZ LEIBER



Hooking his thumb to the mirror-bright panel to provide a fulcrum for his weightless maimed finger, Wolfe pushed the final button. Ions swirled invisibly around the transparent sphere holding Barr and himself.

While the ions built the field, he looked out at the globe of Earth, about as big to his eye as a breakfast grapefruit, but this grapefruit was powdered with clouds and set before him on a black tablecloth of stars.

Barr said, "Twenty thousand miles of hard vacuum should be enough insulation." Wolfe nodded absently at Barr's reflection in the panel.

If the new equations had been read rightly, the climax field would plunge them into the hypothetical spherically-curved, four-dimensional world wherein our whole universe is only a quivering globular surface. Then it would whisk their thin three-dimensionality through the hypersphere as a crack speeds across glass and as swiftly as a man can swing a flashlight from one star toward another.

Finally it would pop them out of the Riemannian hyper-continuum into unoccupied space two light years from the solar system and in the direction of the tiny constellation of the Pleiades. After they had made brief confirmatory observations, a simple reversal of the process would bring Wolfe and Barr back near their starting point—if the new equations had been rightly read.

As the ionic swirl became a blizzard, a dull black, dense monomolecular layer built up from the positive to the negative pole of the transparent sphere. This opaque outer plating was an unavoidable side-effect of the process. First Earth, then Luna, then Sol was blotted out and the stars around them. The last constellation to be obscured was the Pleiades. Wolfe said a silent farewell to the Seven Sisters, though out here he and Barr could see sixteen.

The field neared climax. Wolfe gently rubbed the lopped-off first joint of his right forefinger—which was his

only outward expression of tension.

A nervous grin quirked Barr's lips in the mirror. He said, rather loudly, "I don't care how confident the math boys are, we still must be prepared for any species of disorientation. Did you ever read about the German psychologist who wore lenses that turned everything upside down? After a couple of days his brain accommodated and he saw everything—still through the same lenses—as right-side up. Then when he finally took off the lenses . . ."

A gust of cosmic change swept through Wolfe and Barr with no immediate perceptible effect on them or their vehicle except that two telltales on the panel flashed green, one of them blinking.

Wolfe touched another button. The blinking ceased as deplating of the opaque layer began, the molecules flying off in exact reverse of the order in which they had been laid down. The two men watched the spot where the stars would first show.

"The Pleiades!" Then Barr's voice changed. "But something's happened to them." He laughed oddly. "They're not upside down, at any rate!"

"No, but they're reversed right-to-left," Wolfe said quietly, "The translation effect seems to have been somewhat greater than anticipated. We appear to be not two light years away from Earth, but 440—twice the distance of the Pleiades—and we are seeing them from the opposite side."

When Barr did not reply, Wolfe continued methodically to spell out the obvious, to steady his comrade. He said, "This is possible with the Pleiades since they are an actual group of stars, physically close to one another. It would not be true of most other constellations, whose member stars differ widely in their distance from Earth. For instance, there is no place on the other side of Ursa Major or Orion whence one can see the Dipper or the Hunter reversed."

Deplating continued. The agelessly familiar constellation of Orion appeared, but to the right of the Pleiades, not to the left as one sees it looking southward from Earth's northern hemisphere, and Bellatrix and great yellow Betelgeuse were reversed, and the Sword hung the wrong way from the Belt.

Barr said softly, "This sight is impossible in our home continuum. We appear to have been translated along a diameter of the great Riemannian hypersphere to the mirror-image universe which Muawiya hypothesizes as lying at the fourth-dimensional antipodes." And now it was Wolfe's turn not to reply.

Deplating went on. Fierce Sol appeared, and Luna, and then quickly Earth showing the Americas—but Florida hung from the west coast and Baja California from the east, while by the narrow, near-invisible twig of the Isthmus of Panama, South America hung to the left of the northern continent, and the Caribbean opened into what should have been the Pacific.

"Since the mirror universe duplicates ours in detail," Barr said, "our twins must just now have materialized near our home planet—a mirror you and a mirror me."

"Wait," Wolfe said sharply. He was staring at himself in the mirror-bright surface of the panel and holding out his hands. At first he thought all was as it had been: his right forefinger was the one lacking a joint. Then he reminded himself that plane mirrors give a reversed image, and he looked down directly at his hands. His left forefinger was the lopped one.

"Wait," Wolfe repeated to Barr and pointed to the maimed forefinger. "Since we've been mirror-reversed ourselves, we can't be in a mirror universe, because if we were, it would appear normal to us.

"The new equations were misread completely: they don't refer to translation but to reversion. We have only moved through the fourth dimension enough to accomplish a dextro-levo reversal in our bodies—yes, and in our vehicle too, since—look!—the panel's console pattern is still normal to us. But with respect to the Earth we haven't moved a fourth-dimensional micron."

He took a breath. "Besides," he added more coolly, "it better satisfies the Law of the Conservation of Reality to assume a mirror-reversed microcosm than a similarly reversed macrocosm."

Barr sighed, possibly with relief. "And so all we have to do to unkink ourselves," he said, "is to make our 'return journey' as planned."

"Yes," Wolfe allowed, "but I for one don't approve of running needless risks. Besides, I fancy it would be wise to present the math boys with some more physical proof of the mirror-reversal than our unsupported word. They were *so* positive about their reading of the equations. Barr, what happened to your German psychologist when he took off the lenses?"

"Why, he'd got so used to them that the world looked upside down again. But it straightened out, I mean inverted back to normal, after a couple of days."

Wolfe nodded. "We ought to be able to stand mirror-image people and a mirror-image environment for a couple of days, don't you think? He waited a moment, then turned to the panel's communication sector to raise Earth. He added, "If adjustment proves too troublesome we can come out here and unkink—though I'd enjoy always having a complete right hand."

Barr said, "We'll have to remember to tell our doctors our hearts lie to the right now. I'll spend a bit of the next two days simply being thankful I'm not a virtual man in a virtual world."

Wolfe nodded and said, "Let's shake on that." The two men automatically gripped left hands. And a voice came from the panel, saying: "snoitalutargnoC!"

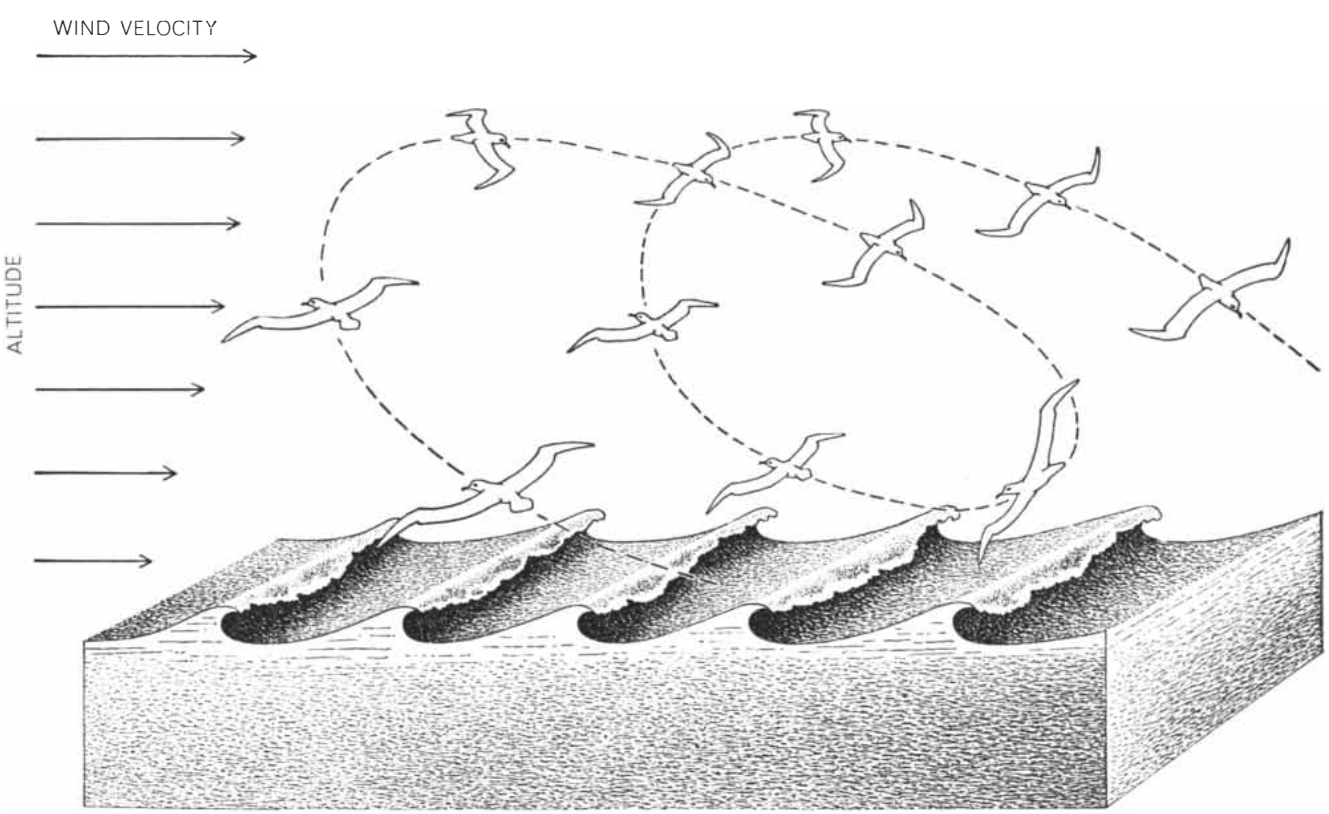
The Soaring Flight of Birds

The effortless circling flight of vultures and similar birds depends on their aerodynamic efficiency and a meteorological phenomenon: air currents in thermal cells powered by the sun

by Clarence D. Cone, Jr.

The majestic and effortless flight of the soaring land birds—the hawks, eagles and vultures—would seem to challenge the laws of physics as well as the poetic imagination. Typically a flight begins with a vigorous beating of the wings, which carries the bird to an altitude of about 100 feet. Then something happens. The bird now alternates the flapping of its wings with long glides as it turns in circles and continues to climb. At 400 to 500 feet all flapping ceases and the bird wheels upward to greater altitudes on motionless wings. If a wind is blowing, the steady circular orbits of its flight appear as a series of loops extending downwind. From the peak of its ascent, from 6,000 to as high as 10,000 feet, the bird begins a long glide on partly folded wings. Then it spreads its wings and again soars aloft on another spiraling course. In this way, alternately soaring and gliding, the bird reconnoiters large areas with almost no expenditure of its own energy for propulsion.

The flapping flight of birds has always been intuitively understood: the beating of the wings clearly generates the forces that sustain and propel the bird. Intuition has not served nearly so well to explain the invisible force that directs and powers soaring flight. It is commonly thought, for example, that the bird extracts energy from the wind on its wheeling flight by exchanging speed, gained on the downwind side of the circle, for altitude on the upwind side. But this notion collides with the uncompro-



DYNAMIC SOARING is based on nonuniform wind velocities, as in wind-shear layers over the ocean. Sea birds soar in these layers. The wind-velocity gradient (*indicated by arrows*) allows the bird to maintain its air speed and hence its lift even as it loses ground speed on the upwind, climbing leg of its flight. Without the gradient the bird would lose altitude and potential energy with each loop.

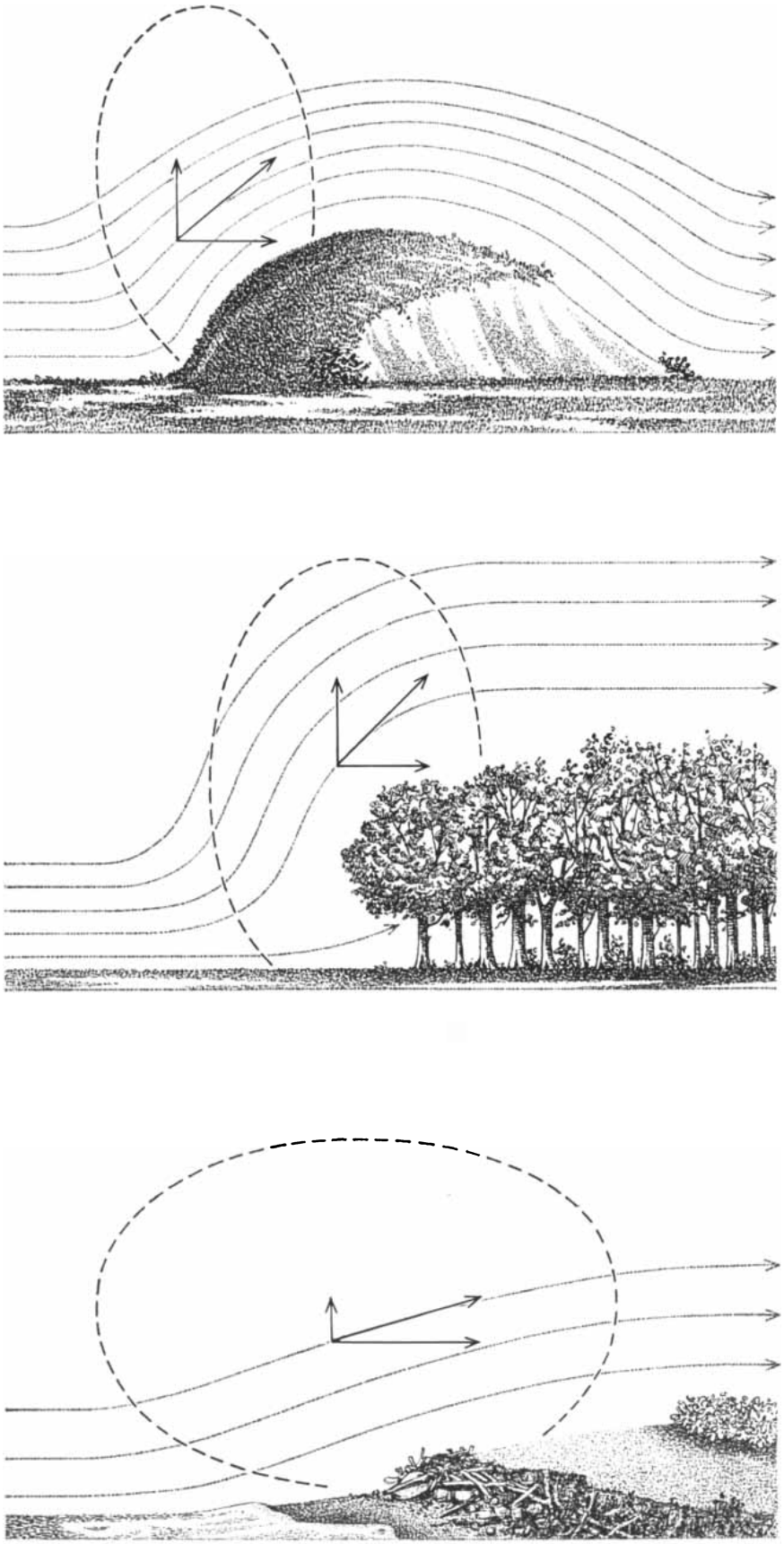
mising laws of mechanics. A more sophisticated idea is that the bird flies upward on a column of air rising from the sun-warmed ground. This comes somewhat closer to the mark—but then soaring birds are often seen aloft when the air shows no sign of motion at the ground.

The question of what powers the flight of soaring birds has proved to be an important one. The right answer—forthcoming from careful observation of the patterns of natural soaring flight—has helped to lead the way to the discovery of a fundamental mechanism of meteorology.

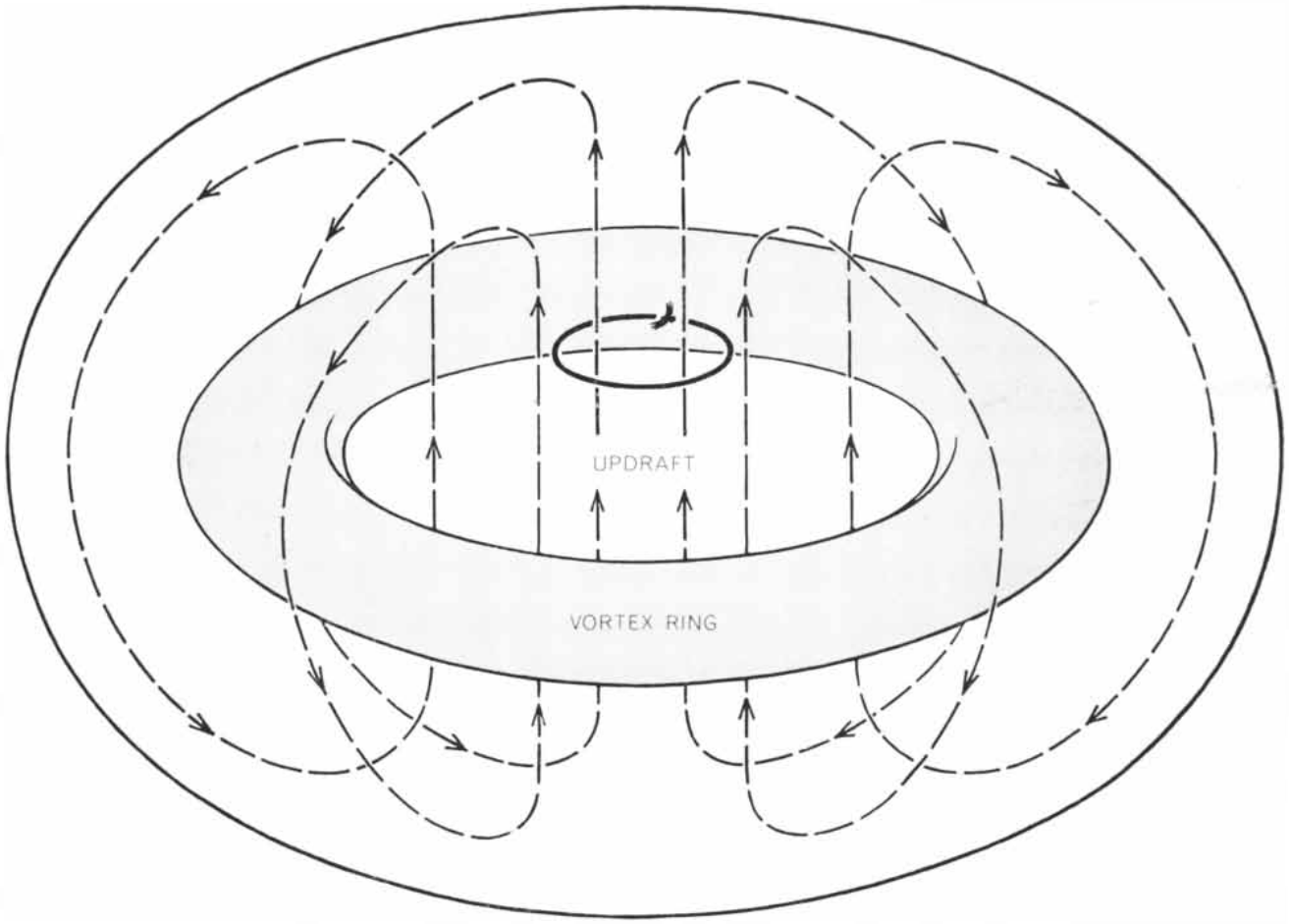
It turns out that the birds are carried aloft in great bubbles of buoyant air that boil upward from the warm earth in the course of the day. But this is only part of the story. The energy that sustains their circling flight within these "thermal shells" is made available by the highly structured circulation of the entrained air, and the geometrically ordered flight of the birds is itself one of the most obvious indications of this circulation. From observation of the birds, from the theory of fluid dynamics and from laboratory experiments has come a picture of the invisible thermal shell. This picture shows the shell to be a closed body of circulating air. In its interior is a doughnut-shaped vortex ring of warm air that pumps a continuous flow of colder air upward through its center and downward on its periphery.

This is the true nature of the "thermals" referred to by airplane and sailplane pilots and the explanation of the turbulence, or "bumpy air," encountered by aircraft flying at lower altitudes. The thermal shell constitutes one of the principal mechanisms by which the radiant energy of the sun powers the vertical motions of the atmosphere.

As long ago as 1883 Lord Rayleigh showed that for soaring flight to be possible one of two conditions had to exist. Either the air must have a horizontal velocity nonuniform in space or time, or it must have a local upward velocity. The soaring sea birds, such as the albatross, find the first of these conditions satisfied at sea, and they are able to soar with great ease and certainty, sometimes for thousands of miles, in the extensive and steady wind-shear layers over the open oceans. The mechanics of this "dynamic" soaring has been well understood for many years. Friction slows the wind at sea level and just above it, with the result that the wind speed increases through the first 50 or 100 feet above the waves. It is from this gradient in velocity



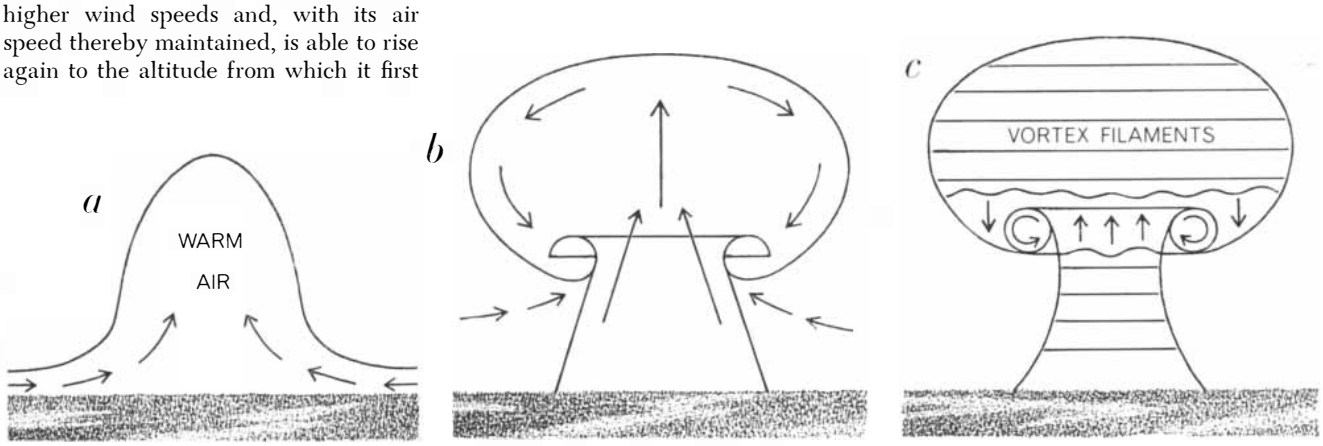
DECLIVITY CURRENTS power one form of static soaring. Such currents are generated when wind is deflected upward by an obstruction: a hill (*top*), a forest (*center*) or a beach (*bottom*). The vector arrows show how the strength of the upward current is related to the velocity of the wind and the angle of deflection. The broken lines indicate soaring zones.



THERMAL SHELL is composed of a vortex ring (*torus, or doughnut*) around which a current of cooler air circulates in closed streamlines (*broken lines*). The soaring bird flies in a circle the radius of which gives the bird an aerodynamic sinking velocity exactly equal to the velocity of the updraft. In this equilibrium position within the shell it is carried aloft as the shell rises.

that the albatross extracts the energy for its flight. The bird glides downwind, converting potential energy to kinetic energy and picking up air speed as well as ground speed. Just above the waves it wheels into the wind, acquiring initial lifting acceleration from an abrupt increase in wing incidence, or angle of attack. As the bird rises it encounters ever higher wind speeds and, with its air speed thereby maintained, is able to rise again to the altitude from which it first descended on its glide without any expenditure of its own internal energy. In this manner it can travel on motionless wings for hours on end. A related kind of dynamic soaring is accomplished, although infrequently, by land birds when they take advantage of the changing horizontal velocity in gusts of wind.

The vertical currents that make possible "static" soaring arise from two sources. The first is the declivity current, caused when the wind is diverted upward over obstructions such as hills and forests or the dead-air layers that form along seashores. Although such currents are often dependable, their lo-



STAGES IN DEVELOPMENT of a thermal shell are diagramed. Warm surface air rises (*a*) and forms a bubble (*b*). Turbulence develops at the surface of the bubble, forming twisting filaments that quickly coil themselves into a toroidal vortex ring much like

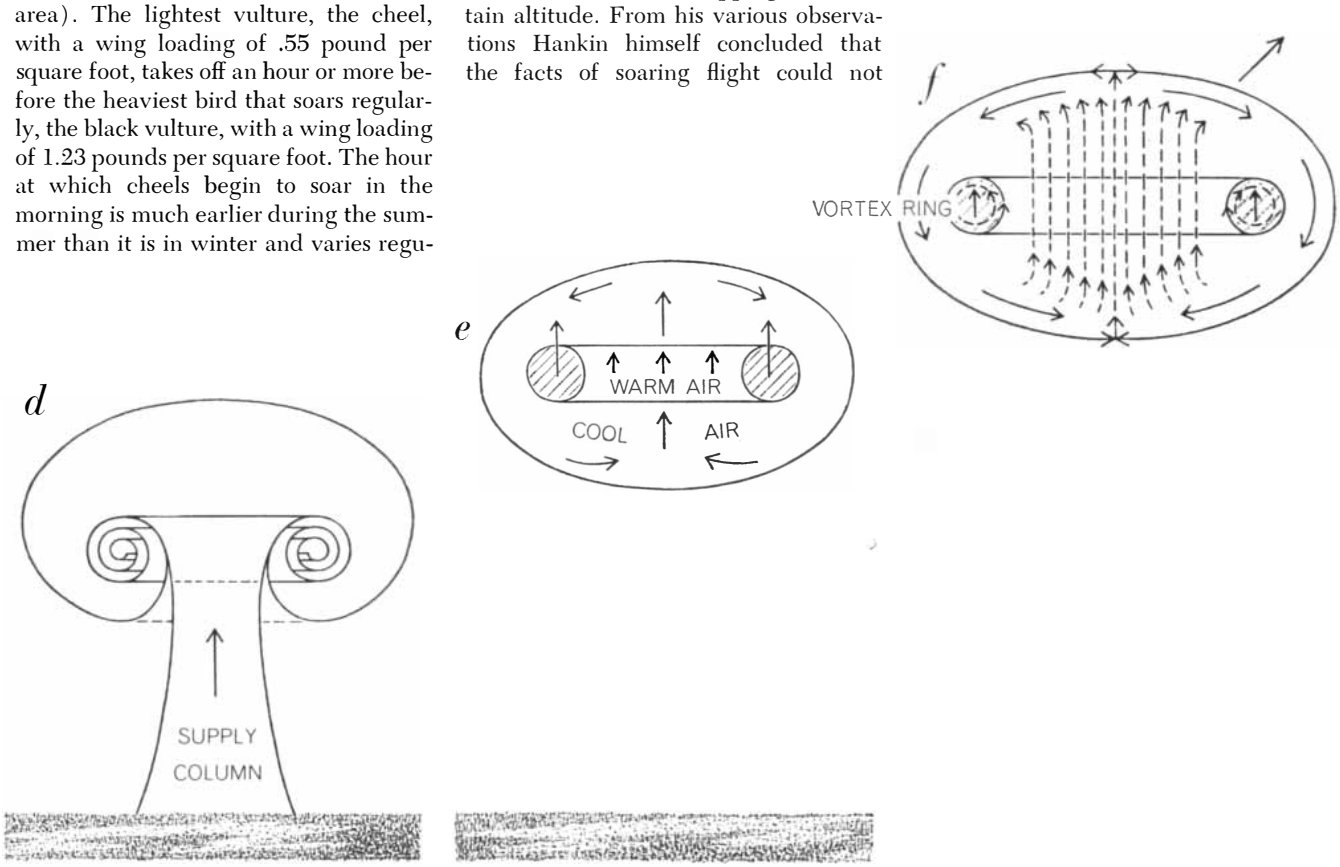
cation is always fixed. Soaring in them is accordingly limited to the immediate vicinity of the topography that generates them; sea gulls, for example, are often seen soaring in the declivity currents that rise over beaches. It is apparent that declivity currents can be of little use to the soaring land birds, whose primary flight mission is to scan large areas in search of food. The evolution of birds capable of this wandering flight required the use of a more nearly ubiquitous source of vertical air currents. That source is sunshine and the thermal shells it generates in the atmosphere over all the land areas of the earth.

Many of the descriptive details of soaring flight were clarified by the extraordinarily complete and accurate observations made in India by a British chemist, E. H. Hankin, between 1910 and 1913. The great variety and abundance of Indian vultures made it possible for Hankin to record and generalize many of the basic features of natural soaring. He found, as have later observers, that the ability of the air to support soaring flight bears a definite relation to the presence and intensity of sunshine. As the sun rises in the morning, the different species of vulture begin to soar in the exact order of their wing loading (the bird's weight divided by its wing area). The lightest vulture, the cheel, with a wing loading of .55 pound per square foot, takes off an hour or more before the heaviest bird that soars regularly, the black vulture, with a wing loading of 1.23 pounds per square foot. The hour at which cheels begin to soar in the morning is much earlier during the summer than it is in winter and varies regularly with the time of year. Certain larger birds, such as the adjutant (wing loading, 1.54 pounds per square foot) and the crane, can soar only in the summer, and then only for a few hours during the hottest part of the day. Clearly sunshine is the basis of the soaring practiced by these birds.

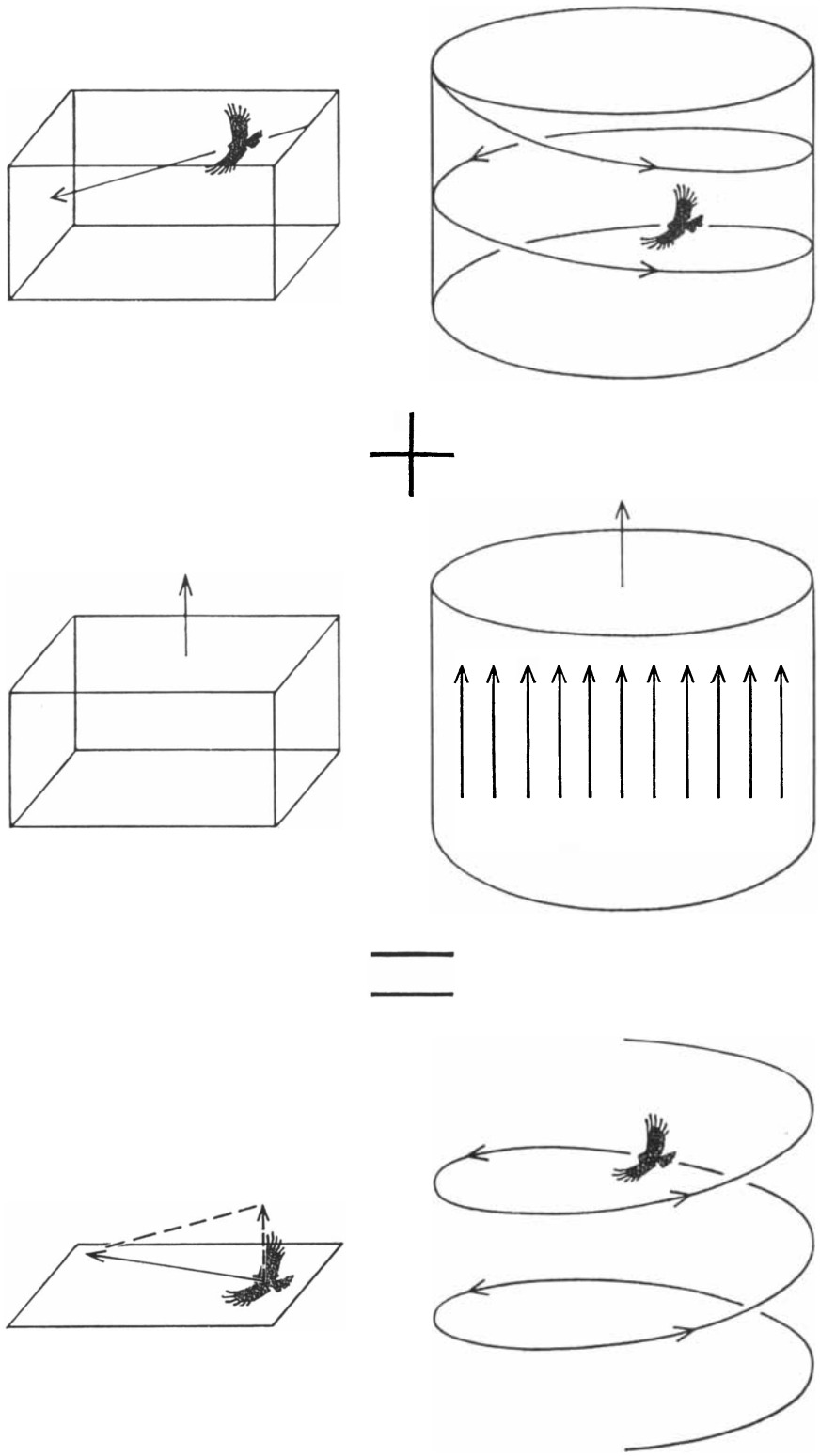
Hankin's careful records also included a number of observations that, in the light of later interpretations, have cast doubt on the idea that the birds circle upward in continuous columns of heated air rising steadily from warm spots on the ground. An appreciable ground wind would be required to supply an inflow of warm air at the bottom of such a column. Hankin noticed that, on the contrary, by far the best soaring conditions occur when the air at the ground is completely calm, disturbed only by an occasional gust. A continuous column would also be expected to produce the strongest updraft close to the ground. Hankin observed, however, that the largest vultures never soar near the ground but always do so at higher altitudes. Finally, he reported that he often saw a group of vultures soaring with ease high above another group, directly below it, that had to resort to continuous flapping to maintain altitude. From his various observations Hankin himself concluded that the facts of soaring flight could not be explained by columns of rising air.

The mechanism has proved indeed to be far more complicated. Deduction from theory has supplied the essential details. These have been confirmed by tests on the formation of free thermal shells from the hot gas clouds of explosions and by laboratory experiments with the convection of fluids of different density. Quite independently of these studies, my earlier investigation of the flight of soaring birds led me some years ago to postulate the structure and dynamics of the thermal shell much as it is now established.

As the sun shines on the earth the absorbed energy is transformed into heat, and the surface temperature rises. The air layer next to the ground is warmed and becomes less dense than the cooler air above it. As this layer, which is usually moving slowly over the surface with the prevailing wind, becomes warmer and more moisture-laden, its equilibrium becomes unstable. Finally some triggering action, such as a local overheating, upsets the equilibrium of the layer and the warm air begins to penetrate the colder air above. The initial protuberance grows rapidly as air from the warm layer flows into it, and a large bubble of warm air forms.



a smoke ring (*c, d*). The buoyant mass of warm air is pinched off at the ground by inflowing cool air and floats away (*e, f*). As it rises it entrains some of the cool outside air, which circulates up through the center of the ring and down around the outside of it.



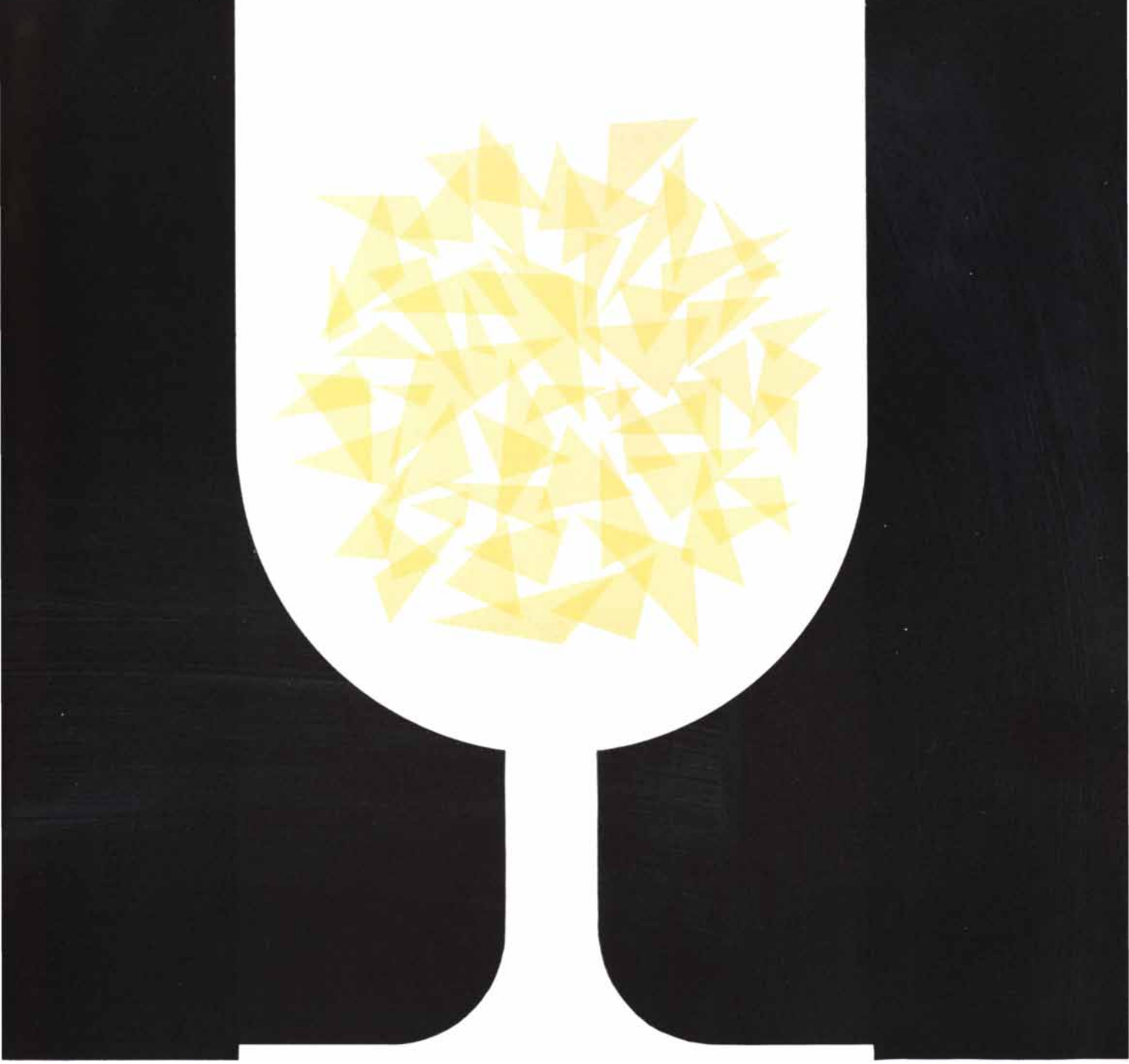
BASIC MECHANISM of static soaring is shown in the vector diagrams at the left. The upward flight of a bird is the resultant of its sinking velocity within an air mass and the upward velocity of the air. The schematic drawings at the right show how this works in the case of thermal soaring: the bird circles downward through the steady updraft that circulates within a rising thermal shell. The bird's final path takes the form of an upward helix.

As the warm air layer becomes exhausted, cool outer air settles in and pinches off the bubble, which then begins to rise and float along with the wind in the manner of a free balloon. This bubble may contain from a few cubic feet to many millions of cubic feet of warm, buoyant air. On a sunny day the earth's surface is like the bottom of a kettle of gently boiling water, with buoyant air masses rising from many points exactly like the vapor bubbles and for exactly the same reasons.

These bubbles, or thermal shells, are in effect self-contained meteorological systems with a complex structure and internal dynamics of their own [*see bottom illustration on preceding two pages*]. As a bubble rises, a shear layer develops at the discontinuity in velocity that marks the boundary between the buoyant mass and the relatively still outside air. This layer of turbulent air reacts on itself and ultimately coils up into a single large vortex ring, a torus of revolving air that, if it were visible, would look like a giant smoke ring. Soon all the warm air becomes concentrated in this ring and rotates in concentric circles around its circular axis.

This vortex ring has a remarkable property: it does not rise alone but gathers and carries along with it a larger external body of colder air. As the entire system rises, the cooler air circulates around the vortex ring in closed paths, rising rapidly through the center and moving down (with respect to the ring) more slowly on the outside. It is the compound upward motion of the cell and the air within it that makes the energy of sunlight available to power the flight of soaring birds.

In still air a bird obtains the necessary power for gliding flight by sinking toward the earth, much as a sled gains energy from gravity to overcome friction and pick up velocity as it coasts downhill. If the air through which the bird glides is rising from the earth faster than the bird is descending through it, the bird will gain altitude. The energy to power the gain in altitude comes from the vertically moving air. A portion of the rising air current is slowed in velocity as it flows over the bird's wings, and the kinetic energy lost by this air is imparted to the bird and is used to overcome the drag on its wings and provide energy for the climb. The motion of the bird as seen from the ground is the sum of its motion through the air (which is exactly the same as if it were gliding through still air) and the motion of the



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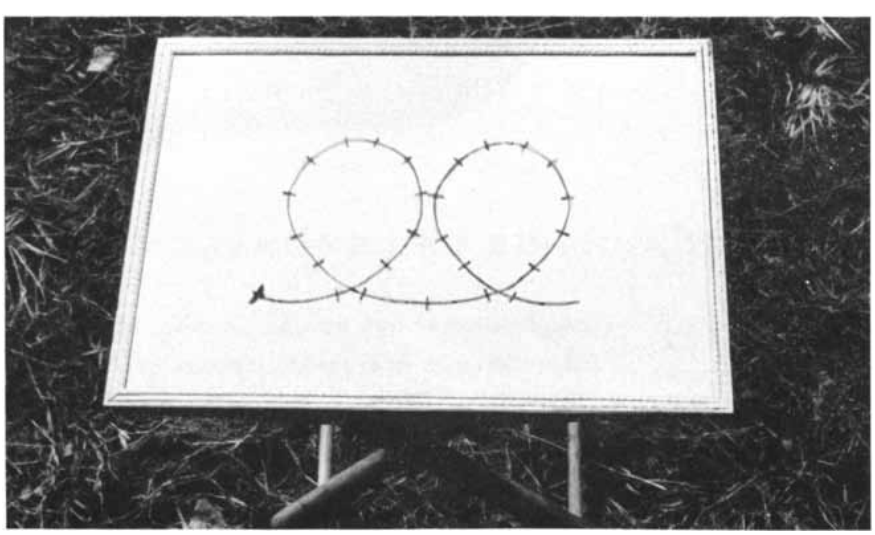
TURKEY VULTURE, a typical soaring land bird, can circle to great heights within the updrafts of thermal shells because of the efficient aerodynamic structure of its wings.

air with respect to the earth [*see illustration on page 134*].

This is the simple explanation of all static soaring. Without further qualification it describes the soaring of a bird in a declivity current. In a thermal shell, however, there is an additional factor: the upward flow within the shell. To soar in a shell the bird circles within the central updraft on a path such that its sinking velocity precisely equals the upward velocity (with respect to the vortex ring) of the air through which it glides. The bird thus maintains a constant altitude in relation to the vortex ring. With respect to the ground the bird gets a "free ride" upward as the entire system rises through the air. It is as if the bird were circling within a rising balloon—with one important exception. In a balloon the bird would be continuously gliding down toward the bottom and would eventually come to rest there. In the thermal shell, however, the circulating air keeps the bird from sinking with respect to the vortex ring. If there were no central updraft, the bird could only enter near the top of the rising thermal and gain a little altitude while sinking through the shell.



LOOPING PATH of a soaring bird is recorded in the field by tracing on a mirror the path of a vulture flying overhead. The bird's position is marked at equal time intervals and the time marks are connected. The combination of the bird's circling flight and the movement of the thermal shell makes the horizontal path take the form of a curve known as a trochoid.

The circular flight path within the thermal shell imposes an extra aerodynamic burden on the soaring bird. It must bank its wings so that a portion of the lift force can provide the centripetal force needed to pull it around the turn. The lift required for circular flight is therefore greater than that required for flight in a straight line. Greater lift means more drag on a wing, and this additional drag can only be overcome by an increase in the sinking velocity to enable the bird to encounter more air per second from which energy can be extracted. The relationship between the weight and aerodynamic characteristics of the bird, on the one hand, and the radius of the thermal shell and the strength of its updraft, on the other, determine whether or not a particular bird can soar within a particular thermal.

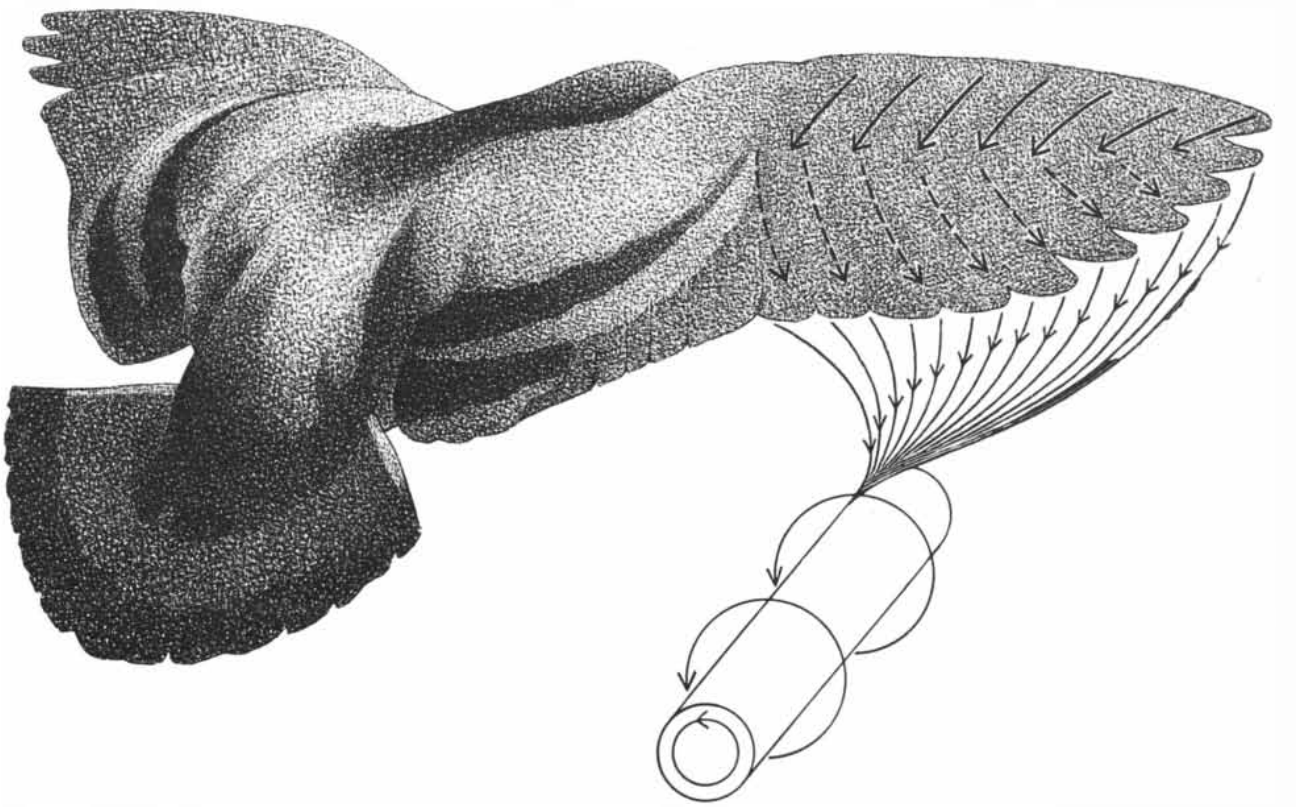
Observation shows that the birds quickly establish their equilibrium flight paths in a rising thermal. The velocity of the updraft with respect to the vortex ring is largest in the plane of the ring and diminishes above and below the plane. It is therefore possible for a bird to find any number of equilibrium flight paths in the top half of the system. If the bird increases or decreases the radius of its circling and thereby increases or decreases the lift of its wings, it automatically rises or descends to a new equilibrium position in the velocity gradient of the updraft—provided, of course, that the radius of its turn is not so large that the bird passes out of the thermal or so small that it sinks through the bottom. If by chance a bird enters a shell at a level below the vortex ring, it may still be able to find an equilibrium flight position. But its position is then unstable because a slight decrease in the radius of its circle will carry it downward into weaker regions of the updraft and through the bottom of the shell.

The ability of soaring birds to establish equilibrium flight paths even in small and weak thermals makes possible their regular and certain daylong flights, since smaller thermals are usually numerous and well distributed. Because the forces that cause the bird to circle are purely aerodynamic in origin, the bird will automatically maintain its position in relation to both the horizontal and the vertical axes of the shell as it makes circle after circle. This explains why one so rarely sees a soaring bird make more than the slightest control motions with its wings and tail.

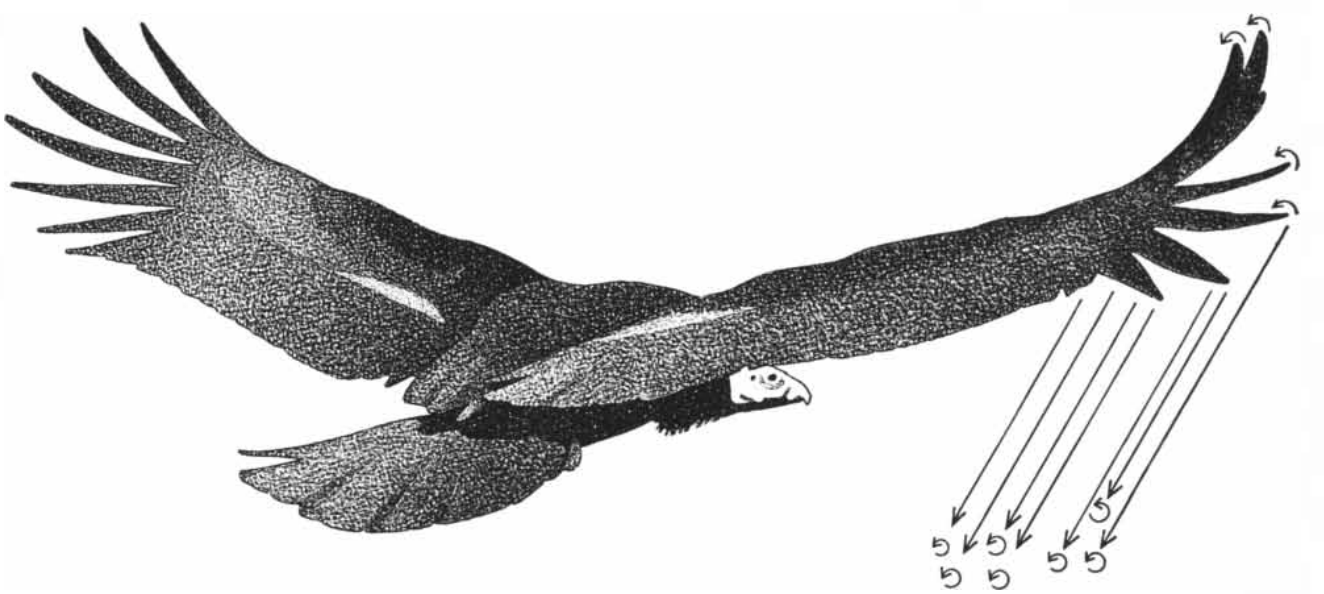
If the vertical axis of the thermal shell were visible, it would appear to the bird that it was flying in circles around

this axis with a constant velocity. But to an observer on the ground the motions of a soaring bird appear to be quite different. The bird's path is seen as a series of loops displaced in the direction the wind aloft is blowing. The velocity of the bird over the ground changes, increasing as the bird moves with the wind and decreasing as it wheels to fly against the wind. (It was this aspect of the flight path as seen from the ground, especially the apparently larger gain in altitude on the upwind side of the circle, that led many ornithologists to think the birds were extracting energy for their climb from the horizontal wind.)

One can record the paths of the soaring birds quite accurately. It is necessary only to aim a large mirror skyward and to mark on it with ink the position of the bird at equal time intervals as in-



SMOOTH-TIPPED WINGS of a bird such as the pigeon are satisfactory for flapping flight but produce too much drag for soaring. The air (*short broken arrows*) below the wing is at a higher pressure than the air (*short solid arrows*) above the wings. So it coils up around the wing tip, creating a trailing vortex of air behind each tip. These vortex tubes exert an "induced" drag on the wing.



SLOTTED WING TIPS of a soaring land bird such as the condor have less induced drag than smooth tips and make it possible for the bird to soar even though its wings are less narrow than those of a sea soarer. The tapered pinions of the condor are separated and curve upward in flight; they keep air from flowing around the tip. Instead of two large vortices there are several tiny ones.

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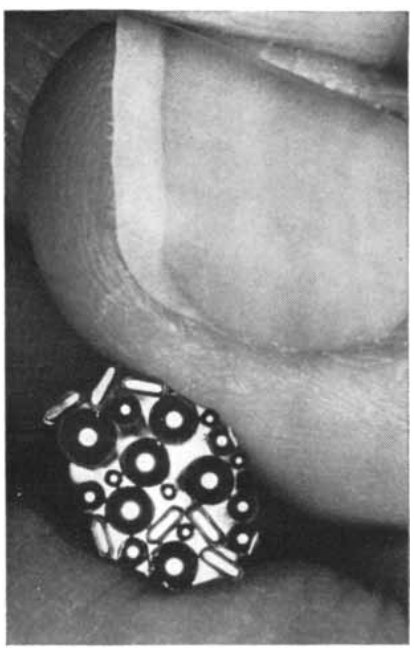

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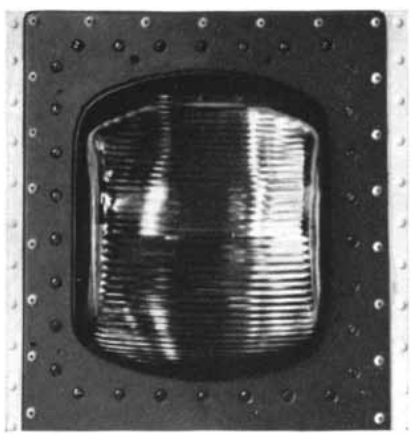

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dicated by a metronome. When these time marks are connected by a smooth curve, the flight path of the bird is obtained on a reduced scale [*see bottom illustration on page 136*]. The tracing usually takes the form of a trochoid: the path generated in a plane by a point on the circumference of a circle as a concentric inscribed circle rolls along a surface. If the size of the reflected image of some characteristic dimension of the bird—say its wingspread—is also traced on the mirror, and if the actual size is known, the scale of the tracing can be determined and the dimensions of the flight path can be calculated. It is possible to learn many things from a single mirror tracing of a flight. For instance, one can determine the radius of the bird's circle and its air speed in the shell, its ground speed, the speed of the wind at the altitude of the thermal and even the bird's velocity of ascent.

Since a bird circling in a continuous column of air rising from a spot on the ground could not generate a sustained trochoidal flight path, it is clear that soaring birds do not in general use such columns for flight. The understanding that the birds are, in effect, passengers aboard rising balloons of air explains many other formerly puzzling facts about soaring flight. Stronger and larger shells form when there is no wind; that is why the best soaring conditions occur on calm days. Hankin was unable to explain why vultures that began to soar just as a sudden gust of wind stirred the air continued soaring with even greater ease after the gust had died. The reason, of course, is that the only ground effect of the formation of a thermal is the momentary inrushing of air that fills the bubble before it leaves the ground. Ground conditions may be perfectly calm while a strong vertical current circulates within a shell only a few hundred feet overhead.

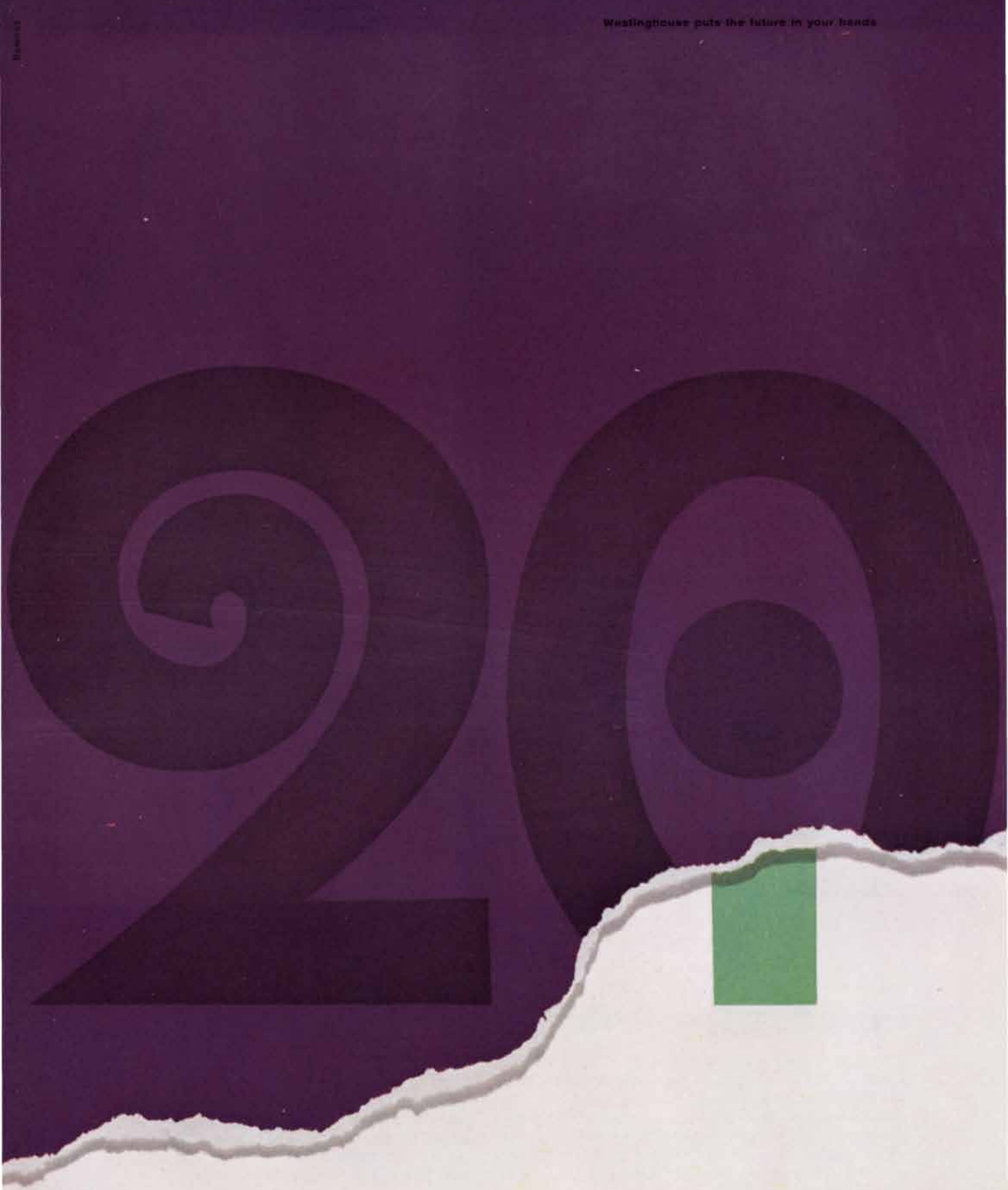
The shell mechanism also explains why two groups of birds flying at different altitudes over the same spot may well find quite different soaring conditions, for free thermal shells are localized not only horizontally but also vertically. Of special interest is the fact that a thermal shell increases rapidly in size as it expands in the colder upper air; in many cases the intensity of the central updraft also increases with altitude. This explains why the heavier birds are seen at the higher altitudes.

The soaring land birds are aerodynamically well designed and equipped for their peculiar mode of flight. In birds that regularly fly by flapping their wings the pinions, or primary feathers, overlap to form a nearly continuous surface at the wing tips. The same is true of many soaring sea birds, such as the albatross. But the pinions of the land soarers are sharply tapered and are spread apart and curved in soaring flight, giving the wing tip the appearance of a fringed fan. This slotting and curvature of the wing tips has the important effect of reducing the drag.

On a normal wing in flight air spills around the tips from the high-pressure bottom side to the low-pressure top side; in so doing it gains a rapid spinning motion and forms a vortex core that trails downstream from each wing tip [*see top illustration on page 138*]. This trailing vortex contains considerable kinetic energy and exerts an "induced" drag on the moving wing. Wings that are long and narrow, like those of the albatross, have only a comparatively small spillage of air, and the drag on such wings is low. Around the tips of a broader wing the spillage would be high and the drag would be prohibitive for thermal soaring. It is to prevent this flow of air at the tip that the land soarers have evolved their special flight feathers. The separate pinions, curved upward in flight, form an aerodynamic fence that keeps air from flowing around the tip. Instead of a large trailing vortex at the end of each wing, a small vortex is generated by each pinion [*see bottom illustration on page 138*] and the induced drag on the wing is minimized.

Apparently sea birds, operating over the broad, unobstructed surface of the oceans, have found the long and narrow wing quite suitable for their way of life. But the soaring land bird, which must continually take off and land in rugged and sometimes forested terrain, has found the sturdy, short-span wing with slotted tips more useful for its needs. Moreover, for equal wing areas the structural weight of a pinioned wing is much lower than that of a long and narrow wing. A soaring land bird can therefore carry the heavy bone and muscle structure and the massive talons and beak needed to snatch up its victims or to tear flesh from animal carcasses and still maintain the low wing loading required for thermal soaring.

Study of the demands of the environment often provides such insights as these into the behavioral and morphological adaptations of animals. Less often does it happen, however, as has happened in the case of the thermal shell, that close study of the behavior of organisms helps to establish the discovery of a major feature of the environment.



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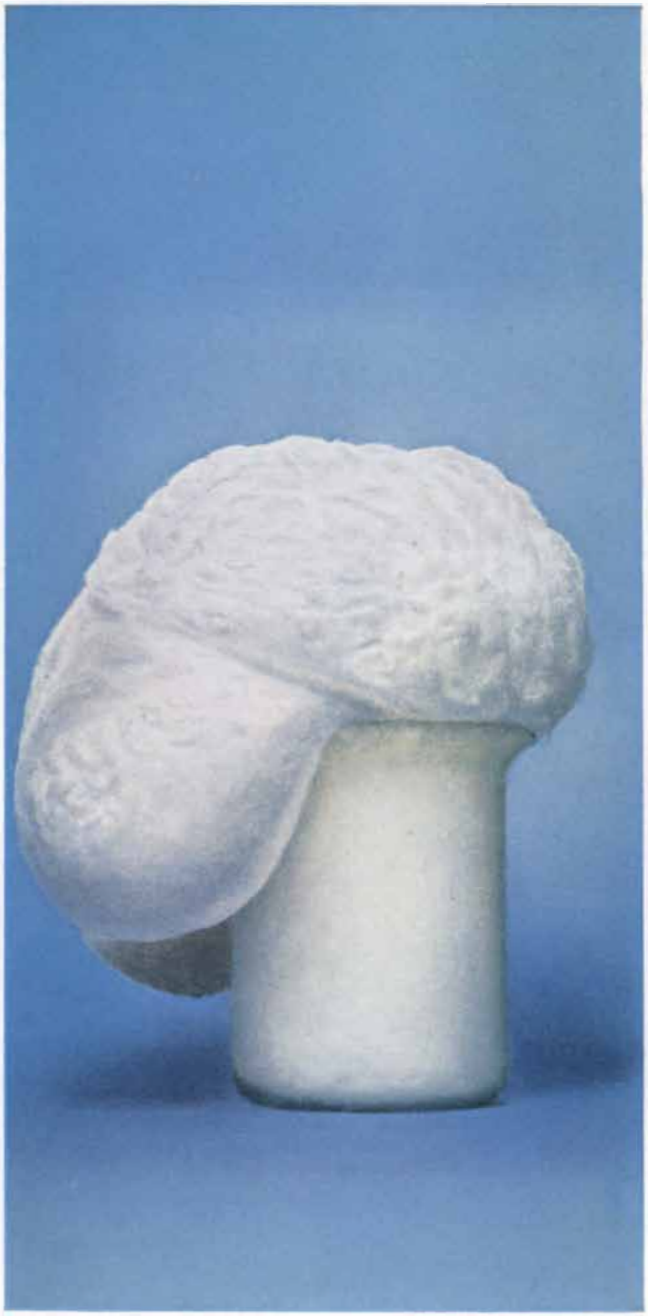

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ATTENTION AND THE PERCEPTION OF SPEECH

If an individual listens to two voice messages at one time, he usually understands only one. This indicates that the brain has an "attention mechanism" for selecting the desired information

by Donald E. Broadbent

Paying attention—and not paying attention—are surely two of the most important abilities of human beings. Yet in spite of their crucial role in learning, and in a host of other intelligent activities, psychologists for many years did not consider them proper topics of study. Attention seemed a subjective quality, associated historically with the introspective method of investigation. That method tends to give inconsistent results and so fell into disrepute among experimental psychologists. Correspondingly, most respectable theorists failed to make use of any concept resembling attention; and, since research in psychology tends to be dominated by theory, there was little experimentation along lines that might have revived the idea.

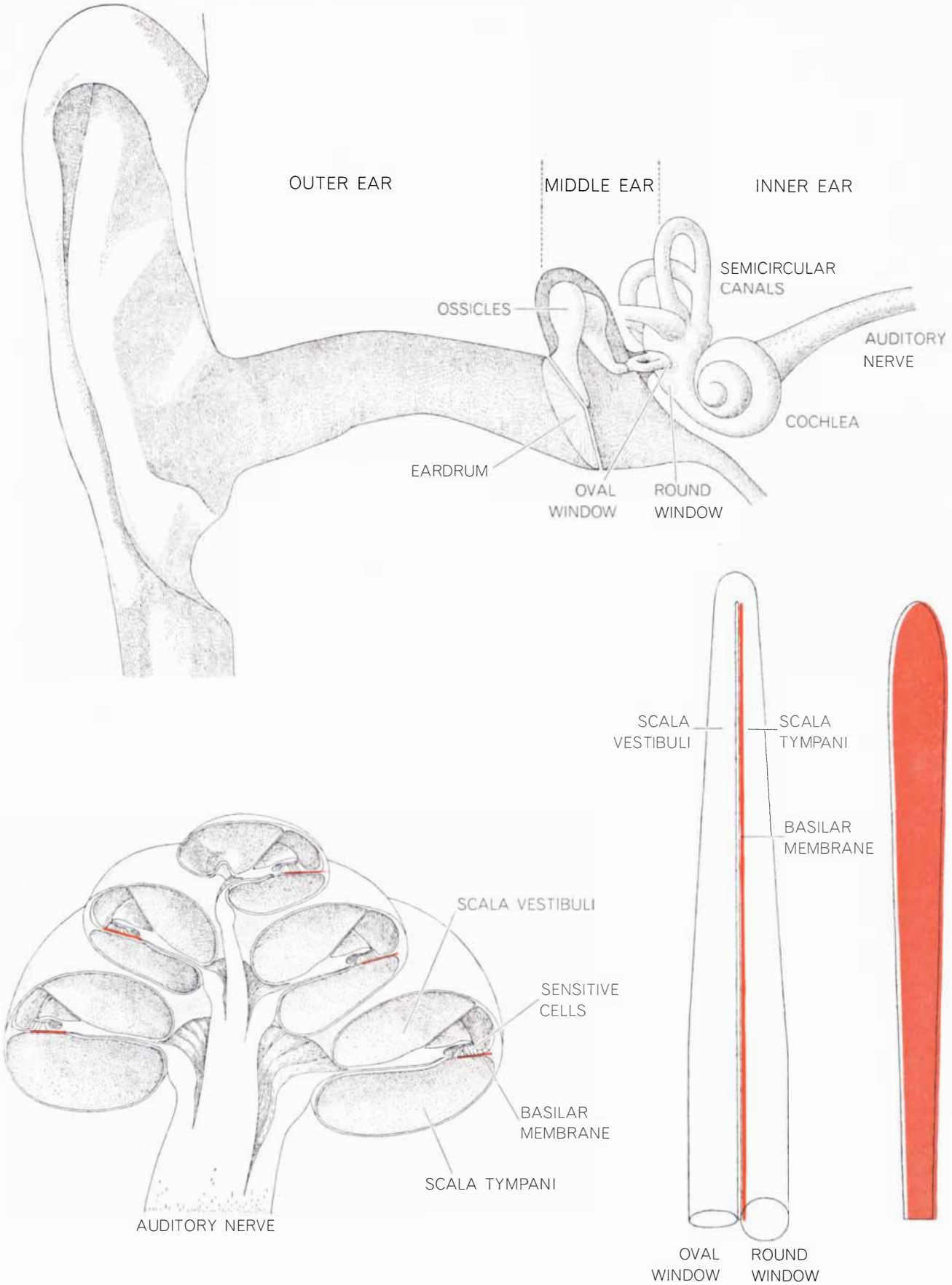
In the past 10 years, however, the concept of attention has begun to force itself on the attention of psychologists in various ways. One is through studies of the efficiency of control systems such as those concerned with the regulation of air traffic at airports. A major cause of failure in these systems is that the human operator has too much information to handle simultaneously, or that he reacts to an unimportant signal when he should be dealing with an important one. These problems require some understanding of phenomena that would commonly be described under the heading of "attention." There is now accumulating a wide variety of experimental results that clarify these phenomena, although the larger part of the work remains to be done. In this article I shall describe some of the research on attention to spoken messages.

One of the earliest findings, and one that agrees with everyday experience, is that it is harder to understand two messages arriving simultaneously than two messages arriving one after the other. One might be tempted to explain this as a purely physical interference between the two stimuli; for example, the louder passages of one message might drown out the softer passages of the other and vice versa, rendering them both unintelligible. Actually the matter is not so simple. By recording the messages on tape and playing them for different subjects instructed to respond in different ways, the intelligibility is shown to depend on psychological factors. Specifically, either message becomes understandable if the listener is instructed to ignore the other. But the two messages together cannot both be understood, even though the necessary information is available to the ear. Another way of making the same point is to insert the words of one message into spaces between the words from the other: "Oh God say save can our you gracious see Queen." Each message is hard to understand, but each word is spoken separately and is fully audible. The difficulty evidently lies inside the nervous system, which somehow prevents an adequate response to signals that are "heard" satisfactorily.

Further experiments demonstrate that comprehension improves if the two messages differ in certain physical characteristics. For instance, it is better if a man speaks one message and a woman speaks the other; or if the loudspeaker removes the lower tones from one voice but not the other. Spatial separation of the two voices gives the best result of all. The different messages should not come through the same loudspeaker or even from separate speakers mounted one above the other; the two speakers should be separated as far as possible from each other in the horizontal plane. Interestingly enough, a listener also comprehends simultaneous spoken messages better when they come from a stereophonic system than when they are played over a single loudspeaker. (This effect, rather than the doubtful gain in realism, is for many people the main advantage of stereophonic high-fidelity systems: the listener can pay attention to different musical instruments played at the same time.)

Physical distinctions are most helpful in promoting understanding when one message has no importance for the listener and does not have to be answered. It would seem that the differences allow the brain to filter the incoming sounds and select some for response while ignoring others.

The need to throw away part of the available information can perhaps be understood by comparing the brain with man-made communication systems. Engineers nowadays talk of capacity for transmitting information, by which they mean the number of equally probable messages of which one can be sent in a specified time. Suppose, for example, that two complicated military plans have been prepared and an order is to be sent to carry out one of them. A simple communication system consisting of a red and a green lamp can transmit the message with maximum efficiency by the lighting of a single lamp. If there were four plans instead of two, however, it would be impossible to give the order by lighting one of the two lamps no matter how simple each plan might be. Either there must be more lamps or more time is needed for sending the order. In the most efficient code for two lamps, two successive flashes of the red lamp would mean one plan, a red flash followed by a green flash would mean another, and so on. One of four possible messages can be transmitted with two lamps, but only by taking two units of time. With eight pos-



PERCEPTION OF SPEECH begins in the ear, shown at top in simplified cross section. The eardrum transmits sound vibrations to the three small bones called ossicles, which cause waves in fluid in the cochlea. The cochlea, seen in cross section at bottom left, contains the basilar membrane (*color*), on which rest the sensitive cells that excite auditory-nerve fibers. At bottom center cochlea is rolled out, with basilar membrane in side view. Front view of the basilar membrane (*bottom right*) shows that it is wider at one end than the other. The wide region vibrates in response to low frequencies, whereas the narrow region responds to high frequencies.

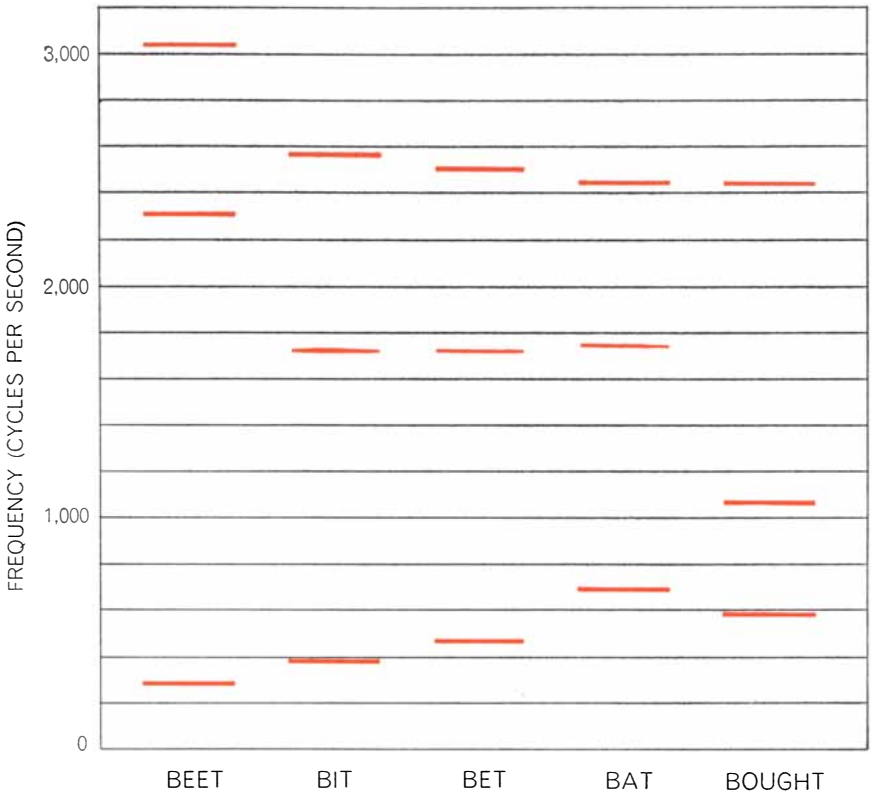
sible messages the code would call for three flashes of the two lamps, taking three units of time; 16 possible messages would require four flashes, and so forth.

Although the human brain has far more than the two states represented by the red and the green lamp, the number of its possible states is presumably limited. One would expect, then, that there is a limit to the number of different possibilities among which it can distinguish in a given time. Indeed, a number of experiments suggest a close parallel with the two-lamp system: in many cases a man's reaction time in responding to one of several possible signals increases by an equal amount every time the number of possible signals is doubled. Since there is a maximum speed at which one signal can be distinguished from others, the brain limits the number of possibilities being considered at any one time by selecting only part of the information reaching the ears. Therefore the degree of difficulty in dealing with two simultaneous spoken messages depends on the number of other messages that might have arrived instead of the two that did arrive. If only a few other messages are possible, the two messages together may not exceed the capacity of the brain and the listener may understand both. On the other hand, if each message is drawn from a very large range of possibilities, it may be all the listener can do to respond appropriately to one of them.

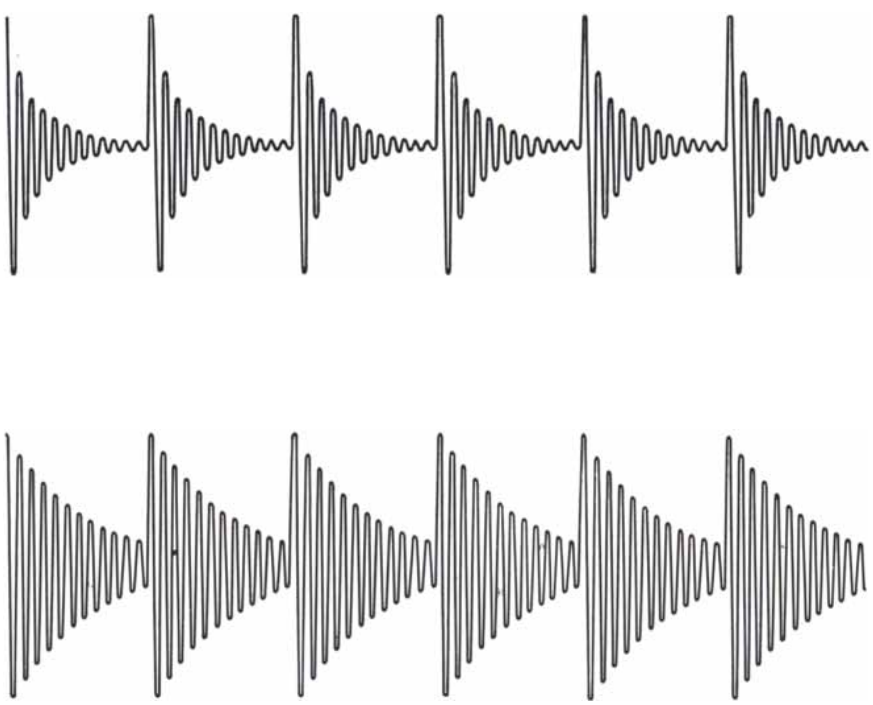
Several studies support these conclusions. John C. Webster and his associates at the U.S. Navy Electronics Laboratory in San Diego, Calif., observed that control-tower operators in San Diego could sometimes identify two aircraft call signs arriving at the same time but could understand only one of the two messages that followed. The call signs penetrated because the operators knew pretty well which aircraft might call. They did not know what the pilots would say.

An experiment at the Applied Psychology Research Unit in Cambridge, England, required a listener to answer a rapid series of questions while pressing a key in response to an intermittent buzzer. The interference produced by the buzzer in the ability to answer questions increased after the subject had been told that he would also have to respond to a bell. Even when the bell did not ring, the subject found the questions harder to answer than when he was expecting only the buzzer.

These results help to explain why a person can sometimes listen to two things at once and sometimes cannot pay atten-



VOWEL FORMANTS, or frequencies that make up each vowel sound, are shown here for five different vowels. The values given are averages for male voices. Actually they differ from person to person. Although three formants are shown here for each sound, quite recognizable vowels can be produced by mechanisms using two filters to make two formants.



DECAY RATE of pulses from vocal cords affects quality of speech. Waves of highest amplitude mark beginning of each pulse. At top, pulses decay rapidly, helping to give the voice a crisp or sharp sound. At bottom, the decay is much slower, giving the voice a mellow quality. In both cases the frequencies of the pulses and the vibrations are exactly the same.

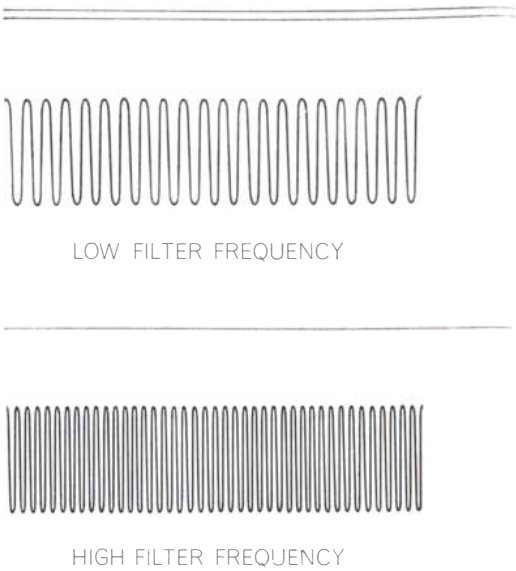
tion to more than one. When the listener is thoroughly familiar with a situation, so that he knows to within a small number of alternatives what each message will be, he can comprehend two simultaneous messages. But when one or both messages are drawn from a large number of possibilities, the filter in the brain lets only one message come through.

How does the filter work? As yet the answer is not known. Enough is known, however, about the physical characteristics of speech and the physiology of hearing to make possible some reasonable speculation. Human speech is produced by the combined action of the vocal cords and the vocal tract, which consists of the cavities of the throat, mouth and nose. Taut vocal cords produce a buzz when air is forced through them. The buzz consists of brief pulses, or puffs of air, at the rate of 100 or more per second, each pulse containing energy at many frequencies. These pulses excite into vibration the air in the cavities of the throat, nose and mouth. The cavities can be tuned to different frequencies by changing the position of the tongue, cheeks, jaw and lips. What emerges is a train of waves that contains a particular group of frequencies and is pulsed about 100 times per second. Each pulse starts out at full strength and decays rapidly until the sound energy is renewed by the next one [*see bottom illustration on preceding page*].

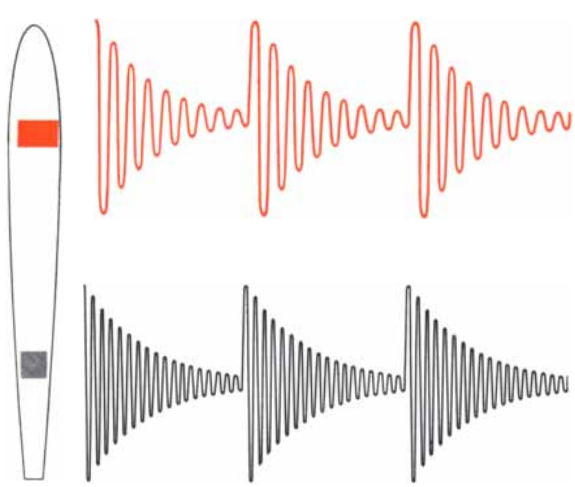
Many vowel sounds contain waves at two or more widely separated frequencies. For example, when the greatest energy is at 375 and 1,700 cycles per second, the vowel sound in the word "bit" is produced; frequencies of 450 and 1,700 cycles per second give the vowel in "bet." (These figures apply to a typical male voice. In the voices of women and children the whole range of frequencies may be higher but the listener takes this into account.) On reaching the ear, the sounds stimulate sense organs arranged along the basilar membrane in the cochlea [*see illustration on page 144*]. Low frequencies stimulate organs at one end of the membrane; high frequencies affect those at the other end. A complex sound made up of several frequencies energizes several different regions of the basilar membrane. Each sense organ on the membrane connects with particular nerve fibers going to the brain; thus the word "bit" stimulates one combination of fibers and the word "bet" another combination.

If both words reach the ear simultaneously, both combinations of fibers would come into play and the brain would have the problem of deciding which belong together. It might seem then that two or more voices would produce so much confusion in the ear that the brain could not select one voice for special attention. Of course, certain obvious features help distinguish one speaker from another: accent, rate of speaking, loudness or softness. But one cannot make use of these features until one knows which frequencies belong to which voice. Thus the problem remains: How does the brain manage to focus attention on one voice? Studies of the artificial generation of speech sounds have begun to throw some light on this problem.

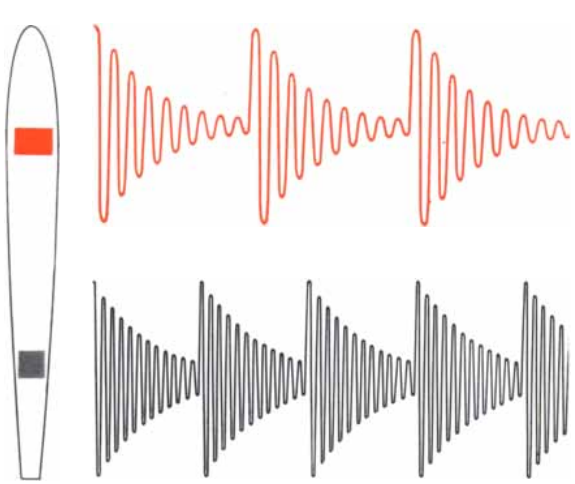
Peter Ladefoged of the University of Edinburgh and I have been experimenting with a device that was developed by Walter Lawrence of the Signals Research Development Establishment in England. Our version of the apparatus sends a series of electrical pulses (analogous to pulses from the vocal cords) through two filter circuits, each of which passes primarily one frequency. The waves from one filter circuit, which are like those from the largest human speech cavity, are mixed with waves from the other, which imitate the frequencies produced by the second largest cavity. To-



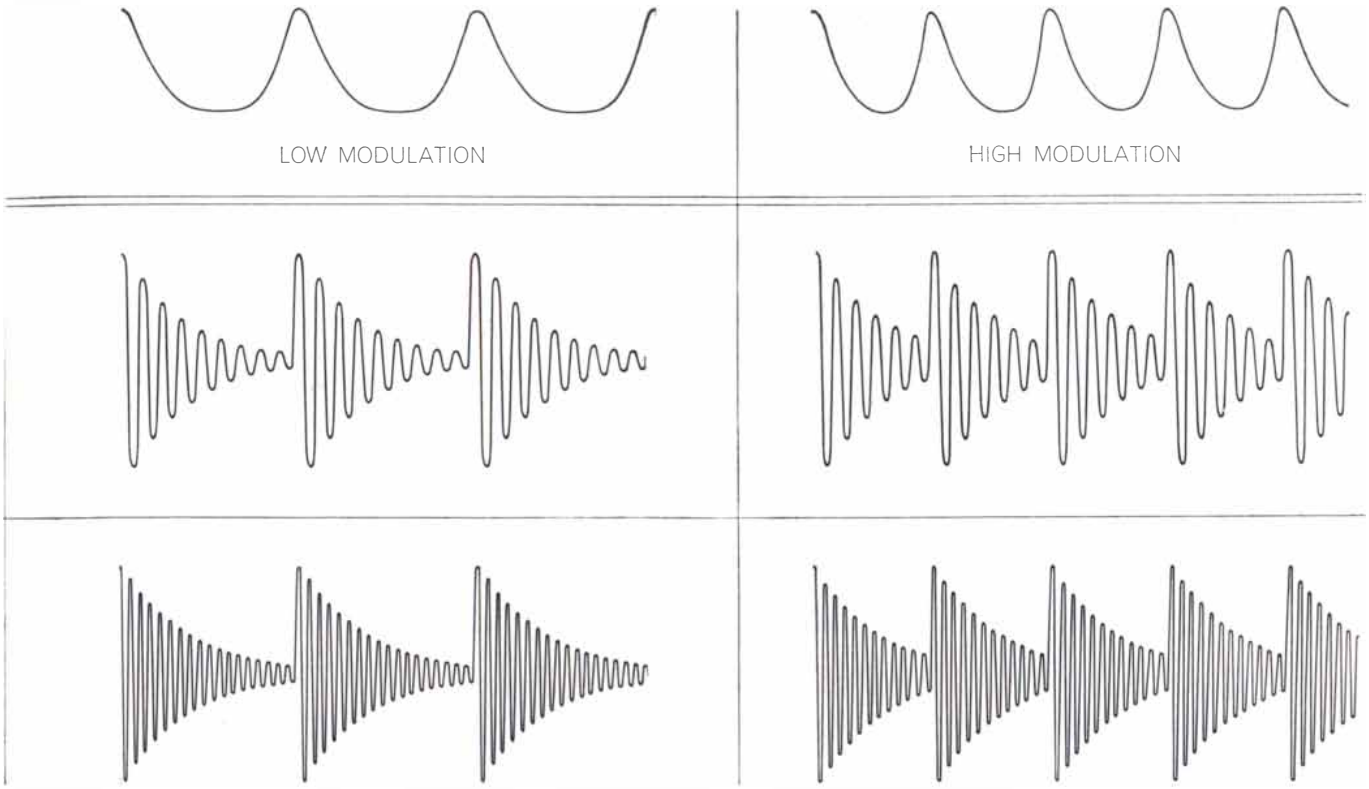
SPEECH SOUNDS consist of pulses of energy from the voice, shown here as high and



DIFFERENT FILTER FREQUENCIES but same rate of pulsation or modulation from voice excites two different regions of a basilar membrane (*left*). Listener reports he hears one vowel sound.



DIFFERENT PULSATION RATES and different filter frequencies make the listener hear two different sounds, even though only one ear or basilar membrane is actually being used for hearing.

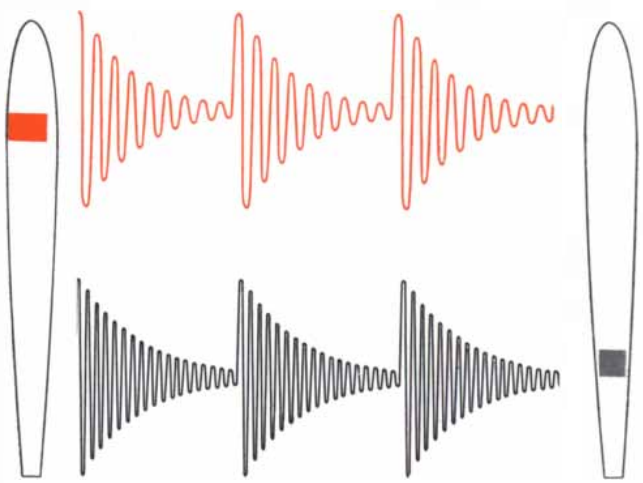


low modulations (*across top*), and of specific frequencies emitted by the mouth and throat "filters," or cavities (*far left*). These two types of wave combine in patterns like those in this diagram. Effects of such waves are shown across bottom of these two pages.

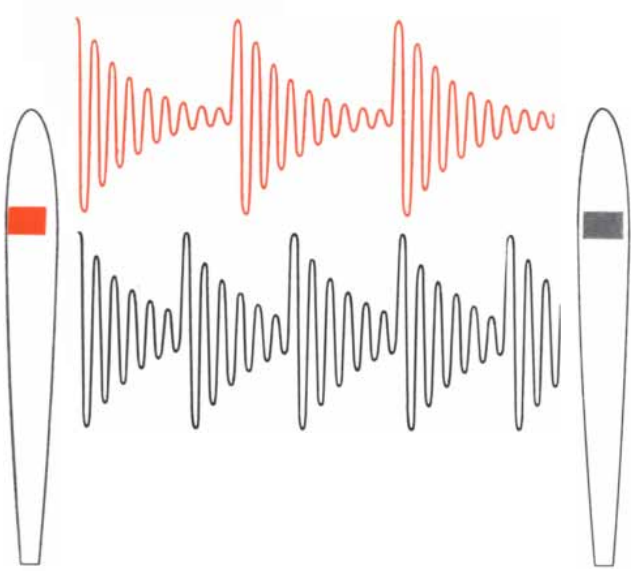
gether the two wave trains are heard as quite acceptable vowel sounds that can be changed by tuning the filters to different frequencies. Varying the pulse rate used to excite the filters alters the apparent pitch or intonation of the "speech": it rises with faster pulse rates and falls with slower ones.

When the same pulses excite both filters, a listener hears the output as readily identifiable vowel sounds. This is true even when the low frequency is fed into one ear and the high frequency into the other. But if the two filters are pulsed at slightly different rates, the "speech" becomes unacceptable and listeners say that they are hearing two sounds coming from two sources rather than a single vowel sound.

Other experiments on the fusion of sounds at the two ears, conducted by Colin A. Cherry and his colleagues at the Imperial College of Science and Technology in London, also support the idea that when the rate of pulsing, or modulation, is the same for two sounds, the hearer perceives them as one sound. It seems reasonable to suppose, therefore, that a man can listen to one person



USING BOTH EARS, listener will hear one vowel sound, although right ear hears one filter frequency and left ear hears another. The pulsation or modulation rate has to be the same.

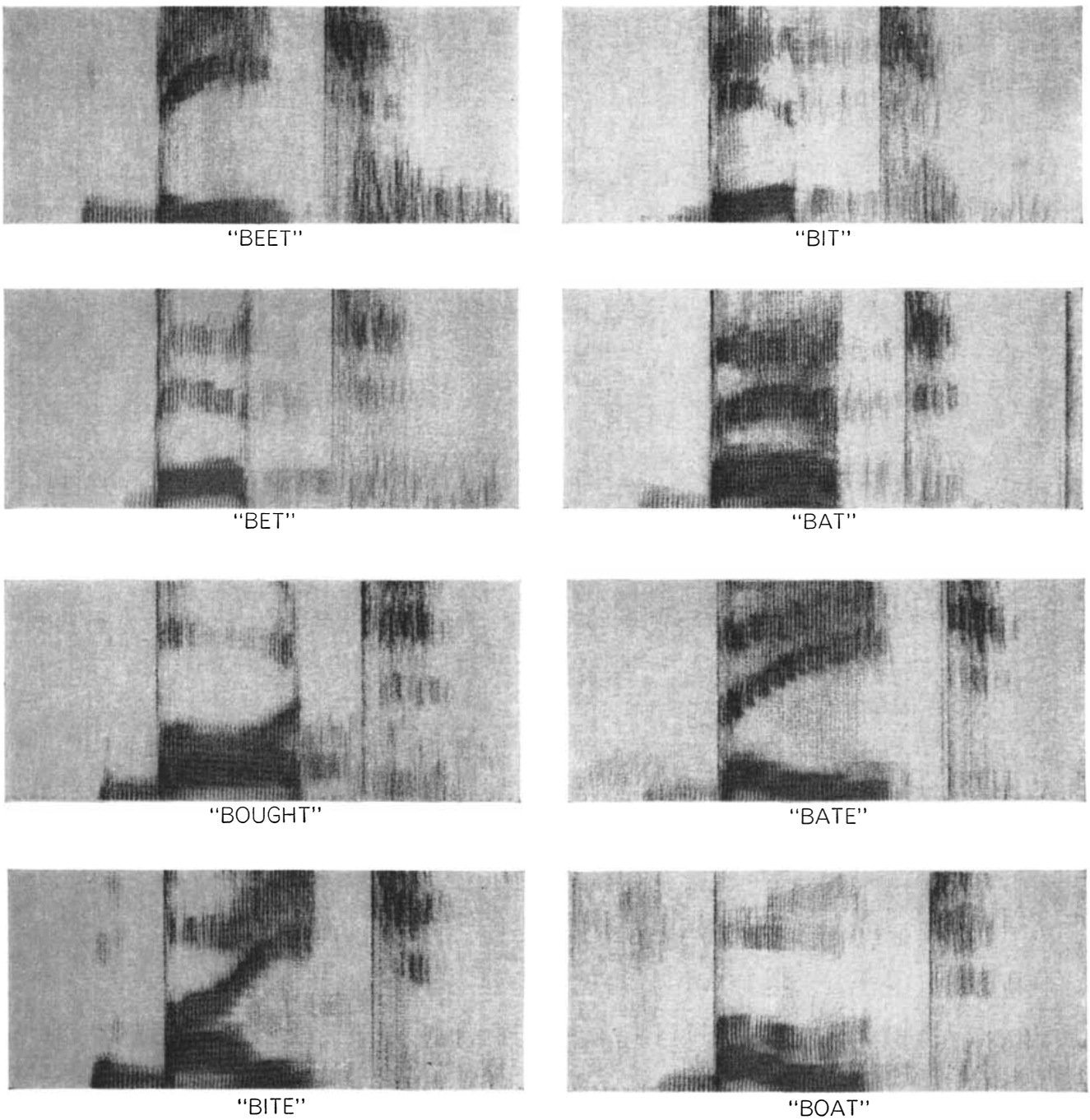


TWO PULSATION RATES, combined with same filter frequency and fed into each ear separately, produce two distinct sounds. The brain evidently focuses its attention on the rate of pulsation.

and ignore another primarily by selecting from the mass of sounds entering his ears all those frequencies that are being modulated at the same rate. Since it is most unlikely that the vocal cords of two speakers would vibrate at exactly the same rate at any moment, modulation would almost always provide an important (if not the sole) means of separating a pair of voices.

It is now a generally accepted principle of neurophysiology that messages traveling along a particular nerve can differ either by involving different nerve fibers or by producing a different number of impulses per second in the fibers. High-frequency and low-frequency sounds stimulate different fibers. It may be that the rate at which the sounds are pulsed controls the rate of firing of the fibers. If so, the brain could pick out one voice from others by focusing its attention on all auditory nerve fibers that are firing at the same rate.

A further indication of the importance of modulation is that it, rather than the frequency of the waves being modulated, seems under certain conditions to determine the pitch of a voice. This can be demonstrated with the artificial speech generator. A filter tuned to, say, 3,000 cycles per second is pulsed at the rate of 100 cycles per second. A listener is asked to match the pitch of the sound with either of two simple sound waves, one at 100 cycles per second and the oth-



SOUND SPECTROGRAMS show that various vowel sounds are made of several different frequencies. Time is shown horizontally, frequencies vertically and intensity of sound by relative darkness. The "b" of each word appears at lowest frequency. Vowel begins suddenly as lips open. After vowel there is a quiet period followed by a burst of noise primarily at high frequency as the "t" explodes. Frequency shifts in "bate" and "bite" are diphthongs. Spectrograms were made by H. K. Dunn of Bell Telephone Laboratories.

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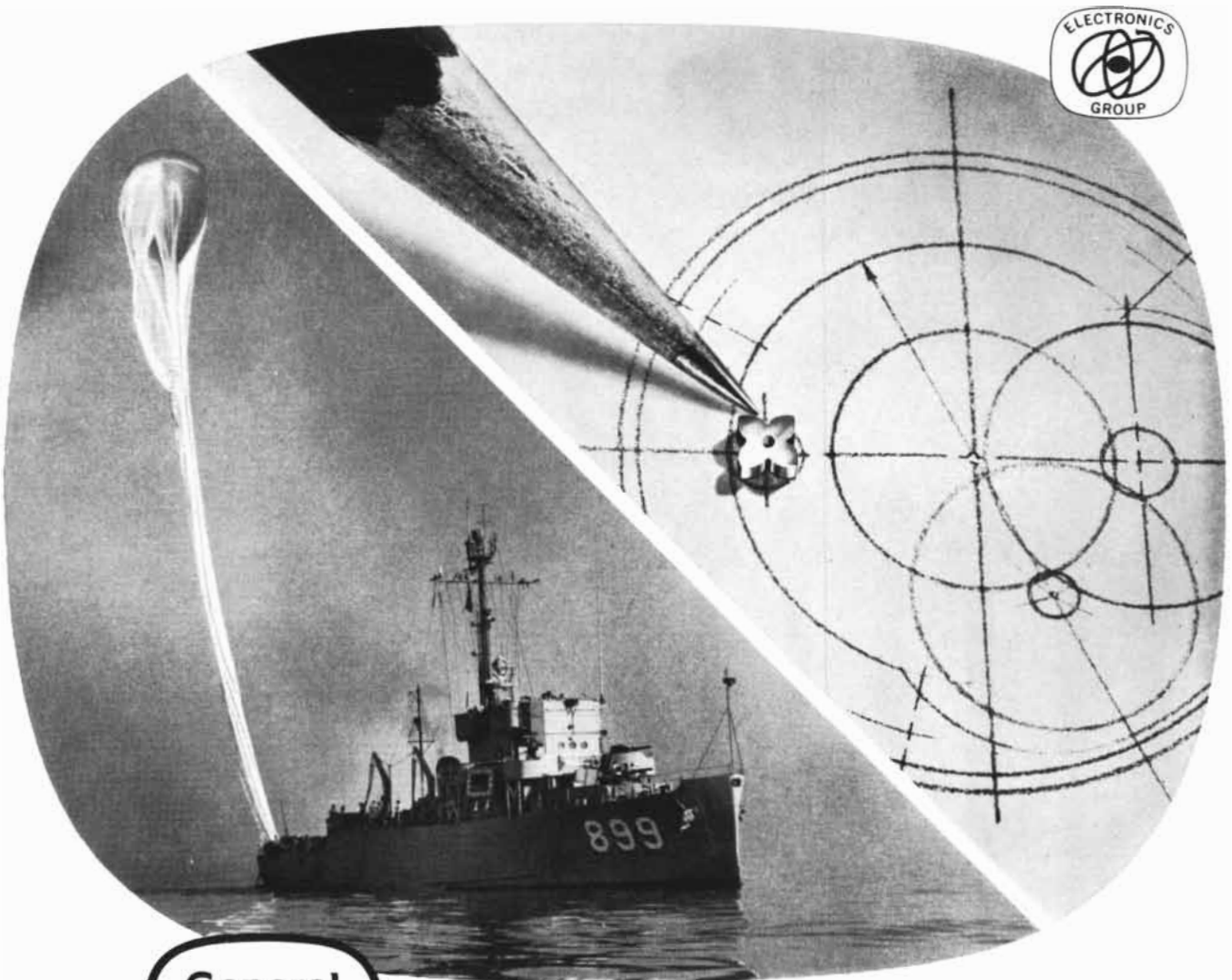

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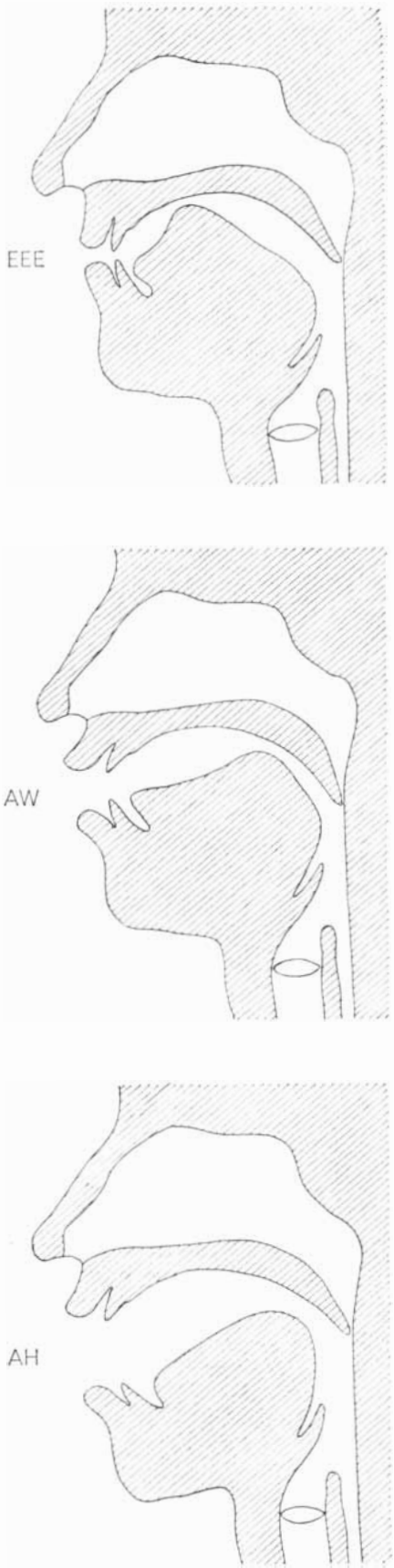
er at 3,000. Usually he selects the 100-cycle sound.

The selection mechanism that has been described is still hypothetical, but I believe that something much like it must exist. There can be no doubt, however, that it is not the only basis for auditory attention. Several experiments have served to make this clear. In one, a listener is equipped with earphones that feed one voice into the right ear and another voice into the left. Normally the subject has no difficulty in understanding the message entering one ear and ignoring the other. But under certain conditions sound from the ear being ignored can break into consciousness. For example, Neville Moray of the University of Oxford has demonstrated that a man fully occupied in listening to speech entering one ear will hear his own name in the other ear even though he remains quite unresponsive to any other word in that ear. Under similar circumstances Anne M. Treisman of the University of Oxford has found that speech entering the rejected ear can break through to the subject's attention if it consists of words that would probably follow the words that have just been heard by the ear that is receiving attention. In these cases the content of the speech has taken precedence over its physical characteristics.

How the brain focuses attention on meaning or content is as yet an almost complete mystery. One thing is clear. If the method proposed for choosing between voices is correct, there must be two attention mechanisms. Selection on the basis of content involves examining a stimulus for its possible appropriateness to a particular set of responses rather than for the presence or absence of a physical marker. At one moment, for example, a person might be ready to write down any of the digits one through nine and highly unready to write anything else, or indeed to respond in any other way. If he hears a sound from any direction or in any voice that can be interpreted as the name of one of the digits, he will respond by writing it down; only if the sound cannot be so interpreted will he not respond. At another time he might be ready to write down letters of the alphabet but not numbers, and so on.

Both types of attention are now the subject of intensive research. The next few years should yield more definite clues to the nature of each and at least a tentative answer to the question of whether or not they depend on different mechanisms.



SHAPE OF CAVITIES in the mouth is primarily responsible for the production of different vowel sounds. The configuration of the tongue plays a key role, along with size of the opening of mouth and position of lips.

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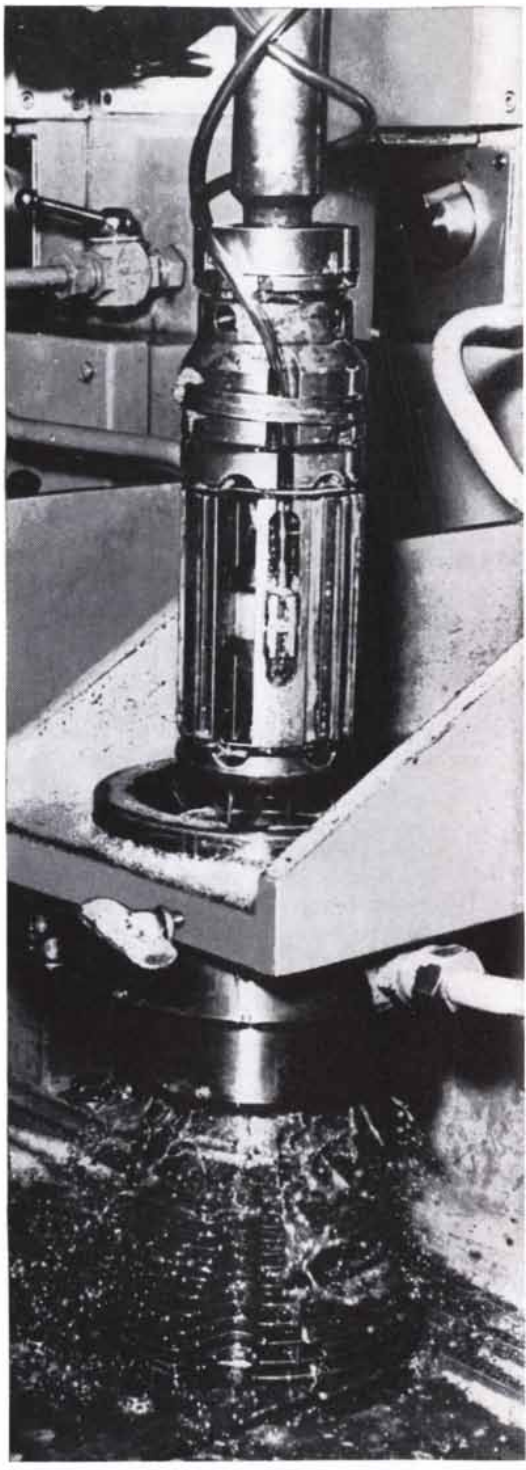

Above: Sperry Gyroscope Co. Ltd. uses natural diamonds to surface-finish copper-plated aluminum memory drums for computers. Variations in the mirror finish do not normally exceed 20 millionths of an inch. Final surface is now produced in as many minutes as it would have taken hours by the former grinding process.

Right: Natural diamond-impregnated hones finish-grind cylinder walls for a major European automobile manufacturer. The metal-bond hones have resulted in very long production runs—from 40,000 to 60,000 cylinders have been machined with a single set of hones.

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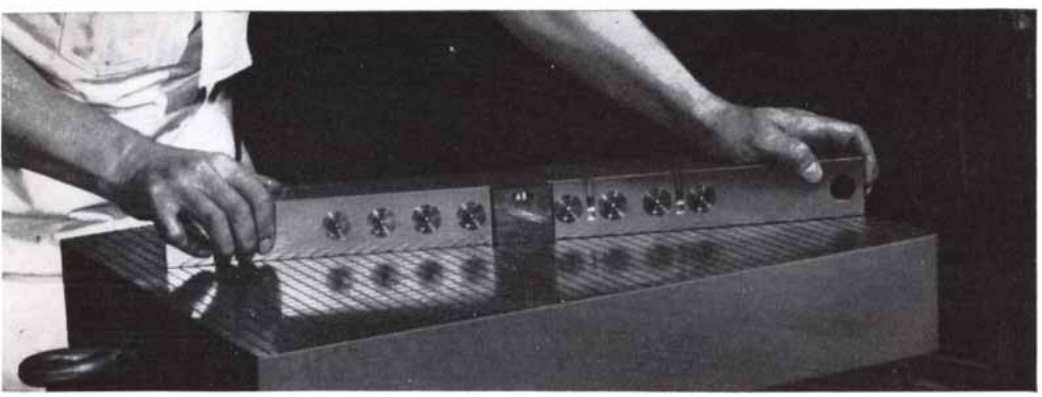

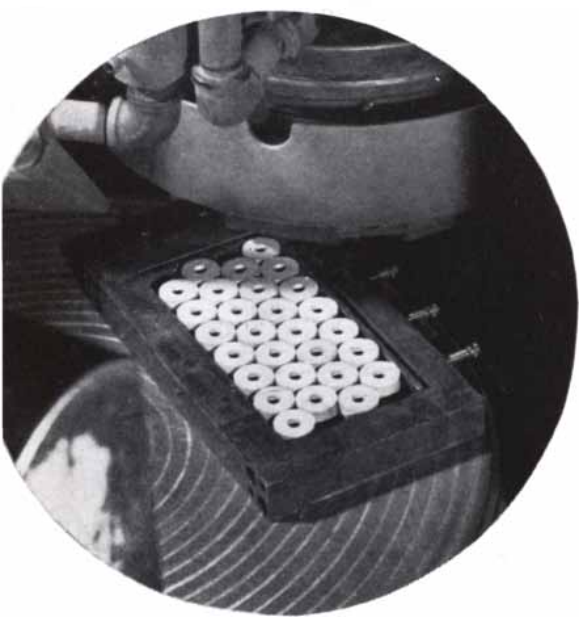

Above: This cheeker (top) for an 8-cavity film-spool mold will fit precisely after lapping operation. The Machine Shop at the Kodak Park Works of Eastman Kodak Company, Rochester, N. Y., uses natural-diamond micron powder in an oil paste for this delicate finishing operation.

Left: Vascoloy-Ramet Corp., Waukegan, Ill., grinds wear-resistant part for the oil industry with vitrified-bond wheel utilizing 100-mesh natural diamond. Carbide is W-505 grade, Rockwell, 89-A hardness. Grinder removes .002″ to .005″ of material on each pass, for a total of .012″ to .015″. Natural diamonds provide the only satisfactory method for this job.

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MATHEMATICAL GAMES

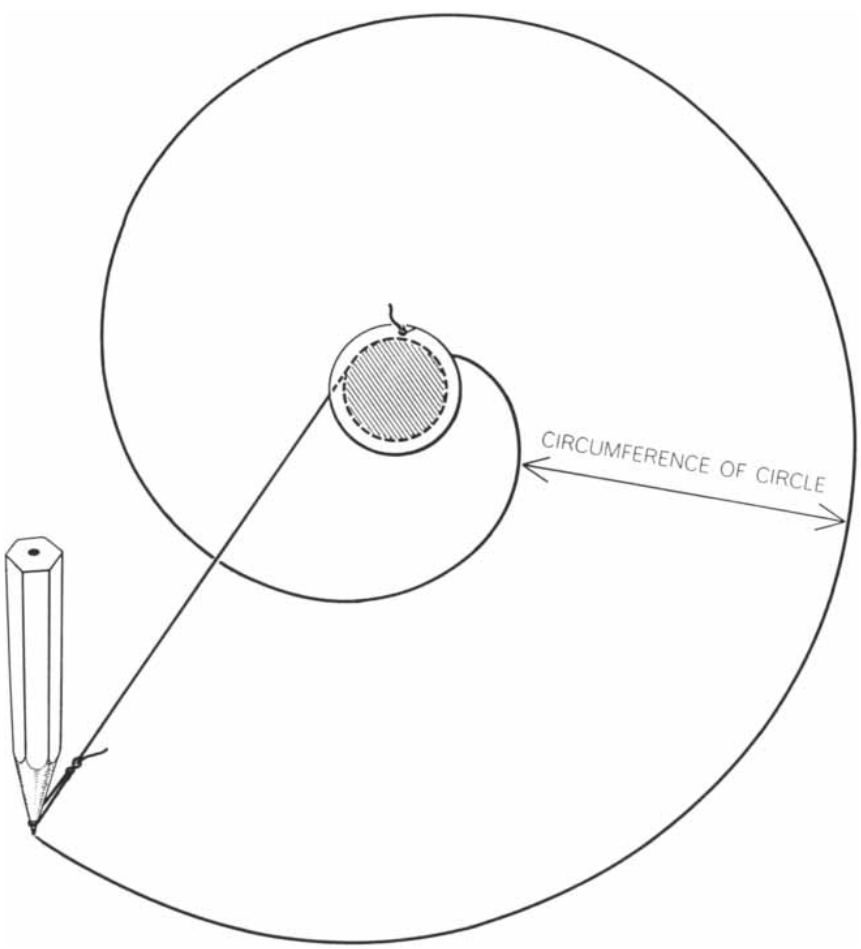
About three types of spiral and how to construct them

by Martin Gardner

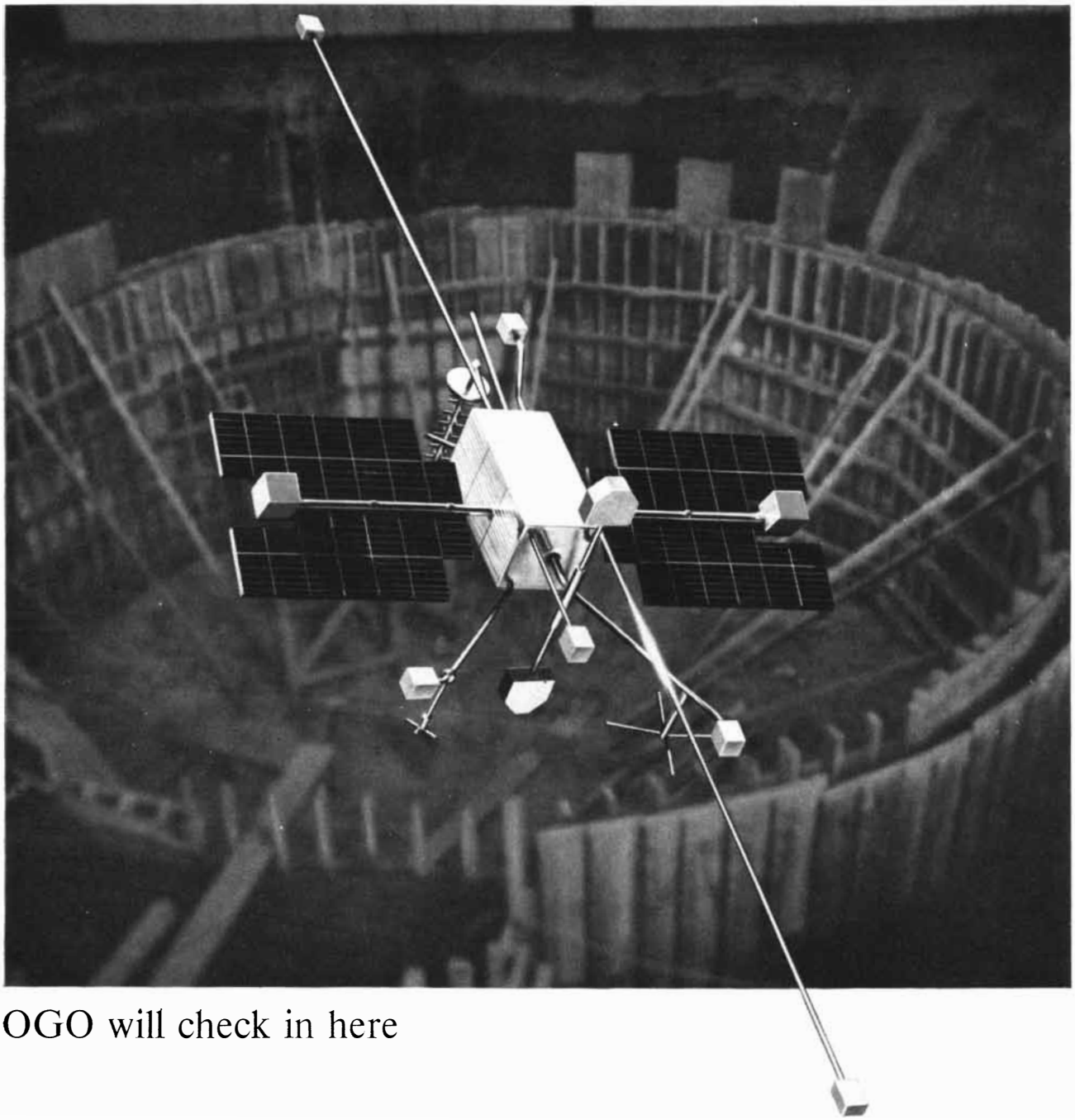
Two farm children have improvised a seesaw by placing a plank over a log. As they go up and down, what sort of curve is traced by every point along the plank? On a moving carrousel the operator walks at a constant speed along a radius of the floor. What type of curve does he trace on the ground beneath the carrousel? Three dogs stand in an open field at the corners of an equilateral triangle. On command each dog runs directly toward the dog on its right. Turning to follow one another as they move, all three run with the same constant speed until they meet at the triangle's center. What sort of paths do they take?

The answer to each question is a different type of spiral. I shall describe the three curves in turn and in doing so try to spiral around as many recreational sidelights as space allows.

The curves traced by all points along the plank of the seesaw are known as involutes of the circle. The involute of any curve is obtained by attaching a thread to the curve, pulling it taut, then "winding" it along the curve. Any fixed point on the taut thread traces the curve's in-



A method of drawing the involute of a circle



OGO will check in here

Soon a new space chamber 30 feet in diameter will fill this deepening bowl of earth. Here OGO (NASA's Orbiting Geophysical Observatory) will be subjected to conditions of solar heating, vacuum, and vehicle radiation to the cold of outer space. The new space chamber will be the sixth at STL. It will enable engineers and scientists working on OGO, Vela Hotel and other STL projects to test large, complete spacecraft as well as major subsystems. And along with other advanced facilities at STL's Space Technology Center, it will provide unusual scope for engineers and scientists to verify and apply new techniques in design, development and fabrication of spacecraft. STL's expanding space programs have created new opportunities for engineers and scientists in the following fields: Aerodynamics, spacecraft heat transfer; Communication Systems; Electronic Ground Systems; Power Systems; Propellant Utilization; Propulsion Controls; Reentry Body Evaluation; Systems Analysis; Thermal Radiation; and Trajectory Analysis. All qualified applicants are invited to write Dr. R. C. Potter, Manager of Professional Placement and Development, for opportunities with STL in Southern California or at Cape Canaveral. STL is an equal opportunity employer.

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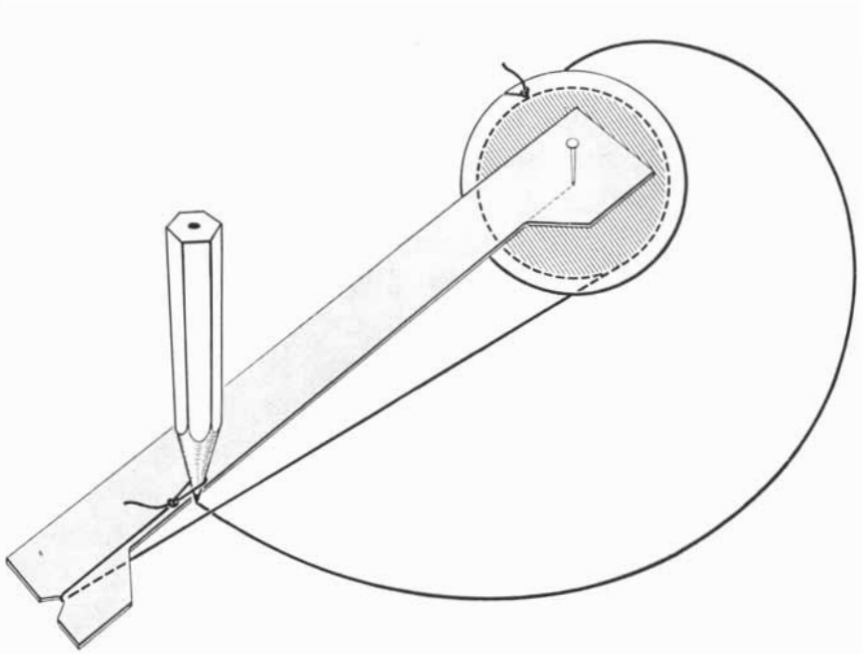


Device for drawing a spiral of Archimedes

volute. Thus a goat tied to a cylindrical post will, if it circles the post so that the rope winds tightly around it, be pulled into a spiral path that is the involute of a circle.

A neat way to draw such a spiral is depicted on page 154. Cut a circle of any desired size from thick cardboard and cement it to the center of a sheet of paper. Cement a slightly larger circle of cardboard on top, with a slot on the rim to hold the knotted end of a piece of string. Wind the string around the smaller circle. The point of a pencil, in a loop at the free end of the cord, will unwind the string and trace the involute. The distance between adjacent coils remains constant and is equal to the smaller circle's circumference when measured along a line that is tangent to one side of the circle. The circle is said to be the evolute of the spiral.

The man on the carrousel traces (with respect to the ground) a curve known as the spiral of Archimedes. (Archimedes was the first to study it; his treatise *On Spirals* is concerned mainly with this curve.) If you place a cardboard disk on a phonograph turntable, you can draw on it a spiral of Archimedes by moving a crayon at a constant speed in a straight line from the center of the disk outward. The groove in a phonograph record is the most familiar example of such a spiral. In polar co-ordinates it is described by saying that at every point the radius vector (distance from the disk's center) is in the same ratio to the vector angle (angular distance from a fixed radius). Spirals have very simple equations in polar co-ordinates but very complicated equations in Cartesian co-ordinates.

A much more accurate Archimedean spiral can be obtained by pinning a strip of cardboard, cut as shown in the illustration above, to a pair of cardboard circles like those used for drawing the involute. As the strip is revolved, the pencil point will be pulled outward along one edge of the strip. It is easy to see that the pencil must move along the edge with a speed that is always proportional to the speed at which the cardboard strip is revolving.

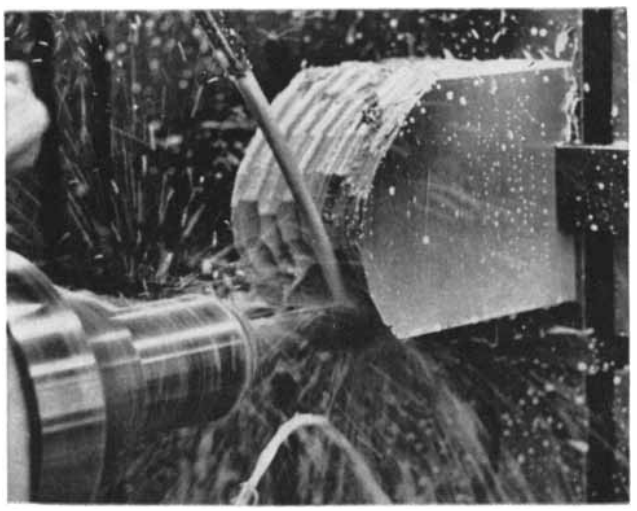
After the first turn the resulting spiral is virtually indistinguishable from the involute of a circle, although the two curves are never exactly alike. The distance between adjacent coils of the Archimedean spiral is constant, but now the distance must be measured along radii instead of along lines tangent to one side of a circle. The most commonly observed spirals are of the Archimedean or circle-involute types: tightly wound springs, edges of rolled-up rugs and sheets of paper, decorative spirals on jewelry, and so on. Such curves are seldom mathematically precise, and one would be hard put to determine whether a given example is in fact closer to a circle involute or a spiral of Archimedes.

Once an accurate Archimedean spiral has been drawn, it can be used for compass-and-straightedge divisions of any angle into any number of equal parts, including three. To trisect an angle, place the angle so that its vertex co-

IBM asks basic questions in computer software

How much work can computers do?

These IBM programmers are describing a machine part in AUTOPROMT, a programming language developed in cooperation with the United Aircraft Corporation.



Following orders generated by an IBM computer from an AUTOPROMT program, this numerically controlled milling machine is shaping a section of a hyperbolic paraboloid.

Men use words to symbolize ideas. Computers use a vastly different kind of language. Present computer logic requires instruction in language so rudimentary that each year millions of words of programming are devoted to basically repetitive procedures. Unless ways are found to economize on this instruction, the usefulness of computers may be limited by the shortage of trained personnel to put them to work.

IBM programmers are simplifying communication with computers. Through careful selection and ordering of references to machine structure, they have developed programming systems that transfer a large part of the repetitive work in programming to the computer itself. These systems permit programmers to express their instructions in language resembling English. They also make different machines "look alike" so that programmers can state their problems with as little difficulty as possible. In addition, IBM programmers are experimenting with systems which use the computer's own capacity to construct new programming systems, such as assemblers or compilers.

Programming systems can extend beyond the level of handling machine references automatically to include applications. AUTOPROMT, IBM's system for numerical control of machine tools, is a codification of machine shop language and practice which enables a computer to determine machining instructions from a description of the part's surfaces. The computer generates the sequence of machine tool paths required to produce the part. IBM has also developed information retrieval systems which reduce the burden of indexing, abstracting or disseminating technical information. One experimental system reduces an article to an abstract by statistically determining the most significant sentences in the article.

Eventually, programming systems may grow beyond boundaries of individual disciplines to include general information on the nature of the physical world. Such systems would be supported by information retrieval systems and inference systems capable of seeing logical consequences of retrieved information. They would allow men who direct computers to focus their attention on creative aspects of future problems. By making systems like these possible, IBM programmers and mathematicians are playing a leading role in applying the computer to ever-widening areas of human knowledge.

If you have been searching for an opportunity to make important contributions in software development, manufacturing research, optics, solid state physics, computer systems development or any of the other fields in which IBM scientists and engineers are finding answers to basic questions, please contact us. Write to Manager of Professional Employment, IBM Corp., Department 659Q, 590 Madison Avenue, New York 22, New York. IBM is an Equal Opportunity Employer.

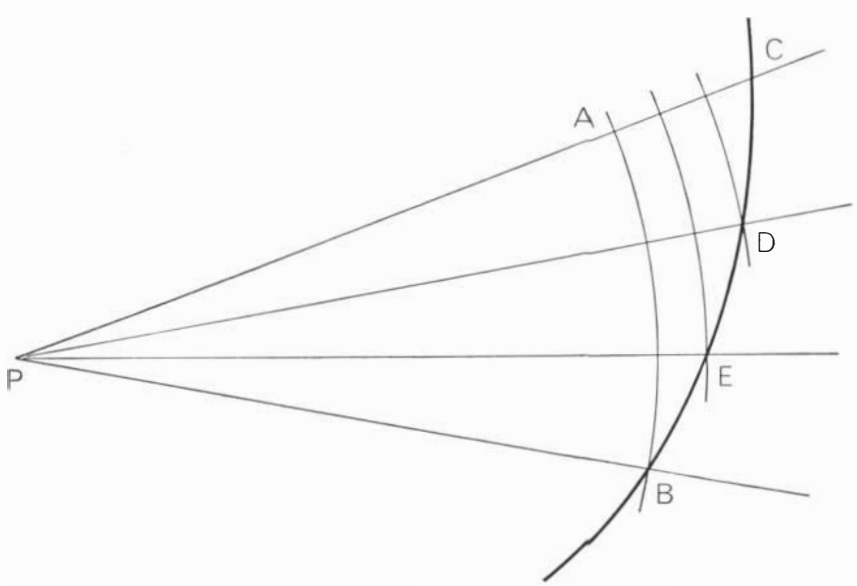
incides with the spiral's pole (origin) and its arms intersect the spiral [*see illustration below*]. With the point of the compass at *P*, draw arc *AB*. The line segment *AC* is trisected by the usual method. Through the two points between *A* and *C* thus established, arcs of circles are drawn to mark points *D* and *E* on the spiral. Lines from the vertex to *D* and *E* complete the trisection. Readers may enjoy proving that this construction is accurate.

Hugo Steinhaus, in his book *Mathematical Snapshots,* pictures the whimsical device shown in the illustration on page 160. The sides of the heart are mirror-image arcs of a spiral of Archimedes. The spiral's properties serve to transform the uniform circular motion of the wheel into a uniform back-and-forth motion of the piston.

The dogs that chase one another to the center of the equilateral triangle follow the lines of a logarithmic, or equiangular, spiral. One way to define this spiral is to say that it cuts every radius vector at the same angle. If mathematical points are substituted for dogs, each point traces a path of finite length (it is two-thirds the side of the triangle), but only after making an infinite number of revolutions around the pole! Logarithmic spirals also mark the paths of any number of dogs greater than two, provided that they start at the corners of a regular polygon. If there are only two dogs, their paths are, of course, straight lines; if there are an infinite number, they keep trotting around a circle. This is a crude way of pointing out that the limits of the equiangular spiral, as its angle to the radius vector varies from 0 to 90 degrees, are the straight line and the circle.

On the earth's surface the counterpart of the logarithmic spiral is the loxodrome (or rhumb line): a path that cuts the earth's meridians at any constant angle except a right angle. Thus if you were flying northeast and always kept the plane heading in exactly the same direction as indicated by the compass, you would follow a loxodrome that would spiral you to the North Pole. Like the dogs' paths, your path to the Pole would be finite in length but (if you were a point) you would have to circle the Pole an infinite number of times before you got there. A stereographic projection of your path on a plane tangent to the Pole would be a perfect logarithmic spiral.

The logarithmic spiral is the most common type of spiral to be found in nature. It can be seen in the coil of the nautilus shell and snail shells, in the arrangement of the seeds of many plants, such as the sunflower and daisy, the scales of the pine cone, and so on. *Epeira*, a common variety of spider, spins a web in which a strand coils around the center in a logarithmic spiral. Jean Henri Fabre, in his book *The Life of the Spider*, devotes an appendix to a discussion of the mathematical properties of the equiangular spiral and its many beautiful appearances in nature. There is an extensive literature, some of it eccentric, on this spiral's botanical and zoological manifestations and its close relation to the golden ratio and the Fibonacci number series. The basic reference here is a 479-page, richly illustrated book entitled *The Curves of Life*,



Trisecting an angle with a spiral of Archimedes

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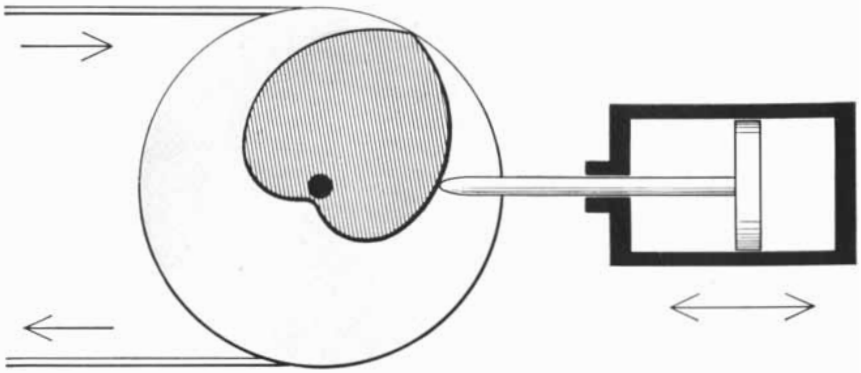

Archimedean spirals change rotary to linear motion

by Theodore Andrea Cook. It was published in 1914 by Henry Holt and has long been out of print.

A device for ruling a logarithmic spiral is easily cut from a piece of cardboard [*see illustration on page 162*]. Angle *a* may be any size you please between 0 and 180 degrees. By keeping one edge of the strip on the spiral's pole and ruling short line segments along the oblique straightedge as this straightedge is moved toward or away from the pole, you produce a series of chords of the spiral in much the same manner that *Epeira* spins its web. The device ensures that all these chords cut the radius vector at the same angle. The smaller you make the oblique straightedge, of course, the more accurate the spiral is. Such a device can also be used for testing a spiral to see if it is logarithmic.

What happens if angle *a* is a right angle? The spiral degenerates into a circle. If the angle is 74 degrees 39 minutes (the exact value is a trifle more than this), the resulting spiral will be its own involute. The involutes of all logarithmic spirals are also logarithmic spirals, but only in this case are the two spirals exactly alike.

The equiangular spiral was first discovered by René Descartes. Jakob Bernoulli, the 17th-century Swiss mathematician, was so entranced by the spiral's property of reappearing after various transformations (e.g., changing it to its involute) that he asked to have it engraved on his tombstone with the words "*Eadem mutata resurgo*" ("Though changed I shall arise the same"). His request was badly carried out. The Latin phrase was omitted, and the best spiral the poor stonecutter could achieve was a crude version of either an Archimedean spiral or an involute of a circle. It can be seen today on the mathematician's gravestone in Basel, and it is obviously not a logarithmic spiral because the width between coils shows no progressive increase as it grows larger.

In terms of sheer size, the logarithmic spiral's most impressive appearance is in the arms of many of the spiral galaxies. Just why it turns up here is a mystery that is bound up with the mystery of the arms themselves. They are known to be glowing lanes of stars and gas that somehow are whirled into spiral shape by the galaxy's rotation. The entire galaxy is a cluster of billions of stars and spins like a monstrous Fourth of July pinwheel. The faint white glow of the Milky Way results from our looking edgewise through two gigantic spiral arms of our own galaxy. Observations show that these arms are rotating much faster near the center of the galaxy than at the edge. This ought to wind up the arms quickly and eventually eliminate them, but the fact that most galaxies have retained a spiral structure suggests that the arms are not winding up at all. One theory has it that as one side of an arm takes on luminous gas, the other side evaporates it, keeping the arm in the same shape with respect to the galaxy [see "The Evolution of Galaxies," by Jan H. Oort; SCIENTIFIC AMERICAN, September, 1956].

Like their space-curve cousin the helix (to be discussed in a later article), all spiral shapes are asymmetric. This means that on a plane every spiral can be drawn in two forms that are identical in all respects except that one is a mirror reflection of the other. When a spiral can be viewed from either side, as is the case with spider webs and (if we could travel far enough out in space) galaxies, then its "handedness" depends on the point of view. But if there is no way to turn a spiral over or to move around in order to see it from the other side, every spiral is either clockwise or counterclockwise.

If you draw a tightly coiled spiral on

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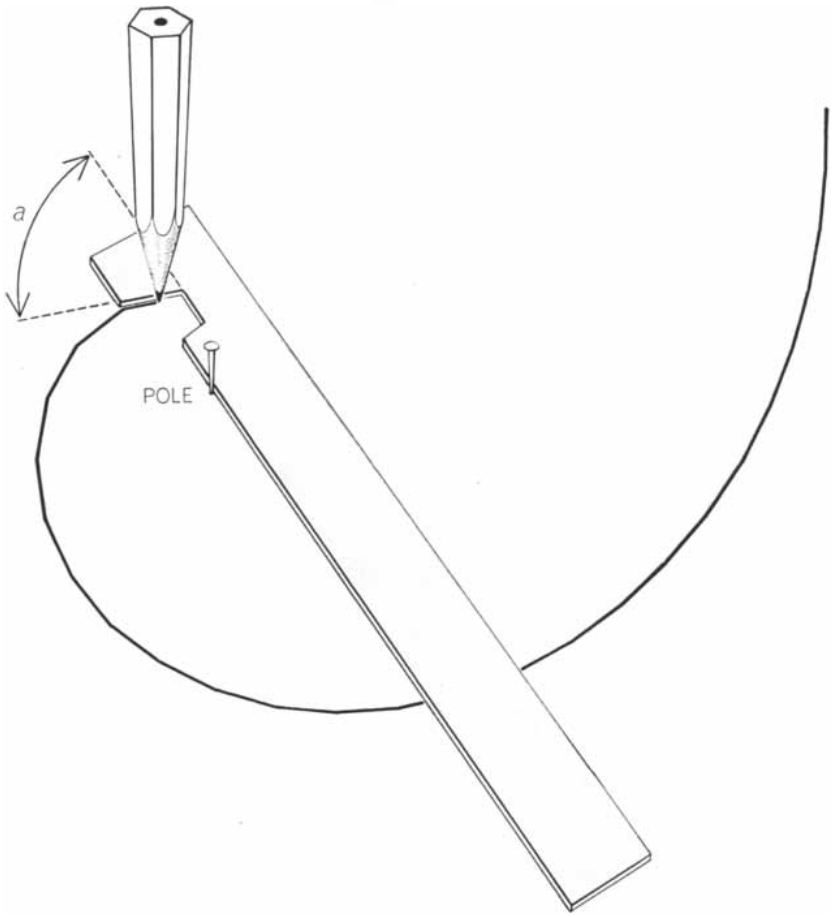

How to draw a logarithmic spiral

a cardboard disk, using a thick black line, and rotate it on a phonograph turntable, a familiar illusion results. The coils appear either to expand or contract depending on the spiral's handedness. An even more astonishing psychological illusion can be demonstrated with two such disks, bearing spirals of opposite handedness. Put the "expanding" spiral on the turntable and stare directly down at its pole for several minutes while it revolves. Now quickly shift your gaze to someone's face. For a moment the face will appear to shrink suddenly. The other spiral has the opposite effect: the face you look at will appear to explode outward.

The asymmetry of the spiral makes it a convenient figure for dramatizing a curious problem of communication. Imagine that Project Ozma has established radio-wave contact with a Planet X somewhere in our galaxy. Over the decades, by the use of ingenious codes, we learn to converse fluently with intelligent humanoids on Planet X. It has a culture almost as advanced as ours but, because of high, dense clouds like the clouds of Venus surrounding it, its inhabitants know nothing about astronomy. They have never seen the stars. After Planet X has been sent a detailed description of a number of major galaxies, the following message is received on earth:

"You say spiral nebula NGC 5194, viewed from earth, has two spiral arms that coil outward in a clockwise direction. Please clarify meaning of 'clockwise.' "

In other words, scientists on Planet X want to be sure that when they record a diagram of nebula NGC 5194, based on information supplied by scientists on earth, they draw it correctly and not in mirror-image form.

How can we communicate to Planet X which way the nebula coils? It is no help to say that as an arm whirls outward above the center of the galaxy it moves from left to right, because we have no way of being certain that Planet X understands "left" and "right" in the same way we do. If we could communicate an unambiguous definition of "left," the problem would of course be solved. The matter is far from trivial. In fact, it leads into profound questions involving space

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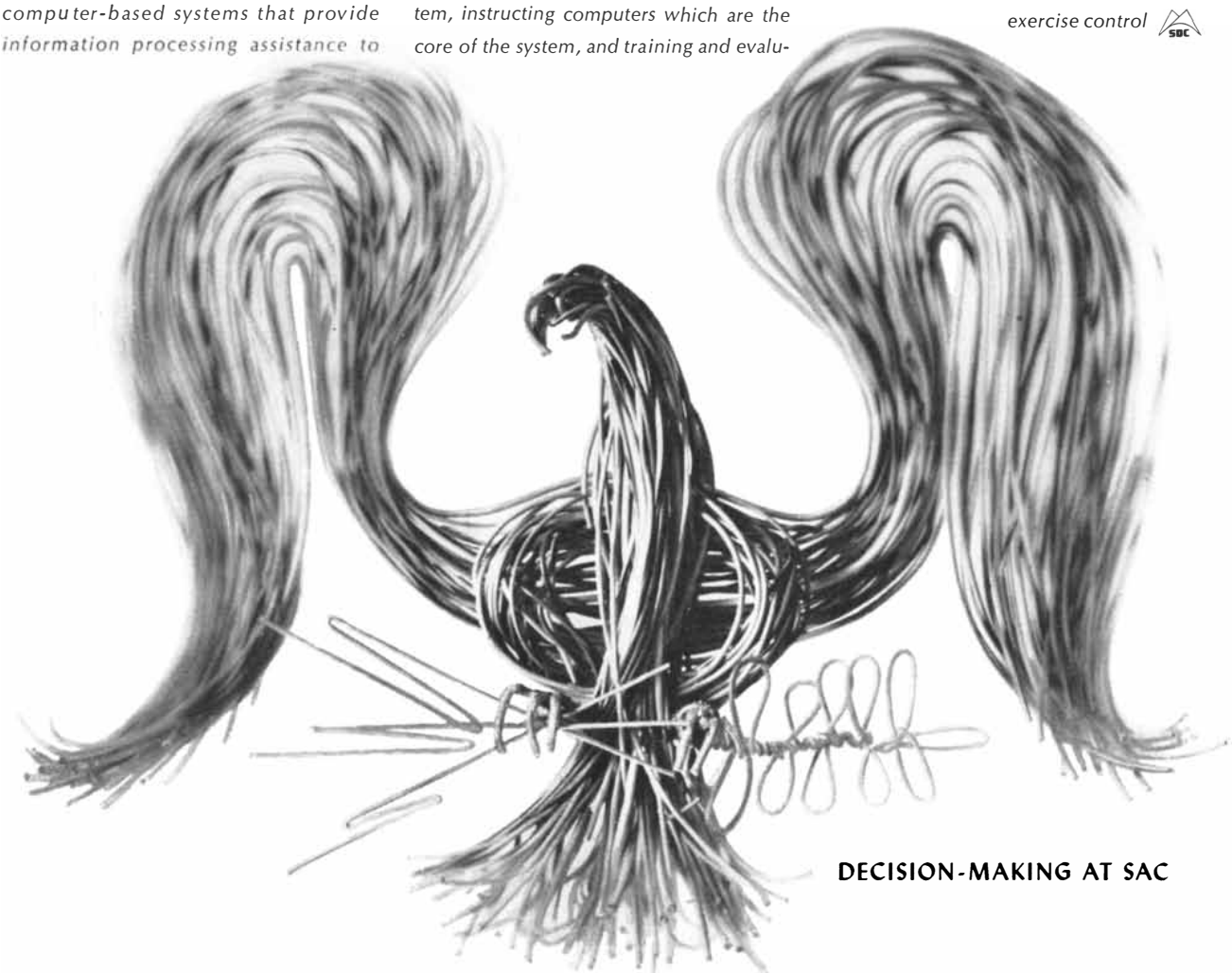


DECISION-MAKING AT SAC

11-215-A

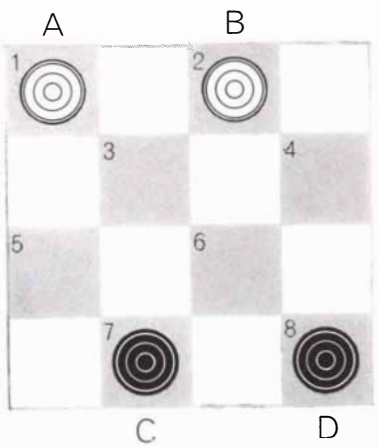
and time. Readers are invited to think about it carefully until next month, when the surprising answer will be furnished.

The answer to last month's problem of analyzing the game of checkers on a 4×4 board is that the game is a draw if both sides play as well as possible. As shown in the illustration below, Black has a choice of three openings: (1) C5, (2) C6, (3) D6.

The first opening results in an immediate loss of the game when White replies A3. The second opening leads to a draw regardless of how White replies. The third opening is Black's strongest. It leads to a win if White replies A3 or B3. But White can reply B4 and draw.

With respect to the 3×3 simplified go game, also mentioned last month as suitable for a matchbox learning machine, I am assured by Jay Eliasberg, vice-president of the American Go Association, that the first player has a sure win if he plays on the center point of the board and rationally thereafter. Incidentally, in its full-scale form go is a game of great intellectual interest. Anyone who wishes to find out more about the game can write to the American Go Association, 96 Cedar Avenue, Hackensack, N.J.

Readers who enjoyed the induction card game of Eleusis, the topic of this department in June, 1959, will be pleased to know that the inventor, Robert Abbott, has privately published a 61-page book entitled *Four New Card Games*. In addition to giving complete rules for Eleusis, the book also tells how to play three other extraordinary and fascinating card games: Babel, Leopard and Construction. One dollar sent to Abbott at Box 1861, General Post Office, New York 1, N.Y., will bring the book postpaid.



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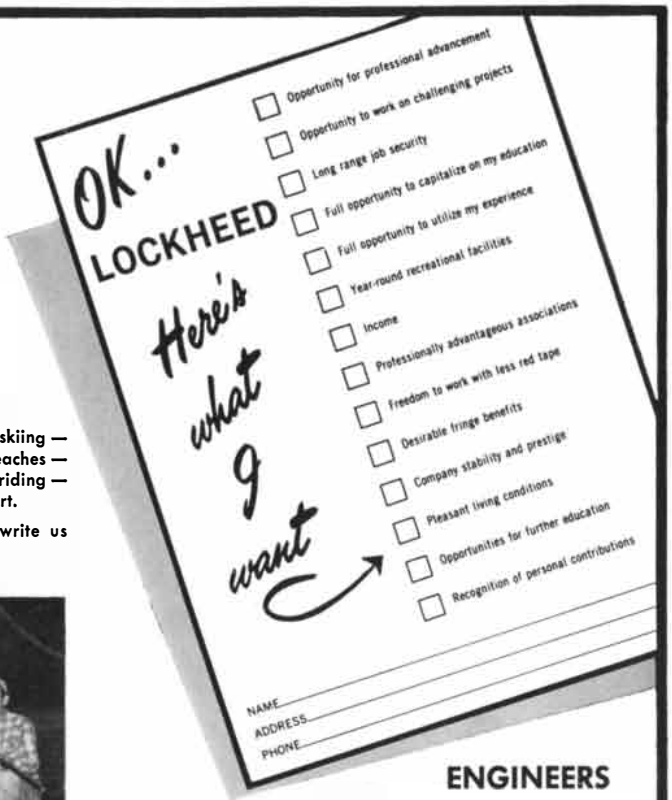

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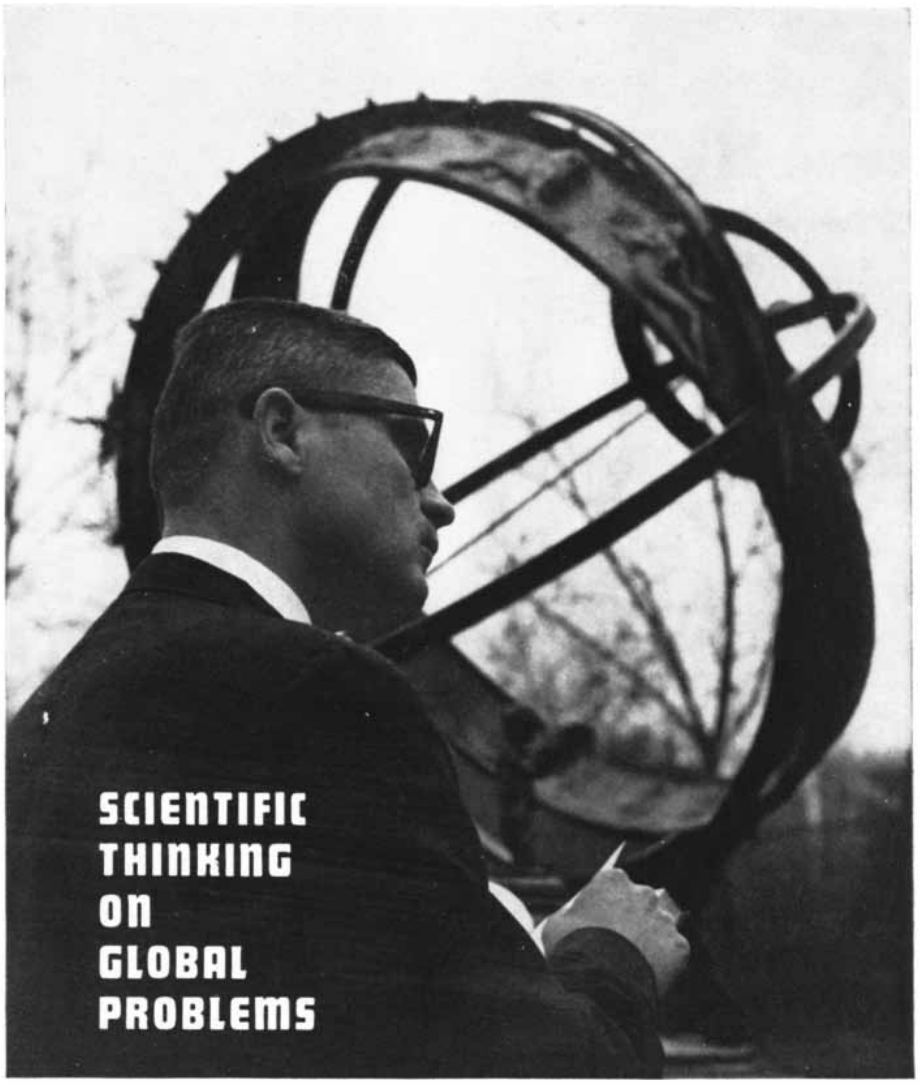

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THE AMATEUR SCIENTIST

Experiments with a plant-growth inhibitor and a report on a fixed-eyepiece telescope

Conducted by C. L. Stong

In their preoccupation with substances that encourage the growth of plants, horticulturists may overlook the fascinating experiments that can be conducted with compounds that plants manufacture to inhibit growth. These potent substances help to preserve the species that manufacture them and to regulate the density of plant populations. By producing a compound that discourages the encroachment of its neighbors a plant can provide living space for itself. Similarly, by elaborating a substance that inhibits the germination of its seeds when conditions are unfavorable the plant can ensure a good start in life for its offspring [see "Germination," by Dov Koller; SCIENTIFIC AMERICAN, April, 1959].

Substances that inhibit germination appear to be almost as various as the plants that make them, and their chemistry is equally diverse. Some of them are among the oldest and best-known drugs, stimulants and poisons in the armamentarium of medicine. The alkaloid strychnine is one. Penicillin, an unsaturated lactone, is another. Many of the germination inhibitors are also insecticides. For the most part they are cyanogens, organic acids, unsaturated lactones, aldehydes, alkaloids and the essential oils. It is reported that even the slightest smear of oil from lemon peel, for example, will prevent the germination of wheat in a dish of otherwise fertile soil.

Inhibitors tend to concentrate in parts of a plant according to function. In the case of leafy vegetables, such as cabbage and lettuce, they are found in the leaf coat. They are concentrated in the leaf sap of spinach, in the bulb of the onion and garlic and in the root of the carrot and the horseradish. In apples and pears they are stored in the pulp of the fruit; in tomatoes they are stored in the juice. Their function in fruits is to delay germination until after the fruit has fallen and decomposed into soil nutrient. The inhibitors are then leached away by rain in preparation for the new crop.

Some inhibitors are built into the seed, and not many of these have been investigated. Last fall Michael Zimler, a high school student in Roslyn Heights, N.Y., was casting about for a science-fair project and hit on the idea of setting up an experiment to learn if the seed of Merion bluegrass, the popular lawn cover, contains an inhibitor and, if so, how effective it is against the germination of other plants.

"I started out," Zimler writes, "on the assumption that the grass seed contains an inhibitor that could be extracted by water in sufficient concentration to be detected. The apparatus used in the experiments was assembled for the most part from materials found around the house: assorted glasses, bottles, jars, Saran Wrap and toy balloons. The specimens exposed to the inhibitor included the seeds of radish, lima bean, green pea, cucumber, corn, morning glory, sunflower, zinnia and gourd. Tests were also run on yeast and bread mold. Packets of fresh seeds were bought from a local store that deals in garden supplies, and the yeast, in dry form, came from the corner grocery. Three germinating media were used: white blotting paper, washed sand and a mixture of washed sand and peat moss.

"To make the extraction I put a half-pound of grass seed in a half-gallon jar, added a quart of tap water and let the mixture stand overnight. I stirred it occasionally before bedtime and again in the morning. At the end of 12 hours the liquor was filtered through a square of nylon mesh cut from an old stocking that had been washed with soap and thoroughly rinsed.

"Enough tap water was added to the filtered liquor to make up two quarts. This was poured into smaller jars, which were wrapped with aluminum foil to keep out the light and stored at room temperature. Within a few days the extract spoiled, turned cloudy and developed an offensive odor. I made up another batch the same way but stored it in the refrigerator at approximately 42 degrees Fahrenheit. This suppressed the growth of microorganisms, and the extract remained clear throughout the period of the experiments.

"My first attempt to germinate seeds also failed. Several conical dessert glasses were lined with white blotting paper. The paper in half the glasses was saturated with the extract; the paper in the other glasses, which were to serve as controls, with tap water. The dry seeds from the packets were inserted between the blotting paper and the glass so that sprouts could be observed without disturbing them. The number of seeds planted in each glass varied from 12 to 50, depending on the variety and size. The arrangement seemed sensible, particularly because it would be easy to keep the paper moist. It turned out, however, that only a small area of each seed made contact with the paper and the seeds did not get enough moisture to sprout.

"The next batches were planted in sand. The glasses were cleaned, dried and nearly filled with dry sand. The seeds were soaked overnight, the controls in tap water and the test specimens in extract, and embedded lightly in the sand. Thereafter the sand was kept moistened with either water or extract as appropriate and maintained at room temperature. Within a week a high percentage of all the controls had germinated with the exception of the lima beans.

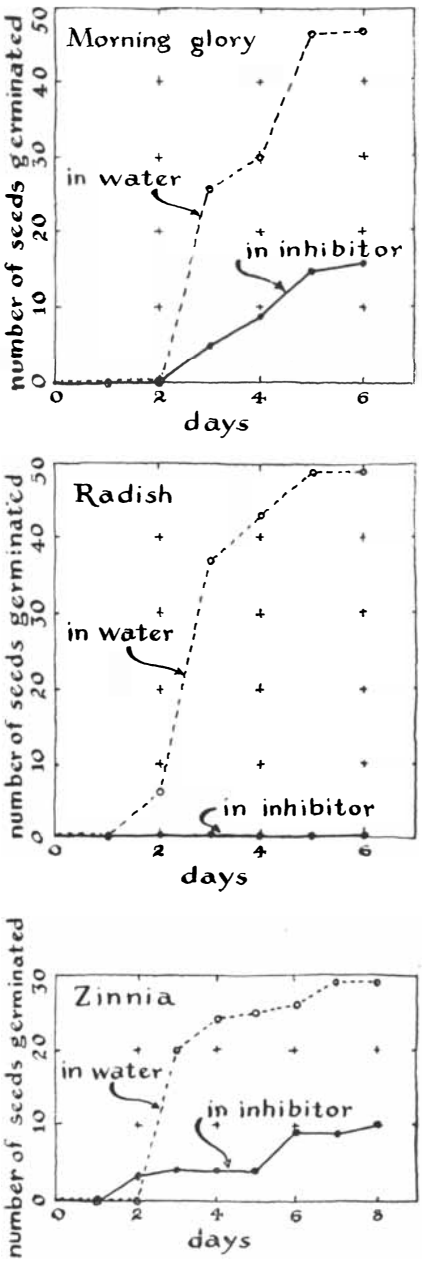
"The presence of an inhibitor was strikingly apparent, particularly in the cases of cucumber, green pea and radish. Within a week 58 per cent of these seeds sprouted in the control plantings but none in the sand to which grass extract had been added. Plants showing maximum resistance to the inhibitor were sunflower, corn, morning glory and zinnia, in that order. The controls, in the case of these four plants, also exhibited more vigor than plants that were susceptible to the inhibitor. Ninety-four per cent sprouted in tap water. The results

are summarized in the accompanying table [*page 170*], and also by graphs for morning glory, radish and zinnia. The number of seeds in the test planting is plotted against growing time in days [*see illustration at right*].

"I performed a similar experiment to test the possible effect of the inhibitor on a fungus, which does not reproduce by seed. The most readily available fungus that can be procured in a relatively pure strain is ordinary baking yeast. Most yeasts can live and grow only in a solution that contains sugar or substances that are easily converted into sugars. Such substances are present in wheat flour.

"Two packages of active dry yeast were dissolved, one in eight ounces of warm inhibitor solution and the other, for a control, in eight ounces of warm tap water. Each yeast solution was then mixed with eight ounces of wheat flour, and the doughs were set to rise in a warm oven for one hour. The dough that was prepared with inhibitor appeared to rise more rapidly and to a somewhat greater volume than the control, but the rates were difficult to measure.

"Accordingly a second experiment was set up in which the influence of the inhibitor was judged by the amount of carbon dioxide liberated by fermentation. A package of yeast was divided into equal parts and each part was softened, one with two ounces of inhibitor liquor and the other with two ounces of tap water. After standing undisturbed at room temperature for four hours the yeast was further diluted so as to make 10 ounces of inhibitor solution and 10 ounces of control respectively. Four tablespoons of granulated sugar had been added previously to each of the diluting solutions as nutrient. The solutions were transferred to 12-ounce soda bottles and capped by rubber balloons from which the air had been squeezed. The capped bottles were then immersed to their necks in a pan of warm water (about 100 degrees Fahrenheit) and incubated for two hours. To maintain the temperature a small amount of cooled water was dipped from the pan occasionally and replaced by hot water. Carbon dioxide, evolved by fermentation, inflated the balloons. The volume to which the balloons expanded could be calculated approximately from measurements of their height and diameter. The calculated volume was taken as an index of the effectiveness of the inhibitor. The 'inhibited' yeast turned out to be approximately 30 per cent more active than the control! Germination inhibitors, according to the literature, can affect or-

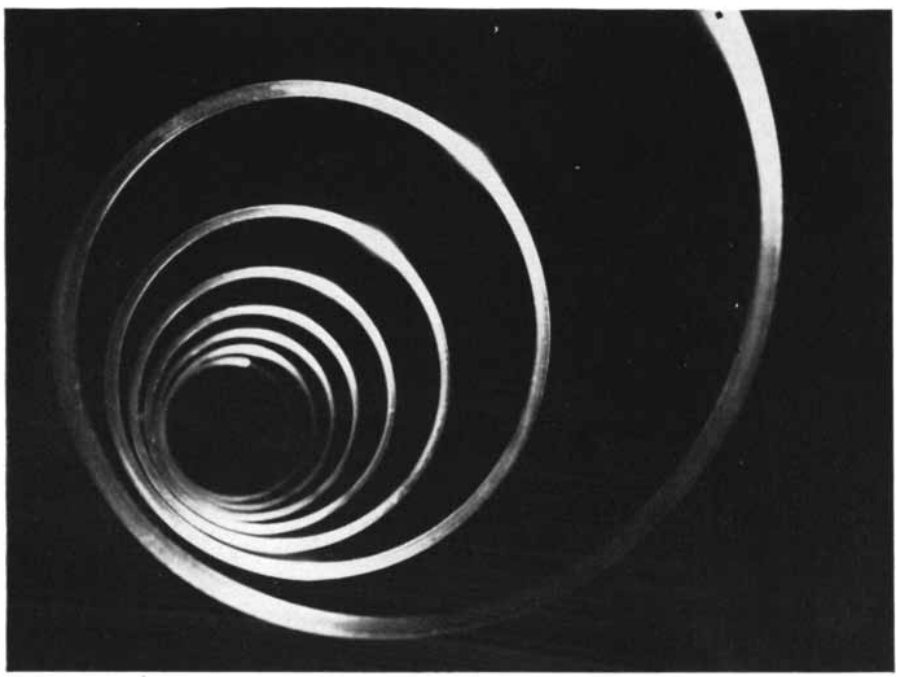


Graphs of three germination trials

ganisms, both plant and animal, in various ways according to dosage and the nature of the organism. Caffeine, for example, will act as a stimulant, a poison or a germination inhibitor, depending on the amount of caffeine administered, how and to what. Perhaps the substance in Merion bluegrass acts as a stimulant for cultured yeast. On the other hand, it is possible that the inhibitor in bluegrass has no effect on the yeast; that nutrients washed from the seed account for the accelerated growth.

"I have not had time so far to check these guesses by experiment. The tests that have been described were made last year while I was a sophomore and are

. . . TO THE EDGE OF SPACE AND BEYOND . .



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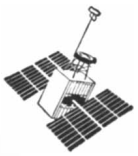
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

being continued this year on a number of molds and bacteria. Before the runs are finished I hope not only to resolve the question of whether the extract can function as a stimulant but also to identify the inhibiting substance. In several closely related plants the inhibitor has been identified as coumarin, an unsaturated lactone that is available commercially. I intend to make simultaneous runs with coumarin and Merion bluegrass inhibitor on a number of organisms and, having tabulated the results, to analyze the two solutions by paper chromatography. If a chromatographic zone of the extract migrates at the characteristic rate of coumarin and exhibits the same inhibiting properties, the extract will probably be coumarin. If no zone migrates at the rate of coumarin, the extract will be compared with other known inhibitors."

Amateur telescope makers who reach the age when physical comfort and convenience take precedence as design criteria over cost usually settle on an instrument that features a fixed eyepiece. The first mounting of this type was made 42 years ago by the late Russell W. Porter, one of the founding fathers of amateur telescope making. Telescopes must be movable so that the observer can point the objective lens or mirror toward any desired region in space and follow selected objects across the sky. With conventional telescopes the whole instrument moves, and the observer has to move too. The eyepiece is mounted rigidly to the tube, either at the rear end in the case of refracting instruments or on the side of the tube at the front end in the case of Newtonian reflectors. In both designs the eyepiece moves with the tube, and it can get itself into some distressingly neck-craning positions. To reach all parts of the sky the tube must rotate in two planes: up and down and from side to side. In making an analysis of these motions Porter observed that the point at which the planes intersect always stays fixed. Why not locate the eyepiece at this point? Mechanically the two axes that are normal to the planes must be offset to provide space for bearings. But they can be brought together optically by equipping the mechanism with a pair of prisms, one centered in each axis. In the reflecting telescope, Porter located one of the two prisms on

NUMBER OF SEEDS	VARIETY OF SEED	MOISTENING AGENT	NUMBER OF SEEDS GERMINATED (DAYS) 1	2	3	4	5	6	7	8
30	CORN	WATER	0	5	17	27	28	28		
		INHIBITOR	0	0	2	9	11	11		
30	CUCUMBER	WATER	0	5	7	10	12	13	13	
		INHIBITOR	0	0	0	0	0	0	0	
11	GOURD	WATER	0	0	0	4	7	7		
		INHIBITOR	0	0	0	2	2	2		
30	GREEN PEA	WATER	0	3	5	7	7	11	11	
		INHIBITOR	0	0	0	0	0	0	0	
50	MORNING GLORY I (BLOTTING PAPER)	WATER	0	0	26	30	47	47		
		INHIBITOR	0	0	5	9	15	16		
30	MORNING GLORY II (SAND)	WATER	6	26	27	27				
		INHIBITOR	0	2	6	6				
50	RADISH	WATER	0	6	36	43	48	48		
		INHIBITOR	0	0	0	0	0	0		
15	SUNFLOWER	WATER	0	6	9	12	14	14		
		INHIBITOR	0	1	2	3	3	8		
30	ZINNIA	WATER	0	0	20	24	25	26	28	28
		INHIBITOR	0	3	4	4	4	8	9	9

Summary of effects of inhibitor on seed germination



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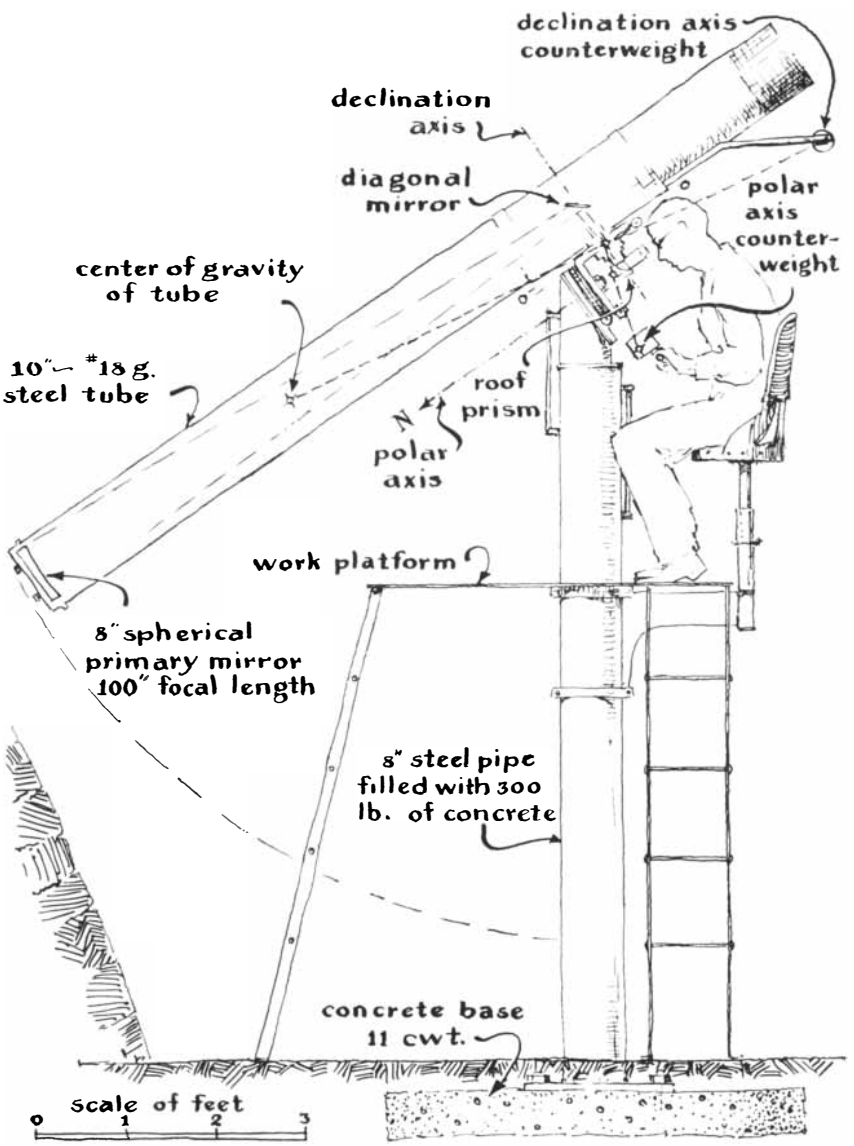
the optical axis of the tube to bend the focused rays at a right angle through a hollow bearing on which the telescope turns up and down. He centered the second prism on the polar axis, on which the telescope turns from side to side. In this location the prism bends the rays into the fixed eyepiece. In astronomical telescopes the polar axis parallels the axis of the earth. Porter's design enables the observer to look down this axis, and at the latitudes of the U.S. the angle of view is most comfortable.

But the design contained one flaw that troubled Porter. The use of hollow bearings meant that the diameter and the loaded surfaces of the bearings had to be large. Moreover, the tube had to be supported near one end and counterbalanced in one plane by a weight supported on a beam that would also provide equilibrium in the second plane. The beam could not be allowed to sweep through the observer's position. Porter solved this geometric puzzle by simply fastening a rod to the front end of the telescope, bending it over the observer's head and hanging a weight on the outer end. This counterbalanced the tube, but it also loaded the bearings with a force in the form of a couple that made the instrument hard to turn. Some years later he suggested that the loads in each axis could be counterbalanced separately by substituting a crescent-shaped slug of lead for part of the weight at the end of the hooked beam and supporting the slug by a short beam that would swing between the observer and the instrument. This stratagem would eliminate the coupling force. "I have never seen such a weight, nor made one except on



Fixed-eyepiece telescope mounting

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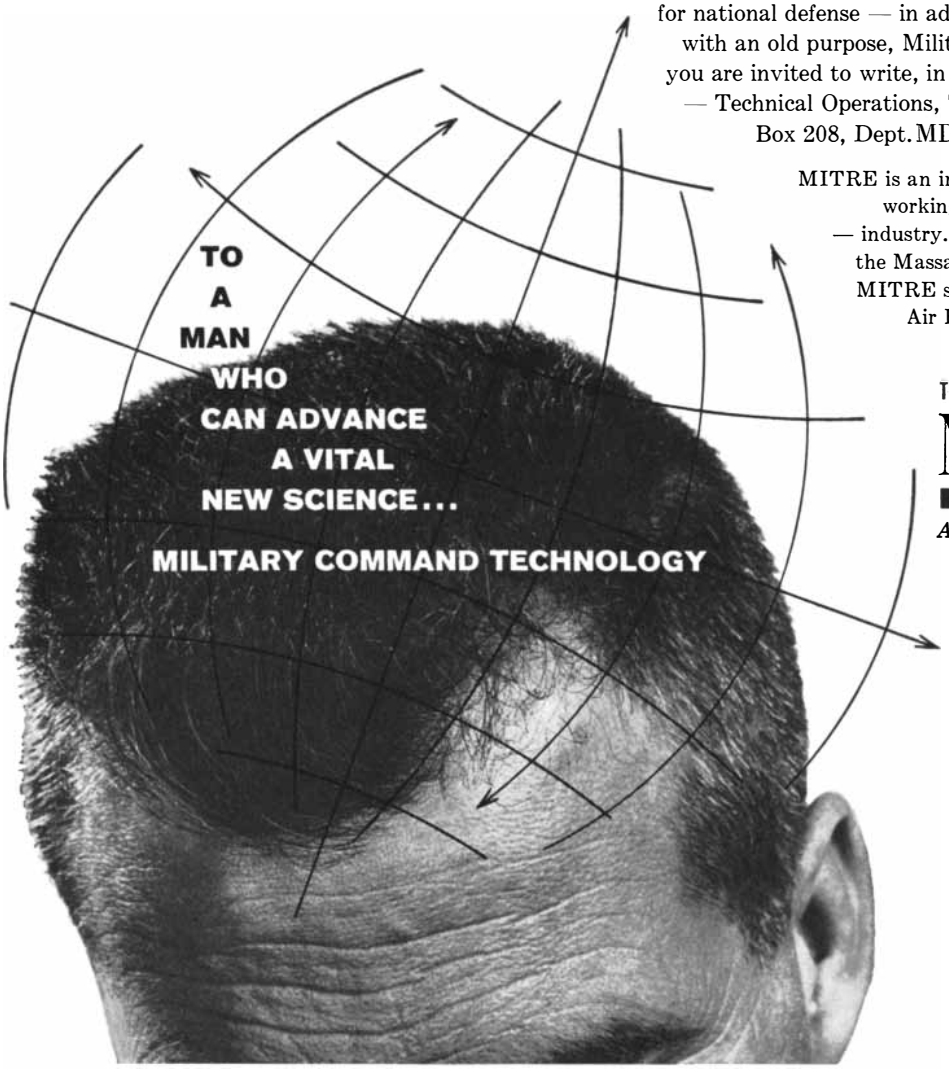

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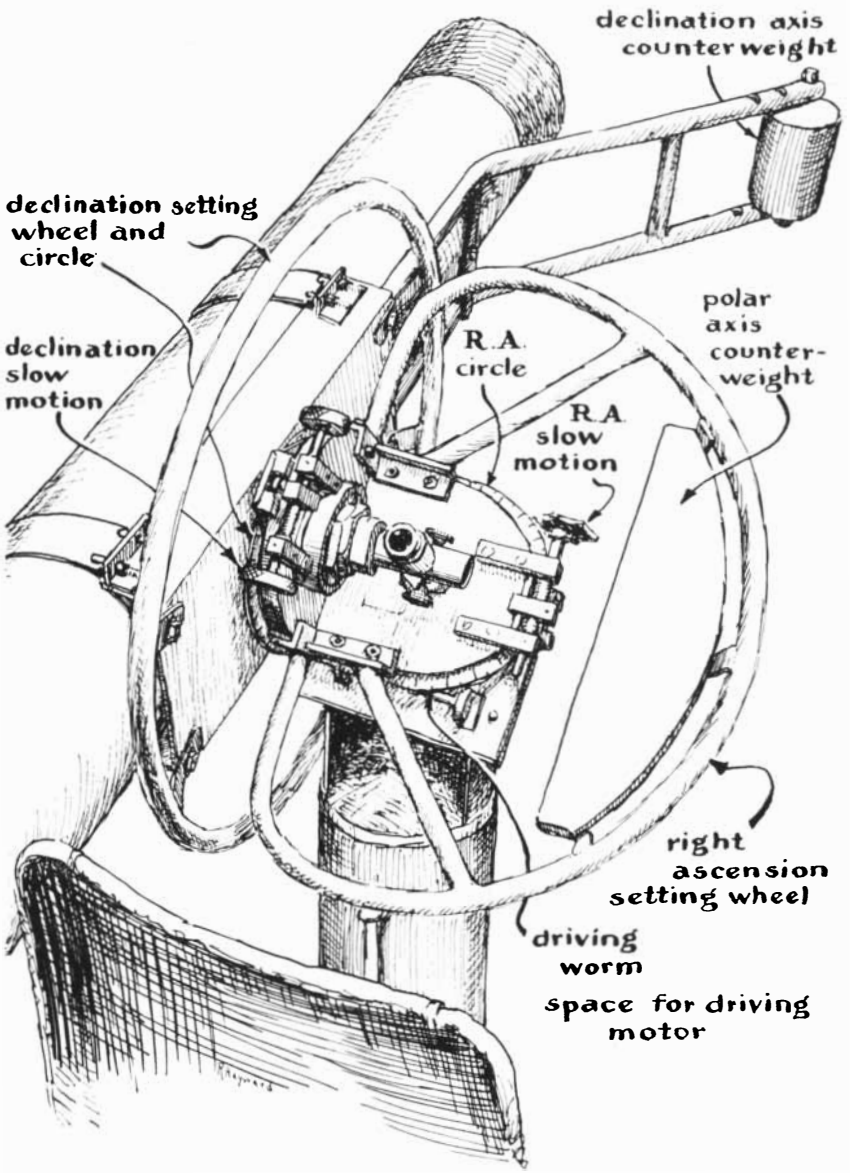


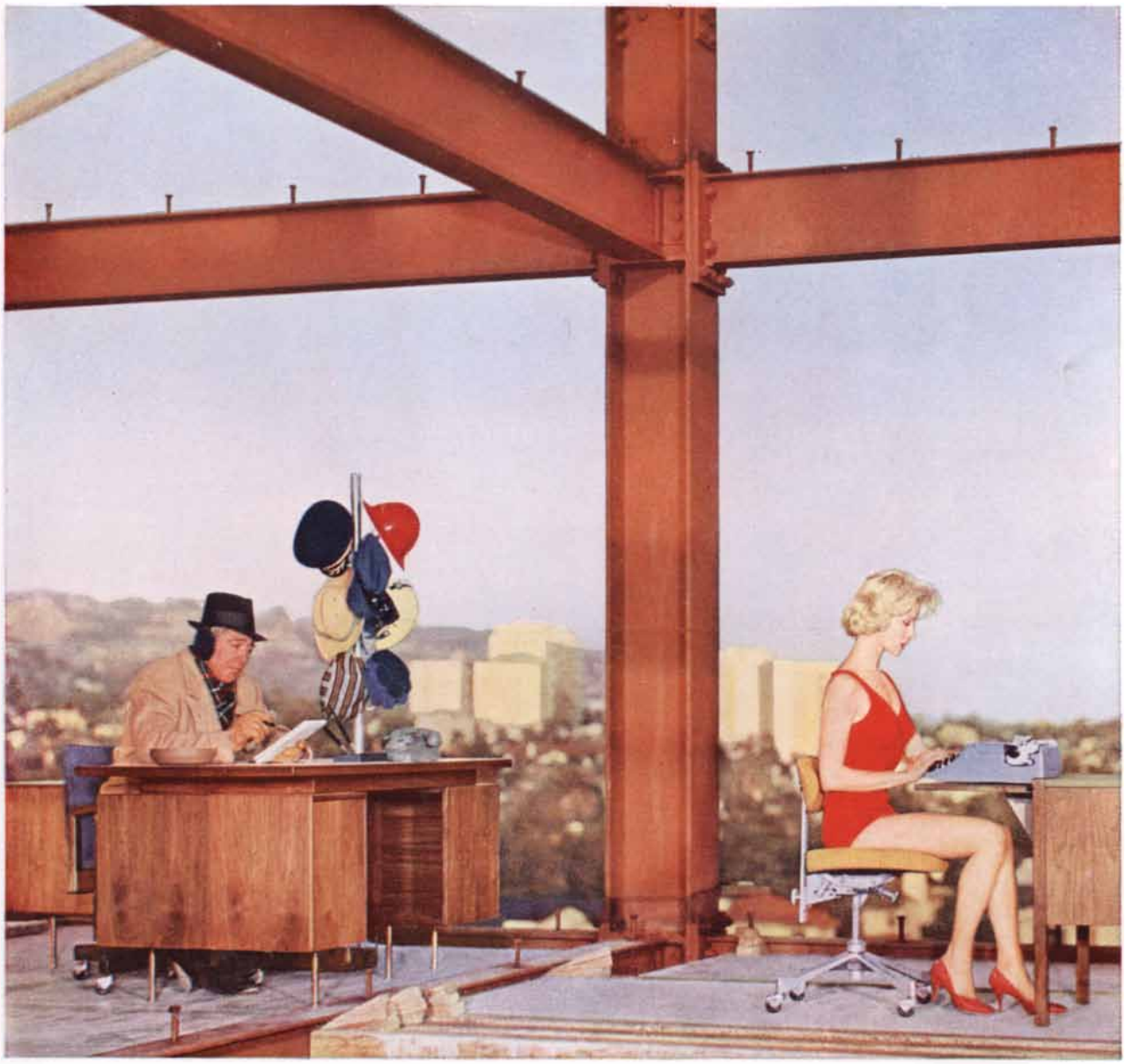
Details of telescope mounting showing crescent counterweight

paper," Porter wrote a few years before his death in 1949, "but I would like to see it tried out."

A telescope that incorporates the idea has now been constructed by Ralph Sangster of Brighton in South Australia, who reports that it works beautifully. "I set out to build an instrument designed specially for making studies of lunar and planetary detail," he writes. "During such studies the observer must keep his eye glued to the instrument for hours on end. If possible, all control knobs and switches should be within easy reach and operable by touch alone. A telescope of the fixed-eyepiece type meets these requirements, and I decided to build one incorporating the revisions that Porter suggested.

"To eliminate guesswork from the optical assembly I also decided to make a long-focus instrument. At focal ratios of $f/12$ and higher, spheroidal mirrors operate about as well as paraboloids and very much better than the poor paraboloids that an inexperienced amateur may make. A good spheroid is almost as difficult to figure as a paraboloid. But it is much easier to test. You may not wind up with a perfect spheroid but at least you know how much it departs from perfection. Moreover, a big focal ratio gives reasonable magnification for observing planets without the use of tricky and expensive eyepieces. The aperture of my mirror is eight inches and the focal length 100 inches. A one-inch eyepiece therefore gives a magnification of 100 diameters.

"The pier that supports the instrument, the observer's platform and the seat is an eight-foot length of steel pipe,



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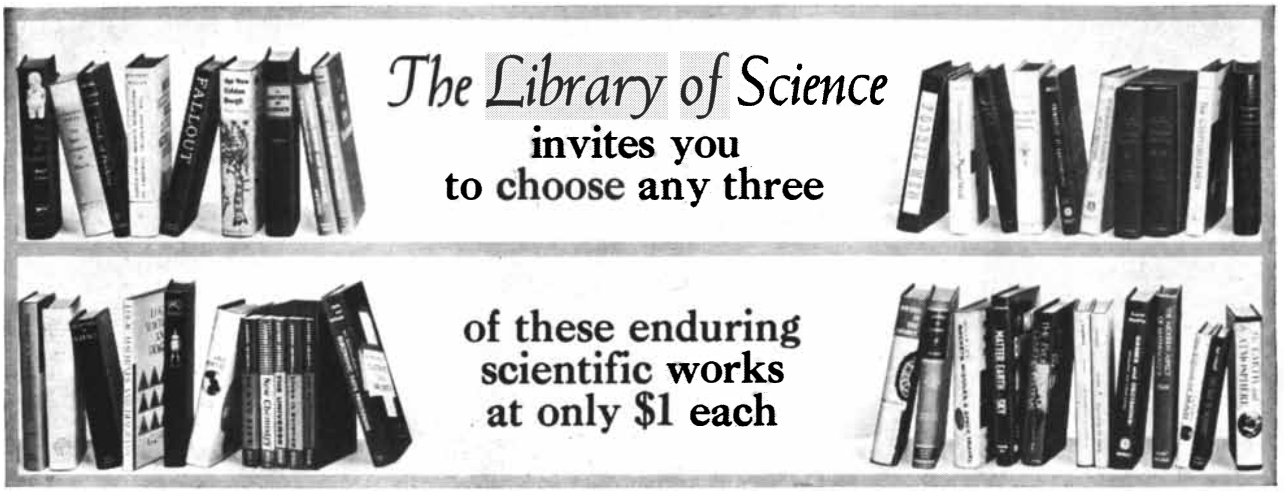
eight inches in diameter, filled with 300 pounds of concrete and anchored upright by a pipe flange that is bolted to an 1,100-pound slab of concrete [*see illustration on page 172*]. The observatory is 20 feet square and nine feet high. If constructed of conventional materials, it would have cost at least $1,500. The actual cost was just a little over $100—plus a lot of labor. Essentially it is a basin scooped out of the sandy ground in my back yard and walled with stone quarried from a nearby outcrop. The observatory is roofed with corrugated sheet iron on a wooden frame that rolls on a pair of elevated rails. The level of the roof is two feet above the ground and allows the telescope to be pointed within 10 degrees of the horizon.

"To carry out Porter's suggestion for balancing the instrument, a 60-pound weight was first suspended by a bracket at the outer end of the tube. The bracket was bent just enough to center the combined mass of the tube and counterweight on the declination bearing. This minimized torque around the declination axis. A thin crescent of lead was then cast in a mold of sand and attached to a beam that also served as a wheel for rotating the instrument in right ascension, as shown in the accompanying drawing [*page 174*]. At our latitude the angle at which the wheel and counterweight are inclined provides eight inches of clearance between the apparatus and the observer.

"The assembly turns as smoothly as the dial of a bank vault and with little more effort. The mounting is fitted with a worm gear for attaching a clock to drive the tube in right ascension, and I believe that a conventional electric-clock motor will power it. The one-revolution-per-minute shaft of the clock will be coupled through an idler gear to a five-to-one set of reduction gears. The output of the gears will drive a worm of 10 threads per inch that engages the 288 teeth of the right ascension worm wheel.

"My greatest satisfaction is in the comfortable bus seat. The seat is adjustable up and down, in and out, and is hinged like a rudder to the pier just beneath the southerly platform. The pier also supports side platforms, which come in handy when making periodic adjustments and fitting accessories to the instrument. The side platforms were made narrow so that they would not impede the movement of the tube. On stargazing nights visitors easily climb the short ladder to the observing seat, and the thrill of steering a telescope this large with the tip of a finger often makes it hard to get them down again."



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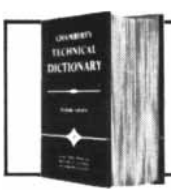

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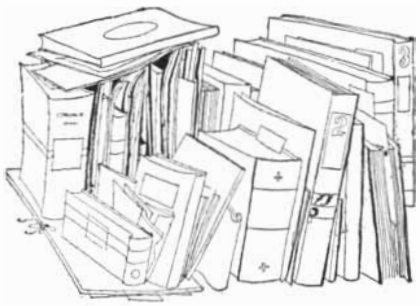

BOOKS

An ambitious examination of the physics and metaphysics of the concept of time

by Max Black

THE NATURAL PHILOSOPHY OF TIME, by G. J. Whitrow. Thomas Nelson and Sons Ltd. ($11).

A rough measure of the philosophical importance of a concept is the amount of nonsense written about it. Judged by this test, the concept of time comes somewhat ahead of the concept of space and behind the concept of deity. The contemplation of time drives laymen to platitude ("Time is always passing"), poets to metaphor ("Time like an ever-flowing stream") and philosophers to paradox ("Nothing is real except a knife-edge present, dividing a non-existent past from a not-yet-existent future"). Nor is science much help. The modern advances in thermodynamics, relativity, cosmology and information theory, instead of clarifying our insight into this basic notion, seem so far only to have added to the general confusion.

This may explain why so few writers have had the temerity to write a book about the logic and philosophy of time. It would be hard to know where to send a student who wanted a comprehensive view of this exceptionally important and difficult topic. J. A. Gunn's *The Problem of Time* (1930) is still valuable for its summaries of the views of major philosophers from Aristotle to Henri Bergson, but Gunn's examination of the way time is involved in physical theory needs revision in the light of 30 years of scientific progress. M. F. Cleugh's *Time, and Its Importance in Modern Thought* (1937) still reads very well. Miss Cleugh attacked her philosophical predecessors with youthful relish but had all too little to say about the relevance of physics.

To this short list must now be added G. J. Whitrow's ambitious and comprehensive work. (Two other recently published books should also be mentioned: Richard Schlegel's *Time and the Physical World* and Milič Čapek's *The Philosophical Impact of Contemporary Physics*, both of which deal with many problems taken up by Whitrow.) It is admirable to find a knowledgeable scientist (Whitrow teaches applied mathematics at the University of London) taking the pains to become thoroughly familiar with the long history of philosophical speculation on time. A quick glance at Whitrow's excellent index is enough to show the extent of his erudition and the amount of sustained work that must have gone into making this valuable book.

Whitrow's choice of a title indicates that he is unwilling to accept the currently fashionable view that physics and philosophy are irrevocably divorced. He is not afraid to draw a metaphysical moral from a scientific tale. This makes his book at once more interesting and more controversial than if he had stayed on solid scientific ground. Whenever he speaks as a philosopher of science rather than as an expert in cosmology and the theory of relativity, his claims will have to be judged by philosophical rather than scientific criteria.

The preliminary account that Whitrow gives of his purpose is somewhat misleading. He implies in the preface that he will develop "that part of science which deals with the concept of time with the same wide scope as 'geometry' deals with space," and he welcomes a suggestion of J. L. Synge's that the subject be called "chronometry." If chronometry were to time as geometry is to space, one might expect Whitrow's work to result in an improved system of axioms for space-time in the manner of the German mathematician David Hilbert. (Valuable studies of this sort have already been made by Alfred A. Robb and Hans Reichenbach.) Whitrow does provide some rather stiff technical discussion of certain relevant mathematical questions, but he suggests that readers with limited mathematical knowledge can skip this and other mathematical sections without detriment to the main argument. As the design of his book quickly shows, Whitrow's main concerns are with the philosophy of time.

A long first chapter entitled "Universal Time" is partly directed against the tradition that "temporal flux is not an intrinsic feature of the ultimate basis of things." (Whitrow agrees with common sense that time is objective.) Whitrow may be right, following Bergson, in maintaining that philosophers and scientists have had a "tendency to subordinate the temporal to the spatial." But it might be better to say that theoretical science is committed, for excellent reasons, to what could be called the mathematization of time (and everything else); that is, the reduction of the layman's concept of time, in all its complexity, irregularity and roughness, to a smooth and idealized concept answering to the physicist's symbol t.

Had Whitrow seen this point sufficiently clearly, I doubt that he would have described a chemical equation as an "expression of a principle of identity, of preservation, of time-elimination—in short a statement that, despite appearances, basically *nothing has happened.*" There is something perverse about the notion that the discovery of a chemical or physical invariant shows that "basically nothing has happened." Imagine saying that to a man whose house has just burned down, with a murmured reference to the conservation of matter! It is one thing to say that science searches for invariants; it is quite another to add the misleading gloss that so far as science has anything to say nothing really happens.

Whitrow's rapid historical sketch whets the appetite, but he has a short way with philosophers. His discussion of Zeno is one of the least satisfactory sections of the book. It is startling to find Aristotle described as "an empiricist whose exclusive concern was the actual physical universe *as he conceived it*"—a remarkable verdict on a great thinker who was a rationalist through and through, deeply convinced that scientific knowledge must come by the intellectual apprehension of necessary truth. Whitrow's discussion of Immanuel Kant's famous antinomies is equally slapdash. Kant might have been prepared to agree, at least provisionally, that "an elapsed in-

finity of acts is a self-contradictory concept" (although what does "act" mean here?), but he would have goggled at Whitrow's contention that "the concept of a first moment of time is not a self-contradictory concept, for it may be defined as the first event that happened." This will not do, even on Humpty Dumpty's famous principle of making a word mean "just what I choose it to mean—neither more nor less." An event happens *at* a time, whether we are talking common sense or physics, and to identify the "first event" (supposing that the expression makes sense) with the "first moment of time" is to commit a logical howler.

Whitrow's long and interesting chapter on what he calls "individual time" is of central importance to his design. As Alfred North Whitehead admirably emphasized in his philosophy of science, it is necessary to trace the logical connections between the idealized scientific concept and the layman's rough concept from which it is derived. Such connections must be present between what the man in the street calls "time" and what the theoretical physicist calls "*t*," however hard the concepts may be to disentangle and analyze. Otherwise to speak of *t* as time, as Whitrow, like all of us, constantly does, would be to indulge in an outrageous pun. Unfortunately Whitrow, like most of his predecessors, is dominated by a simplified conception of the logical relations between "individual time" and "physical time" that is bound to foster obfuscation.

It is tempting to suppose that the link between the two concepts is to be found in some distinctive experience of temporal relations. In the technical literature this conception is manifested in a puzzling notion of the "specious present" that William James borrowed from E. R. Clay and planted like a roadblock in the way of all subsequent discussion of time. James's own statement is a paradigm of conceptual confusion, not at all mitigated by the enthusiasm his words betray: "The practically cognized present is no knife-edge, but a saddle-back, with a certain breadth of its own on which we sit perched, and from which we look in two directions into time. The unit of composition of our perception of time is a *duration*, with a bow and a stern, as it were—a rearward- and a forward-looking end." Whitrow uses a more sober definition of the specious present as the "finite segment of time which constitutes our immediate experience." He sees, like others before him, the misleading suggestions of the adjective "specious" (as though we somehow know in advance that the "present" must really be a knife-edge) and suggests a "mental present" as being "more neutral." I fear it is not neutral enough. The label begs a most important question by implying that there is something "mental" or subjective about the temporal relations of events perceived in rapid succession. All that survives a cool examination of the notion of an alleged "specious present" is the truism that we may hear, say, one musical note following another so quickly that it would be impossible to say that we remember one while hearing the other. But it by no means follows that there is something "mental" and therefore outside the scope of physical science in what we notice about the sounds. Unless one has already accepted some sweeping argument against the reality of secondary qualities (which Whitrow apparently has not), a special argument would be needed to show that there is something unreal or merely subjective in what we notice when we observe succession, motion or change. Whitrow does not provide such an argument.

The "present," whether specious or not, is, after all, no more than a convenient substantialization of the adverb "now." Convenience apart, we could manage sufficiently well in English, or in any other language, with such "indicators," or "occasion words," as "now," "later" and "soon," even if the nominative forms "the past," "the present" and "the future" were forbidden as ungrammatical. But if we think that the curious phrase "the present" stands for something, we shall soon be indulging fantasies of a distinctive experience of the present, which will then be conceived as if it were a moving spotlight projected onto a dark stage and progressively revealing a motionless panorama. (Alternatively it is the panorama of past, present and future that moves and the "spotlight" that stands still.) To take such a picture literally is to be bedeviled by an inadequate analogy: there is no distinctive experience of "the present" (no quality manifested in "the now") any more than there is a distinctive experience of, say, "the proximate" ("the here"). Hypostatization of adverbs is bound to cause trouble and to lead to absurd inquiries into the "length" of the "mental present," into fruitless speculations about the contraction or dilation of "the now" during time-retarding journeys, and so on.

The root of such troubles is a refusal to take seriously the central roles played in our common-sense concept of time

by such occasion words as "now" and "then." It is easy to understand why theoretical physics should express its formal results in a language that is independent of context, using formulas or sentences from which the occasion words are absent. This procedure has the great advantage of no reconstruction of the original context being required on the part of any reader. It gives a god's-eye view of the universe, as it were. If a scientist were to say, "I *then* saw a green flash at the edge of the sun's disk," anyone who was absent at the time of the original observation would need to know *who* spoke, and where and when, in order to obtain the intended information. No such supplementary information is needed in order to understand Boyle's law or any other freely repeatable scientific statement. A scientist must still use the occasion words at the level of craft and technology: he needs them in his laboratory when he gives instructions, orders supplies or makes predictions. Without them he would be the chimera of a human being lacking a concept of time altogether. We need only perform the mental experiment of trying to imagine a tribe of men able to perceive relative temporal order (before, later than, at the same time as) but with no way of saying or indicating something equivalent to our "now" to see that absurdity results. It is perhaps sufficient to see that such creatures—we could hardly call them men—would be unable to give or to understand orders. So when Whitrow, with apparent approval, says that "the relativistic picture of the world recognizes only a difference between earlier and later and not between past, present, and future," the proper comment ought to be: "So much the worse for the relativistic picture." To pass from "Such-and-such a physical theory recognizes X but not Y" to "X is real but Y is not" is plainly illegitimate. Yet it is remarkable how many scientists of high standing commit this elementary error of reasoning. No less an authority than Hermann Weyl has said: "The objective world simply *is*, it does not *happen*. Only to the gaze of my consciousness, crawling upward along the life-line of my body, does a section of the world come to life as a fleeting image in space which continuously changes in time." But this picture of a "block universe," composed of a timeless web of "world-lines" in a four-dimensional space, however strongly suggested by the theory of relativity, is a piece of gratuitous metaphysics. Since the concept of change, of something happening, is an inseparable com-

ponent of the common-sense concept of time and a necessary component of the scientist's view of reality, it is quite out of the question that theoretical physics should require us to hold the Eleatic view that nothing happens in "the objective world." Here, as so often in the philosophy of science, a useful limitation in the form of representation is mistaken for a deficiency of the universe.

The difficulty of getting clear about such matters stems from the extraordinary complexity of the common-sense concept of time. To point out the central role in that concept of the distinctions among past, present and future is to make only a beginning in the requisite logical analysis. An unprejudiced exploration of the logical geography of the concept would be a difficult task. Instead of starting from the misleading model of a distinctive temporal experience occurring in the "mental present," we should need to take account of an intricate system of intellectual powers, manifested notably in the intelligent use of a temporal vocabulary. All the following features of the English language as we now use it are relevant and would need careful investigation in such an inquiry: the occasion words such as "now," "then," "soon," "ago" and so forth already mentioned; the closely related devices for indicating the tenses of verbs; devices for referring to the temporal order of events, such as "later," "earlier," "at the same time as," together with their modifiers "much," "very much," "somewhat" and so on; the expressions we use for rough comparisons of the durations of time intervals—"longer than," "shorter than," "twice as long as" and so on; the rules governing our uses of verbs referring to actions, motions and changes; the special logical patterns of such verbs as "anticipate," "predict," "expect" and "wish," which are tied to future references, and of other verbs, notably "remember" but also "regret" and "blame," that are tied to past references; and much else.

This remarkably intricate web of linguistic and related nonlinguistic capacities, present in its entirety in every language of which we have knowledge, is highly organic: very little of it can be conceived as being absent from any language that could be used by human beings. For instance, it is impossible to imagine a race of humanoids from some conveniently distant galaxy having only the temporal capacities of what might be called "pointer-reading men"; that is, having the power to detect local simultaneities and the mere order of separation of events by being able to tell whether *A* occurs *between B* and *C*, but lacking the power to determine the "direction" of time (whether *A* occurred earlier than *B*). Science fiction is allowed many liberties, but violation of the logic of the concept of time as we know it should not be one of them. We can, of course, easily enough imagine or even construct recording devices limited in just the way that the "pointer-reading men" would be; but then *we* would have to read such devices and would need to continue being able to know which of two events came first—on pain of being unable to understand and manipulate the records of the observations.

If the intelligent uses of temporal words are as inseparable as I have been maintaining they are, speculations about variations in temporal conceptions between different individuals and different cultures will be correspondingly hard to verify. To say that the ancient Egyptians "conceived the world as essentially static and unchanging" or that for the ancient Hindus and Mayas "time was regarded merely as the eternal repetition of the cosmic rhythm" may pass as picturesque loose talk by cultural historians in search of a compendious summary, but it cannot be taken to imply that the ancient peoples in question, who had well-developed technologies, enjoyed a concept of time essentially different from our own. The fact that we can understand their documents and make sense of their modes of life is enough to disprove that fanciful suggestion. In his use of such sources, as well as the challenging but often paradoxical pronouncements about time made by psychologists, biologists and neurologists in their slippered moments, Whitrow is too ready to accept a popular rendering of the results of scientific investigation as representing sober truth.

So wide is the gap between the common-sense notion of time and the physicist's t that clarity would be fostered if physicists were to imitate the psychologist's practice of talking about g rather than about intelligence by referring to their own concept as t rather than as "time." It is not shocking to be told that t may have a unique origin like the absolute zero of the temperature scale, or may have several dimensions, or even that it may "run backward"; it is only when such aphorisms are transformed into the corresponding statements about time that paradox emerges and philosophical hackles rise.

The basic connection between t and time is not hard to discern: clocks meas-

ure only lapses of time, answer only questions about how much later one point-event (a tick, a flash, a beep) occurs than another point-event. All the other logical features that enter the constitution of the common-sense concept of time are deliberately excised. So, in order to read a clock, an observer is theoretically not required to be able to detect motion or its sense, or to recognize the distinction between past and present. There result sets of numbers, as timeless as all sets of numbers are, in which the number corresponding to temporal position (the value of t) has no distinctive or privileged role. In an important sense it could be said that time and motion are deliberately omitted from such recordings and it is therefore not surprising that the applied mathematician's description of the universe is "timeless." Such a detemporalized, expurgated time is just what is needed in order to supply the mathematician with a compact series having the same structure as the ordered set of real numbers. In the corresponding mathematical operations on space, the loss of conceptual content entailed by such idealization is relatively unimportant, and the "homogeneity" of the mathematical continuum reflects admirably the lack of privileged directions in the space of experience. In the case of time, however, t is constructed by deliberately neglecting those features of "becoming," or "passage," that sharply distinguish time from space. Thus physical time plausibly masquerades as merely another dimension of a timeless manifold, within which what has all too confusingly come to be called a "direction" of time still remains to be discovered.

Several senses of "time reversibility" need to be distinguished. First, any abstract physical law can be regarded as an attempt to supply in a concise mathematical formula an invariant characterizing a certain class of sets of numbers (some of them resulting from measurements of t). Whatever formula expresses such a law, it is plain that exactly the same information about the original observations could also be expressed by changing the sign of t and modifying the mathematical expression of the law accordingly. Thus if the original law were $p - kt = 0$ (where p is some magnitude varying linearly with time and k is a constant), the same information could be conveyed by the law $p + kt' = 0$, where t' is t "read backward," as it were. Every scientific law can be "read backward" in this way, the second law of thermodynamics not excepted. Next, in

a special class of physical laws, roughly speaking those into whose formulation t occurs only in even powers, a reversal of the sign of t, as indicated above, also leaves the form of the original law unchanged. Thus in the formula $x = \frac{1}{2}gt^2$, for the distance covered during free fall from rest, it makes no difference whether we read the clock forward or backward, and the same will be true for all motions in fields where the force is independent of time. It is certainly a remarkable fact that the laws occurring throughout the whole range of theoretical physics as we know it, quantum physics not excluded, are covariant in this way with respect to changes in the sign of t. We know no reason why physics, quite undesignedly, should have proved to have this character, and no satisfactory explanation is yet available. Earlier reliance on the second law of thermodynamics as an exception broke down after the statistical basis of that law was understood, and Reichenbach's ingenious efforts to determine an "arrow of time" by reference to the properties of pairs of systems "branching" off into conditions of relative isolation have fared no better. Whitrow's speculations about "cosmic time" are too nebulous to induce conviction. The reason that physics can rove backward in time as freely as forward may be that the subject has limited itself to the investigation of relations that are essentially symmetrical. But whatever the explanation, it can have no bearing on the confused question "Why does time (not t) always flow in the same direction?" It is a feature of the common-sense concept of time that it is impossible to speak of time "running backward," as it also makes no sense to speak of "past, present and future existing all at once," or of "a moment of time occurring twice," and so on. These features of the concept of time cannot be accounted for by any empirical discoveries about asymmetries along the temporal dimension. By the same token the failure of physics so far to explain such familiar asymmetries in ordinary experience as the failure of omelets to unscramble themselves, or the impossibility of converting oaks into acorns, cannot be used to support a metaphysical conclusion. As for establishing an "arrow of time," the physicist needs only to record the direction of a single motion, say the direction of fall of an unsupported body, to accomplish the trick. I am sympathetic with Whitrow's repeated stress on the "ultimacy" of time and with his concluding remarks: "Nor is time a mysterious illusion of the intellect. It is an essential feature of the universe." But I cannot see that he has

established this. Metaphysical conclusions need metaphysical premises, and these he has not supplied.

Short Reviews

THE IMAGE: OR WHAT HAPPENED TO THE AMERICAN DREAM, by Daniel J. Boorstin. Atheneum Publishers ($5). What has happened to the American dream? It has been transformed, this book argues, into a congeries of illusions. The dream was the hopes of Americans, their aspirations to attain in the New World what seemed unattainable in the Old. Much has been attained: great strides have been made against the ancient menaces of class war, tyranny, poverty, disease and illiteracy, all of which still plague most of the world. Yet now "we are threatened by a new and a peculiarly American menace . . . the menace of unreality." We are, Boorstin says, the "most illusioned people on earth." We have built and we live in a house of make-believe, in which almost everything is fake and to which we have become so habituated that we can no longer tell the difference between the phony and the factual; and even if we could distinguish between them, we dare not risk the cost—to our economy, our social organization, our interpretation of experience, our system of ethical values, our very self-respect—of becoming disillusioned. The news, as reported in the various media of communication, is filled with "pseudo events": we do not so much gather news as make it. Our heroes are manufactured. "Fame," wrote Milton, "is no plant that grows on mortal soil"; but we make it grow by assiduous manuring, elaborate irrigation, artificial sunlight. What we get is a synthetic plant called a "celebrity," which is a "person who is known for his well-knownness." This human pseudo event may be a television "personality," an actor, a boxer, a night club entertainer, a quiz kid, a squalid but noisy politician. Experiences of all kinds are diluted, homogenized, counterfeited. Travel, for example, is robbed of every possibility of adventure, of every trace of novelty. The important thing is to make the plane, the ship, the hotel seem cozy and familiar; thus the Chihuahua Hilton, the Istanbul Hilton, the Castellaña (Madrid) Hilton, the Paris, Tokyo and Addis Ababa Hiltons are designed, in the words of their owner, both to convey, in quickly assimilable doses, "the antiquity, romance and mystery" of each ancient city *and* the feeling of being in "a little bit of America."

Our literature and our art have undergone similar transformations; books, for instance, are written to order for the movies, or they are "treated" so that they can be metabolized on the screen; and books are written based on movies. But the most serious aspect of this national alchemy of illusion is the transmutation of the ideal into the "image." This hagridden concept infects commerce, education, communication, foreign and domestic politics. The magic of the image has its ludicrous as well as its grave aspects. "Almost any evening on television," Boorstin says, "I can watch in my own home a celebrity performing in a skit which is the television version of a movie (made from a novel), to the accompaniment of dubbed-in laughter and applause—the whole performance sponsored by a steel manufacturer or an oil company, by a manufacturer of cosmetics to cure imaginary ailments, or by a brewer or cigarette manufacturer of products indistinguishable from those of his competitor—all put on in order to create a more favorable corporate image." Having fabricated our experience and deluded ourselves into believing it real, we have taken the final step of making the very yardstick with which to measure it. The heart of the matter has thus become the shadow, and since we judge ourselves by the shadow, we expect the people of other countries not only to judge us by it but also to adopt it as their own ideal, to imitate and worship it, to conform their ways to ours. When they reject this image or, worse, laugh at it or, worse yet, expose and denounce it, our reactions run the gamut of sulking, of assuming an air of alienated majesty, of nervous (but always fruitless) self-inspection and self-investigation toward the end of refurbishing the image; and, not infrequently, of proclaiming entire nations our deadly enemies.

To whom do we owe this progress toward stultification? Can we blame the press, Madison Avenue, the power elite, the organization men, the hidden persuaders? Boorstin acquits and convicts them. They play their part, but we play ours. All are guilty. Our culture is our culture, our image the image we have made. "The idol," said James Russell Lowell, "is the measure of the worshipper." Boorstin's book is too long, too diffuse. He drags in his learning, although it is wide, by the hair, and he fancies that every story should be told from the beginning, which means from man's first disobedience. He also fancies himself a paradoxer and an epigrammatist, and this does not always come off, so that important points are muffled and

the argument outclevers itself. All the same, this is an engrossing book—sensitive, thoughtful, damning, dead on target and in most respects unanswerable.

THE DEATH AND LIFE OF GREAT AMERICAN CITIES, by Jane Jacobs. Random House ($5.95). This angry young woman attacks our contemporary, conventional city-planning wisdom and its obsession with cataclysmic urban renewal. Her lengthy book is not a literary masterpiece, but it has already jolted the city planners and stands a good chance of having the same profound effect on their craft as the Garden City theory did more than 60 years ago. This theory, first proposed by the London court reporter Ebenezer Howard, who believed that country life would uplift the poor, is still the basis for almost all that is done about cities today. It was augmented only once, when, in 1922, Le Corbusier offered his plan for the Radiant City. The Swiss-French architect brought the garden into the city, planting high-density, high-rise apartment blocks on endless lawns that flanked endless superhighways. Mrs. Jacobs' indictment of the boredom, inconvenience and numerous other social ills of this still prevalent form of housing, public or private, has led her to a refreshingly nonstatistical and nonsociological (but all the more plausible) explanation of how cities really work. Life, excitement, convenience and safety, she maintains, exist only in streets that have shops, restaurants, short blocks and a well-mixed variety of uses and people. A thousand eyes are watching the children who play on such streets, who are consequently far safer there than on fenced-off playgrounds in the shadow of lonely apartment-house towers. People who live on such streets can leave the key for a friend or relative with the grocer downstairs. They have privacy without insularity and any desired degree of "togetherness" without chumminess and unwelcome entanglements. But such true neighborhoods usually cannot stave off decay, they cannot unslum themselves, because, as Mrs. Jacobs has discovered, they are credit-blacklisted by the bankers who share the planners' Garden City notions. Refused gradual money for improvements, old city districts everywhere soon become ripe for the ruination of cataclysmic money. At first it comes from the shadow world that profits from slums. Then the Government finances total "renewal." In addition we flood suburbia with easy mortgage money and thereby further hasten city decay and urban sprawl. No one in particular is to blame. Our society wants

it that way. We still believe in the inherent evils of the city as opposed to the virtue of nature, which must therefore be smothered under the crab grass and asphalt of suburbanization. What's more, our city-planning theorists still mistake cities as being problems of simplicity or of disorganized complexity and try to analyze and treat them thus. These misapplications of physical theory, says Jane Jacobs, "stand in our way; they have to be hauled out in the light, recognized as inapplicable strategies of thought, and discarded."

FOUR THOUSAND YEARS AGO, by Geoffrey Bibby. Alfred A. Knopf ($6.95). This panorama of life in the second millennium B.C. by the Director of Oriental Antiquities at the Prehistoric Museum of Aarhus in Denmark is a mixture of fiction, fact and conjecture. It is Bibby's aim to give the general reader a feeling of what it was like to be alive during the period of Stonehenge and the Hyksos, of the Minoan and Indus Valley civilizations, of the Trojan War and the Exodus, of Hammurabi and Abraham, Tutankhamen, Rameses the Great, Moses, Saul, Samson, Agamemnon, Theseus, Tiglath-pileser. How did Scandinavians get to the Mediterranean? How did the battle-ax people and the beaker people differ in their treatment of the lands to which they migrated? What did the people of the British Isles know about Egypt? Why did the wild horsemen of the steppes of southern Russia move to India and Greece? How did hunters and farmers and traders and innkeepers and sailors and children live? These are among the questions the book strives to answer. The result is sometimes a little confusing, not only because of the crowded scene but also because the story interweaves threads of reliable archaeological data and pure make-believe, to which the author leans; but he has tried to make it clear in summaries at the end of each chapter to what degree he has deliberately "misled" his readers as to the reliability of his "facts," and his account offers a good measure of enjoyment and enlightenment. Illustrations.

ELEMENTARY PARTICLES, by Chen Ning Yang. Princeton University Press ($2.75). This book represents the 1959 Vanuxem Lectures by the 1957 cowinner of the Nobel prize in physics, giving a short, unusually readable history of some discoveries in atomic physics, from J. J. Thomson's celebrated experiment that determined the ratio of the charge and the mass of the cathode rays to present work on the proliferating menagerie of strange particles. Clearly and simply written, the book conveys the wonder, excitement and mystery of this branch of intellectual adventure. Yang makes the noteworthy point, among others, that modern atomic research has become so enormously expensive, so dependent on immense machines and so tied to the efforts of large groups of investigators that the notion of a breakthrough or brilliant advance by a single person—such as was made by Thomson and Ernest Rutherford and Niels Bohr—is almost inconceivable. He laments this tendency toward bigness because "it hinders free and individual initiative [and] makes research less intimate, less inspiring, and less controllable." He says, however, that this must be accepted as a fact of life. An amusing, almost ludicrous example of the team approach is given in a reproduction of the title page of a paper "On the Masses and Modes of Decay of Heavy Mesons Produced by Cosmic Radiation," which lists as coauthors no fewer than 36 physicists from 10 institutions in Great Britain, Denmark, Ireland, Belgium and Italy. In the last lecture Yang discusses the concept of symmetry and attempts a popular explanation of his work on parity. In this he is not conspicuously successful, but the book as a whole can certainly be recommended to the general reader.

MCGRAW-HILL ENCYCLOPEDIA OF RUSSIA AND THE SOVIET UNION, edited by Michael T. Florinsky. McGraw-Hill Book Company, Inc. ($23.50). In some 4,000 entries this volume gathers a variety of information on Russia before and after the Revolution of 1917. The principles of coverage are not made clear, and the work is something of a hodgepodge even though it presents a good deal of ready reference material on such topics as Russian cities, academies, rivers, literary figures, politicians, medieval food and drink, ballet, weights and measures, security police, mathematics, dialectical materialism, foreign policy, the Fedchenko Glacier, St. Vladimir, cotton crops, reindeer breeding and hydroelectric power. If you want a fact about Russia and can find it in this book, and if the account is accurate, the book will be useful. Maps, graphs and charts.

THE BIRDS OF BRITISH SOMALILAND AND THE GULF OF ADEN: VOLS. III AND IV, by Sir Geoffrey Archer and Eva M. Godman. Oliver & Boyd, Ltd. (nine pounds nine shillings). The first two volumes of this work, which aims to give details of the life history, breeding habits and eggs of the birds of the area of the

Red Sea and the Horn of Africa, appeared in 1937; the present two volumes complete the work. This survey of a region of great ornithological interest, because it is at the crossroads of major migration routes, is in the admirable, relaxed tradition—now almost vanished—of natural history written by dedicated amateurs. The observations are systematic but leisurely; the account is technically accurate yet free of jargon, and is therefore accessible to any bird lover. Archer, who has spent the larger part of his life as a high-ranking British civil servant in Somaliland and the Anglo-Egyptian Sudan, patiently accumulated a vast amount of ornithological information, formed a large collection of bird eggs and with the help of Miss Godman, of the British Museum, presents the fruits of his labors in an affable study enlivened by anecdotes and digressions.

ADONIS ATTIS OSIRIS, by Sir James George Frazer. University Books, Inc. ($10). A reprint of Part IV of the 13-volume edition of *The Golden Bough*, this book epitomizes Frazer's thesis that the King of the Wood in the grove of Diana was "invested with powers which control the fertility, and thus the continuity, of living beings." The three figures treated here were all "a personification of the great yearly vicissitudes of nature, primarily spirits of vegetative fertility, but permeating all aspects of life." Very few people who are not specialists will ever read Frazer unabridged, and it is fashionable in our period to dismiss his anthropological ideas and to refer to his work as little more than an imposing literary accomplishment. The point is arguable, but at any rate Frazer makes superb reading, and this volume, which exhibits the architecture and stately pace of the entire work, is a very good introduction.

RAILROADS IN THE WOODS, by John T. Labbe and Vernon Goe. Howell-North Books ($10). An enjoyable picture book showing the various types of locomotive, flatcar, track system and cable train used in logging beginning in the 1880's. The photographs are first-rate. Many of them are action shots of hair-raising operations over almost impossible terrain (some of the railroads had to climb grades in excess of 70 per cent). A solid contribution to the literature of the vanishing iron horse.

THE FUR TRADE, by Paul Chrisler Phillips. University of Oklahoma Press ($16.50). This massive work, the fruit of a lifetime of research, organiza-

tion and writing, is a history of the fur trade in the Western portions of the U.S. and Canada from its beginnings in the early 16th century. Phillips describes not only the adventures of the men who carried on the trade—hunters, explorers, trappers, merchants, bankers—but also the great influence it had in shaping European and American history and in opening the North American continent. It is a dramatic story of the political and economic effects of the commerce in furs, and of its impact on everything from clothing to national ambitions. Many illustrations and an extensive bibliography.

PHILOSOPHICAL REASONING, by John Passmore. Charles Scribner's Sons ($3.50). An able Australian philosopher, who thinks clearly and writes clearly, examines some of the fundamental reasoning procedures of philosophers. He discusses, among other things, the infinite regress, the two-worlds argument, self-refutation and the verifiability argument. The book is based on a series of seminars that Passmore held at Brandeis University and the University of Oxford.

Notes

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THE LIFE AND WORK OF SIGMUND FREUD, by Ernest Jones; edited by Lionel Trilling and Steven Marcus. Basic Books, Inc. ($7.50). A one-volume edited and abridged edition of Jones's well-known biography, the abridgment being effected mainly by deletion of the portions of the original trilogy that dealt with "the technical aspects of Freud's work."

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BIBLIOGRAPHY

Readers interested in further reading on the subjects covered by articles in this issue may find the lists below helpful.

STEPS TOWARD DISARMAMENT

CRITIQUE OF SOME CONTEMPORARY DEFENCE THINKING. P. M. S. Blackett in *Encounter*, Vol. 16, No. 4, pages 9–17; April, 1961.

THE LIMITS OF DEFENSE. Arthur I. Waskow. Doubleday & Company, Inc., 1962.

EXPLODING STARS

CLOSE BINARY SYSTEMS. Zdenek Kopal. John Wiley & Sons, Inc., 1959.

DYING STARS. Jesse L. Greenstein in *Scientific American*, Vol. 200, No. 1, pages 46–53; January, 1959.

THE GALACTIC NOVAE. C. H. Payne-Gaposchkin. Interscience Publishers, Inc., 1957.

THE SPECTRA OF NOVAE. Dean B. McLaughlin in *Stellar Atmospheres*, edited by Jesse L. Greenstein, pages 585–652. The University of Chicago Press, 1961.

SPECTROSCOPIC BINARIES. Otto Struve and Su Shu Huang in *Handbuch der Physik*, Vol. 50, pages 243–273; 1958.

THE MEMBRANE OF THE LIVING CELL

THE FORMATION FROM THE SCHWANN CELL SURFACE OF MYELIN IN THE PERIPHERAL NERVES OF CHICK EMBRYOS. Betty Ben Geren in *Experimental Cell Research*, Vol. 7, pages 558–562; 1954.

HOW THINGS GET INTO CELLS. Heinz Holter in *Scientific American*, Vol. 205, No. 3, pages 167–180; September, 1961.

THE MOLECULAR STRUCTURE AND CONTACT RELATIONSHIPS OF CELL MEMBRANES. J. D. Robertson in *Progress in Biophysics and Biophysical Chemistry*, Vol. 10, pages 344–418; 1960.

TEXTBOOK OF GENERAL PHYSIOLOGY. Hugh Davson. Little, Brown & Co., 1959.

THE ULTRASTRUCTURE OF ADULT VERTEBRATE PERIPHERAL MYELINATED NERVE FIBERS IN RELATION TO MYELINOGENESIS. J. D. Robertson in *Journal of Biophysical and Biochemical Cytology*, Vol. 1, No. 4, pages 271–278; 1955.

THE ULTRASTRUCTURE OF CELL MEMBRANES AND THEIR DERIVATIVES. J. D. Robertson in *Biochemical Society Symposia*, No. 16, pages 3–43; 1959.

PARADOX

FROM A LOGICAL POINT OF VIEW. Willard Van Orman Quine. Harvard University Press, 1953. See pages 80–139.
THE FOUNDATIONS OF MATHEMATICS. Evert W. Beth. North-Holland Publishing Company, 1959. See pages 481–518.
METHODS OF LOGIC. Willard Van Orman Quine. Holt, Rinehart & Winston, Inc., 1959. See pages 225–252.
RIDDLES IN MATHEMATICS: A BOOK OF PARADOXES. E. P. Northrop. D. Van Nostrand Co., Inc., 1944.

FRACTIONATING THE FRUIT FLY

CONTRIBUTION TO THE PHYSIOLOGICAL AND BIOCHEMICAL GENETICS OF PTERIDINES AND PIGMENTS IN INSECTS. Ernst Hadorn in *Proceedings of the 10th International Congress of Genetics*, Vol. 1, pages 337–354; 1959.
DEVELOPMENTAL GENETICS AND LETHAL FACTORS. Ernst Hadorn. John Wiley & Sons, Inc., 1961.
PATTERNS OF BIOCHEMICAL AND DEVELOPMENTAL PLEIOTROPY. Ernst Hadorn in *Cold Spring Harbor Symposia on Quantitative Biology*, Vol. 21, pages 363–373; 1956.
PROPERTIES OF MUTANTS OF DROSOPHILA MELANOGASTER AND CHANGES DURING DEVELOPMENT AS REVEALED BY PAPER CHROMATOGRAPHY. Ernst Hadorn and Herschel K. Mitchell in *Proceedings of the National Academy of Sciences*, Vol. 37, No. 10, pages 650–665; October, 1951.

THE ACTION OF ADHESIVES

THE AREA OF REAL CONTACT AND THE SHEAR STRENGTH OF MONOMOLECULAR LAYERS OF A BOUNDARY LUBRICANT. Anita I. Bailey and J. S. Courtney-Pratt in *Proceedings of the Royal Society, Series A*, Vol. 227, No. 1171, pages 500–515; February 8, 1955.
ATTRACTIVE FORCES BETWEEN FLAT PLATES. M. J. Sparnaay in *Nature*, Vol. 180, No. 4581, pages 334–335; August 17, 1957.
THE FORCE BETWEEN MOLECULES. Boris V. Derjaguin in *Scientific American*, Vol. 203, No. 1, pages 47–53; July, 1960.
GLASS-TO-METAL SEALS. Albert W. Hull and E. E. Burger in *Physics*, Vol. 5,

No. 12, pages 384–405; December, 1934.

THE WATER-PROTECTING PROPERTIES OF INSECT HAIRS. D. J. Crisp and W. H. Thorpe in *Discussions of the Faraday Society*, No. 3, pages 210–220; 1948.

THE SOARING FLIGHT OF BIRDS

ANIMAL FLIGHT. E. H. Hankin. Iliffe & Sons, Ltd., 1913.

THE DESIGN AND PERFORMANCE OPTIMIZATION OF THE THERMAL SAILPLANE. Clarence D. Cone, Jr. Publication CC-L-1713. Langley Research Center, NASA; September, 1961.

THE SOARING OF BIRDS. Lord Rayleigh in *Nature*, Vol. 27, No. 701, pages 534–535; April 5, 1883.

THE THEORY OF SOARING FLIGHT IN VORTEX SHELLS, PARTS 1, 2 AND 3. Clarence D. Cone, Jr., in *Soaring*, Vol. 25, Nos. 4, 5 and 6, pages 8–13, 8–12 and 6–8; April, May and June, 1961.

ATTENTION AND THE PERCEPTION OF SPEECH

CONTEXTUAL CUES AND SELECTIVE LISTENING. Anne M. Treisman in *Quarterly Journal of Experimental Psychology*, Vol. 12, No. 4, pages 242–248; November, 1960.

ON THE FUSION OF SOUNDS REACHING DIFFERENT SENSE ORGANS. D. E. Broadbent and Peter Ladefoged in *The Journal of the Acoustical Society of America*, Vol. 29, No. 6, pages 708–710; June, 1957.

PERCEPTION AND COMMUNICATION. D. E. Broadbent. Pergamon Press, Inc., 1958.

THREE AUDITORY THEORIES. J. C. R. Licklider in *Psychology: A Study of a Science*, edited by Sigmund Koch, Vol. 1, pages 41–144. McGraw-Hill Book Company, Inc., 1959.

MATHEMATICAL GAMES

THE COMMON SENSE OF THE EXACT SCIENCES. William Kingdon Clifford. Dover Publications, Inc., 1955. See pages 152–164.

SPIRALS IN NATURE AND ART. Theodore Andrea Cook. J. Murray, 1903.

THE AMATEUR SCIENTIST

AMATEUR TELESCOPE MAKING ADVANCED. Edited by Albert G. Ingalls. Scientific American, Inc., 1949.

PHYSIOLOGY OF SEEDS. William Crocker and Lela V. Barton. Chronica Botanica Company, 1953.

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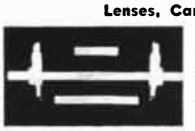

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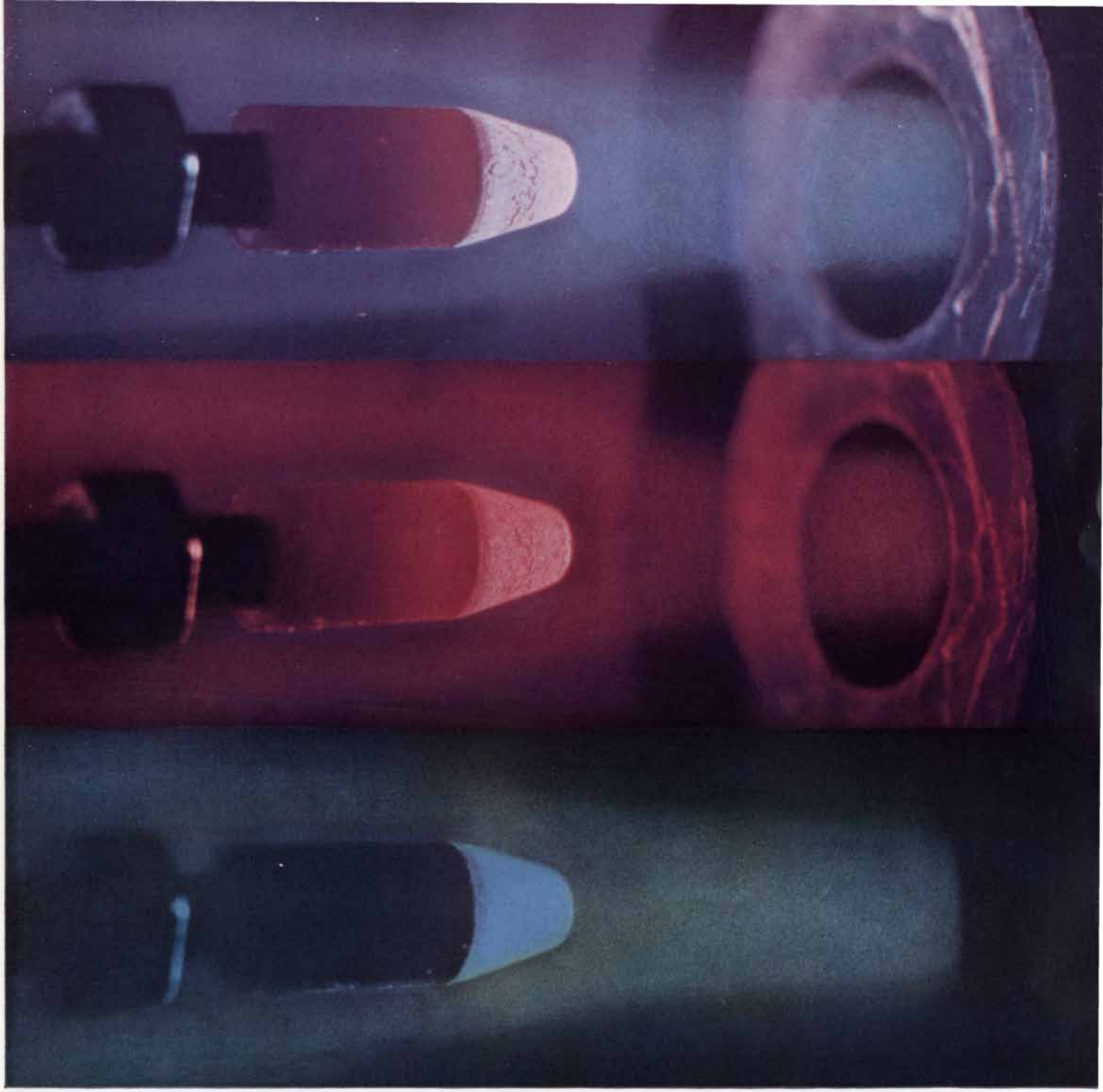

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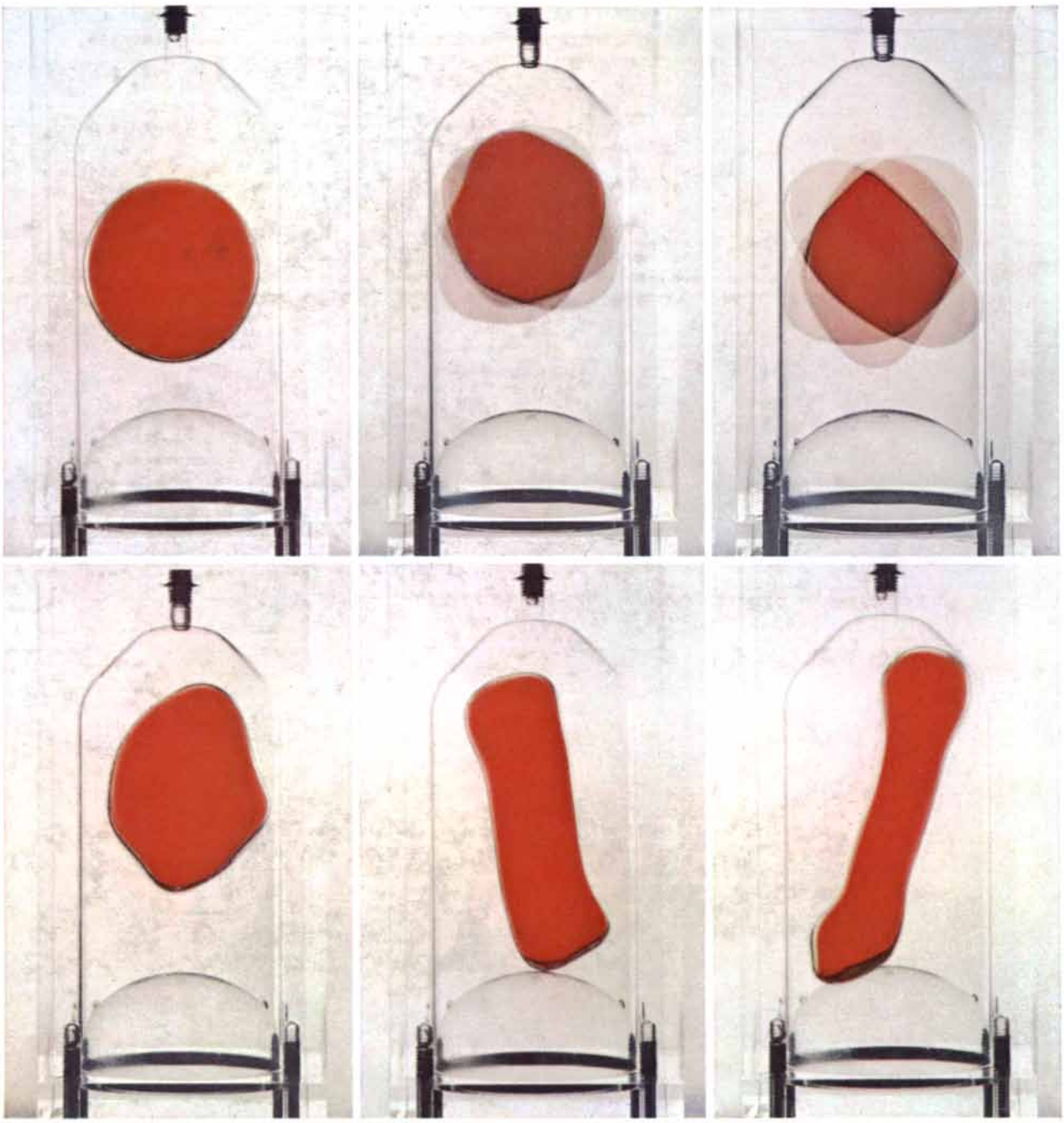

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