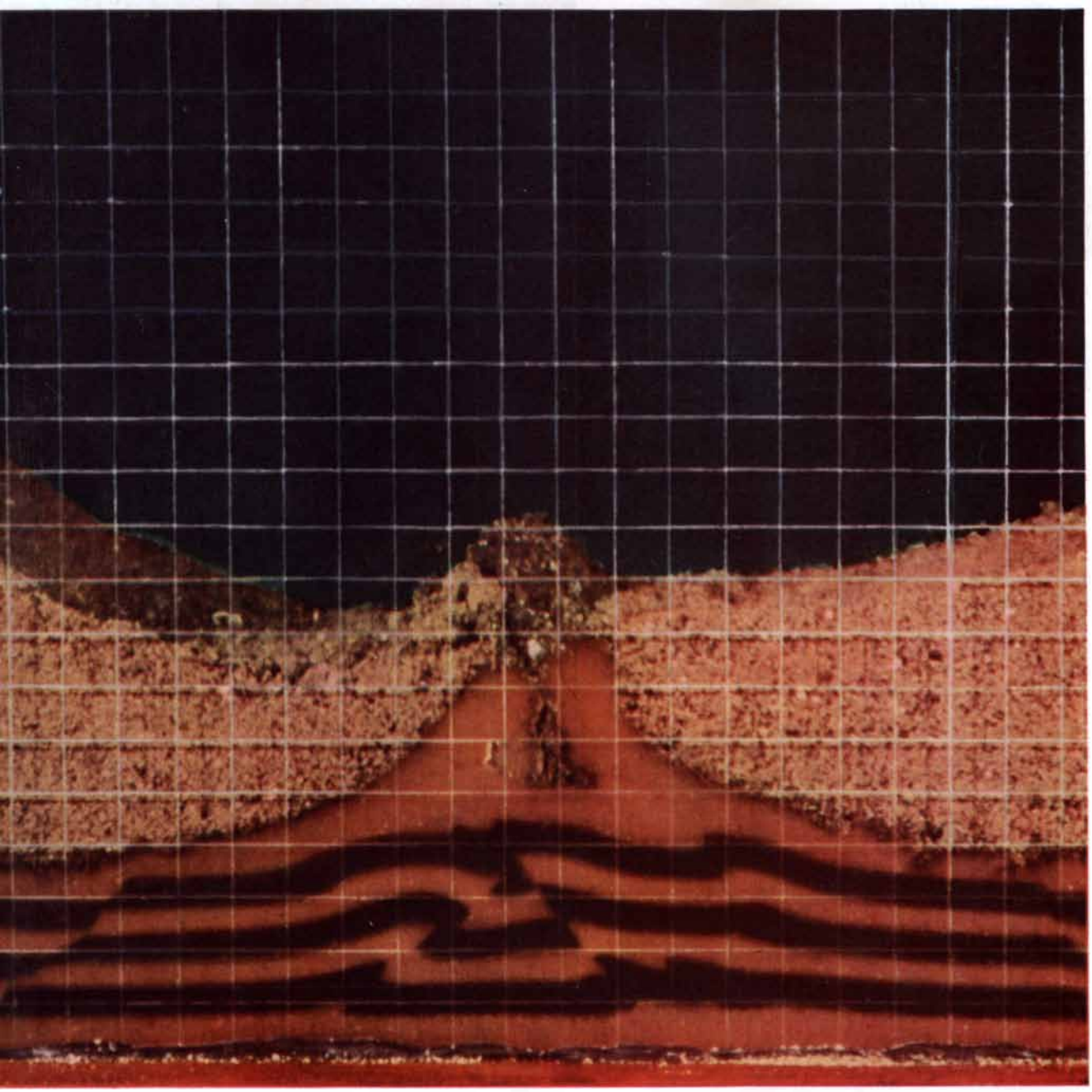
SCIENTIFIC AMERICAN



EXPERIMENTAL GEOLOGY

FIFTY CENTS

February 1961

ZIRCON—A JEWEL OF PHYSICAL ADVANTAGES

Zirconium appears most abundantly as zirconium silicate, or "zircon"—a valuable industrial mineral. Granulated, it affords foundries a core sand chemically inert at molten metal temperatures. As "flour," zircon imparts a very smooth refractory coating, improves heat dissipation to avoid distortion. Milled exceedingly fine, zircon provides ideal chemical and physical characteristics, as well as opacity, in ceramic glazes. M&T mines this versatile metallic mineral; has a high temperature research center for end-use studies.

FOAM BY THE MILE IN MINUTES

Urethane foam manufacture was changed almost overnight to a simple "one-shot" system for cured foam in minutes. The stannous and organotin catalysts responsible for this breakthrough were pioneered by M&T. By greatly accelerating the typical foaming-curing reactions, M&T catalysts allow far more efficient production of foams for cushioning, packaging, insulation and moldings.

Metals meet Chemistry at M&T

Diverse as M&T's activities are, they have a common denominator...a union of metals with chemistry. You may see the result in a better ceramic opacifier; or a more powerful fungicide; or a superior catalyst that really says "go" to a chemical reaction. In each case, M&T contributes importantly to scientific or industrial progress.

FOILING THE SPOILING OF WOOD

Wood is delectable food to a great variety of insects, bacteria and fungi. Unless destructive appetites are curbed, wood rots. M&T's TBTO®—an organotin chemical—is so potent that wood brushed with a very dilute solution repels or kills the hungry micro-organisms that contact it. So important is the budding area of organometallics, M&T operates one of the largest plants devoted to combining metals into the molecules of various organic chemicals.

Metal & Thermit Corporation

General Offices: Rahway, N. J.

chemicals / coatings / metals / minerals

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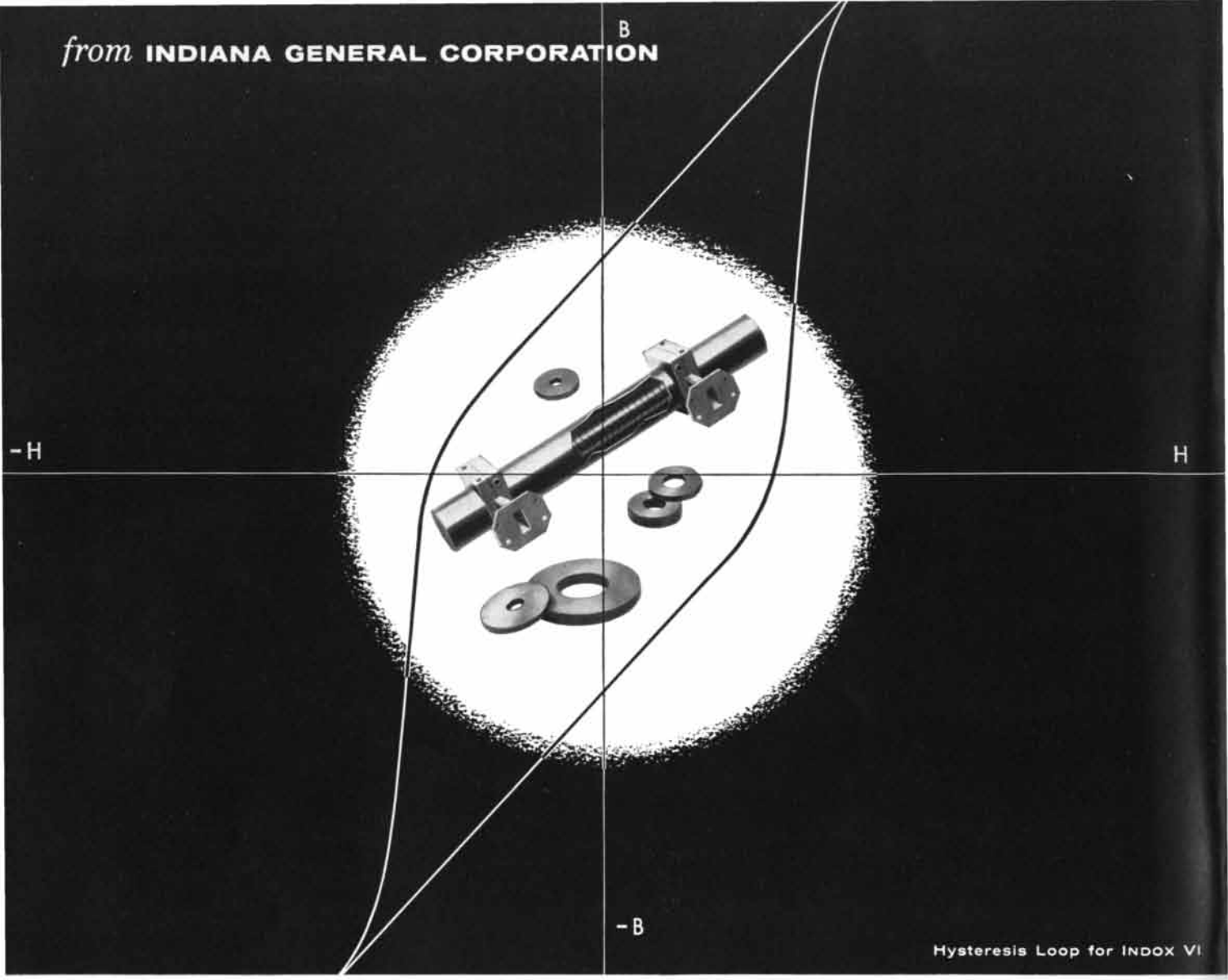
Dear American Airlines:
Your passenger service reflects outstanding selection of personnel. The neat and efficient young ladies in front of the counters are a credit to a company who cares about the customer
M. J. McDonough

UNSOLICITED IN-FLIGHT LETTER FROM M. J. MC DONOUGH EQUIPMENT SALES DIVISION, AMERICAN CAN CO.

Our Passenger Service Representatives, Mr. McDonough, are another reason why American Airlines is the *first choice of experienced travelers*. They are "goodwill ambassadors"; experts to the tips of their prim white gloves, roving information specialists who smooth your journeys with a smile.

AMERICAN AIRLINES
America's Leading Airline

from **INDIANA GENERAL CORPORATION**



Hysteresis Loop for INDOX VI

CREATIVE MAGNETICS

TO OUTFLANK MICROWAVE ROADBLOCKS

New magnetic materials, developed by Indiana Steel Products and General Ceramics Divisions, have led the way to simpler, more compact, better-performing microwave components.

The R & D team at Indiana Steel Products Division is meeting the challenge of new ideas in microwave equipment design. INDOX VI, one of several exciting new ceramic magnet materials, has permitted designers to reduce size, weight and cost of periodic focusing traveling wave tubes while improving performance. This material, with a typical coercive force of 2,550 Oersteds, has exceptional resistivity to demagnetization—just one of several properties that makes it ideal for TWT use.

And still the search goes on. Newly developed materials and component assemblies for microwave applications are now under test.

From our General Ceramics Division come exclusive gyromagnetic ferrite compounds for microwave devices such as rotators, resonance isolators, circulators, phase shifters and filters.

The microwave field is just one of many where Indiana General ferrites and permanent magnets have improved component performance. Our engineering and research staffs welcome the opportunity to offer assistance on your magnetic applications. We will be happy to send literature. Write us, stating your general areas of interest.

INDIANA GENERAL CORPORATION VALPARAISO, INDIANA

Permanent Magnets • Ferrites • Technical Ceramics • Memory Products • Magnetic Separation and Handling Equipment

Established 1845 **SCIENTIFIC AMERICAN** February, 1961 Volume 204 Number 2

ARTICLES

DEPARTMENTS

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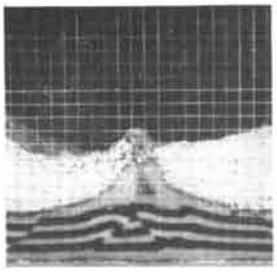

THE COVER

The photograph on the cover shows a scale model of strata of rock being folded by pressure (*see page 96*). The model is one of a number that have been set up for an experimental investigation of tectonic processes in the Institute of the Physics of the Earth of the Academy of Sciences in Moscow.

THE ILLUSTRATIONS

Cover photograph by William Vandivert

Page	Source
42-43	School of Medicine, University of California at Los Angeles, Veterans Administration Hospital, Long Beach, Calif. (*left*), John Langley Howard (*right*)
44-45	John Langley Howard
46-47	Neal E. Miller (*left*), John Langley Howard (*right*)
48-49	John Langley Howard
50-51	W. J. McDonald Observatory, University of Texas
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90-91	William H. Stein and Stanford Moore
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96	William Vandivert
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100	James Egleson
102	William Vandivert (*top and middle*), V. V. Belousov (*bottom*)
104	James Egleson
108-109	Peter Satir
110	Bunji Tagawa (*left*), Peter Satir (*right*)
111	Peter Satir
112	Bunji Tagawa
113	Peter Satir
114	A. W. Sedar and K. R. Porter (*top left*), Irene Manton (*middle left*), Samuel Dales (*bottom left*), E. G. Gray (*top right*), K. R. Porter (*middle right*), W. H. Miller (*bottom right*)
115	W. Bernhard (*top*), M. H. Burgos and D. W. Fawcett (*bottom*)
116	Eichi Yamada, K. R. Porter (*second from right only*)
118-121	New York Public Library
122	New York Public Library (*top*), Skåne-Reportage (*bottom*)
123	James Egleson
124	New York Public Library
126	James Egleson
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133-135	Charles E. Lane
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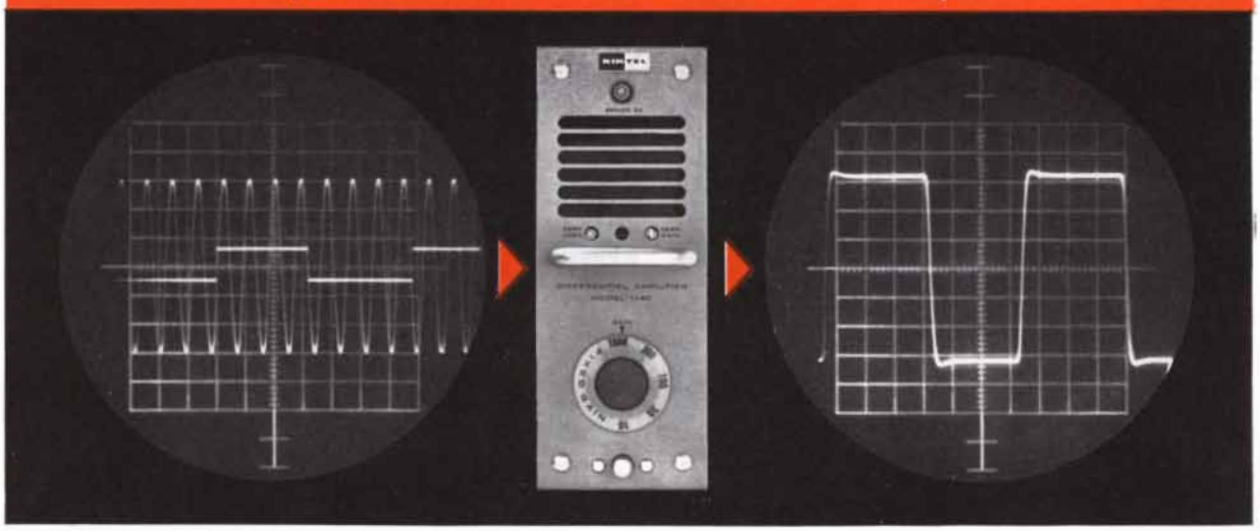
140-142	Charles E. Lane
146-154	Alex Semenoick
160-168	Roger Hayward
170	Gene Udell

(picture of a KIN TEL differential amplifier at work)

6 volts of 60∿ common-mode noise and 6 millivolts of signal in here

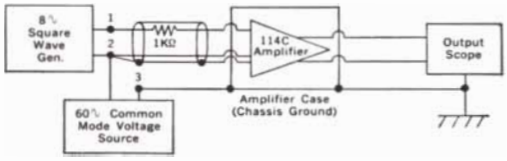
2 microvolts of 60∿ noise (equivalent input) and 6 volts of signal out here



If you measure the output of thermocouples, and the thermocouples are bonded to a rocket engine or almost any other grounded object, and the distance between thermocouples and amplifiers is more than a few feet, you should consider the above illustration carefully. While we'll admit your thermocouples probably aren't producing square waves, nine chances out of ten you *do* have a problem with 60-cycle common-mode noise. Nearly everybody does.

What can be done about it? Well, KIN TEL differential amplifiers reject ruinous 60-cycle common-mode hum and noise by a factor of 3,000,000 to 1 with any unbalance up to 1000 ohms in series with either side of the input, 1,000,000 to 1 with 10,000 ohms unbalance. Rejection for DC is practically infinite and both input and output can be floated up to ±300 volts DC or peak AC. The secret of this exceptionally high common-mode rejection in the presence of high input unbalance is isolation. Input signal terminals are isolated from chassis ground by 10,000,000 megohms and 0.6 micromicrofarads. Input and output signal terminals are completely isolated from each other. Output signal terminals are isolated from ground to almost the same extent as the input. With this virtually perfect isolation, you can rescue microvolt level signals from volts of common-mode noise, regardless of whether load and transducer are floating or grounded, balanced or unbalanced.

Before you send us that letter... the input scope photo is a double exposure. The square wave input signal was taken with the scope connected across points 1 and 2 (see drawing below) with 5 mv/division sensitivity. To show the noise, the scope was connected between points 2 and 3, and sensitivity was 1 v/division. The scope on the output was set for 1 v/division sensitivity and, of course, no noise is evident.



Specifications other than common-mode rejection are equally impressive. Linearity is 0.01% of full scale (10 volt) output for either polarity, 0.02% of full scale for plus-to-minus or minus-to-plus polarities. Equivalent input drift is less than 2μv; noise at full amplifier bandwidth is less than 6μv. Input impedance is 30 megohms, output impedance less than 0.25 ohms. Standard bandwidth is less than 3 db down at 80 cps, and the amplifier settles to within 99.9% of final value within 50 milliseconds for an output change of 5 volts. Plug-in input and output filters allow bandwidth options from 3 cps to 120 cps, transient response as good as 25 milliseconds. Gain is 10 to 1000 in 5 steps. A front panel vernier control provides 1 to greater than 3.3 times continuous adjustment of each gain step. Gain stability is ±0.05%. Output capability is 10 volts at 10 milliamps. Amplifiers have integral power supplies. Enclosures include six-amplifier and single-amplifier 19-inch rack modules, and portable single amplifier cabinets.

To meet your exact requirements at minimum cost, two models are now available: the 114A at $775, and the 114C (described) at $875. Delivery on both models is currently from stock. Write for detailed technical data or a demonstration. Engineering representatives in all major cities.

KIN TEL
A DIVISION OF
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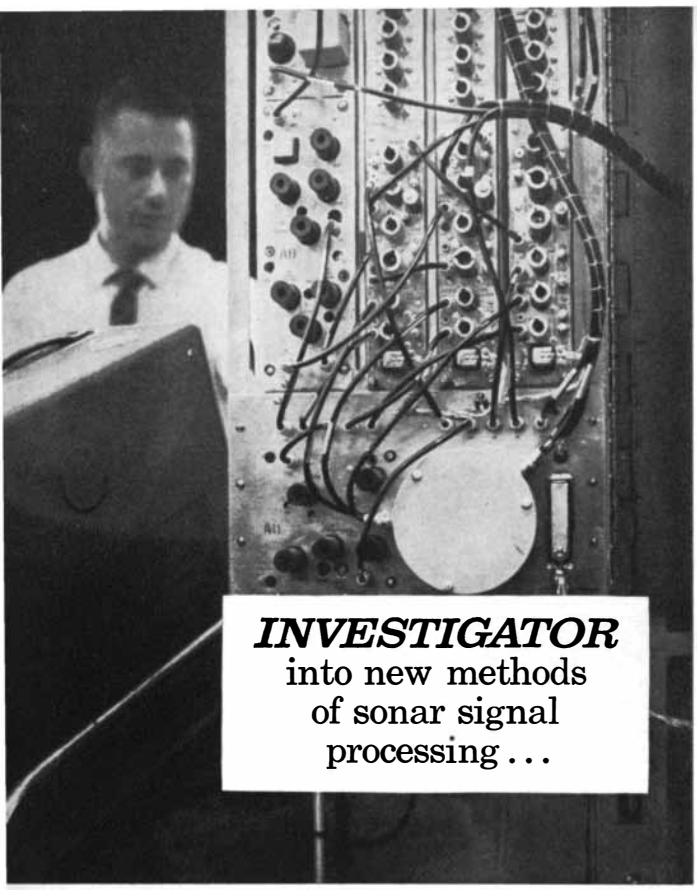
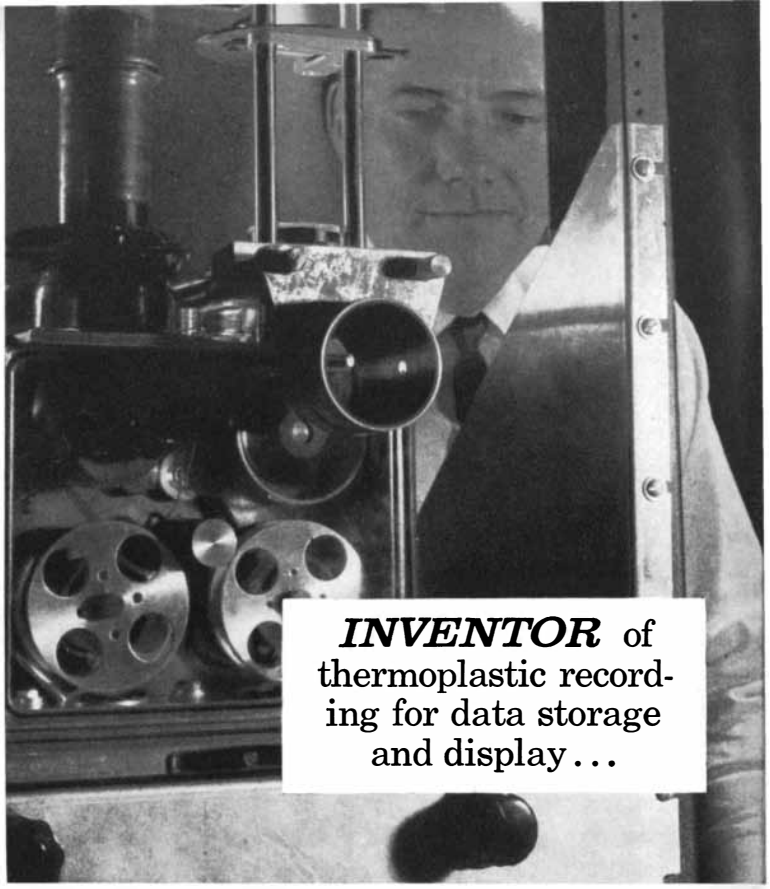
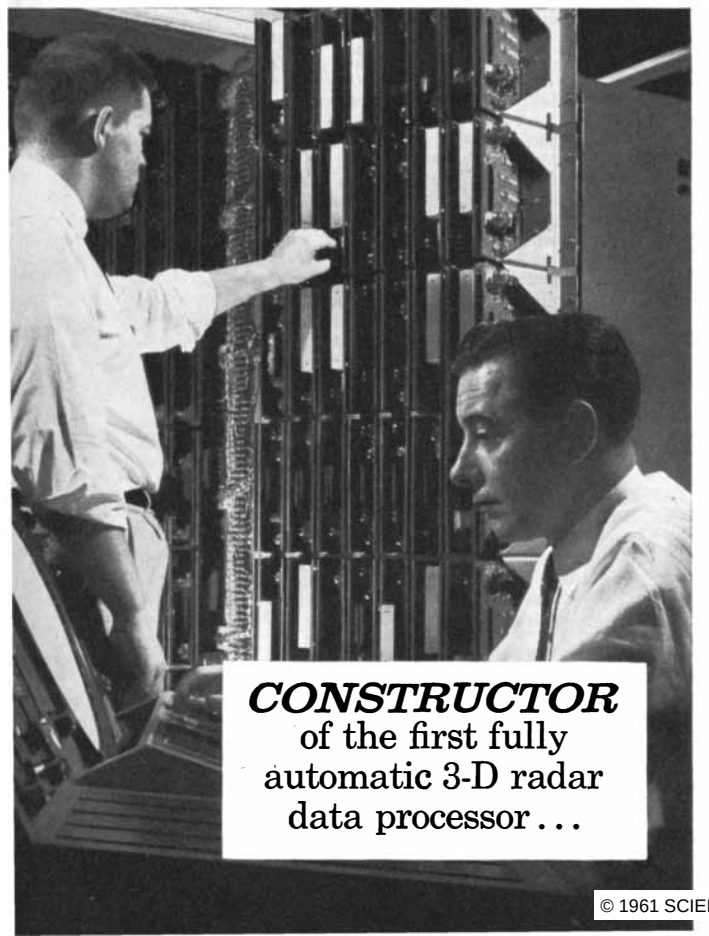


INVESTIGATOR into new methods of sonar signal processing . . .

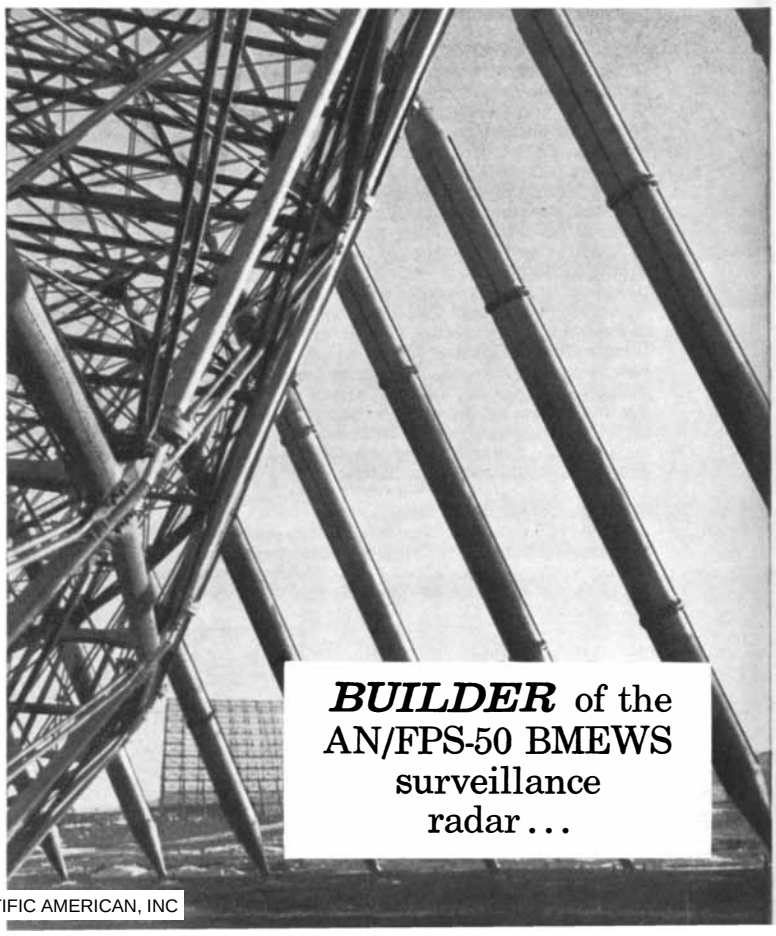


INVENTOR of thermoplastic recording for data storage and display . . .

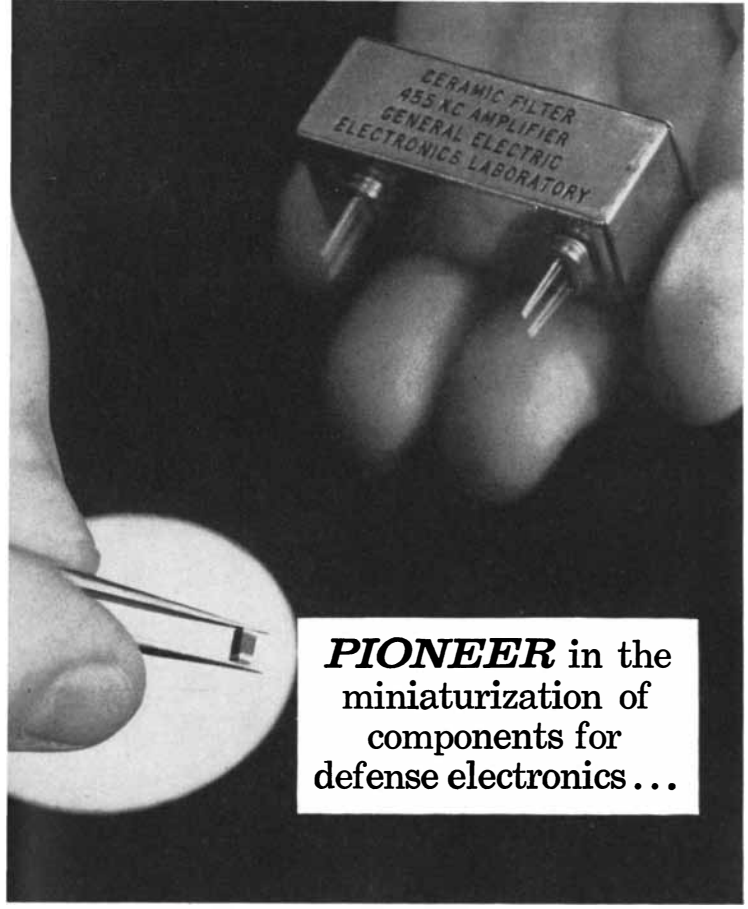
The Many



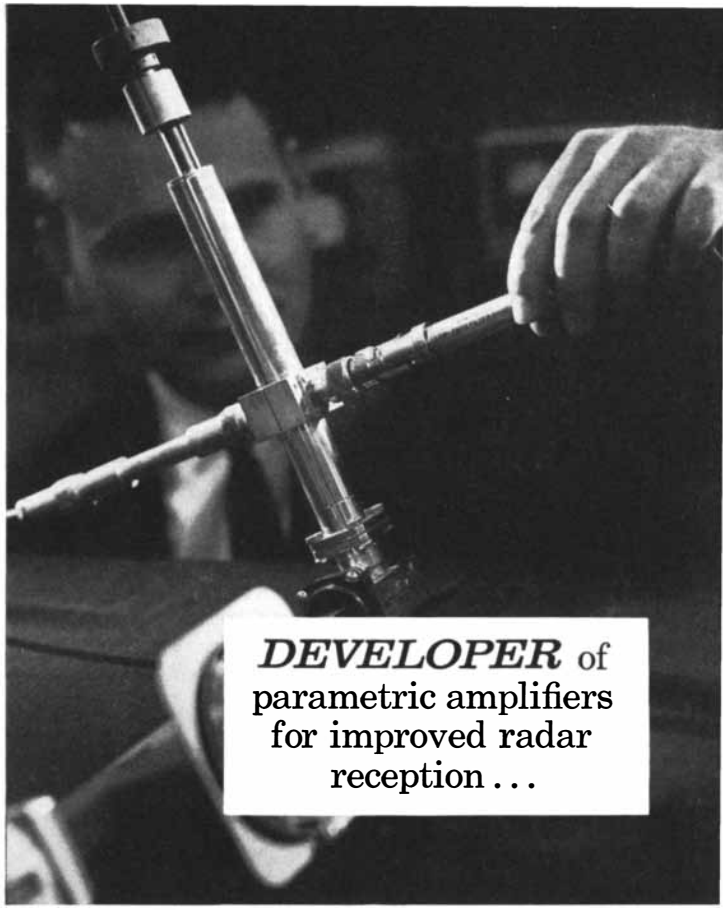
CONSTRUCTOR of the first fully automatic 3-D radar data processor . . .



BUILDER of the AN/FPS-50 BMEWS surveillance radar . . .

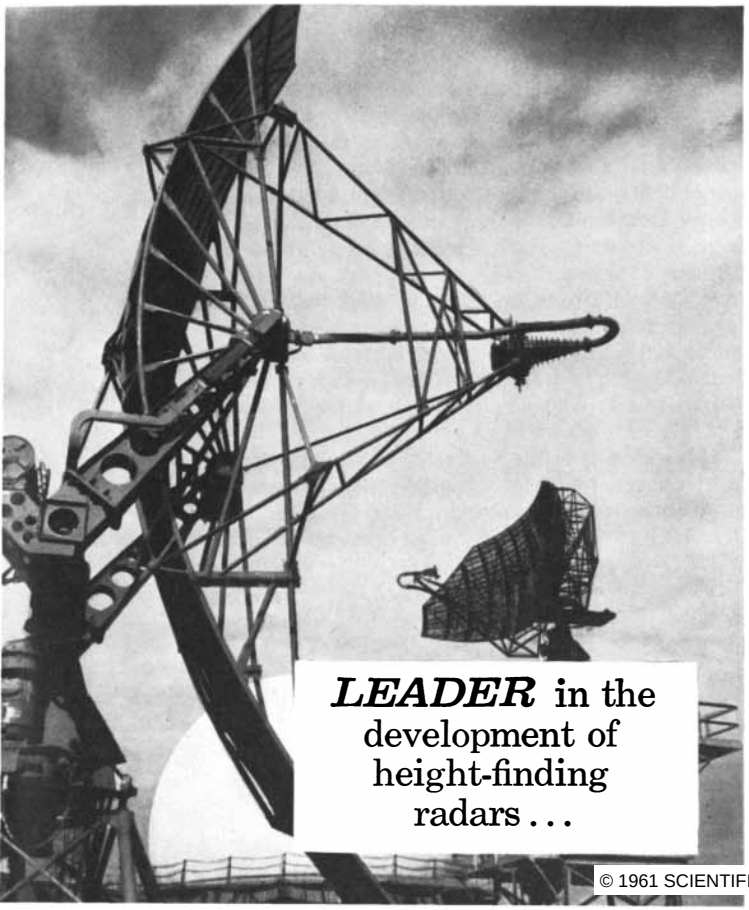


PIONEER in the miniaturization of components for defense electronics . . .



DEVELOPER of parametric amplifiers for improved radar reception . . .

Roles of HMED*



LEADER in the development of height-finding radars . . .

*General Electric's Heavy Military Electronics Department

Seven examples of the roles that General Electric's Heavy Military Electronics Department is playing in contributing to U.S. defense strength are illustrated here. Of course, the full spectrum of HMED activities is much broader. It includes work in radar, sonar, missile guidance and control, and computers; in data handling, communications, counter measures, and ground warfare; in air defense, missile defense, and product service. 176-10A

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DEFENSE ELECTRONICS DIVISION, SYRACUSE, N. Y.

THERMODYNAMICS *in action*

TRANSIT HEET® shipping container for Polaris Program SINS gyroscopes.

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Today's quest for knowledge takes men to the depths of the Pacific while others "reach for the moon" and beyond. Each pursuit presents problems in environmental extremes. Important among these are the effects of drastic temperature changes on men and materials. Equally significant are developments for stabilizing internal temperatures independent of power supplies and regardless of ambient conditions.

A new concept in this field is Transit Heet® which permits precise temperature control of an entire area or single component. It utilizes the permanently reversible absorption and release of the latent heat of fusion of chemical compositions. Transit Heet is a thermodynamic solution applicable to a multitude of temperature-control and heat-transfer problems. It may be utilized in systems of any size and in temperature ranges from cryogenic to 300°C. Each Transit Heet formula is chosen to yield maximum thermodynamic efficiency in its temperature range, and a simple patented CRYO-THERM® heat transfer unit maintains the required temperature well within tolerable limits.

A current major application for Transit Heet is in the packaging of temperature-sensitive instruments such as the gyroscopes for Polaris inertial guidance systems. CRYO-THERM engineers specialize in solving problems involving low-high temperature control and application. Why not consult us for suggestions on your specific requirement. We may have the solution to your problem.

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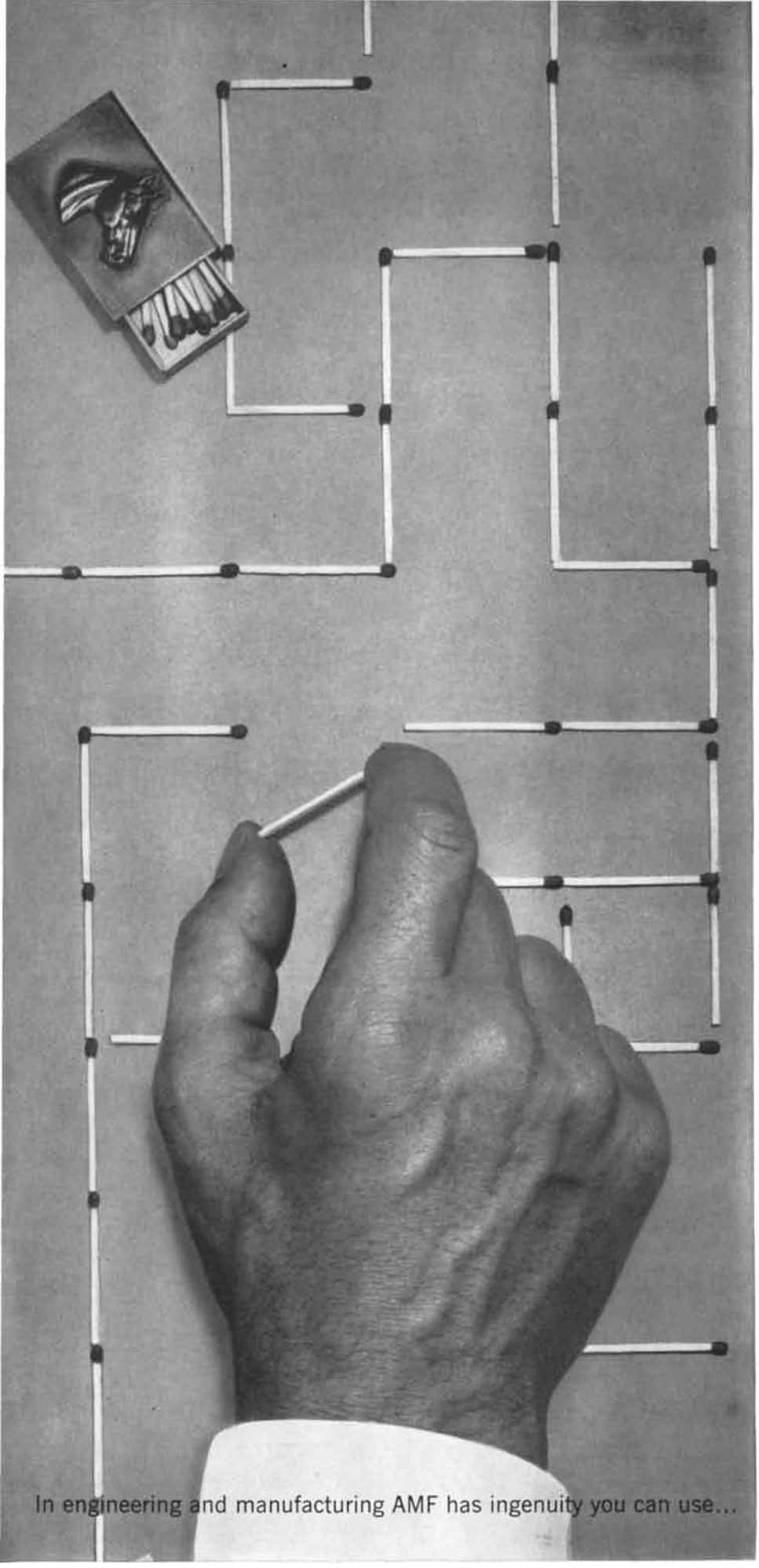
Precision-Controlled Thermodynamic Systems

A member of the NYTRONICS GROUP, an affiliate of NEFO



He designed a new interchange for radio traffic

This AMF engineer, part of an AMF-U.S. Army team, solved the problem of traffic delays and personal danger in manual re-connection of jumpers when interchanging R.F. transmitters and antennas.

His solution is a push-button-operated, coaxial crossbar switching system, using vacuum switches for circuit selection. A typical system consists of 4 transmitter inputs, 7 antenna outputs plus a dummy load, in a 4 x 8 matrix that can be mounted in a 19″ rack. It can be controlled locally or remotely over any type of communication network having a bandwidth of at least 200 cycles.

AMF's coaxial crossbar switching system provides 100% flexibility in circuit path selection and accommodates power levels as high as 500,000 watts and frequencies up to 30 megacycles. It allows 100% utilization of all transmitting equipment. Stubs are automatically eliminated.

To insure fail-safe operation, power is required for the vacuum switches *only* during change of condition. Selection rate: 1 per second. Operating transmitters are safety-interlocked to insure a load. There are no hazards from open wires or inadvertent application of power to dead-lined antennas.

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

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- *Space Environment Equipment*
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GOVERNMENT PRODUCTS GROUP,
AMF Building, 261 Madison Avenue,
New York 16, N. Y.

AMF

AMERICAN MACHINE & FOUNDRY COMPANY

LETTERS

Sirs:

In emphasizing automatic control systems as a means to an end for air-traffic control problems, Seymour Deitchman and Alfred Blumstein ["Air-Traffic Control"; SCIENTIFIC AMERICAN, December] seem to leave one with the definite impression, in a number of instances, that certain things *could be done* rather than *are being done.*

Starting with the Curtis Report, which gave rise to the Airways Modernization Board, whose functions have been consolidated with the Federal Aviation Agency, an air-traffic control modernization program has been in effect.

In October, 1957, the AMB placed a contract with the GPL Division of General Precision, Inc., to engineer, design and build a model of an air-traffic control data-processing central system for the New York area. Elements of this system have been under evaluation at the National Aviation Facility Experimental Center of the FAA for some time. As part of its modernization program FAA has placed under order for the Boston center a number of the elements of this system and plans to have a modernized center in operation by late 1962.

Three main points are put forth in the article but a positive indication is not left with the reader in all cases:

1. Available airspace. The presently installed traffic-control system, which does use data-processing equipment in certain centers, is restricted to airway flying due to the double restriction of machine capacity to handle nonfixed airway flying for the preparation of flight-progress strips and the controller capability to predict conflicts for nonfixed airways. A newer generation of data processors, however, is not so limited. The data processor developed by the Librascope Division of General Precision, Inc., for the data-processing central will be able not only to prepare flight progress strips for nonfixed airway flying as well as fixed but also to update these strips for the controller and provide a function redundant to the controller in being able to predict conflicts as well. The capability of this newer data processor has been sufficiently proved for the FAA to have placed it on order for installation in the Boston center.

2. Utilization of data-processing equipment. Mechanization of the controller's data-processing task to release him for his primary task of preventing and resolving potential conflicts and delays is being done. The planning of the FAA and the design of its data-processing central is concerned not only with mechanization but also with the primary goal of maintaining a proper balance between two types of data processors: man and machine. Against the unlikely chance of complete machine failure, the man-machine interface has been designed so that the information available to the controller is in the same form and has been prepared in the same manner as though the machine were not available.

3. Airport airspace service capacity. Sequencing of aircraft to provide better utilization of airspace is presented as not providing a significant gain in available airspace. However, sequencing based on minimum time-separation at the airport runway does provide the flexible separation standard supported by the authors. It is true as stated by the authors that more data must be given to the controller so that this sequencing can be carried out. Such data and its required display is now being evaluated as part of the data-processing central.

A presentation of what could be done in air-traffic control needs to be complemented by what is being done to leave a true picture in the readers' minds of this most vital element in our modern society.

A. M. GOLDSMITH

GPL Division
General Precision, Inc.
Pleasantville, N.Y.

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Change of address: Please notify us four weeks in advance of change. If available, kindly furnish an address imprint from a recent issue. Be sure to give both old and new addresses, including postal zone numbers, if any.

This assembly, 1½" square, shows 8 thermoelectric couples arranged in typical configuration.

Westinghouse extends the frontiers of thermoelectrics in refrigeration and power generation

New thermoelectric semiconductor materials, many of them developed by Westinghouse research in the last two decades, have transformed Peltier and Seebeck devices from laboratory curiosities into practical military and industrial apparatus.

Initial thermoelectric applications employed the cooling Peltier effect. Westinghouse developed the first complete line of thermoelectric cooling devices commercially available in a wide range of configurations for cooling temperature-sensitive electronic components. These thermoelectric devices were the first to provide cooling below ambient with no moving parts. Compact size and light weight made them ideal for missile and new aircraft requirements. In addition to cooling, component heating can be accomplished by simply reversing the direction of the current flow. Thus thermoelectric coolers give full-range temperature control (both negative and positive) in widely varying ambients.

More recently, by applying the Seebeck effect to power generation, Westinghouse has designed and constructed a wide variety of generators ranging from one watt to several kilowatts. Power-to-weight ratios of 15 watts per pound are already feasible and comparable to typical gasoline-powered 500-watt portable generators.

Many industrial and commercial applications are becoming feasible as Westinghouse research develops new, more efficient thermoelectric materials. New compounds have been formulated which provide higher thermoelectric performance in the higher temperature ranges. Thus over-all system efficiency can be increased by "cascading" the Carnot cycle in stages over a range of materials. This cascading technique is used in a Westinghouse gas-fired thermoelectric system, built in cooperation with the U. S. Navy, capable of delivery 5 kilowatts. Units involving still larger levels of power generation are in the developmental stage.

Future applications of thermoelectric cooling and power generation are virtually unlimited. Your inquiries about your specific requirements are invited. Write or call: Westinghouse Electric Corporation, Semiconductor Dept., Youngwood, Penna. SC-1020

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ELECTRONIC DATA PROCESSING
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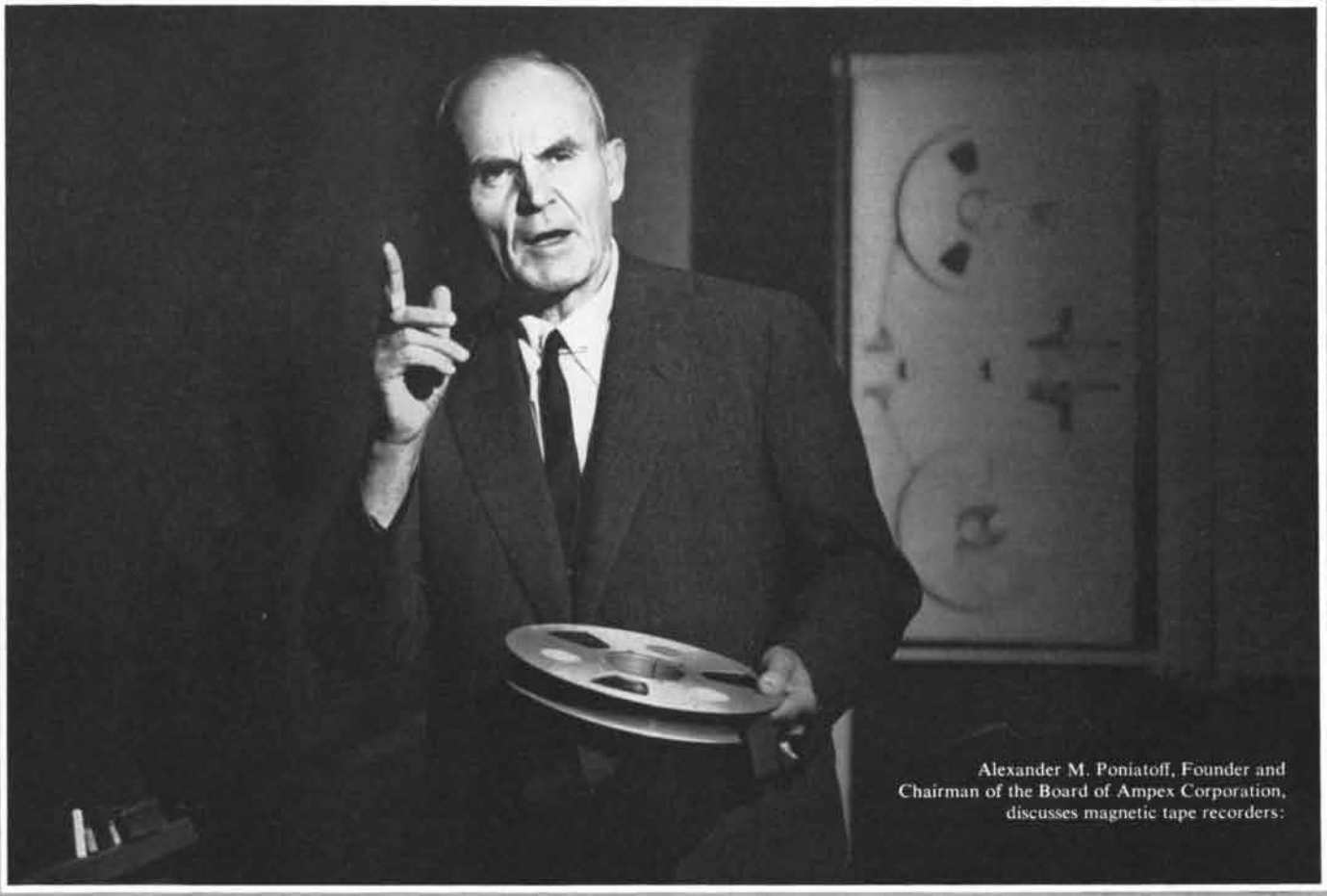
Constructive discontent at Ampex...

. . . has been setting instrumentation standards for years



Alexander M. Poniatoff, Founder and Chairman of the Board of Ampex Corporation, discusses magnetic tape recorders:

"Everything Ampex recorders stand for – service, quality, reliability, technological leadership – stems from this attitude.

"The first commercial 'live-quality' audio recorder was developed by Ampex because of the disc record's fidelity drawbacks. Discontent with the capabilities of all data recorders using visual traces spurred Ampex's evolution of special purpose magnetic tape data recorders. Frequency limitations bothered us, so we gave you the 4-megacycle FR-700.

"A need for compact equipment with high performance caused us to introduce the CP-100 – a transistorized 200 kc 14-track data recorder less than 7 cu. ft. small. Striving for versatility and high efficiency, we perfected the FR-600; it records 500 kc at 120 ips – double the previous standard, but still fully compatible.

"And we were even constructively discontented with the way we made these advanced recorders available to you. Now, Ampex instrumentation recorders can be leased or purchased on time as well as outright. You can free working capital for other projects, and invest in your Ampex data recorder as it works for you."

Some significant specifications:

AR-300, FR-700: 10 cps to 4 mc ±3 db; 12½ and 25 ips record and playback. FM recording. Two data, two auxiliary tracks. 2″ tape, 10½″ reels. AR-300 airborne record only.

CP-100: 300 cps to 200 kc ±3 db at 60 ips; 60, 30, 15, 7½, 3¾, 1⅞ ips with proportional response. Direct or FM recording. All-transistorized. ½″ or 1″ tape, 10½″ reels.

FR-600: 300 cps to 500 kc ±3 db at 120 ips; 60, 30, 15, 7½, 3¾, 1⅞ ips with proportional response. Direct, PDM or FM recording by plug-in modules. ½″ or 1″ tape, 10½″ or 14″ reels.

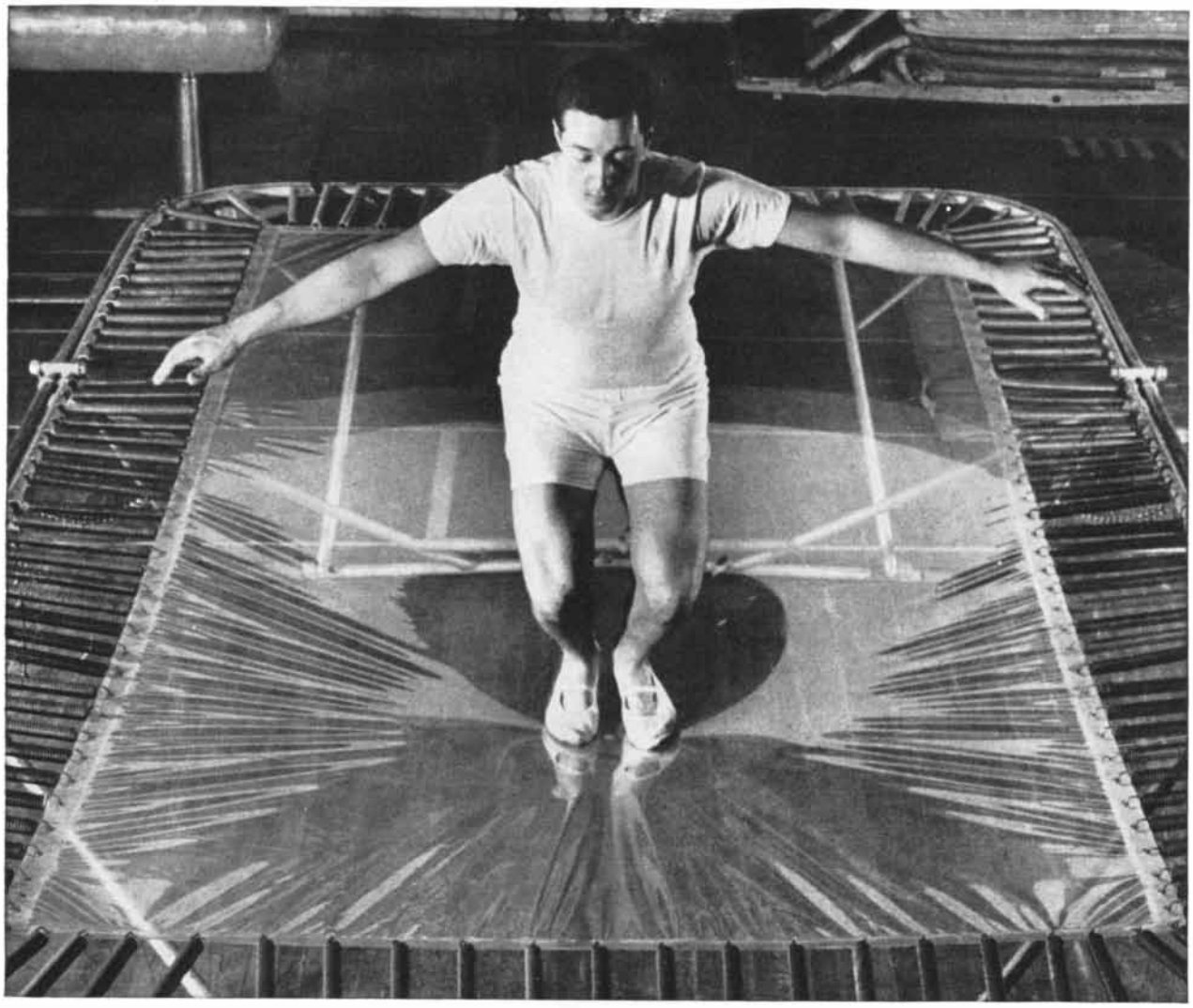
For detailed information on the complete Ampex line of data recorders, write:

AMPEX INSTRUMENTATION PRODUCTS COMPANY

Box 5000, Redwood City, California

AMPEX

Experienced engineers eager to contribute to Ampex's pioneering reputation are invited to write the Manager, Technical Recruiting.



Tough, durable Mylar® cuts costs . . . improves product performance

1. Huge (100 ft. diam.) inflatable satellite of metalized "Mylar" stays strong and flexible in sub-zero outer space.

2. Permanent collar stays of "Mylar" last the life of the shirt . . . keep their shape even after hundreds of launderings.

3. Capacitors with insulation of "Mylar" give long-lasting reliability . . . need for costly encapsulation is eliminated.

For example, "Mylar"* polyester film gives many products extra resistance to heat, cold and aging . . . lengthens their life. Today, "Mylar", with its resistance to chemicals and moisture, is improving the performance of products as different as surgical bandages and intercontinental ballistic missiles.

Can this unique plastic film and products made with it help you? For more information on "Mylar", write the Du Pont Co., Film Dept., Room S-8, Wilmington 98, Del.

DU PONT
REG. U. S. PAT. OFF.

*"Mylar" is Du Pont's registered trademark for. its brand of polyester film.

Better Things for Better Living . . . *through Chemistry*

DU PONT **MYLAR®** POLYESTER FILM

COMPUTENCE . . . TOTAL COMPETENCE IN COMPUTATION

. . . provides effectiveness for new system of mobile defense against multiple airborne targets

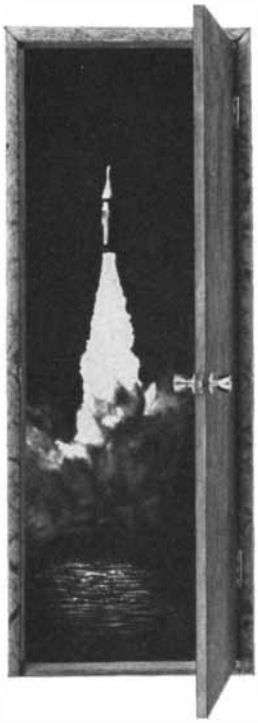
The program: MAULER, U.S. Army's newest automatic-firing air defense system, involving missile-firing vehicles transported by air and parachuted into battle areas. **Basic Burroughs contribution:** design and production of the miniaturized electronic computer systems which will provide radar data processing and computation for MAULER. Among special design features will be the Burroughs Logi-Mod packaging technique, to protect sensitive computer components from shock during air transport and parachute drop. **Behind the news:** Still another vote of confidence in Burroughs Corporation's Computence—total competence in computation—from basic research through production and field service to system management. Confidence in Burroughs performance, already proved in such vital programs as ATLAS, SAGE and ALRI.

Burroughs—TM

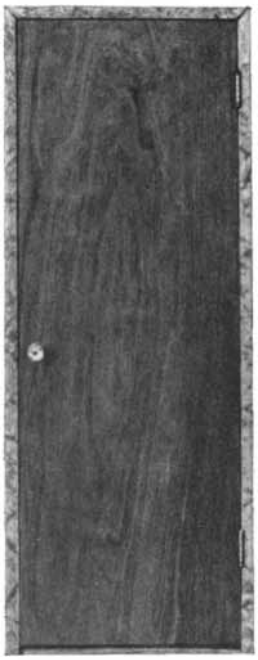
Mauler is being developed by Convair-Pomona, Convair Division of General Dynamics, for ARGMA, an element of the Army Ordnance Missile Command.

Burroughs Corporation

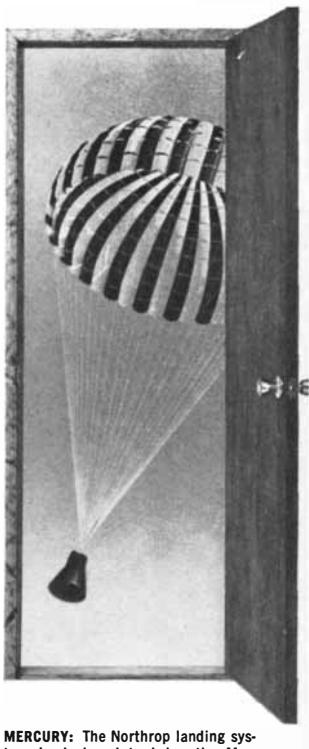
"NEW DIMENSIONS / in computation for military systems"



POLARIS: Northrop's Datico checks out Polaris at all levels of maintenance and operation.

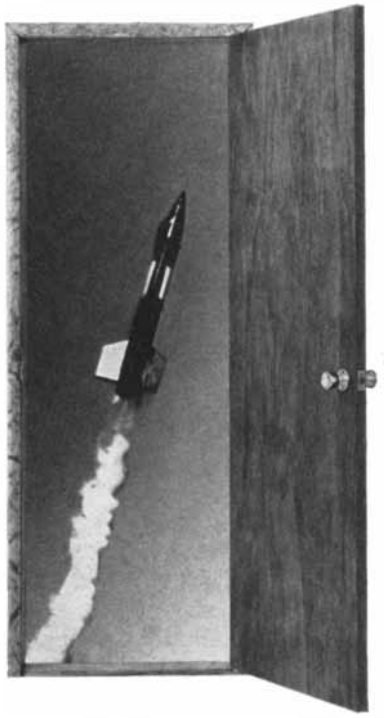


SKYBOLT: Guidance and navigation systems are being developed by Northrop for this new and highly secret air-launched ballistic missile.



MERCURY: The Northrop landing system is designed to bring the Mercury astronaut down safely.

Northrop is now active in more



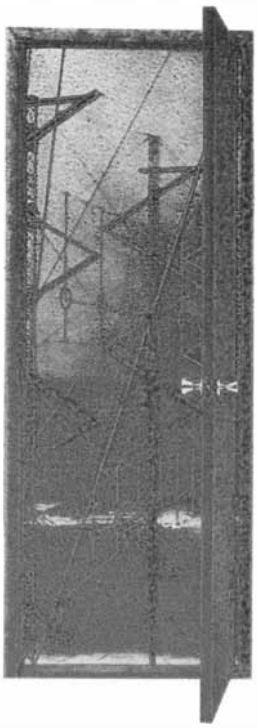
X-15: Northrop produces Q-Ball, the flight angle sensor for safe re-entry of X-15 and other aerospace vehicles.

AERODYNAMICS: Northrop's Laminar Flow Control technique is designed to greatly increase aircraft range, flexibility, cargo and passenger capacity.

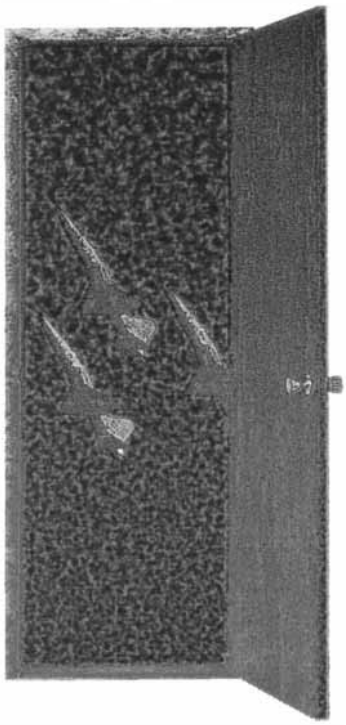
TITAN: Northrop supplies complete technical and industrial management to activate the T-2 Titan missile base.

For work on these advanced programs, we seek exceptional engineers, scientists and mathematicians.

HAWK: Northrop produces airframe components, ground handling and launching equipment for this air defense missile.

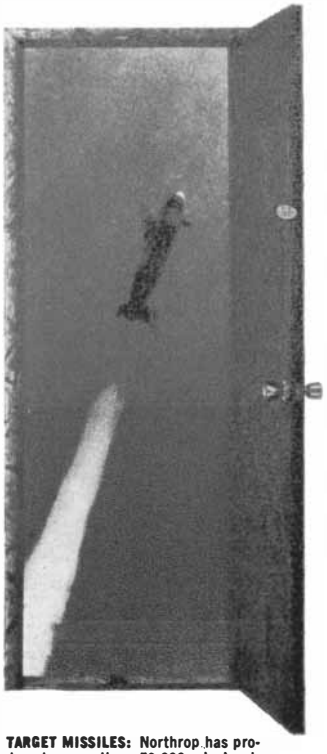


COMMUNICATIONS: Northrop designs the trans-Pacific Scatter Communications Network and other worldwide communication systems for U.S. and free world governments.

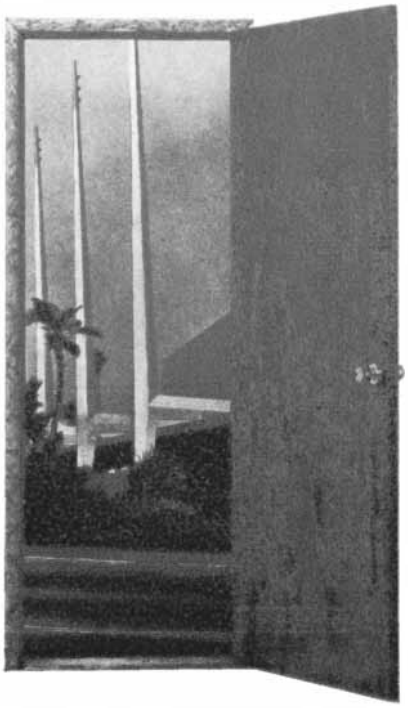


T-38: World's first supersonic twin-jet trainer is built by Northrop for the United States Air Force.

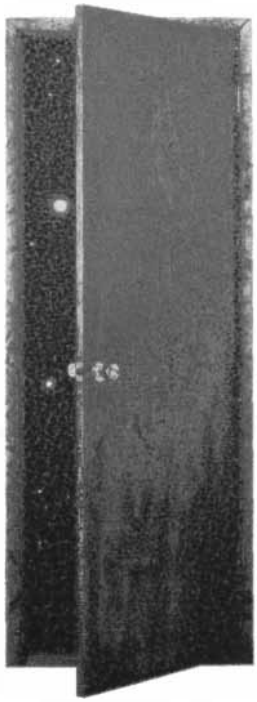
than 70 important programs



TARGET MISSILES: Northrop has produced more than 50,000 electronically-controlled aerial targets, and surveillance drones.



COMMERCIAL METAL PRODUCTS: Northrop produces aluminum architectural shapes for many important industrial and commercial buildings.



SPACE RESEARCH: Northrop's accelerated space research programs reach into such advanced areas as maneuverability, rendezvous, space vehicle maintenance, space probes, and the survival of men in space.

Write Northrop Corporation, Box 1525, Beverly Hills, California. Divisions: Norair, Nortronics, Radioplane.

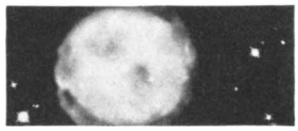
50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

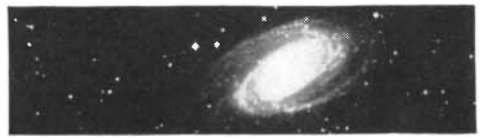
FEBRUARY, 1911: "Madame Curie was defeated for election in the Academy of Sciences. Édouard Branly received one vote more than she. There can be no question of the value of M. Branly's contributions to physics and, above all, to the art of wireless telegraphy, nor of his fitness to sit in the Academy as one of its most distinguished members. Yet one cannot but feel that Madame Curie's defeat was due entirely to her sex. We have sufficiently commented on this matter in our editorial columns. Branly was the inventor of the coherer, which was such an important factor in the early stages of wireless telegraphy, although it is now hardly ever used, except for small experimental stations."

"In an appreciation of his distinguished contemporary Arrhenius, Wilhelm Ostwald writes: 'Svante Arrhenius attained the degree of doctor of physics in 1884. His graduate thesis, *A Study of the Conductivity of Electrolytes*, published in the same year, made a profound impression upon me. I was then connected with the polytechnical school of Riga, and there I repeated and extended the experiments by which Arrhenius had proved the approximate proportionality of the chemical affinities of acids and bases to their electrolyzed conductivities. Then I went to Uppsala to support Arrhenius, whose views were regarded as heterodox, in obtaining a position in the university. A year later we worked together for several months at Riga. In 1887 Arrhenius published his theory of electrolytic dissociation, probably the most important and prolific of his many achievements. In 1903 he astonished the scientific world with his two-volume *Text Book of Cosmical Physics*, containing many bold and original ideas in regard to the constitution and origin of the heavenly bodies. Still more recently appeared *Worlds in the Making*. The most striking novelty in the cosmogony of Arrhenius is the introduction of the pressure of radiation, which appears to be a very active factor, not only

WE'RE REACHING INTO SPACE



Bell Laboratories research with chilled ruby amplifiers speeds the day we may telephone via satellites



A strange combination of Nature's forces at Bell Laboratories foreshadows the day when world-wide phone calls may be relayed via man-made satellites orbiting the earth. It is a union of synthetic rubies and extreme cold, making it possible to amplify microwave signals from these satellites clearly.

Synthetic rubies possess an extraordinary property when deeply chilled and subjected to a magnetic field. They can be excited to store energy at the frequencies of microwave signals. As a signal passes through an excited ruby, it releases this energy and is thus amplified a thousandfold.

Bell Laboratories scientists chose a ruby amplifier because it's uniquely free of "noises" that interfere with radio signals. For example, it doesn't have the hot cathodes or hurtling electrons that generate noise in conventional amplifiers. It is so quiet that only the noise made by matter itself in heat vibrations remains. But at a temperature close to absolute zero, this also is silenced. Even very faint signals from satellites can be clearly amplified and studied for their possibilities.

Bell Laboratories scientists were first to discover that matter itself generates electrical noise. They also discovered that stars send radio waves, and thus helped found radio astronomy. It is particularly fitting that the same scientists, in their endless research on noise, should now battle this number-one enemy of telephony in the dramatic new field of communication via satellites. The ultimate goal, as always, is the improvement of your Bell System communications services.

BELL TELEPHONE LABORATORIES

WORLD CENTER OF COMMUNICATIONS RESEARCH AND DEVELOPMENT

in the formation of comets' tails but also in many more cosmical processes.' "

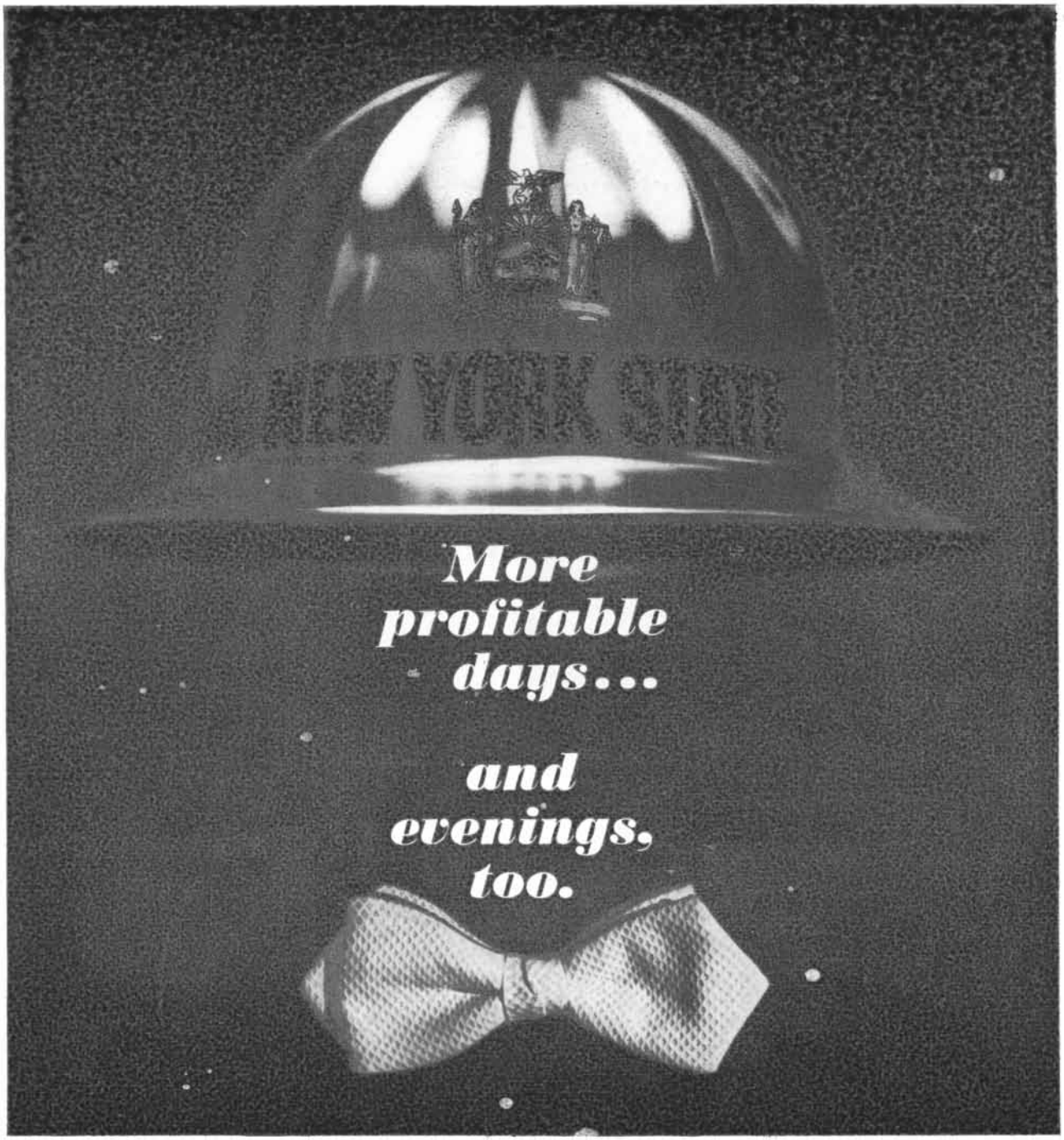
"On January 15th a number of important tests were made at bomb dropping at San Francisco. Lieut. Myron Crissey, of the Coast Artillery, dropped a special shrapnel bomb from a height of 550 feet when flying in a Wright biplane driven by Parmalee. Lieut. Crissey succeeded in dropping the bomb with a considerable degree of accuracy. He believes that it will be a comparatively simple matter to hit an object the size of a battleship from a height of 3,000 feet. From the height it was dropped the bomb tore a large hole in the ground and scattered its contents within a radius of 50 yards. This is the first time that an actual bomb has been used in such an experiment."

"By means of the new submarine telephone cable from Dover to Cape Gris Nez, on the French coast, and suitable land lines, it will be possible to carry on a conversation from two ends of the wires in towns 850 miles apart, and it will be easy to speak from London to St. Petersburg. By introducing small self-induction or loading coils into each of the wires at spaces of about one mile apart, the defects of indistinctness and weakening of the sound noticeable in long cables of the old time have been overcome."

Scientific American.

FEBRUARY, 1861: "Chemical analysis by spectrum observations is one of the most important inventions of the present century. Professor Robert Bunsen, of Heidelberg, has now published the first precise investigations in this direction, the consequences of which can scarcely yet be realized. Their beginning, though, is sufficient to indicate that they may probably lead to the solution of hitherto inaccessible problems. By the aid of this process, the unexpected fact was demonstrated that lithium, which was believed to be one of the rarest elements, pertains to the most distributed substances of nature, as small particles of it were found in many minerals, in sea and spring waters, in the ashes of plants, in the air, etc."

"There is no better test of the advancement of our country in manufactures and commerce than the quantity of coals which are annually raised from



A New York State businessman finds his rewards around the clock. On the job he's stimulated by an atmosphere charged with success. He's working in the nation's most favorable business climate . . . created by Governor Rockefeller and his "hard-hat" administration. ■ The businessman can also gratify his cultural and entertainment interests, not only in New York City, but all over the state. In Manhattan alone, he has the choice of concerts, operas, plays on Broadway and off . . . many featuring world-famous artists. ■ Lincoln Center, America's "Culture Center," is scheduled for a 1961 opening. ■ Further opportunities to divert his mind or give it a fresh point of view range from catching the latest headline act at a smart supper club to taking a course in oil painting, a foreign language or advanced electronics.

We'll compile a report tailored to your specific new plant needs. Write Commissioner Keith S. McHugh, Dept. of Commerce, Room 258, 112 State St., Albany 7, N. Y. (All contact between your office and ours will be kept *under* our hat.)

GET UP TO DATE ON NEW YORK STATE... WHERE THEY'RE TALKING THE BUSINESSMAN'S LANGUAGE

our mines. Judging by this standard, the coal product of our mines for 1860 affords us evidence of the great progress our country has made since 1850. In that year, the anthracite coal product was 3,321,126 tuns, while in 1860 it was no less than 8,131,234 tuns."

"Among the curiosities of London life is the appearance of Lord Caithness in that metropolis, guiding his steam carriage. He has driven through the most crowded parts without frightening the horses, and threaded the vehicles with ease and elegance."

"The present annual production of tobacco has been estimated by an English writer at 4,000,000,000 pounds. This is smoked, chewed and sniffed. Suppose it was all made into cigars, 100 to the pound, it would produce 400,000,000,000. Four hundred billions of cigars! Allowing this tobacco, unmanufactured, to cost on the average 10 cents a pound, and we have $400,000,000 expended every year in producing a noxious, deleterious weed."

"In the course of our patent work we have received the following letter, the writer of which gives as part of his address 'Republic of South Carolina': 'As I do not consider myself a citizen of the United States, I cannot take the oath required of me. If you can strike that out of the papers, and then let me sign them, I will do it; but if not, I withdraw my petition. Please answer immediately, as I expect to leave this place soon to go and defend my State. Allow me to thank you for the promptness with which you have always done my business. Yours, S. L. B.' We publish the above merely to show the state of public sentiment among some of our Southern citizens. The writer is willing to sacrifice his legal right in an invention of value to him, rather than make the required oath of citizenship. We admire the spirit which induces a person to sacrifice his means in preference to principle. At the same time, we would advise all our Southern clients who consider themselves foreigners to the United States, and cannot take the prescribed oath, to wait awhile, rather than abandon their claims to a patent by a withdrawal of their applications."

"Another great cannon was lately cast in Pittsburgh, Pa., and called the 'Union.' It is of a 12-inch bore; the metal used in the casting amounted to 78,104 pounds, and it is expected to carry a ball a distance of six miles."

HIGH PURITY ELEMENTS

New Standards of Purity...

ASARCO's search for improvement in the purity of its basic elements has led to development of refining and analytical techniques which result in frequent improvement in control of minute impurities. The purity of ASARCO elements is, therefore, higher than the analyses indicate.

This improvement in quality of ASARCO high purity elements has made them preferred elements for numerous research projects and for many other applications, particularly in electronics.

ASARCO's latest analyses, dated and reproduced below, assure higher standards of purity than ever before. As research in this field continues, still higher quality can be expected.

ASARCO HIGH PURITY ELEMENTS ANALYSIS as of Feb. 1, 1961
Impurities, sometimes found, at maximum levels, parts per million
(*less than ppm indicated)

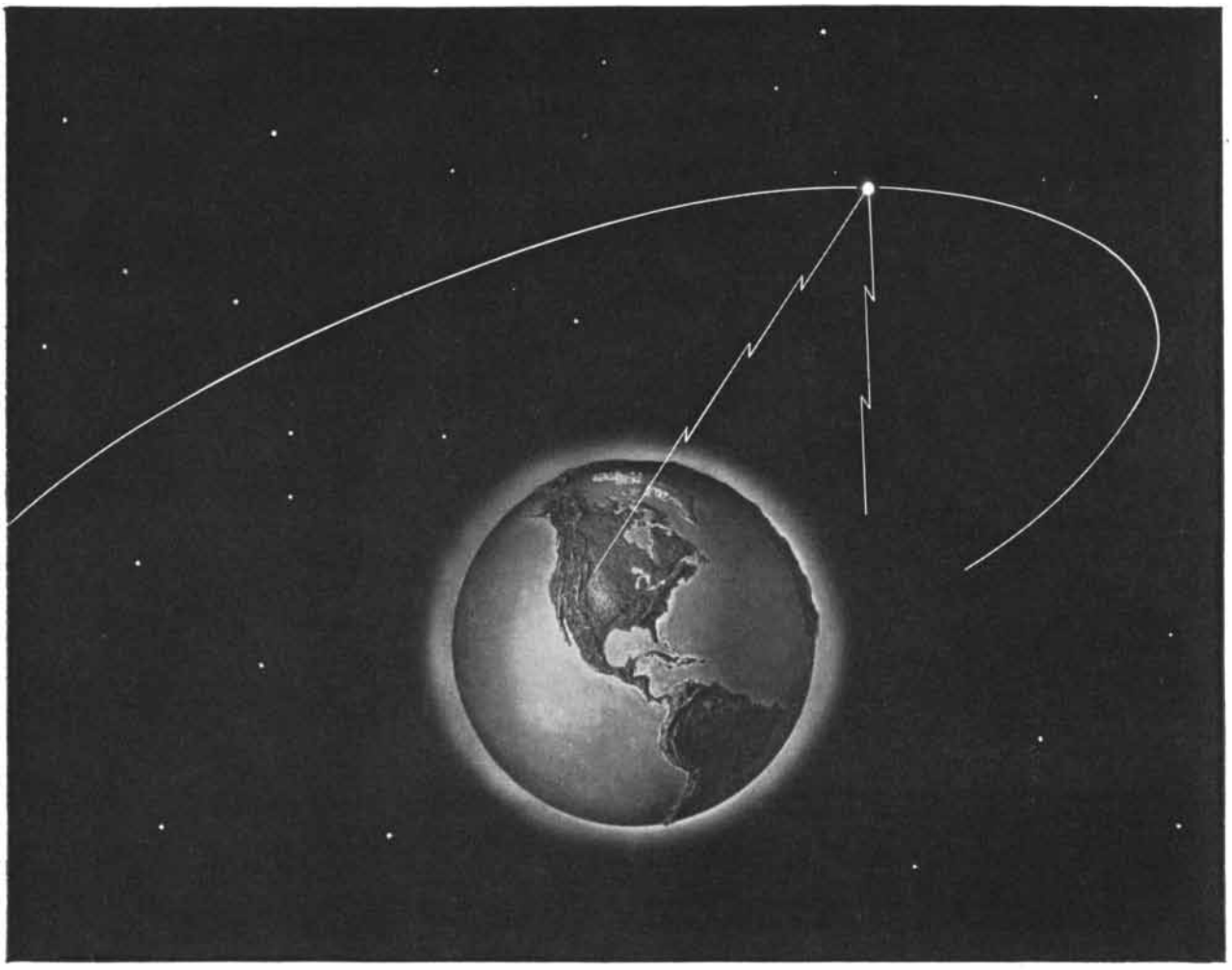
ASARCO High Purity Element and Grade**		Bi	Cu	Fe	As	Pb	Ag	Tl	Sn	Te	Au	Na	Cl	Cd
ANTIMONY	A-60	1*	1*	1*	1-5	1*								
ARSENIC	A-58		1*	1*										
BISMUTH	A-58		2	1		1	2						1*	
CADMIUM	A-60	1*	1*			1*								
COPPER	A-58	No Impurities Detectable by Spectrographic Analysis												
GOLD	A-59		1*	1*		1*	1*							
INDIUM	A-58		1*			1		1*	1					
LEAD	A-60	1*	1*	1*										
SELENIUM	A-58		1*		1*					1			1*	
SILVER	A-60		1*	1*		1*								
SULFUR	A-58											1	1	
TELLURIUM	A-58		1*	1*										
THALLIUM	A-60		1	1		1*	1*					2	1*	
ZINC	A-59		1*	1*		1*								1*

***A change in grade number always denotes improvement in purity.*

If you use high purity elements, save this page as a current buying guide.

ASARCO

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



OPENING A NEW ERA IN GLOBAL COMMUNICATIONS

A new era of great potential will be ushered in when satellites orbiting thousands of miles above the earth serve as radio relay stations in space to receive and transmit global messages, both from the ground and from flying aircraft.

In this historic undertaking, Bendix is developing the radio equipment which will be used on the satellites, on the aircraft, and at the ground terminals. For use in this project, we have developed highly reliable receivers and transmitters using our "selective redundancy" principle.

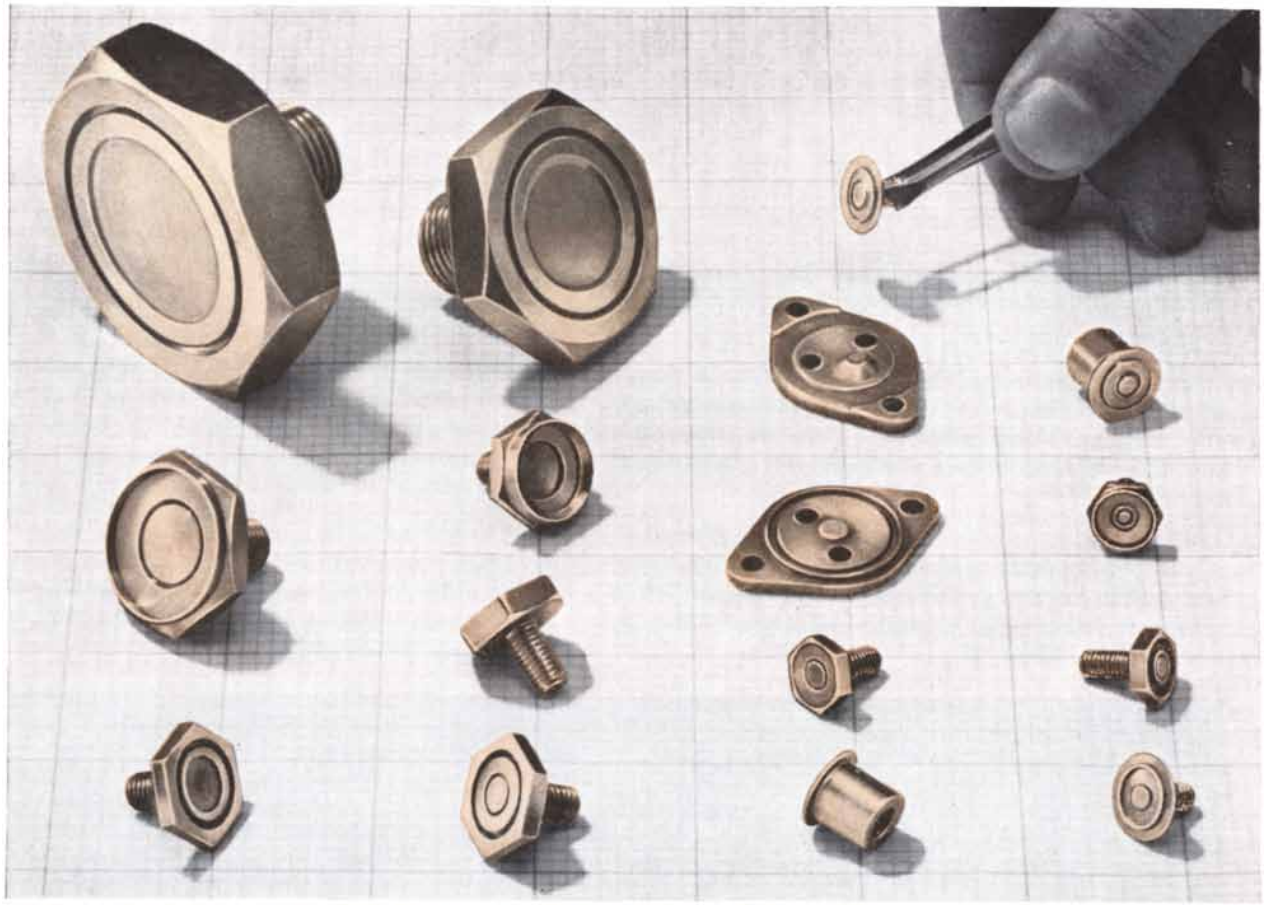
Bendix has been responsible for many new achievements in man's efforts to conquer space. Our Reaction Jets have already helped put Discoverer series capsules in orbit, steered them, and helped to recover them. We have developed a Free Reaction Sphere which is a new automatic pilot concept for interplanetary flight.

For Project Mercury, the daring adventure to put a man into orbit, Bendix has the responsibility for ground-to-capsule voice communication equipment; radars for tracking the spacecraft in flight; command links which make it possible to control certain spacecraft functions from the ground; and a telemetry receiving system and data processing equipment for the 18 stations in the global network.

In addition, two of the three U. S. tracking systems, which keep constant vigil over space travelers, were built and are operated by Bendix. One is Minitrack, a network of tracking stations built to Navy specifications. Minitrack is operated by Bendix for the National Aeronautics and Space Administration. It has tracked all satellites that have emitted radio signals. The other is SPASUR, operated by Bendix for Naval Research Laboratories which performs the difficult task of detecting "dark" satellites—those which may be intended to orbit undetected or whose transmitters have stopped operating.

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

A THOUSAND DIVERSIFIED PRODUCTS SERVING THESE FIELDS:
automotive • electronics • missiles & space • aviation • nucleonics • computer • machine tools • sonar • marine



SEMICONDUCTOR BASES

These Anaconda coppers help you achieve economical volume production of essential electronic components.

As the use of semiconductor devices soars, production methods must be geared to economical volume production, and the selection of metal for the bases becomes critical. Electrolytic Tough Pitch (ETP) Copper has the high electrical and thermal conductivity required, but the severe heat cycling encountered in degassing and brazing the devices during manufacture limits its use. The copper alloy must be deoxidized or oxygen-free to resist hydrogen embrittlement. For secondary operations, it must also have good machinability. And where high torque is used to tighten the base to the heat sink, it must in addition have relatively high strength.

COPPER METALS. Various combinations of the desired properties are found in these Anaconda alloys: DLP Copper-104 (deoxidized low phosphorous), OFHC* Copper-120 (oxygen-free high-conductivity), Tellurium Copper-127, Chromium Copper-999, and Amzirc® (Zirconium Copper)-134.

FABRICATING METHODS. Anaconda specialists can help you select the right alloy and form of metal—and the manufacturing method best suited to meet your design and fabrication problems. Depending on the size and design of the base, the production runs involved, parts may be produced in a variety of ways. Cold heading may be most economical for some, others might be die-pressed forgings, screw machine or punch-press parts. And for many of the smaller parts, multiple-plunger-press fabrication could offer the greatest economies. These specialists can also help you utilize such cost-cutting techniques as roll threading of studs, and advise you on welding and brazing procedures.

Whatever your problem, Anaconda offers specialized technical help—yours for the asking. See your Anaconda representative or write: Anaconda American Brass Company, Waterbury 20, Conn. In Canada: Anaconda American Brass Ltd., New Toronto, Ont. 6075

*Trade-mark of American Metal Climax, Inc.

ANACONDA®

COPPER PRODUCTS FOR THE ELECTRICAL INDUSTRY

Anaconda American Brass Company

This Value Engineer represents the "loyal opposition." His job is to question, "Is this product good enough—can it perform its function better—and at lower cost?"

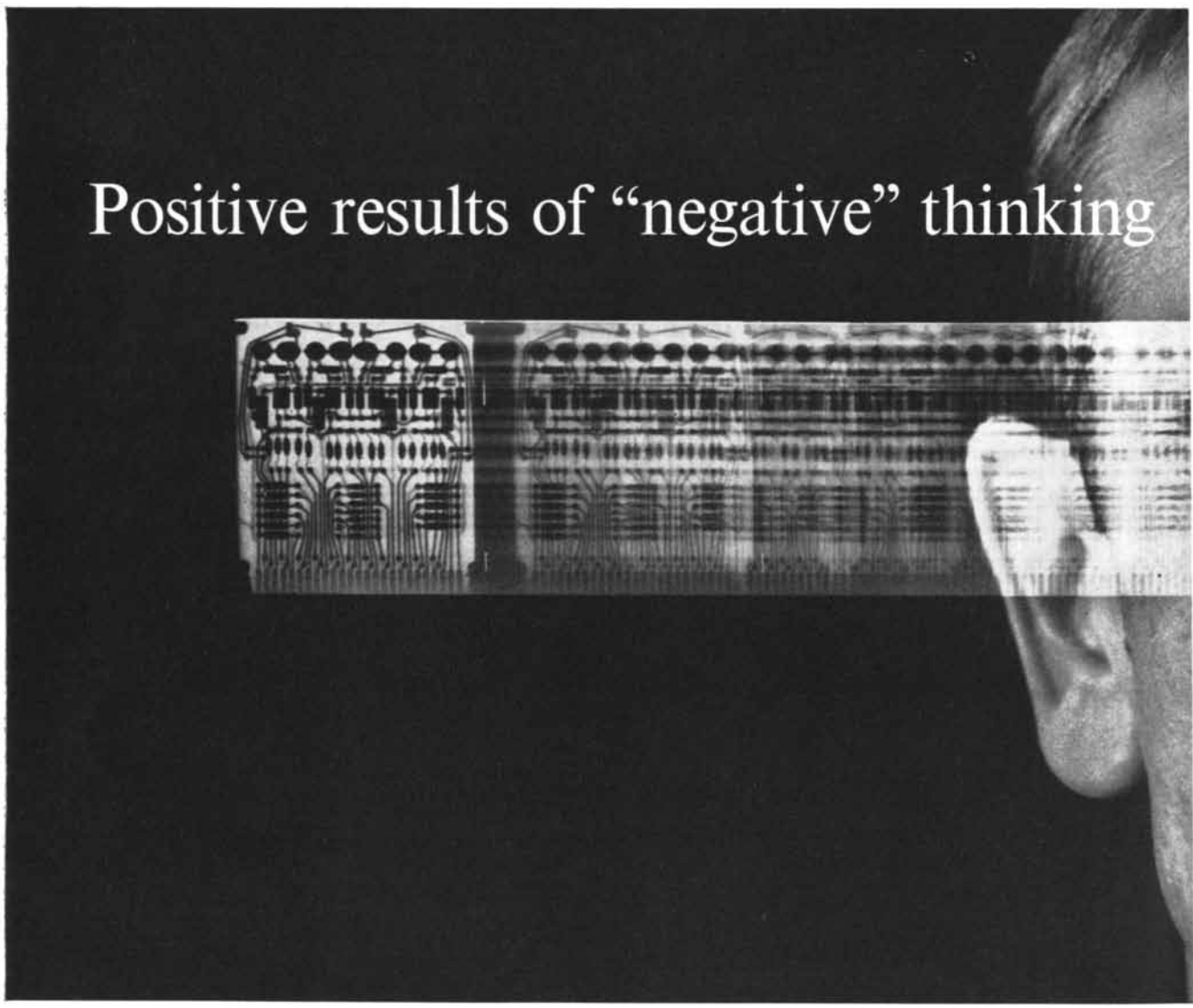
But he doesn't just challenge. At the same time he visualizes new and better ways of answering his own questions. As a Hughes Value Engineer he is active throughout the product cycle, from design and development to final manufacturing.

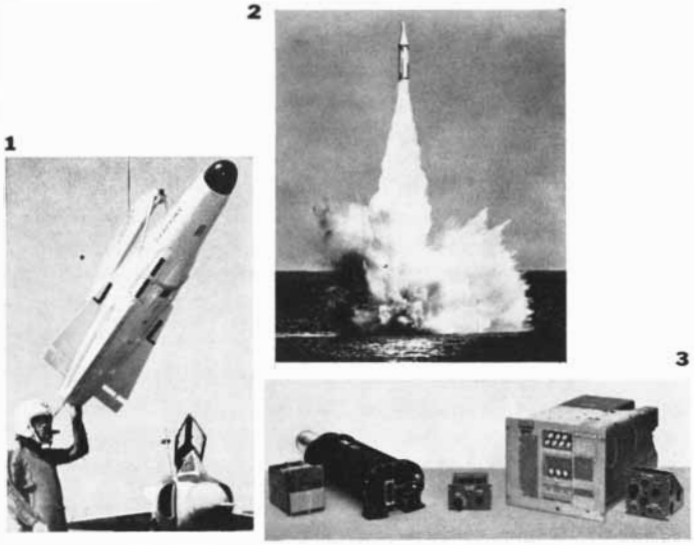
For the year 1960, Hughes saved $5.3 million through its Value Engineering Program. Conservative estimates show that a dollar invested in Value Engineering returns $13 at Hughes. Good news for taxpayers and buyers of Hughes commercial products, too.

Hughes was a pioneer in developing Value Engineering techniques and methods. Here, in the fast moving field of advanced electronics, Value Engineering helps insure the efficient, economical production of systems and components for both commercial and defense applications.

Advanced electronics is our business. Over 5,000 Hughes engineers constantly search for the best way to do jobs never done before—for new ways to do old jobs better. Your problem may be an opportunity for both of us.

We invite you to write for your free copy of our booklet on Value Engineering. Address inquiries to Hughes Aircraft Company, Value Engineering—General Office (K), Los Angeles 45, California.



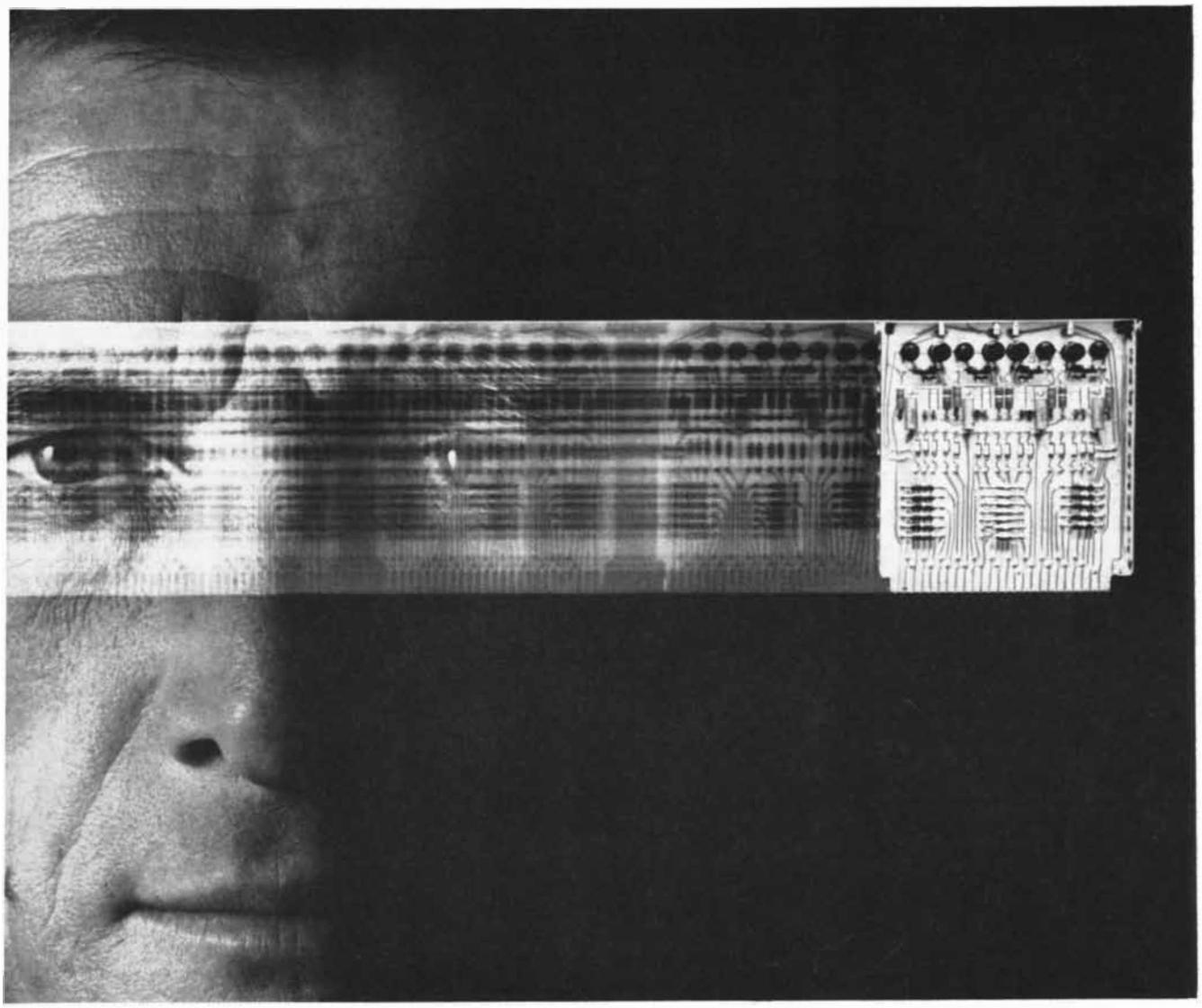


Thanks to Value Engineering, Hughes products deliver more for every dollar. (1) New Hughes Nuclear Falcon Missile. (2) Guidance Systems for the Navy's Sub-fired Polaris Missile. (3) Long Range Communications System for supersonic jets.

Creating a new world with electronics

HUGHES

Hughes Aircraft Company



THE AUTHORS

RONALD MELZACK ("The Perception of Pain") is assistant professor of psychology at the Massachusetts Institute of Technology and a member of the Research Laboratory of Electronics at that institution. He was born and raised in Montreal and received his B.S. and M.S. from McGill University in 1950 and 1951 respectively. After a year of research at the University of Chicago he returned to McGill, obtaining his Ph.D. in 1954. In the preceding year Melzack had read an article in SCIENTIFIC AMERICAN called "What Is Pain?" This led to correspondence with the author, W. K. Livingston, and to a fellowship in Livingston's laboratory at the University of Oregon Medical School. "My fellowship," Melzack writes, "was extended to permit me to spend three very happy years" at the laboratory. "They were years that had a profound influence on my thinking about pain, and about sensory perception in general." Melzack taught and studied abroad during the next two years, first as a visiting lecturer at University College London and then as a research fellow at the Institute of Physiology of the University of Pisa. He joined the faculty of M.I.T. in 1959.

MARGARET and GEOFFREY BURBIDGE ("Peculiar Galaxies") are respectively an astronomer and an astrophysicist on the staff of the University of Chicago's Yerkes Observatory at Williams Bay, Wis. The Burbidges, who are English, met and married while she was working at the University of London Observatory and he was studying meson physics. After Geoffrey Burbidge had received his Ph.D. from the University of London in 1951, he came to the Harvard College Observatory as an Agassiz Fellow, while his wife became a fellow at the Yerkes Observatory. In 1953 they returned to England, where he worked in the Cavendish Laboratory of the University of Cambridge. They joined the Yerkes Observatory in 1957.

MARJORIE B. ZUCKER ("Blood Platelets") is an associate member of the Sloan-Kettering Institute for Cancer Research and associate professor of physiology at the Cornell University Medical College. She received her B.A. from Vassar College in 1939. "One of my chief claims to fame there," she writes, "was to marry at the end of my junior year, which was much more unusual then than now." She acquired a Ph.D. in physiology at Columbia University in 1944 and until 1949 was a research assistant at Columbia's College of Physicians and Surgeons. Her initial work at Columbia involved research on the perfusion of organs and on hypertension. At the time "studies in both these areas were plagued by a potent vasoconstrictor substance that appeared during clotting or traumatization of blood." The presence of this active substance (later identified as serotonin) in blood platelets "led me to a study of the relationship of the release of serotonin to the various stages of blood clotting, and then on to other aspects of platelet physiology." She continued this research at the New York University College of Dentistry, and since 1955 at the Sloan-Kettering Institute.

WILLIAM H. STEIN and STANFORD MOORE ("The Chemical Structure of Proteins") are both professors of biochemistry on the faculty of the Rockefeller Institute, where they began to collaborate on the chemistry of proteins more than two decades ago. Stein, who took his B.S. at Harvard University in 1933, did graduate work in biochemistry under the direction of Edgar G. Miller and Hans T. Clarke at Columbia University, receiving his Ph.D. in 1937. He went to the Rockefeller Institute in 1939 to work in the laboratory of the noted biochemist Max Bergmann. Moore joined Bergmann's laboratory that year, having acquired a B.A. at Vanderbilt University in 1935 and a Ph.D. in organic chemistry at the University of Wisconsin in 1938. During World War II Stein remained at the Institute to work on problems connected with chemical warfare, while Moore served with the Office of Scientific Research and Development in Washington. They resumed their joint research in 1945.

V. V. BELOUSOV ("Experimental Geology") is head of the department of geotectonics at the Institute of the Physics of the Earth in Moscow. He was born in Moscow in 1906 and took his degree in geology at the Moscow State University in 1930. A corresponding member of the U.S.S.R. Academy of Sciences since 1953, Belousov is vice-president of the International Special Committee on Geological Co-operation and of the International Union of Geodesy and Geophysics, as well as a member of the Geological Society of America.

PETER SATIR ("Cilia") is a Graduate Fellow of the Rockefeller Institute.

when men must make large-scale decisions

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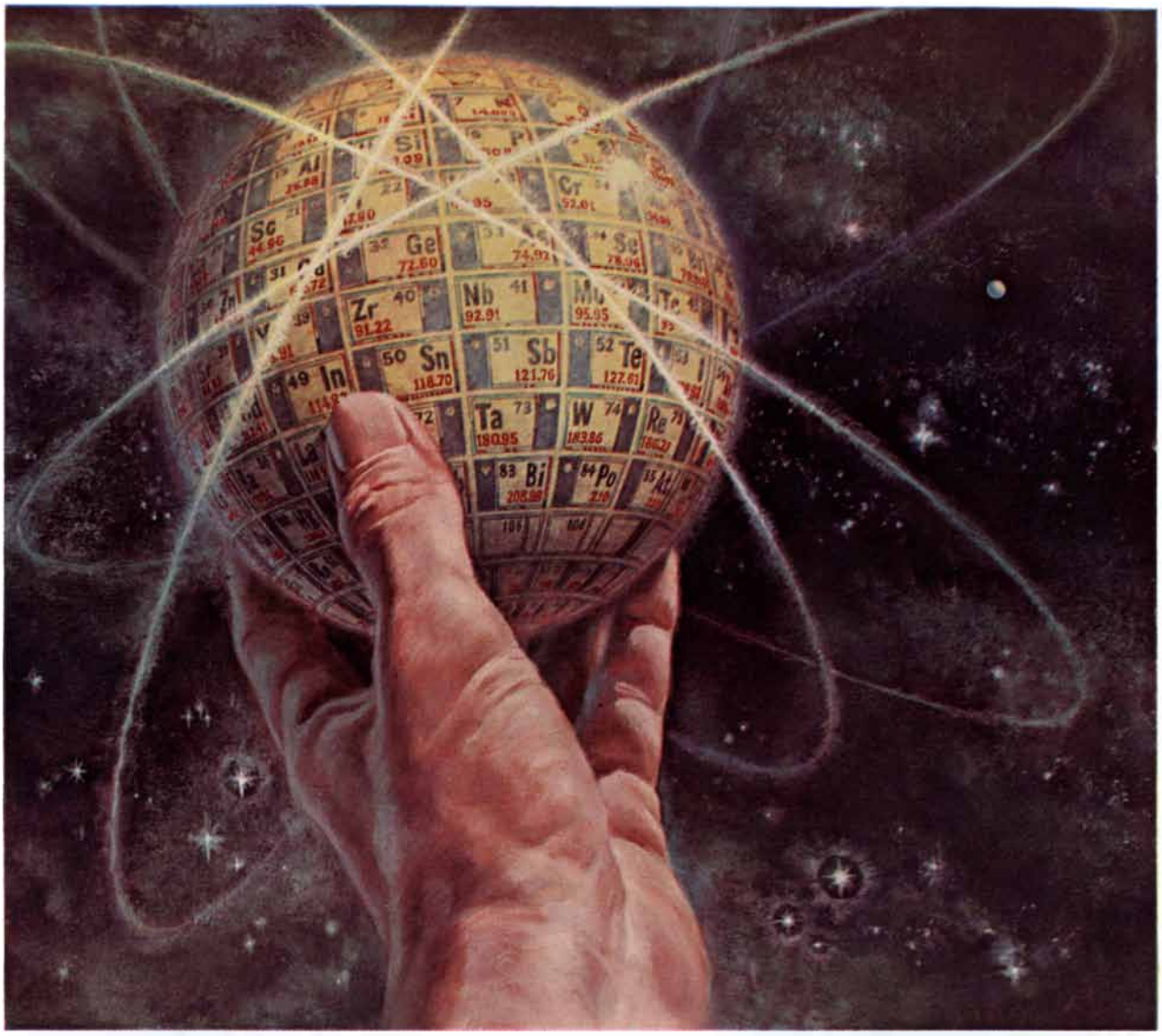
Born and raised in New York, Satir attended Columbia University, where he received his B.A. in 1956. He then spent the summer working with the Columbia physiologist Teru Hayashi at the Marine Biological Laboratory in Woods Hole, Mass. During that summer he was invited to continue his research at the Rockefeller Institute. In 1958 Satir went to the Carlsberg Foundation Biological Institute in Copenhagen to do research with Erik Zeuthen on problems of cell growth and cell division. At present Satir is working with Keith R. Porter of the Rockefeller Institute."

JOHN CHRISTIANSON ("The Celestial Palace of Tycho Brahe") holds a teaching assistantship in European history at the University of Minnesota, where he is currently working toward a Ph.D. degree. He was born in Mankato, Minn., 27 years ago and received a B.A. in history from Mankato State College in 1956. Following a year of study at the University of Copenhagen, Christianson went to Minnesota in 1957. He received his M.A. *in absentia* from that institution two years later (while serving with the U. S. Army) and returned there last September. He writes that "within the field of history I have leanings toward Danish history, the 16th century and the history of science. These three lines of interest cross at a point marked 'Tycho Brahe.' I am also interested in that part of the historian's job which consists of presenting man's past to people who are not primarily concerned with digging it up."

CHARLES E. LANE ("The Teredo") is professor of marine biology at the University of Miami. He was born in Riverton, Wyo., in 1909 and took three degrees at the University of Wisconsin, obtaining a Ph.D. in physiological zoology in 1935. Before he entered the Army Air Force in 1942 Lane had taught and done research at Wisconsin, the University of Wichita and Stanford University. From 1945 to 1949 he worked in the Special Products Division of the Borden Company, studying the biological synthesis of various substances produced by marine organisms. Since joining the faculty of Miami in 1949, he has investigated the general biology of the Portuguese man-of-war, the teredo and other wood-boring animals, and the natural history of the local land crab.

SIDNEY MORGENBESSER, who in this issue reviews Mario Bunge's *Causality: The Place of the Causal Principle in Modern Science*, teaches philosophy at Columbia University.



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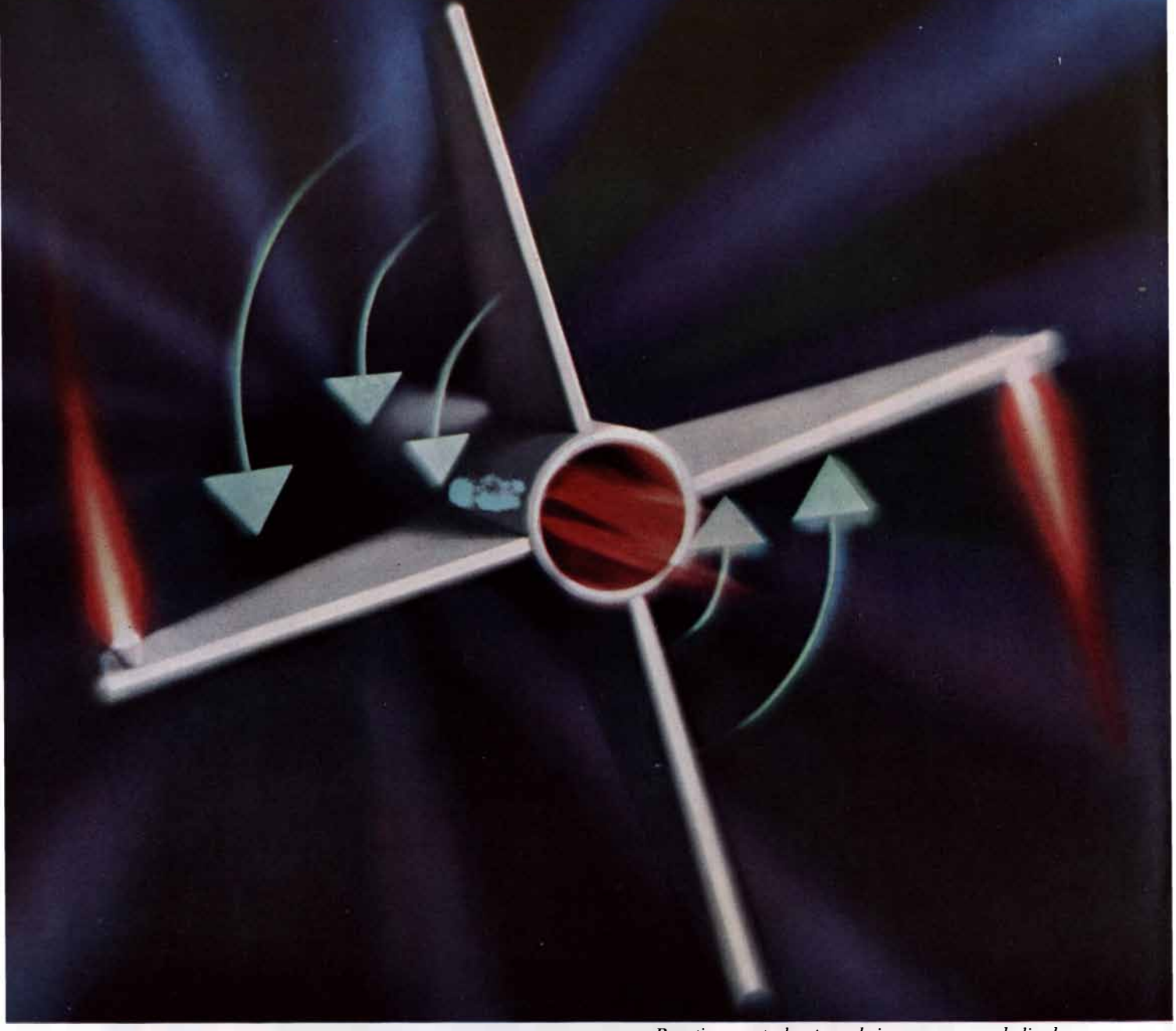

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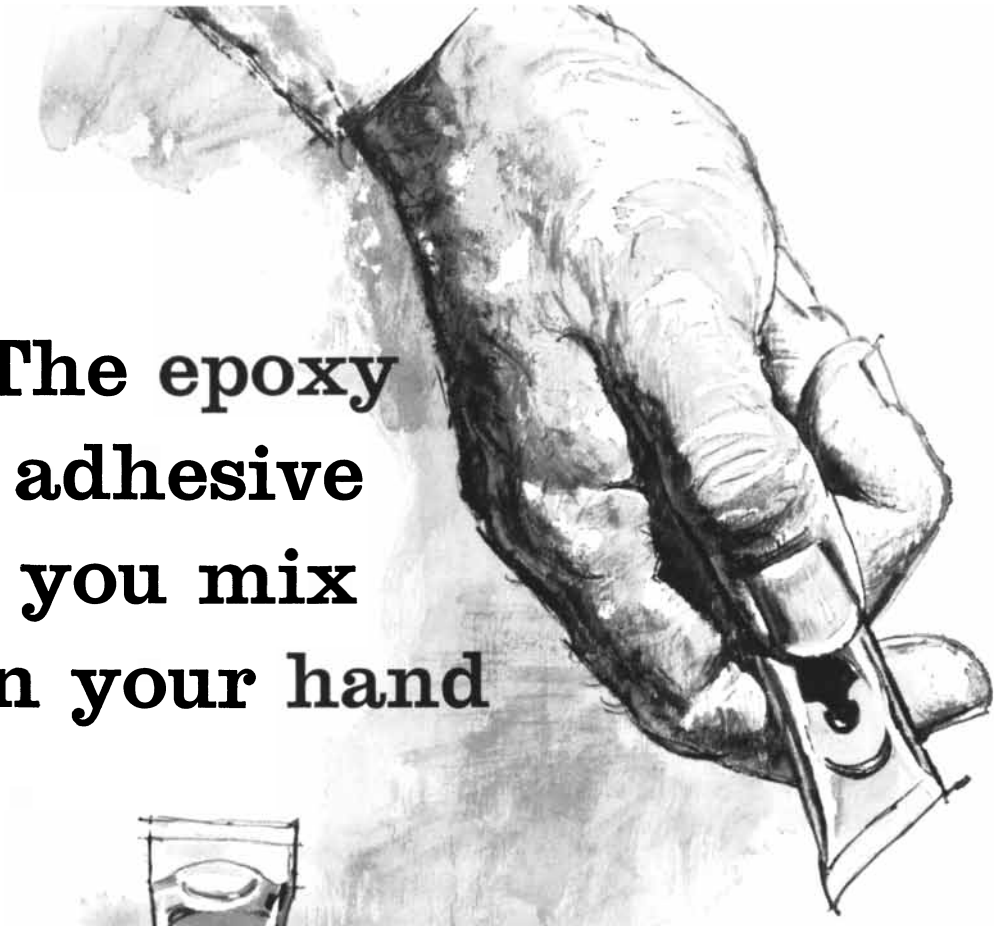

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Interaction of Electrons And Gases

The frequency and nature of interactions between electrons and gaseous atoms or molecules are only partially understood. Theory provides some understanding but at the same time the phenomena are so complex that they are beyond present mathematical techniques. Quantitative data in this field are essential to the further understanding of the upper atmosphere and to further developments in gas discharge devices. Physicists at Honeywell's Research Center are using new techniques to provide this information.

The presence of ions in the atmosphere was first noted over 50 years ago. An early clue was in the unexplained discharge of electroscopes. Imperfect solid insulation was assumed to be the trouble. This was not the case, however, as the electroscopes discharged through the atmosphere.

From time to time since then many contributions have been made to the field. The present renaissance of activity has been brought about by the intense interest in gas discharge tubes and the new importance of charged particles in the upper atmosphere.

The frequency of interactions between electrons and gaseous molecules depends upon the cross section which in turn is a function of the energy of the electron. Cross sections are not easily determined over the complete range of energies and there are many gaps in the data to date.

As we know, in an elastic collision the electron recoils from the gas atom, changing its direction of travel and losing at most a small fraction of its energy. An inelastic collision occurs when the electron loses part of its energy to the gas atom or molecule. It may be an ionizing collision whereby the electron releases an additional electron from the gas. Both electrons may accelerate, continuing the process, giving rise to a geometrically progressive increase called an "avalanche effect." This phenomenon occurs in a geiger tube.

Gases conduct currents because of the motion of electrical charges. These charges move either by diffusion due to the particle's own energy or mobility—the added force of an electrical field. Both types of motion depend on the interaction of charged particles with the gas.

The prediction of these interactions is complicated by various factors. For example, in elastic collisions the wave length of the electron may be comparable to the size of the atom. In inelastic collisions a large proportion of the energy is lost.

In one classical experiment a beam of electrons is directed through a tube containing gas molecules and the number of electrons getting to the other side is measured. The results of this experiment are relevant to the computation of the momentum transfer collision probability. However, this experiment gives no clue as to how much the electron has been deflected. A different experiment treats the electrons as a swarm but the resulting information represents an average over the electron energy. It is vital to know the cross section for each energy rather than an average.

A general knowledge of the behavior of electrons is needed before we can understand gas discharges. In particular, better and more complete determinations of cross sections over a wider range of energies are essential.

In studying inelastic collisions, Honeywell scientists will repeat earlier experiments using a retarding potential technique. At the same time they will independently observe the number of ions produced using a pulse technique. By doing this, they can determine the inelastic collision cross section or the probability of an electron having an inelastic collision. Using a shower technique, they will measure the total amount of ionization produced by electrons of a given energy. Cross sections obtained by this technique will extend the energy range so as to overlap the range of the retarding potential technique. Comparison of the two measurements will add to our knowledge of inelastic collision cross sections.

Getting the proper cross sections for each gas studied will enable scientists to fill gaps in their knowledge of gaseous electronics. It is conceivable that new information will be obtained on the structure of atoms. We will understand more about gaseous discharge phenomena, for example, the avalanche process in a photon sensing tube. In this case if we were to better understand the phenomena in a photon sensing tube it could lead to material improvements in these devices.

At present, the interactions between electrons and gas molecules occurring in the upper limits of the earth's atmosphere are incompletely understood. They have an effect on communications and the spreading of ionization from high altitude nuclear bombs. The knowledge that is gained in our laboratories may offer valuable assistance in understanding the events that occur at high altitudes and in solving the practical problems associated with space.

If you are engaged in scientific work relating to gaseous electronics and would like to know more about Honeywell's research in this field, you are invited to correspond with Dr. B. T. McClure or Dr. L. M. Chanin, Honeywell Research Center, Hopkins, Minnesota.

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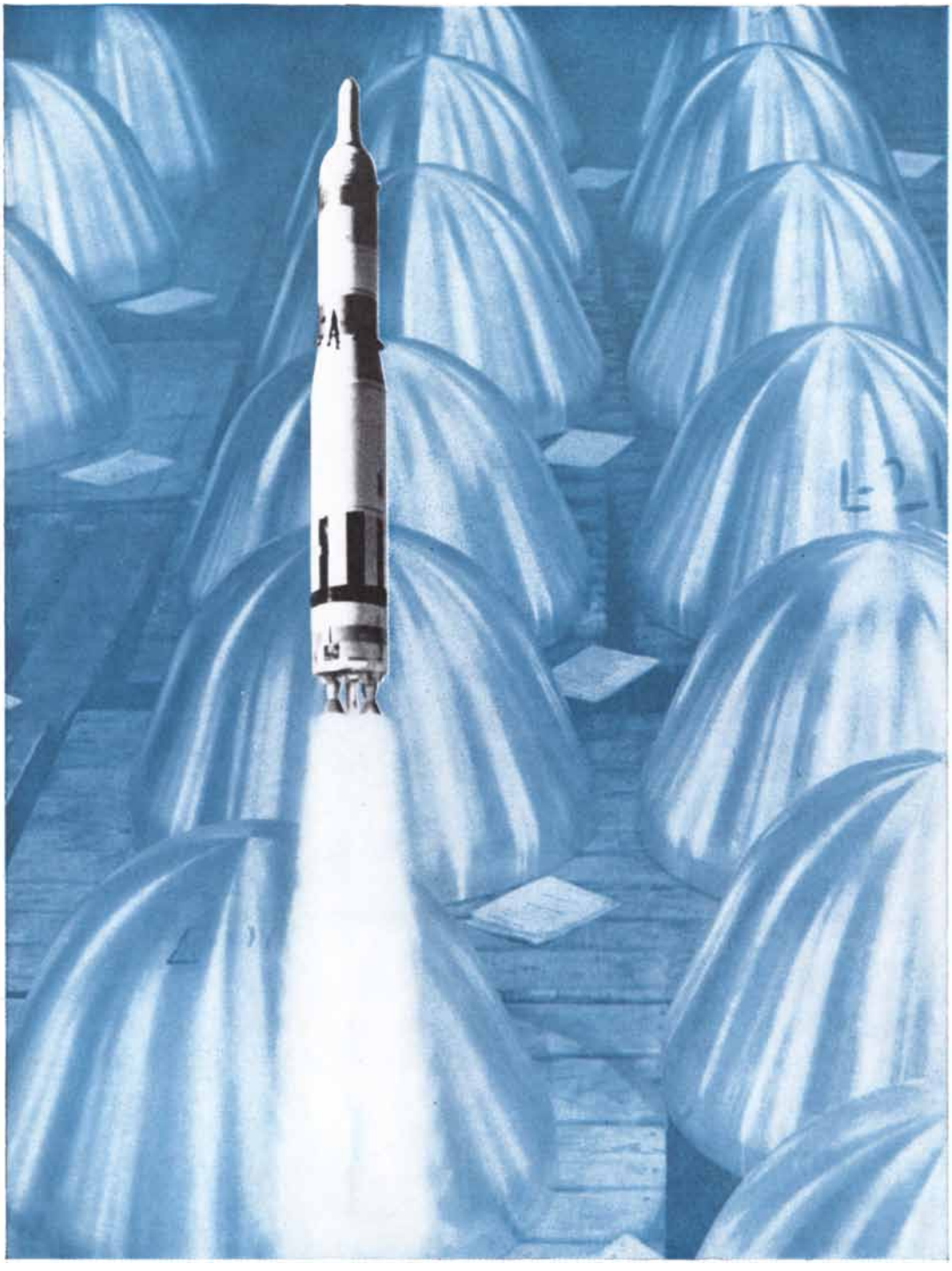

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John Stuart Mill...on method

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The Perception of Pain

Pain is not a fixed response to a hurtful stimulus. Its perception is modified by our past experiences, our expectations and, more subtly, by our culture

by Ronald Melzack

Even though pain is a private and personal experience, we rarely pause to define it in ordinary conversation. Indeed, no one who has worked on the problem of pain has ever been able to define pain to the satisfaction of all his colleagues. When compared with vision or hearing, for example, the perception of pain seems simple, urgent and primitive. We expect the nerve signals evoked by injury to "get through," unless we are unconscious or anesthetized. But experiments show that pain is not always perceived after injury even when we are fully conscious and alert. Thus a knowledge of pain perception goes beyond the problem of pain itself: it helps us to understand the enormous plasticity of the nervous system and how each of us responds to the world in a unique fashion.

A vast amount of study has been devoted to the perception of pain, especially in the last decade, and from it is emerging a concept of pain quite different from the classical view. Research shows that pain is much more variable and modifiable than many people have believed in the past. Moreover, direct recordings of nerve signals are helping us to see, in physiological detail, why pain is such a complex experience.

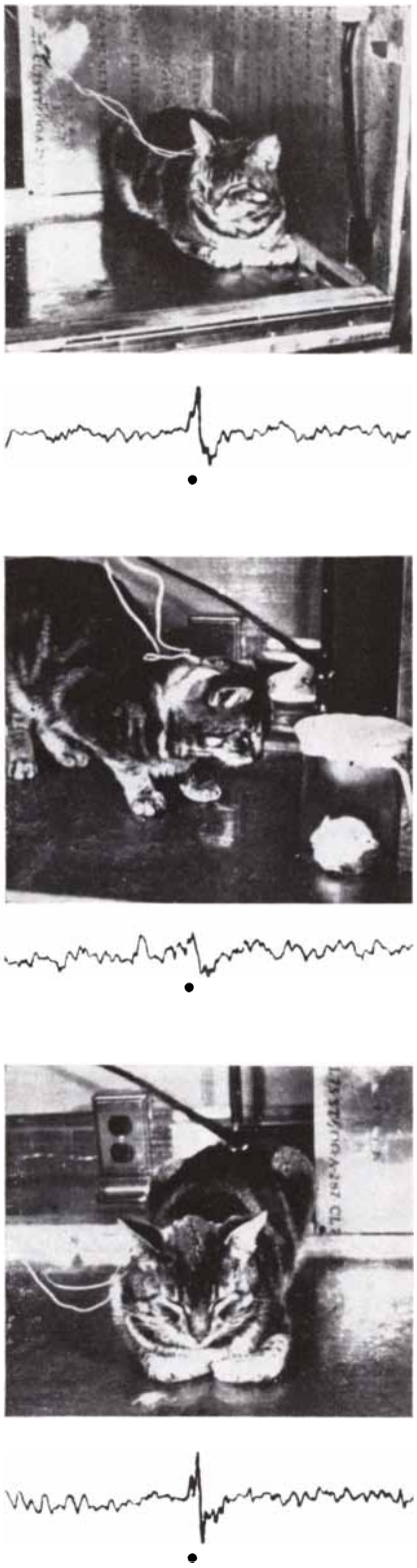
Anyone who has suffered prolonged, severe pain comes to regard it as an evil, punishing affliction that is harmful in its own right. Yet everyone recognizes the positive aspect of pain. It warns us that something biologically harmful is happening. The occasional reports of people who are born without the ability to feel pain provide convincing testimony on the value of pain. Such a person sustains extensive burns and bruises during childhood, frequently bites deep into his tongue while chewing food, and learns only with difficulty to avoid inflicting severe wounds on himself.

It is the obvious biological significance of pain that leads most of us to expect that it must always occur after injury and that the intensity of pain we feel is proportional to the amount and extent of the damage. Actually, in higher species at least, there is much evidence that pain is not simply a function of the amount of bodily damage alone. Rather, the amount and quality of pain we feel are also determined by our previous experiences and how well we remember them, by our ability to understand the cause of the pain and to grasp its consequences. Even the significance pain has in the culture in which we have been brought up plays an essential role in how we feel and respond to it.

In our culture, for example, childbirth is widely regarded as a painful experience. Yet anthropologists have observed cultures in which the women show virtually no distress during childbirth. In some of these cultures a woman who is going to have a baby continues to work in the fields until the child is about to be born. Her husband then gets into bed and groans as though he were in great pain while she bears the child. The husband stays in bed with the baby to recover from the terrible ordeal he has just gone through, and the mother almost immediately returns to attend the crops.

Can this mean that all women in our culture are making up their pain? Not at all. It happens to be part of our culture to recognize childbirth as possibly endangering the life of the mother, and young girls learn to fear it in the course of growing up. Books on "natural childbirth" ("childbirth without fear") stress the extent to which fear increases the amount of pain felt during labor and birth and point out how difficult it is to dispel it.

The influence of early experience on the perception of pain was demonstrated a few years ago in experiments my colleagues and I conducted at McGill University [see "Early Environment," by William R. Thompson and Ronald Melzack; SCIENTIFIC AMERICAN, January, 1956]. We raised Scottish terriers in isolation from infancy to maturity so that they were deprived of normal environmental stimuli, including the bodily knocks and scrapes that young animals get in the course of growing up. We were surprised to find that when these dogs grew up they failed to respond normally to a flaming match. Some of them repeatedly poked their noses into the flame and sniffed at it as long as it was present. If they snuffed it out, they reacted similarly to a second flaming match and even to a third. Others did not sniff at the match but made no effort to get away when we touched their noses with the flame repeatedly. These dogs



ATTENTIVE CAT (*middle*) **watching mouse in a jar presumably does not hear a click as loudly as when it is in repose** (*top and bottom*)**. Assumption is based on shape of nerve-signal recordings picked up by electrode implanted in auditory pathway. Clicks were sounded at the dots. This experiment was performed at the School of Medicine of the University of California at Los Angeles by Raúl Hernández-Peón and his associates.**

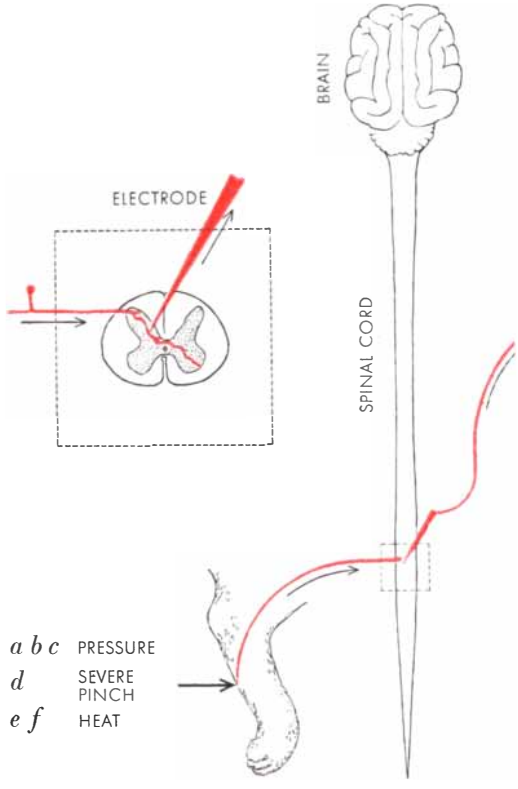
also endured pinpricks with little or no evidence of pain. In contrast, littermates that had been reared in a normal environment recognized potential harm so quickly that we were usually unable to touch them with the flame or pin more than once.

This astonishing behavior of dogs reared in isolation cannot be attributed to a general failure of the sensory conducting systems. Intense electric shock elicited violent excitement. Moreover, reflex movements made by the dogs during contact with fire and pinprick indicate that they may have felt something during stimulation; but the lack of any observable emotional disturbance, apart from reflex movements, suggests that their perception of actual damage to the skin was highly abnormal.

We have considerable evidence to show that people too attach variable meanings to pain-producing situations and that these meanings greatly influence the degree and quality of pain they feel. During World War II Henry K. Beecher of the Harvard Medical School observed the behavior of soldiers severely wounded in battle. He was astonished to find that when the wounded were carried into combat hospitals, only one out of three complained of enough pain to require morphine. Most of the soldiers either denied having pain from their extensive wounds or had so little that they did not want any medication to relieve it. These men, Beecher points out, were not in a state of shock, nor were they totally unable to feel pain, for they complained as vigorously as normal men at an inept vein puncture. When Beecher returned to clinical practice as an anesthesiologist, he asked a group of civilians who had just undergone major surgery and who had incisions similar to the wounds received by the soldiers whether they wanted morphine to alleviate their pain. In contrast with the wounded soldiers, four out of five claimed they were in severe pain and pleaded for a morphine injection.

Beecher concluded from his study that "the common belief that wounds are inevitably associated with pain, that the more extensive the wound the worse the pain, was not supported by observations made as carefully as possible in the combat zone." He goes on to say: "The data state in numerical terms what is known to all thoughtful clinical observers: There is no simple direct relationship between the wound per se and the pain experienced. The pain is in very large part determined by other factors, and of great importance here is the significance of the wound.... In the wounded soldier [the response to injury] was relief, thankfulness at his escape alive from the battlefield, even euphoria; to the civilian, his major surgery was a depressing, calamitous event."

The importance of the meaning associated with a pain-producing situation is made particularly clear in conditioning experiments carried out by the Russian physiologist Ivan Pavlov. Dogs normally react violently when they are given strong electric shocks to a paw. Pavlov found, however, that if he consistently presented food to a dog after each shock, the dog developed an entirely new response. Immediately after a shock the dog would salivate, wag its tail and turn eagerly toward the food dish. The electric shock now failed to evoke any responses indicative of pain and became instead a signal meaning that food was on the way. The dog's conditioned behavior persisted when Pavlov increased the intensity of the electric shocks and even when he supplemented them by burning and wounding the dog's skin. Jules H. Masserman of Northwestern University carried the experiment still further. After cats had been taught to



NEURON-FIRING PATTERNS, recorded from single cells in the spinal cord of a cat, show the initial response in the central nervous system to various stimuli applied to the cat's leg. Pattern *a* was caused by

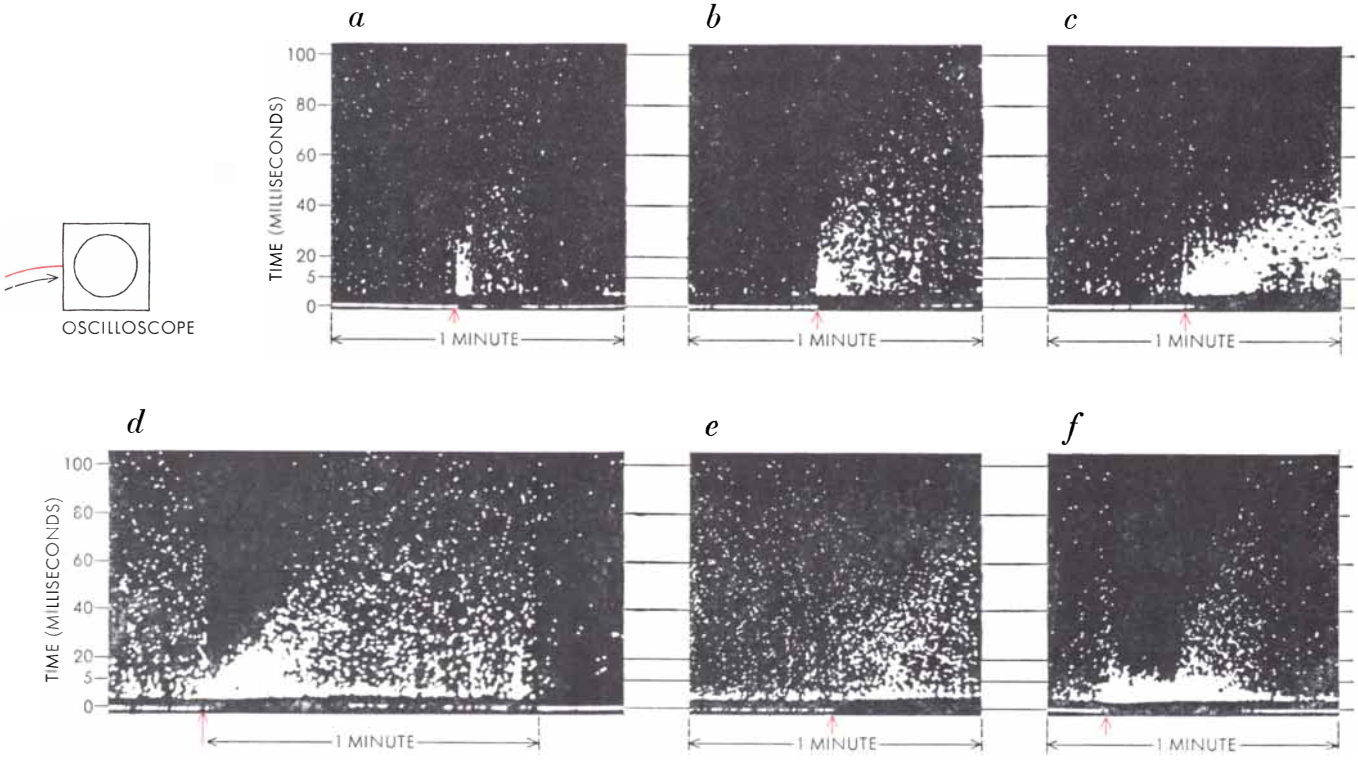
respond to electric shock as a signal for feeding, they were trained to administer the shock themselves by walking up to a switch and closing it.

It is well known that prize fighters, football players and other athletes can sustain severe injuries without being aware that they have been hurt. In fact, almost any situation that attracts intense, prolonged attention may diminish or abolish pain perception. Formal recognition of this fact has led to increasing medical interest in hypnosis. Like pain itself, the hypnotic state eludes precise definition. But loosely speaking hypnosis is a trance state in which the subject's attention is focused intensely on the hypnotist while attention to other stimuli is markedly diminished. Evidently a small percentage of people can be hypnotized deeply enough to undergo surgery entirely without anesthesia. For a larger number of people hypnosis reduces the amount of pain-killing drug required to produce successful analgesia.

If, however, the subject's attention is focused on a potentially painful experience, he will tend to perceive pain more intensely than he would normally. K. R. L. Hall and E. Stride in England found that the simple appearance of the word "pain" in a set of instructions made anxious subjects report as painful a level of electric shock they did not regard as painful when the word was absent from the instructions. Thus the mere anticipation of pain is sufficient to raise the level of anxiety and thereby the intensity of perceived pain. Similarly, experiments carried out by Harris E. Hill and his colleagues at the U. S. Public Health Service Hospital in Lexington, Ky., have shown that if anxiety is dispelled (by reassuring a subject that he has control over the pain-producing stimulus), a given level of electric shock or burning heat is perceived as significantly less painful than the same stimulus under conditions of high anxiety. Hill was also able to show that morphine diminishes pain if the anxiety level is high but has no demonstrable effect if the subject's anxiety has been dispelled.

The influence of psychological processes such as anxiety, attention and suggestion on the intensity of perceived pain is further demonstrated by studies of the effectiveness of placebos. Clinical investigators have found that severe pain (such as postsurgical pain) can be relieved in some patients by giving them a placebo, such as sugar solution or saline solution, in place of morphine or other analgesic drugs. About 35 per cent of the patients report marked relief from pain after being given a placebo. Since morphine, even in large doses, will relieve severe pain in only some 75 per cent of patients, one can conclude that nearly half of the drug's effectiveness is really a placebo effect. This is not to imply that people who are helped by a placebo do not have real pain; no one will deny the reality of postsurgical pain. Rather, it illustrates the powerful contribution of psychological processes to the perception of pain.

Taken together, the observations described so far indicate that the same injury can have different effects on different people or even on the same person at different times. A stimulus may be painful in one situation and not in another. How can we account for such variability in terms of what we know about the nervous system? First, we must recast the psychological facts into physiological terms. We must assume that



hanging a two-gram weight on a single hair; *b* shows effect of a 20-gram weight; *c* is effect of a mild pinch. All three stimuli start at arrows and continue for duration of the recording. In *d* the skin was severely pinched for one minute. In *e* and *f* a heat lamp was directed at the skin for 15 seconds after the arrows, raising the skin temperature four and 12 degrees centigrade respectively. Each dot in the recordings represents a single nerve impulse; height above base line represents time interval between recorded impulse and preceding one. These experiments were performed by Patrick D. Wall at Massachusetts Institute of Technology.

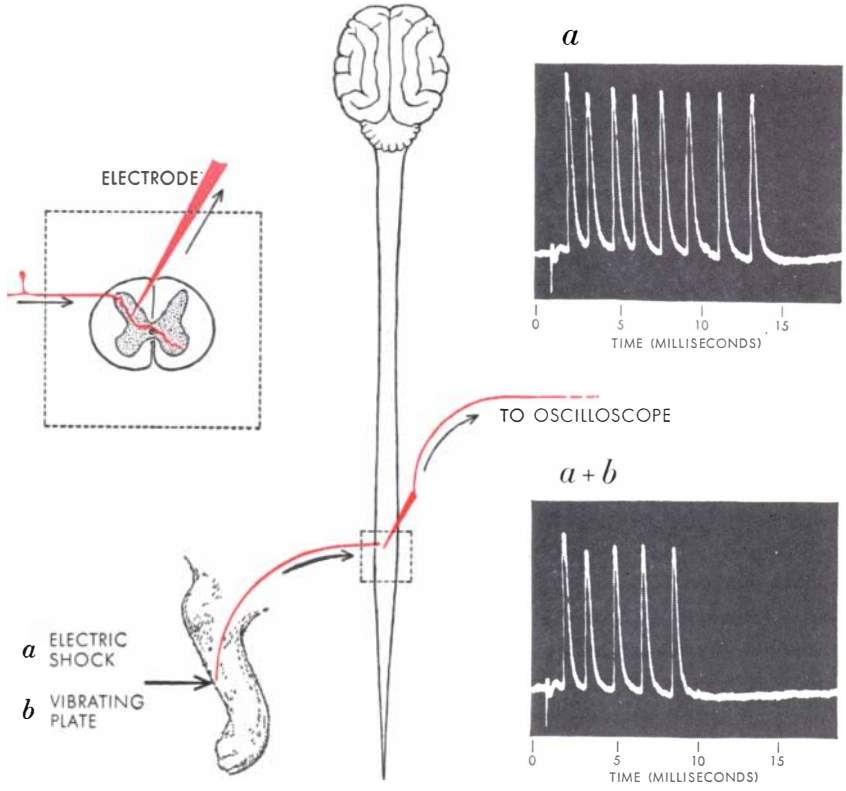
psychological processes such as memories of previous experiences, thoughts, emotions and the focusing of attention are in some way functions of the higher areas of the brain—that they represent the actual activities of nerve impulses. What the psychological data suggest, then, is that these higher brain functions are able to modify the patterns of nerve impulses produced by an injury. Remarkable evidence for such complex neural interplay has recently been observed in physiological laboratories.

When energy from the environment stimulates the skin, a message is transmitted along nerve bundles to the spinal cord of the central nervous system. Until recently it was believed that the message, once fed in, was relayed without interference direct to a particular area of the brain cortex; the arrival of the message at this cortical area produced the sensation of pain, touch, warmth or cold, depending entirely on the physical characteristics of the initial stimulus. We now know that this is only a part of the picture. Investigators in a number of countries have recently demonstrated the presence of systems of nerve fibers that run from the higher areas of the brain downward to make connection with the message-carrying nerve pathways in the spinal cord. Electrical activity induced in these higher brain areas is capable of suppressing or modifying the message; it may never get beyond the lower levels of the central nervous system or an entirely different message may reach the brain [*see illustration on opposite page*].

There is no longer any doubt that these message-modifying fibers exist; it has been found that electrical stimulation of widespread regions of the brain is able to modify the messages transmitted through every major sensory system. The origins and terminations of these message-controlling fibers have not yet been fully established. But even at this stage it is reasonable to speculate that the fibers provide the mechanism whereby higher brain activities such as memories, thoughts and emotions can modify the sensory messages after injury. We can assume, moreover, that this modification can occur throughout the entire axis of the central nervous system, at every junction at which nerve messages are relayed from one neuron to the next in the course of their ascent to the highest areas of the brain. If this view is right, we have a conceptual physiological model to account for the fact that psychological events play an essential role in determining the quality and intensity of the ultimate perceptual experience.

We may ask at this point: What is the nature of the sensory nerve signals or messages traveling to the brain after injury that permits them to be modified in the course of their transmission? Let us say we have burned a finger; what is the sequence of events that follows in the nervous system? To begin with, the intense heat energy is converted into a code of electrical nerve impulses. These energy conversions occur in nerve endings in the skin called receptors, of which there are many different types. It was once popular to identify one of these types as the specific "pain receptor." We now believe that receptor mechanisms are more complicated. There is general agreement that the receptors that respond to noxious stimulation are widely branching, bushy networks of fibers that penetrate the layers of the skin in such a way their receptive fields heavily overlap with one another. Thus damage at any point on the skin will activate at least two or more of these networks and initiate the transmission of trains of nerve impulses along bundles of sensory nerve fibers that run from the finger into the spinal cord. What enters the spinal cord of the central nervous system is a coded pattern of nerve impulses, traveling along many fibers and moving at different speeds and with different frequencies [*see illustration on preceding page*].

Before the nerve-impulse pattern can begin its ascent to the brain, a portion of it must first pass through a pool of short, densely packed nerve fibers that are diffusely interconnected. The fibers comprising these pools, found throughout the length of the spinal cord, are called internuncial neurons. It is in the course of transmission from the sensory fibers to the ascending spinal cord neurons that the pattern of signals may be modified. Patrick D. Wall of the Massachusetts Institute of Technology has been able to insert microelectrodes into single spinal cord neurons in cats and record the patterns of neural firing evoked when painful stimuli are applied to the skin. He has shown that these patterns of firing can be altered and limited in duration by subjecting the surrounding skin to a vibratory stimulus [*see illustration below*]. Wall has directly confirmed with human subjects that normally painful electric shocks and pinpricks are not perceived as painful when the surrounding skin is stimulated with a rapidly vibrating device.



MODIFICATION OF SENSORY MESSAGES can take place within the spinal cord under certain conditions. In experiment at left, performed by Wall, the long train of nerve impulses following a single shock (*a*) is shortened when the skin around the shocked region is simultaneously vibrated by a metal plate (*b*). In experiment at right an afferent nerve

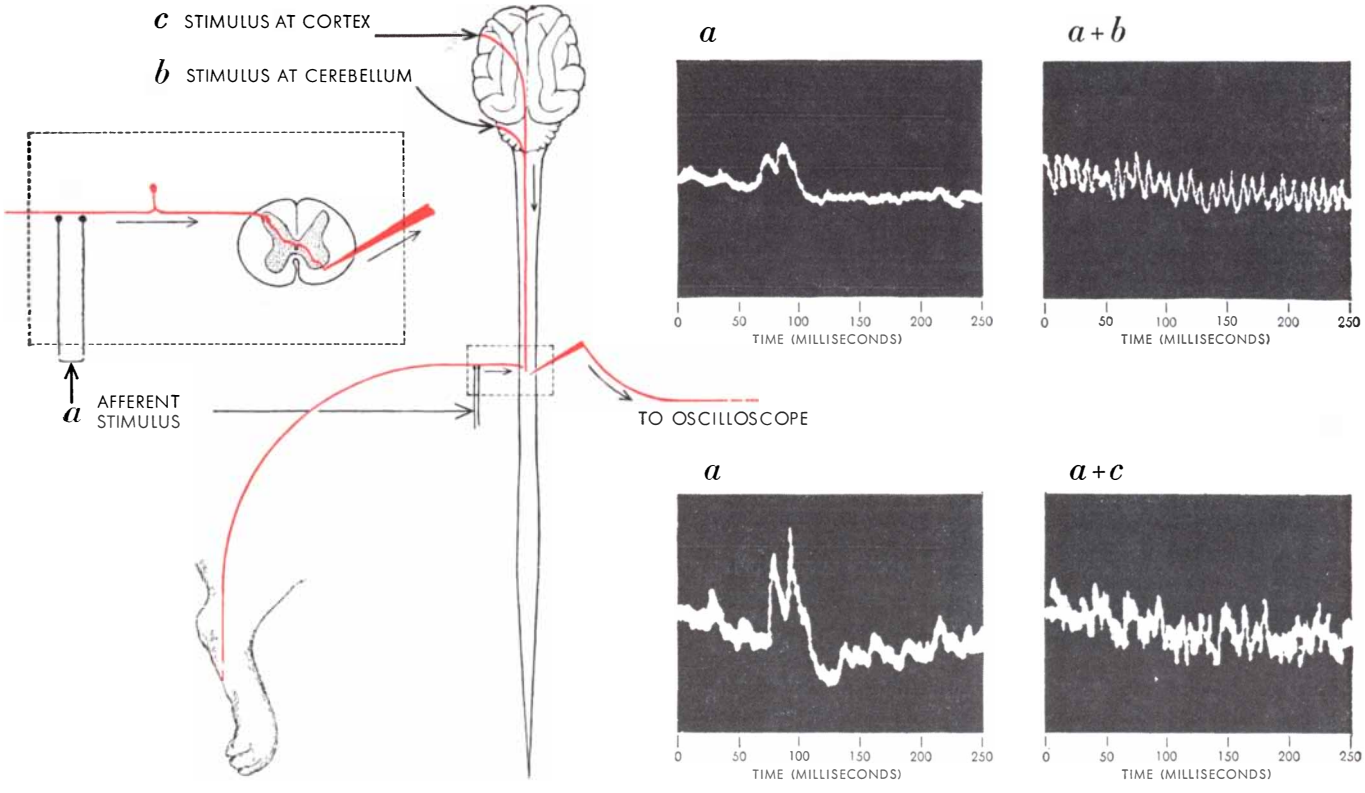
Once the sensory patterns or signals have entered the spinal cord neurons they are transmitted to the brain along nerve bundles that occupy the anterolateral (front and side) portions of the spinal cord. Many fibers belonging to these bundles continue to the thalamus, forming the spinothalamic tract. The majority of the fibers, however, penetrate a tangled thicket of short, diffusely interconnected nerve fibers that form the central core of the lower part of the brain. Out of this formation of "reticulated" cells there emerges a series of pathways, so that the sensory patterns now stream along multiple routes to the higher regions of the brain.

When I was working with W. K. Livingston at the University of Oregon Medical School, our group found that electrical impulses evoked by painful stimuli are transmitted through the lower part of the brain along five distinct routes [*see illustrations on next two pages*]. Three of them—the spinothalamic tract, the central tegmental tract and the central gray pathway—appear to represent major conduction systems for sensory pain patterns since their electrical activity is significantly depressed by analgesic agents (such as nitrous oxide) that are capable of abolishing the awareness of pain in human patients without similarly affecting vision and hearing. Analgesic drugs also produce a striking reduction in the electrical activity in the fourth region, the central core of reticulated cells, which has been shown by other investigators to have the role of arousing the whole brain into alert activity. The final pathway, a major sensory system called the lemniscal tract, plays an undetermined role in the total pain process since its transmission capacity is unaffected by anesthetic or analgesic drugs.

In order to determine the role played by these various ascending pathways in the perception of pain, we studied the behavior of cats in which some of the pathways had been selectively destroyed [*see illustration on page 49*]. We found that cats with lesions of the spinothalamic tract often failed to respond to normally painful stimuli, confirming earlier evidence that had demonstrated the importance of this pathway in the sensory pain process. But we found that it is not the only pathway involved. Cats with lesions in the central gray pathway also failed to respond to the stimuli. In contrast, cats with the lemniscal tract made inactive responded immediately to the stimuli.

To our surprise, the picture turned out to be even more complex than this. Lesions of the central tegmental tract had the opposite effect of making the cats excessively responsive to some kinds of painful stimuli, and many of these cats showed behavior suggesting "spontaneous pain" in the absence of external stimulation.

A recent development in the surgical control of pain in human patients lends striking confirmation to the results obtained in the cat study. Frank R. Ervin and Vernon H. Mark of the departments of psychiatry and neurosurgery at the Massachusetts General Hospital have found that patients suffering unbearable pain from cancer and other pathological sources may obtain excellent relief from pain after a small surgical lesion is made in that part of the human thalamus which receives fibers from the spinothalamic tract as well as from the pathways that stem from the reticular formation. If, however, the lesion is made just a few millimeters in front of this area, destroying the thalamic fibers of the lemniscal pathway, the experience of pain remains unchanged. Direct obser-



fiber entering the spinal cord is electrically stimulated directly (*a*). The signal passes through a pool of neurons and is recorded on the other side of the cord (whence it ascends to the brain), producing tracing *a*. If the cerebellum (*b*) or cortex (*c*) is stimulated simultaneously, the afferent signal is almost completely suppressed, as shown in tracings $a + b$ and $a + c$. These experiments were performed at the School of Medicine of the University of California at Los Angeles by K.-E. Hagbarth and D. I. B. Kerr.

STIMULATION OF BRAIN STEM impels a cat to rotate a paddle wheel that turns off the weak electric stimulus. The stimulus was turned on between top and middle photographs. The cat's quickly learned behavior has all the characteristics of pain avoidance. These are frames from a motion picture made by Neal E. Miller of Yale University.

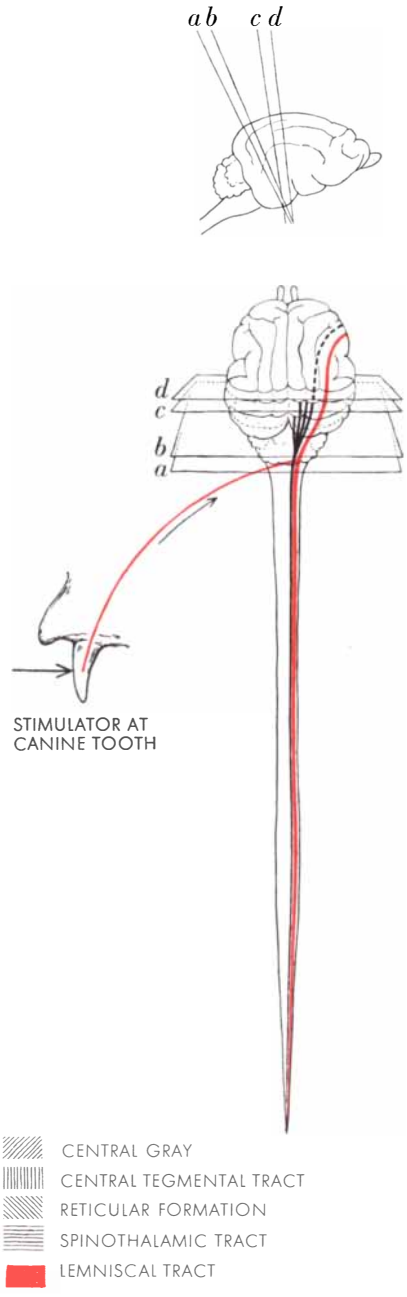
vations such as these on the sensory mechanisms of the pain process have provided us with valuable information on the nature of pain.

But we still cannot account for the complexity of many pain phenomena, especially bizarre pain syndromes sometimes encountered in hospital clinics. One in particular—phantom-limb pain—is both fascinating and terrible. In 1552 Ambroise Paré described it thus: "Verily it is a thing wondrous strange and prodigious, and which will scarce be credited, unless by such as have seen with their eyes, and heard with their ears, the patients who have many months after the cutting away of the leg, grievously complained that they yet felt exceeding great pain of that leg so cut off."

The majority of amputees report feeling a phantom limb soon after amputation and it may remain for years without bothering them. About 30 per cent, however, have the misfortune to develop pains in their phantom limbs, and in about 5 per cent the pain is severe. These pains may be occasional or continuous, but they are felt in definite parts of the phantom limb. W. K. Livingston reports the case of a young woman who described her phantom hand as being clenched, fingers bent over the thumb and digging into the palm of her hand, so that the whole hand became tired and painful. When she was able to open her phantom hand as a result of her physician's treatment, the pain vanished.

Phantom-limb pain tends to decrease and eventually disappear in most amputees. There are a few, however, for whom the pain increases in severity over the years. In addition, the disturbance spreads and other regions of the body may become so sensitized that merely touching them will evoke spasms of severe pain in the phantom limb. Even emotional upsets such as seeing a disturbing film may sharply increase the pain. Still worse, the conventional surgical procedures, such as cutting the spinothalamic tract, usually fail to bring permanent relief, so that these patients may undergo a series of such operations without any decrease in the severity of the pain. Phenomena such as these defy explanation in terms of our present physiological knowledge. A few psychiatrists have been tempted simply to label these amputees as neurotic, but the evidence argues against such an explanation for all cases.

So far we can only speculate on the nature of phantom-limb pain. We know that irritation of the nerves of the remaining part of the limb contributes to the pain process, since stimulation of these nerves can trigger severe pain. But the spread of the trigger sites and the frequent failure of conventional surgical procedures make it clear that this is not the whole story. All the evidence suggests that the primary focus of physiological disturbance lies in the central nervous system itself. Livingston believes that the initial damage to the limb, or perhaps the trauma associated with its removal, disturbs the patterning of neural activity in the internuncial pools of the spinal cord, creating reverberating, abnormally patterned activity. Even minor irritations to the skin or nerves near the site of the operation can then feed into these active pools of neurons and keep them in an abnormal, disturbed state over periods of years. Im-

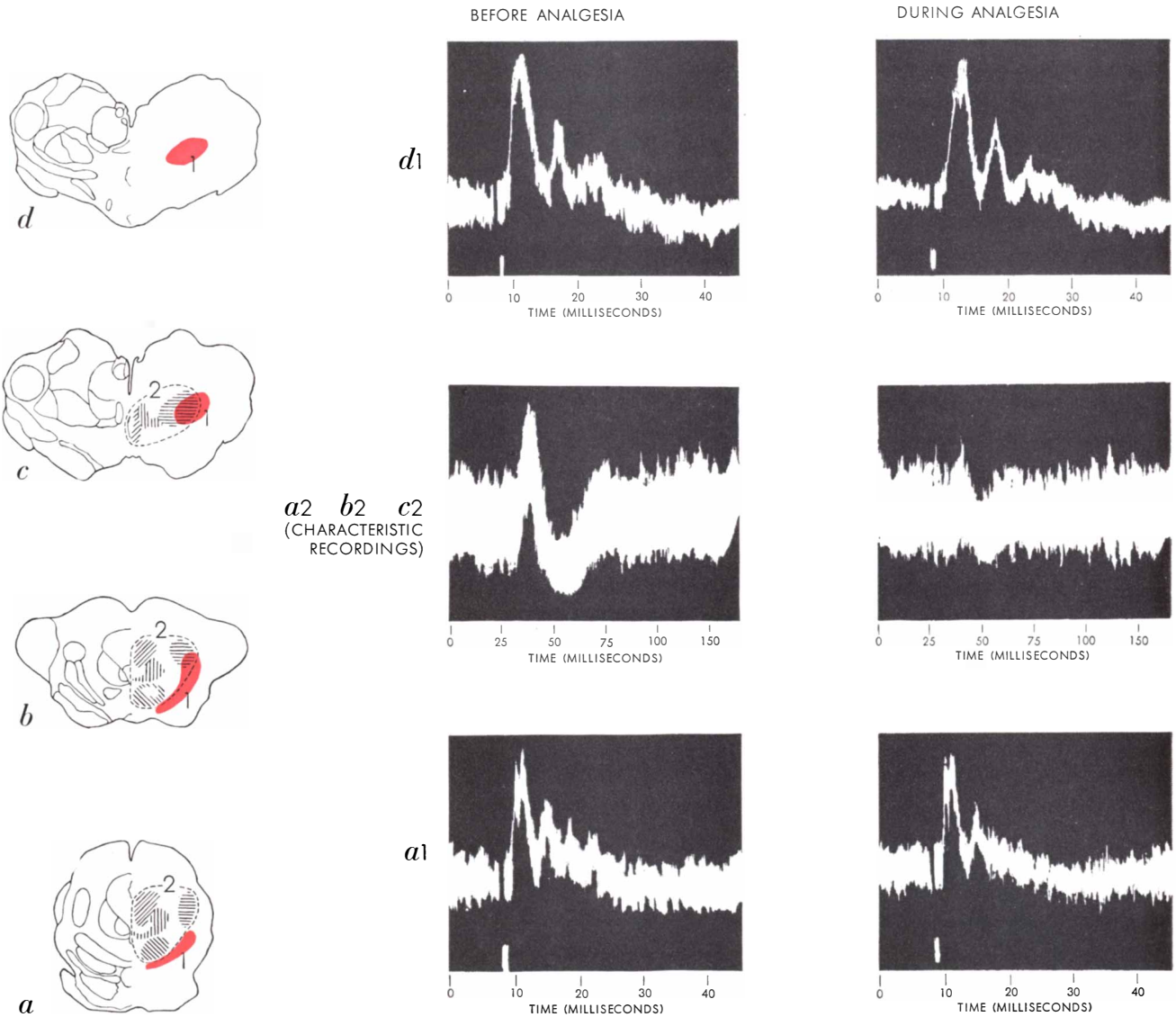


pulse patterns that would normally be interpreted as touch may now trigger these neuron pools into greater activity, thereby sending volleys of abnormal patterns of impulses to the higher areas of the brain and bringing about the perception of pain. Although there is no direct evidence that the internuncial pools play this role in phantom-limb pain, the concept helps us to understand facts that are otherwise difficult to explain.

So far we have been discussing pain primarily as a sensory experience somewhat similar to sight or hearing. But there is something missing. Pain has a unique, distinctly unpleasant quality that wells up in consciousness and obliterates anything we may have been thinking or doing at the time. It becomes overwhelming and demands immediate attention. Pain has a strong emotional quality that drives us into doing something about it. We seek desperately to stop the pain as quickly as we can by whatever means we can.

Introspectionist psychologists at the turn of the century made a sharp distinction between the sensory and the emotional, or affective, dimensions of pain. The psychologist Edward B. Titchener was convinced that there is a continuum of *feeling* in conscious experience, distinctly different from sensation, that ranges through all the degrees of pleasantness and unpleasantness. "The pain of a toothache," Titchener wrote, "is localized at a particular place, 'in the tooth'; but the unpleasantness of it suffuses the whole of present experience, is as wide as consciousness. The word 'pain' . . . often means the whole toothache experience."

These two dimensions, the sensory and the affective, are brought clearly into focus by clinical studies on prefrontal lobotomy, a neurosurgical operation for intense pain in which the connections between the prefrontal lobes and the rest of the brain are severed. Typically these patients report after the operation that they still have pain but it does not bother them; they simply no longer care about the pain and often forget it is there. When they are questioned more closely, they frequently say that they still have the "little" pain, but the "big" pain, the



FIVE PATHWAYS in the brain stem transmit signals evoked by stimulating the nerve of a cat's tooth. The sections *a*, *b*, *c* and *d* show how the pathways progress through the midbrain and thalamus; two of the pathways, the spinothalamic and lemniscal, send projections to the cortex [*see also illustration on next page*]. An analgesic mixture of nitrous oxide and oxygen largely blocks the signals in four (*2*) of the five pathways. The signal is not blocked, however, in the lemniscal pathway (*1*), which projects to the cortex. These experiments were performed by D. I. B. Kerr, Frederick P. Haugen and the author at the University of Oregon Medical School.

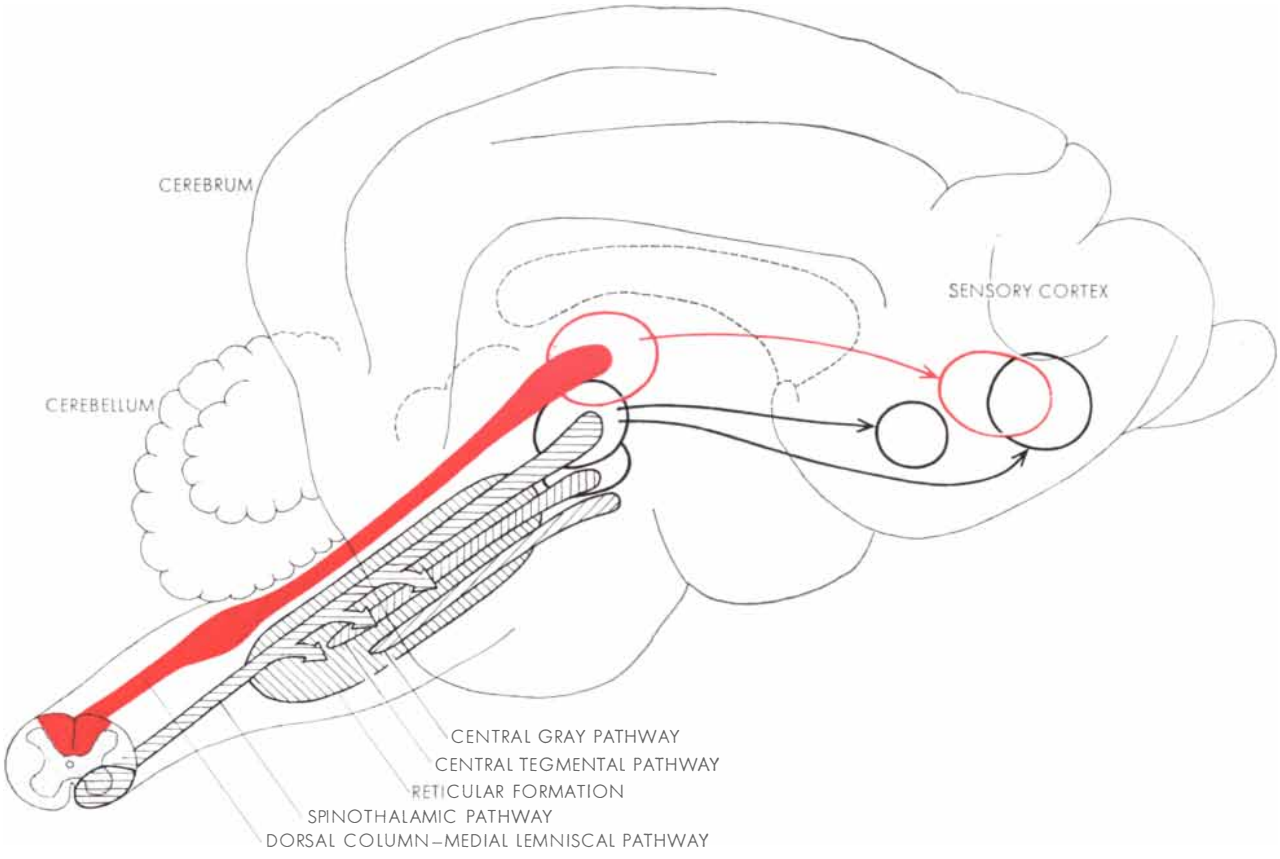
suffering, the anguish are gone. Yet they complain vociferously about pinprick and mild burn. It is certain that the operation does not stop pain perception entirely, since the sensory component is still present. Its predominant effect appears to be on the emotional coloring of the total pain experience; the terribly unpleasant quality of the pain has been abolished.

How are we to account for these effects? It is known that prefrontal lobotomy lowers the anxiety associated with pain to a striking degree: the fear of death is greatly diminished as well as the patient's preoccupation with his painful disease. It is often suggested that the reduction of anxiety brings about a concomitant reduction of pain intensity; specifically that the brain's prefrontal lobes, which are presumably involved in higher psychological processes, fail to elaborate the sensory nerve patterns as they ascend from the source of the pain. Such an explanation is consistent with the perceptual approach to pain that we have been discussing.

But is it only this? The emotional quality of the pain experience and its remarkable capacity for acting as a drive are both so different from touch, warmth or cold that to explain its psychological and neural basis seems to require something more than different patterns of nerve impulses arriving at the higher sensory areas of the brain. We might infer that distinctly different parts of the brain are involved in addition to the sensory areas.

Where, then, do the streams of sensory nerve impulses go after they are transmitted through the lower portions of the brain? We know that the spinothalamic tract has a relay station in the thalamus and there is good evidence that at least a portion of its impulse patterns is transmitted upward to the sensory cortex. The central gray neurons and the central tegmental tract, however, make connection with other neural systems, so that impulse patterns produced by painful stimuli have access to large areas of the brain that lie beneath the cortex.

Various experiments suggest that some of these subcortical areas are particularly concerned with the "driving" or motivating aspects of behavior. Neal E. Miller and other investigators at Yale University have used implanted electrodes to make a systematic exploration of areas deep within the brains of cats and other animals. When certain areas are stimulated, the animals cry out and behave exactly as if they were in pain [*see illustration on page 46*]. To call these areas "pain centers" would be misleading, since the evidence we have been discussing points to a complex interaction of sensory and cognitive processes involving other major portions of the brain. But there can be little doubt that these subcortical areas make a major contribution to the total pain process. Is it possible that the activities in these areas provide the neural substrate for the affective, "driving" component of pain perception? There is great temptation to speculate that they do—but in fact we do not know. All we can say for the present is that the ascending sensory patterns arouse activities in the brain that somehow subserve the broad category



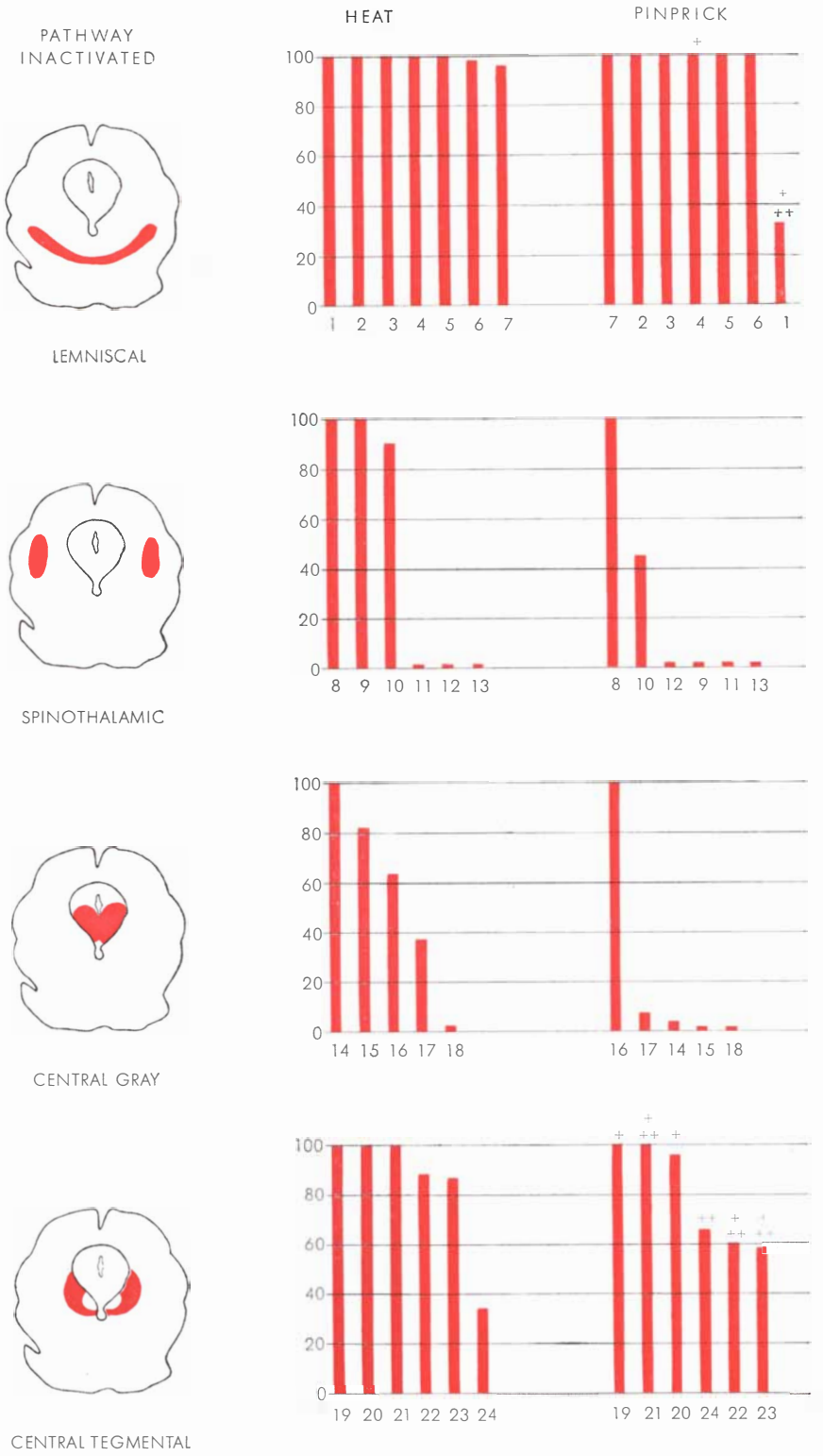
SIGNALS REACH THE CORTEX via projections from at least two of the five pathways ascending through the brain stem: the spinothalamic and the dorsal column–medial lemniscal pathways. Fibers from the former also penetrate the brain stem reticular formation, which is capable of arousing the whole cortex into activity. Surgical experiments [*see illustration on opposite page*] and analgesia experiments, suggest that pain perception is associated least with signals reaching cortex from lemniscal pathway.

of perceptions we describe as "pain."

It is now almost eight years since W. K. Livingston attempted to answer in these pages the question "What Is Pain?" [see SCIENTIFIC AMERICAN; March, 1953]. He argued against the classical conception that the intensity of pain sensation is always proportional to the stimulus. He proposed instead that pain, like all perceptions, is "subjective, individual and modified by degrees of attention, emotional states and the conditioning influence of past experience." Since that time we have moved still further away from the classical assumptions of specific "pain receptors," "pain pathways" and a "pain center" in the brain, all of which implied that stimulation of a "pain receptor" will invariably produce pain, that the pain will have only one specific quality and that it can vary only in intensity.

Pain, we now believe, refers to a category of complex experiences, not to a single sensation produced by a specific stimulus. In her essay "On Being Ill" Virginia Woolf touches on precisely this point. "English," she writes, "which can express the thoughts of Hamlet and the tragedy of Lear, has no words for the shiver and the headache.... The merest schoolgirl, when she falls in love, has Shakespeare and Keats to speak for her; but let a sufferer try to describe a pain in his head to a doctor and language at once runs dry."

We are beginning to recognize the poverty of language for describing the many different qualities of sensory and affective experience that we simply categorize under the broad heading of "pain." We are more and more aware of the plasticity and modifiability of events occurring in the central nervous system. We are aware that in the lower part of the brain, at least, the patterns of impulses produced by painful stimuli travel over multiple pathways going to widespread regions of the brain and not along a single path going to a "pain center." The psychological evidence strongly supports the view of pain as a perceptual experience whose quality and intensity is influenced by the unique past history of the individual, by the meaning he gives to the pain-producing situation and by his "state of mind" at the moment. We believe that all these factors play a role in determining the actual patterns of nerve impulses ascending to the brain and traveling within the brain itself. In this way pain becomes a function of the whole individual, including his present thoughts and fears as well as his hopes for the future.



SURGICAL INACTIVATION OF BRAIN STEM PATHWAYS gives added evidence of complexity of pain perception. The surgery was performed on cats that had been trained to jump out of a box to avoid having their paws pricked or burned. Brain sections at left indicate the pathways inactivated in various animals. After surgery the animals were retested. The code number of each animal appears at the bottom of the bar graphs. Height of bar indicates percentage of avoidance responses when paws were pricked or heated. The marks + and ++ indicate, respectively, animals that became hyperresponsive to pain or that gave evidence of "spontaneous" pain. Inactivation of the spinothalamic and central gray pathways reduced the behavioral evidence of pain; inactivation of the lemniscal path had little or no effect. Inactivation of the central tegmental pathway seemed to heighten pain sensitivity.

PECULIAR GALAXIES

Most galaxies are spiral, spherical or ellipsoidal aggregations of stars, but some have irregular configurations. These unusual objects may very well be galaxies in an early stage of evolution

by Margaret and Geoffrey Burbidge

The observable matter in the universe appears to aggregate in units that can be arranged in a hierarchy of sizes. Stars, taken as the fundamental unit, typically have diameters of 10^{11} centimeters (a million kilometers). One next observes clusters of stars with diameters of 10^{20} centimeters (100 light-years). Stellar clusters are a prominent feature of spiral galaxies such as our own, which have dimensions of the order of 10^{23} centimeters (100,000 light-years). The galaxies themselves are gathered in clusters that may contain a few galaxies or many thousands and measure up to 10^{25} centimeters (10 million light-years) across. Whether there are clusters of clusters remains uncertain at this time. The ultimate hierarchical unit is of course the universe, the radius of which is 10^{28} centimeters, or 10 billion light-years.

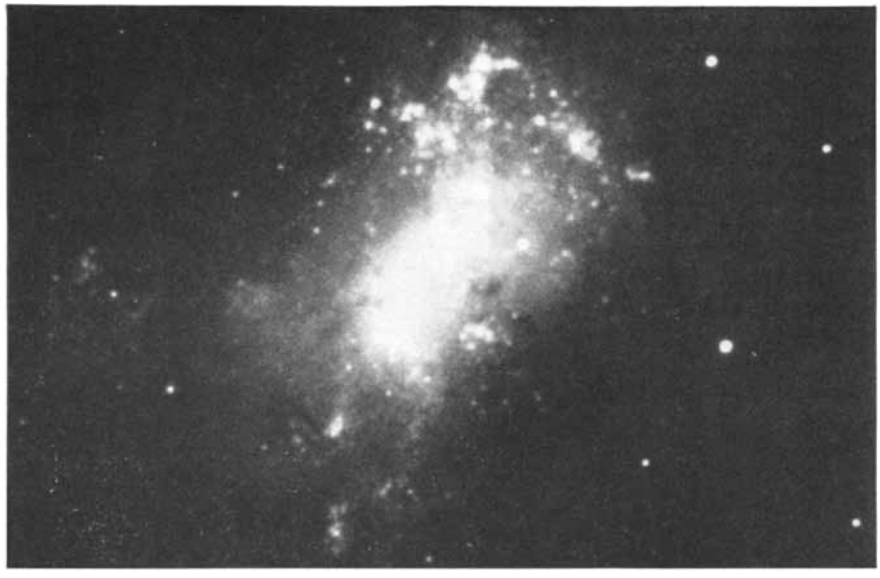
To explain how these aggregations came to be is the task of the astronomer and cosmologist. Stars are formed out of interstellar gas and dust. Although there is much evidence that this is still going on in regions of our own galaxy such as the Great Nebula in Orion, theories about how it takes place are still rudimentary. Once a star has become hot enough for thermonuclear reactions to occur within it, its evolution can be predicted quite well, at least up to the point where the star becomes a red giant.

Presumably star clusters form in the condensation of large interstellar clouds. It is postulated that by an analogous process the galaxies and clusters of galaxies condensed—and may now be condensing—from matter diffusely spread throughout the universe. But when it comes to these larger units in the cosmic hierarchy, the data are uncertain and cosmologists are divided.

Of all the possible cosmologies only two broad types have been worked out in any detail, and at present theories about the formation of galaxies must stay within these two frameworks. For one category of cosmological models the universe can be thought of as originating in a gigantic explosion at the instant of creation. These are called evolutionary cosmologies, because they assume a universe that has changed radically since the time of its origin. In such a universe all the galaxies would have been formed at an early stage. Against this view is opposed the steady-state cosmology, which holds that the universe has always had a constant density—its expansion is balanced by the genesis of new matter and the new matter continues to condense into new clusters of new galaxies.

To the meager body of available astronomical evidence there has recently been added a set of observations that supports the idea that galaxies and clusters of galaxies are now being formed. The Soviet astronomer B. A. Vorontsov-Velyaminov, in a systematic search of the sky-survey plates made with the 48-inch Schmidt telescope on Palomar Mountain, has assembled a catalogue of "irregular," multiple and otherwise peculiar galaxies visible from the Northern Hemisphere. His catalogue lists several hundred of them.

For the past two years the authors have been using the 82-inch reflecting telescope of the W. J. McDonald Observatory at the University of Texas to study some of these galaxies. Our investigations suggest that many peculiar galaxies are galaxies in the earliest stage of evolution and so perhaps still in the process of formation. Analysis of clusters



IRREGULAR GALAXY, NGC 4449, is studded with luminous spots that appear to be great patches of ionized hydrogen containing hot stars. It is very likely a young galaxy.

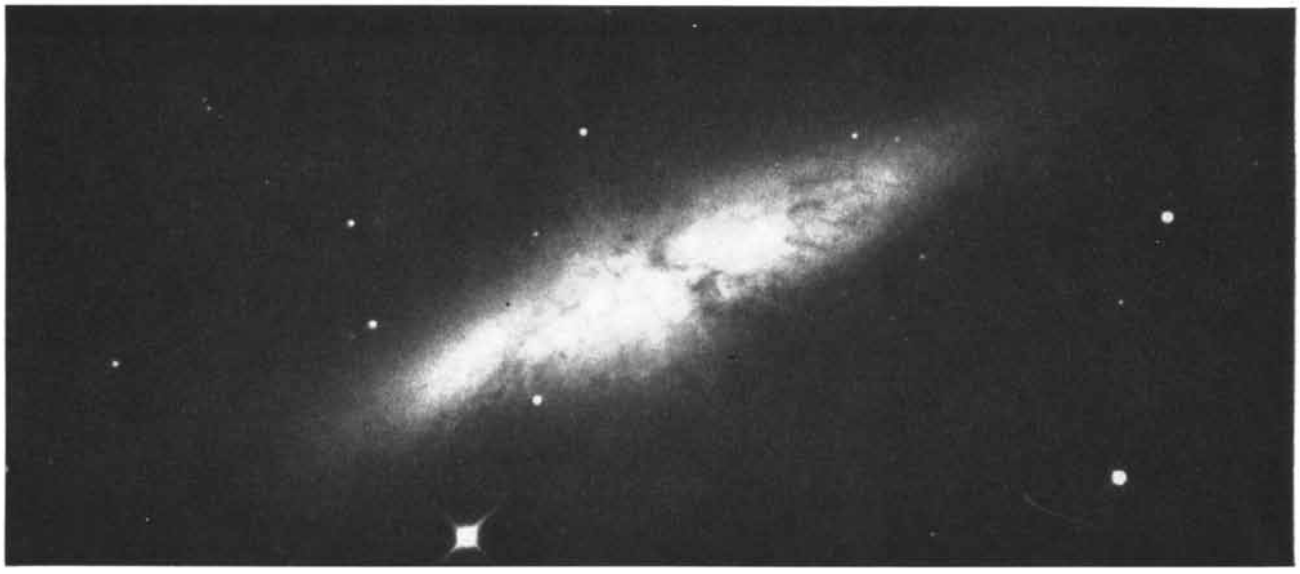
in which such galaxies occur indicates that the clusters too are much younger than the universe. These observations are few and preliminary and even further studies giving the same result would not of themselves provide a basis for choice between an evolutionary and a steady-state cosmological model. The observations, in fact, raise difficulties for both schools.

In the first place, it is difficult to explain how galaxies can condense out of intergalactic matter if it is thinly diffused throughout space. (The matter may, for example, be condensed into cold lumps that are invisible from the earth.) Thinly diffused intergalactic material may be very hot or very cold. If it is cold, it will consist of un-ionized atoms and molecules and perhaps some dust, in which case it might absorb or scatter light and show some observable effects. If it is hot, then it must be ionized; that is, the atoms must be dissociated into their component nuclei and electrons. In this case it would have a negligible absorbing or scattering effect upon light from distant parts of space. In either case it is so thin that it has so far escaped observation. Apart from the bridges of luminous material that join a few pairs of galaxies, there is only indirect evidence for the existence of intergalactic matter. This is based upon computation of the mean density of matter in the universe, and the computation in turn depends upon the distance scale of the universe and the cosmological model used. Present ideas suggest that this density is of the order of one atom per 100,000 cubic centimeters of space. For the universe as a whole, however, this represents a mass of material so great that no more than 1 per cent of it has ever formed into galaxies.

Such a low density in the intergalactic gas raises no difficulties for evolutionary cosmology. In the first epochs after the explosive moment of creation the average density of the universe would have been far higher than it is today. Under these conditions density presents no problem in explaining the origin of galaxies. But a corollary of such an explanation must be that the galaxies are nearly as old as the universe and that the clusters have sufficient inherent stability to have endured for a corresponding length of time. Until recently neither assumption has been questioned. Actually the evolutionary cosmology has had to withstand a quite different test. Recent observations and calculations have suggested that stars in our own galaxy and some of the chemical elements are older than the age of the universe as estimated from the expansion rate. For example, calculations of stellar evolution made by Fred Hoyle of the University of Cambridge indicate that the rich star cluster Messier 67 has an age of about nine billion years, and a class of old stars, typified by Delta Eridani (a star quite near the sun), was found to have an age of 15 billion years. Similarly, calculations by Hoyle, William A. Fowler of the California Institute of Technology and ourselves originally found an age of eight billion years for the elements, based upon the observed abundances and decay rates of the isotopes thorium 232, uranium 235 and uranium 238. A revised calculation has increased this age to about 15 billion years with an uncertainty of several billion years.

How does this compare with the expansion age of the universe? The expansion age can be calculated from the present-day rate of expansion and the correct cosmological model. Most models will give an age that is less than $1/H$, where H is the Hubble constant, or expansion rate. Allan R. Sandage of the Mount Wilson and Palomar Observatories has currently estimated $1/H$ to be about 13 billion years, giving an expansion age of eight billion years with the cosmological model that he uses. Though this may be modified by future work, at present all indications point to an age of the order of 10 billion years. Thus current arguments suggest that all of these ages are comparable, although if taken at their face value the ages of some objects in our galaxy may be significantly greater than the expansion age. However, the expansion age is only a very approximate value for the age of the universe, and it depends on the cosmological model.

The steady-state cosmology, propounded by Hoyle, Hermann Bondi of King's College in London and Thomas Gold (now at Cornell University), postulates no upper limit for the age of the universe. But the average age of an observable sample should be a fraction of the time scale given by the expansion rate of the observable universe. In a steady-state universe, in other words, it is expected and indeed demanded that the hierarchical units should show a considerable disparity of ages, with young galaxies and young clusters of galaxies to be seen still in formation along with



ANOTHER IRREGULAR GALAXY, M 82, photographed through a red filter, is full of dust (*dark spots and lanes*) and gas not yet condensed into stars. These two photographs were made with the 82-inch reflector of the W. J. McDonald Observatory in Texas.

galaxies and clusters in late phases of evolution.

If time-scale discrepancies eventually discredit evolutionary models, and other arguments rule out the steady-state model, we may have to abandon the so-called cosmological principle. This principle states that, except for local irregularities, the universe looks the same from every point in it. The consequences of abandoning the principle have not as yet been seriously considered. So it seems that theoretical considerations alone cannot settle the question of whether the condensation of galaxies took place in the distant past or whether formation is going on at an appreciable rate today. More to the point is the evidence offered by direct observation.

Of the billion or more galaxies detectable by modern instruments, several thousand are close enough to permit detailed inspection. Some of them are spiral in structure—great pin wheels consisting of a central core of stars with more or less wide-flung, spiral arms described by lanes of bright stars and bearing much dust and gas. In some galaxies, known as barred spirals, the arms trail out from a bar across the center. Many of the galaxies are "elliptical," consisting of a single dense globular or ellipsoidal mass of smoothly distributed stars, with hardly any gas and no dust between them. A still smaller class of galaxies is labeled SO. They are flat, like spirals, and in outline look somewhat like spirals that have lost their arms. They contain almost no gas and little or no dust. Finally, there are the irregular galaxies, which contain conspicuously large amounts of dust and gas and exhibit no particular structure.

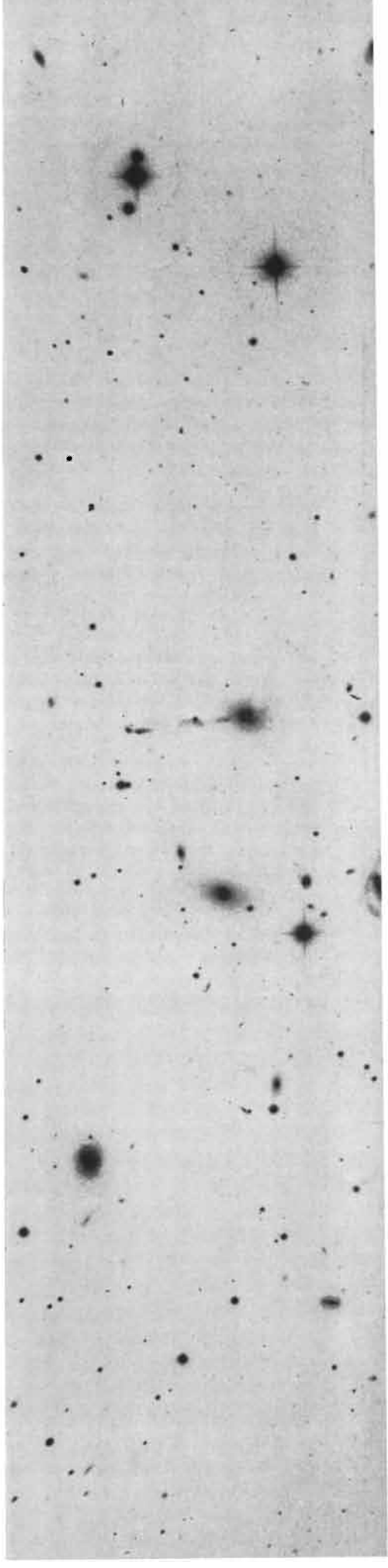
Now if one were looking for a galaxy that is young in the evolutionary sense, one would expect to find in it a number of huge stars in process of formation. The larger protostars contract far more rapidly than do smaller ones. Stars that have the mass of the sun take 50 million years to contract; stars 50 times more massive need only a few hundred thousand years. Therefore if a number of protostars of a wide range of masses all begin to contract at the same time, those of greater mass will become stars and will go through their whole evolutionary sequence, turning into dying white-dwarf stars long before stars of solar mass have even begun to radiate. On this basis a young galaxy would be an irregular system full of highly luminous, hot, massive stars embedded in a large amount of dust and gas.

Several of the irregular galaxies appear to be just such objects. One of the most remarkable is known as NGC 2444–45 [*see top illustration on page 54*]. The designation NGC means that it was noted in the New General Catalogue of the Danish astronomer John L. E. Dreyer in 1888. Vorontsov-Velyaminov first pointed out the unusual character of this galaxy and brought it to our attention.

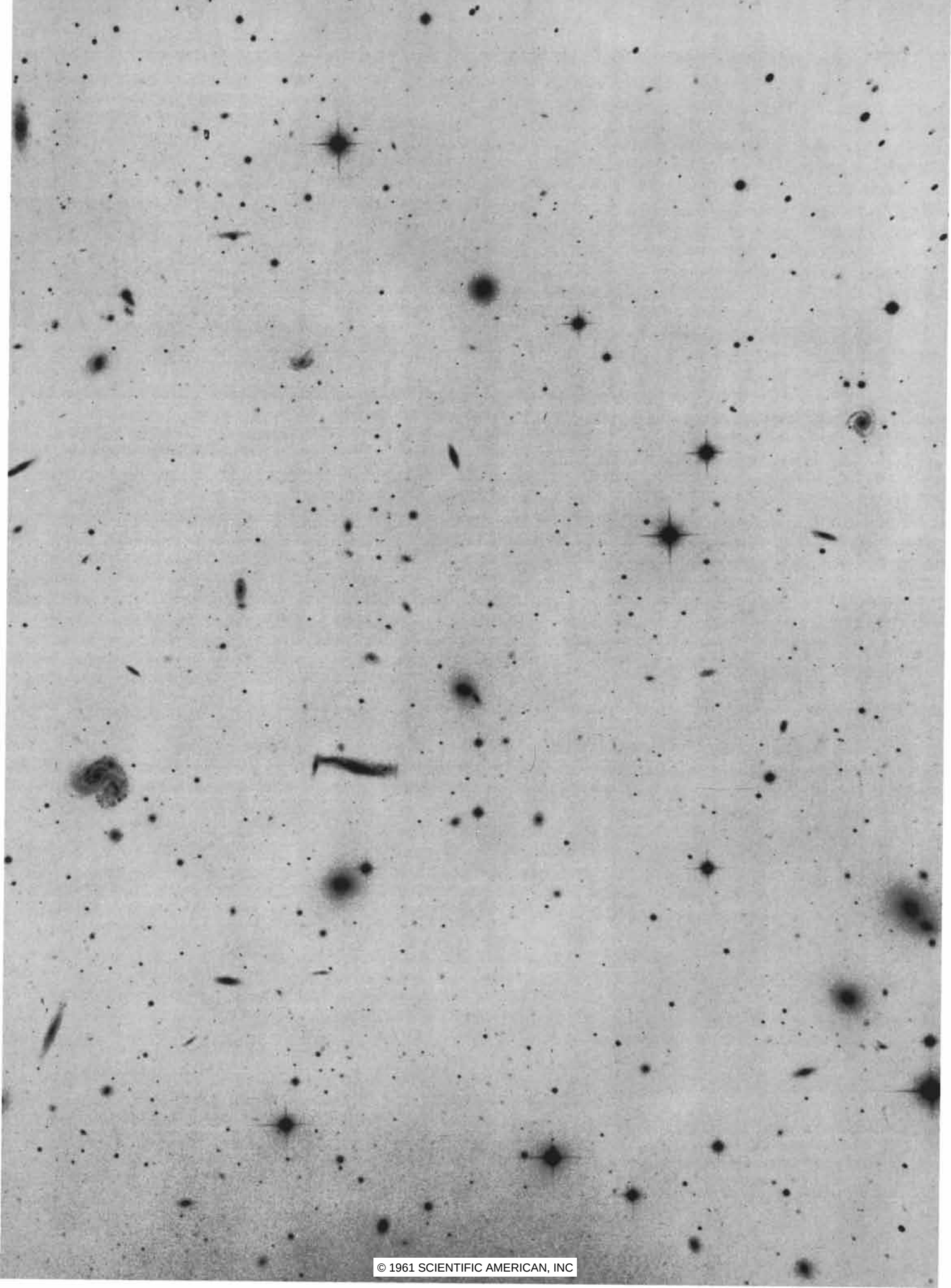
As its label indicates, NGC 2444–45 is really two different objects. One is apparently a normal elliptical galaxy; such galaxies are thought to be old in the evolutionary sense because all their dust and gas have condensed into stars. The second object consists of a number of bright knots, which are gigantic regions of hot gas—mainly ionized hydrogen—each several thousand light-years in diameter, embedded in a more tenuous, luminous haze, which may contain stars and cooler gas.

From the spectra of each of these knots we have measured the Doppler effect (the shift in the lines of the spectrum due to motion) and have calculated the velocity with which the system appears to be receding from us. Both the knots and the elliptical galaxy are receding at about 4,000 kilometers per second. Both lie about 150 million light-years away. Since both objects are the same distance from us, it can be assumed that they form a physical group. The energy that makes the large knots glow must come from many high-luminosity stars embedded in them. These gigantic regions of ionized hydrogen can only be rather short-lived features, characteristic of the early stages of the formation of a galaxy. Thus NGC 2444–45 is an old galaxy alongside what may be a new one. It is tempting to conclude that the young system started to form with the help of the older one.

We have studied two other rather similar systems [*see illustrations at middle and bottom of page 54*]. In each case a normal elliptical galaxy is seen near



HERCULES CLUSTER of galaxies contains many double and peculiar systems. This photograph of the cluster's central region was made by the late Walter Baade with the 200-inch telescope on Palomar Mountain. The reproduction is from a negative print, which increases the contrast and makes faint objects more visible. Small round objects and those with four spikes are stars. Other structures are galaxies seen at many angles.



PECULIAR GALAXY associated with an elliptical galaxy in top photograph is NGC 2444–45. The elliptical galaxy is above the gaseous peculiar system. Objects in middle and bottom photographs appear to be similar, but they may not be together in space.

what appears to be an agglomeration of hot gas and luminous stars. Here we do not as yet have observations proving that the objects in the pairs are actually together in space. The irregular galaxy might be in front of or behind the other as seen from the earth.

Another irregular galaxy that is hardly likely to remain stable in its present form is NGC 4676 [*see illustration at bottom left on opposite page*]. It is one of a number of objects that are characterized by long tails or plumes, which are possibly fans of matter seen edge-on. NGC 4676 has two nuclei, one with a long tail and the other with a faint, curving plume extending in the opposite direction. Spectra show that the galaxy is receding at 6,500 kilometers a second. It lies in the outer part of the cluster of galaxies in the constellation Coma Berenices, one of the richest clusters known. The average recession velocity of the cluster is 6,900 kilometers per second. NGC 4676 therefore belongs to the cluster, which is made up mostly of old elliptical and SO galaxies.

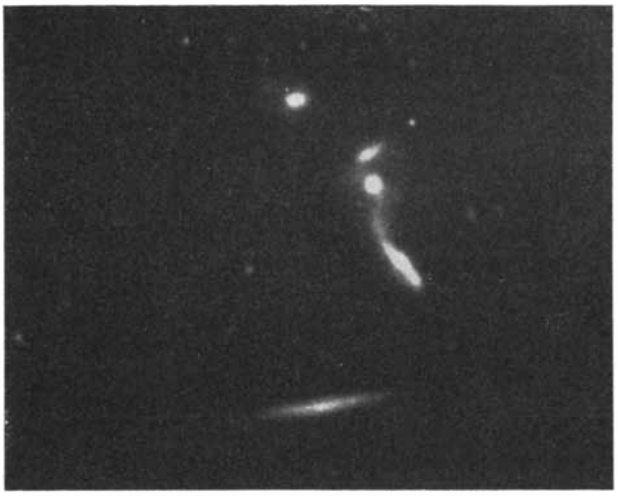
Spectral analysis of the two nuclei of NGC 4676 shows stars of high luminosity and much ionized gas. Furthermore, both nuclei are rotating rapidly. Since we cannot determine the direction of the axes of rotation we cannot calculate the total amount of rotation. However, the outer part of each nucleus is moving in the line of sight at a velocity of 200 kilometers per second with respect to the center. The tail stretches across at least two minutes of arc, which means that it is approximately 150,000 light-years long. This does not seem to be a very stable structure on the time scale associated with galaxies. It follows that the object may be evolving rapidly and may even have arisen "recently" from gas left over after the majority of the Coma Berenices galaxies were formed.

Two other systems similar to this have been studied [*see illustrations at bottom center and bottom right on opposite page*]. We have as yet no data on their recession velocities or on how large they are. They may be even farther away than NGC 4676, because they appear smaller (in the illustrations they have been enlarged so that they all appear to be the same size). Another kind of irregular system that we are investigating has a single loop or ring [*see illustrations in middle of opposite page*].

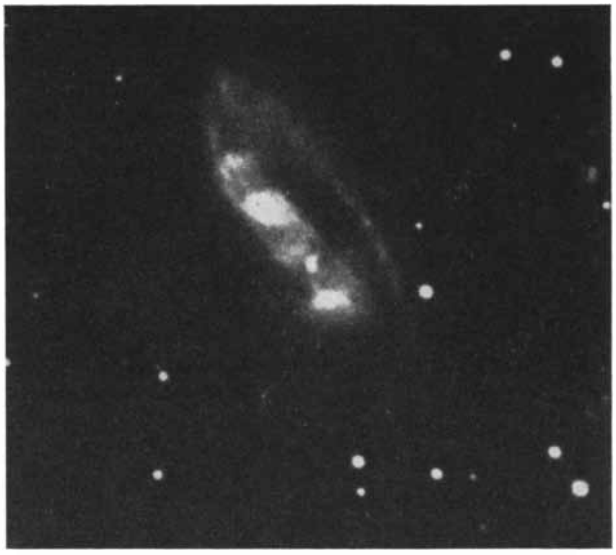
Still another type of peculiar object consists of pairs of galaxies linked by streams of matter. In the past it has been supposed that pairs that are bound together by gravity have been formed by collisions between previously separate systems. However, the Soviet astronomer Victor A. Ambartsumyan has argued that double and multiple systems are too common to have been formed in this way. He has proposed that galaxies often actually arise in pairs or groups analogous to the many stars that originate as members of multiple-star systems. For protostars this appears to be a feasible way of redistributing the colossal amount of angular momentum (energy of rotation) in the system so that the system can become stable as it contracts. Perhaps galaxies form multiple systems for the same reason. The pair of galaxies shown in the top illustration on page 57 both display rather irregular structures and both contain much hot gas.

The "tuning fork" classification of galaxies proposed by Edwin P. Hubble of the Mount Wilson Observatory more than 25 years ago [*see illustration on page 56*] was not at the time advanced as an evolutionary model. But speculation about galactic evolution was inevitably stimulated by this purely structural diagram. At present it seems likely that the spiral and the elliptical galaxies have followed their own course of evolutionary development starting from different conditions in the protogalaxies that gave rise to them [see "The Evolution of Galaxies," by Jan H. Oort; SCIENTIFIC AMERICAN, September, 1956]. On the other hand, there are indications of an evolutionary trend from irregulars to spirals. Irregular and spiral galaxies have an important feature in common: they are on the average less massive than elliptical galaxies, though the mass ranges of all three types overlap. Some irregulars may very well evolve into spirals. This would occur because an irregular mass of gas and dust that possesses some angular momentum will revolve faster as it contracts, and in a few revolutions such a mass will tend to acquire a more orderly and symmetrical structure. Gas and dust clouds with little or no angular momentum may never go through this progression.

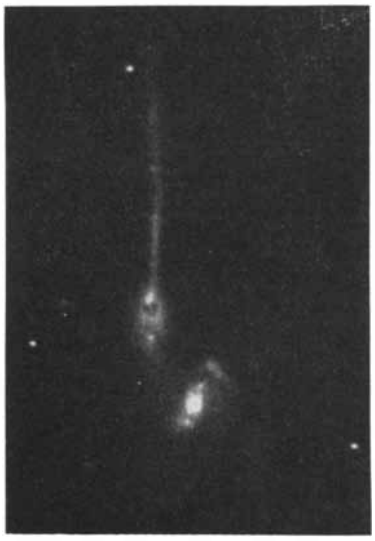
Before much progress can be made in understanding any evolutionary sequence, several problems associated with spiral galaxies must be solved. For example, it is not known why the spiral arms persist. A few rotations should wind them up and distort them beyond recognition. Furthermore, the arms are made up of giant hot young stars and the gas that such stars illuminate. Since stars of this kind have a short lifetime, they will evolve and fade before the galaxy



TWO CHAINS OF GALAXIES are probably unstable configurations. They were catalogued by Soviet astronomer B. A. Vorontsov-Velyaminov. Photographs on these two and the following pages were made with 82-inch telescope of W. J. McDonald Observatory.



ASYMMETRICAL LOOPS of gas, dust and luminous stars characterize these two irregular galaxies. After a few rotations they may assume the regular spiral form. Photograph at the right has been enlarged more from original plate than the photograph at the left.



THREE STRANGE SYSTEMS that are probably evolving display long tails or plumes. At left is NGC 4676, an outlying member of a cluster of galaxies in Coma Berenices. Other two systems are probably farther away than NGC 4676; they are smaller on the plate.

has made one revolution. Spiral arms must somehow be continually renewed.

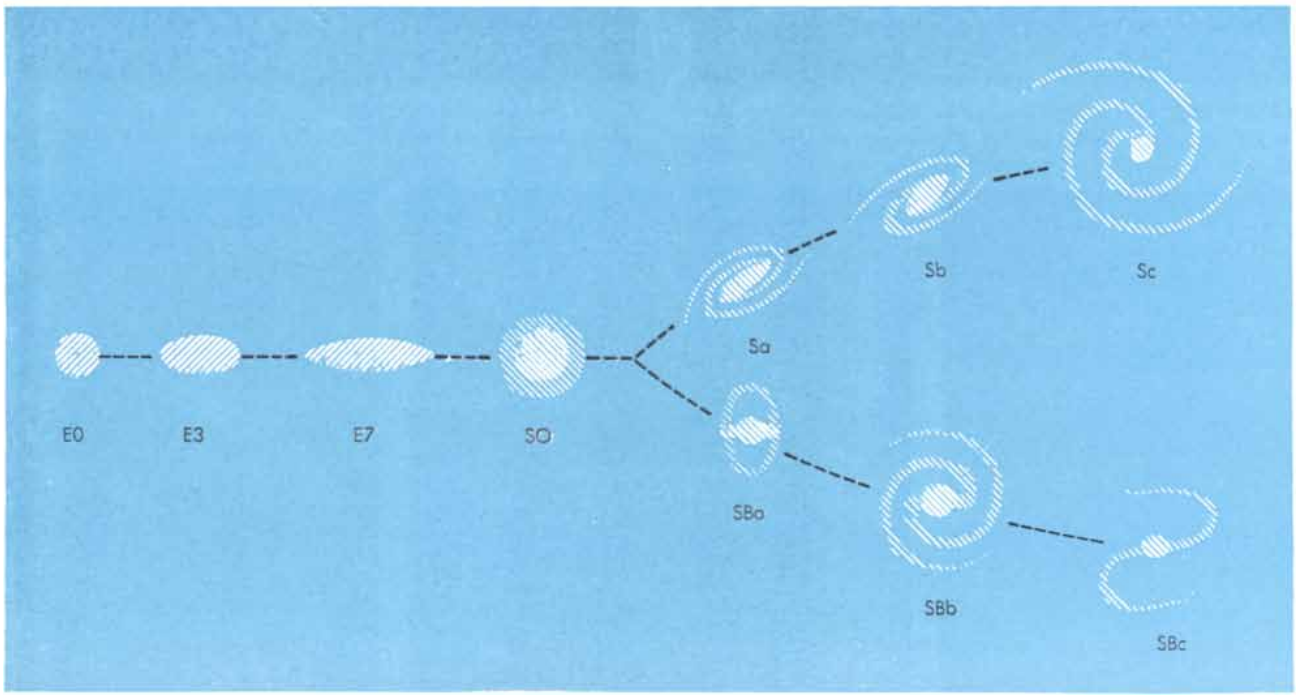
It is not understood either how the bar across the center of barred spirals is formed or how long it will last. Bars made up mainly of stars have presumably lasted a long time by evolutionary standards and are fairly stable; those with a large supply of gas and dust may have shorter lifetimes. There may even be a tendency for barred spirals of a certain sort to change into normal spirals.

The new evidence for the presence of young galaxies in the universe fits well into the increasingly persuasive picture of galaxies as unstable and continuously evolving systems. It may apparently be concluded that the galaxies are by no means all the same age and that a significant number of them are younger than the universe.

An equally striking result has come from an examination of the evidence for the stability and age of clusters of galaxies. Until recently it has been tacitly assumed that all clusters of galaxies are gravitationally stable and therefore all have an age commensurate with that of the universe, as befits the evolutionary cosmology. It is possible to check this hypothesis by detailed studies of the galaxies in a cluster. For the cluster to be stable the gravitational potential energy (the energy with which each part of the system attracts all the other parts) must be twice the kinetic energy (the energy of the galactic motions tending to pull the system apart). This statement is called the virial theorem. The potential energy can be estimated as a function of the unknown total mass by measuring the distances between the galaxies on a photographic plate. By measuring the recession velocities of individual galaxies and subtracting them from the average recession velocity of the cluster one can determine the line-of-sight velocities of the galaxies with respect to the system. By introducing some further assumptions one can derive an estimate of the total kinetic energy of the system as a function of the unknown mass. On the assumption that the system is stable, these two quantities can be put into the equation given by the virial theorem and the total mass can be derived. Division of the mass by the number of galaxies then gives an average mass for the galaxies in the cluster.

Only a few of the rich clusters of galaxies have so far been investigated by this method. The galaxies in the great Coma Berenices cluster turn out to be about twice as massive as they should be in comparison with similar galaxies for which it has been possible to obtain individual mass measurements. If this discrepancy were significant, it would suggest a choice of two alternatives: either the extra mass is distributed in the intergalactic space of the system or the cluster is not so stable as it has been assumed to be. Either conclusion would have great significance; the Coma Berenices group is a "classical" cluster, one of the largest of all, made up principally of old elliptical and SO galaxies distributed with a high degree of symmetry in increasing concentration toward the center. But in view of the assumptions involved in deriving the average mass, it is an open question whether there is any real discrepancy here.

Considerably greater difficulty for the prevailing assumptions about the dynamics of clusters is presented by the findings of a similar investigation of two other clusters—the Virgo cluster, which is relatively near our galaxy, and the Hercules cluster [*see illustration on pages 52 and 53*]. They differ from the Coma Berenices cluster in two important respects. First, both clusters have a high proportion of spiral and irregular galaxies; 70 per cent of the bright galaxies in the Hercules system fall into these younger classifications. Second, the Virgo and Hercules systems show none of the symmetry of the Coma Berenices cluster; both are irregular in outline, with very little concentration of mass at the center. The Hercules cluster, in fact, looks rather like several chains of galaxies. Calculations from the virial theorem yield an average mass for the Virgo and Hercules galaxies 20 times the mass of the single galaxies near enough to earth to be studied in detail. Thus either the two systems contain about 20 times more



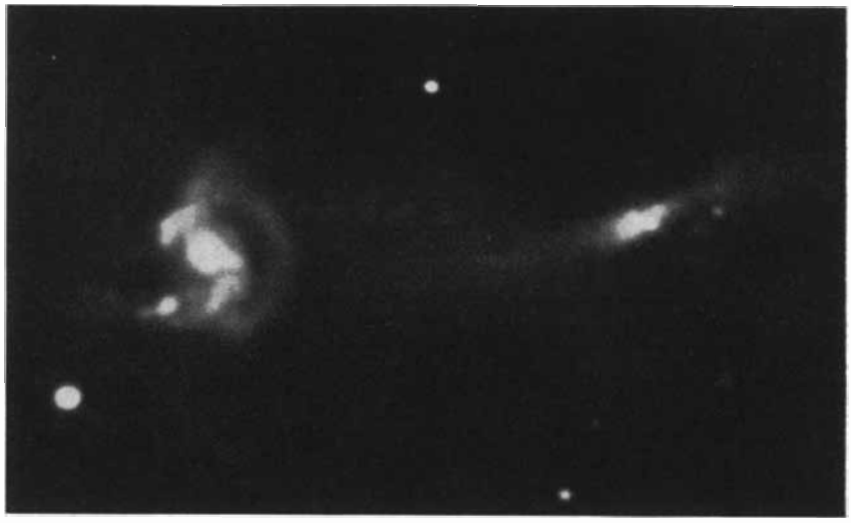
"TUNING FORK" DIAGRAM by the late Edwin P. Hubble represents typical galaxies in a sequence that may be in part evolutionary. "Handle" is made of elliptical and SO galaxies, tines of normal spirals (*top right*) and barred spirals (*bottom right*). The diagram originally appeared in Hubble's book *The Realm of the Nebulae*, published in 1936 by the Yale University Press.

uncondensed material between the galaxies than they do within the galaxies or the virial theorem cannot be applied to the systems at all because they are unstable. If clusters such as these are unstable, the evolutionary cosmology is faced with the difficult problem of explaining how they formed in the immediate past, at a time much later than the "beginning." Some astronomers have nevertheless argued that a large amount of invisible uncondensed material must be present.

In spite of these difficulties a number of astronomers are leaning to the view that these clusters are unstable. The large number of peculiar galaxies in the Hercules cluster, which may well be interpreted as a group with a preponderance of young galaxies, and the geometrical configuration of the Hercules and the Virgo clusters both point in this direction. Similar arguments may also be applied to a few small groups of galaxies. Vorontsov-Velyaminov has found two small clusters that are actually chains of galaxies and could hardly be stable for more than a few billion years. The mutual gravitational interaction would rearrange the galaxies into some other distribution within this period of time.

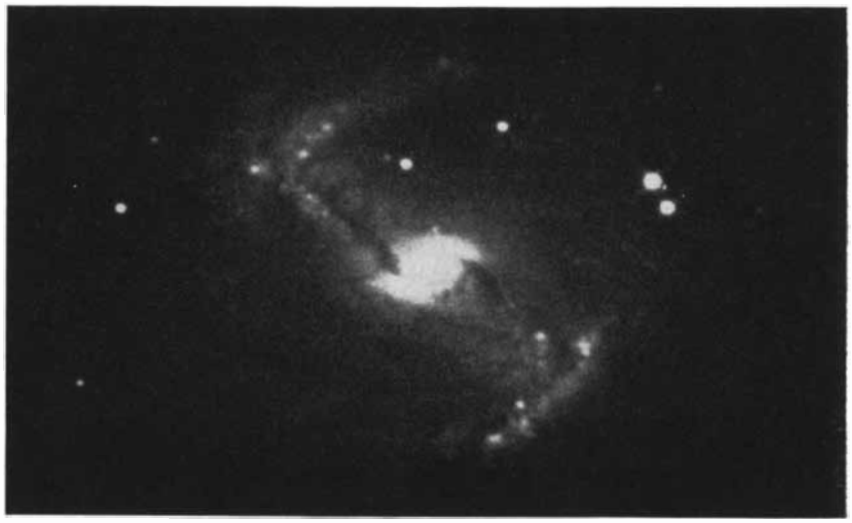
A growing body of circumstantial evidence therefore indicates that galaxies and clusters of galaxies are still forming today. The conclusion agrees well with the steady-state theory of cosmology. It can be accommodated, however, within the terms of evolutionary cosmology. The argument can be made, for example, that a protogalaxy might have formed 10 billion years ago and not have condensed into stars, remaining dark and invisible until conditions were right for the condensation of stars. A strong magnetic field in such a gigantic cloud of gas might prevent star formation for a very long period. If the stars had formed in the last 100 million years, the ancient protogalaxy would now appear as a very young galaxy.

To sum up, we believe there are galaxies and clusters of galaxies that seem to be young because they evidently cannot last long in their present form, and because the natural forces acting in a rotating mass of gas always tend to produce order from disorder—symmetry from dissymmetry. That young galaxies exist implies that galaxies may be forming even today. Yet although the steady-state cosmology predicts the continuous formation of galaxies, we still cannot go further and choose one cosmological model over another.



A STRANGE DOUBLE GALAXY, NGC 7714–15, has luminous bridge between two objects. These structures may be evolving into a pair of mature galaxies linked by gravitational force.

TYPICAL ELLIPTICAL GALAXY, NGC 720, consists of a ball of stars containing little dust and no gas. Galaxies such as this are generally believed to be old in the evolutionary sense.



BARRED SPIRAL GALAXY, NGC 5383, like almost all spirals, contains much dust and gas and is therefore thought to be considerably younger than the elliptical and the SO galaxies.

BLOOD PLATELETS

These minute disks of protoplasm circulate in the bloodstream along with red and white cells. When a blood vessel is broken, platelets plug the break. They also play a key role in the formation of clots

by Marjorie B. Zucker

The blood transports its load of food, oxygen, waste products and other substances through a closed system of resilient tubes—the blood vessels. Because this network of vessels is far from indestructible the body must have a mechanism that rapidly seals leaks in the tubes, holding in the blood. Appropriately enough the blood carries the patching material in the form of certain dissolved substances and the tiny coin-shaped particles known as thrombocytes, or platelets. Platelets automatically clump together at a break in a blood vessel, forming the major constituent of a plug that stops the bleeding. (Hemostasis, the sealing process, actually involves a series of complex reactions among the platelets, blood vessels, nearby tissues and several substances from the blood plasma.) Masses of platelets also contribute to the formation of the abnormal and sometimes lethal clots, or thrombi, within coronary arteries and other blood vessels.

Recent studies have revealed that the platelets are far more complicated than the moribund bits of living matter they were once thought to be. For example, it is now known that platelets, like cells, engage in metabolic activity. A substance that plays an important role in muscle contraction and other life processes—adenosine triphosphate (ATP)—is found in surprisingly large quantities in platelets. Such discoveries are making platelets an object of study in their own right, although much of the work is still directed toward the elucidation of their role in the formation of clots.

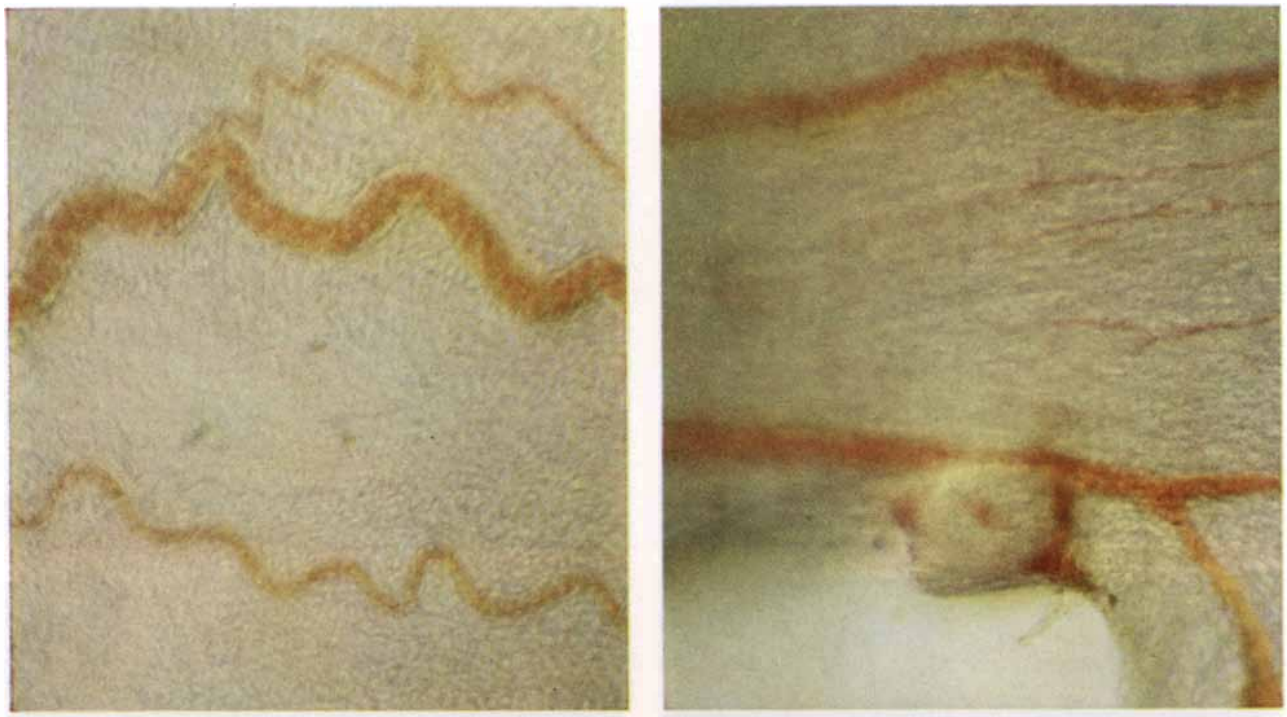
The blood of an average individual contains more than a trillion platelets, yet they are so unstable outside the circulatory system and so small that in the 19th century their very existence was debated. The 25 trillion erythrocytes, or red blood cells, in an individual make up almost half the blood volume and would fill two quart bottles; the platelets and the much less numerous (though larger) leucocytes, or white blood cells, together compose less than 2 per cent of the blood volume. Normally every cubic millimeter of the blood contains some five million red cells, about 7,000 white cells and about 250,000 thrombocytes. The leucocytes are true cells, made up of a nucleus surrounded by cytoplasm. The red cells come by the name less honestly because they lose their nuclei as they mature. The term cell should probably never be applied to platelets, because each platelet is only a fragment of the cytoplasm of a giant cell known as a megakaryocyte. These precursor cells, like the parent cells of red cells and some kinds of leucocytes, normally reside in the red marrow that fills the spongy interior of many of the bones. In adults blood-forming marrow is found mainly in the ribs, the vertebrae, the pelvic bones and the skull. In children the long bones of the limbs also contain such marrow. The spleen as well as the marrow of some lower forms of mammal produces blood cells and platelets. (Such nonmammalian vertebrates as birds, reptiles and amphibia have no platelets and use certain special whole cells as plugs in hemostasis.)

Megakaryocytes probably originate in the undifferentiated cells that give rise to the marrow tissue. Initially both the nucleus and the cytoplasm of the maturing megakaryocyte divide, but the daughter cells recombine to form a multinucleate cell. Subsequently the nuclei divide several times but the cytoplasm does not. These phases of maturation may take a week or more. Then the cytoplasm becomes grainy; the cell may produce long pseudopods that seem to break into bits, each becoming a platelet. Sometimes no projections form and the cytoplasm simply falls apart into platelets, leaving the denuded nuclei to die. Like newborn blood cells, the thrombocytes pass through the walls of the blood-filled cavities in the marrow to enter the circulatory system.

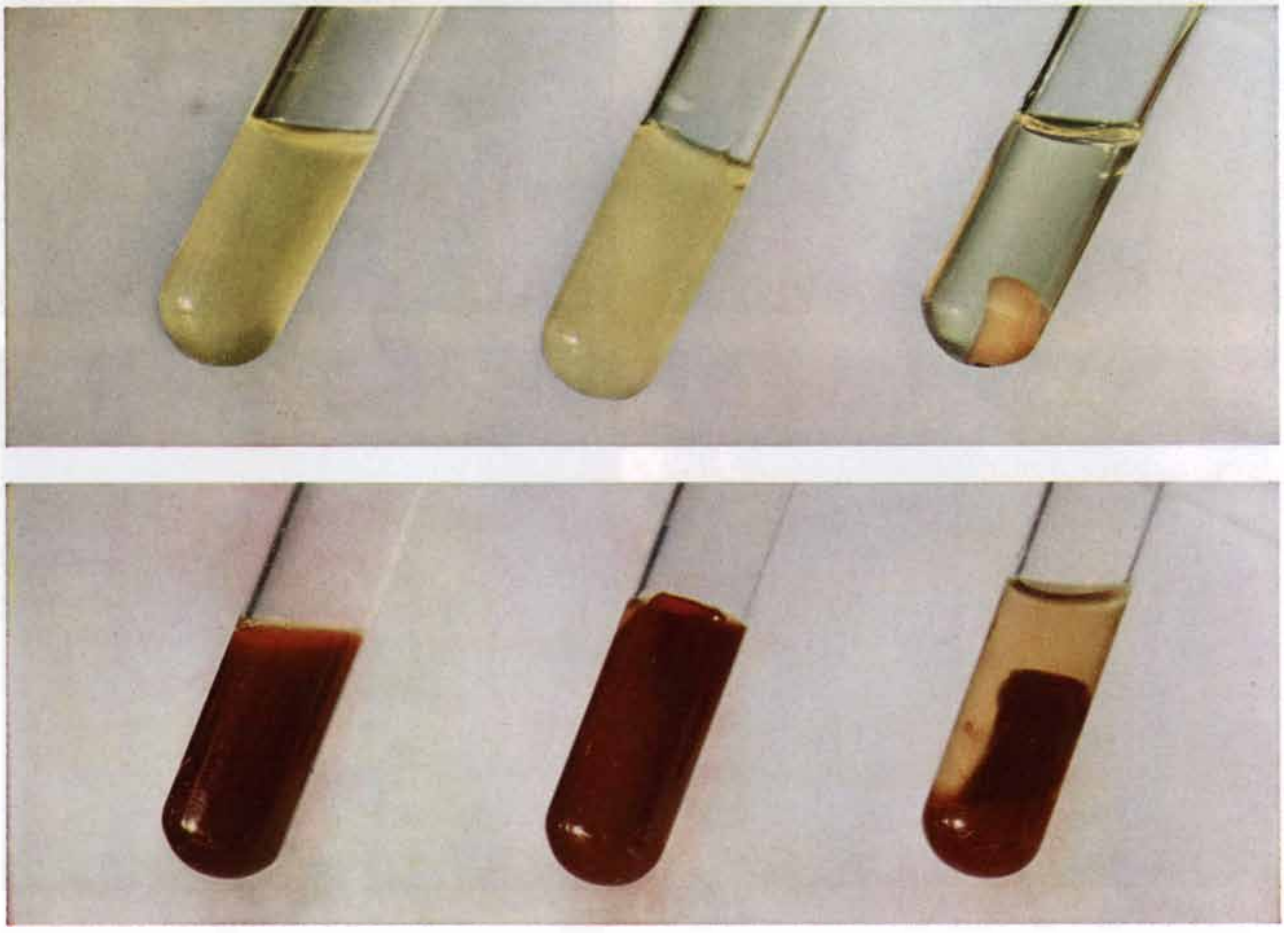
From the manner in which they are created the platelets might be expected to have irregular shapes, but this is not the case. The microscope shows that in the capillaries of a living animal most platelets are thin disks. In blood withdrawn from the body they change shape before clotting occurs. Long processes project from the rims and the disks become fatter, rounding up into sticky spheres with spiny surfaces. Thrombocytes will retain their normal shape for several hours, however, when clotting is prevented by the addition of an anticoagulant such as sodium citrate. In this condition they can be forced to turn into spheres by cooling the blood or lowering the concentration of magnesium in it. They revert to disks if the blood is rewarmed or supplied with magnesium. Apparently thrombocytes engage in some form of metabolic activity in order to maintain their normal shape.

Platelets in contact with glass display another change. Within a few minutes after a drop of blood is placed between a glass slide and a cover slip each platelet spreads thinly over an area several times its original diameter. Granules that are hardly detectable in the intact disk clump at the center to form the so-called granulomere; this body is surrounded by a thin periphery of clear material, the hyalomere. In ordinary stained blood-smears the granulomere is reddish-purple and the hyalomere is blue.

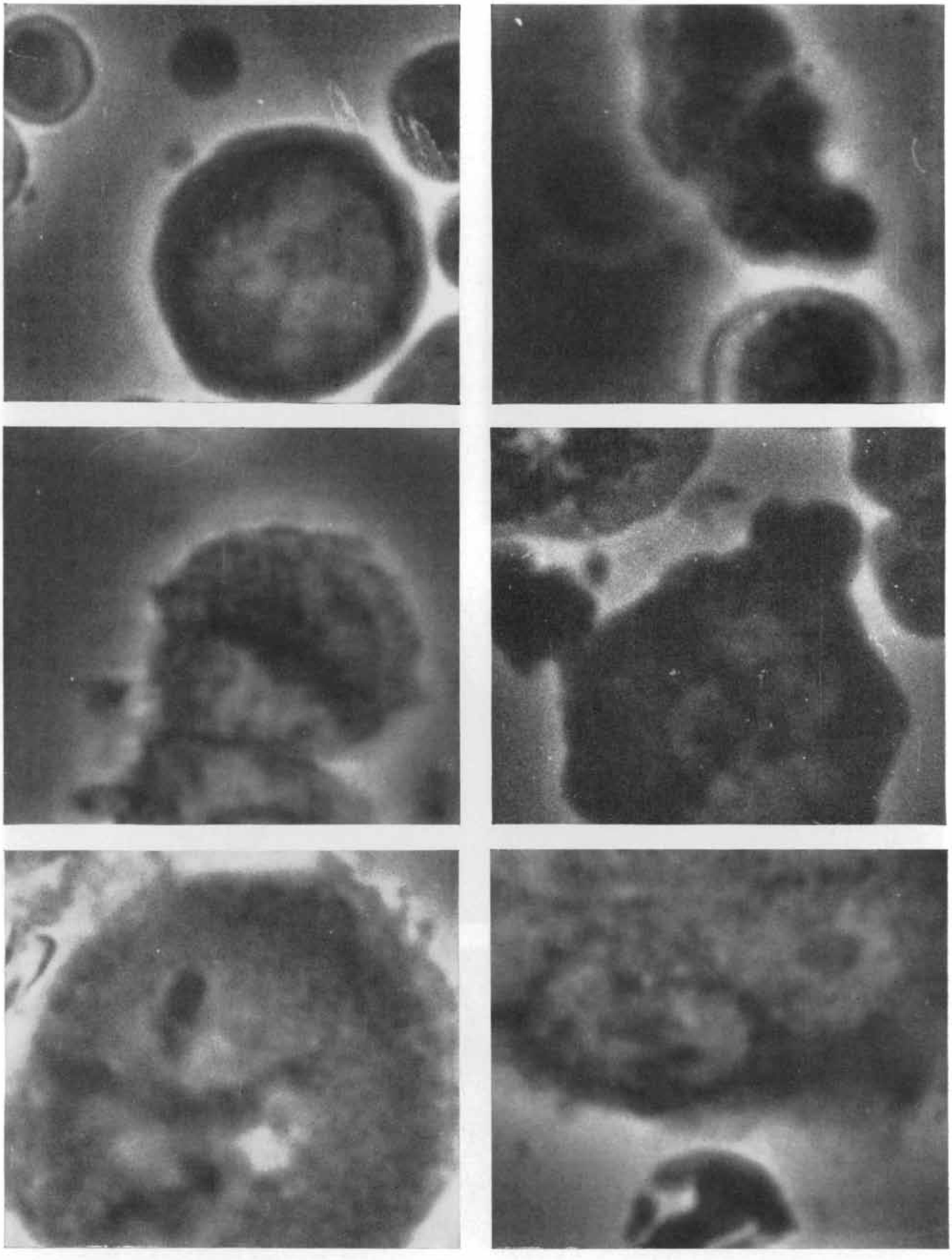
Although platelets are highly unstable outside the bloodstream, they are remarkably durable within it. Estimates



PLUG OF PLATELETS forms when a blood vessel is broken. At left, enlarged some 200 diameters, are blood vessels in the mesentery of a rat. At right a break made with a razor blade in the lower vessel is plugged at bottom center by a round mass of platelets.



CLOTTING OF BLOOD is shown in plasma containing platelets (*test tubes at top*) and in whole blood (*test tubes at bottom*). After a few minutes both fluids solidify, as indicated by the tilt of the surface in the center test tubes. In tubes at right clot has retracted into a dense mass. The retracted clot that has formed in whole blood is red and is larger because it has trapped red blood cells.



MATURATION OF A MEGAKARYOCYTE, the cell that gives rise to blood platelets, begins with young cell (*top left*) that has two sets of chromosomes. It divides and its daughter cells fuse into a single promegakaryocyte (*top right*) with four sets of chromosomes. This cell divides and its daughters join together (*middle left*) to make a cell that has eight sets of chromosomes. The cell bulges (*middle right*) but its cytoplasm does not divide. The chromosomes double (*bottom left*) and then double again to make 32 sets just before cell disintegrates into platelets (*bottom right*). The sequence is completed on the opposite page.

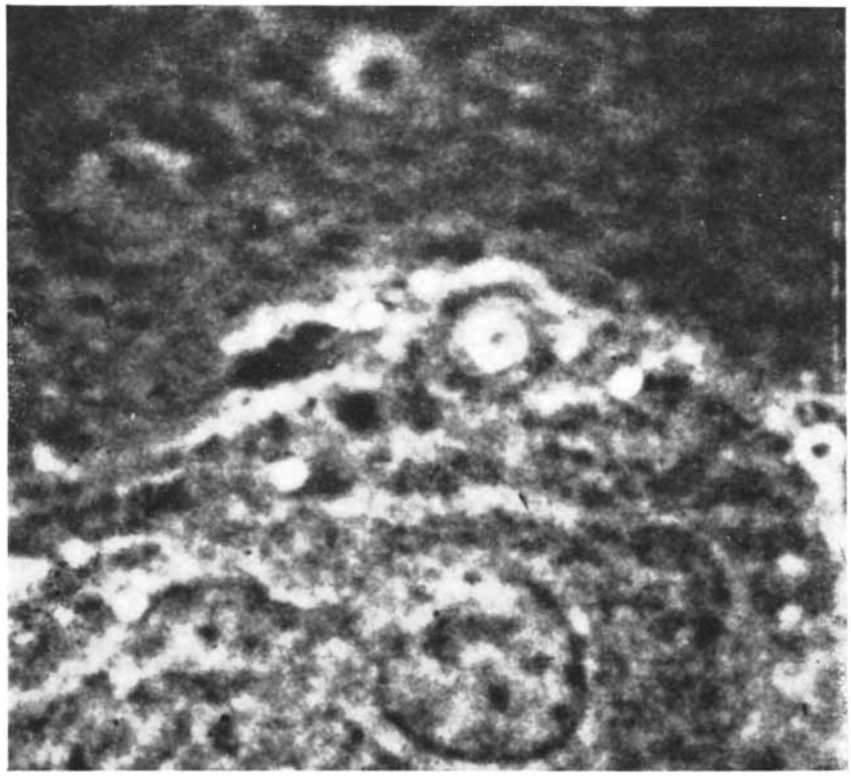
of their survival in the circulation were first made with people who had only a few platelets in their circulation. Large quantities of platelets were injected into these people and then were counted in samples taken on successive days. The number decreased with time; after five days only the original number remained. Thus at least the youngest of the transfused thrombocytes had survived for five days. More recent measurements of platelet life span have been carried out in normal people by labeling platelets with radioactive substances. Two compounds have proved particularly useful: sodium chromate containing the radioactive isotope chromium 51, and diisopropylphosphorofluoridate (originally developed as a poison gas and called DFP) containing the radioactive isotope phosphorus 32. After a few minutes of incubation with a sample of platelets removed temporarily from the circulation, the radioactive sodium chromate becomes attached to them. Then the thrombocytes are reinjected. Labeled DFP, on the other hand, is simply injected intravenously and combines with the platelets in the circulation. Samples of blood taken each day reveal a steady decline in radioactivity. The radioactive label disappears almost entirely after eight to 10 days. In many studies the graph of the decline is a fairly straight line. This suggests that the oldest platelets are removed from the circulation first and that platelets have a definite life span of eight to 10 days in man, and four to seven days in laboratory animals.

The process by which thrombocytes form a plug to arrest a hemorrhage can be studied in a simple manner. The mesentery (the thin membrane that supports the intestine) of an anesthetized animal is exposed by an abdominal incision and arranged so that the blood vessels can be seen through a microscope. A slow drip of warm salt solution bathes the mesentery to prevent drying and cooling. A small blood vessel—an arteriole or venule—is cut; the salt solution washes away the blood that escapes, maintaining visibility. Within seconds platelets begin to adhere to the margins of the cut vessels. More platelets stick to the first, and in a minute enough have collected over the break to form a whitish body barely visible to the naked eye. After a few minutes the plug solidifies and bleeding ceases. Slides made from cut skin tissue show the same picture: large masses of platelets covering the open ends of the severed blood vessels.

The formation of the impermeable plug depends in part upon thrombin, an enzyme that plays a key role in the clotting of the blood. Thrombin converts the soluble plasma protein fibrinogen into insoluble fibrin, which forms the solid meshwork of a clot. Thrombin is not present in the circulating blood. Indeed, an injection of it would be lethal because it causes the blood to solidify. In the body thrombin is generated from its inactive precursor, prothrombin, when it is needed for hemostasis. The formation of thrombin from prothrombin in the test tube requires the participation of calcium ions, platelets or phospholipids (substances supplied by platelets) and at least six proteins that are found in trace quantities in the plasma. In the test tube the process is rather slow: the blood does not make a solid clot for about 10 minutes. Fortunately in the body lipoproteins leaking from the damaged tissues initiate and greatly accelerate the process of thrombin formation, so that clots can appear quickly. Thrombin can also form in the body independently of the reaction with lipoproteins from damaged tissue. For this mechanism the phospholipid compounds found in platelets are essential, and thrombin probably forms more readily on the surface of the thrombocytes than in the plasma, because the platelets concentrate clotting factors from the plasma on their surface.

Thrombin in turn exerts profound effects upon platelets. When it is added to a suspension of platelets they clump; within a few minutes they appear to melt together until they can no longer be separated either visually or physically. This process, called viscous metamorphosis, changes the loose clump of platelets into a tough, impermeable plug. Thrombin added to plasma or a test-tube solution of fibrinogen with platelets suspended in it converts the fibrinogen into an insoluble fibrin network clogged with platelets melting together. Soon the clot begins to shrink; within half an hour it has compressed itself into a small nubbin. This almost certainly results from the contraction of the platelet pseudopods that have adhered to the fibrin meshwork. Retraction also occurs when blood is allowed to clot in a test tube by generation of its own thrombin, though the retracted clot is larger because the red corpuscles are caught in its meshwork. The mechanisms responsible for clot retraction are closely related to those causing viscous metamorphosis.

Local production of thrombin, how-



PLATELETS APPEAR when cytoplasm of mature megakaryocyte breaks up. This photomicrograph and those on opposite page are from a motion picture of living rabbit bone marrow, made by Riojun Kinosita of the City of Hope Medical Center in Duarte, Calif. This first film of living marrow revealed that in early stages the cell twice divides and recombines, and that disintegration of cytoplasm of mature cell into platelets kills the cell.

ever, does not appear to be solely responsible for the development of the platelet plug at the site of vascular injury. The first platelets adhere to the margins of the break in a blood vessel within one or two seconds, faster than the thrombin evolves. Recent work at Jacques Roskam's laboratory at the University of Liège in Belgium, and in my laboratory at the Sloan-Kettering Institute in New York, has shown that platelets adhere to connective tissue fibers and even appear to melt together when mixed with minute particles from connective tissue or muscle. Severing a blood vessel must expose the blood to connective tissue and muscle in the vessel wall or surrounding tissue, and this process, which does not require thrombin, probably causes the initial rapid formation of a platelet plug.

The clot-forming function of platelets has a significant role in pathology as well as in the repair of torn blood vessels. Even if the vessel is not torn open, platelets may display their striking tendency to gather in large numbers at the site of an injury or abnormal constriction in the vessel. The mass of platelets may become the nucleus of an intravascular blood clot or thrombus and fill the channel, stopping the flow of blood. When this occurs in a coronary artery afflicted with atherosclerosis, the heart muscle, deprived of its circulation, cannot function properly and the individual suffers a heart attack, or "coronary."

Thrombi may even form in blood vessels that are not atherosclerotic and whose walls seem entirely normal. These thrombi are commonest in the leg or pelvic veins of patients who have been operated on or patients with cancer. The clots may break loose, becoming emboli that travel through the bloodstream to lodge in the vital pulmonary artery. Venous thrombi also begin as clumps of platelets, but the reasons for their formation remain obscure.

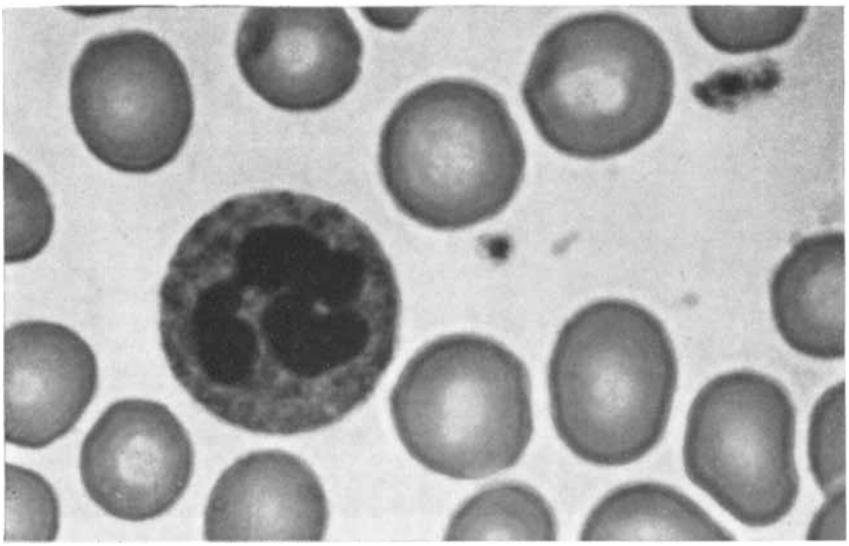
An entirely different pathological condition is associated with the failure of the blood to form clots. In small skin wounds, as opposed to experimental injuries made in the exposed mesentery, strands of fibrin are interlaced in the platelet plug and the wound itself. These strands probably strengthen the platelet plug, but the fibrin has a subsidiary role in arresting bleeding. People born with virtually no fibrinogen have less tendency to bleed abnormally than do those with a severe shortage of platelets. Victims of the rare genetic affliction hemophilia bleed excessively because their blood lacks one of the plasma proteins necessary for conversion of prothrombin into thrombin. This deficiency prevents the rapid evolution of thrombin necessary for forming platelet plugs.

Another hereditary condition not adequately explained is known as von Willebrand's disease, or pseudohemophilia, which is characterized by prolonged bleeding from minor injuries. The victim of this disease has enough platelets, and they react normally with thrombin and with connective-tissue particles. The thrombin evolves from prothrombin in the test tube; at worst the reaction is only mildly impaired. Yet the platelets do not seem to form effective plugs when blood vessels are cut. Because the thrombocytes and the clotting mechanism seem to be normal, von Willebrand's disease has been ascribed to a defect in the blood vessels. But recently Inga Marie Nilsson of the University of Lund in Sweden has shown that the injection of a protein prepared from normal plasma shortens the bleeding time. The function of this protein is entirely unknown. There are other rare diseases in which the victim suffers excessive bleeding. In some the platelets appear to be qualitatively abnormal; in others something is wrong with the blood-clotting mechanism.

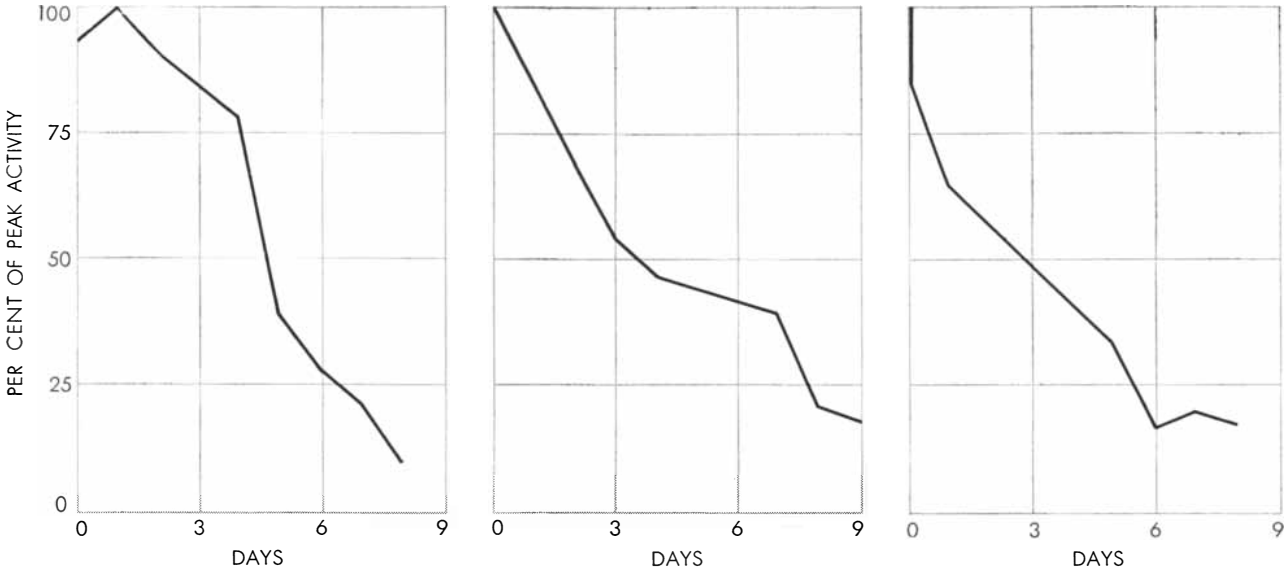
The most common abnormality associated with platelets, however, arises from a shortage of them. The characteristic result of this is bleeding; even small cuts bleed for an abnormally long time. Moreover, the patient bruises easily. Tiny hemorrhages (petechiae) may appear in the skin or mucous membranes; the nose, gums, bowels or urinary tract may bleed. The condition can manifest itself in a most dangerous way: hemorrhage into a vital area of the brain.

A normal person can have as few as 150,000 or as many as 400,000 platelets per cubic millimeter of blood, but the count for any individual remains remarkably constant. When platelets are lost, production rises. Sometimes after a hemorrhage the number of platelets rises above normal, but later it returns to its usual level. On the other hand, Eugene P. Cronkite of the Brookhaven National Laboratory has shown that the number of platelets in the circulation drops below normal several days after injection of a large number of platelets from a donor.

An unusual subject, studied by Irving Schulman of Children's Memorial Hospital in Chicago, has provided some understanding of the way the body controls platelet production. This individual had had a very low platelet count all her life. Her bone marrow contained an adequate number of megakaryocytes, but despite the need for platelets the megakaryocytes showed no signs of breaking up. After the subject's spleen was removed—a measure that proves helpful in some patients—injection of blood plasma from a normal donor had a dramatic effect. The large precursor cells matured and fragmented and the platelet count climbed for eight days, reaching a very high level. Then the count fell, returning to its previous low level about three weeks after the plasma injection. Apparently a genetic defect had deprived this subject of a substance necessary for



CONSTITUENTS OF BLOOD include leucocyte, or white cell, with multilobed nucleus (*large cell toward left*). The smaller bodies are red cells. The dark dot to the right of the leucocyte is a platelet. The dark, irregular mass at upper right is a group of platelets that are clumped together on the glass slide. The magnification is approximately 2,500 diameters.



LIFETIME OF PLATELETS is indicated by decline of radioactivity after injection of DFP (diisopropylphosphorofluoridate), containing radioactive isotope phosphorus 32. Each chart shows results with a different subject, the first two injected intramuscularly; the third, intravenously. Radioactivity is measured in number of counts per minute. It drops almost to zero in nine days.

maturation of the megakaryocytes. It is tempting to speculate that in normal people the level of this unknown substance controls platelet production.

In many patients with low platelet counts the shortage can be traced to a shortage of megakaryocytes. The megakaryocytes mature in the normal fashion but these individuals simply do not have enough of them. In fact, they usually do not have enough functional bone marrow. Drug toxicity or some unknown cause can bring on a rare disease called aplastic anemia, in which virtually all the productive marrow tissue disappears. In diseases such as leukemia rapidly growing abnormal cells replace normal marrow cells. Radiation easily destroys marrow cells because they are among the most rapidly dividing cells of the body. Thus the platelet count drops when much of the body has been irradiated either accidentally or during extensive therapy. Furthermore, drugs used in cancer chemotherapy to destroy the rapidly dividing tumor cells almost always affect bone marrow as well, and the treatment of cancer may be limited by the thrombocyte deficiency that is a by-product.

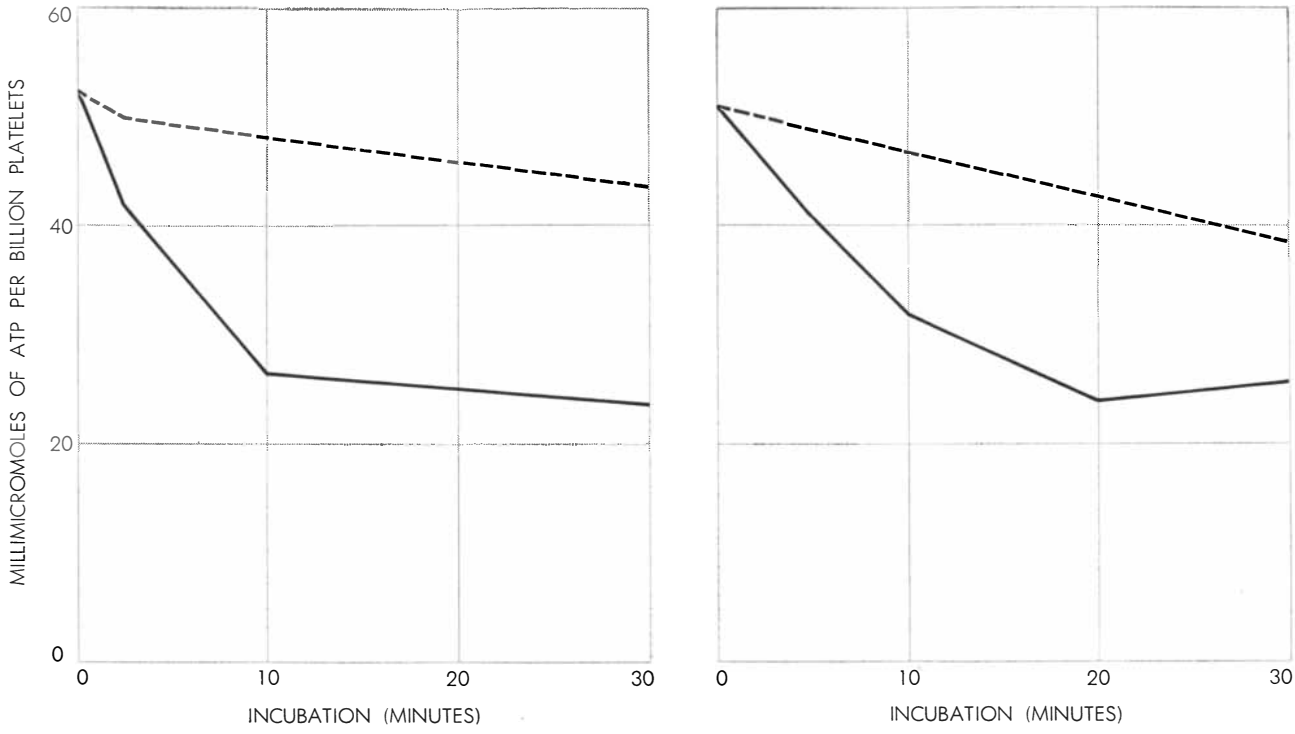
As in economics, scarcity may be the result of overconsumption as well as of underproduction. This is seen in a disease known as idiopathic thrombocytopenic purpura, or ITP. Idiopathic means the cause is unknown; thrombocytopenic means low platelet count; purpura means hemorrhages into the skin. The bone marrow contains sufficient megakaryocytes, but the number of platelets is always low. In at least some people with ITP the blood plasma contains a substance that destroys platelets. William J. Harrington of Washington University in St. Louis dramatically demonstrated this when he had plasma from an ITP patient injected into his own bloodstream. His platelet count dropped quickly. Normal platelets injected into the bloodstream of a person with ITP survive for only a few hours, whereas platelets injected into subjects whose thrombocytopenia results from underproduction survive for days. Unfortunately no one has so far been able to demonstrate unequivocally in the test tube that the blood of people suffering from ITP contains a platelet-damaging substance.

Individuals suffering from thrombocytopenia have not been helped by the remarkable progress in the storage of blood in blood banks during the past 20 years. When blood is transfused directly and rapidly, some platelets will survive for several days. But platelets exposed to an anticoagulant and storage in a blood-bank bottle for even a day will not survive when injected. Recent attempts to preserve platelets by quick freezing have been encouraging, however.

Another difficulty encountered in transfusing platelets is the development of an immune response that destroys foreign platelets. The survival time of transfused thrombocytes is shorter after each injection. Perhaps this indicates that people have different platelet types just as they have different red cell types, but it has so far proved impossible to type platelets.

In some people with very low platelet counts the skin and the mucous membranes may show numerous minute bruises that have no apparent cause. It thus appears that platelets not only arrest hemorrhages but prevent spontaneous bleeding and keep red corpuscles from leaking through the walls of the microscopic blood vessels. That the tiny blood vessels are abnormally fragile in the absence of platelets can be demonstrated easily by putting a suction cup on the skin or by tying a tourniquet on the arm. Pressures that do not affect the blood vessels of normal people make the skin of thrombocytopenic individuals break out in a veritable rash of small hemorrhages. Cronkite has obtained evidence suggesting that platelets furnish some material that helps to maintain the integrity of the blood vessels. He injected platelets heavily labeled with radioactive sulfate into thrombocytopenic animals and then detected radioactivity along the walls of small blood vessels. Although technical problems make this experiment difficult to interpret, it seems to indicate that platelets contribute some of their substance to the vascular wall.

Recent chemical analyses have revealed that platelets possess several unexpected qualities. Although they are only fragments of cytoplasm, they contain a remarkably high concentration of ATP, the ubiquitous storehouse of cellular energy. According to Gustav Born of the University of London the concentration of ATP in platelets exceeds



CHANGES IN AMOUNT OF ATP (adenosine triphosphate) during viscous metamorphosis (*left*) and clot retraction (*right*) are indicated. Broken lines show decline in amount of platelet ATP when no thrombin is added to the test tube. Solid lines show decline when thrombin is included. The greater decline of the solid lines indicates that thrombin is essential to both processes.

that of almost all other mammalian tissue, including skeletal muscle. Born found that much of the ATP disappears from platelets when blood clots. ATP probably plays an important role in viscous metamorphosis and clot retraction. In fact, these phenomena appear to be basically similar to the contraction of muscle. The protein actomyosin is abundant in muscle and its contraction under the influence of ATP and magnesium is believed to be the basic mechanism of muscle action. M. Bettex-Galland and E. F. Lüscher of the University of Bern in Switzerland recently isolated a protein from platelets that similarly contracts when ATP and magnesium ions are added. Work in Lüscher's laboratory and mine has established that the disappearance of platelet ATP during clotting is associated with clot retraction and viscous metamorphosis, rather than with the earlier process of thrombin formation. Phosphate ions are split from ATP, but we do not yet know the fate of the rest of the ATP molecule.

Since platelets have such a high concentration of ATP, it is not surprising that they have an active metabolism. Platelets consume oxygen, produce such wastes as carbon dioxide and lactic acid, and metabolize glucose both in the presence and in the absence of oxygen. They also contain glycogen, the storage form of glucose. Platelets possess the enzymes and intermediate products that play a role in carbohydrate metabolism. Lüscher has demonstrated an interesting relationship between metabolism and clot retraction. When thrombin is added to a platelet suspension, the production of lactic acid increases for about 10 minutes, whereupon metabolism stops. The importance of metabolic activity in clot retraction is further indicated by the fact that unless platelets are used soon after they are withdrawn from the body, glucose as well as thrombin must be added before retraction will occur.

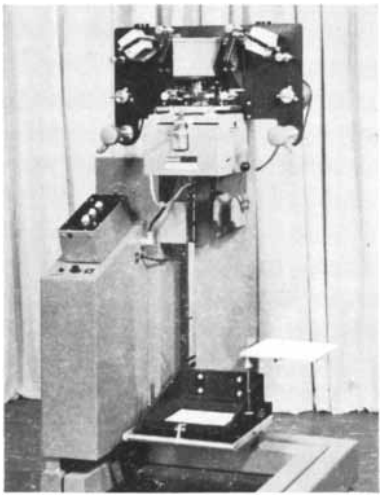
Metabolic activity and high level of ATP are probably responsible for another remarkable property of platelets: their ability to take up tremendous quantities of serotonin. This substance, related to the amino acid tryptophan, is formed in the brain and the intestine and may be important in their function. Serotonin makes smooth muscles contract. If the serotonin that is bound to platelets were released all at once, it would have profound and devastating consequences for the body. Platelets are somehow able to absorb serotonin even when they already contain a concentration a thousand times greater than that in the surrounding solution. There is some evidence that serotonin liberated from hemostatic plugs helps to arrest bleeding by constricting local blood vessels, but this process does not seem to be of major importance. Circulating platelets do not liberate their serotonin readily. Hence they may trap the substance in order to protect the body from it rather than simply to transport it. Platelets can also take up two other substances, epinephrine and norepinephrine, and at least one protein clotting-factor found in the plasma.

It now appears that platelets offer a rich field for further research. Like other blood constituents, they can be collected from normal individuals with a minimum of pain and damage. Methods for isolating, counting and observing them, using phase and electron microscopes and other apparatus, have been improved; platelets can be made to behave in the test tube, to some extent at least, as they do in the body. Their high content of ATP and their ability to cause clot retraction suggest that they may be able to throw new light on muscle function. Since they are isolated bits of cytoplasm without nuclei, they should provide a means for acquiring information about the role of the nucleus in the cell. And the study of platelet clumping may not only benefit people with bleeding diseases but also increase knowledge of thrombosis, so often the cause of heart attacks and other circulatory disasters.

Kodak reports on:

a definition of "very good"... an interesting sandwich... what Gutenberg might have done with photography

High-fi photography for highbrows



This enlarger was custom-built. The client's affairs are of such a nature that to supply him with anything short of the best-performing merchandise that money can buy could have disastrous consequences for all men of good will. The enlarger is a link in an astonishing chain on which much depends.

It is indeed a very good enlarger. We are tempted to resort to the cant of the times and call it a breakthrough in enlargers. We shall resist the temptation because we hate to lie. Nothing as climactic as a "breakthrough" has occurred in enlargers.

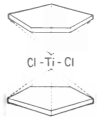
The reason it's a very good enlarger (the best in the world, we hope) is that some years ago it became apparent that descriptions like "very good" don't help much in dealing with such problems and that more precise-sounding terms like resolving power don't tell a full and honest story either. Progress came when we adopted the *weltanschauung* of the sound engineer, of all people!

Can you imagine the audacity of treating a photographic lens or a photographic emulsion or a combination of the two as though it were a loudspeaker or a telephone line and developing equations for its sine-wave frequency response? Yet this is what we were forced to do and it worked. The enlarger above can prove that it worked. The photographic-emulsion men and the lens men are given a common language, which they had lacked. The frequency response of a combination as in the above enlarger can be cascaded with the frequency response of other elements in the total picture-handling system, including the electronic, if any.

We have good reason to want to convince you that this nonsense is not as foolish as it sounds. We think that in the long run we shall be better off if we let you in on the principles by which we design a photographic *system* even though, under certain circumstances, we wish you would let us (George's successors) do it for you.

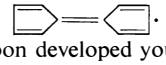
Education had best begin by studying a review paper, "Methods of Appraising Photographic Systems," by one of our men who has been up to his ears in this subject for a couple of decades. Get your free copy from Eastman Kodak Company, Apparatus and Optical Division, Rochester 4, N. Y. Freshman calculus and doggedness required.

Aromatic titanium



Our first entry in the class of compounds called ferrocene is a little item that goes by the name *Dicyclopentadienyltitanium Dichloride*. That is to say, the first member of the class obtainable as an Eastman Organic Chemical (Eastman 8057, 5 grams for $4.45). Statements must be carefully worded when mentioning a compound reputed to be a stereospecific catalyst for polyolefins. Wealth of empires hangs on such things. Nobody make a move, nobody drop or pick up a hint without first consulting his or her patent department.

Academics can afford to be carefreer. *They* can follow knowledge where e'er it leads. *They* can revel in ferrocenes and rejoice to see a broadening of the whole concept of aromaticity in organic chemistry. Benzene, naphthalene, such old-fashioned aromatic nuclei are essentially two-dimensional. Here aromaticity enters the third dimension. Whee!!!!

Considerations like zero dipole moment, non-polar nature, a single C-H absorption band, and the x-ray diffraction pattern cinched the pentagonal anti-prismatic "sandwich" structure for ferrocenes. Look at it up there. You would almost think that the science of chemistry has come to resemble the art of constructing ship models inside abandoned whiskey bottles. The image is historically false, however. Ferrocenes are the offspring of a casual liaison between two problems: preparation of organo-iron compounds and the hunt for a route to fulvalene,  .

It soon developed you could have a filling in the sandwich other than iron. Our titanium ferrocene has a bright, gleaming copper-bronze sheen to it. The original iron ferrocene is also orange-colored. Maybe the color has more to do with the bread than with the filling. Maybe we see too many images.

There is a lot of literature around on ferrocene chemistry. We ourselves put out a review article on it a couple of years ago. We had no ferrocenes to sell then, but we did have a ferrocene expert on the payroll and wanted to show him off. Request a copy from Distillation Products Industries, Rochester 3, N. Y. (Division of Eastman Kodak Company). Same address to order five grams of the compound. Need a copy of "Eastman Organic Chemicals, List No. 42"?

Try these paragraphs:

Routine commercial news item: *Kodak Phototypesetting Film* and *Kodak Phototypesetting Paper* are now sold by your* Kodak dealer.

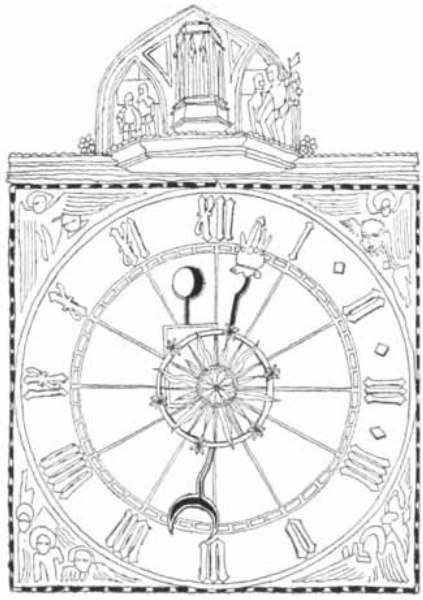
Deeper historical significance: Gutenberg did a fine thing by inventing movable type. The fellows who improved on his idea with hot-lead-casting typesetting machines also did their bit for civilization. Now, however, too many authors want to convey too many complicated thoughts to too many splinter groups of readers. The hot-lead machines are at their best with neat paragraphs of well-carpentered prose. Well-carpentered prose has its place, but for expressing the more severely logical varieties of thought it is limiting, imprecise, unclear, windy, and cumbersome. A more agile symbolism is needed at popular prices. Alert printing houses are trying to provide this symbolism through photographic methods rather than through the brutish hewing of lead. Give them time and encouragement. We have added our little touch of encouragement by having these two paragraphs phototypeset. Whether severely logical or not, they look all right, don't they?

*Everybody, more or less, has a Kodak dealer. One person can have several different Kodak dealers, even as one person at different times can have different interests and needs. If you ever hear of a Kodak product that interests you, never fester in doubt as to where to turn. Just write "Eastman Kodak Company, Rochester 4, N. Y." on the front of a postcard and write your question, name, and address on the back. Don't forget to mail it.

Price 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

A.A.A.S. Meeting

The interaction of science and society once again, as in recent years, preoccupied the annual meeting of the American Association for the Advancement of Science, which was held in December in New York. Symposia and conferences on "The Scientist's Role in the Community," "Psychological and Sociological Implications of Nuclear Arms," "The Urban Frontier: A Conquest of Inner Space," "Obstacles to the Application of Science for Human Welfare," "Encouragement of the Participation of Women in Science," "Interdisciplinary Approach to Methods of Implementing Desegregation" and "The Sciences in Communist China" (see below), on scientific manpower, juvenile delinquency, land zoning and science teaching crowded the traditional schedule of contributed papers and symposia on technical topics.

The American Society of Zoologists, whose program had featured a symposium on "Evolution and Dynamics of Vertebrate Feeding Mechanism," concluded its sessions by adopting two resolutions on political issues. One denounced the so-called Cooper Bill, now before the U. S. Senate, which would regulate the use of animals in research and teaching; the other expressed the society's concern over world population growth, urged the Government to sponsor research and education in the control of human fertility and attacked local U. S. statutory restrictions on the distribution of medical and scientific information on contraception.

"The Moral Un-Neutrality of Science" was the title of an address delivered at a dinner meeting of the association by the novelist Sir Charles Snow, who characterized himself as an "ex-scientist." He cited the responsibility of scientists in the questions of a ban on nuclear weapons testing and the control of nuclear armaments. "All physical scientists *know*," he pointed out, "that it is relatively easy to make plutonium.... We can work out the number of scientific and engineering personnel needed for a nation-state to equip itself with fission and fusion bombs. We *know* that for a dozen or more states it will only take perhaps six years, perhaps less.... We know, with the certainty of statistical truth, that if enough of these weapons are made—by enough different states—some of them are going to blow up. Through accident, or folly or madness—but the motives don't matter. What does matter is the nature of the statistical fact. . . . On the one side, therefore, we have a finite risk. On the other side we have a certainty of disaster. Between a risk and a certainty, a sane man does not hesitate."

Lunar False Alarm

"Radar reflections from the moon set off a missile scare at the nation's air defense centers on October 5," the Associated Press reported early in December. "The incident . . . occurred when computers at the Ballistic Missile Early Warning Station at Thule, Greenland, picked up radar signals it had bounced off the moon, 250,000 miles away."

According to the Air Force, the dispatch continued, "the scare was only momentary, since a quick check turned up the error. . . . The Air Force said that its equipment had been adjusted to avert more such flurries."

Science in Communist China

Science, along with industry and agriculture, has been pushed into a "great leap forward" on the Chinese mainland during the past decade of Communist rule. This was the picture painted by 25 speakers in the course of a two-day symposium held at the annual meeting of the American Association for the Advancement of Science under the joint sponsorship of the National

THE CITIZEN

Science Foundation and 13 scientific societies.

The Communist Government has followed a policy of "advancing on two legs." Although the number of well-qualified scientists is still small, the research and engineering enterprises carried on by a complex network of institutes under various ministries are employing the most sophisticated techniques, and less well-trained personnel are engaged on a large scale with considerable effect.

At the end of World War II China had only 200 geologists and was widely considered poor in mineral resources. By 1959, Edward C. T. Chao of the U. S. Geological Survey reported, 21,000 "geological workers," the great majority scantily trained, were engaged in the field. With the aid of some 400 foreign geologists they had made large mineral finds, including iron ore deposits comparable in size and iron content with the Mesabi Range deposit in the U. S. and deposits of molybdenum sufficient to give China the world's largest known reserves of that important alloying agent. No large uranium finds have been reported, however, and petroleum discoveries continue to lag behind needs.

In iron and steel smelting, according to K. P. Wang of the U. S. Bureau of Mines, a third of China's rising production (now at the level of 15 million tons of steel a year) continues to come from "backyard" furnaces. But the greater part comes from large mills employing modern techniques. The Chinese themselves have developed a novel method of tapping open-hearth furnaces, which they claim to be more efficient than methods used elsewhere. Similarly, coal mining—already approaching the total volume of that in the U. S.—is carried on both in small, unmechanized mines and in large mines in which up-to-date techniques are employed, including the novel procedure of breaking up coal seams with water under pressure.

The development of other earth sciences is likewise being pushed. J. Tuzo Wilson of the University of Toronto, who visited both Formosa and Red China two years ago, told of a search by 150 Chinese historians through ancient records for evidence of earthquakes as a guide to the location of dams and large industrial structures. The Chinese in-

vented the seismometer in the second century and they have accurate records of earthquakes dating back to the 12th century B.C.

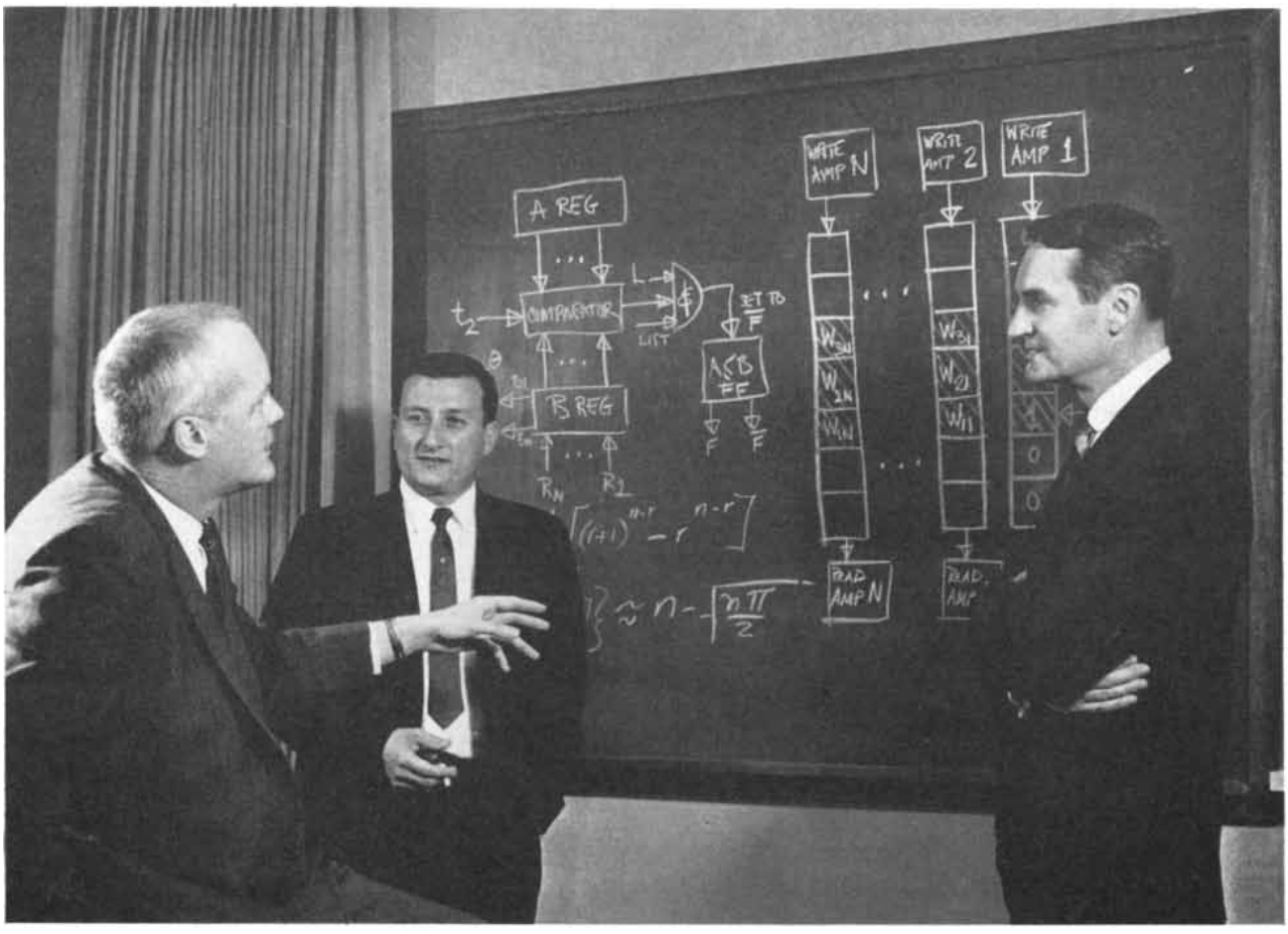
A decade ago China had fewer than 100 weather stations. More than 400 are now in operation and 60 make daily observations with high-altitude balloons. Upper-air weather maps from China, Malcolm Rigby of the American Meteorological Society said, compare in quality with those from the U.S.S.R.

At least four reactors for nuclear research have been built with the aid of the Russians. Several nuclear-physics laboratories are equipped with particle accelerators, including a number said to have been built entirely by Chinese physicists. Research in solid-state physics is likewise under way, and an institute for computer technology has been established in Peiping.

In medicine the country suffers an extreme shortage of trained physicians and modern facilities. This, along with a conviction that traditional Chinese medicine contains much of value, has prompted the government to retain herbalists and other traditional healers in the practice of medicine. But antibiotics are being manufactured and even such advanced procedures as open-heart surgery are being carried out in a number of centers. The intensive, widely publicized antivermin campaign of a few years ago has resulted in a marked drop in deaths from infectious and parasitic diseases.

The key scientific organization, the Academia Sinica, is modeled after the Academy of Sciences of the U.S.S.R. It now has a total of 40,000 employees in its laboratories and offices, including 800 scientists of Ph.D. grade, 800 of master's or bachelor's grade and more than 7,000 technicians and students. According to John M. H. Lindbeck of Harvard University, the Chinese government is now spending the equivalent of $400 million a year in support of scientific and technical research.

A few days before the symposium the State Department removed an obstacle that has hitherto kept U. S. Government scientists from participating in scientific meetings attended by scientists from Communist China or other "unrecognized regimes." Such meetings are always held abroad, as Chinese Communist scientists are not admitted to the U. S. In the future, the department announced, scientists may take part in "nongovernmental meetings at Government expense without accreditation if the Department of State determines that their participation is in the national



Mr. R. J. Shank, President (right), with Dr. R. E. Fagen (center) and Dr. R. B. Dawson (left) of the Information Sciences Division.

A Report from American Systems Incorporated...

A New Organization for Advanced Systems Technology

American Systems Incorporated was launched a year ago for research and development in the electronic systems field. With an across-the-board interest in systems technology, the Corporation has formed five Divisions:

ELECTROMAGNETIC SYSTEMS

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

COMMAND AND CONTROL SYSTEMS

Logic of command and control complexes; systems design and development; data acquisition, processing and display; communications.

COMPONENT DEVELOPMENT

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

INFORMATION SCIENCES

Mathematical and statistical research; computer programming, and development of advanced programming systems; computation services; digital system studies; logical design of military and industrial systems; advanced systems analysis.

RESEARCH LABORATORIES

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

We are gratified that the past year has been one of significant growth. Operations were started in a leased 10,000-square-foot building. Recently, we moved into our own 27,000-square-foot plant, on a 13-acre site in Hawthorne, California. This plant, which is the first unit in a long-range building program, has custom technical and scientific facilities, including an ultraclean laboratory for thin-film developments and advanced devices research projects.

We are proud that we have been able to attract an outstanding staff of technical people. We believe that scientists and engineers are our primary resource, and it is to utilize this resource that we have founded this corporation. Our operating concept has been to establish an organization which both sought new ideas and provided the facilities in which the creative mind could also be a builder, seeing his ideas through to a practical product.

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

AMERICAN SYSTEMS *Incorporated*

1625 East 126th Street, Hawthorne, California

interest. Without accreditation, a participant does not represent or speak for his government."

Leather Polisher

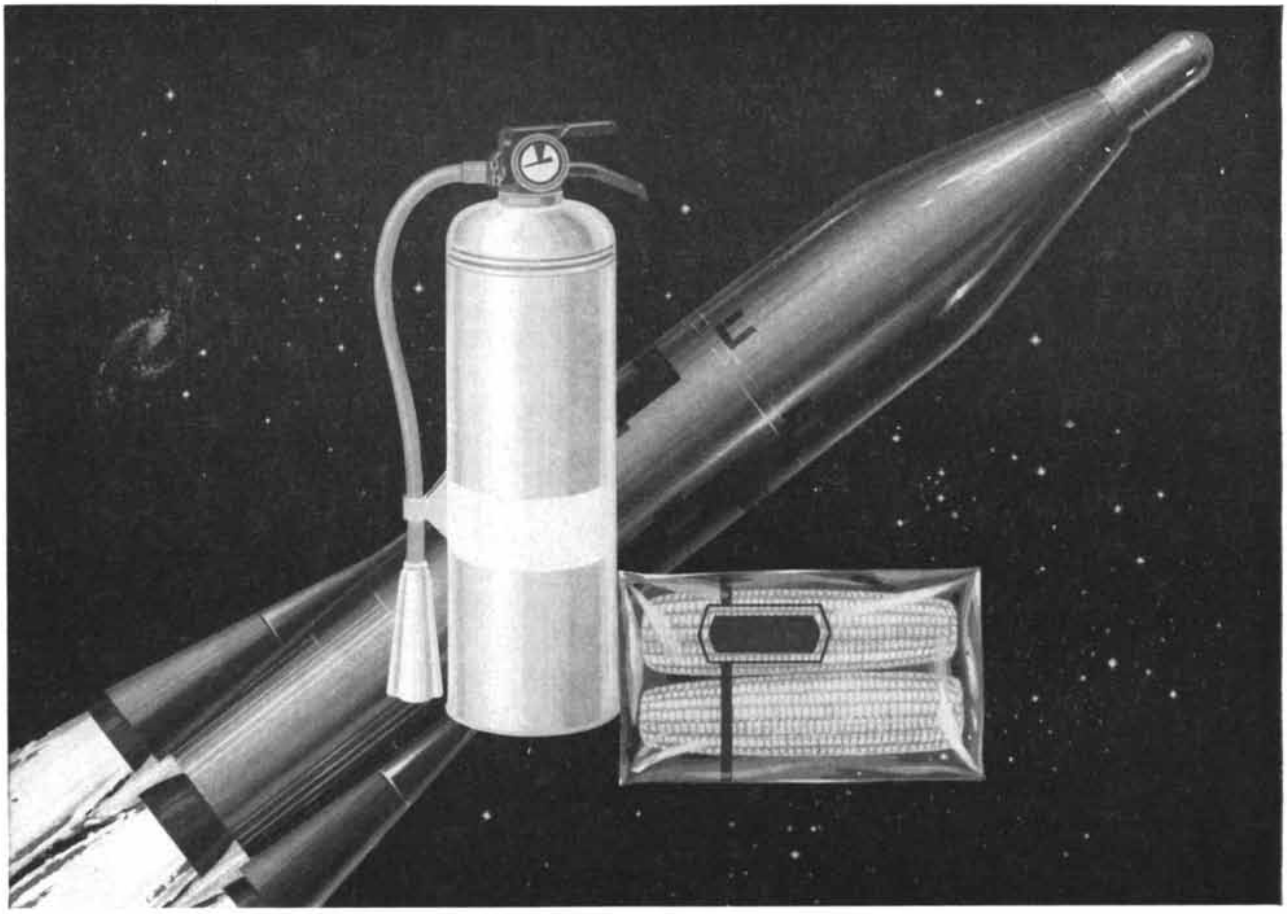
Zinjanthropus, the "nutcracker" man-ape who lived in and near the Olduvai Gorge in Tanganyika more than half a million years ago, may have dressed or slept in skins. Not far from the site where L. S. B. Leakey of the Coryndon Museum in Kenya and his wife found the first remains of Zinjanthropus in 1959, Leakey has now uncovered two more deposits dating to the time of this early hominid. One has yielded many broken animal-bones and stone tools and flakes. In the other Leakey has found bones from a second Zinjanthropus individual plus a curiously shaped bone tool, pointed at one end and roughly squared off at the other. "This would appear," Leakey notes in *Nature*, "to be some sort of a 'lissoir' for working leather. It postulates a more evolved way of life for the makers of the Olduvai culture than most of us would have expected."

The newly found deposit that yielded the leather polisher contains few other tools, but it does have a "remarkable collection" of animal fossils, including some "unquestionably new to science." The new Zinjanthropus skeletal remains include fragments of a skull, some teeth, two clavicles, two ribs, a large part of a left foot and six finger bones. "The discovery of parts of hand and foot," Leakey points out, "are of very special importance, for we have had no knowledge of these parts of the skeleton in early hominids."

Resonant Air

The space between the surface of the earth and the ionosphere is a gigantic reverberating chamber for radio waves. This was demonstrated recently by investigators at the Massachusetts Institute of Technology, who tuned in the very low-frequency oscillations of the natural "cavity resonator."

In 1952 a German physicist, W. O. Schumann, pointed out that since the terrestrial surface and the ionosphere are concentric reflectors of electromagnetic radiation, they should form the walls of a resonating chamber that would be set continually in vibration at its resonant frequency by natural disturbances such as lightning flashes. The larger the dimensions of any such enclosure, the lower the resonant frequency. In the case of the earth and the



Inert gases with an active future —from Du Pont fluorine chemistry

More efficient freezing of vegetables—or a side of beef. New guidance systems for missiles. Quick control of dangerous fires. North Pole environment in midsummer. These are just a few of the diversified roles already being played by Du Pont's low-boiling, inert "Freon"* gases. Perhaps they can perform a similar role, or an entirely different one, for you. For these gases are inert in the chemical sense only. Their future promises to be a very active one.

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"F-116"	CF_3-CF_3	138.0	−108.8	75.8
"F-13"	$CClF_3$	104.5	−114.6	83.9
"F-23"	CHF_3	70.0	−115.7	78.6
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BETTER THINGS FOR BETTER LIVING . . . *THROUGH CHEMISTRY*

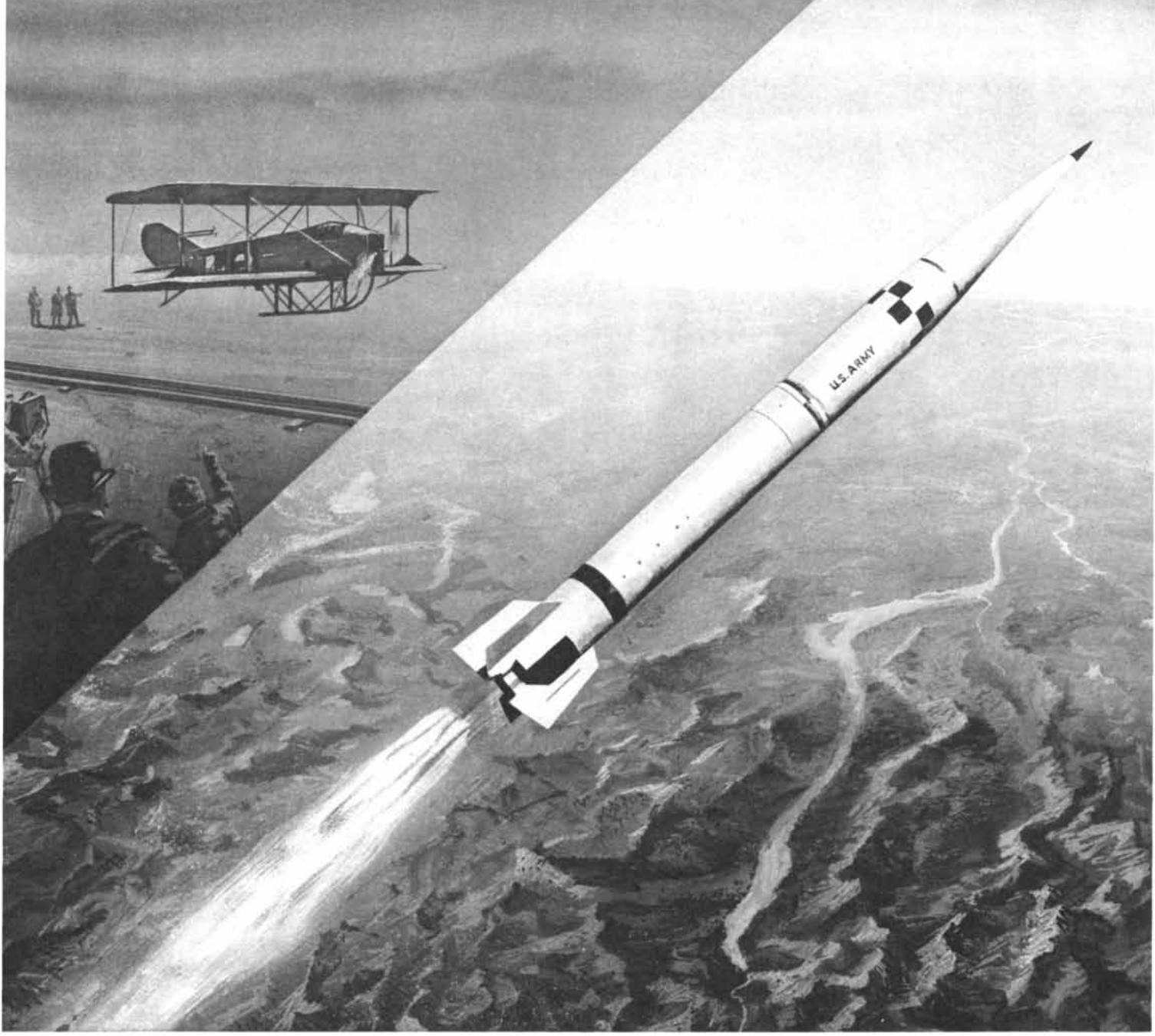
ionosphere the frequency was expected to be less than 10 cycles per second (corresponding to a wavelength of some 20,000 miles).

Atmospheric radio waves with frequencies below a few hundred cycles per second are difficult to detect, however, because power lines carrying alternating current also generate low-frequency radio waves that carry several miles. Martin Balser and C. A. Wagner of the M.I.T. Lincoln Laboratory first tried to pick up earth-ionosphere resonant waves with a portable antenna installed on a boat in Boston Harbor, and then at an isolated spot in New Hampshire 10 miles from the nearest power line, but the results were equivocal. Finally they put up a 120-foot antenna on a tower in a field near Ipswich, Mass., connected it to a receiver equipped with special filters to cut out interference from power lines and fed the resulting signal into a digital computer for analysis. The result, reported in *Nature*, was a distinct peak at 7.8 cycles—not far from the predicted fundamental frequency for the earth-ionosphere resonator—and four higher harmonics up to 32.5 cycles.

Fatherless Turkeys

Parthenogenesis—embryonic growth without fertilization—has become almost the rule rather than the exception in a strain of turkeys developed by an embryologist of the U. S. Department of Agriculture. The unfertilized eggs of these birds show some growth in two cases out of five. Most of them stop developing before an embryo is fully formed, but one of every three parthenogenetic eggs reaches the embryo stage. In the past five years 67 parthenogenetic turkey poults have been hatched. Several of these have lived to maturity; three have produced viable sperm; and last year one sired offspring.

The breeding experiment goes back to 1952, when Marlow W. Olsen noted the beginnings of embryonic growth in a surprisingly high proportion—one in six—of unfertilized eggs from a flock of hens of the Beltsville Small White turkey breed developed at the Agricultural Research Center in Beltsville, Md. By mating hens whose eggs had shown the highest incidence of parthenogenesis with cocks whose daughters' eggs exhibited the same tendency, he soon obtained not only a pronounced increase in the proportion of eggs showing parthenogenetic growth but a marked rise in the percentage reaching advanced stage of development. Summarizing the results



Missilry: 45 years ago, and today

There was a guided missile nearly a *half-century* ago. It was Sperry's Aerial Torpedo for the Navy—the world's first guided missile, 14 feet in length, and with a range of 50 miles at 90 mph.

Since then, a family of missiles and of missile guidance systems of ever-increasing power—and "brainpower"—has evolved at Sperry. Notable was the Navy's Sparrow I, the first operational air-to-air missile. An outstanding example today—when it becomes operational—will be the Army's Sergeant, for which Sperry is prime contractor. A medium range, surface-to-surface, inertially-guided ballistic missile, Sergeant has had a brilliant record of successful test firings. It is highly mobile and easy to operate—approaching conventional artillery in speed of emplacement and displacement.

In systems and components for missiles, too, Sperry has made major contributions. For the Army's Nike Zeus – the nation's only anti-missile missile system now in the advanced development stage for intercepting ICBMs—Sperry developed for Bell Laboratories and Western Electric extended range target tracking and discrimination radar transmitters. Other Sperry radar systems acquire, track and guide the Navy's Terrier and Talos missiles, providing precision fire control for missile cruisers, destroyers and carriers.

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SEA • SURFACE • AIR • SPACE

SPERRY 50 YEARS 1910 1960

in *Proceedings of the Society for Experimental Biology and Medicine*, Olsen reports that no less than 15 parthenogenetic poults were hatched in 1960. In all cases examined so far the parthenogenetic birds had the diploid number of chromosomes, the normal number for body cells. Evidently the chromosomes of the unfertilized egg from which they grew had doubled. Moreover, all the birds were males. This was to be expected, because in birds individuals with two identical sex chromosomes are always males.

Official Word on Fat

For nearly 10 years cardiologists and physiologists have been debating whether the rich U. S. diet is bad for U. S. arteries. At its recent annual meeting the board of directors of the American Heart Association released a report from its "highest medical and scientific body" suggesting that it is. The report, called "Dietary Fat and Its Relation to Heart Attacks and Strokes," was prepared by a special committee headed by Irvine H. Page, research director of the Cleveland Clinic.

The report notes that heart attacks are almost always caused by atherosclerosis, the most common form of artery hardening, and that strokes often have the same cause. The report attributes atherosclerosis to multiple factors, including elevated blood cholesterol, elevated blood pressure, diabetes, obesity and excessive cigarette smoking. The report's recommendations focused on lowering cholesterol levels and weight reduction. It concluded: "The reduction or control of fat consumption under medical supervision, with reasonable substitution of poly-unsaturated for saturated fats [*i.e.*, fats in vegetable oils for those in dairy products and meat], is recommended as a possible means of preventing atherosclerosis and decreasing the risk of heart attacks and strokes."

Flatter Space?

The scant body of observational data against which models of the universe can be tested has recently been augmented. According to a report in *Nature*, a set of measurements made at the Nuffield Radio Astronomy Laboratories at Jodrell Bank in England seems to rule out one of the most famous models, the Einstein–De Sitter universe.

In such a universe, expanding from a compact origin, space over great distances would be highly curved and non-Euclidean. The curvature would create

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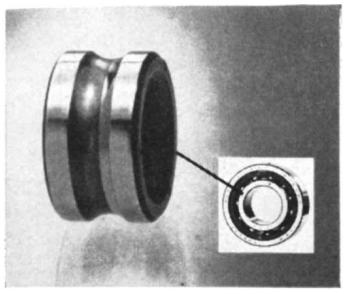

▲ Unretouched photo of inner ring from BarTemp bearing that ran 2727 hours—1010 hours at 500°F. plus an additional 1717 hours at 575°F. Dark band in raceway is lubricant transferred from retainer.
▼ Excerpts from lab and field test results.

Bearing	Temperature	Speed (RPM)	Hours
SR3HX110	500°F. 575°F.	1,200	2727
SR4HX110	338°F.	10,000	2500+
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SR3BSSX112	500°F.	4,500	1036+
SR2HX110	575°F.	2,500	1628

NEW DESIGN DEVELOPMENTS

Two design innovations made BarTemp possible—a Barden-developed heat treatment for stainless steel used for the bearing rings, and a new retainer that serves as a dry lubricant and a ball separator. The BarTemp retainer, reinforced Teflon compounded with a solid lubricant, is the sole lubrication required. As the bearing rotates, the balls transfer microscopic particles of the lubricant to the raceways.

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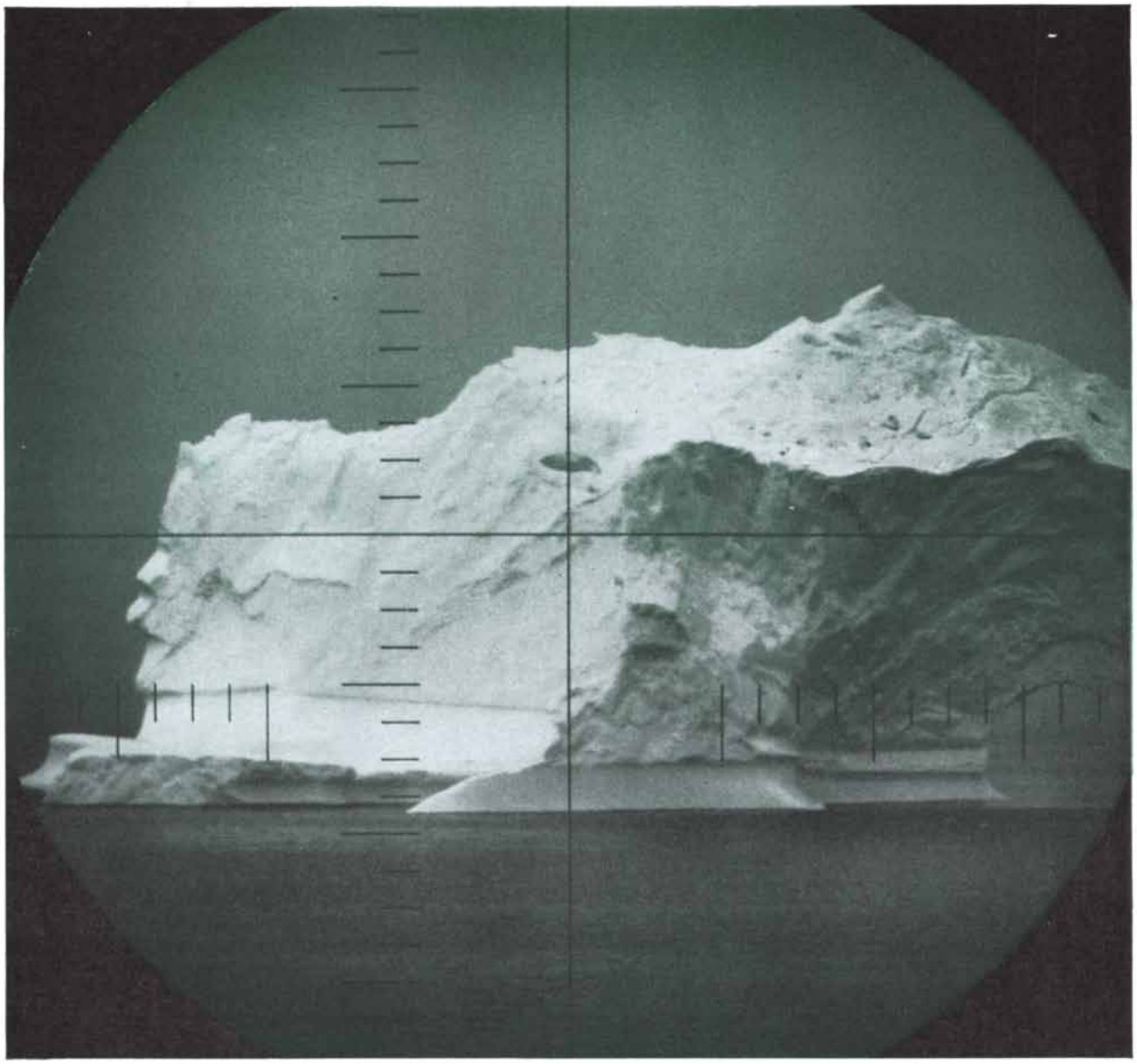
distortions, so that very distant galaxies would appear to have a substantial diameter instead of being mere points, as they would appear in a strictly Euclidean universe. Thus galaxies some eight to 10 billion light years away should have apparent angular diameters in excess of 15 seconds of arc. In a moderately curved steady-state universe galaxies at the same distance would have minimum angular diameters of about four seconds of arc.

Such galaxies presumably lie within the range of radio telescopes. However, these instruments have not had sufficient resolving power to determine so small an angular limit. Now, by linking Jodrell Bank's 250-foot steerable radio telescope with auxiliary aerials 40 miles away, L. R. Allen, H. P. Palmer and B. Rowson have created an interferometer with a far larger base line and therefore with much higher resolving power than heretofore available. Operating at a wave length of 1.89 meters, the combined antenna system has a length of 32,000 wave lengths, which means it can measure angular diameters as small as one or two seconds of arc. Of 38 radio sources examined thus far—presumably including some colliding galaxies beyond the six-billion-light-year range of optical telescopes—none had a measurable angular diameter greater than about six seconds of arc and at least seven had diameters smaller than three seconds. Hence seven appear to be even a little smaller than they should be on the steady-state model, and completely out of the range predicted by the Einstein–De Sitter model.

George W. Gray

George W. Gray, who had written 18 articles for Scientific American since its reorganization in 1948, died of a heart attack on December 29. His age was 75.

Born in Texas, Gray studied English at Harvard College, worked on newspapers and fell in love with science in the days of James Jeans and A. S. Eddington. He became a free-lance writer specializing in scientific subjects and over the years wrote numerous articles and books. Both the man and his writing had the virtues of simplicity, directness and, above all, veracity. He set a standard for what has come to be called science writing.



Official U. S. Navy photograph taken through the Kollmorgen 8B Periscope of the Seadragon during its polar cruise in August, 1960.

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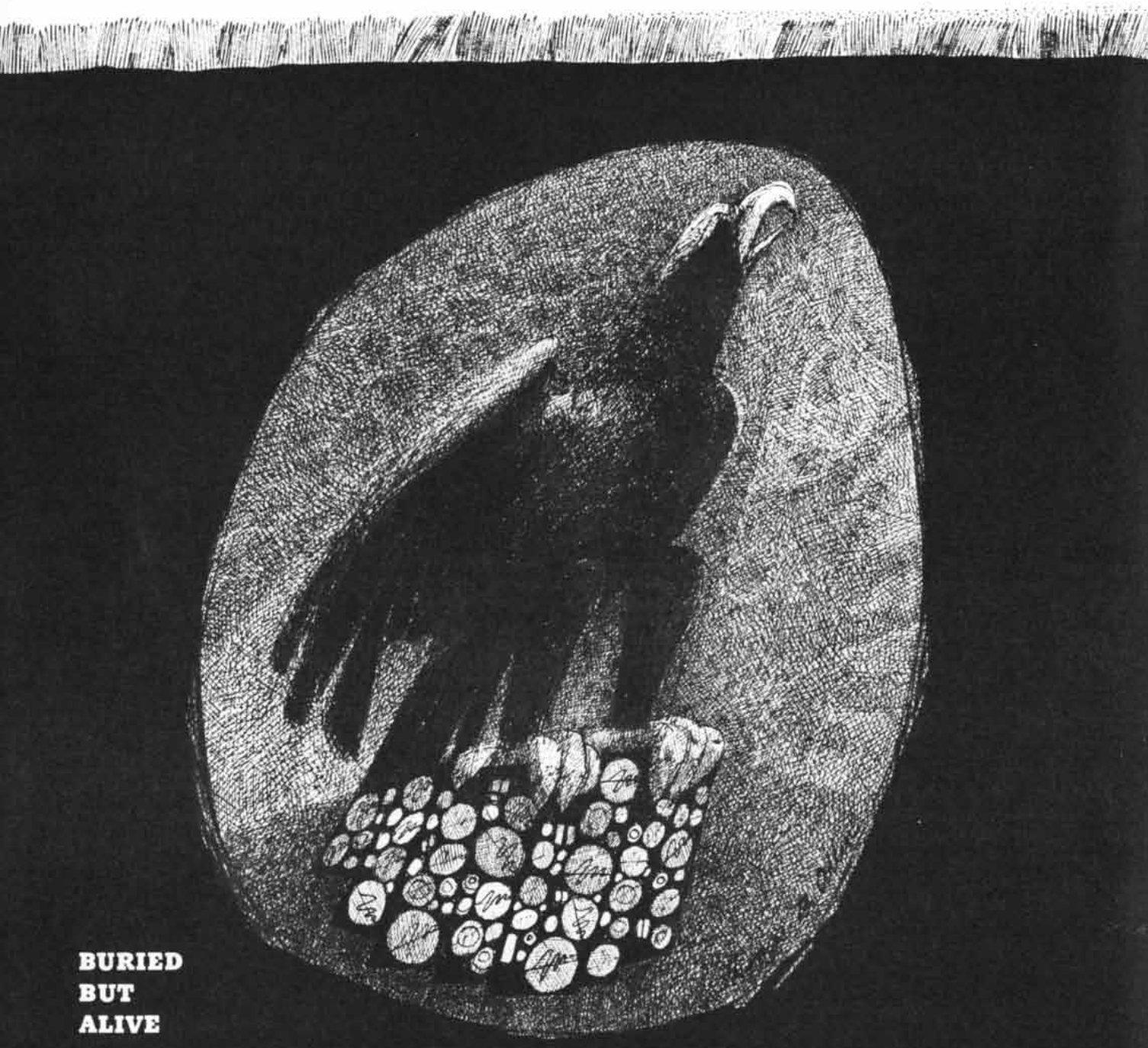

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The Chemical Structure of Proteins

The atom-by-atom structural formulas of three proteins have now been worked out. This knowledge should help in understanding how the structures of proteins are related to their biological activity

by William H. Stein and Stanford Moore

Six years ago, after a decade of pioneering research, Frederick Sanger and his colleagues at the University of Cambridge were able to write the first structural formula of a protein—the hormone insulin. They had discovered the precise order in which the atoms are strung together in the long chains that make up the insulin molecule. With this truly epochal achievement, for which Sanger received a Nobel prize in 1958, there opened a new chapter in protein chemistry.

Some idea of the significance of this chapter for chemistry and biology can be gained from the realization that proteins comprise more than half the solid substance in the tissues of man and other mammals. Proteins are important mechanical elements and perform countless essential catalytic and protective functions. Only when the structures of large numbers of proteins have been worked out will biochemists be in a position to answer many of the fundamental questions they have long been asking. The goal is still far off, but there has been much progress in this challenging field.

Before embarking on a summary of some of the recent developments, it is well to point out that the chemical approach does not provide a complete solution to the problem of protein structure. The order of links in the chain is not the whole story. Each chain is coiled and folded in a three-dimensional pattern, no less important than the atom-by-atom sequence in determining its biological activity. Chemical methods can provide only a partial insight into this three-dimensional, or "tertiary," structure. In the past few years the spatial problem has begun to yield to X-ray analysis. The present article, however, is primarily concerned with the chemical rather than the physical line of attack.

Proteins are very large, they are complex and they are fragile. The molecule of insulin, one of the smallest proteins, contains 777 atoms. Some protein molecules are thought to be 50 times bigger, although even the size of the largest ones is not definitely settled. Fortunately most of them are constructed on the same general plan. The links, or building blocks, in the molecular chains are amino acids. In their uncombined form each of these substances consists of an amino group (NH_2) and a carboxyl group (COOH), both attached to the same carbon atom. Also attached to this carbon are a hydrogen atom and one of 24 different "side groups." When the amino acids link together in a protein molecule, they join end to end, the carboxyl group of one combining with the amino group of the next to form a "peptide bond" (–CO–NH–) and a molecule of water (HOH). Since each component has lost a molecule of water, it is called an amino acid "residue." Under the action of acids, alkalis or certain enzymes, peptide chains break apart, the –NH– groups regaining a hydrogen atom and the –CO– groups a hydroxyl group (OH). Thus each residue regains a molecule of water and the peptide bonds are said to have been hydrolyzed.

Among the amino acids the one called cystine is unique. Its molecule is a sort of Siamese twin containing two $-NH_2$ and two –COOH groups, with identical halves of the molecule joined by a disulfide bond (–S–S–). One cystine molecule can therefore enter into two separate peptide chains, cross-linking them by means of the disulfide bond. Cystine can also cause a single chain to fold back on itself.

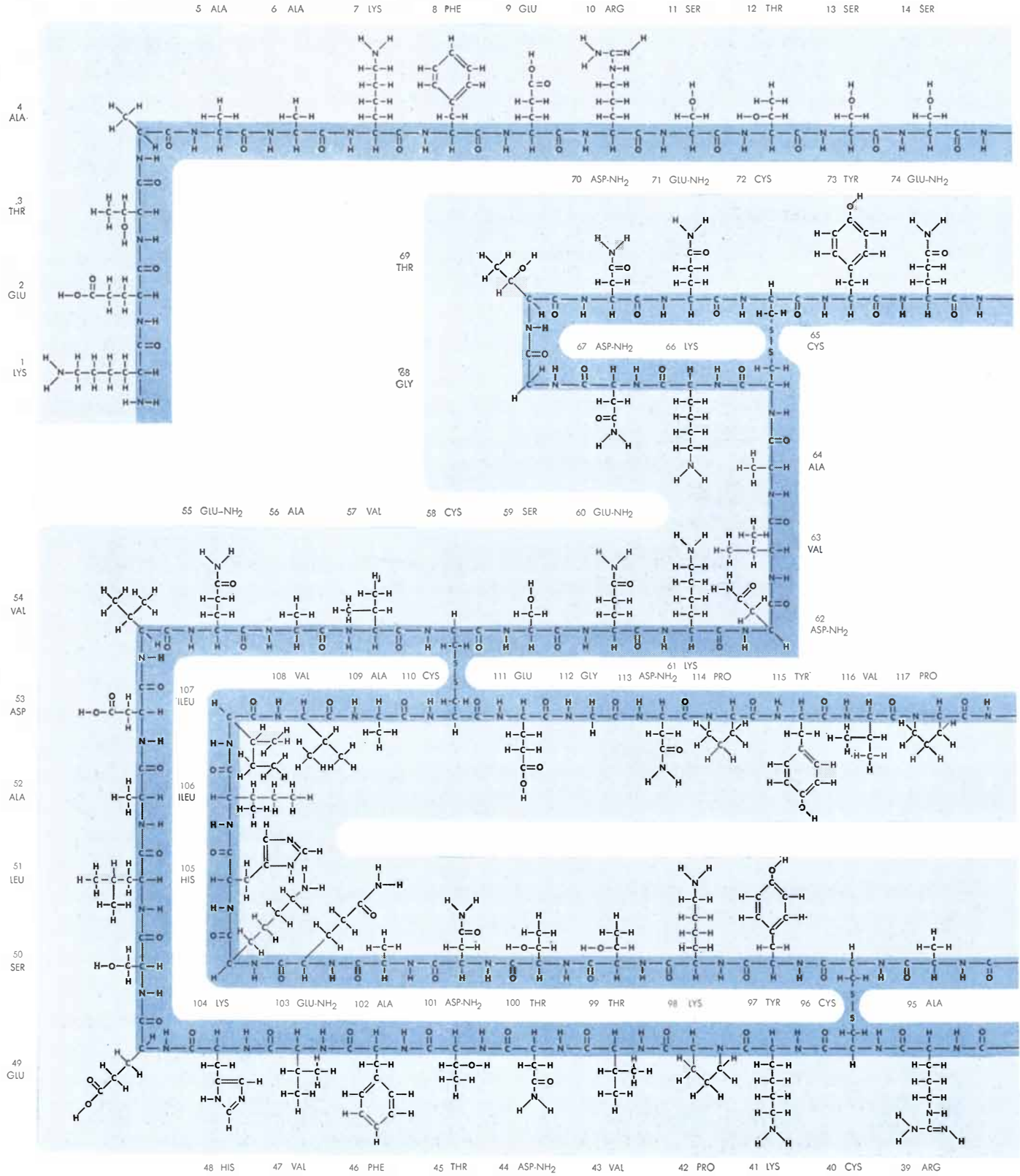
The Insulin Molecule

Much of the chemistry of proteins had been laboriously uncovered in many years of research before Sanger took up the study of insulin. His success rested largely on two advances in technique. One was the development of paper chromatography by the British chemists A. J. P. Martin and R. L. M. Synge. By means of this elegant method tiny samples of complex mixtures can be fractionated on a piece of filter paper and their components identified [see "Chromatography," by William H. Stein and Stanford Moore; SCIENTIFIC AMERICAN, March, 1951]. The second key to the problem was Sanger's discovery of a way to label the amino group at the end of a peptide chain. He found that a dinitrophenyl (DNP) group could be attached to free amino groups to form a yellow compound. Even when the peptide is fragmented into separate amino acids, the DNP group remains attached to the residue at the end of the chain, thus making it possible to identify this residue.

The details of Sanger's analysis have already been described in this magazine by one of his co-workers ["The Insulin Molecule," by E. O. P. Thompson; May, 1955]. Here we shall review their work very briefly. With the help of the DNP method they first established that the insulin molecule consists of two chains. These chains are held together by the –S–S– bonds of cystine residues. By treating the hormone with a mild oxidizing agent the experimenters were able to open the disulfide bonds and thus separate the two intact chains. One proved to contain 21 amino acids; the other, 30. They then proceeded to cleave each chain into smaller pieces by treating it with acid, which hydrolyzes peptide bonds more or less at random. The fragments were separated by chromatography and by other means, labeled at their amino ends by the DNP method, broken down further, separated again,

relabeled and so on. In this way the order of amino acids in a large number of small pieces was established. By shattering the chain many times and noting overlapping sequences in the various fragments the Cambridge group at last deduced the complete succession of amino acid residues in each part of the molecule.

After the completion of this Herculean task an almost equal effort was required simply to determine the pairing of the half-cystine residues. One chain was found to contain four half-residues of cystine and the other chain two. To find out which ones were paired it was necessary to break the molecule into smaller fragments containing different pairs of half-cystine residues with their disulfide bonds intact. In the process, however, the cystine halves tended to trade part-

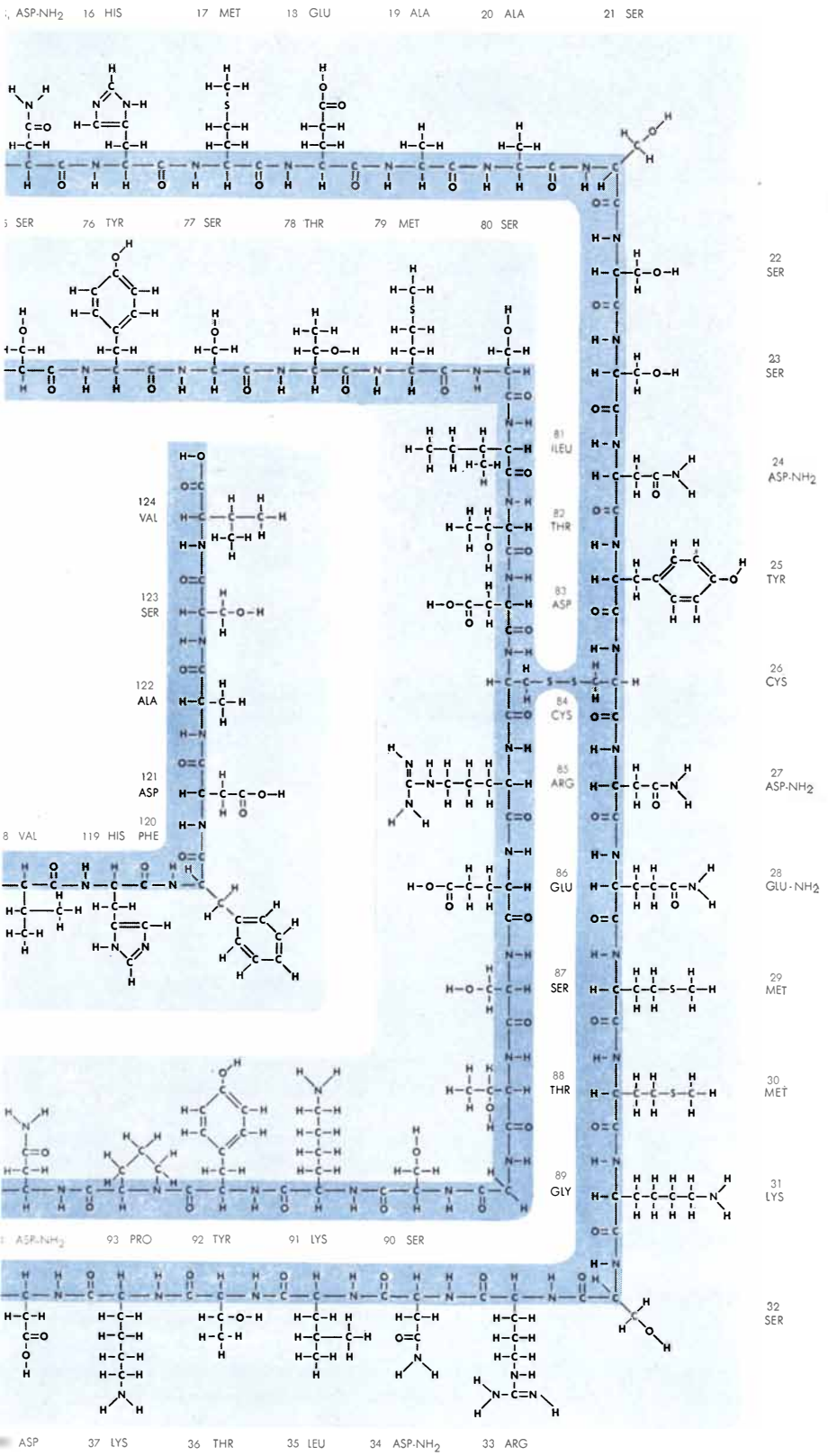


ners and produce spurious pairings. Finally a way around the difficulty was worked out, and the disulfide bonds were unequivocally pinned down.

Once Sanger had shown that the problem was solvable a number of workers began to attack the structure of larger proteins. In the six years that have passed two more molecules have been completely delineated and others are on the way. Last year the analysis of the structure of ribonuclease, an enzyme that digests ribonucleic acid, was completed in the authors' laboratory. Ribonuclease contains 124 amino acid residues. As this article was in preparation Gerhard Schramm and his associates in Germany and Heinz L. Fraenkel-Conrat, Wendell M. Stanley and their colleagues at the University of California announced that they had finished working out the structure of the 158-amino-acid-residue protein in tobacco mosaic virus.

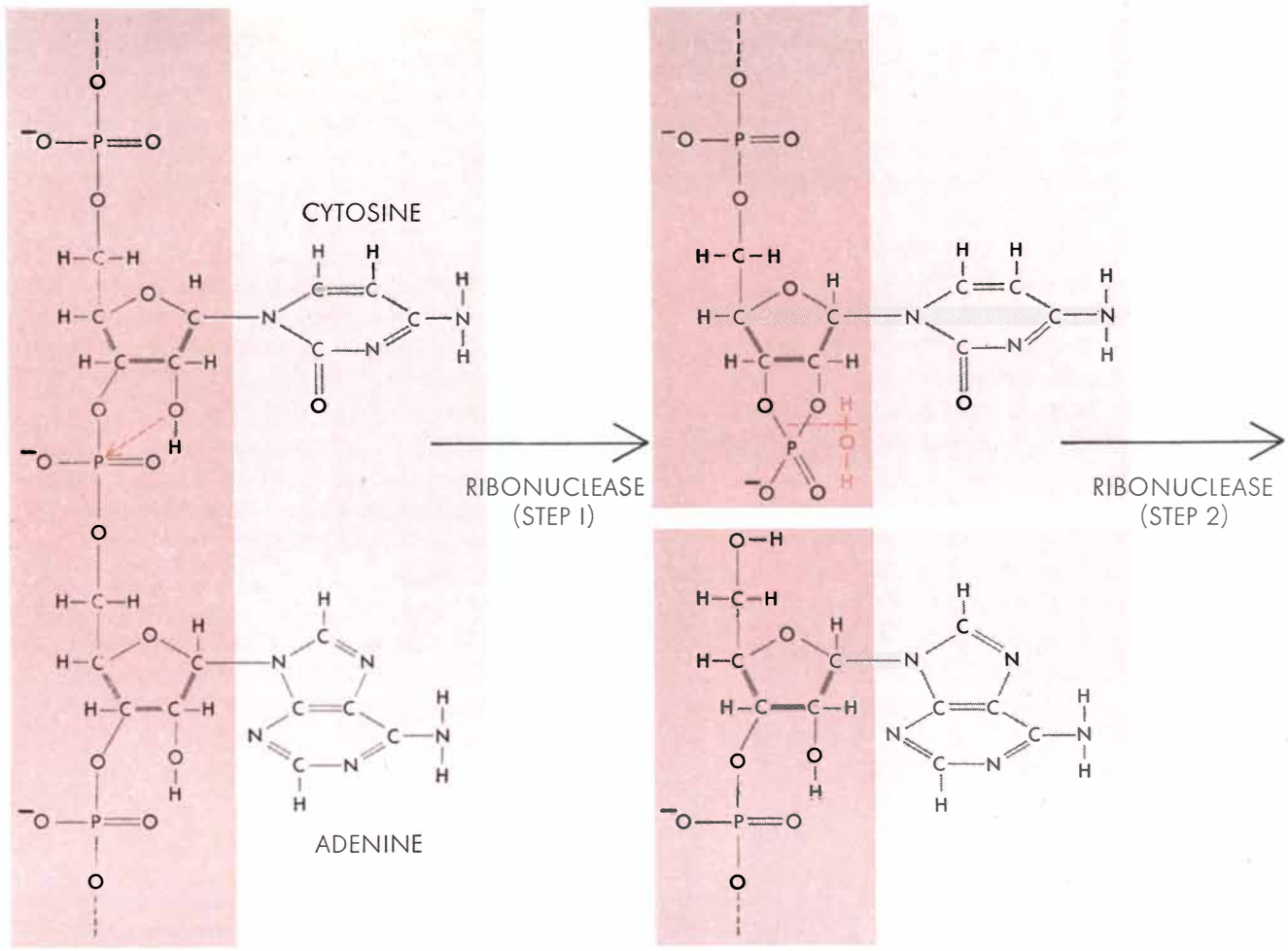
At first sight it might seem that any protein should yield to a massive effort along the lines used so successfully with insulin. As Sanger and others realized, however, it is not so simple as that—if simple is the word for 10 years of unremitting work. Problems multiply rapidly with increasing molecular size, and an approach that was difficult and time-consuming in the case of insulin can become fruitless and interminable.

One aid to further progress has been the development of more precise methods for identifying and measuring small quantities of amino acids. Several years ago the authors undertook to apply column chromatography for this purpose. Instead of filter paper we use a five-foot



ALA	ALANINE
ARG	ARGININE
ASP	ASPARTIC ACID
ASP-NH2	ASPARAGINE
CYS	CYSTINE
GLU	GLUTAMIC ACID
GLU-NH2	GLUTAMINE
GLY	GLYCINE
HIS	HISTIDINE
ILEU	ISOLEUCINE
LEU	LEUCINE
LYS	LYSINE
MET	METHIONINE
PHE	PHENYLALANINE
PRO	PROLINE
SER	SERINE
THR	THREONINE
TYR	TYROSINE
VAL	VALINE

MOLECULE OF RIBONUCLEASE, an enzyme that digests the cellular substance ribonucleic acid (RNA), is diagramed in two dimensions on these two pages. In this structural formula are 1,876 atoms: 587 of carbon (C), 909 of hydrogen (H), 197 of oxygen (O), 171 of nitrogen (N) and 12 of sulfur (S). The backbone of the chain of amino acid residues is in the darker shaded area; the side chains characteristic of the various amino acids are in the lighter shaded area. The amino acid residues are numbered from 1 to 124, beginning at the amino end of the chain. Abbreviations for amino acids appearing in the diagram are indicated above.



SPLITTING OF RIBONUCLEIC ACID molecule by ribonuclease takes place in two steps. Backbone of the molecule, of which a segment is shown in dark shaded area, is attacked at the phosphorus atom following cytosine (or uracil) but not adenine (or guanine). In the first step the bond between phosphorus and the oxygen atom below it opens, splitting the molecule, a different oxygen uniting

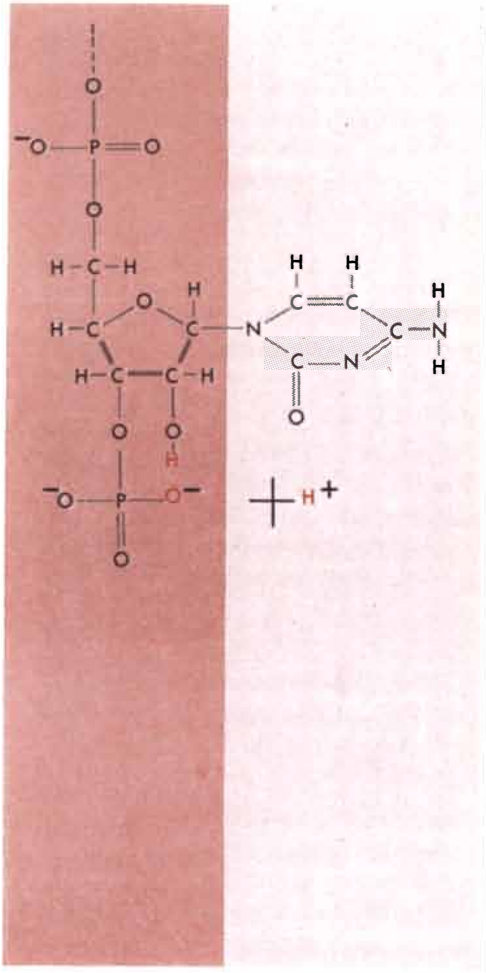
column of an ion-exchange resin. One or two milligrams of an amino acid mixture placed at the top of the column are washed down through the column by solutions of varying acidity. Depending on their relative affinity for the solutions and for the resin, the individual amino acids move down the column at different rates. By proper choice of salt solutions, acidity and temperature, it is possible to adjust the rates of travel so that the separate amino acids emerge from the bottom of the column at predetermined and well-spaced intervals. To detect the colorless amino acids we heat them with ninhydrin, a reagent that yields a blue color. The intensity of the color is proportional to the amount of amino acid.

In the final version of the device, developed in collaboration with D. H. Spackman, the amino acid analysis is accomplished automatically. The outflow from the column is continuously mixed with ninhydrin, sent through a heating bath and then analyzed by a photometer attached to a recorder. As it flows out of the bath and into the photometer the solution is alternately colorless (when it contains no amino acid) and blue (when an amino acid is present). A continuous plot of the intensity of the blue color shows a series of peaks, each corresponding to a particular amino acid, the area under the peak indicating the amount of that amino acid in the sample. With the automatic amino acid analyzer one operator, working part time, can carry out a complete quantitative analysis of the amino acids from a hydrolyzed protein in 24 hours. The device played an essential role in the work on ribonuclease.

The Ribonuclease Molecule

We chose ribonuclease for study for several reasons. The protein, first isolated from beef pancreas in 1920, was available in relatively pure form, having been crystallized by Moses Kunitz of the Rockefeller Institute in 1940. It was known to be a rather small protein, with a molecular weight of about 14,000. (The molecular weight of insulin is 5,733.) Moreover, the manner in which ribonuclease breaks down the ribonucleic acid (RNA) molecule had been worked out in several laboratories. As a result there was a chance of correlating its structure, once that was established, with its biochemical function.

As a first step in the program C. H. W. Hirs, together with the authors, further purified crystalline ribonuclease with the aid of ion-exchange resins. When a hydrolyzed sample was analyzed, it proved to contain a total of 124 amino acid residues of 17 different kinds, plus a quantity of ammonia [*see illustration on pages 90 and 91*]. The presence of ammonia indicated that some of the aspartic acid and glutamic acid that showed up in the analysis came not from residues of these amino acids in the protein molecule but from the related amino acids, asparagine



with the phosphorus (*dashed arrow*). In second step another phosphorus-oxygen bond is cleaved with addition of water (H-O-H).

and glutamine. When the last two are hydrolyzed, they are converted to aspartic and glutamic acids and ammonia. Thus the intact ribonuclease molecule contains 19 different kinds of amino acid residue.

There were four residues of cystine and therefore four disulfide bonds. At about that time Christian B. Anfinsen of the National Heart Institute demonstrated, by the DNP method, that ribonuclease consists of a single peptide chain. Therefore the disulfide bonds must cause the folding together of sections of the same chain.

After opening up the disulfide bonds by oxidation, Hirs proceeded to break the 124-link chain into smaller pieces. Here Sanger's method of random hydrolysis with acid did not seem promising. It probably would produce so many small fragments that they would be almost impossible to separate. And even if they were isolated and their structure determined, it seemed unlikely that the se-

quence of amino acids in the complete chain could be deduced from these small bits and pieces. For a more selective method of dissection we turned to the protein-splitting enzymes. A number of these had been purified and their mode of attack on peptide chains elucidated at the Rockefeller Institute by Max Bergmann and Joseph S. Fruton and their colleagues. The most specific is trypsin, which cleaves only bonds involving the carboxyl groups of the amino acids arginine and lysine. Others, such as chymotrypsin and pepsin, also confine their activity to certain bonds, though not so selectively as does trypsin.

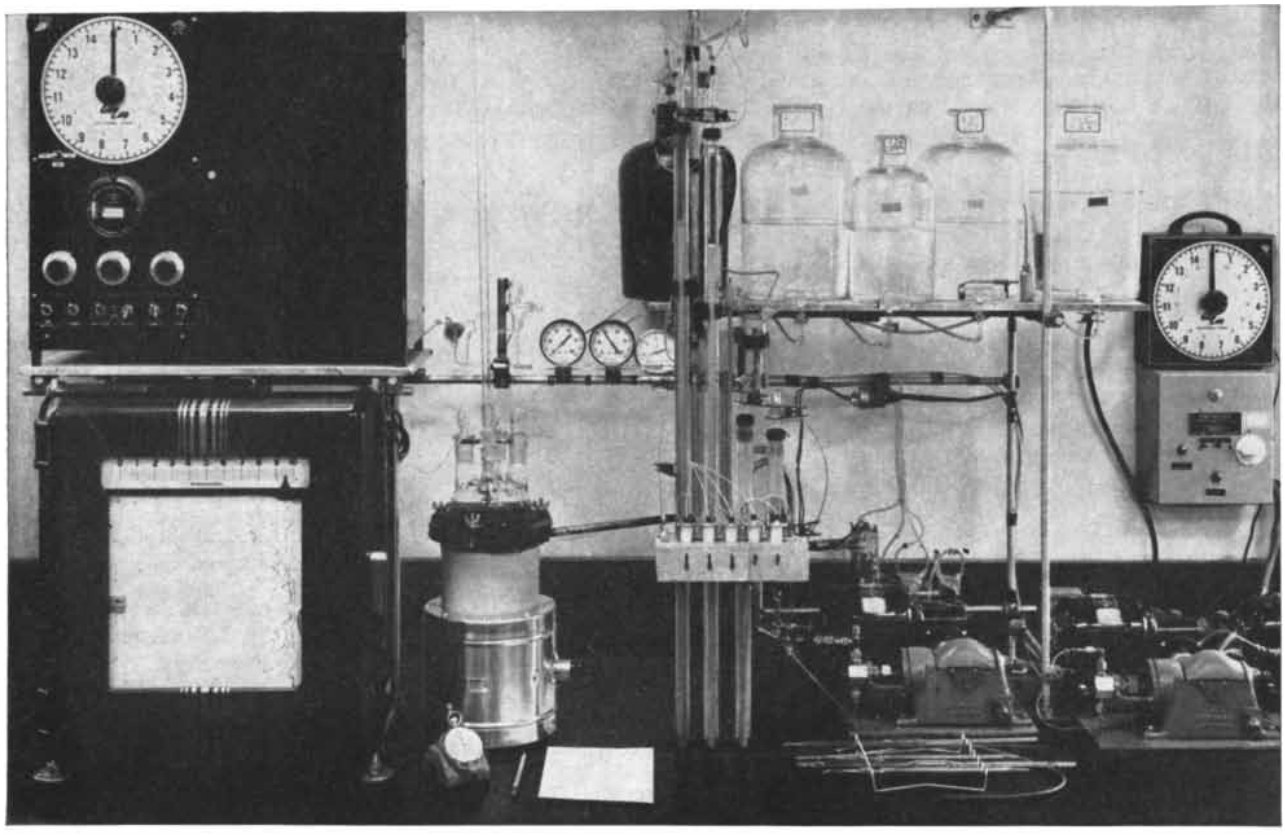
Since there are 10 lysine and four arginine residues in ribonuclease, Hirs first treated the protein with trypsin. The products were separated from one another by the use of columns of ion-exchange resins, and each was then analyzed for amino acids. All told, 13 peptide fragments were isolated, ranging from peptides with only two amino acid residues to some containing more than 20. Among them they accounted for all of the 124 amino acid residues of ribonuclease. To obtain additional fragments Hirs and J. L. Bailey also split the molecule at other points with chymotrypsin and with pepsin.

The amino acid composition of all the fragments was determined, and the residue at the amino end identified in some of them. With this knowledge it was possible, in a sort of crossword-puzzle fashion, to derive a partial structural formula that showed the order in which the various peptides produced by the different enzymatic cleavages must have been arranged in the parent molecule.

The next step was to determine the sequence of amino acid residues within the fragments. One extremely valuable tool, developed by Pehr Edman in Sweden, was a reaction that can clip off one amino acid unit at a time from the amino end of a peptide sequence. There was also a pair of enzymes that can do the same sort of job in some cases, one at the amino and the other at the carboxyl end. Using these and other means, Hirs analyzed 24 peptides completely and examined parts of many more. Each step of each manipulation was monitored on the amino acid analyzer.

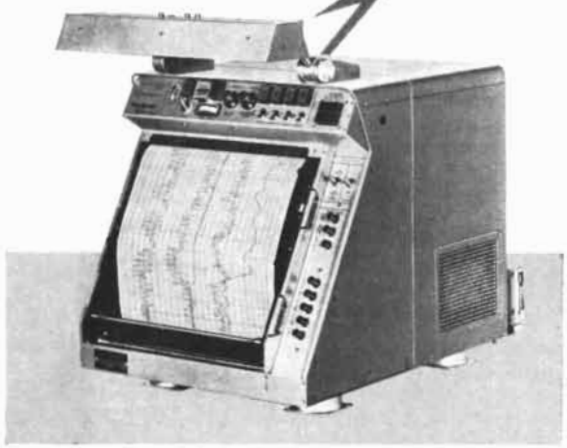
After five years of work the complete sequence of the ribonuclease chain was finally established [*see illustration on pages 82 and 83*]. Spackman then undertook to determine the arrangement of the four disulfide bonds. As in the case of insulin, the problem turned out to be difficult. Two of the bonds were particularly fragile. Only after a long study did Spackman find out how to break ribonuclease into peptides that contained cystine residues with their disulfide bonds intact. Once this had been accomplished the crosslinks could be located and the complete formula written down.

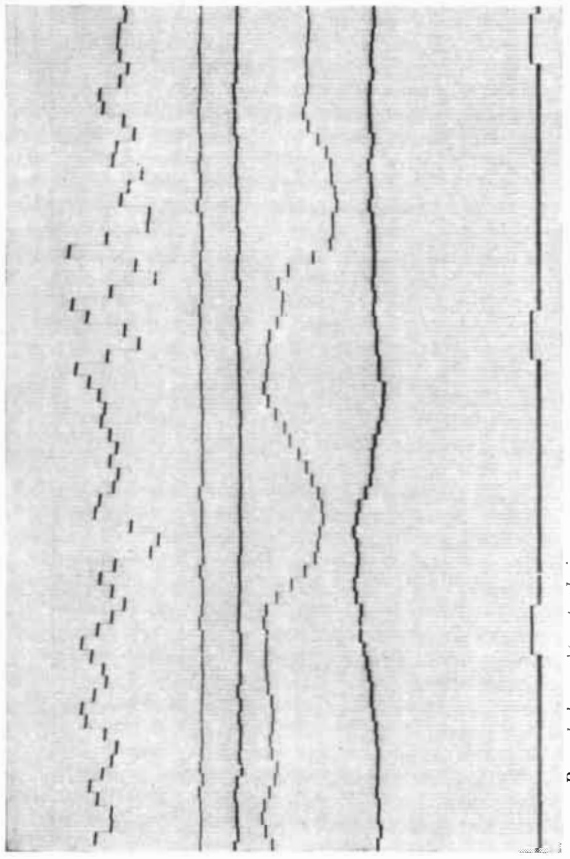
Here we must emphasize that, while the complete formula is certainly correct in most respects, it must still be considered a working hypothesis. Although a great deal of quantitative data supports it, and although Anfinsen's laboratory has derived about a quarter of it independently, we still cannot be completely certain of the results. Degradative experiments, in which molecules are broken down, do not offer final proof for an organic chemical structure; the last word comes when a postulated structure is synthesized and then shown to have all the same properties as the natural product. In spite of the substantial advances of the past few years in the synthesis of complex peptides, it will probably be some time before a molecule of the size of ribonuclease is put together. Until then we must be on the lookout for surprises, because it is entirely possible that ribonuclease contains chemical linkages that are not revealed by the deg-



AMINO ACID ANALYZER is photographed in the authors' laboratory at the Rockefeller Institute. Vertical tubes in center are ion-exchange columns. Photometer unit is enclosed in case at top left; recorder is at bottom left. Next to it on the bench is heating bath.

Tracking a Surveillance Drone with the Visicorder





Record shown ¼ actual size.

Drone surveillance and reconnaissance gives U.S. Army combat units a high-altitude vantage point with much broader horizons from which to view battlefield action and terrain.

If effective use of the data gathered by the drone—the "eye in the sky"—is to be made, accurate instruments have to be on hand to monitor the drone's position and movement, its operational behavior and its response to flight commands. Telemetry supplies the radio link which transmits all this behavior information to a thoroughly-instrumented mobile tactical command post developed by Tele-Dynamics Division of American Bosch Arma Corp.

The Honeywell Model 1012 Visicorder has been selected as the direct readout unit in the Tele-Dynamics Drone Surveillance Telemetry system. In use with its companion instrumentation, the 36-channel Visicorder simultaneously displays the 22 channels of information required to track a drone, plus the timing traces.

In the Tele-Dynamics van, which serves as a tactical command post, the Visicorder provides both an instant "quick look" and a permanent record of the drone's operational parameters.

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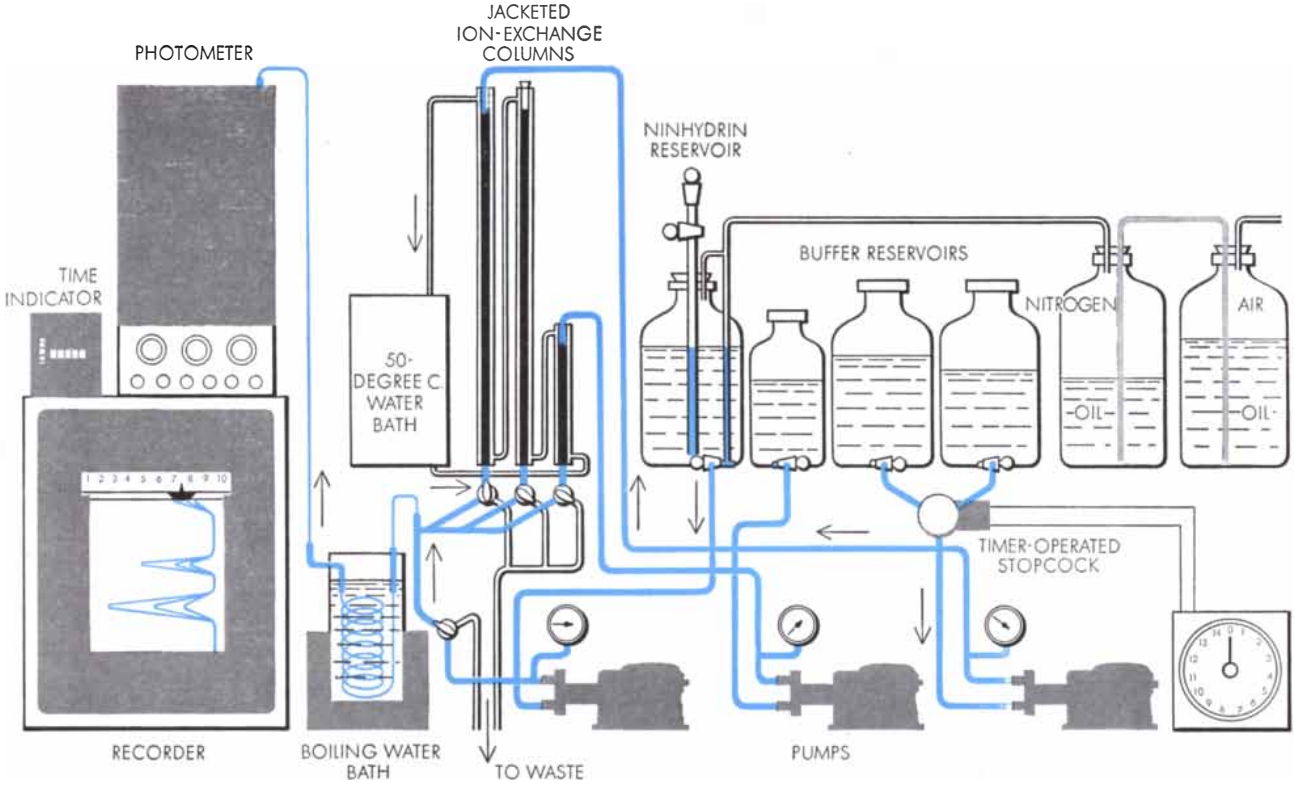
radative techniques we employed. (For example, unusual linkages have already been found in peptide antibiotics by Lyman C. Craig and his associates at the Rockefeller Institute.)

In any case, our formula has one important deficiency: it is two-dimensional. As we have mentioned, the biological activity of a protein molecule usually depends not only on the sequence of its amino acids but also on how the peptide chain is coiled. Ribonuclease is no exception: it is inactivated by disruption of its three-dimensional structure. Of course, the order of amino acids in any peptide chain must influence its spatial arrangement. Certain sequences are known to preclude certain kinds of folding. To what extent a given sequence may require a given kind of folding is not yet clear.

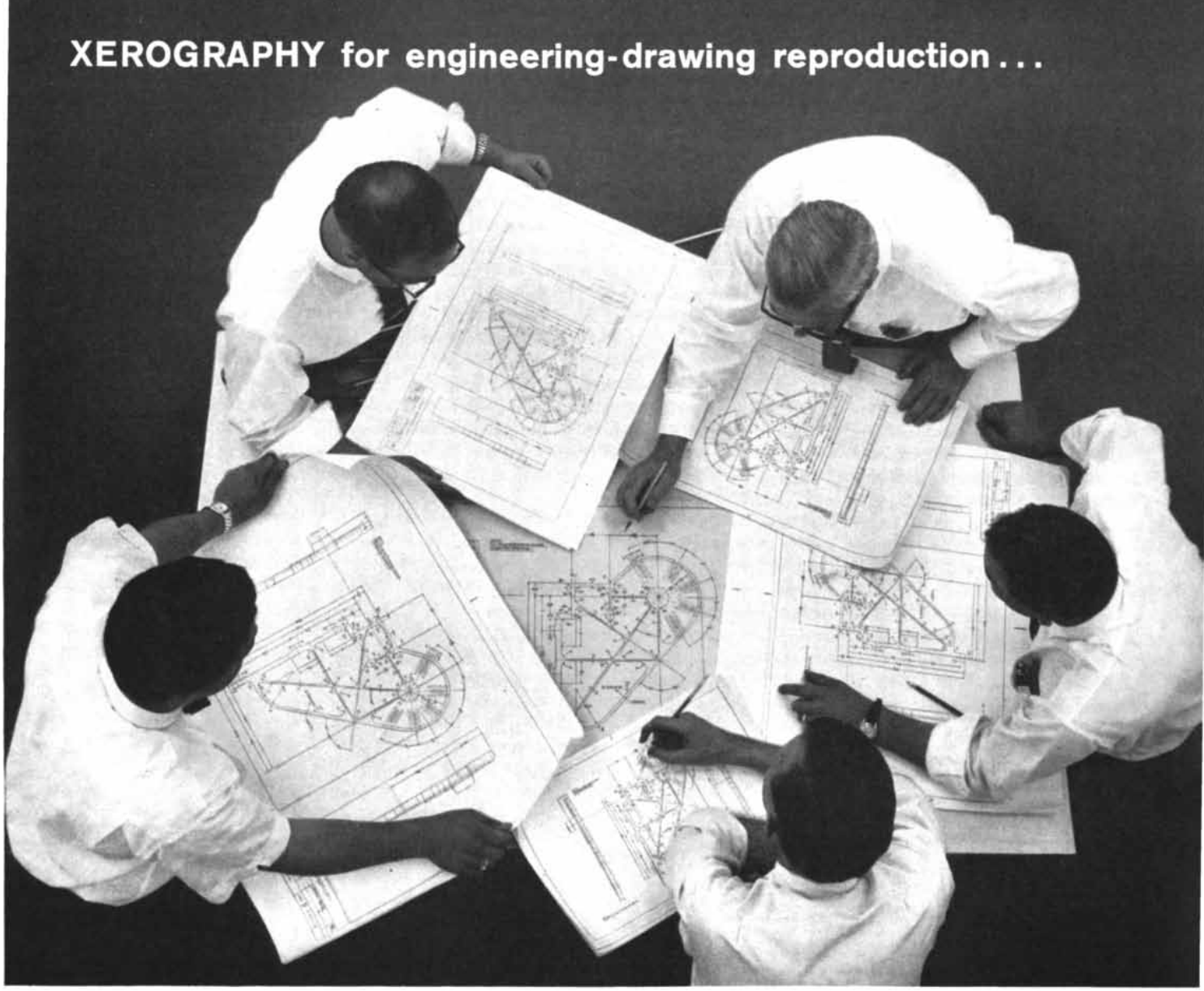
Although much structural information can be obtained through chemical techniques, they can go only part of the way with a molecule as big as that of a protein. For many years X-ray crystallography has been applied to the problem, recently with striking success. A description of this work must await a separate article. Here we shall merely mention that in a series of brilliant investigations British groups headed by J. C. Kendrew and Max F. Perutz have worked out, respectively, the complete spatial arrangement of the peptide chains in the oxygen-carrying proteins myoglobin and hemoglobin. The sequences of amino acids in these molecules have not yet been determined, although they doubtless will be soon. Indeed, it may prove possible to discover the order by X-ray methods alone, which would provide a valuable check on the methods of organic chemistry. When the sequences are found, it will be possible to place each amino acid residue in its proper position on the models of the coiled chains derived from X-ray studies. At that exciting moment the first true picture of a protein will have been drawn. Unfortunately the methods used by Kendrew and Perutz have not yet been successful with insulin or ribonuclease. Sooner or later, however, the difficulties will be resolved and we shall have the complete portraits of these molecules as well.

Active Sites of Enzymes

In the meantime the techniques of organic chemistry are throwing considerable light on one aspect of the relation between the structure of proteins and their function. That is the question of the "active site" of enzymes. Being proteins, enzymes are all large molecules. Often their substrates—the substances they act on—are very much smaller. For example, ribonuclease splits not only ribonucleic acid but also the comparatively small molecule cyclic cytidylic acid [*see illustration on page 92*]. In such a case only a small portion of the enzyme molecule can be in contact with the substrate when the two are joined together, as they are during the reaction catalyzed by the enzyme. This portion is known as the active site. The concept of an active site does not imply that the rest of the enzyme has no function. Sometimes part of the molecule is dispensable; sometimes it is not. The whole molecule may perhaps be something like a precision lathe, where a ton or more of machinery is required to bring a few ounces of metal in the cutting tool to bear accurately on the work. Similarly, the bulk of the enzyme molecule may be required to bring the active site into proper contact with the substrate. The



AUTOMATIC ANALYZER for amino acids is diagramed schematically. The two pumps at lower right drive salt solutions through ion-exchange columns. The third pump delivers color reagent (ninhydrin) to a stream emerging from bottom of column. The mixture passes through boiling water bath, where blue color is developed. Intensity of the color is measured by the photometer.



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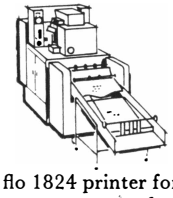

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problem facing the chemist is to discover which amino acid residues make up the active site and just what biological function the rest of the molecule performs.

Now that the structure of an enzyme —ribonuclease—is known, one can hope to find its active site and see how that section is related to the rest of the molecule. Workers in a number of laboratories are engaged in the effort and are making good progress. Before considering their results, it is appropriate to look at some of the earlier work on the active sites of enzymes.

A particularly illuminating series of investigations began in a most unlikely fashion with the study of nerve gases. Developed by the Germans during World War II but happily never used, these substances are phosphate esters of various organic alcohols. (An ester is the compound formed by the reaction of an acid and an alcohol.) They are extremely toxic, rapidly causing death by respiratory paralysis when they are inhaled or even absorbed through the skin. Studies of their physiological action showed that they inactivate choline esterase, an enzyme that breaks down acetylcholine in the body. This last substance plays an essential part in regulating the transmission of nerve impulses. When allowed to accumulate in excessive amounts, it deranges the nervous system, destroying its control over the breathing apparatus.

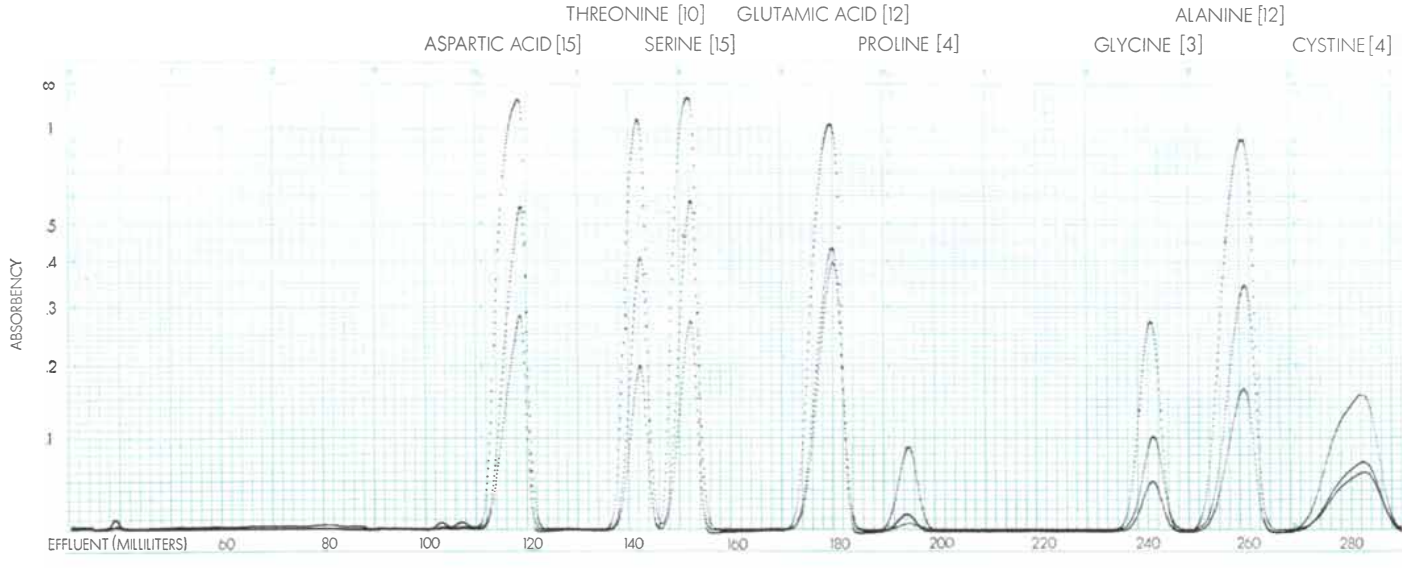
As soon as the relationship between nerve gas intoxication and choline esterase was established, several laboratories set out to discover the nature of the reaction between the two substances. It was quickly discovered that one molecule of nerve gas combined with one molecule of choline esterase to give an inactive product. The next question was: What part of the large protein molecule is involved? This could not be answered directly because the choline esterase molecule is too large to be studied in detail by the methods available. Besides, it has not been isolated in sufficient amounts. Irwin B. Wilson and David Nachmansohn of the Columbia University College of Physicians and Surgeons approached the problem from the other side; they determined how the reaction between the enzyme and the nerve gas or other inhibitors was influenced by the exact chemical structure of the much smaller organic phosphate molecules. They could then deduce many properties of the enzyme surface. As a result of these investigations a compound was devised that could displace the nerve gas from its combination with choline esterase and so reactivate the enzyme.

Then came an important observation. A. K. Balls and E. F. Jansen of Purdue University found that an organic phosphate called DFP (for diisopropylphosphorofluoridate) also inhibits the enzyme chymotrypsin. This protein was available in large quantities and it had already been extensively studied. On examination of the reaction with DFP, Balls and Jansen found that again one molecule of phosphate combined with one enzyme molecule. Subsequently the point of attachment was identified as a specific serine residue in the enzyme molecule.

There must be something special about this particular serine residue: DFP does not react with the free amino acid serine. No more than one molecule of DFP combines with each molecule of chymotrypsin in spite of the fact that the enzyme has 25 serine residues. And any treatment that destroys the enzymatic activity of chymotrypsin, even temporarily, also destroys its ability to react with DFP. Concluding from this evidence that the reactive serine is part of the active site of the enzyme, several groups of chemists have investigated the sequence of amino acids around it. They labeled the serine with DFP containing radioactive phosphorus and then broke down the inactivated chymotrypsin with other enzymes. From the mixture of fragments a peptide containing the labeled serine was isolated. The serine residue proved to be flanked by an aspartic acid residue on one side and a glycine residue on the other.

Meanwhile several other enzymes had been found to be sensitive to DFP. In all of them the inactivation proved to involve a reaction with a single serine residue. Analysis disclosed that in two of the enzymes the serine had the same neighbors as in chymotrypsin. In two others the sequence proved to be glutamic acid followed by serine and alanine. The two arrangements are in fact much alike because glutamic acid and aspartic acid are closely related chemically, as are glycine and alanine.

Finding the same type of sequence in so many enzymes strikingly confirms a major tenet of biochemistry: a similarity in function must reflect a similarity in structure. But this cannot be the whole



AMINO ACID ANALYSIS is recorded as a series of peaks by an automatic analyzer. The trace reproduced here was obtained in the analysis of a hydrolyzed sample of ribonuclease. The names of the amino acids that were found appear above their corresponding peaks. The number of residues of each in the ribonuclease molecule, determined by the intensity of blue color formed with a special reagent, is shown in brackets. (Proline gives proportionately less color than the other amino acids.) Histidine, lysine, arginine

story. Although the enzymes are alike in some respects, they are not identical. They do not all catalyze exactly the same reactions and so their active sites must differ in some ways. Of course the sequence aspartic acid, serine and glycine is not by itself biochemically active, nor are the larger peptide fragments that contain it. The serine in them does not react with DFP. Additional residues are required, but which ones, and how they are oriented in space with respect to the active serine, is still largely unknown.

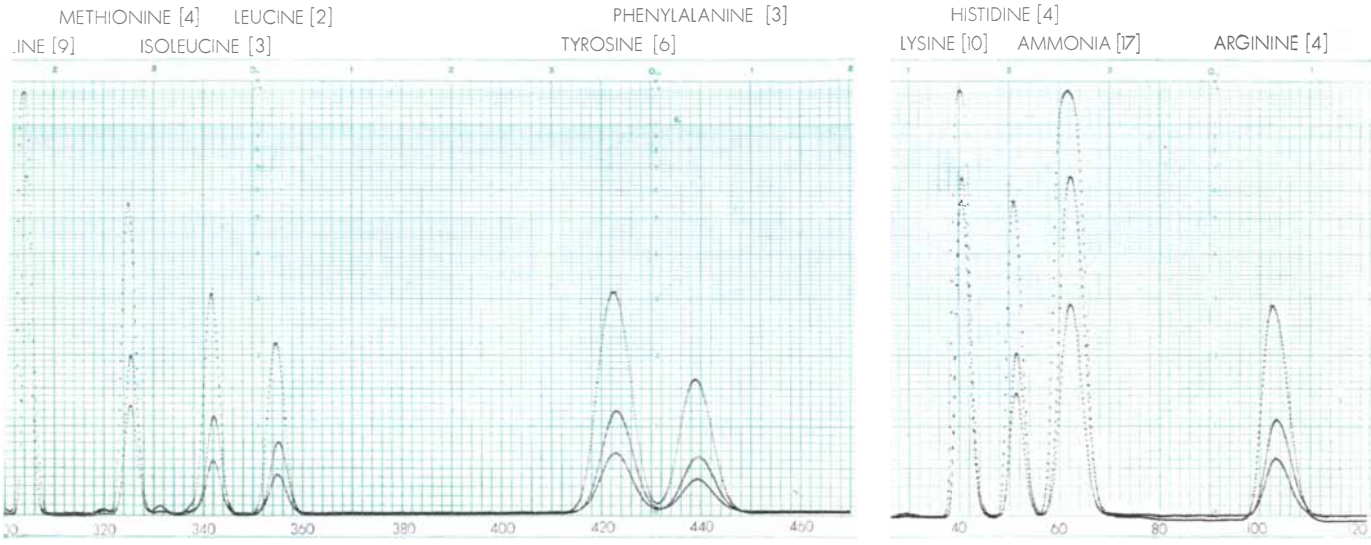
There is persuasive evidence that the active site of these enzymes also includes a histidine residue. Yet in two of the enzyme molecules quite a number of residues on each side of the crucial trio have been identified, and histidine is not among them. If histidine does form part of the active site and is near the active serine, it must be brought there by a folding of the chain. Although still hypothetical, the idea that the amino acid units in an active site are brought into juxtaposition from different sections of a peptide chain by three-dimensional coiling is attractive. Among other things, this hypothesis explains why disrupting only the three-dimensional structure of an enzyme leads to loss of activity. The picture will become much clearer when the complete structures of the DFP-sensitive enzymes are worked out.

Ribonuclease is not sensitive to DFP, but it too can be inactivated by a specific chemical reaction involving a particular amino acid residue. The inactivating agent is either iodoacetic acid or bromoacetic acid, and it combines with a histidine residue. Two investigators in England, E. A. Barnard and W. D. Stein, have obtained evidence that the histidine residue concerned is the one at position 119, six residues from the carboxyl end of the ribonuclease chain. Neither reagent reacts with any of the other three histidines in the molecule. Unfolding the chain or otherwise destroying the activity of ribonuclease prevents the reaction with this residue. Thus the histidine residue at position 119 seems almost surely a part of the active site of ribonuclease. Other studies implicate the aspartic acid at position 121 (removing it together with the last three residues inactivates the molecule, whereas splitting off the last three alone does not) and perhaps also the lysine at position 41.

Some remarkable experiments by F. M. Richards at Yale University have provided much information about the relationship between the activity of the enzyme and its over-all structure. Using a bacterial enzyme called subtilisin, Richards succeeded in splitting the ribonuclease molecule at a single point—the bond between the alanine at position 20 and the serine at position 21. Although the peptide link had been broken, the two fragments did not separate from each other nor did the combination lose enzymatic activity. Treatment with mild acid, however, separated the altered ribonuclease into two parts, one a peptide of 20 residues, the other a large fragment of 104 residues. Neither fragment by itself exhibited activity. But when dissolved together in a neutral solution they recombined instantly, and enzymatic activity was regained. The peptide bond did not re-form under these gentle conditions. Instead the two fragments were held together by so-called secondary forces, probably analogous to those that unite enzymes and their substrates. The simplest explanation, though not the only one, for these results is that activity depends on the juxtaposition of one or more amino acid residues from among the first 20 with one or more in the rest of the molecule.

This brief account of the research on active sites by no means exhausts the work being done on ribonuclease, nor does it exhaust the list of enzymes under investigation. To mention another, the protein-digesting enzyme papain (found in the papaya) has been studied for years at the University of Utah School of Medicine by Emil L. Smith and his colleagues. They have gone far toward determining its structure and have, in addition, made the striking observation that more than 100 amino acid residues of the 185 in the native enzyme can be whittled away without abolishing its activity. The structures of trypsin and chymotrypsin are also being energetically studied, particularly by Hans Neurath and his associates at the University of Washington.

As structural chemistry advances, answers to a number of other fascinating biological problems begin to appear. One can study the differences among analogous protein molecules produced by different species. Sanger is the pioneer in this field, with his studies of the structure of the insulin produced by the cow, the pig and the sheep. Also of great interest are the differences in protein molecules produced by members of

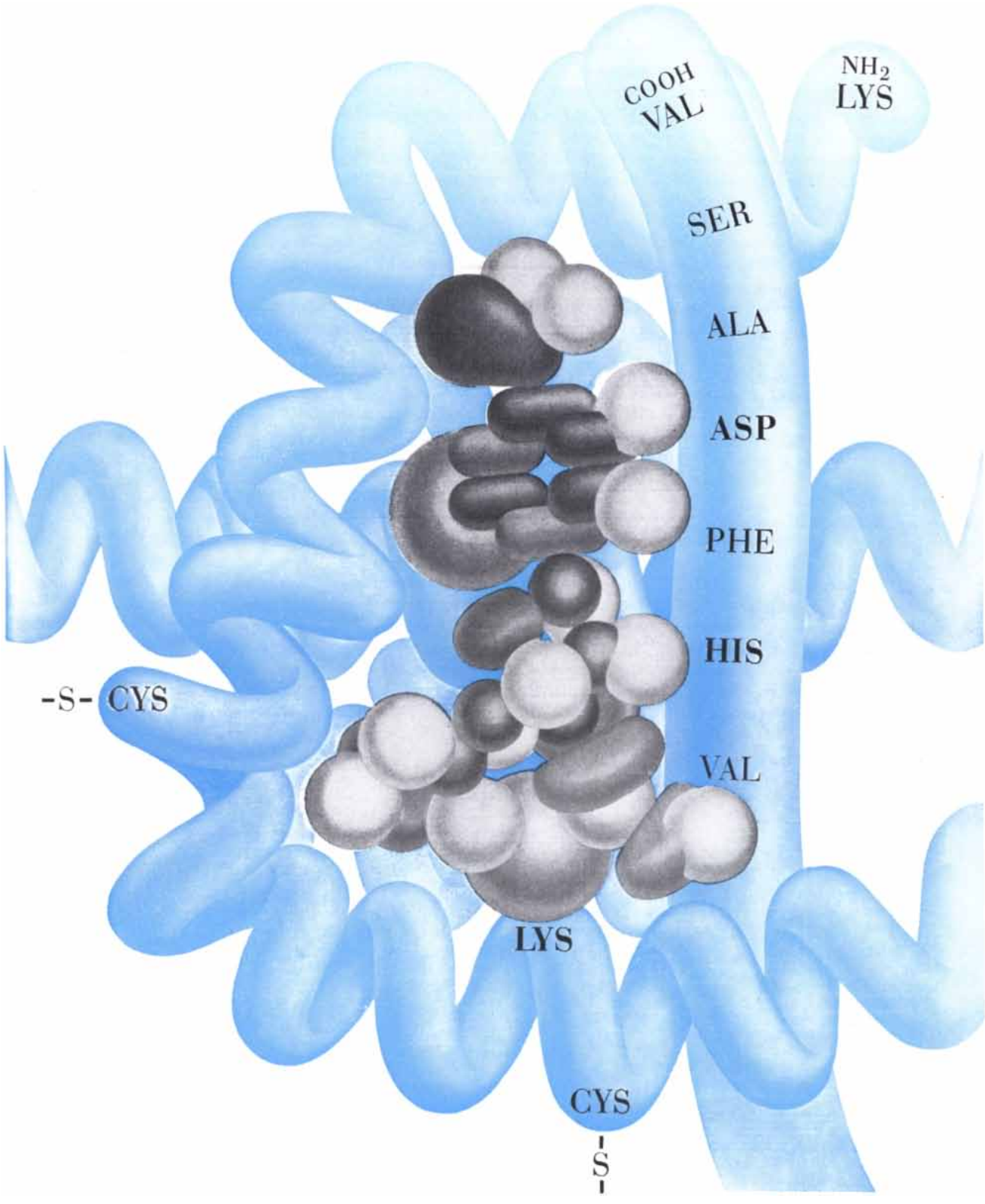


and ammonia are determined with a separate ion-exchange column and recorded separately (*right*). The ammonia is released by the hydrolysis of residues of asparagine and glutamine in the intact ribonuclease molecule. In the process these substances are converted to aspartic acid and glutamic acid respectively. Horizontal scale measures milliliters of solution to have passed through the columns; vertical scale, color intensity. Different curves show absorbencies at different wave lengths and depths of solution.

the same species under the influence of genetic mutation. In this area a good deal has already been learned about abnormal hemoglobins, and much more will be known when the complete structure of the hemoglobin molecule has been worked out.

Finally, the recent elucidation of the complete amino acid sequence in the protein of tobacco mosaic virus opens the way to a deeper understanding of the natural synthesis of proteins. The virus consists of protein and ribonucleic acid. According to present theory, the protein is synthesized by infected tobacco-plant cells under the direction of the viral nucleic acid. Now it may be possible to follow this process in detail.

The next few years of research on proteins should be exciting ones, both for chemists and biologists.



ACTIVE SITE of ribonuclease is represented in this strictly hypothetical conception. A small molecule on which the enzyme acts is shown in gray, nested in a form-fitting cavity on the enzyme surface. Peptide chain, some of which is believed to be helical and some not, is shown in color. Some of the amino acid residues thought to form part of the active site are shown in bold type.

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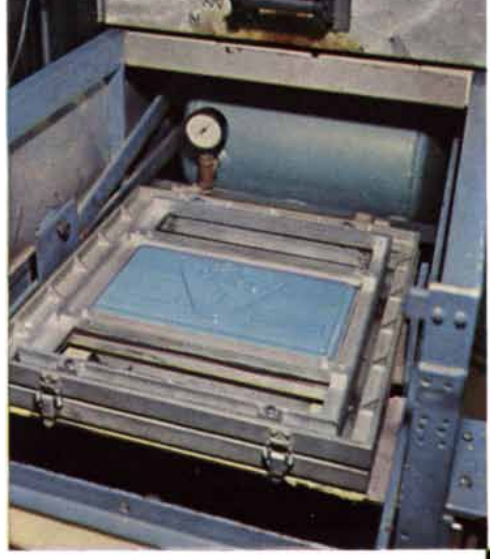
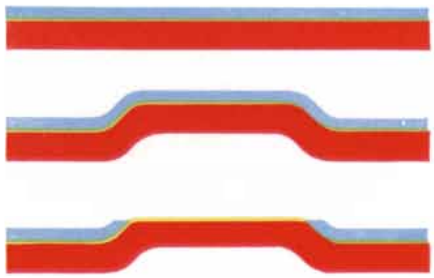


Duplex sheet is formed in the same manner as regular Butyrate sheet for signs.



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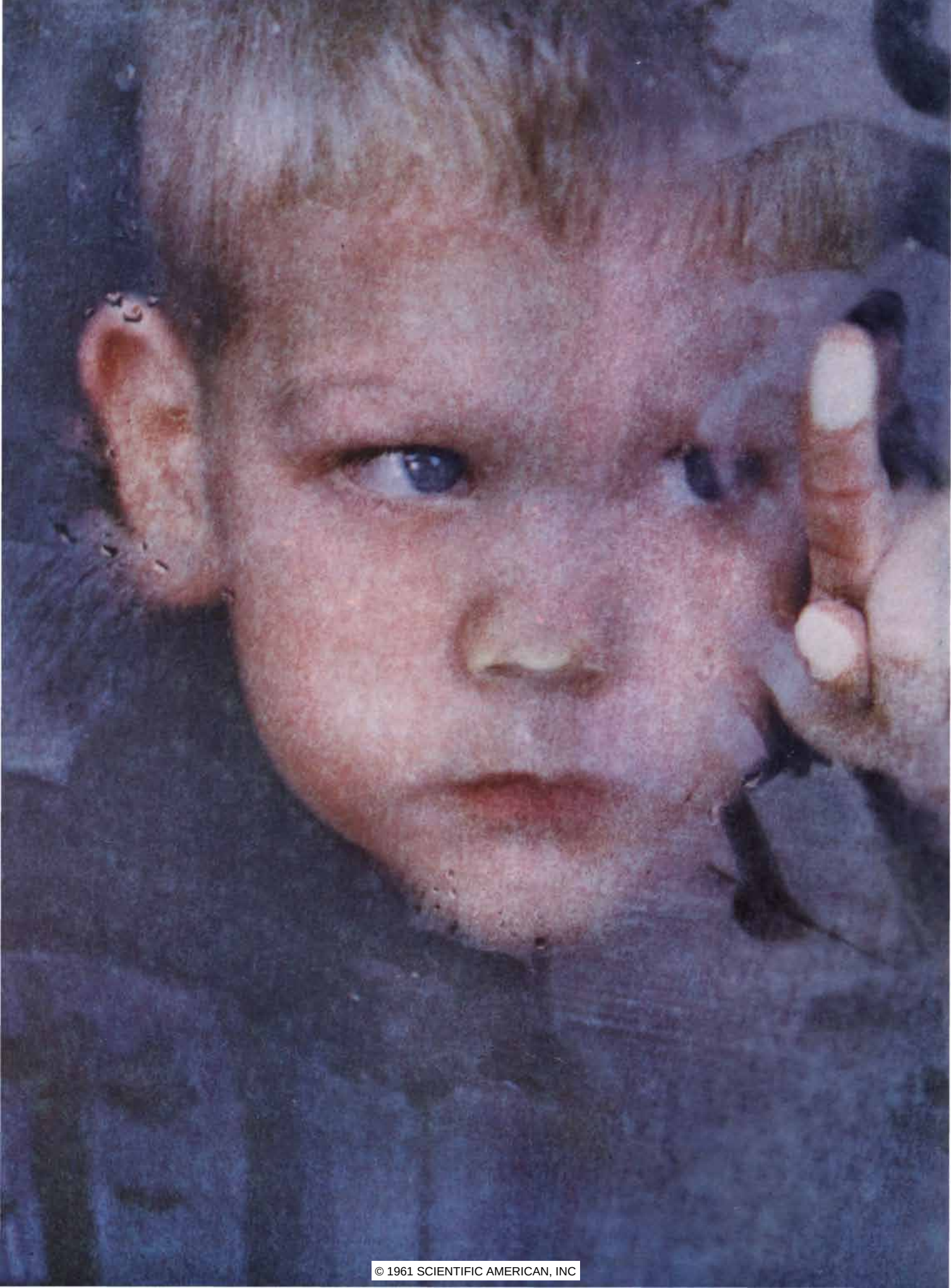

Why can I draw on the window?

I can't see outside. The window is wet. I put my finger on the wet. I move my finger and draw pictures. *Why*? Why can I draw pictures on the window today? *Why*?

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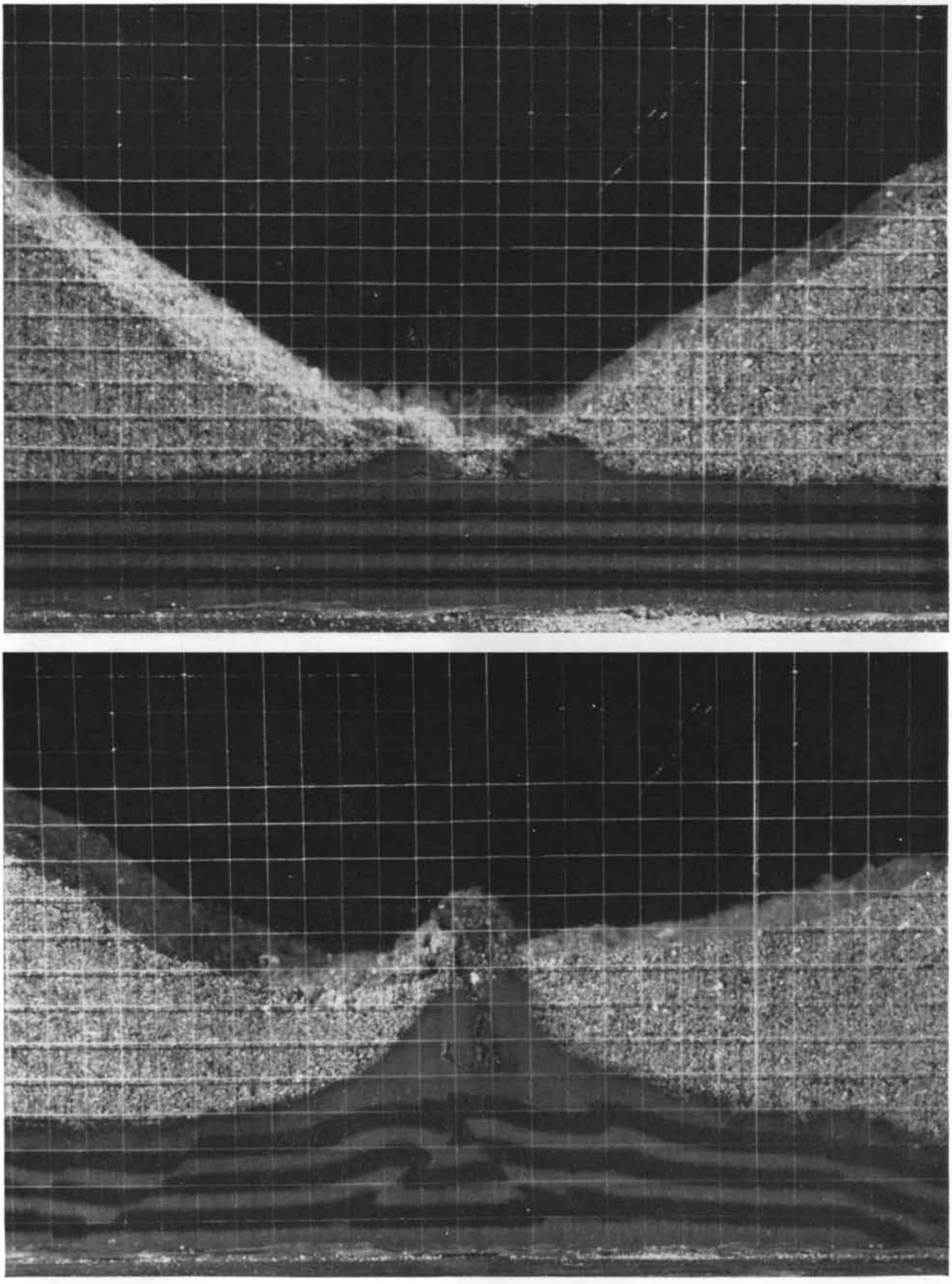


PRESSURE FOLD forms when a layer of plastic material (such as clay) is squeezed to the surface by an unevenly distributed mass of overlying rock. In this model layers of petrolatum represent the clay and mounds of sand represent the rock. Photograph at top shows model shortly after sand was added; photograph at bottom shows model several hours later. The upwelling clay at the center of the formation is called a "piercing core." Several faults are visible in strata beneath pressure fold (*left, center and right*).

EXPERIMENTAL GEOLOGY

An account of Soviet work on the use of scale models to visualize tectonic processes. Because rigidity must be scaled down with time and space, rocks are represented by such materials as clay and syrup

by V. V. Belousov

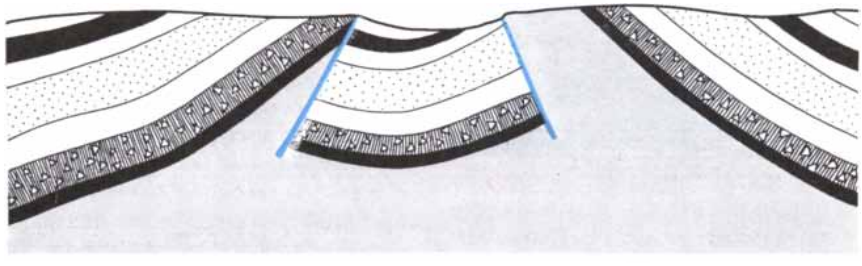
Landscapes everywhere testify to the working of gigantic forces that originate deep inside the earth. Layer upon layer of rock is crumpled by folding, and the crust itself appears broken, tilted and displaced by faults. From comparative study of many such formations the geologist is able to arrange them in a sequence and reconstruct the processes that created them. His conclusions, however, must always be qualified as deductions. He can see only the static results of these processes; he cannot observe them directly. The forces that deform the crust of the earth act over large expanses of territory and over periods that are much longer than his lifetime.

Failing direct observation of the tectonic processes, some geologists have been finding that they can learn a great deal from scale models set up to simulate such processes in the laboratory. Experiments with these models yield no proof but they do make it possible to see processes that can otherwise be visualized only in the mind's eye. Since 1944 in our laboratory at the Institute of the Physics of the Earth at the U.S.S.R. Academy of Sciences in Moscow (and more recently in other institutes associated with us in our work) we have been employing scale models to sharpen our perceptions of real geological structures and to check our deductions from what we observe in the field. The technique has helped us to bring about the revision of a number of cherished theories in tectonics and has shown that the development of some of the most complex geological structures can be explained in rather simple terms.

There is no great trick to making such models. One must only remember that their function is to portray not a structure but a process; it is not so much how the models look as how they perform that counts. Above all, in scaling down geologic time and distances to the dimensions of a laboratory bench and a few minutes or hours of observation, it is necessary also to scale down the rigidity of the earth's crust. In various models we have found that petrolatum, gun grease, rosin and sugar syrup, and sometimes soft modeling clay, serve excellently to demonstrate the deformation of hard rock.

The first attempts to build models of tectonic processes go back to the beginning of geology itself. More than a century and a half ago investigators tried to reproduce the crumpling of strata into folds. The urge to find experimental confirmation was felt by every 19th-century geologist who went beyond field observation to the building of theories about tectonic processes. It must be said, however, that this protracted and, as it were, preparatory period did not do much for the development of tectonophysics. In arranging their experiments the workers often tried to achieve only a morphological similarity between their models and the natural structures and failed completely to consider physical similarities. The materials for the models were selected by chance and, as is now evident, not only lacked any physical correspondence but also were often in sharp contradiction to the actual materials. In obtaining mere likeness of appearance the experimenters submitted their models to entirely contrived dynamic conditions. One author, attempting to reproduce the tectonic structure of the Alps in a model made of crude layers of gypsum and clay, was compelled to resort to a complicated system of levers and loads that had little to do with geological circumstances. Among the more successful models was one that Bailey Willis of Stanford University constructed in 1893 out of paraffin wax, rubber sheets and lead shot to reproduce the folded structure of the Appalachians. Though there was little theoretical justification for his choice of materials, the experiment long stood as a classic demonstration of tectonic folding.

These efforts may be recalled sympathetically today when it is recognized that the geologists of that period had little to work with by way of concepts from what is now known as solid-state physics. The study of plastic, elastic and solid matter had just begun. As work in

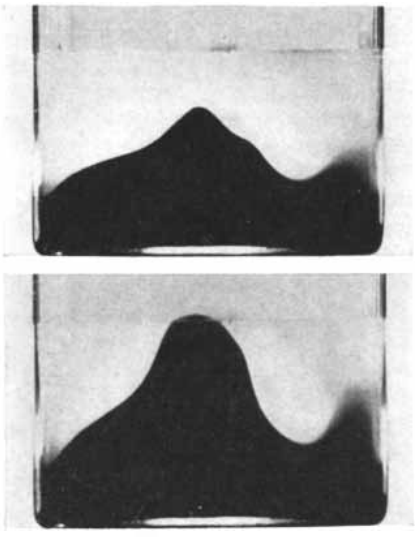


CROSS SECTION OF PRESSURE FOLD in the Kerch Peninsula of the U.S.S.R. resembles the model in the photographs on opposite page. Here plastic clays (*gray*) have been pushed to the surface through overlying strata of sandstone, marl and clay. The clay has cut out a section of the overlying strata (*center*). Top of pressure fold has been eroded away.

the mainstream of physics progressed the situation of geology improved correspondingly.

It was not until the late 1920's that students of tectonics comprehended the principle of "physical similarity" as the ruling consideration in laboratory investigations in their field. The leading advocate of the idea was the German geologist Hans Cloos. Acting on a suggestion made in 1892 by his distinguished countryman Eduard Reyer, Cloos showed that in experiments designed to simulate tectonic deformation it was necessary to bring the plasticity or viscosity of the materials into scale with the other dimensions of the model. In the late 1930's the concept was given formal theoretical expression by M. King Hubbert, then at Columbia University, and by other workers in Europe. The substance of the idea lies in the self-evident statement that two processes are similar if they can be described by the same equations. This becomes possible for the model and nature if the dimensions of the natural process are scaled down in reasonable relationship to one another in the model. Since the model necessarily involves huge diminutions in space and time, the physical characteristics of the materials employed in it must be correspondingly rescaled. With sufficient data about the natural conditions and a little computation, it is possible to set up quantitative criteria of physical similarity to be met by the materials in the model.

Investigation of the physical nature of rock under conditions of high temperature and pressure had meanwhile laid a foundation for at least approximate determination of such criteria. In 1940 Lewis L. Nettleton and Milton B. Dobrin of the Gulf Research and Development Company were able to build a model to reproduce the formation of salt domes, employing materials that were chosen on theoretically defensible grounds. The process was modeled more precisely in the 1950's by Travis J. Parker and A. N. McDowell of the Agricultural and Mechanical College of Texas and also by investigators in the U.S.S.R.



GROWTH OF SALT DOME is modeled with asphalt and viscous syrup. Model shows how salt (a light, viscous material) rises slowly toward the surface through overlying layers of a denser, more viscous material such as rock. Asphalt represents the salt, and heavy sugar syrup represents the dense rock.

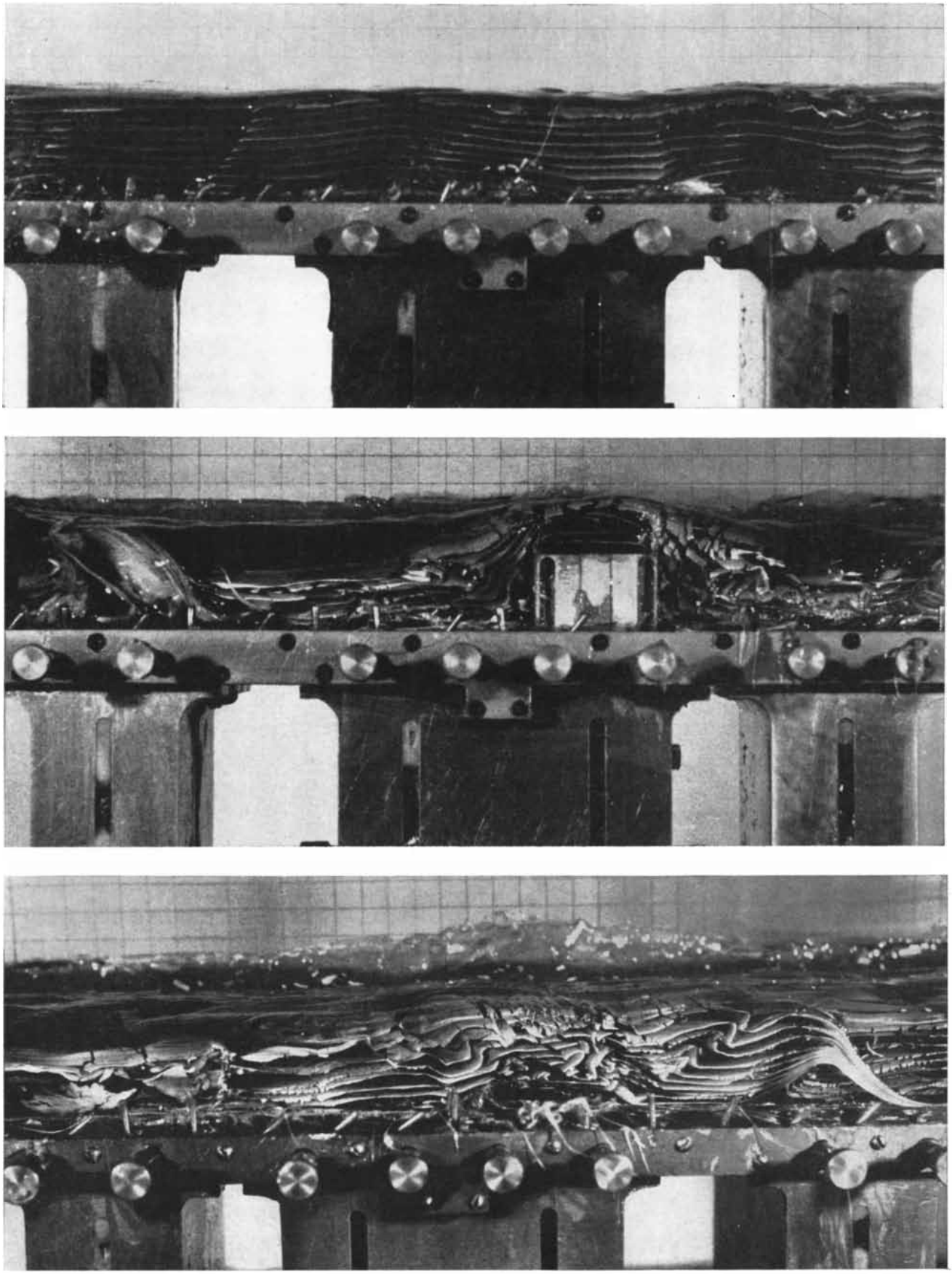
The salt-dome model set up in our laboratory nicely illustrates how the criteria of physical similarity are calculated and how such calculation dictates the characteristics of the materials. In nature molten salt—a light, viscous material—pushes its way upward toward the surface through layers of heavier and more viscous rock, ultimately forming a rounded "diapir" dome in the undersurface of the overlying strata. Our laboratory model employed low-density black asphalt to represent the rock. Since the crucial factor in this demonstration was the viscosity of the asphalt "salt," its value was adjusted after determination of the reduction in density, time and space imposed by the other conditions of the experiment. The density of the asphalt was about .6—a reduction by a factor of two. The height of the salt column beneath natural domes (that is, the distance the salt rises from the salt layer toward the surface) is roughly three miles, or about 500,000 centimeters; in the model the height of the salt column was about 50 centimeters—a reduction by a factor of 10,000 (10^4). Finally, the time required for a natural salt dome to form is about 50,000 years; in the model the dome would form in about an hour—a reduction by a factor of 400 million (4×10^8). Multiplication of these reduction factors yielded the factor by which viscosity of the asphalt salt had to be scaled down in the model: roughly 10^{13}. The viscosity of natural salt is about 10^{22} poises (a poise is a measure of resistance to flow expressed in dyne-seconds per square centimeter); scaled down 10^{13} times, this figure becomes 10^9 poises. The viscosity of the asphalt was adjusted accordingly.

In putting the model to work asphalt is poured into a large beaker and sugar syrup is poured on top of it. The asphalt rises sluggishly through the syrup in a thick black column with a rounded, bulging top [*see illustration at left*]. In larger models with more viscous materials it is possible to observe the growth of a number of domes rising simultaneously or in succession.

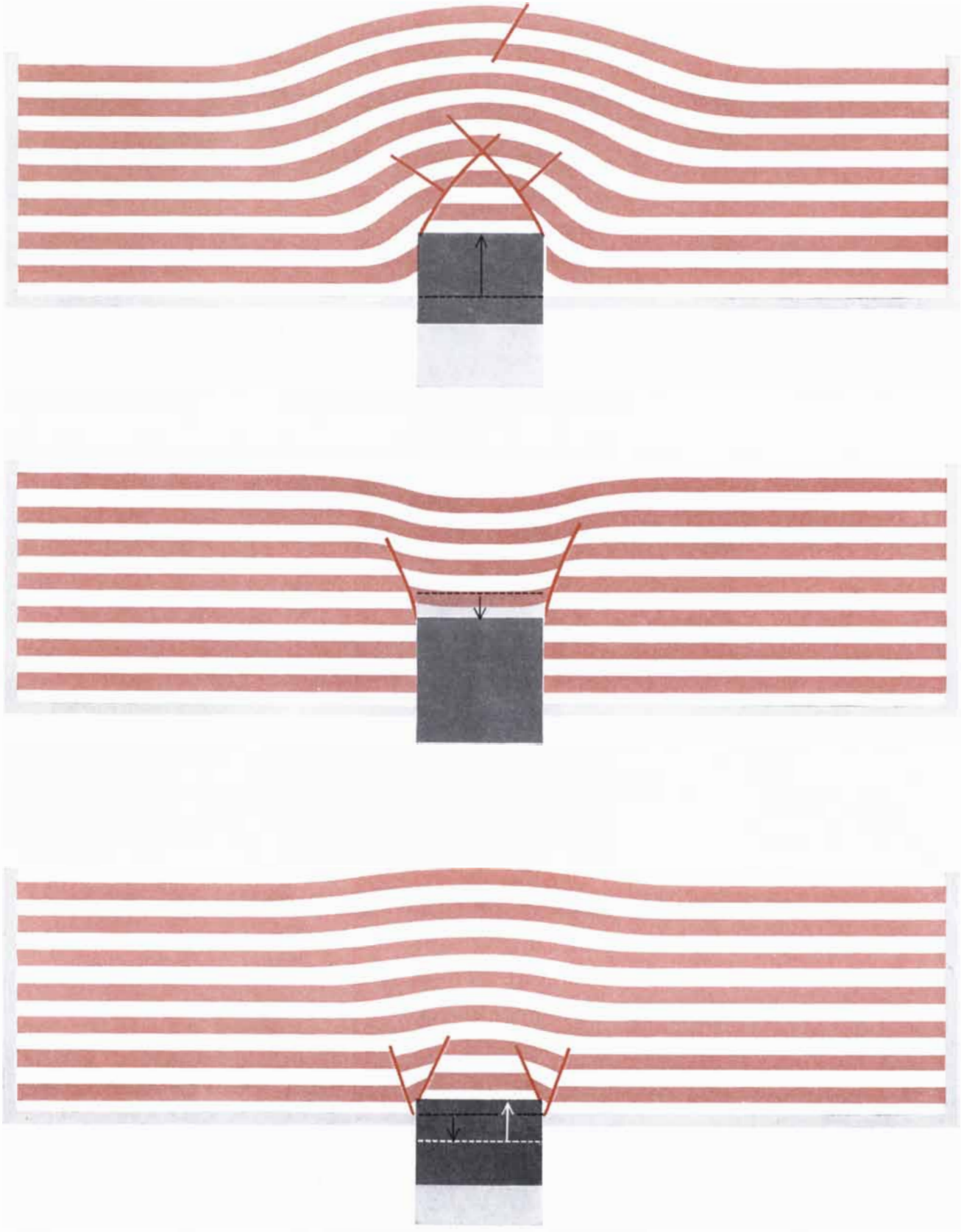
Such models have yielded significant insights into the process of salt-dome formation in nature. They have indicated that the domes tend to form where the salt layer is thickest and, quite surprisingly, that their formation is enhanced by the presence of thick layers of overlying rock. These results have been confirmed by studies in the field.

In a similar experiment employing entirely different materials we have studied the somewhat analogous process that forms clay injection or pressure folds. These formations are observed in the delta of the Mississippi (where they are known as "mud volcanoes") and in the Kerch-Taman region on the northern coast of the Black Sea in the U.S.S.R. Field studies had indicated that the clay in a subterranean layer tends to be squeezed laterally under the unevenly distributed burden of overlying material and forced upward, where the burden is lighter, to form an uplift or swell in the terrain. In the models—variously employing soft clay, petrolatum and sheets of rosin to simulate the clays, and sand to serve the function of the overburden—we have observed the same lateral and upward flow. Significantly, the uppermost layers of "clay" can be seen to flow more rapidly, moving in from the periphery of the model and entering the upward flow ahead of the lower layers of material closer to the center of vertical movement. In this respect the model faithfully reproduces what has been observed in pressure folds in the Kerch Peninsula. Where the overburden in the model is thinnest and lightest the upwelling clay assumes the characteristic diapir form, in this case known as a piercing core, and may break through the surface [*see illustration on page 96*]. In nature where erosion has reduced the arch of the uplift and carried away the clay of the piercing core, clay that moved inward from deeper strata at the periphery of the structure will be found at the surface next to the upper strata of clay in the static central mass [*see illustration on page 97*].

The investigation and development of criteria of physical similarity in our laboratory by B. L. Schneyerson, E. N. Lustig and especially M. V. Gzovsky have placed the use of tectonic models on a sound methodological basis. At present it is not easy to attain similarity between the materials in the model and those in nature with respect to all the salient characteristics—plasticity, elasticity



CRUMPLED FOLDS are caused by vertical oscillations of separate blocks of the earth's crust. Here folds are modeled in a glass-walled box. Layers of rosin and moist clay represent overlying rocks, and a piston (*visible at right in middle photograph*) represents an upthrust block of basement rock. Top photograph shows model at start of experiment; middle photograph shows how layers of rock are stretched when piston is raised; bottom photograph shows how stretched layers crumple into folds when piston is lowered.



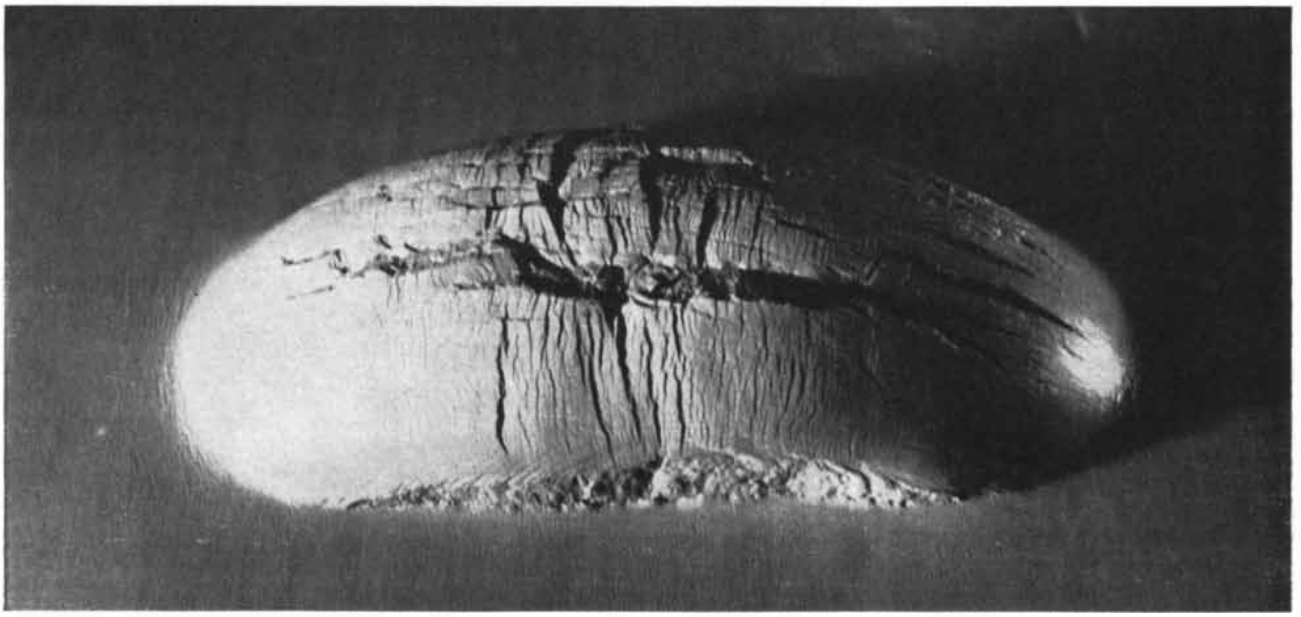
PATTERN OF FAULTS that accompany block folds were studied in a clay model. A piston represents a block of basement rock, and layers of clay (*color*) represent the overlying rock strata. Black broken line and light gray shaded area indicate the original position of the piston; dark gray shaded area indicates its final position. When the piston is raised (*top*), it cuts out a prism of clay; the faces of the prism are faults (*heavy colored lines*) that incline upward and converge. When the piston is lowered (*center*), it produces a pattern of diverging faults. When the piston is first lowered and then raised (*bottom*), both types of fault appear.

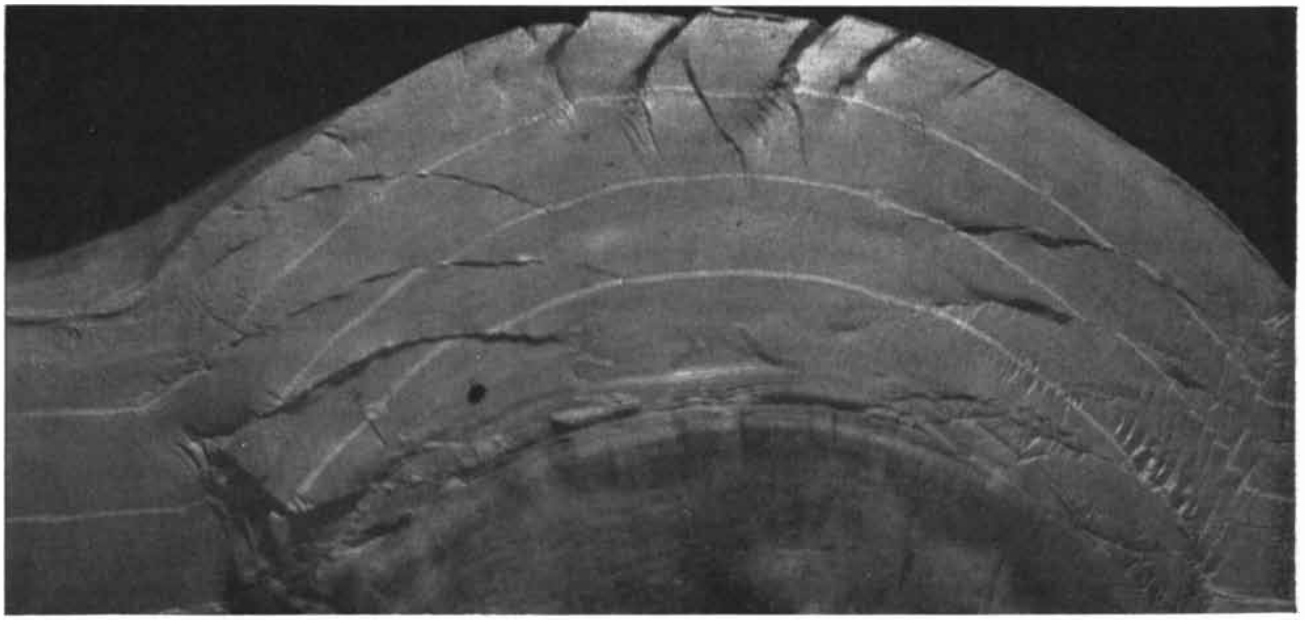
and solidity (*i.e.*, initial strength under stress)—at the same time. We accordingly employ different models for separate study of plastic deformation (principally in connection with folding), solidity (principally in connection with faults) and elastic deformation (in connection with both processes).

Models have played an especially fruitful role in our investigation of the process of folding, the first major enterprise undertaken by our institute at the end of World War II. Until recently respectable geological opinion has held that folding is the result of general causes acting on a planetary scale. In particular, the extreme formation of the crumpled fold has been advanced as evidence for presumed world-wide wrinkling of the earth's crust attendant upon the cooling and contraction of the sphere. By its very nature this theory discouraged investigation, because it implied that the process of folding could not be studied in any given folded region that was limited in space.

Our work in the field and in the laboratory has already established sufficient basis for the conclusion that folding is entirely a local process that goes on in the upper layered thicknesses of rock as the result of vertical oscillations in the earth's crust. The process is the more localized by the fact that the underlying foundation rock often splits up into separate blocks that undergo differential vertical displacement in the course of these oscillations. Under the force of gravity the surface material lifted by a rising block flows downward upon the neighboring stationary or descending blocks. Given the long time intervals involved, the plasticity of solid rock is such that it will thus flow and stretch to a considerable degree. This becomes dramatically evident when the upthrown block at last descends, for the lengthened surface strata are often crumpled into intricate folds as they subside into the area they originally occupied. Thus folding results not from the shrinking of the earth's surface but from the stretching of its surface layers.

The very best material for modeling the process of folding has turned out to be rosin. The material is laid down in thin layers, separated by layers of soft clay, on the floor of a glass-fronted box. Pistons with flat oblong surfaces pushing upward through the floor perform the function of the crustal blocks. With this apparatus we have been able to observe the significant structural results of block movement and gravitational flow within the lengths of time, from a few hours to a few days, feasible for experi-





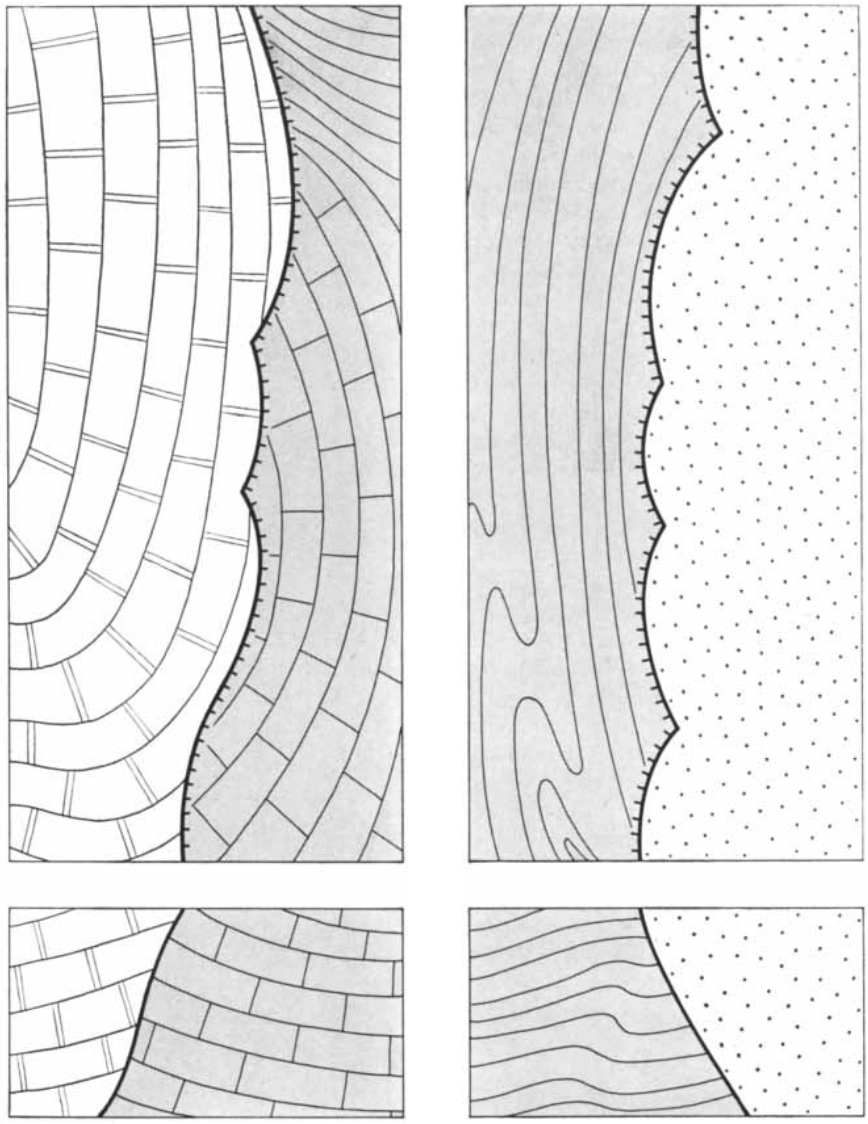
mentation. The only trouble is that the rosin is too cohesive to demonstrate the formation of the faults that so often attend the process of folding in nature.

By moving the pistons in various sequences and waiting for various intervals of time between movements to give the rosin a chance to flow under the influence of gravity, we have reproduced the most varied complexes of folds. The stretching of the rosin strata by the upward movement of a single piston and the crumpling of these lengthened strata when the piston is lowered demonstrate the production of crumpled folds in an especially satisfactory manner. After analogous operations with several pistons we have obtained whole folded zones in the model. It is perfectly obvious that the crumpling of the rosin strata takes place not as the result of any shrinkage of the width of the model but through the stretching of the strata by the vertical movements of the pistons.

Our modeling of the "reflected" block fold has attracted particular interest. This formation reflects in its contours the shape of the foundation block and so provides direct evidence of the presence and action of the block. In the field it may be observed as a more or less gentle uplift (anticline) or downbend (syncline) in the terrain. With the formation exposed in cross section in the model, the boxlike shape of the piston is most faithfully repeated in the curvature of the deeper strata and fades out upward in the more gently sloping, longer curvature imparted to the upper strata. The model has also shown that where the overlying strata are deep enough the separate block folds produced by two different blocks may merge into a single larger uplift or downbend at the surface.

Since our rosin strata do not develop the faults that accompany folding in rock, we must turn to a different material to model this problem. The floor of the glass-fronted piston-box is now covered with a few inches of wet clay. In this material a single upstroke and downstroke of the piston reproduces a variety of complex fault systems that are fre-

LONGITUDINAL AND CROSS faults appear in regions subjected to prolonged uplift. In this model a piston represents a block of basement rock and layers of clay represent the overlying rock strata. When the piston is raised, longitudinal faults appear first (*top*), followed by cross faults (*middle*). The photograph at bottom shows a close-up cross-sectional view of the model.



GIANT FAULTS often have a wavy or scalloped form. These diagrams show two such faults as seen from above (*top*) and in cross section (*bottom*). Each curve in the faults was once a small "embryonic" fault. Change in local distribution of stress caused these faults to curve. The curved faults grew longer and finally joined to form giant faults depicted here.

quently observed in folded structures. On the upstroke the piston cuts out a prism of clay; the faces of the prism are faults that incline upward from the edges of the piston and converge some distance above it. Within the prism the strata lie flat and do not take part in the arching produced in the surrounding material. On the downstroke the piston produces a complementary pattern of diverging faults. When the piston has returned to its original position, the two types of fault strike upward through the clay from each of the piston's edges. The occurrence of these two fault systems separately and together in the field is persuasive evidence in favor of the role of block movement in the folding process.

Surveys of large natural faults, which may run for miles through a folded structure, have shown that they often have a curious wavy or scalloped form. Our own field investigations led us to the conclusion that each curvature in such a fault represents a separate "embryonic" fault. We surmised that the curvature in each case had been caused by a change in the distribution of stress in the rock as the fault arose and grew. Growing past the embryonic stage, the many smaller faults finally intersect one another to form the giant fault.

This sequence of events was nicely demonstrated in our clay models. When the clay was deformed by the piston, a series of small cracks appeared. They developed the characteristic scalloped form and spread at different speeds, eventually joining in a single fault.

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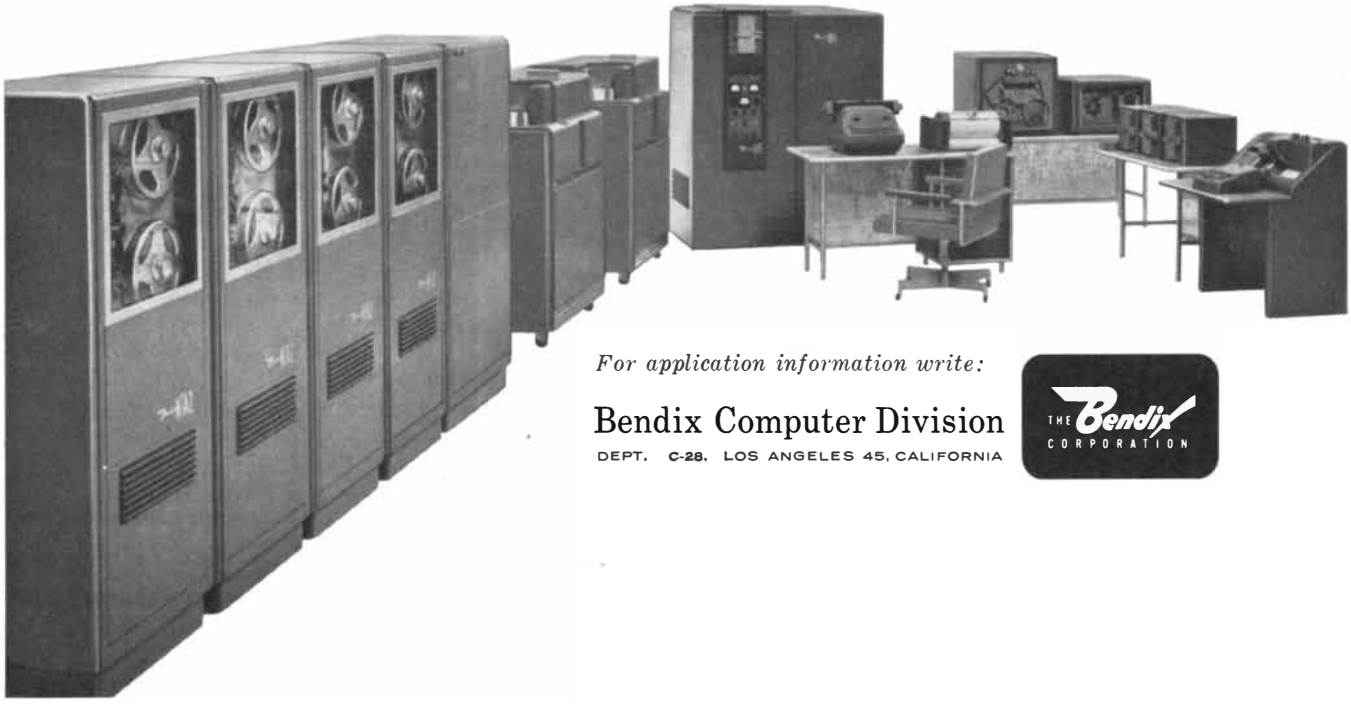

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dergone prolonged uplift geologists have observed numerous fault systems oriented in different ways to one another and to the structures with which they are associated. These regions have been cited in support of the idea that portions of the earth's crust may be subjected at different times to forces acting first in one direction and then in another. Advocates of the idea are compelled, however, to resort to complicated and artificial assumptions about the source and nature of the supposed forces.

Upon close study of such a region we succeeded in classifying the faults into two major groups. A set of longitudinal faults was found to run parallel to the long axis of the uplift; these appeared characteristically in the arch and at the base of the uplift. The second set of smaller cross faults intersected the longitudinal faults at right angles. In the laboratory model Gzovsky was able to show that the stresses generated by the upward push of a piston were sufficient to account for both fault systems. In the uplifted clay the longitudinal faults appeared first and then the cross faults.

In collaboration with D. N. Osokina, Gzovsky developed a model of another kind for study of the patterns of stress that produce this combination of faults. The material in this case is a transparent gel; when viewed in polarized light it reveals in a pattern of colored bands the distribution of the stresses that may be set up in it by an external force. The model showed that the piston initially exerts the greatest stress in the plane of greatest curvature, that is, at right angles to the long axis of the uplift. The stress here is relieved by the formation of the longitudinal faults that run parallel to the long axis. Thereupon the greatest stress comes to bear parallel to these faults and so sets up the cross faults at right angles to the faults and to the long axis of the uplift [*see illustration on page 102*].

The results of this investigation open a straighter path to the understanding of a highly complicated fault system. They show that the single force exerted by the vertical movement of one of the earth's foundation blocks will account for this phenomenon as well as for the most intricate system of folding.

Experimental tectonics has thus come to serve as an important supplement to classical geological methods. In many cases it can explain aspects of tectonic processes that are inaccessible to those methods. And it can open the geologist's eyes to important details in those processes that he might otherwise overlook.

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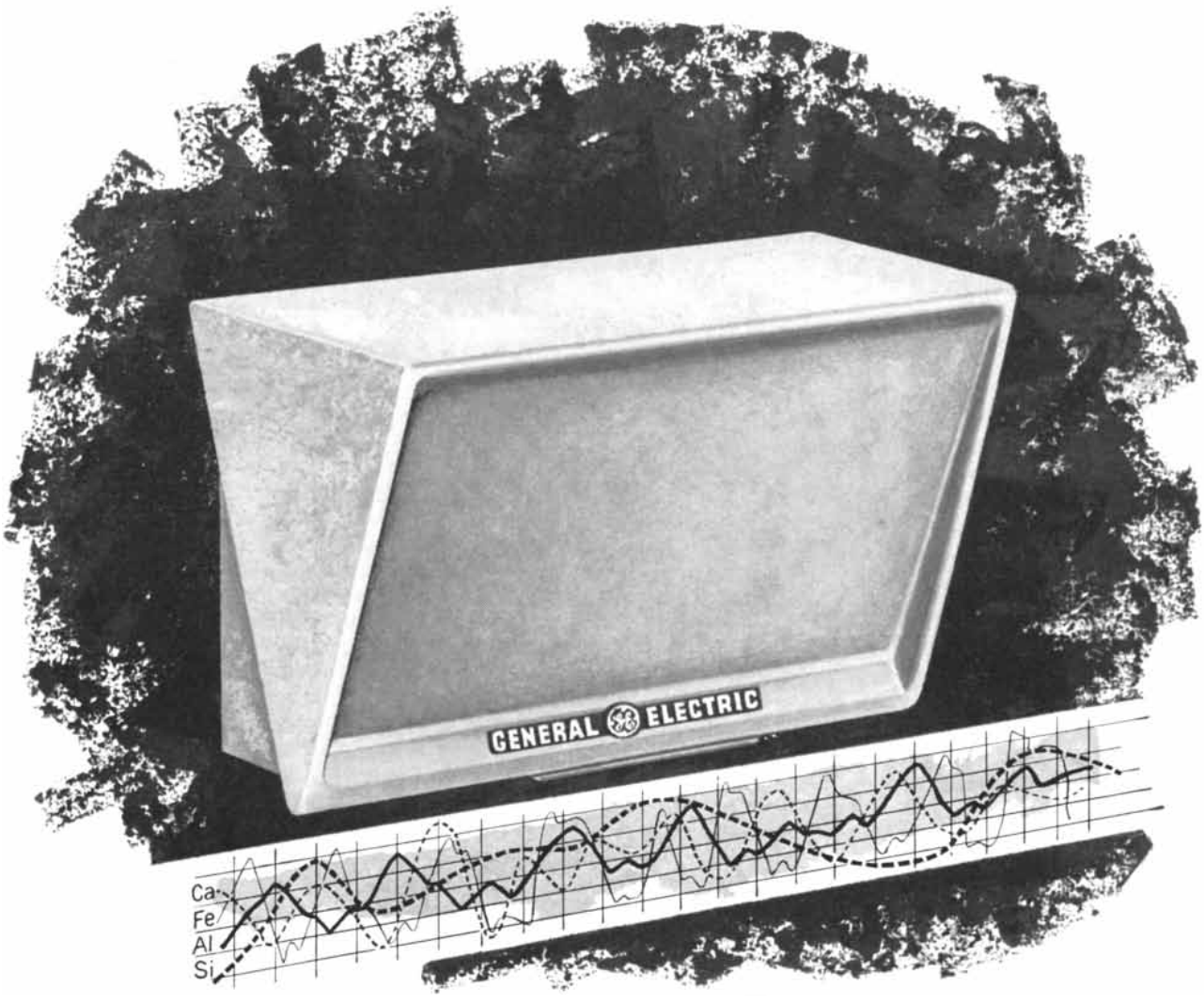

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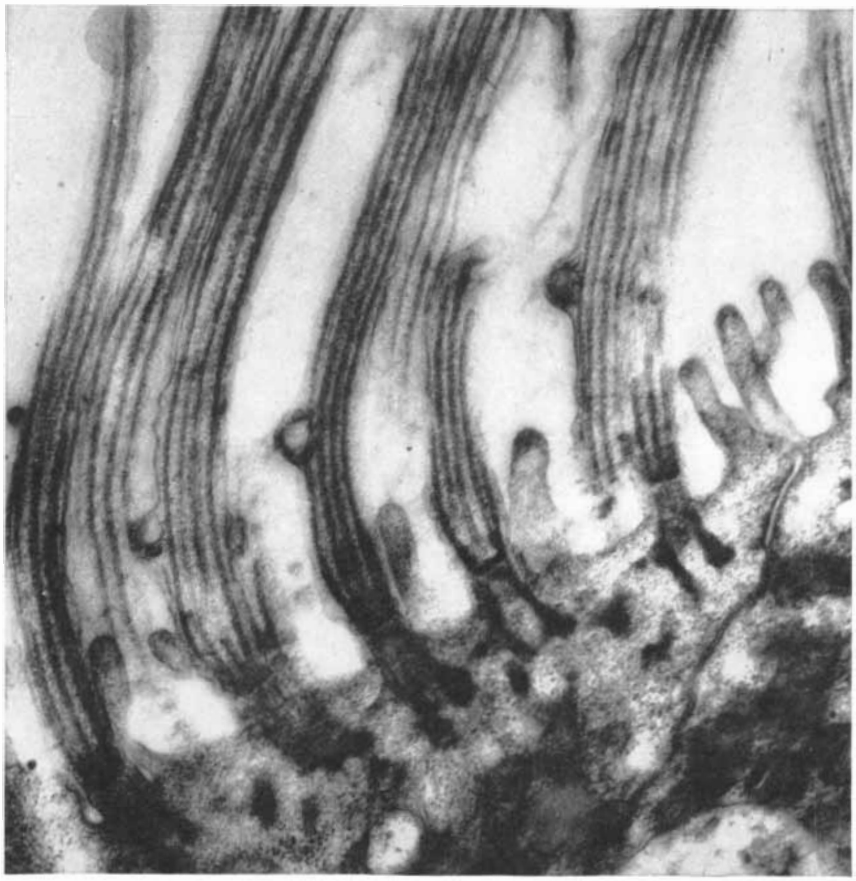
In a wide variety of organisms from both the plant and animal kingdoms these tiny hairlike projections have the same basic structural plan: two long filaments surrounded by nine others

by Peter Satir

In 1676 Antony van Leeuwenhoek, the Dutch naturalist and microscope maker, described an animalcule he had been watching through one of his instruments: its "belly is flat," he wrote, and "provided with diverse incredibly thin feet, or litile legs, which were moved very nimbly." The nimble legs that Leeuwenhoek saw were cilia. After he described them they were discovered on a wide variety of living cells, from protozoa to the cells that line the human trachea.

These appendages, which really look more like fine hairs than legs, are one of the most easily seen "organelles"—specialized parts of single cells that correspond to the organs of more complex living forms. When the appendages are less numerous, they are called flagella, but there is no essential difference between the two types. In most of the cells where cilia or flagella occur their primary function is obvious: they move back and forth like oars. When attached to a movable, boatlike object such as a protozoon, they propel it through the liquid around it. On a stationary object, for example a tracheal cell, they move the surrounding liquid over the surface of the cell. They either bring the cell into new environments or bring new environments to the cell.

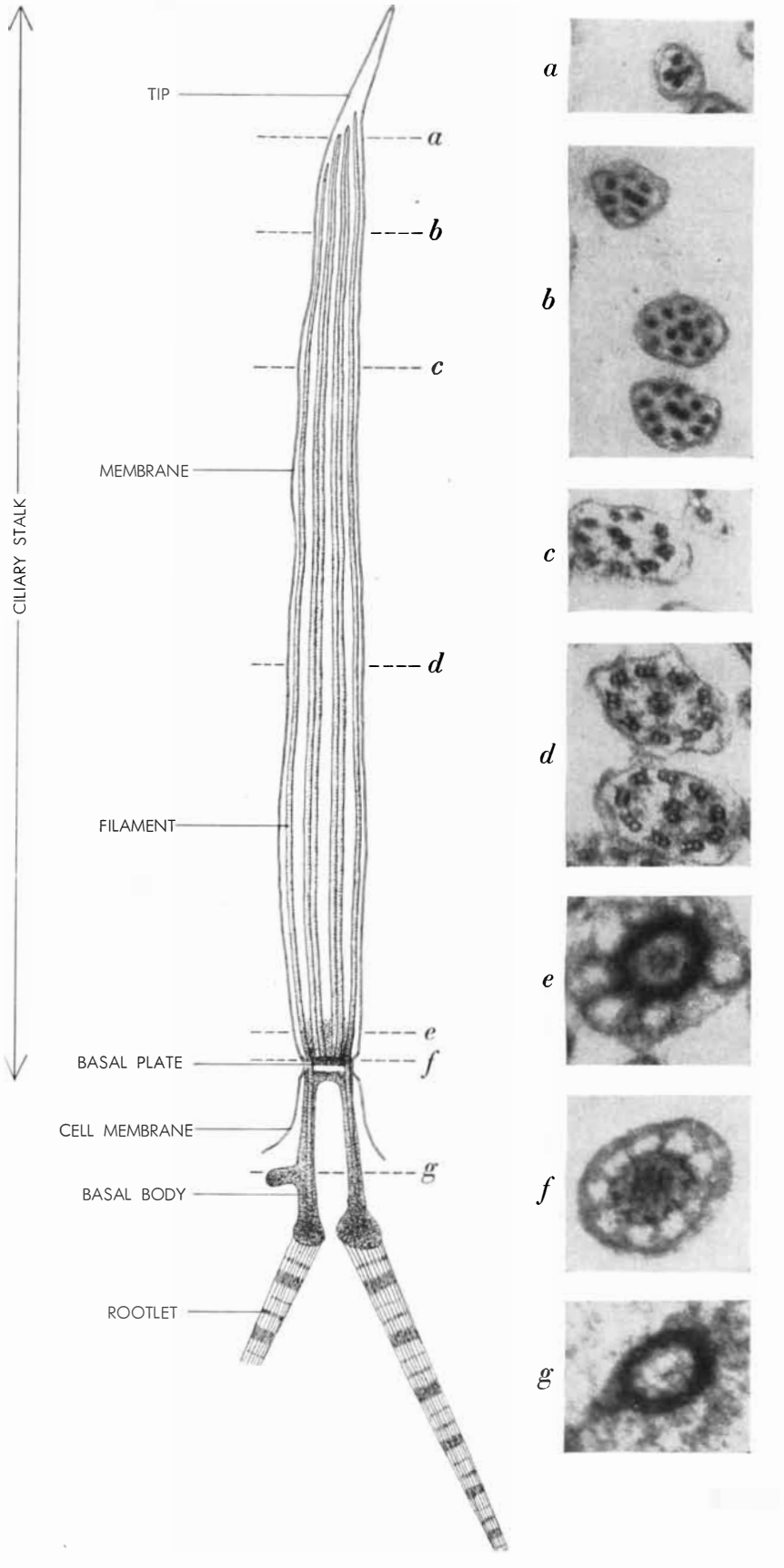


GROUP OF CILIA projecting from the gill cells of a fresh-water mussel is magnified 34,000 diameters in this electron micrograph. Long dark lines are filaments; dark areas at bottom of cilia are basal plates and bodies. (These and other ciliary features are detailed in illustrations on opposite page and on page 110.) The smooth protuberances on the cell surface (*slope*) are microvilli. Irregular line (*right center to bottom*) marks cell boundaries. The micrographs on the first six pages of this article were made by the author.

Until about 10 years ago there was little more to be said on the subject. Since then the study of cilia, as of other parts of the cell, has undergone a major revolution, brought about by the electron microscope. It is now possible to examine the detailed substructure of cilia, mitochondria, microsomes and other organelles and to compare them in many different types of cell. The method of "comparative cytology" is providing new insights into the design and evolution of the cell, playing a role similar to that of comparative anatomy for larger living structures.

Perhaps the most remarkable part of these investigations is the correlation they reveal between form and function. Cellular structure, down to its minute details, remains constant as long as function is constant. When the structure of an organelle changes from one type of cell to another, the difference usually corresponds directly to a change in its function. Taking advantage of this fact, one can interpret the features seen in electron micrographs. By comparing the

PRINCIPAL FEATURES OF CILIA of mussel-gill epithelium are magnified 51,000 diameters. Cross sections of cilia (*upper left*) reveal common pattern of two central filaments surrounded by nine peripheral ones. Longitudinal sections of several ciliary stalks (*large gray projections*) show filaments (*thick gray lines*) and stalk membrane, an extension of cell membrane (*rough sloping line*). Bar of elongated H (*bottom*) is basal plate; lower legs, basal body. Rootlets (*bifurcation at right*) extend from basal body.



DETAILS OF CILIARY STRUCTURE are depicted somewhat schematically in longitudinal section of cilium (*left*). As shown, cilium has been sectioned parallel to the plane of ciliary motion (*i.e., left and right in the plane of this page*); rootlet at bottom right generally does not appear in actual section. In electron micrographs at right cross sections corresponding to different levels (*broken lines*) of cilium are magnified 49,000 diameters.

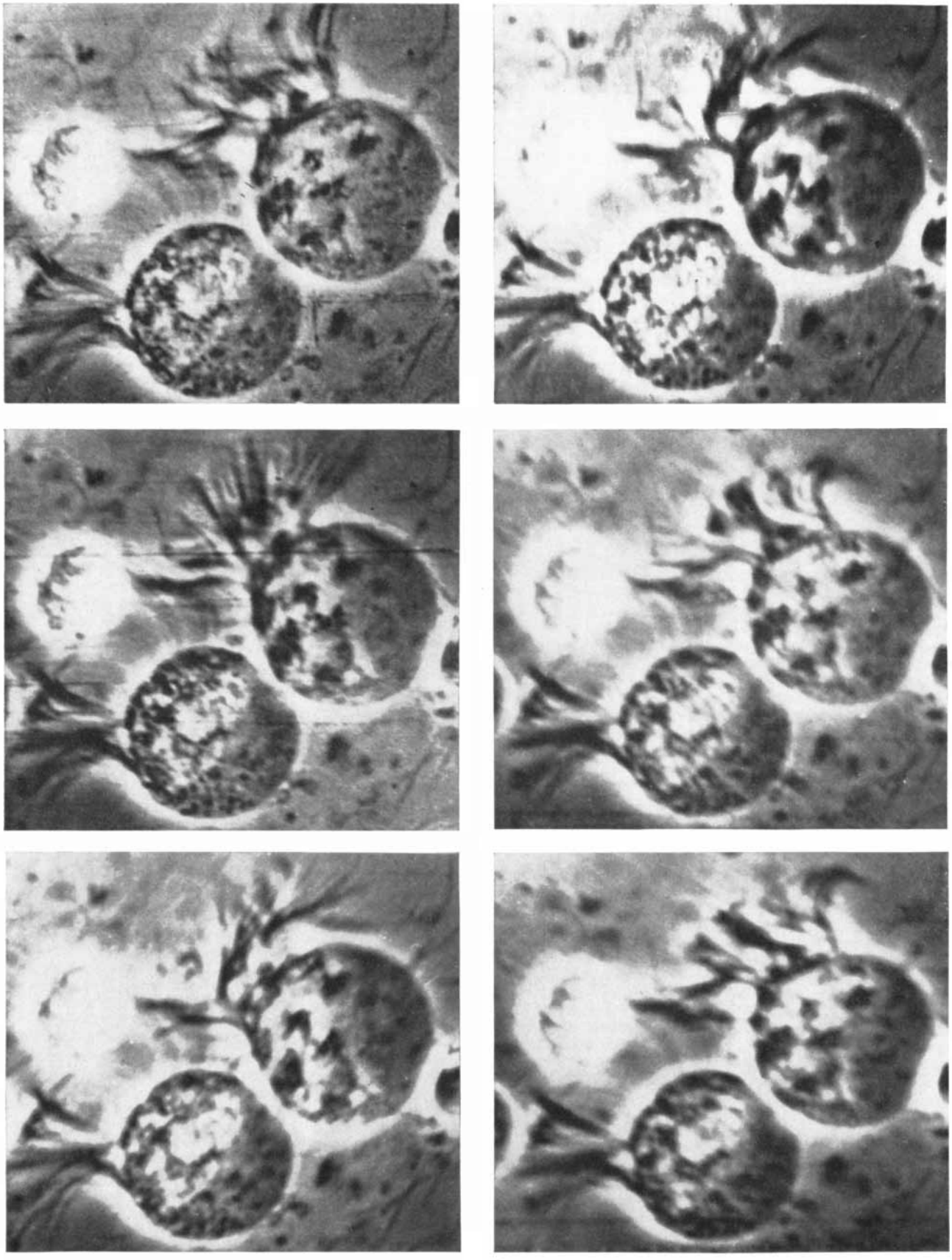
structures of homologous bodies with different functions, the roles of the various features in the over-all workings of the organelle can be determined.

What functions, then, do most cilia perform? Two are obvious: contraction and conduction. Any structure that can move must contain some component that contracts in response to an impulse conducted through it. In this respect a cilium is not much different from a muscle: an impulse conducted to a muscle by a nerve, and through it by a system still imperfectly understood, causes the muscle fibers to contract. There must be elements in the ciliary structure that perform the same tasks. The third function is rather more special: it is duplication. Since cells reproduce by direct division, producing two structures where there was only one, their parts must duplicate themselves, or be duplicated, during each generation. Cilia are self-duplicating and therefore they must have a component that is concerned with this function as well.

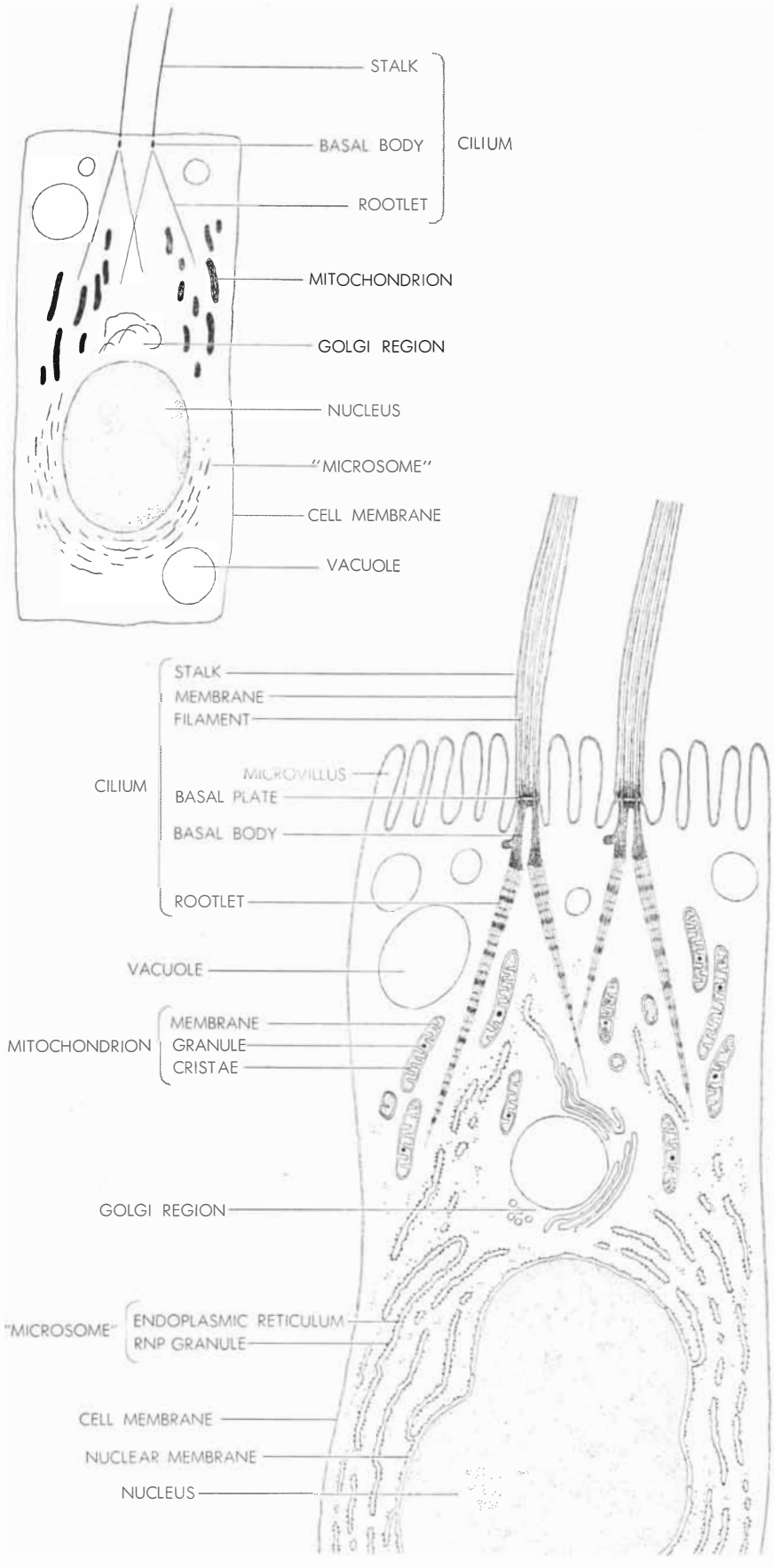
Cilia are very small. The stalk extending from the body of the cell is about .0002 millimeter in diameter and .005 to .015 millimeter long. This is not the complete structure, however. There is a part, the "basal body" and its associated "rootlet fiber," extending deep into the cell. Also connecting cilium and cell body is the common membrane that encloses both.

Not surprisingly, ciliary stalks fail to function when their connection with the rest of the organelle is disrupted. This was demonstrated some 30 years ago by the English zoologist James (now Sir James) Gray. He studied the cilia in the gill of the mussel. Normally their beating is timed so that a wave motion, called the metachronal wave, appears to pass down the row of stalks [*see illustrations on page 113*]. When Gray stripped some of the stalks away from their cell bodies, the wave traveled as far as the stripped region and then stopped. The separated stalks did not move at all. Recently the German investigator H. Hoffman-Berling has refined Gray's observation. Working with sperm flagella, he found that isolated stalks are motionless, but he made them move by adding adenosine triphosphate (ATP). This substance, which supplies energy for almost all biological reactions, was known to cause the proteins in muscle to contract. Evidently the proteins of a flagellar stalk also have inherent contractile ability that is usually controlled through the connection with the rest of the cell.

For a more detailed picture of the cil-



CILIARY BEAT involves effective stroke (*sequence at left*) and recovery stroke (*sequence at right*). Cilia of single mussel-gill cell (*top right in each frame*) are in motion. Effective stroke can be followed by noting successive positions of cilium that stands nearly vertical (*top left*). Cilium bends stiffly to position 45 degrees from vertical (*middle left*), then to horizontal position (*bottom left*) at end of stroke. In recovery stroke cilium straightens from horizontal (*top right*) to vertical (*bottom right*). Cilium is limp during stroke. The frames were selected from a motion-picture sequence. Magnification is 1,800 diameters.



CILIATED CELL is depicted schematically as it would look under light microscope (*top*) and in electron micrograph (*bottom*). Organelles depicted (*e.g.*, cilium and mitochondrion) are found throughout plant and animal kingdoms. Electron microscope reveals subunits of organelles. In mitochondrion the cristae are the light internal finger-like projections.

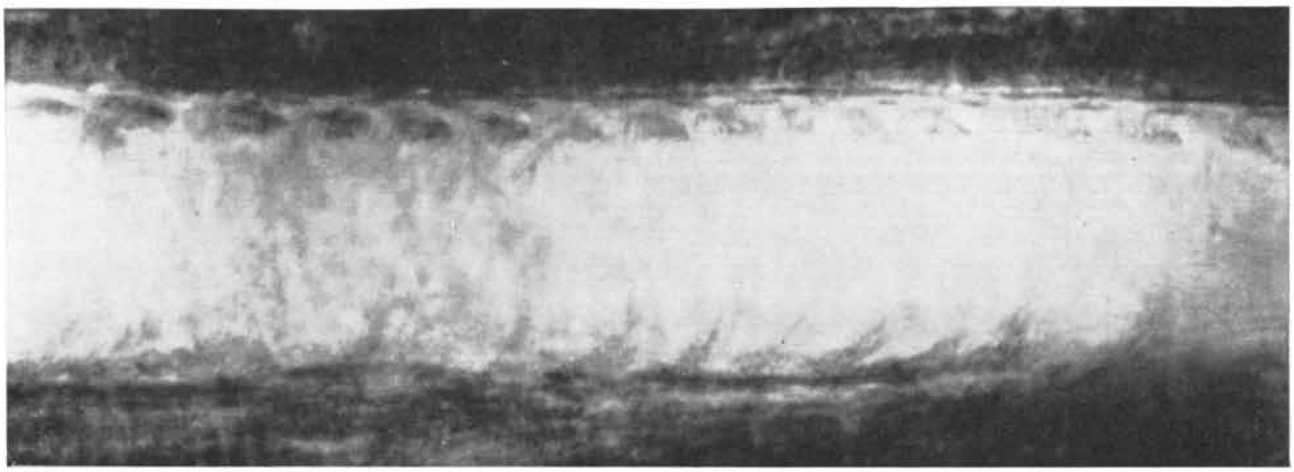
iary apparatus let us turn to the electron microscope studies. To begin with, we find that all movable cilia or flagella, no matter from what type of cell they come, are built on an identical plan. The cytoplasm of the stalk is enclosed in an extension of the cell membrane, and in it are embedded 11 filaments running up from the basal body. They are distributed in a distinctive manner: two central filaments are surrounded by nine others, an arrangement that has come to be known as the 9 + 2 pattern. The nine peripheral filaments are not simply round rods; in cross section they appear as figure eights with hooks at one end. The central filaments, on the other hand, have a circular cross section. Some fibrous connections can be seen between the central pair and the nine peripheral filaments and occasionally between the outer filaments and the ciliary membrane.

At their tips cilia are narrow and probably closed. Some of the filaments in the stalk come to an end before the tip, so that the 9 + 2 pattern is lost in the cross section of the outer region. There the remaining filaments no longer have a complex structure but appear as simple black dots.

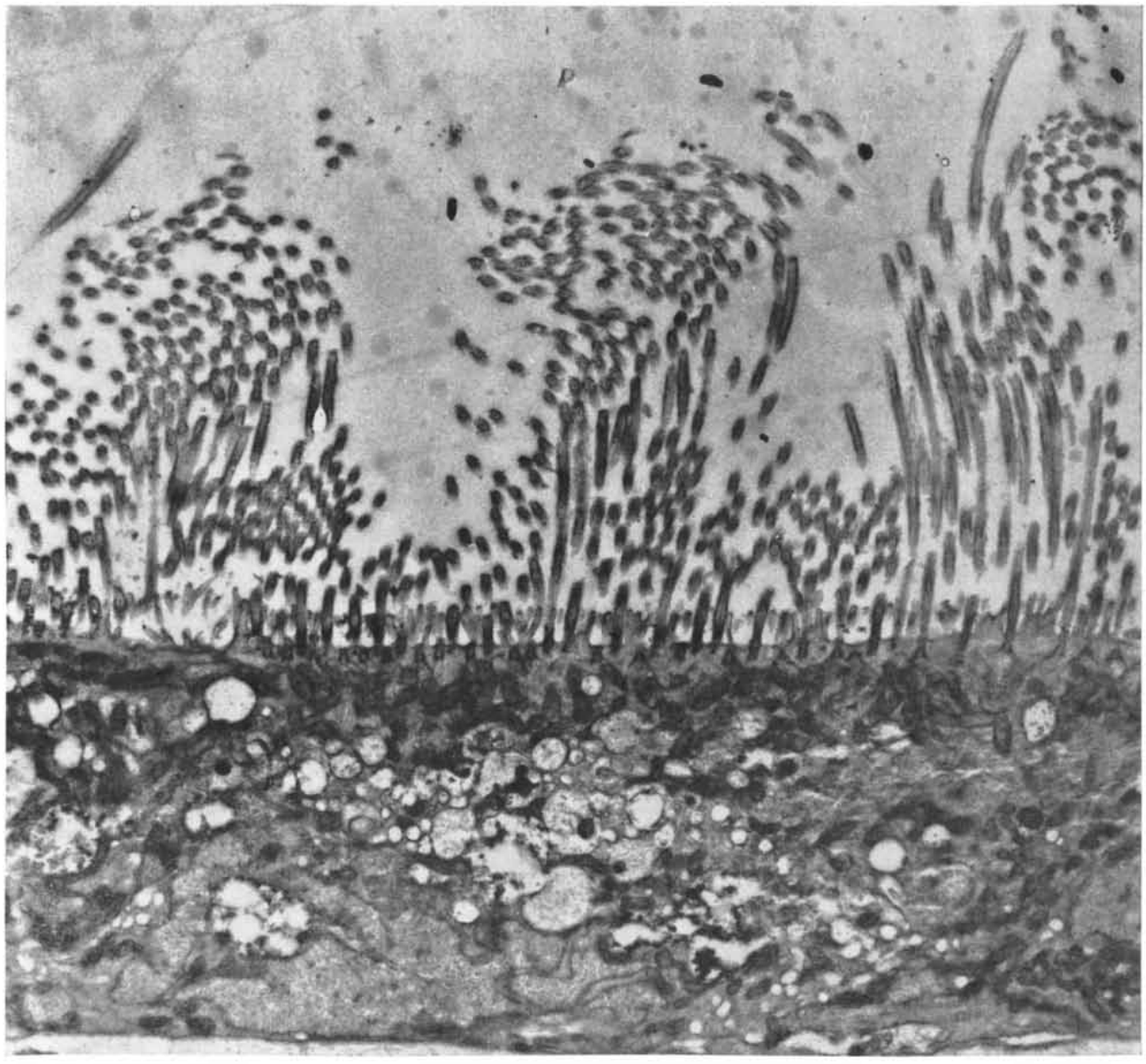
The 11 ciliary filaments run down to the surface of the cell, where the ciliary membrane becomes the cell membrane, ending at this level in a plate. Opposite it is a second plate, which forms the end of the basal body. This body is a cylindrical object about .0004 millimeter long, containing nine filaments that are continuations of the nine peripheral filaments of the stalk but with somewhat more variable and complex form. From the bottom of the basal body the rootlet fiber, striated along its length, extends deeper into the cytoplasm of the cell, where it may become part of a complex network of fibers.

Since the electron microscope does not work with living material, the foregoing description undoubtedly does not apply exactly to the intact cell. Some of the details are surely "artifacts" resulting from reactions between the material of cilia and osmium tetroxide, the chemical used to kill and fix the tissue. Nevertheless, the universal prevalence of the 9 + 2 pattern, even down to the form and arrangement of the filaments, in all electron micrographs of all motile cilia or flagella is convincing evidence of a common molecular arrangement in the live organism.

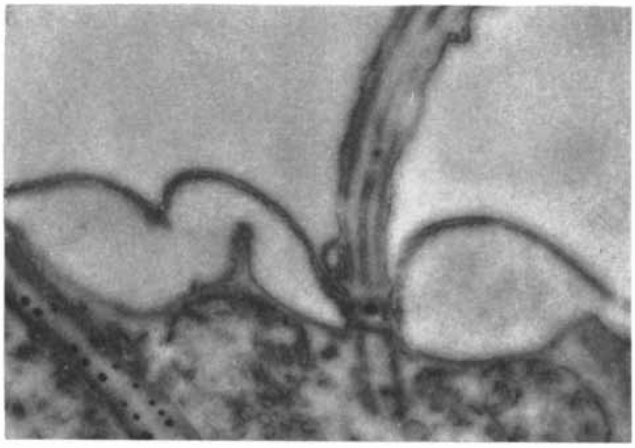
Which structures correspond to which functions? The question cannot yet be answered in full, but certain facts have been established. The 9 + 2 pattern, for



METACHRONAL WAVE consists of repeating patterns of crests and troughs that move along a row of ciliated cells. In this light micrograph of mussel gill, the cilia are magnified 860 diameters. Electron micrograph of metachronal wave appears below.

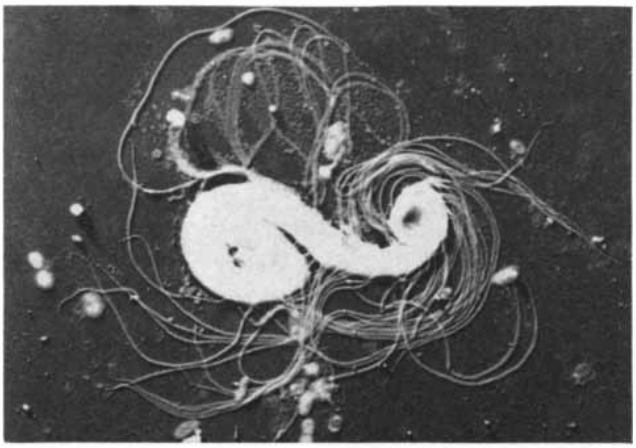


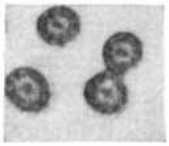
ELECTRON MICROGRAPH OF METACHRONAL WAVE shows that pattern of crests and troughs results from cilia in different phases of their "beat" at the same time. At crest cilia are beginning the effective stroke; trough occurs at or near beginning of the recovery stroke. In mussel gill the cilia beat at right angles to the direction of wave motion. Magnification is 6,500 diameters.



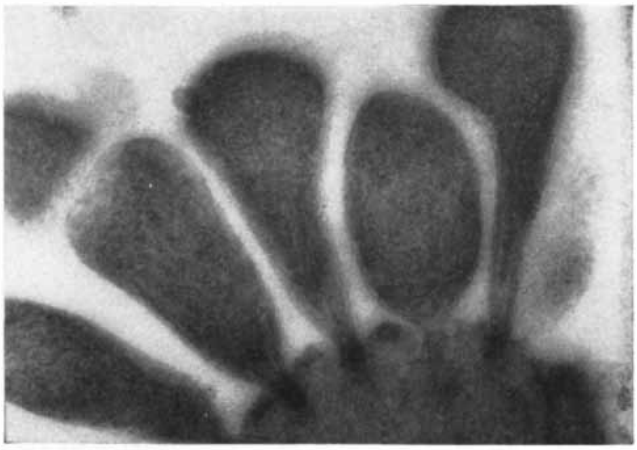
PARAMECIUM CILIA propel organism. In cross section (*left*) cilium shown above has central filaments characteristic of motile cilia. A. W. Sedar and K. R. Porter of the Rockefeller Institute made electron micrographs.

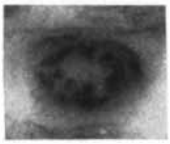
CILIA OF INSECT EAR are nonmotile. Cross section (*left*) of cilium shows two central filaments missing, a characteristic of nonmotile cilia. Micrographs were made by E. G. Gray of University College London.



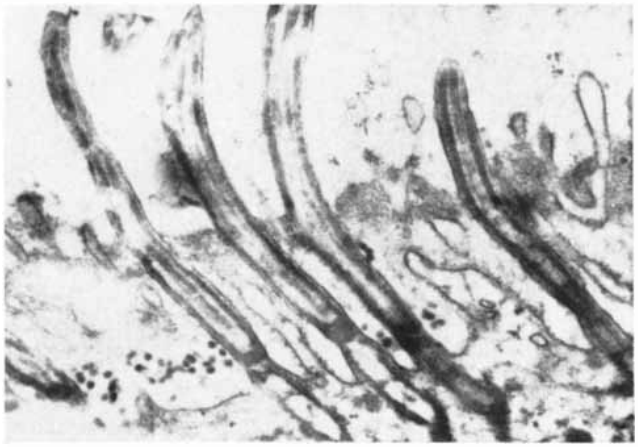


FERN SPERMATOZOID (*white area*) moves by means of cilia (*long threadlike strands*). Four of these cilia are shown in cross section at left. Micrographs were made by Irene Manton of the University of Leeds.

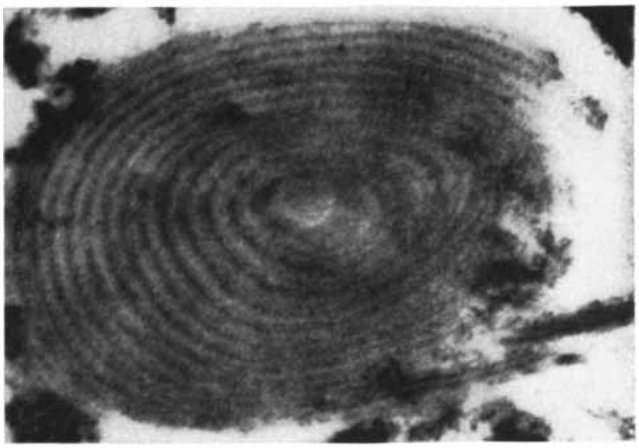


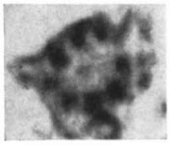


CROWN CELL OF FISH BRAIN has modified cilia. Central filaments are missing in cross section (*left*); such cilia usually perform a sensory function. K. R. Porter of Rockefeller Institute made the micrographs.



CILIA IN RESPIRATORY ORGAN of tubed polychaete (marine worm) drive current of water over the surface of cells (*thin horizontal gray area*). Samuel Dales of the Rockefeller Institute made both of these micrographs.





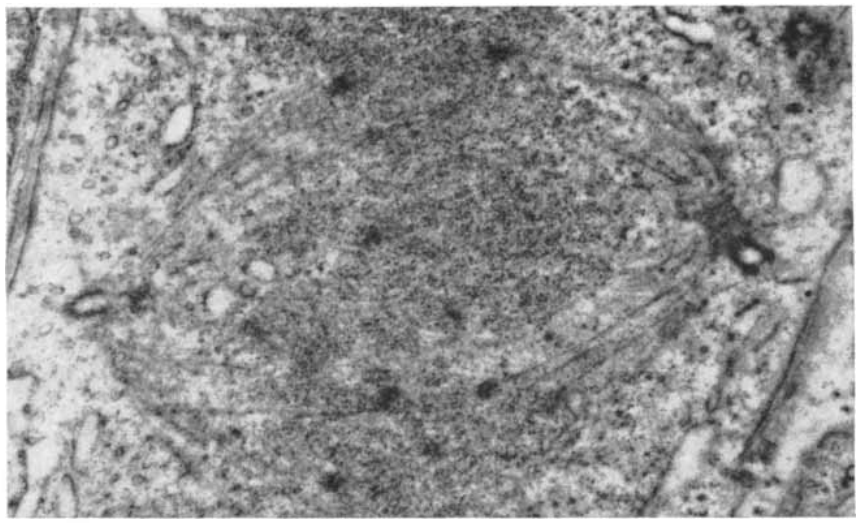
WHORL ON RETINAL CELL of scallop eye is composed of modified cilia. Cross section (*left*) of ciliary stalk shows typical nine-filament pattern. W. H. Miller of the Rockefeller Institute made these electron micrographs.

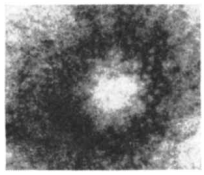
example, must play a fundamental part in contraction. It appears in the motile cilia of all protozoa, higher animals and plants. Some organisms contain cilia that have been modified so that they conduct impulses but do not move. And in these the central pair of filaments is usually missing.

A striking example is found in the eye of vertebrates. Its sensory elements—rods and cones—have evolved from cilia, as is demonstrated by their possession of basal bodies and striated rootlet fibers. The stalks, however, have been radically altered. Instead of terminating in a narrow tip they now lead to bulbous stacks of light-sensitive rhodopsin molecules. The only connection between these molecules and the inner part of the cell (and hence the nerves and the brain) is a piece of cilium-like stalk about .001 millimeter long. The stalk does not move but merely transmits impulses to the sensory nerves. And although it contains the usual nine peripheral filaments, the central pair is missing. Similarly modified cilia are found in the eyes of scallops, the ears of insects and the brains of fishes. These cilia can transmit impulses but so far as we know cannot contract.

Another kind of modification is seen in the ray, a fish related to the shark. In its labyrinth (an organ concerned with hearing and balance) are cilia fixed with respect to the surface of the cells to which they are attached. They can be moved only by an external force. When a force moves them, an impulse is conducted to the cells and sense centers. The movement is a necessary preliminary to the conduction; the two functions are linked together. Hence their operation is the reverse of that in normal cilia: contraction produces an impulse instead of vice versa. But the important point is that these cilia do move, and they possess the pattern of filaments always associated with motion: 9 + 2.

If the filaments, and especially the two in the center, are involved in motion, what part of the structure has to do with the conduction of impulses? Considerable evidence implicates the ciliary membrane. Cilia that conduct but do not move always have a membrane that links the stalk to the cell. In rods and cones, at least, the membrane is known to contribute to the development of the sensory portion of the organelle. Moreover, the cell membrane plays an important part in the transmission of impulses, especially in nerve and muscle cells. Since the ciliary membrane is an extension of the cell membrane, it can logically be assigned the same function.

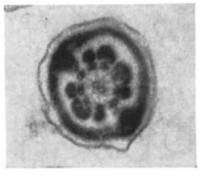




CENTRIOLE closely resembles the basal body of a cilium in structure and function. Two centrioles (*small dark C-shaped areas at left and right*) appear in a chicken-spleen cell during division. In cross section of centriole (*left*) the central filaments are missing. The micrographs were made by W. Bernhard of the Institute for Scientific Research on Cancer of the University of Paris.

There is also experimental evidence for this conclusion. Cutting into a cell near the bottom of ciliary stalks destroys the co-ordination of their motion. Although there may be other explanations for the result, the cell membrane is clearly disrupted by the cuts, and this is a likely cause of loss of co-ordination. Secondly, a number of experiments indicate that impulse conduction in cilia is electrical in nature, as is conduction by the membranes of nerve fibers. In particular, the beating cilia of an isolated mussel-gill have recently been shown to produce an electrical effect much like that associated with the passage of impulses along a cell membrane.

Finally, we should like to account for the self-duplication of cilia. Here we turn to the basal body. Electron microscope studies of various cells show that the basal body has the same structure as another cellular body, the centriole. Both are short cylinders with nine sets of

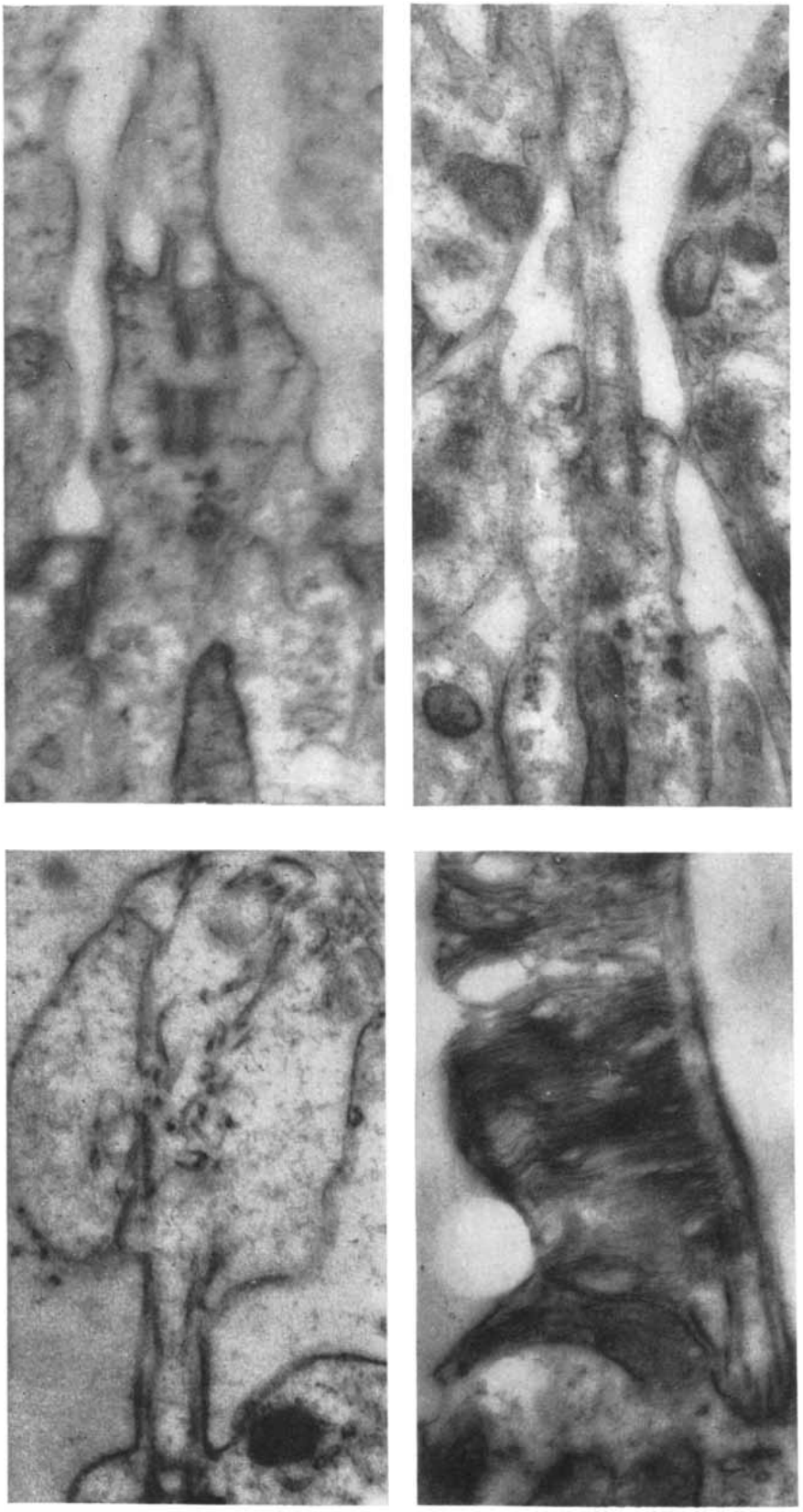


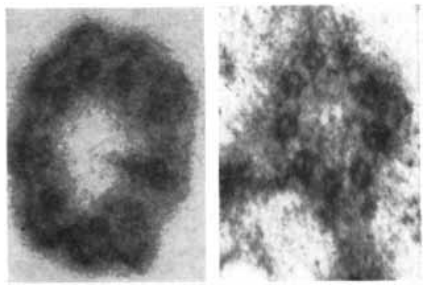
TWO CENTRIOLES are present in developing sperm of cat. Ring with bright center below dark area is one centriole. Other, from which flagellum (*short gray lines at lower right*) grows, does not appear. Section of guinea-pig sperm tail (*left*) shows extra filaments. M. H. Burgos and D. W. Fawcett of the Harvard Medical School made micrograph above, Fawcett that at left.

filaments. In certain cells their functions apparently overlap as well. As the sperm cell matures, for example, a centriole gives rise to a flagellum and becomes a true basal body. The normal function of the centriole is to manufacture, or at least to help organize, the paraphernalia of cell division—the filamentary assembly called the mitotic apparatus. In the process the centriole precisely duplicates itself. Similarly, the basal body is a self-duplicating organelle concerned with synthesizing or organizing the cilium. This is not to say that the basal body plays no part in the contraction or conduction processes, but what part it plays, if any, is still unknown.

Still less is known about the function of the rootlet fibers. From the fact that some fully functioning cilia do not even have a rootlet fiber, we judge it to be of secondary importance. There is no lack of guesses as to its purpose, but so far there is little agreement.

In cytology, as in other branches of biology, comparative studies are intimately connected with the theory of evolution. At this point we can only speculate on the origin of cilia. Judging from the importance of the centriole and its near universality, it seems reasonable to suppose that this organelle emerged first. Then, sometime still near the dawn of evolution, a centriole may have become linked to a cell membrane, an alteration that somehow conferred an advantage in responding to the environment. A little later one of its descendants may have synthesized two extra filaments, a sort of mistaken mitotic apparatus, in the center of the already existing ring of nine. If these filaments had the power of contraction, the cell had acquired a new motile element, which was then conserved and extended by the process of selection.





VERTEBRATE RETINAL ROD is a modified cilium. In developing visual cell of newborn kitten, one centriole (*top pair of short dark lines at top left*) attaches itself to cell membrane, becoming a basal body. Stalk grows from basal body (*top right*). Outer portion of cilium widens (*bottom left*) and assumes primitive shape of outer segment of rod. Unchanged lower section of stalk is "connecting cilium." Micrograph of outer segment of adult rabbit rod (*second from bottom left*) shows connecting cilium (*light gray margin*) and filaments (*thin double lines near bottom*). In cross section rod stalk of rat (*third from left*) shows nine-filament ring characteristic of modified cilia, as does basal body of rabbit rod (*right*). The micrograph of the rat stalk was made by K. R. Porter of the Rockefeller Institute. The other five micrographs shown here were made by Eichi Yamada of Kyushu University in Japan.

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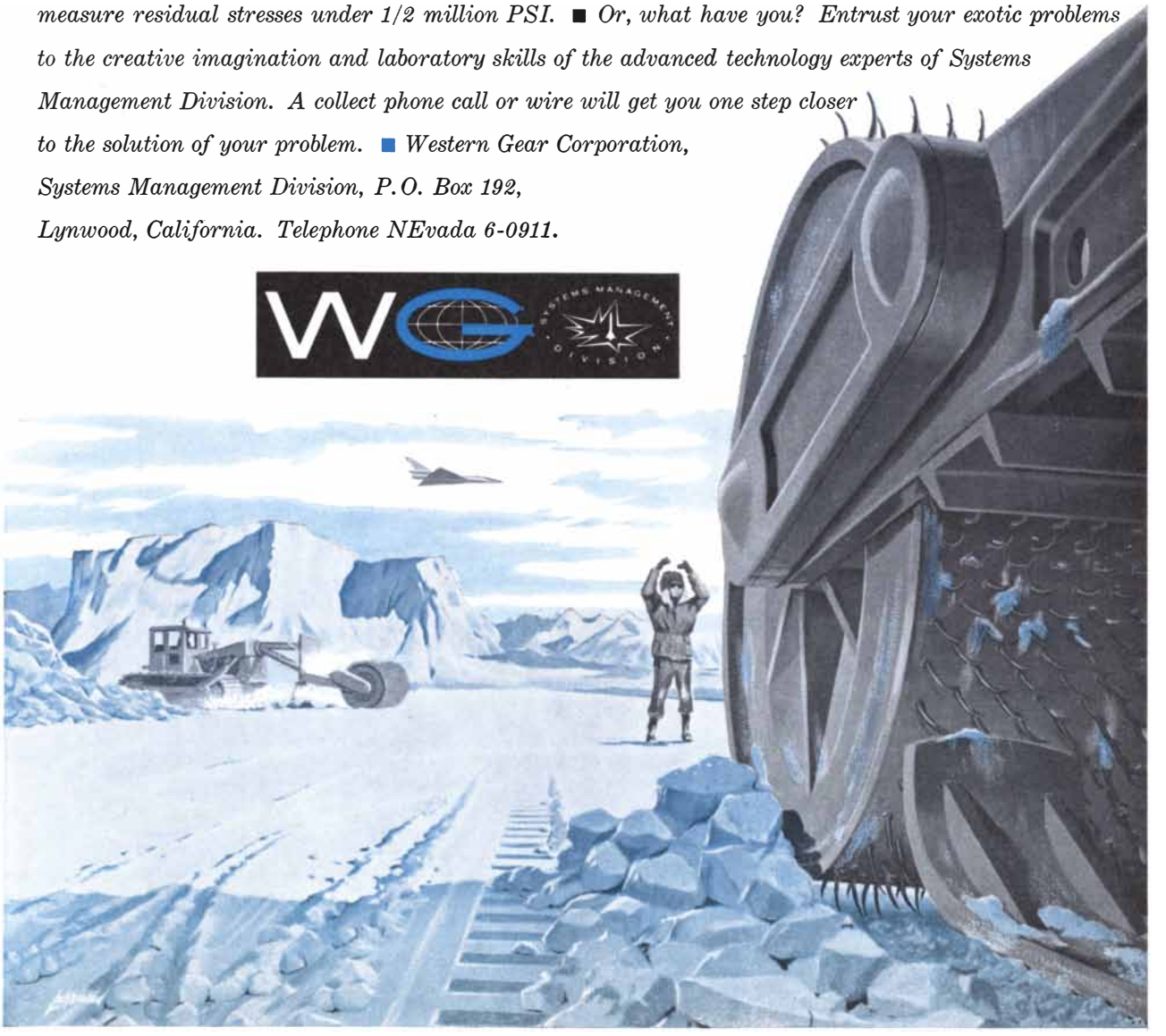
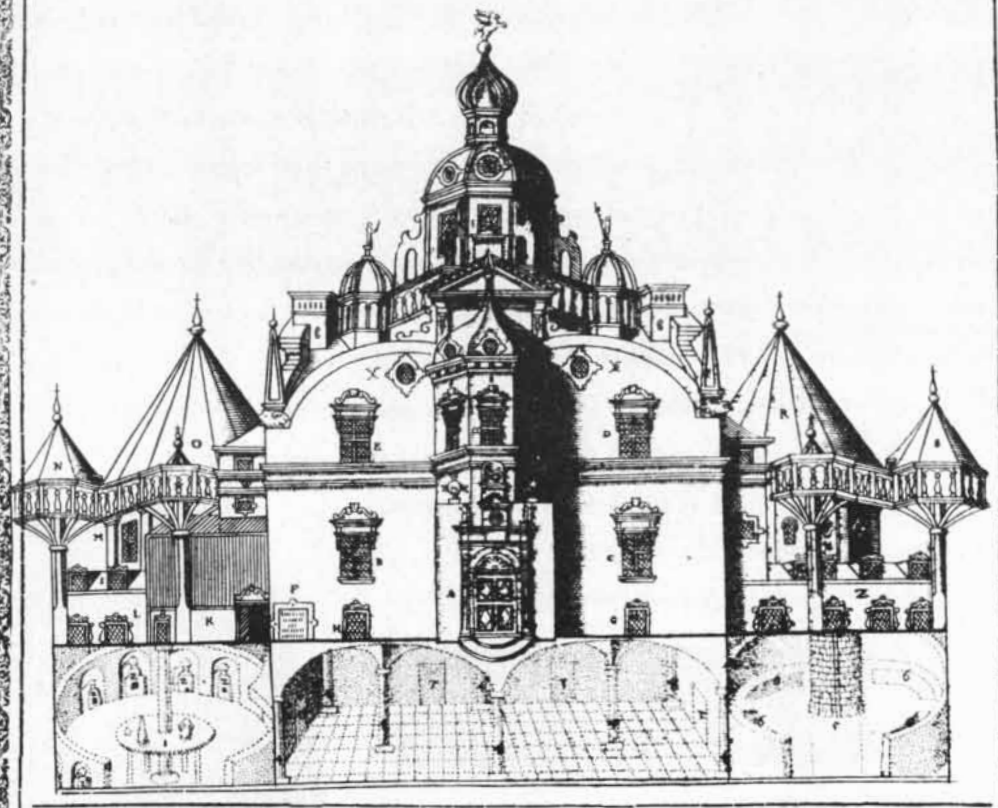
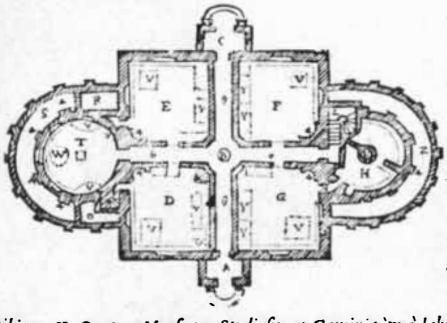


ORTHOGRAPHIA
PRÆCIPVÆ DOMVS ARCIS VRANIBVRGI
IN INSVLA PORTHMI DANICI VENVSIA Vulgo HVENNA, ASTRONOMIÆ INSTAVRANDÆ GRATIA CIRCA ANNVM 1580 à TYCHONE BRAHE EXÆDIFICATÆ.



ICHNOGRAPHIA ET EIVS EXPLICATIO



A Janua Orientalis. C. Oculos rectos concurrentes, qui Cœnaculum hybernum sive hypocauangulo post fornacem parvum quodgyricum esset, in quo tamen quinq; ptuis ad manus isthic operi Pyronjus illud descendendum foret. B. qui aquas hinc inde cùm lubuit, in culum illud hybernum. E. F. G. pro ascensu in superiorem contignacementitius 40. ulnas profundus, quas per siphones hinc inde occultè Cameras tam superiores quam infedescensu in laboratorium Chymibus magnus Orichalcicus num. exhibitus. V. Quatuor Mensæ pro Studiosis, 4. Camini tàm è laboratorio inferiori ascendentes, quàm in quatuor angulis conclavium. Y. Lecti in ijsdem conclavibus. hinc inde dispositi. Cætera acutus inspector propriâ intentione facilè discernet. Intelligenda autem sunt hæc omnia in eâ quantitate, veluti fundamento majoris domus supra depictæ quadrare poterunt: Licet hic coarctationis loci gratiâ in duplo quasi minoris formâ exhibeantur.

cidentalis. Q. Transitus 4. ad antamen posteà in tres redacti sunt, ut ftum D. ampliaretur, atq; in ejus dam & secretum laboratorium spadistinctim erant furni, qui prommico inserviebant nè semper in ma. Fons aquarium volubilem rotans, sublime ejaculabatur. D. Cœna. Cameræ pro hospitibus. L. Gradus tionem. H. Coquina. K. Puteus artificio hydraulico serviens & aper murum transeuntes in singulas riores distribuens P. Gradus pro cum. T. Bibliotheca. V V. Glo

TYCHO'S CELESTIAL PALACE, the Castle of Uraniborg, was completed in 1586 on the island of Hven between Denmark and Sweden. Many of Tycho's instruments were housed under the sliding conical roofs *N*, *O*, *R* and *S*. The sextant, the bipartite arc and the small equatorial armillary, all illustrated on page 124, were located at *O*, *R* and *S* respectively. Tycho's great brass globe, on which he plotted the positions of 1,000 stars (*page 128*), is denoted by *W* in the library marked *T*.

The Celestial Palace of Tycho Brahe

In the late 16th century a Danish nobleman built on the island of Hven the most ambitious astronomical observatory the world had yet seen. Its precise instruments created modern astronomy

by John Christianson

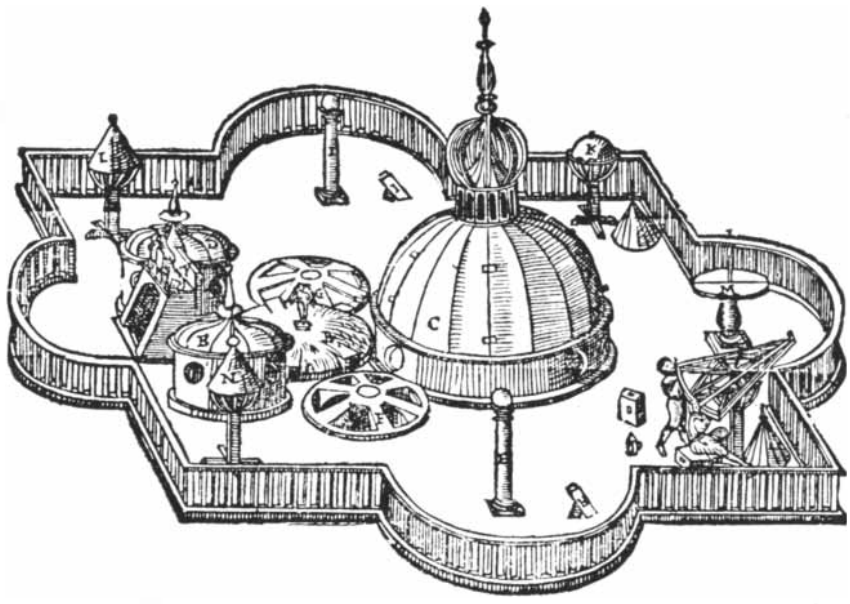
Swordplay was a favorite pastime of young gallants in 16th-century Germany—almost as popular as carousing and wenching. So when the young Danish nobleman Tycho Brahe came south to study at German universities he quite naturally became involved in a duel, and during the contest part of his nose was cut off. Even in his youth Tycho was not one to settle for second best: he scorned a false nose of wax for the elegant prosthesis of gold and silver that he wore for the rest of his days. By the same token, when the more mature Tycho took to astronomy, he insisted on having an observatory that was the finest in all Europe.

The great observatory was established in an unlikely place: off the coast of Denmark on the island of Hven, not far from Elsinore (Helsingör), the scene of Shakespeare's *Hamlet*. Tycho Brahe would have preferred to view the heavens from central Europe, but in May, 1576, Frederick II of Denmark conferred Hven upon Tycho, then 30 years old, "to have, enjoy, use and hold his life long, and so long as he lives and desires to continue and pursue his *studia mathematics*." Tycho left Germany and returned to his homeland to build his observatory. There he spent 21 years peering at the sky and compiling his observations into the first massive body of accurate data that astronomy had ever known.

These precise observations were made entirely without the aid of a telescope. It was not until 1609, eight years after Tycho's death, that Galileo first used the telescope for astronomical purposes. Tycho's instruments consisted of ingenious improvements on ancient devices: quadrants, armillary spheres and parallactic rulers. All were aimed at celestial objects by means of simple metal sights. Tycho's goal, like that of astronomers before him, was to establish exact positions for as many fixed stars as possible and to plot the motions of the planets visible to the unaided eye: Mercury, Venus, Mars, Jupiter and Saturn. Tycho's celestial catalogue eventually listed positions for 777 stars, or more than three-fourths of those that can be seen with the naked eye from the latitude of Denmark. The catalogue gave stellar and planetary positions in the universal co-ordinate system based on declination and right ascension. (How these co-ordinates differ from simple altitude and azimuth will be discussed below.)

In a tireless quest for accuracy Tycho filled his observatory with a succession of instruments, each more ambitious than the last. He recognized that by increasing the distance between the sights of his instruments, and by increasing the size of the calibrated arcs from which he read positions, he could gain accuracy. But he also came to realize that when he made his instruments too large, they bent and twisted of their own weight, introducing a new class of errors in place of those that size was supposed to eliminate. He recorded that this great observatory at Hven cost Frederick II "more than a tun of gold," the equivalent of about $1.5 million today.

From Tycho's painstaking data his protégé Johannes Kepler was able to derive the comprehensive laws that com-



STJERNEBORG, or Star Castle, was a second observatory that Tycho built on a hill about 400 feet south of Uraniborg. Most of Stjerneborg's instruments, including some of Tycho's finest, were installed below ground to shield them from the wind. The great equatorial armillary (*page 124*) was under dome (*C*). The ruins of Stjerneborg are shown on page 122.

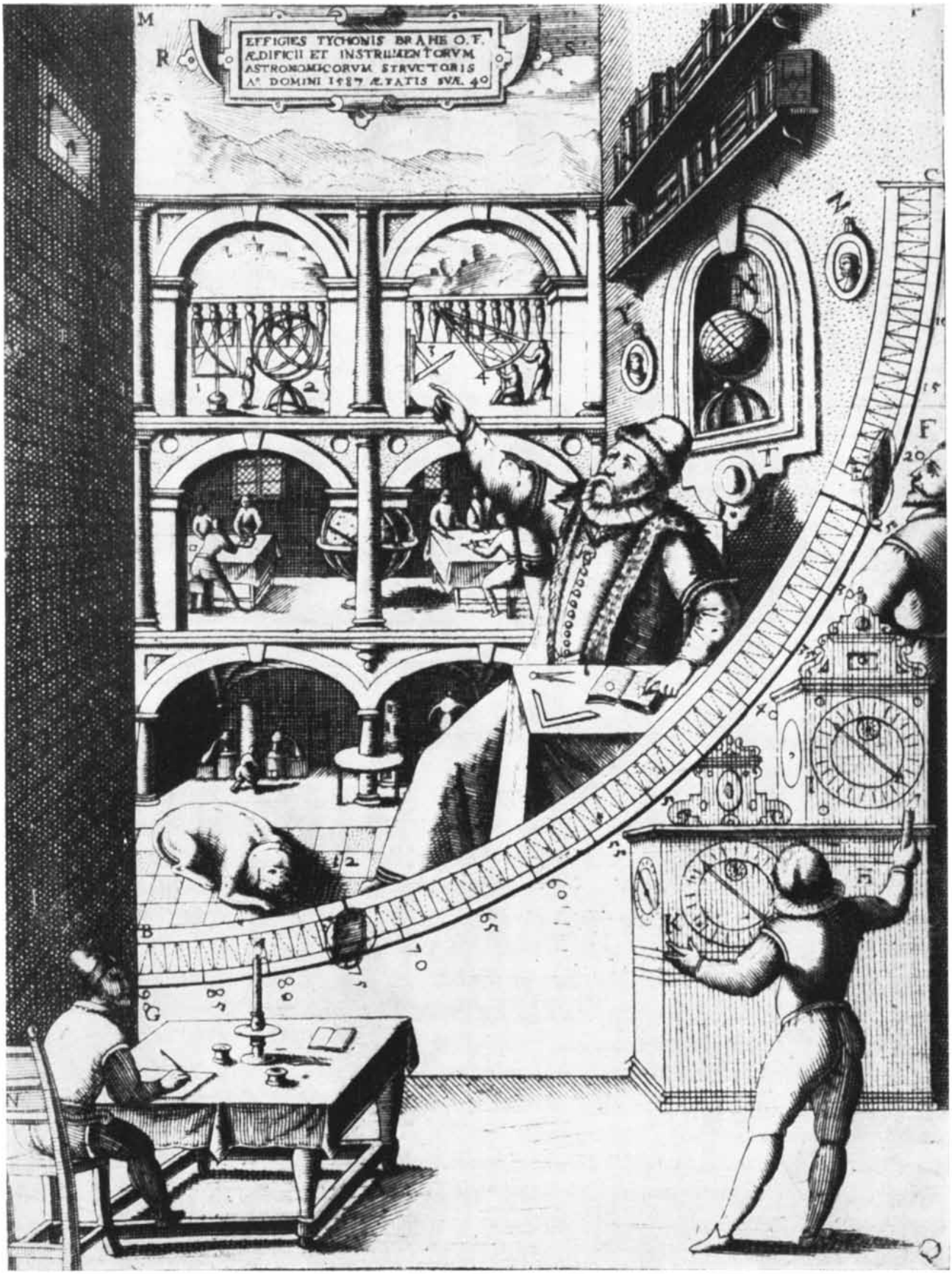
pleted the Copernican revolution. Kepler worked out a circular orbit for Mars that came within eight minutes of arc of Tycho's observations of that planet—a discrepancy amounting to no more than the thickness of a penny viewed edgewise at arm's length. But because Kepler knew that Tycho's data were accurate to within as little as four or five minutes of arc, he discarded the assumption of a circular orbit, started his calculations afresh and eventually arrived at an elliptical orbit that fitted the observations. This was a step of immense importance: out of it came the two most fundamental of Kepler's three laws of planetary motion. The first states that the planets have elliptical orbits with the sun occupying one of the two foci of the ellipse. The second states that a line drawn between the sun and a planet sweeps out equal areas in equal intervals of time. But Kepler's Mars computations had a still deeper significance. For perhaps the first time in the history of science the theoretician had enough respect for the accuracy of a set of observations to abandon his original prejudices and search for a totally new hypothesis.

Tycho realized in 1563, when he was only 17 years old, that astronomy was in need of fresh data. The standard references of his day were the old Alphonsine tables (which derived from Ptolemy's geocentric ideas) and the Prutenic tables (which had recently been compiled after the heliocentric theory of Copernicus). Both tables gave the impression of considerable accuracy: they stated positions in degrees, minutes and even seconds of arc. But Tycho found the Alphonsine figures in error by a full month in predicting a conjunction of two planets in 1563. The newer tables were hardly better: their margin of error ran into days. Never one to underestimate his abilities, Tycho determined to amend the lack of accurate data and establish a new basis for astronomical studies. He was convinced that the true scheme of the universe could never be discovered until men knew exactly where the stars and planets really stood in the dome of the heavens. Yet many years later, after he had amassed his tremendous body of astronomical data, he still failed to recognize that Copernicus was right—that the earth moves around the sun and not vice versa.

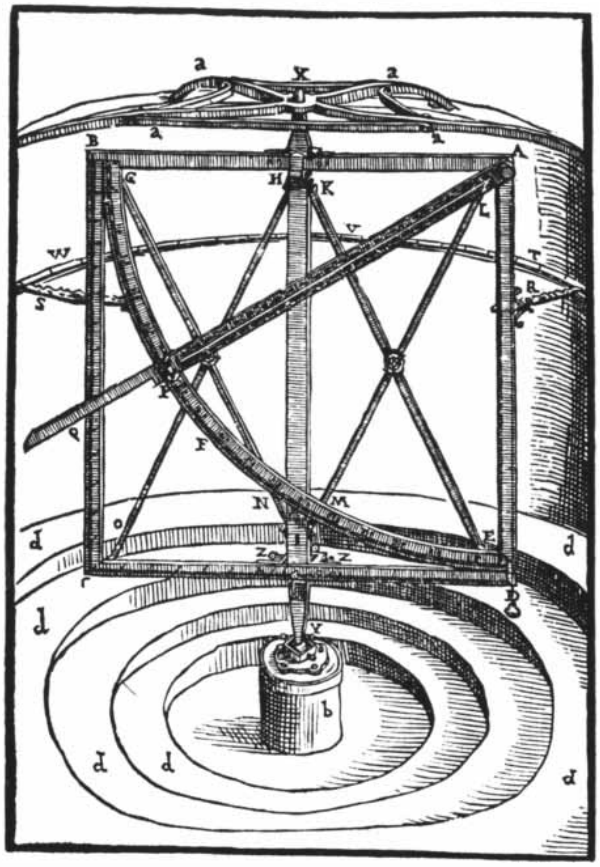
Tycho made his first crude observations with, as he wrote, "a rather large pair of compasses as well as I could, placing the vertex close to my eye and directing one of the legs toward the planet to be observed and the other toward some fixed star near it." All his future instruments were to be nothing but elaborations of this first one. Between the ages of 17 and 29 Tycho traveled extensively in Germany and Italy, observing the celestial bodies whenever possible. He was planning to settle near Basel and pursue astronomy in earnest when he was bidden to the court of his king to receive the fief of Hven.

"LIKENESS OF TYCHO BRAHE," runs the Latin inscription under this portrait, "son of Otto the Dane, Lord of Knudstrup and originator of Uraniborg Castle on Hven Island in the Danish Hellespont, inventor and builder of the astronomical instruments used there. Completed 1586 at age 40." *Non haberi sed esse* means "Not to be esteemed but to be."

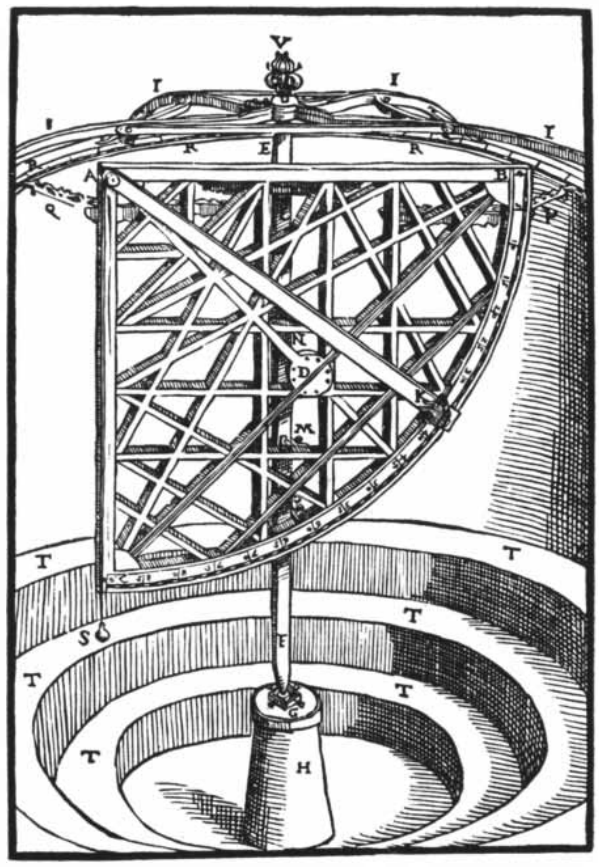
Hven was cold and damp much of the year and so far north that Tycho saw less of the heavens than he might have wished. The planet Mercury, in particular, lay frequently out of his sight below the southern horizon. Despite its northerly latitude, the island had its attractions. It rose like a mountain from the sea, "free from the commotion of the common herd" but still within comfortable visiting distance of Copenhagen, where Tycho could make an occasional appearance at the university or announce himself at the court of his patron Frederick. To walk around the island required 8,160 of Tycho's vigorous strides. A single village called Tuna lay toward the north. Tuna's 40 peasant families lived in cautious suspicion of their lord, the wizard-astronomer. Around Tuna were the three great fields of the village, divided into narrow strips and covering



GREAT MURAL QUADRANT, in which Tycho had "great faith," measured over six feet (76.5 inches) from the cylindrical front sight (in opening of the wall at upper left) to the rear sight, or pinnule, which could be moved along the arc. At lower right are two clocks of "the greatest possible accuracy." The quadrant was used to measure the altitude of celestial bodies as they crossed the north-south meridian. The full-size figure of Tycho was actually part of a wall painting depicting Uraniborg's multiple activities.



GREAT STEEL QUADRANT had as large an arc radius (76.5 inches) as the mural quadrant on the preceding page. Tycho said he depended chiefly on these two quadrants and the one at the right.



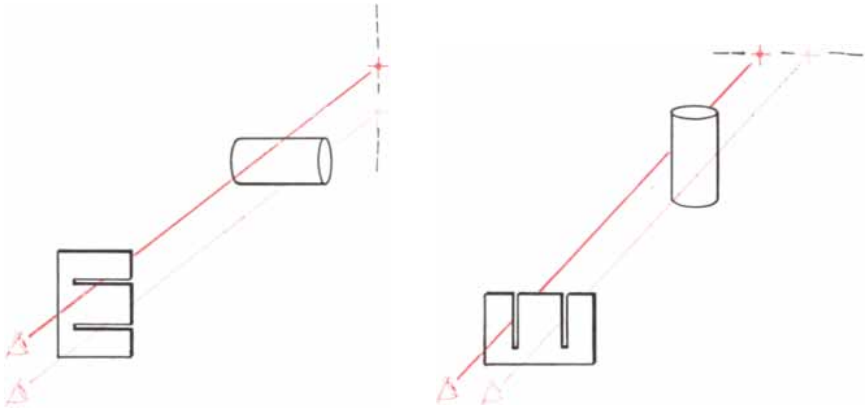
REVOLVING AZIMUTH QUADRANT had an arc radius only 15 inches smaller than that of quadrant at left. Tycho advised astronomers "to consider this construction as particularly commendable."

RUINS OF STJERNEBORG confirm in detail the diagrams in Tycho's published works. The concentric steps (*upper left*) were at the base of the great steel quadrant illustrated at the left at top of page. The quadrant shown at top right stood slightly to the right and beyond the men in the photograph. A large sextant stood at lower right. The base of the great equatorial armillary (*page 124*) is just visible at lower left. The small rectangular area to the left of the men contained a bed (off the furnace room), where Tycho said he would sometimes rest "when accidentally there were clouds and we could not enjoy a constant clearness of the sky."

the northern half of the island. Beyond the fields were open meadowland and a small hazelnut grove. There was game enough for a noble sportsman and many fish in the sea.

Tycho built his castle-observatory exactly in the center of the island. He called it Uraniborg in honor of Urania, the Greek muse of astronomy. The inspiration came from the famous Villa Rotonda, built near Vicenza by Andrea Palladio, the Italian master of Renaissance architecture. Tycho might actually have seen the villa when he toured Italy in 1575, but in any case he would have been familiar with it through Palladio's work *I quattro libri dell'architettura*. The books were a landmark of architectural literature and caused a sensation throughout Europe when they were published in 1570. The Villa Rotonda described therein is an open, airy building, clean and restrained in surfaces and in detail, a delightful Italian jewel. Tycho's Uraniborg, on the other hand, was a snug northern building, constructed solidly of brick against the Danish winter, trimmed with blocks of limestone that marched up the corners to the copper roof, and enriched with the many grotesque details and embellishments of Northern Renaissance style. But there was a similarity to the general plan of Villa Rotonda. Palladio's villa is admirable for its symmetry and for the way its chief axes extend beyond the villa to create an unprecedented unity between building and landscape. The villa itself consists of a circle enclosed within a square, which in turn is surrounded by a larger square; from the circle four corridors extend to the middle of each outer wall, and the rooms are arranged symmetrically around the axes of the building. The plan of Uraniborg followed that of Palladio's villa, except for the addition of circular projections on the sides and towers front and rear [*see illustration on page 118*]. Despite these functional additions, Tycho adhered to Palladio's example of using only pure geometric shapes.

Tycho also adhered to Palladian precepts in laying out the grounds of his castle. Geometrical relationships were expressed among the various elements of the grounds and between building and surroundings. The corners of the garden wall stood squarely on the points of the compass. In front of and behind the castle were identical two-story gatehouses, with snarling mastiffs caged in the upper levels to announce the arrival of guests and to discourage intruders. At the side corners of the walls were two larger buildings, one housing Tycho's printing shop and the other the servants' quarters. The grounds were completely symmetrical, laid out in paths and formal gardens and bound through the formal scheme of design to the central castle.

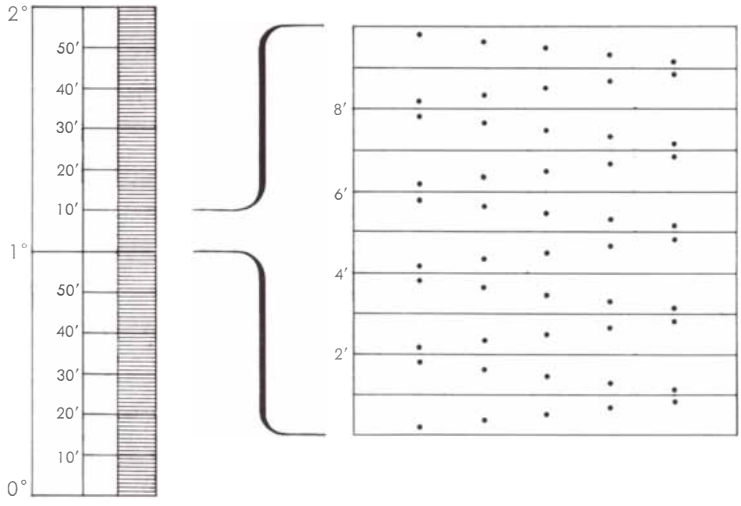


TYCHONIC SIGHTING METHOD used a cylinder as a front sight and two slits, with a spacing equal to the diameter of the cylinder, as a rear sight. In making a sighting (*of altitude, at left; of azimuth, at right*) the sights are aligned so that a celestial object appears equally bright on both sides of the cylinder when the eye is moved from one slit to the other.

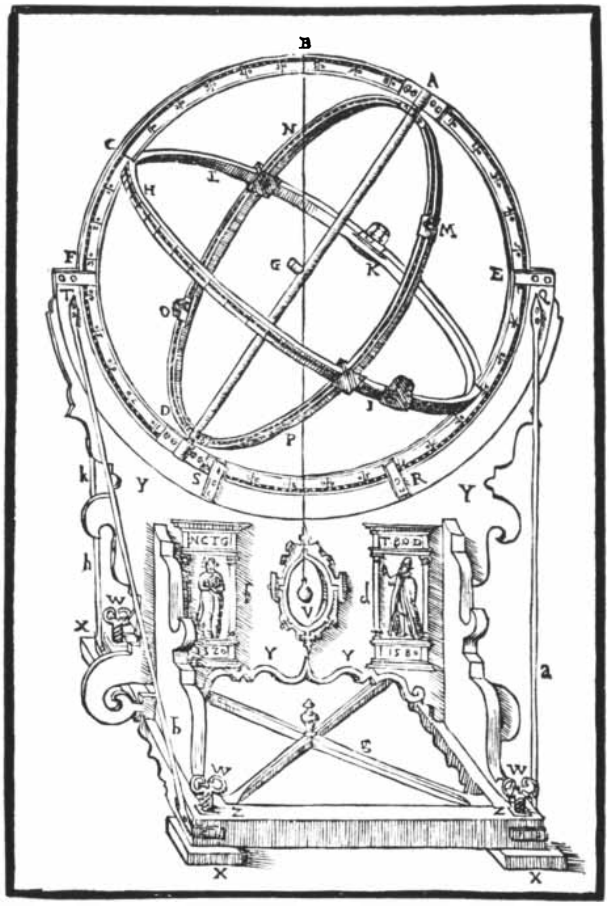
Uraniborg was three stories high. In the basement were salt cellars, wood cellars and a mysterious alchemic laboratory, where according to the tales of wide-eyed peasants a golden-nosed wizard performed weird experiments and transmutations. The basement indeed contained 16 chemical furnaces of various sorts. On the ground story of the palace were living rooms, guest chambers and a kitchen. Another room held the mighty mural quadrant, which provided the standard of accuracy for all Tycho's instruments. The museum-library in the southern round chamber was where Tycho kept his celebrated celestial globe. It had been specially constructed by the finest instrument makers at Augsburg. Upon it Tycho assiduously marked each star within his ken—1,000 in all—after careful observation had fixed its exact position in the skies.

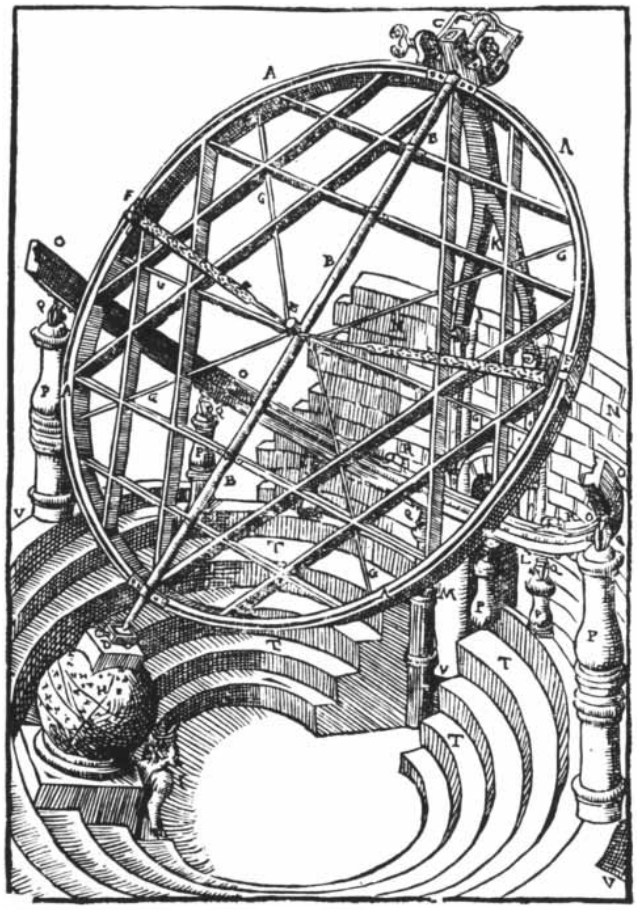
On the second story of Uraniborg were the Summer Room, the Queen's Chambers (where Queen Sophia stayed when she visited) and the King's Chambers. King James VI of Scotland (later James I of England) called upon Tycho in 1590, but because James's Danish bride was waiting in Copenhagen he did not linger in Uraniborg overnight to occupy the royal chamber.

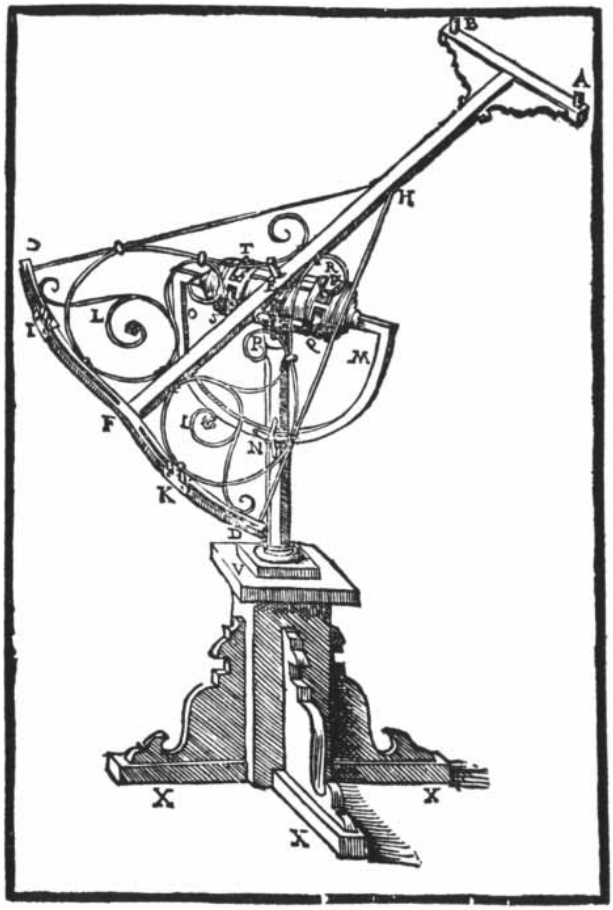
At the sides of the second level, above the round chambers of the ground story, Uraniborg had circular porches upon

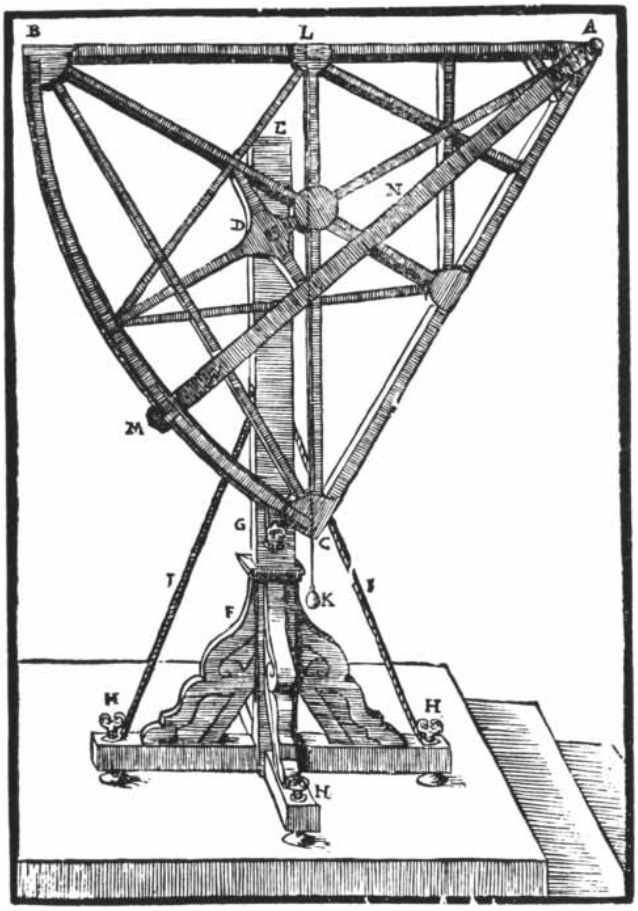


TYCHONIC CALIBRATION METHOD employed so-called transversal points. The scale at left represents a full-size section of the arc of the mural quadrant (*page 121*). Tycho claimed that each minute was subdivided into six parts as shown enlarged at right. Evidently he did not realize that the eye limited his sighting accuracy to about two minutes of arc.









which large instruments were mounted under sliding conical roofs. Out beyond these were two smaller circular observation platforms, each mounted on a single pillar and also covered with conical roofs. Above the main part of the building was a third story, where Tycho's students and assistants slept in eight unheated garret rooms. All in all, Uraniborg was a compact combination of a residence, an observatory and a school of astronomy.

The palace was full of strange devices and innovations. There was running water—a luxury unknown even to such contemporary monarchs as Queen Elizabeth at Hampton Court or King Henry III in the Louvre. Another device contributed to Tycho's reputation for wizardry. When guests were present in his study, Tycho would sometimes whisper an assistant's name and then enjoy the general astonishment when he came running. Actually the assistant had been signaled surreptitiously by a mechanical system of bells and wires running from the study up to the garret. Uraniborg set the pace in northern Europe with its remarkable technical innovations as well as its advanced architectural style and integrated scheme of landscaping. Even if it had not been the observatory of a great astronomer, it would still have demanded a place in the history of European architecture.

A short distance outside the walls of the main palace was a subsidiary observatory called Stjerneborg—the Star Castle. It was sunk below ground level so that the wind would not affect the instruments, and it further contributed to Tycho's reputation as a sorcerer. Peasants marveled to hear that their lord descended into the earth in order to study the stars. Actually the second observatory had an eminently practical value: it allowed Tycho to divide his students between Uraniborg and Stjerneborg and then check their observations before they had a chance to compare notes among themselves.

Stjerneborg was entered through a portal over which were three elaborately carved crowned lions. On the back of the portal was a grandiloquent inscription in gold letters, which proclaimed, in part, that "Tycho Brahe [had] invented and with incredible labour, industry and expenditure constructed various exact instruments . . . and placed them partly in . . . Uraniborg . . . partly in these subterranean rooms for a more constant and useful application."

The entranceway led down into a square warming room, which carried on its walls portraits intended to inspire the students at their labors. Seven of the portraits represented astronomers from Timocharis and Hipparchus to Copernicus and Sir Tycho himself. The eighth portrait was of the yet unborn Tychonides, whom Tycho hoped would come from his own lineage. In the inscription Tychonides expressed the wish that he might be worthy of his ancestor.

From this room passages led to five round chambers containing instruments. The roof of each projected above the ground and could be removed or swung aside. The whole underground structure was surrounded by a low fence, which repeated the square shape broken with semicircles described by the walls of Uraniborg.

In addition to these two principal buildings there were several others. Tycho, who combined a nobleman's arrogance with a scholar's passion for perfection, realized the necessity of publishing and disseminating the results of his work, but he did not trust the casual skill of Copenhagen typesetters. So about 1584 he hired his own printer, a man named Joachim, and dispatched him to Wittenberg to buy presses and supplies. Before the year was out Joachim had his printing shop set up and was turning out broadsides of Tycho's own Latin poems. The shop was no paltry back-room affair: it had two presses and 12 fonts of type, fancy initial letters and woodcut illustrations. When Tycho had difficulty in finding paper that was up to his standards, he built a mill and made his own, bearing a watermark picture of his castle and the legend VRANIBVRGVM. The presses turned out elegant editions of Tycho's scientific works as well as various works by his assistants. Tycho exchanged letters with scholars throughout Europe and was one of the first to realize the value of such correspondence and to print volumes of collected letters.

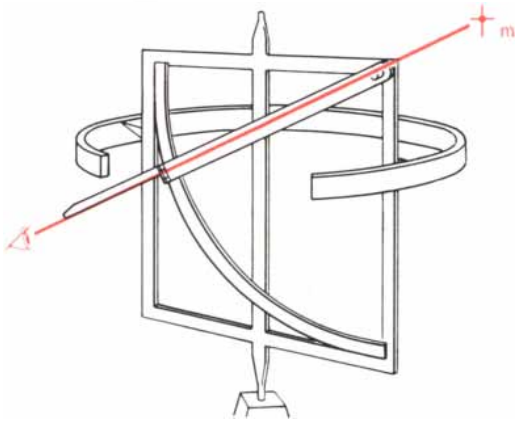
Other outbuildings on Hven included a tannery (which incidentally made parchment for book bindings), a grain mill and a machine shop, where skilled workmen executed the new instruments Tycho invented and remodeled or repaired old ones. The establishment on the island of Hven was altogether a reflection of Tycho, who set his sights on the Renaissance ideal of the Universal Man. Nobleman, courtier, poet, scholar, architect, instrument maker, astrologer, alchemist, printer and astronomer—Tycho was one of the proudest expressions of that ideal in all northern Europe.

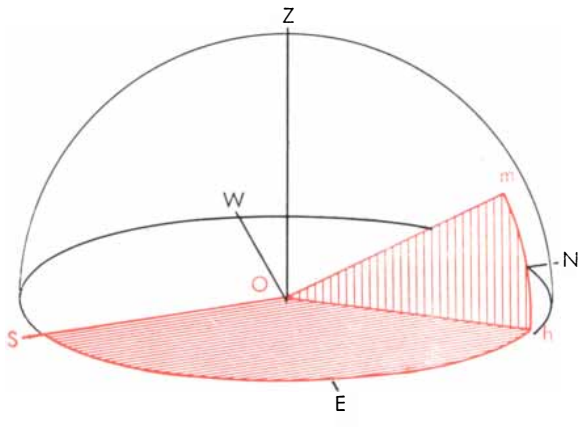
It was as instrument maker that Tycho excelled all astronomers who had lived before him. Some of the devices he built were of his own invention but most were refinements of traditional types. The basic instrument of astronomy in his day was the quadrant, a quarter-circle that was normally sighted from the angle to the arc. One of the quadrant's arms was made precisely horizontal and the other precisely vertical. The whole instrument was usually pivoted so that it could be rotated 360 degrees. When the sighting arm, or alidade, was pointed at a star or planet, the altitude was read off the 90-degree arc and the azimuth off a 360-degree circle within which the quadrant revolved.

Tycho designed at least two such instruments that had a radius of more than six feet. One was the *quadrans magnus chalibeus,* or great steel quadrant [*see illustration on page 122*]. A still more accurate instrument, rigidly fixed in a north-south plane—hence incapable of providing azimuth—was the *quadrans muralis sive Tichonicus:* the mural, or Tychonian, quadrant [*see illustration on page 121*]. This instrument did not survive, but Tycho declared that its scale could be read directly to 10 seconds of arc and that by interpolation five seconds could "be read without difficulty." Even allowing that the 10-second calibrations were made by using so-called transversal points [*see illustration on page 123*], Tycho's statement seems almost incredible.

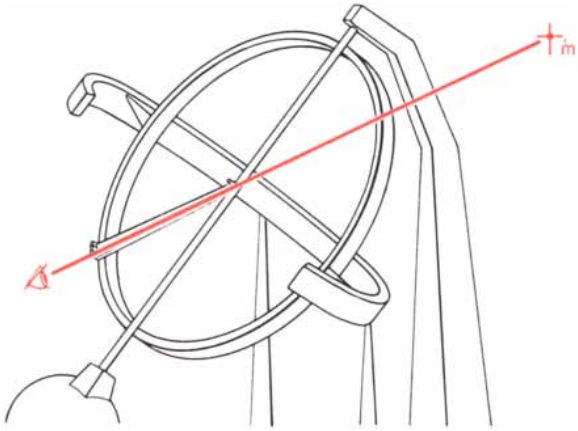
Assuming, however, that he did indeed inscribe the arc of his mural quadrant to read to 10 seconds, he deceived himself in a way that was to become familiar in later science. He tried to extract from his observational method greater accuracy than its least accurate element permitted. In Tycho's method

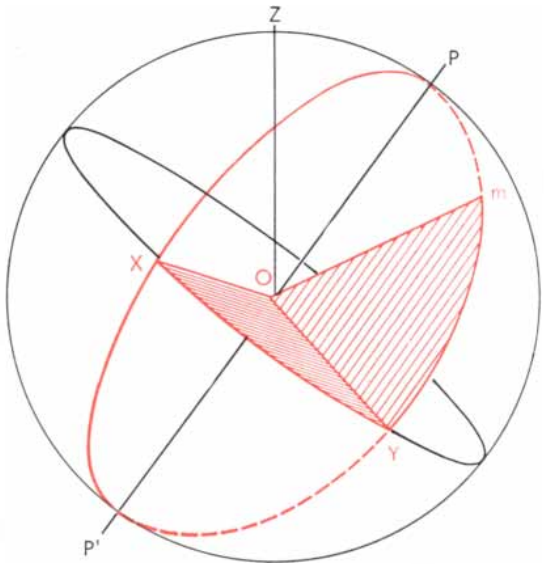
VARIETY OF INSTRUMENTS on opposite page illustrates Tycho Brahe's mechanical ingenuity. Equatorial armillary (*upper left*) was a standard device for determining declination and right ascension of a celestial body (*see middle illustration on next page*). The great equatorial armillary (*upper right*) was a typical Tychonic enlargement; the diameter of the revolving circle was nine feet. The bipartite arc (*lower left*), which carried two front sights (*A and B*) and two rear sights (*I and K*), was used to determine the angular distance between two celestial objects. The astronomical sextant (*lower right*) did the work of a quadrant or, with a modified mount and an extra pair of sights, the work of a bipartite arc. This instrument, which had a radius of five feet, was portable.



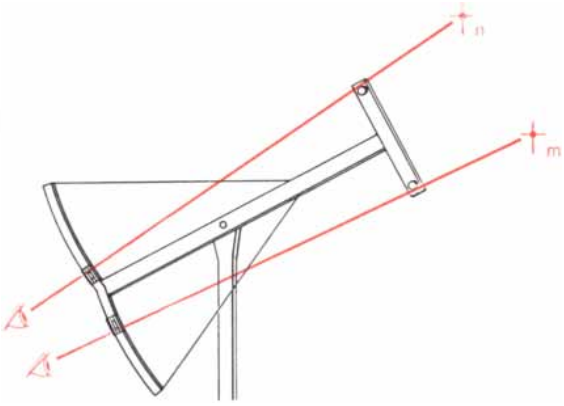


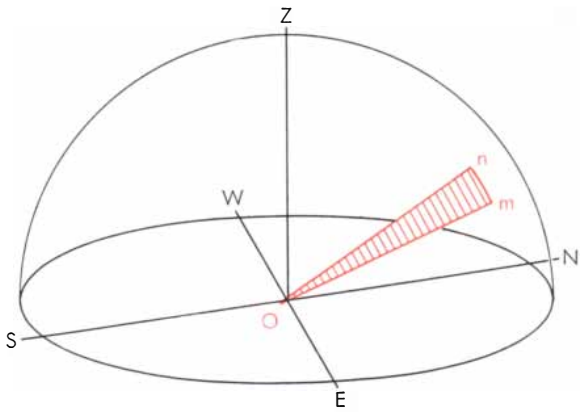
ALTITUDE AND AZIMUTH of a celestial object are the basic astronomical measurements. With a quadrant or sextant Tycho could determine an object's altitude above the horizon and its azimuth, or angular distance, from the north-south meridian. In the diagram at right these angles for object *m* are *mOh* and *SOh* respectively. The two values vary with the observer's position on earth.





DECLINATION AND RIGHT ASCENSION of a celestial object are independent of the observer's position on earth and may either be calculated from altitude and azimuth or determined directly by means of an armillary (*left*). Declination (*angle mOY at right*) is the angle above the celestial equator. Right ascension (*XOY*) is the angle measured eastward from a prescribed meridian (*PXP'*).





ANGULAR DISTANCE between celestial objects is of secondary astronomical interest, but its determination gave Tycho a check on his other measurements. Tycho measured angular distance (*angle nOm at right*) with either a bipartite arc (*page 124*) or with a sextant fitted with two pairs of sights. This variety in method he recommended as "not only the spice of life, but also useful."

the fundamental source of inaccuracy was the human eye; unaided, it cannot resolve points that are separated by less than about two minutes of arc. Actually Tycho's stellar and planetary positions fall regularly within about four minutes of modern values. In other words, his mean error was less than half the distance that separates the twin stars Mizar and Alcor in the handle of the Big Dipper. (The ability to distinguish Mizar and Alcor was often used as a test of visual acuity in earlier times.)

Because Tycho liked to make observations when he traveled through Europe, he designed a lightweight, portable instrument that did the work of a quadrant. It had an arc of 60 degrees; thus he called it a sextant. When fitted with one fixed and one movable sight, it could be used by a team of two observers to determine the angular distance between celestial objects. Tycho took particular pride in one portable sextant with a five-foot radius [*see illustration on page 124*]. "An astronomer," he wrote, "more than the student of other branches of knowledge, has to be a citizen of the world, and consider every place to which circumstances or necessity might lead him as his native country."

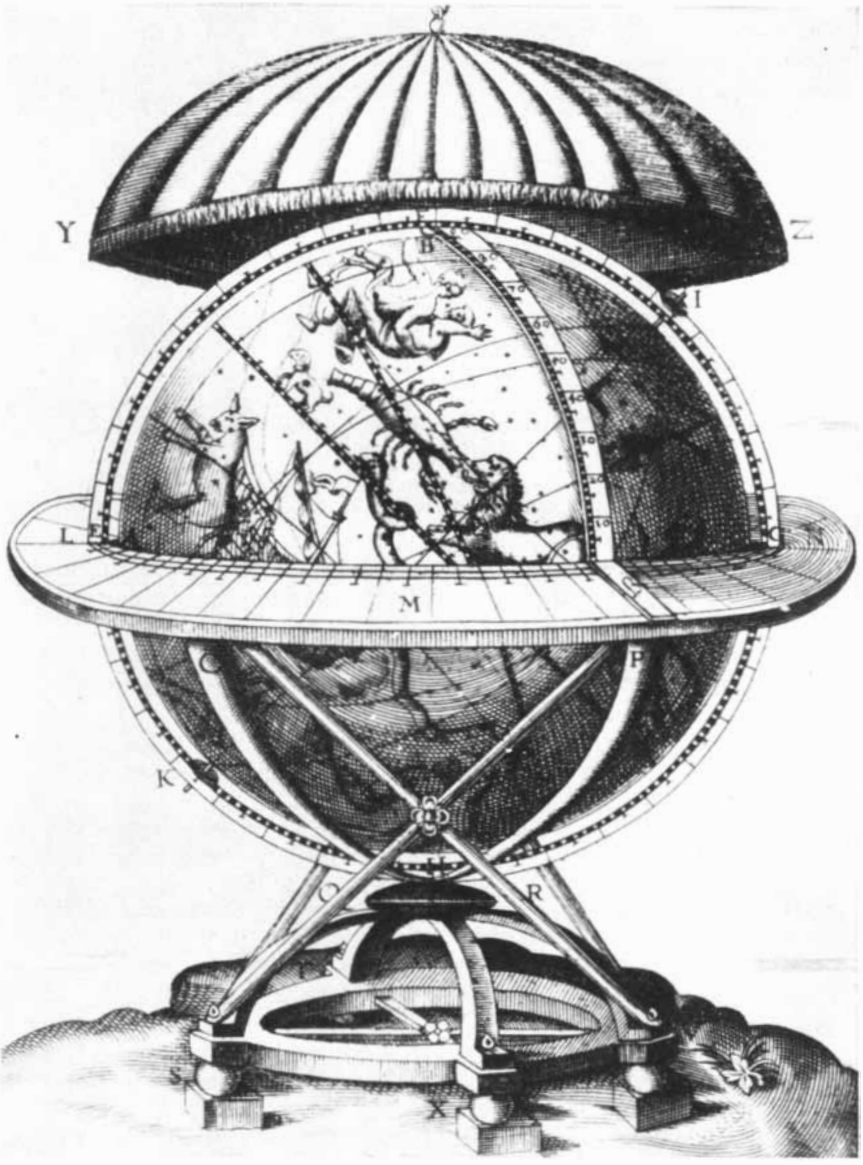
Another standard device was the parallactic, or ruler, instrument. Tycho made a huge one, more than 10 feet long, that completely filled one of the towers of Uraniborg. This instrument gave azimuth directly on a brazen scale over 20 feet in diameter. Altitude had to be calculated from the positions of two hinged arms, one of which was the sighting arm.

Long before Tycho, astronomers had recognized the need for giving star and planet positions in co-ordinates that would be valid for an observer anywhere on earth. Altitude and azimuth, being related to the observer's position, must be translated if they are to be useful elsewhere. Universal co-ordinates are obtained by imagining that the earth is enclosed in a celestial sphere whose equator is directly above and concentric with the earth's equator. A star's angular distance north or south of the celestial equator is called its declination. Its angular distance east of a prescribed meridian line (established by the position of the sun at the vernal equinox) is called its right ascension. To obviate the need for calculating declination and right ascension from altitude and azimuth, ancient astronomers invented the armillary sphere, a star-sighting instrument from which declination and right ascension can be read directly. Its basic feature is a revolving circle pivoted on an axis that can be set parallel to the axis of the earth, thus providing an automatic transformation of co-ordinates. The armillary sphere was therefore one of the earliest analogue computers. Tycho characteristically disdained its use. It was a device, he said, for "people who shun labor." He nonetheless built several and housed the largest at Stjerneborg [*see illustration on page 124*].

Some indication of the way Tycho must have driven his instrument makers is revealed in the following passage: "Only this I wish to state here with regard [to these instruments], namely, that all of it has to be as nearly perfect as is possible in every respect and that, therefore, one should employ skillful craftsmen, who know how to carry out this sort of work artfully, or else can learn to do it. And even if they cannot perhaps do it all perfectly the first time, the constructor must not let himself be discouraged, but have the work repeated and improve the defects in every way until none is left."

But Tycho did more than simply put together elegant blown-up versions of old astronomical tools. He made technical innovations that greatly increased the quality of observations, particularly when these innovations were applied to his well-made giant instruments. Perhaps the most important were his instrument sights. The Tychonic sight had adjustable slits in the eyepiece in place of the customary peephole. The slits could be opened to admit the light of a faint star or closed to observe a star of greater magnitude. The front sight was a cylinder exactly as wide as the slits were far apart. The observer sighted through one slit and then the other until he saw the star just touching each side of the cylinder [*see illustration on page 123*]. Such a sighting device proved much more accurate than a simple pierced eyepiece.

With his magnificent observatory and instruments Tycho made a number of significant discoveries in addition to producing his great catalogue of stars. He concluded from the appearance in 1572 of the New Star—what would now be called a nova or supernova—that the sphere of the heavens was not immutable, for the new star demonstrated that it could change. He discovered that comets were true celestial bodies and not the mere atmospheric disturbances Aristotle had decreed them to be. He also concluded from his comet observations that the heavens could not consist



GREAT BRASS GLOBE measured almost six feet in diameter and carried the positions of 1,000 stars, as determined by Tycho over a period of 21 years. "A globe of this size," Tycho wrote, "so solidly and finely worked, and correct in every respect, has never I think been constructed up to now . . . anywhere in the world. (May I be forgiven if I boast.)"

of real celestial spheres—presumably solid and transparent—as many of his illustrious forebears had maintained. These and others were major accomplishments; Tycho did much to sweep away old misconceptions and superstitions concerning the heavens.

In spite of his close and unprecedented study of planetary motions, Tycho Brahe never acknowledged the Copernican theory. Instead he put forward his own Tychonic theory, a combination of the geocentric and heliocentric views; the earth retained immobility, and the other five planets were allowed to circle the sun while the sun circled the earth.

In 1597 Frederick's successor, Christian IV, lost patience with Tycho's lordly ways and withdrew his fief at Hven. Tycho left his beloved Uraniborg and moved to Prague to serve the Holy Roman Emperor Rudolph II. It was there that Tycho met the young German mathematician Johannes Kepler and took him on as an assistant.

Tycho and Kepler turned out to be the most fortunate combination in the history of astronomy. Tycho's years of patient observation combined with Kepler's mystical, almost magical, skill at mathematics founded modern astronomy. In his palace of brick and limestone the golden-nosed astronomer had laid the foundations of a structure that, though more ethereal, was even more glorious than Uraniborg.

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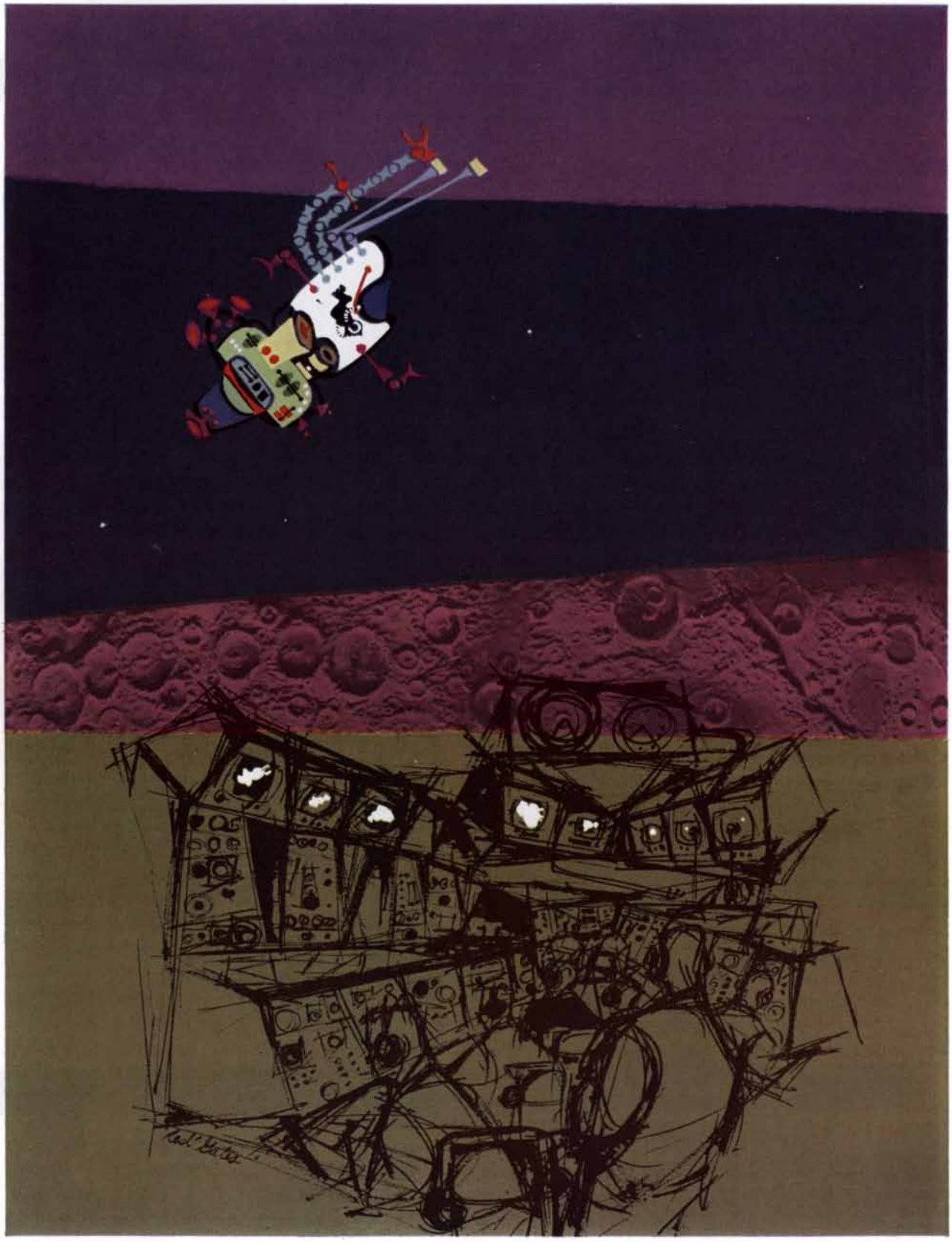


the scope of

The Teredo

Otherwise known as the shipworm, this distant relative of the clam destroys submerged wood by honeycombing it with burrows. Its way of life is predicated on its unusual ability to digest cellulose

by Charles E. Lane

The seas of the world provide a vast array of environmental niches that have been variously exploited by marine organisms. One group of animals has specialized in the invasion of wood. This way of life must have evolved in the flotsam that litters the surface of the high seas and is finally cast up on the beaches of the world as driftwood. With the advent of man and his employment of wood as a construction material, the environment available to this group of animals expanded considerably. Among the agents most destructive to wood is a specialized group of mollusks, the family *Teredinidae,* the most familiar member of which is *Teredo navalis,* familiarly known as the shipworm.

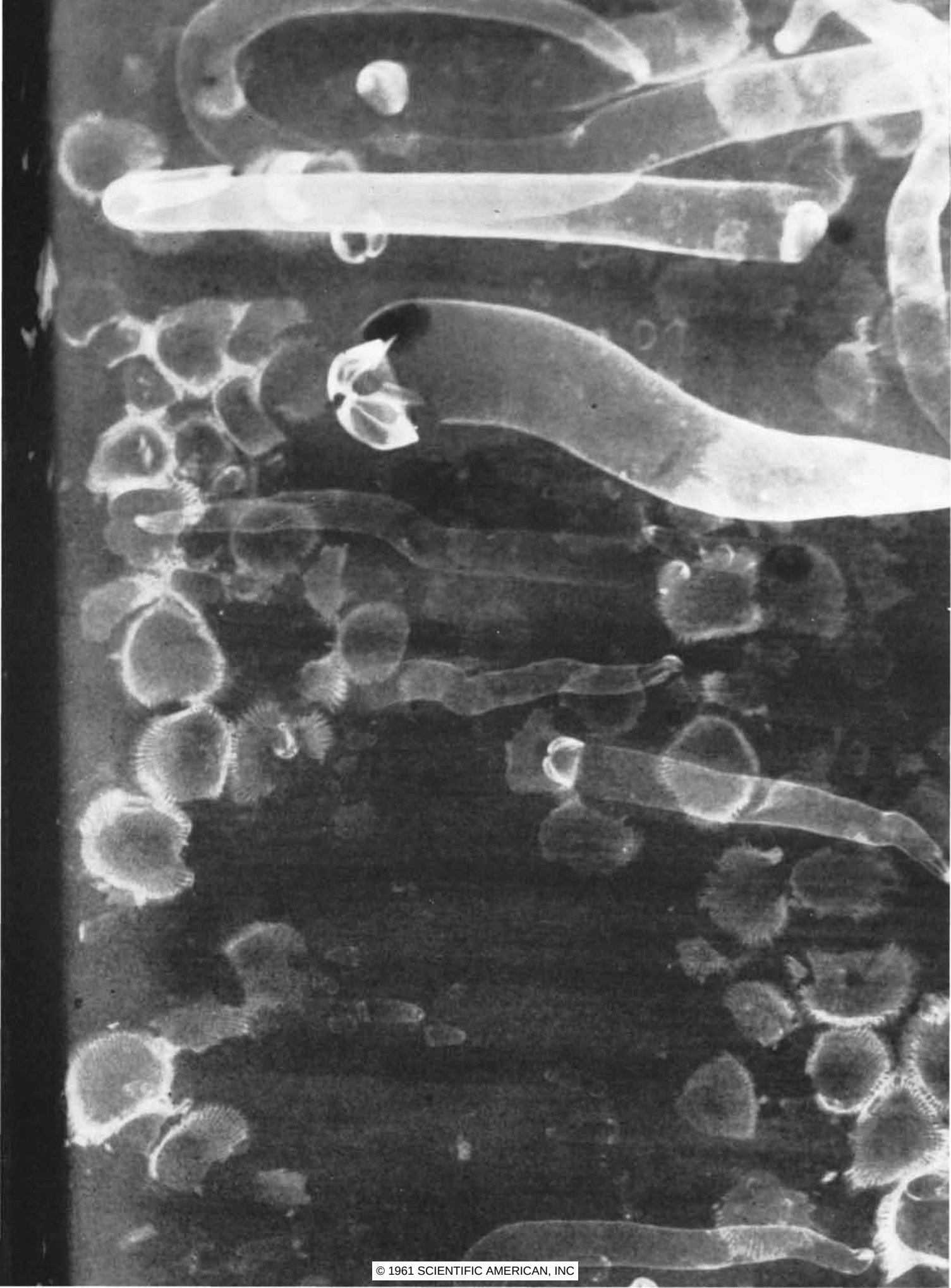
Teredo spends its entire adult life within the confines of a single piece of wood. Thousands of teredos may colonize each square foot of exposed surface. Except for tiny pores marring the surface, even a badly infested piece of wood gives no sign of the destruction within. Submitted to stress, however, the wood crumbles, revealing an interior honeycombed with burrows and almost without substance. Shipworms have the ability, remarkable in a multicelled organism, to digest and metabolize cellulose. They grow inside the wood by enlarging the space they occupy, converting the tough fibers of the wood to the soft substance of their bodies and finally to empty space when they die. No wooden structure exposed to sea water for any appreciable portion of the tidal cycle is immune to the pest. The U. S. Navy has estimated that the damage to boats, barges, bulkheads, piles, docks and bridges in the U. S. alone exceeds $50 million every year.

The shipworm is not a worm but an elongated sort of clam. The shell of the animal covers only its forward end; the plates of the shell are almost hemispherical and are equipped with ridges of microscopic rasplike teeth. Through a gap formed by two deep adjacent notches in the plates, teredo extends a long and muscular "foot." When the animal braces itself with its foot and rocks back and forth, the scraping action of the toothed shells rasps away the wood. Growing as it drives the head wall of its burrow into the wood, teredo eventually reaches a length of four to six inches.

The shipworm's body, filling the length of the burrow out to the entrance pore, ends in a pair of extensible siphons flanked by two leaf-shaped plates of shell called pallets. Siphons and pallets are the only parts of the animal that stick out from the burrow into the surrounding water. Like other bivalves, teredo inhales water through one siphon and flushes out the waste products of its metabolism through the other. The siphons lead into the mantle cavity, which is divided into two distinct channels by the gills. Organs of reproduction as well as respiration, the gills occupy fully four-fifths of the animal's length. Microscopic fibers called cilia [see "Cilia," by Peter Satir; page 108] cover the gills and the interior surfaces of the mantle, and the beating action of these microscopic fibers, in conjunction with the peristaltic action of the mantle wall, keeps a stream of water constantly coursing through the animal. Should the water become noxious, or should the water level fall and expose the siphons to air, teredo retracts the siphons and shuts the burrow entrance by means of its pallets. The almost perfect seal against the environment thus effected is further secured by a lining of shelly material secreted by the mantle along the entire length of the burrow.

Even in this isolated state teredo not only survives but flourishes. Deprived of its normal source of oxygen in the inhaled water, it exploits a capacity for emergency metabolism that is associated with the remarkable efficiency with which it converts wood to nourishment. The animal is able to break down cellulose because its digestive juices include the enzyme cellulase. This enzyme is secreted by glands in the fore-gut and is intimately mixed with the finely divided particles of ingested wood before these are passed into the caecum. In this capacious chamber the cellulose and cellulase are kept in extended contact, giving the enzyme time to do its work. The absorptive portion of the gut shows a corresponding adaptation for efficiency: its internal surface area is greatly increased by a longitudinal fold in the intestinal wall that projects into the cavity. An optimum portion of the cellulose in the wood is thus cleaved into its component simple sugars during passage through the caecum, and these are converted with high metabolic efficiency to glycogen, the molecular form in which nutritional fuel is commonly stored in animal tissue. Glycogen in fact constitutes up to 50 per cent of the adult teredo's total dry substance. This contrasts with the fattest oyster (oyster "fat" is also glycogen), in which the glycogen seldom exceeds 30 per cent, and with

X-RAY PHOTOGRAPH of a panel of wood that had been left in the water for three months shows the burrows of teredos. The roughly horizontal light areas are burrows; the smaller round light areas are barnacles on the surface of the wood. Some of the burrows are curved because the teredos in them turned as they ate into the wood in order to avoid entering the adjacent burrows.



the glycogen content of human liver or muscle, which rarely goes even as high as 5 per cent.

Teredo is able to survive without oxygen during long periods of entombment because, in common with other mollusks, it can extract the energy stored in its glycogen without the aid of oxygen. Within a few hours after it has shut its burrow the water in its mantle no longer contains enough oxygen to support normal, aerobic metabolism. In our laboratory at the University of Miami we have shown experimentally that the animal survives, grows and continues to maintain circulation in its mantle when placed in water totally devoid of oxygen. In three weeks of this emergency regimen the animal uses up as much as 75 per cent of its initial glycogen reserve and shows a complementary accumulation of lactate and other products of an anaerobic glycogen metabolism.

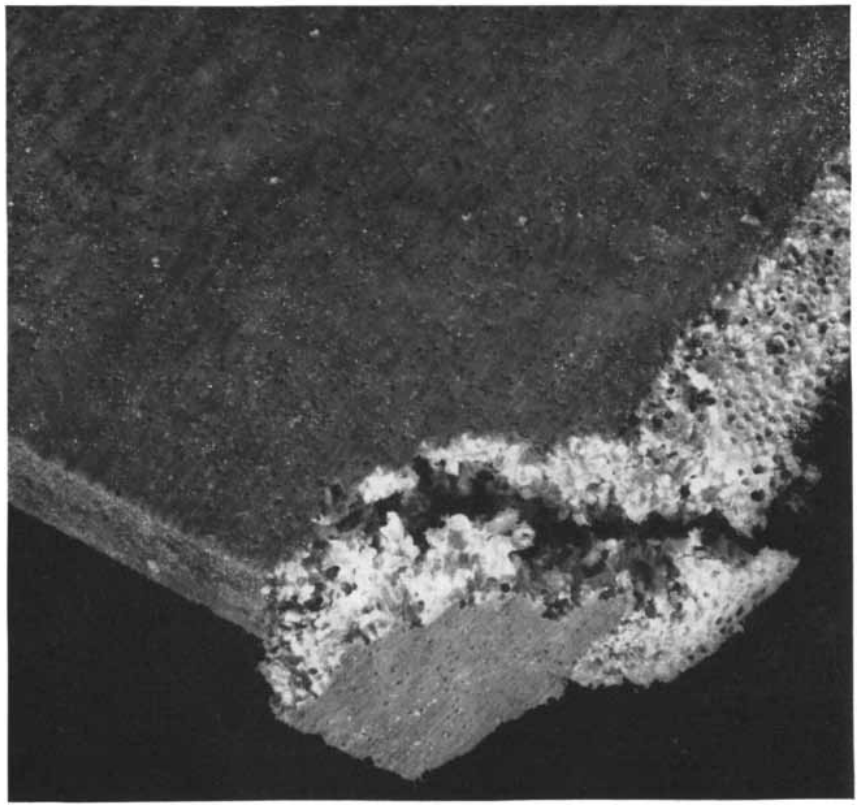
This unusual mechanism of survival probably accounts for the generally unsatisfactory results for the owner of a small boat who hauls his craft out of the water and leaves it exposed to the air for several days, hoping that this procedure will kill the borers. Our experiments indicate that the exposure period must last for 30 days or more. During any shorter period teredo, sealed in by its pallets against a hostile environment, survives and grows because of its ability to metabolize glycogen anaerobically and continues to destroy the wood that houses it.

Although the adult teredo can survive appreciable periods of entombment, it cannot in that circumstance reproduce, for the ambient waters are its medium of reproduction. The adult teredo assumes one sexual form and then the other in succession. The testes develop first, and the animal functions as a male, discharging sperm through its exhalant siphon into the water. Later the gonad changes into an ovary, and the animal functions as a female; the spermatozoa liberated in the ambient water by neighboring teredos that are still in the male form are drawn into the inhalant siphon and fertilize the ova. Self-fertilization is unusual in the teredo because it takes time for the gonads to transform from one sexual function to the other.

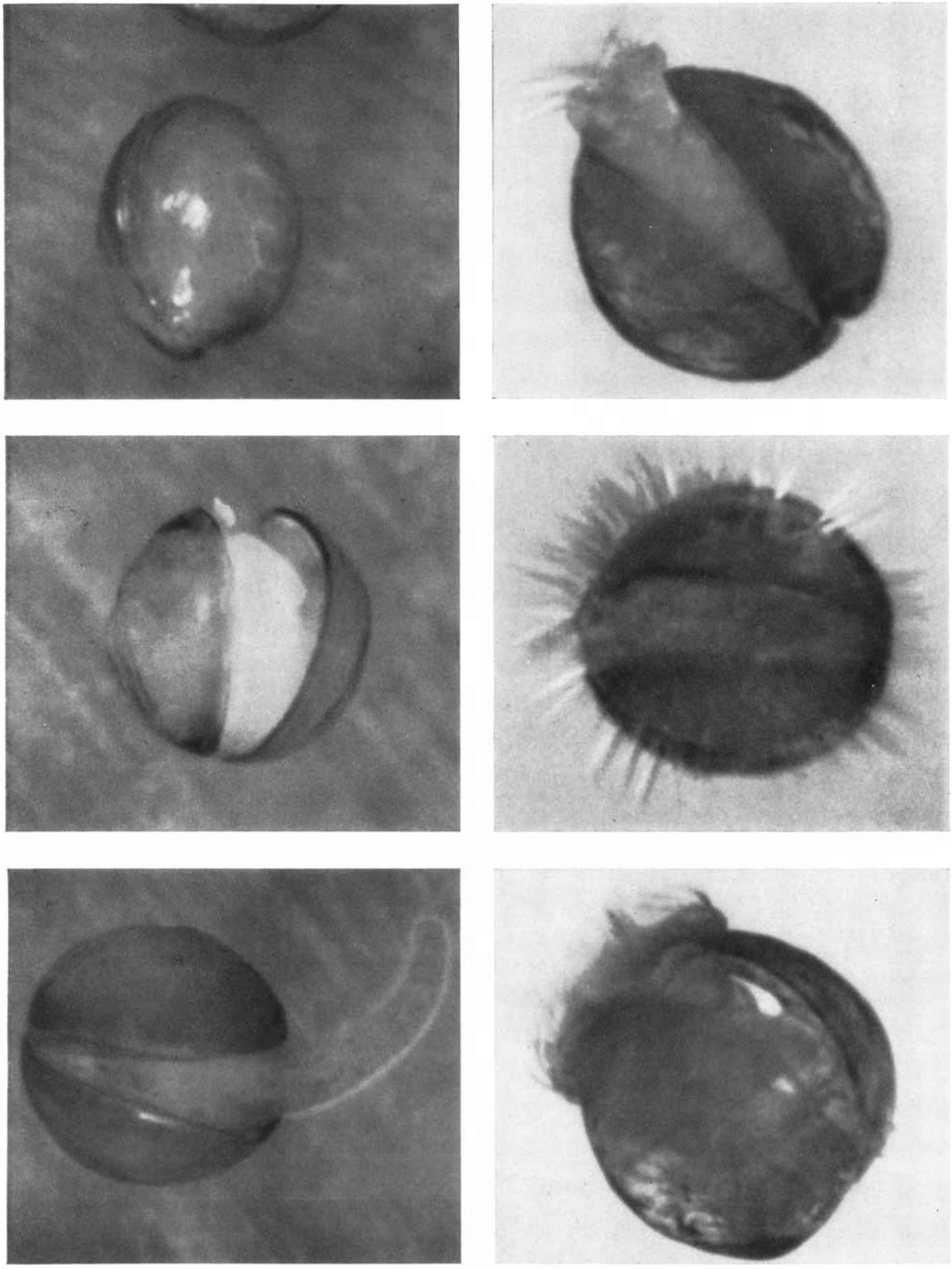
The fertilized ova become embedded in specialized areas of the parental gill much as the mammalian egg becomes embedded in uterine tissue. At this critical time the normal respiratory flow of water through the mantle slackens, reducing the danger that ova will be flushed out in the exhalant stream. The ova develop quickly. During the brief period of embryonic growth glycogen becomes concentrated at the implantation sites in the gill tissue and is transferred to the larvae. This initial endowment of energy fuels the earliest independent activities of the young. As the larvae mature they are shed in enormous numbers from the maternal gill tissue within a few hours, are carried off in the siphonal stream and are ejected as a cloud in the water outside the burrow.

The newly liberated teredo resembles a tiny clam. It is enclosed in a pair of shells about a hundredth of an inch in diameter, which at this stage are not shells in the generally accepted sense but thin, horny scales. The larval teredo shows its kinship to the clam in another significant way. Like the larval (or veliger) clam, the free-swimming young teredo hangs in the water from a velum, an extraordinary mobile structure that looks like an animated umbrella and functions as an organ of locomotion. The beating of long cilia on the upper surface of the velum propels the animal in the manner of a helicopter either vertically or, when the velum is tilted, horizontally. The larval teredo appears to swim at considerable speed when it is observed under the microscope, but in fact it moves only inches an hour. Since its true speed is entirely insufficient to account for the spread of the animals from a center of infection, currents generated by the tide and wind must largely account for local dispersal as well as for the wide geographical distribution of the species.

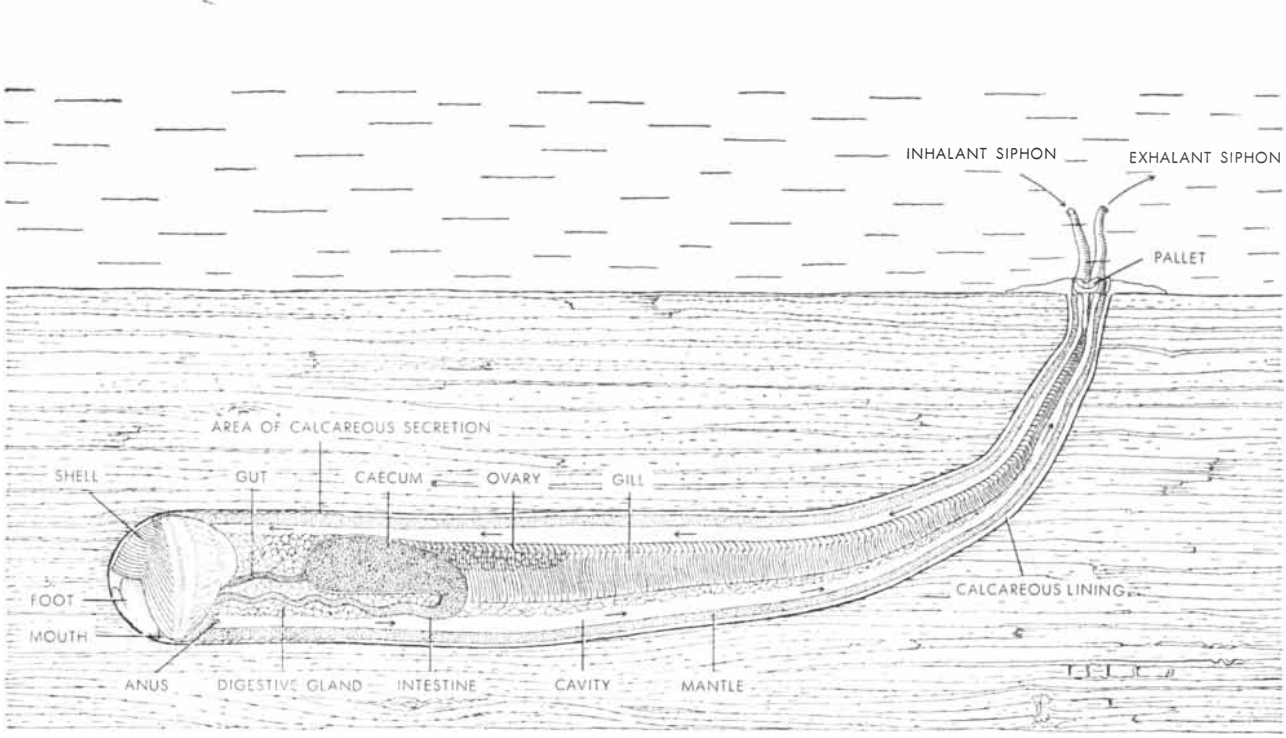
During the first 24 hours of its free-living existence the teredo spends most of its time and energy in apparently aimless swimming. It rests briefly on any solid object it encounters and may occasionally explore the surface with its foot. During the second day of the teredo's free-living existence, when the animal remains fastened for longer periods to the solid surfaces it happens to touch, the foot becomes its chief means of locomotion. The larval foot is muscular, extensible and extremely sensitive; it is constantly seeking out and exploring microscopic irregularities on the surface of an object. A viscid mucous fastens down the extended foot; then the foot muscles shorten, drawing the animal forward in a lurching, unsteady progress. In the course of this second 24-hour period the animal frequently abandons its methodi-



SURFACE PORES ON A PLANK are the only evidence of teredo infestation. Submitted to stress, the plank crumbles, revealing an interior that teredos have all but eaten away.



TEREDO LARVAE 24 hours old were photographed with stroboscopic light and enlarged about 270 diameters. Photographs at left show larvae resting on wooden surface (*top and middle*) and exploring surface with "foot" (*bottom*). Photographs at right show ciliated velum emerging from shell (*top*), velum propelling animal through water (*middle*) and velum being retracted (*bottom*).

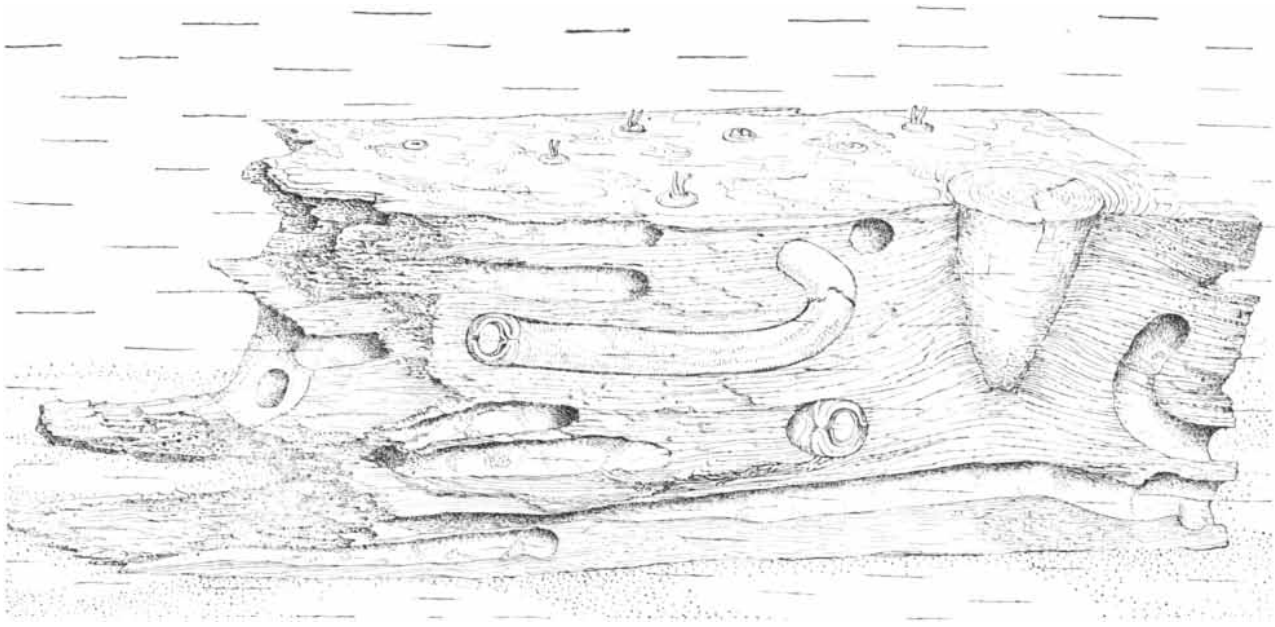


ANATOMY OF ADULT TEREDO features rasplike bivalve shell that drills into wood. Wood filings enter capacious caecum, where they are broken down by enzyme secreted by digestive gland. Animal throws off waste via anus and exhalant-siphon stream. Animal's posterior is permanently fixed to burrow entrance. Spermatozoa enter through inhalant-siphon stream, fertilize ova in mantle cavity. Fertilized ova mature in gill tissue. Larvae reach ambient water via exhalant-siphon stream. The adult is from four to six inches long.

cal exploration of solid surfaces and moves away on still further flights of exploration, carried along by its velum. By this time the larva has exhausted the endowment of glycogen received from its parent and probably fuels its activities by feeding on microplankton.

The third day of larval life brings a complete change in the pattern of activity. This portion of its free-living existence can be said to be the most critical period for the young teredo, because it is the last during which it still retains the ability to colonize wood. If it fails to effect a satisfactory penetration in these hours it is doomed.

Now the teredo interrupts its erratic progress over the surface to which its swimming and the current have brought it, remaining fixed for longer times in one place. The "heel" of the foot (the portion nearest the body) attaches itself firmly by mucous secretion and the teredo moves its "toe" tentatively about,



TEREDO-INFESTED TIMBER depicted in drawing shows appearance of exposed surface (*top*), with siphons extending from burrows, and cutaway view of timber interior (*front*). Siphons near forward edge of upper surface belong to teredo occupying long burrow (*center*). Section of calcareous lining is intact at upper end of burrow. Below it is head-on view of teredo showing bivalve shells with which animal bores into wood. Teredo burrows with grain of wood, turns away from denser areas such as knots (*right*).

often making impatient squirming motions with its shell as though trying to make itself comfortable.

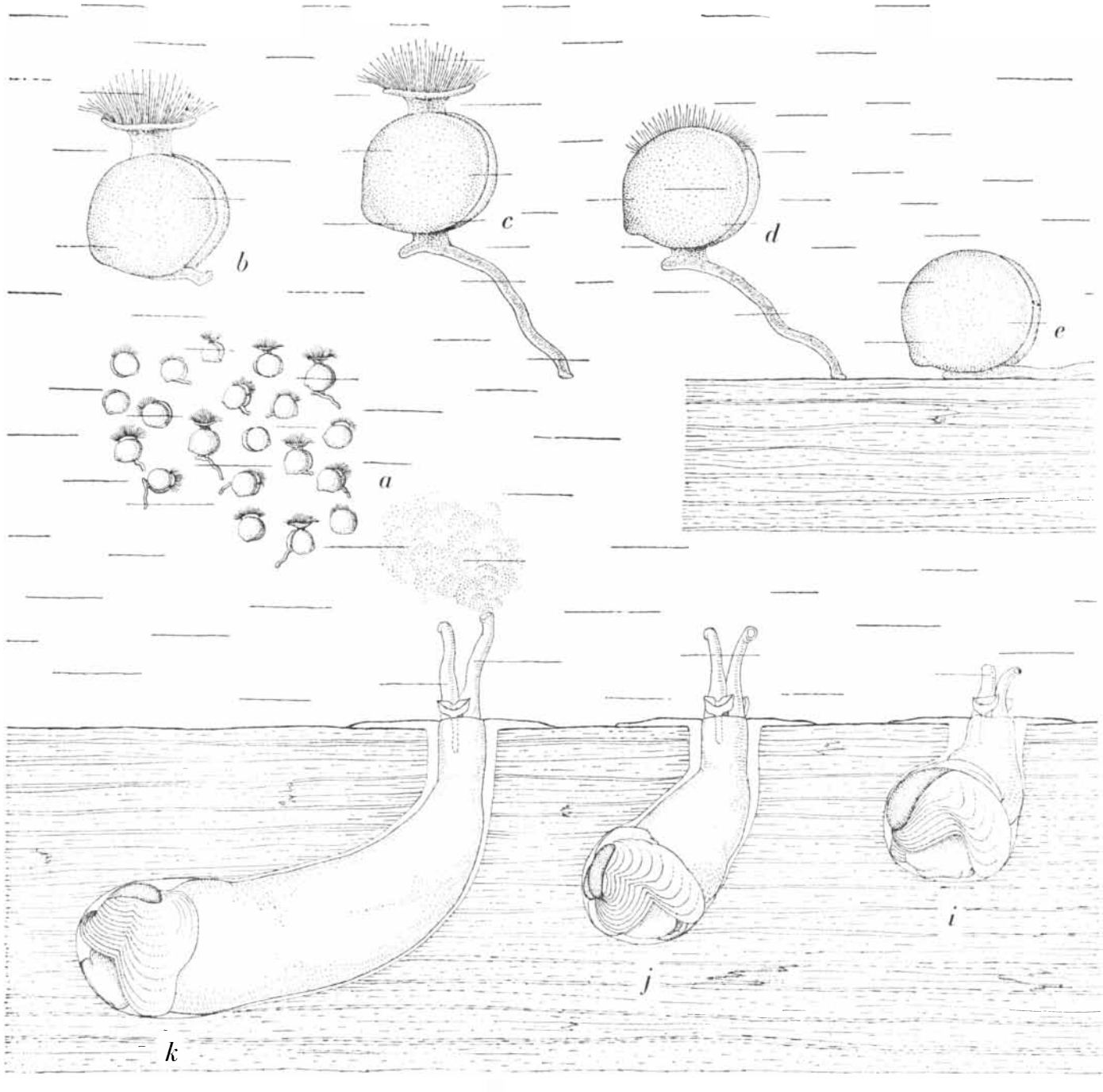
When a suitable spot is found (just what makes a place suitable is one of the questions that may lead eventually to control of the shipworm), there begins a chain of events that results in penetration of the wood by the larva. Its shells open and close rhythmically, scraping at the surface. The motions of the foot become accentuated, and the tip of the foot rotates full circle as though sweeping out the debris abraded from the site. A considerable pile of debris—consisting of wood fragments, bacterial slime and silt—accumulates. Soon the larval teredo becomes difficult to distinguish in the midst of this micromidden.

It appears that the larval teredo cannot perform this task of excavation unaided. The larval shell, as yet unhardened, has not developed the rasp-like teeth of the adult and does not do so until the animal has completed its initial penetration. There is reason to believe that the initial penetration is facilitated by the microscopic organisms that populate all underwater surfaces. Recent observations made in our laboratory have revealed that a wooden panel supports a population of 40 live bacteria on every square micron (.000039 square inch) of exposed surface after only 24 hours of immersion in the waters of Miami's Biscayne Bay. Since the figure does not change significantly with continued immersion, it can be assumed that these live organisms constitute only the most superficial stratum of the developing layer of organic material, composed largely of dead bacterial bodies. Some of the organisms are doubtless capable of breaking down cellulose fibers; others probably decompose the binding substance in wood. These microbial agents, acting in conjunction with the shells and the foot of the larva, make the initial penetration of the wood possible. It is also likely that the young borer makes use of some components of the surface slime as food. Some such supply of nourishment is necessary during this period to account for the measured oxygen consumption. In any case the young teredo is apparently so dependent upon suitable microbiological agents that we have never observed successful penetration of completely sterile wood.

These observations also explain several well-documented anomalies in the settlement and boring activities of shipworm larvae. The survival and metamorphosis of the animal is exceedingly infrequent in any material other than wood. Yet the larvae frequently try to colonize

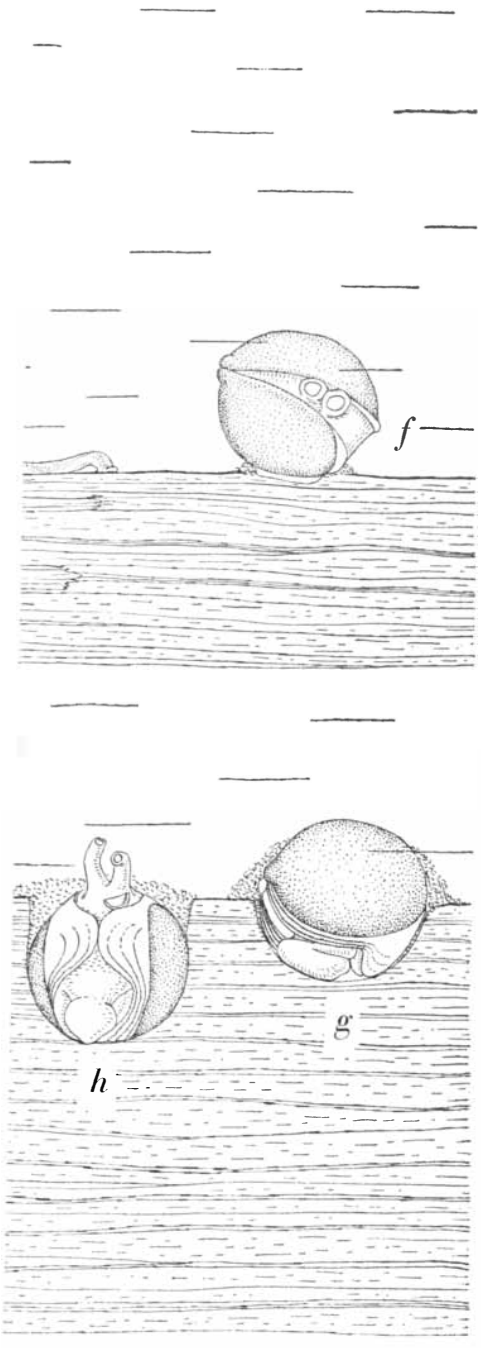
materials entirely unsuited to the sustaining of the adult teredo. They have been reported attempting to burrow into Manila cordage, cork and various plastic materials; they have even been held responsible for the microimpressions that are often observed in the lead sheathing of submarine cables. It is possible that the receptors of the larvae of the teredo are more sensitive to the character of the microflora adhering to the surface of an object than they are to the nature of the surface itself.

About 12 hours after the young borer begins the work of penetration, at which time it may be half-buried in the mound of debris around its pit, a wave of calcification sweeps over it. The shells become calcified and teeth begin to develop. Glands in the animal's mantle secrete a limy substance that lines the walls of the



LIFE CYCLE OF TEREDO begins with birth of tens of thousands of young, each about a hundredth of an inch in diameter (*shown greatly enlarged at "a"*). Newborn larva swims by means of velum, a ciliated rotor-like organ (*b*), and explores surfaces with foot (*c and d*). Pattern of activity changes on third day: forsaking velum, animal uses foot to find suitable penetration site on wooden surface (*e*), then begins boring (*f*). Larval shells calcify on fourth day (*g*) and siphons develop (*h*). Later in fourth day animal secretes a limy substance that lines burrow and covers excavation mound at entrance pore (*i and j*). Adult bores into head wall of burrow,

burrow and cements the mound of debris, fastening the animal's posterior to the burrow entrance. As the metamorphosis proceeds, the body of the teredo begins to elongate, the siphons develop and start the circulation of water between the encapsulated animal and its



feeds on wood it rasps away. Retractable siphons are flanked by calcareous, crutch-shaped pallets that can fold over burrow entrance and seal it. Young emerge from exhalant siphon (*k*). Cycle is about 10 weeks.

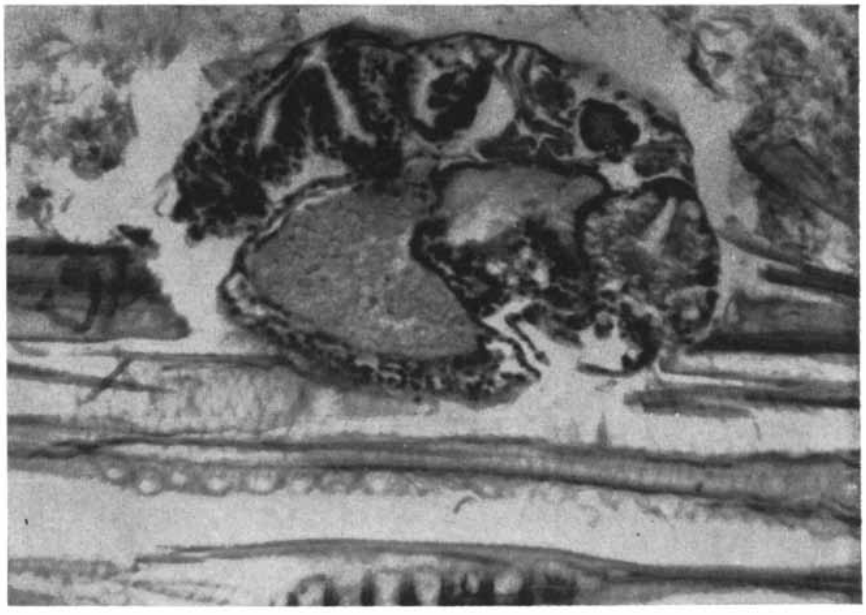
environment, and the pallets grow into place at the mouths of the siphons, ready to shut out the external environment. With the completion of this process the larva has become an adult.

Weekly X-ray examination of infected panels has revealed many details of the rate of growth and of the total life span of the adult borer. In subtropical waters the average length of life is only 10 weeks. Throughout this period the average weekly growth is approximately equal to the diameter of the animal. From its tiny clamlike larval form it grows to be a wormlike creature that may be a quarter of an inch in diameter and be up to six inches in length. In the process it consumes a volume of wood equal to its own maximum volume.

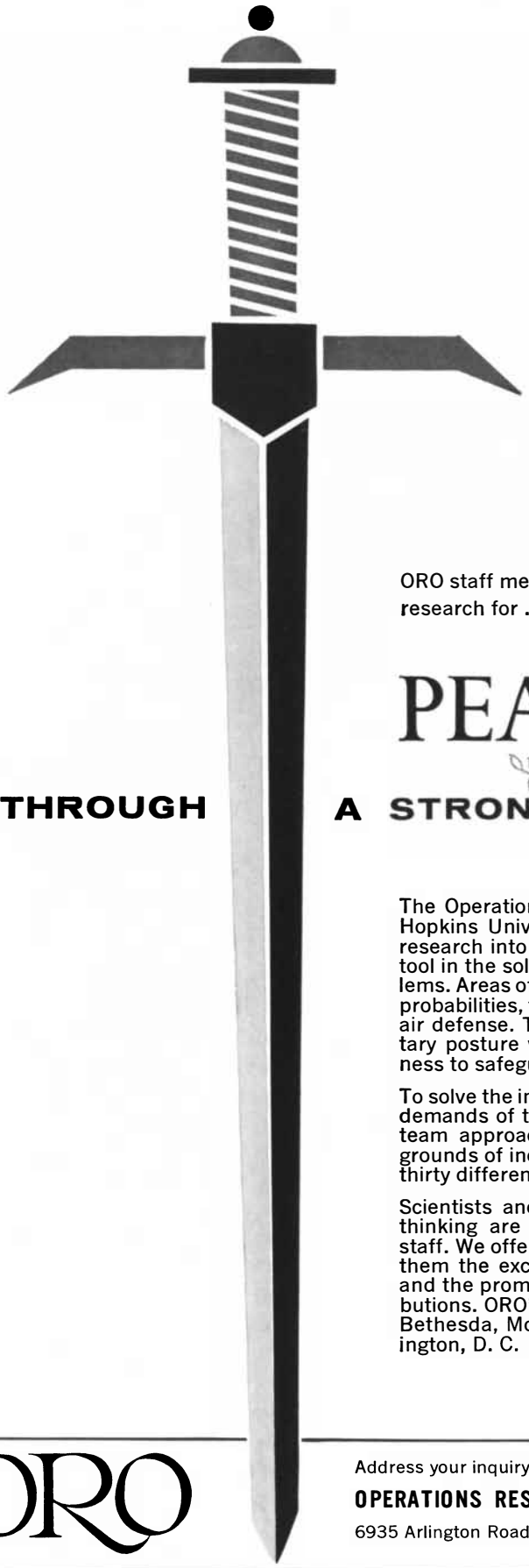
The adult teredo is apparently equipped with sensory receptors that help direct its burrowing through the wood. The fact that burrows tend to run parallel to the grain of the wood and to avoid knots and other areas of increased density certainly suggests that the teredo has receptors that are sensitive to the density of the wood around it. A similar faculty probably accounts for another peculiarity of shipworm behavior. X-ray examination of many thousands of burrows has never shown a single animal to have broken through the surface of a panel from the inside. Moreover, in experimental panels, which often contain more than 5,000 teredos per square foot of surface, we have never seen a single instance of intercommunication between burrows.

A simple experiment at our laboratory recently provided a dramatic illustration of the animal's capacity for orientation within its wooden burrow. We embedded a quarter-inch wooden dowel, about two inches long, in a Lucite block, leaving only one end of the dowel bare and available for colonization. A teredo that entered the wood grew normally and proceeded to eat its way up the length of the dowel [*see illustration on page 142*]. In several instances the animal's course, deviating slightly from the long axis of the dowel, approached the surface of the wood. The animal responded by changing direction. Its new course carried it obliquely across the dowel and brought it close to the opposite surface. The teredo again changed direction and arrived at the opposite surface. In this fashion it tacked its way up the length of the dowel until it approached the end surface. The only escape from this cul-de-sac lay in the direction from which the animal had come, but now it had to weave its way in a spiral around the inbound tunnel, which was occupied by its own elongated body. This devious route used up most of the remaining wood and brought the teredo to a point where it could no longer eat its way around its burrow. It thereupon expired. We exposed three other dowels at different times and each time observed the same behavior.

From such insights into the secluded



BURROWING TEREDO LARVA (*center*), **magnified some 225 diameters in this photomicrograph, is shown cutting through fibers of wood** (*dark horizontal bands*). **Debris** (*top*) **half-covers animal. Black areas in curved structure near top are wood filings in larva's gut.**



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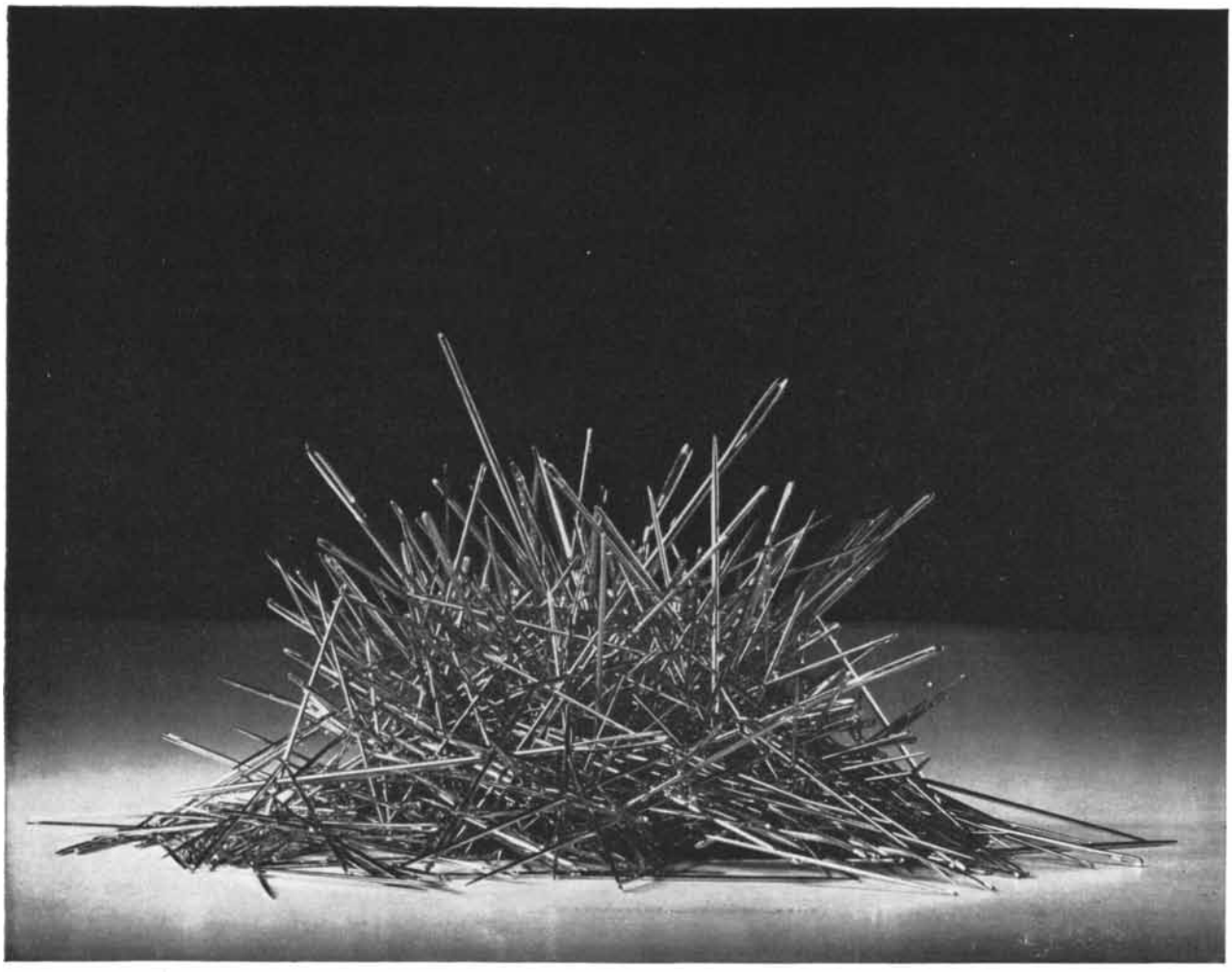
life of the teredo some measure of control will doubtless come someday. Meanwhile, even though the shipworm is no longer the catastrophic threat to human life that it was in the days of wooden ships, it remains a nuisance whose control demands unflagging vigilance.

SPIRALING BURROW, enlarged five diameters in this X-ray photograph, was drilled by teredo as it proceeded up and down length of quarter-inch dowel, avoiding penetration of dowel surface and walls of its burrow. When it could no longer avoid either, it sealed entrance pore and died.



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Florida

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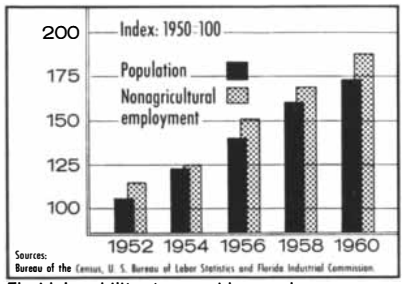
Plant opening: still a month away. Job openings for scarce scientists, engineers and highly skilled technicians: already 90 per cent filled.

This was the experience of Minneapolis-Honeywell in West Palm Beach last summer. It is typical of the experience of many manufacturers, but it tells only half of the Florida manpower story.

At the other end of the state, in the small town of Foley, Buckeye Cellulose Corporation found that native Florida workers with no previous pulp mill experience "quickly developed into an excellent manufacturing organization and achieved an outstanding record of high quality production." The Buckeye plant now employs over 750 workers.



Florida's ability to provide ample manpower for industry is shown by a rate of increase in non-agricultural employment which is even greater than that for total population. Nonagricultural workers now number approximately 1.3 million.

MANPOWER POOL REMAINS AMPLE

Most new industries in Florida have found that their needs can be quickly filled from existing manpower pools, which include skilled workers drawn to the state by the lure of Florida living. In Florida, men and women in the highly employable 18 to 44 year age group make up 36.3 per cent of the total population. This compares with 35.0 per cent for the nation as a whole.

When out-of-state recruitment is necessary, however, the words "location-Florida" are a powerful magnet. Advertisements offering employment in Florida have outpulled identical advertisements in which other locations were specified by as much as 30 to 1.

In 1957, The Martin Company of Baltimore received over 20,000 applications from every section of the country when it announced its intention to establish a new division in Orlando.

Year after year, a Florida location has proved a major asset to Radiation Incorporated, in recruiting skilled personnel, according to President Homer R. Denius. The company, which specializes in data processing, telemetry and test equipment, was founded in Melbourne in 1950 with 25 workers. Today, Radiation has three plants in Florida and employs 2,000 people — three-fourths of them engineers and technicians drawn largely from other states.

General Electric was deluged by 17,000 inquiries when it built an X-ray plant in St. Petersburg.

Fairchild Aircraft Company obtained 3,000 applications for approximately 200 jobs merely as the result of news releases about its St. Augustine facility.

WORKERS "LOOK FORWARD" TO MOVE

At no time is the Sunshine State's appeal to workers more vividly demonstrated than by employee reaction when a company moves to Florida.

When the Atlantic Coast Line Railroad shifted its general headquarters to Jacksonville last summer, less than ten per cent of its thousand-odd workers elected to remain behind; and many of these were near retirement age.

Seventy - five technicians willingly moved from Ohio to Fort Lauderdale with Univis Lens Company last year. Sherman Classics, Inc., a leading manufacturer of women's sportswear, said that key personnel were actually "looking forward" to a move from New England to Hollywood last fall.

Florida's sunshine-living has been one of the main reasons why Pratt & Whitney Aircraft has drawn an average of 18 applications for every job available at its research and development center in Palm Beach County. Here, employees enjoy the luncheon patio outside the plant. More than 3,000 workers are employed, half of them engineering and technical personnel.

EDUCATION MEETS THE CHALLENGE

Recognizing industry's need for skilled workers, Florida is rapidly expanding its facilities for technical training.

The state's vocational training program ranks sixth in the nation in enrollment. Industrial courses, primarily for adults, are offered in 33 counties, with instruction in 60 separate centers.

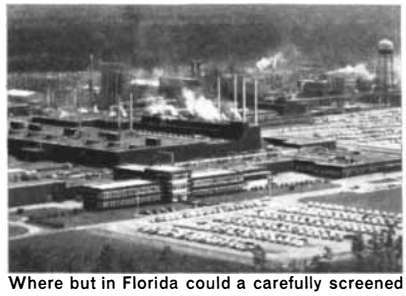
To broaden facilities for post graduate professional study, a program of *in-service training* leading to advanced degrees in electrical and mechanical engineering was inaugurated last fall by the College of Engineering of the University of Florida. Courses, currently offered in St. Petersburg and Palm Beach, include advanced mathematics, electronics, transient phenomena and electro-magnetic theory.

EXPANDING MARKETS IN FLORIDA PROVIDE AMPLE ROOM FOR GROWTH

On the Industrial Front: Using value added by manufacture as a yardstick, the industrial market in Florida is growing more rapidly than in any other major state. The latest census of manufactures shows a Florida gain of 78.2 per cent between 1954 and 1958.

In Retail Sales, Florida rose from 15th to 10th place in the U.S. between 1948 and 1958, with a volume of $5,840 million in the latter year.

In Wholesale Sales, the Miami Metropolitan area ranked first in the nation in rate of increase between 1948 and 1958. Miami's gain was 239 per cent. The Tampa-St. Petersburg and the Jacksonville areas were also among the eight major areas in the country in which sales more than doubled.



Where but in Florida could a carefully screened work force of more than 4,000 men and women be assembled in a city of 50,000 in three short years? That was the record set by Chemstrand Corporation which opened this giant nylon plant in Pensacola in 1953. Included among these employees were 400 engineers. Chemstrand now employs approximately 6,500.

SEND FOR THE BOOKLET "GUIDE FOR LOCATING YOUR PLANT IN FLORIDA"

This new 16-page booklet explains in detail how the Industrial Services Division of the Florida Development Commission can help you select the most suitable location in the state.

It describes special studies which can be prepared for potential locations covering markets, manpower, transportation and supplier industries as related to your individual needs.

Meetings with community leaders may be arranged, but unless authorized, your identity will not be revealed.

Write to B. R. Fuller, Jr., Exec. Dir., Florida Development Commission, 4016-7 Carlton Building, Tallahassee.

For more general information about industrial Florida, ask for the nine-part file folder, "Profile of Progress."

Vacation in Florida. For 100-page "Guide Book," write State of Florida, Dept. B, Carlton Bldg., Tallahassee.

MATHEMATICAL GAMES

Diversions that involve one of the classic conic sections: the ellipse

by Martin Gardner

Mathematicians have a habit of studying, just for the fun of it, things that seem utterly useless; then centuries later their studies turn out to have enormous scientific value. There is no better example of this than the work done by the ancient Greeks on the noncircular curves of second degree: the ellipse, parabola and hyperbola. They were first studied by one of Plato's pupils. No important scientific applications were found for them until the 17th century, when Kepler discovered that planets move in ellipses and Galileo proved that projectiles travel in parabolas.

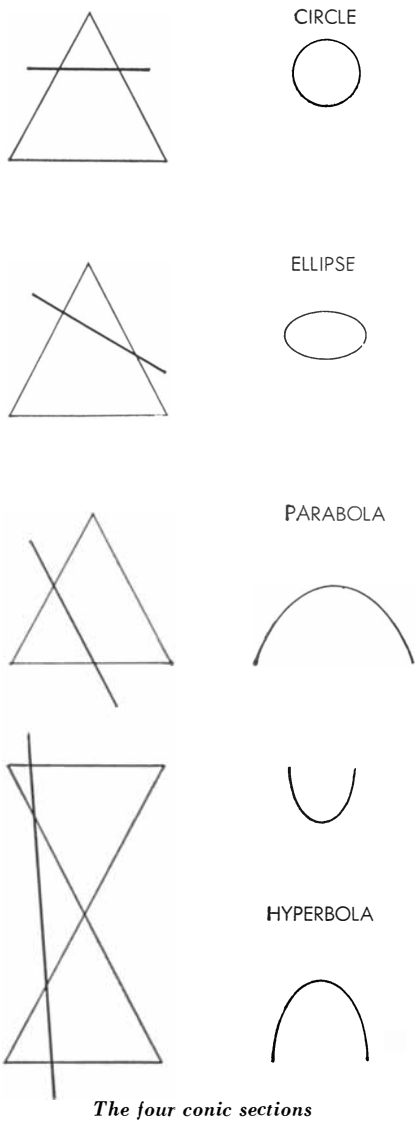
Apollonius of Perga, a third century B.C. Greek geometer, wrote the greatest ancient treatise on these curves. His work *Conics* was the first to show how all three curves, along with the circle, could be obtained by slicing the same cone at continuously varying angles. If a plane is passed through a cone so that it is parallel to the base [*see top of illustration at right*], the section is a circle. If the plane is tipped, no matter how slightly, the section becomes elliptical. The more the plane is tipped, the more elongated the ellipse becomes, or, as the mathematician puts it, the more eccentric. One might expect that as the plane became steeper the curve would take on more of a pear shape (since the deeper the slice goes, the wider the cone), but this is not the case. It remains a perfect ellipse until the plane becomes parallel to the side of the cone. At this instant the curve ceases to close on itself; its arms stretch out toward infinity and the curve becomes a parabola. Further tipping of the plane causes it to intersect an inverted cone placed above the other one [*see bottom of illustration at right*]. The two conic sections are now the two branches of a hyperbola. They vary in shape as the cutting plane continues to rotate until finally they degenerate into straight lines. The four curves are called curves of second degree because they are the Cartesian graph forms of all second-degree equations that relate two variables.

The ellipse, the topic of this month's department, is the simplest of all plane curves that are not straight lines or circles. It can be defined in numerous ways, but perhaps the easiest to grasp intuitively is this: An ellipse is the locus, or path, of a point moving on a plane so that the sum of its distances from two fixed points is constant. This property underlies a well-known method of drawing an ellipse. Stick two thumbtacks in a sheet of paper, put a loop of string around them and keep the string taut with the point of a pencil as shown in the top illustration on page 148. Moving the pencil around the tacks will trace a perfect ellipse. (The length of the cord cannot vary; therefore the sum of the distances of the pencil point from the two tacks remains constant.) The two fixed points (tacks) are called the foci of the ellipse. They lie on the major axis. The diameter perpendicular to this axis is the minor axis. If you move the tacks closer together (keeping the same loop of cord), the ellipse becomes less and less eccentric. When the two foci come together, the ellipse becomes a circle. As the foci move farther apart the ellipse becomes more elongated until it finally degenerates into a straight line.

There are many other ways to construct ellipses. One curious method can be demonstrated with a circular cake pan and a cardboard disk having half the diameter of the pan. Put friction tape or masking tape around the inside rim of the pan to keep the disk from slipping when it is rolled around the rim. Anchor a sheet of paper to the bottom of the pan with strips of cellophane tape at the edges. Punch a hole anywhere in the disk with a pencil, place the point of the pencil on the paper and roll the disk around the pan [*see bottom illustration on page 148*]. An ellipse will be drawn on the paper. It is best to hold the pencil lightly with one hand while turning the disk slowly with the other, keeping it pressed firmly against the rim of the pan. If the hole is at the center of the disk, the pencil point will of course trace a circle. The nearer the hole is to the edge of the disk, the greater the eccentricity of the ellipse will be. A point on the circumference of the disk traces an ellipse that has degenerated into a straight line!

Here is another pleasant way to obtain an ellipse. Cut a large circle from a sheet of paper. Make a spot somewhere inside the circle, but not at the center, then fold the circle so that its circumference falls on the spot. Unfold, then fold again, using a different point on the circumference, and keep repeating this until the paper has been creased many times in all directions. The creases form a set of tangents that outline an ellipse [*see top illustration on page 150*].

Though not so simple as the circle,



The four conic sections

Recently, an IBM computer began instructing one of the largest petroleum refinery units how to operate at peak efficiency. The computer reads 196 instruments every four minutes, makes reference to 75,000 stored instructions, and every 20 minutes types out instructions to refinery operators. The loop soon will be closed all the way and a computer will run on-line, exercising direct control of the process.

The IBM team that developed this system solved its problems through the interplay of many professional skills. For example, mathematicians developed a mathematical model that completely describes the system. Then electronic and mechanical engineers developed the terminal and logic equipment that picks up the analog information of the process and converts it into the digital language of the computer.

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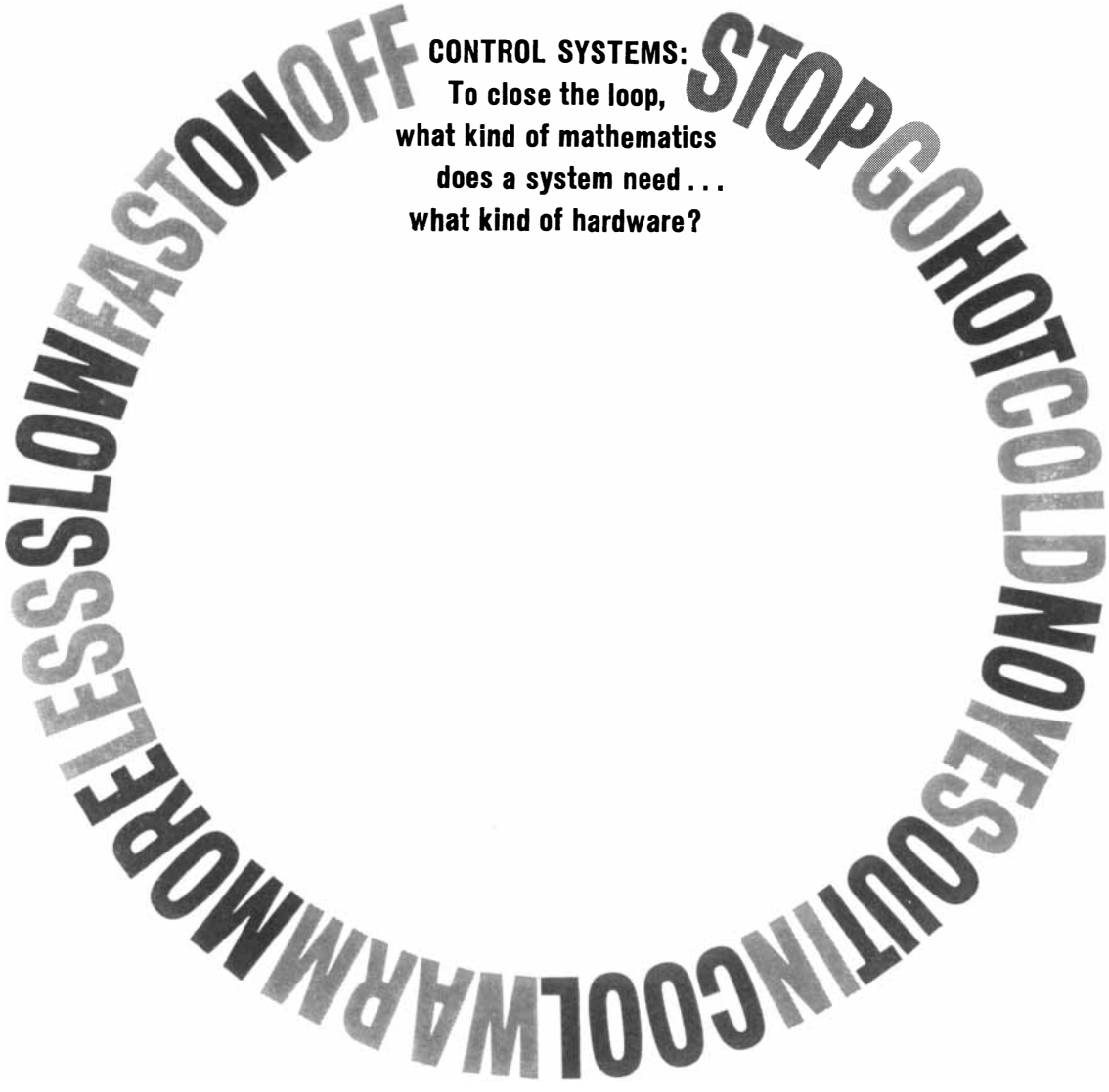
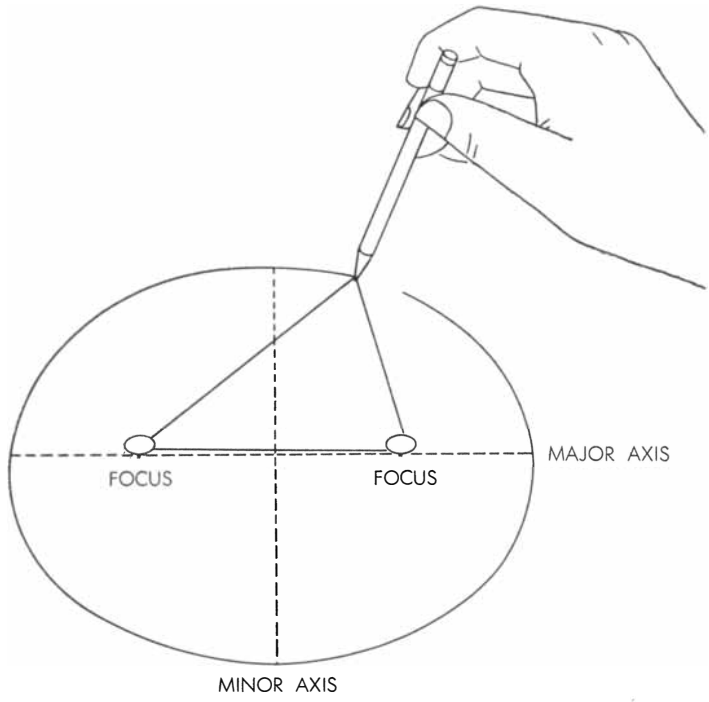


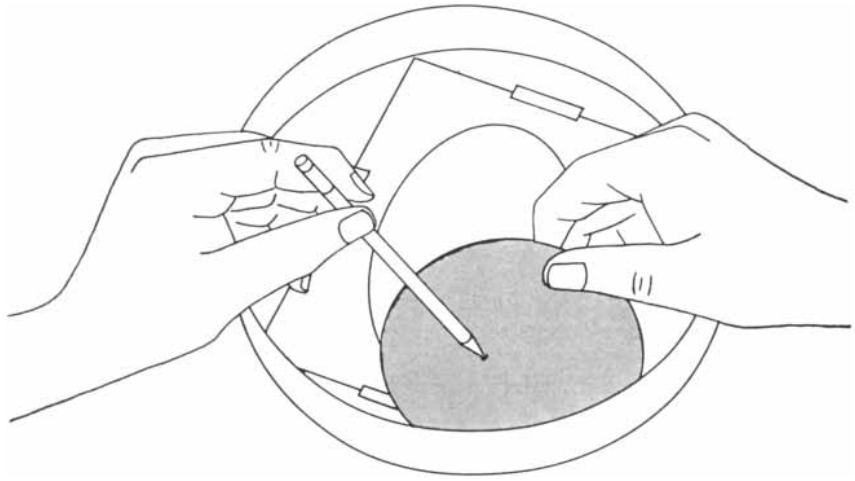


The simplest way to draw an ellipse

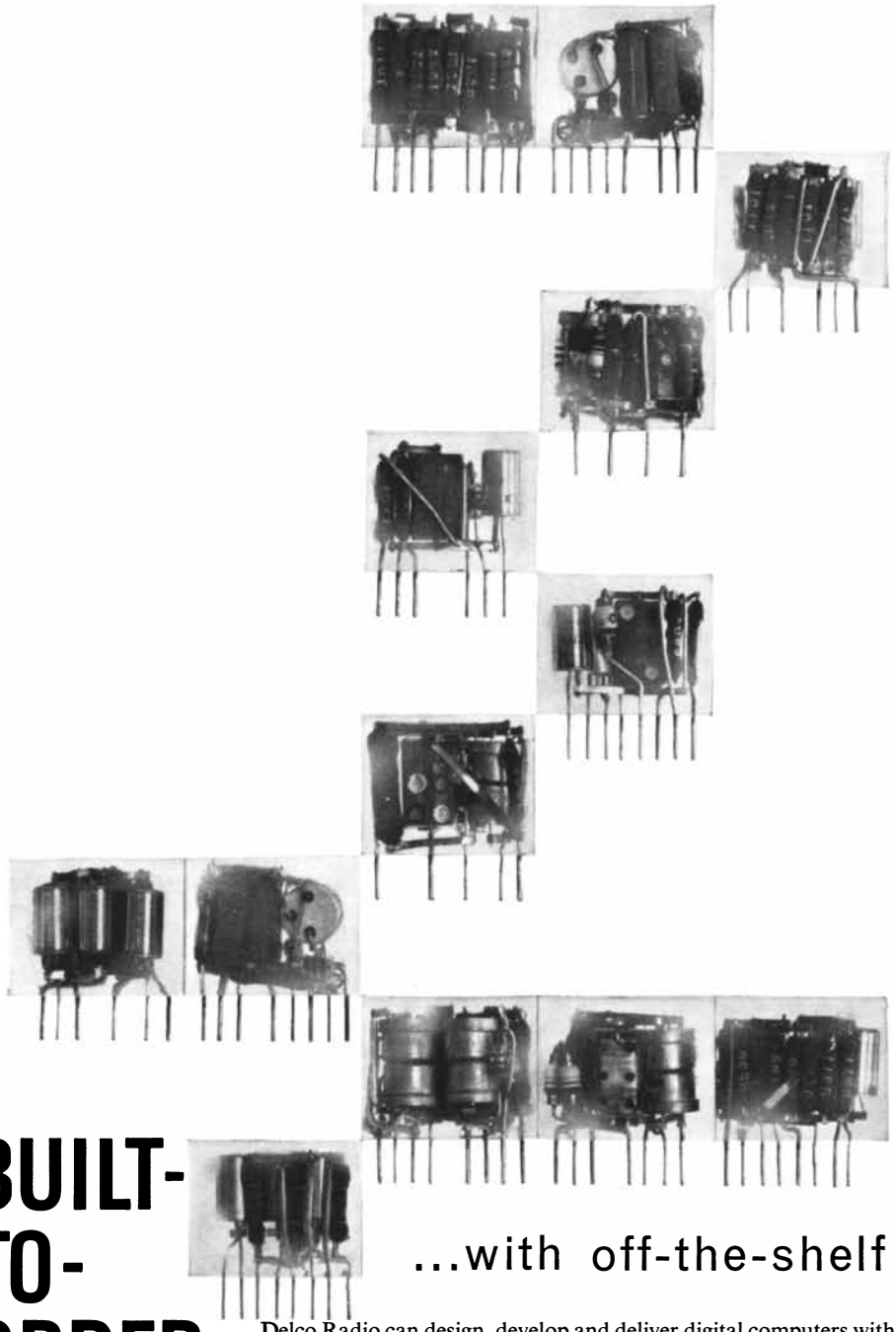
the ellipse is nevertheless the curve most often "seen" in everyday life. The reason is that every circle, viewed obliquely, appears elliptical. In addition, all closed noncircular shadows cast on a plane by circles and spheres are ellipses. Shadows on the sphere itself—the inner curve of a crescent moon, for example—are bordered by great circles, but we see them as elliptical arcs. Tilt a glass of water (it doesn't matter if the glass has cylindrical or conical sides) and the surface of the liquid acquires an elliptical outline.

A ball resting on a table top [*see bottom illustration on page 150*] casts an elliptical shadow that is a cross section of a cone of light in which the ball fits snugly. The ball rests precisely on one focus of the shadow. If we imagine a larger sphere that is tangent to the surface from beneath and fits snugly into the same cone, the larger sphere will touch the shadow at the other focus. These two spheres provide the following famous and magnificent proof that the conic section is indeed an ellipse.

Point A is any point on the ellipse. Draw a line [*shown in color in the illus-*



An ellipsograph made with a circular cake pan and a cardboard disk



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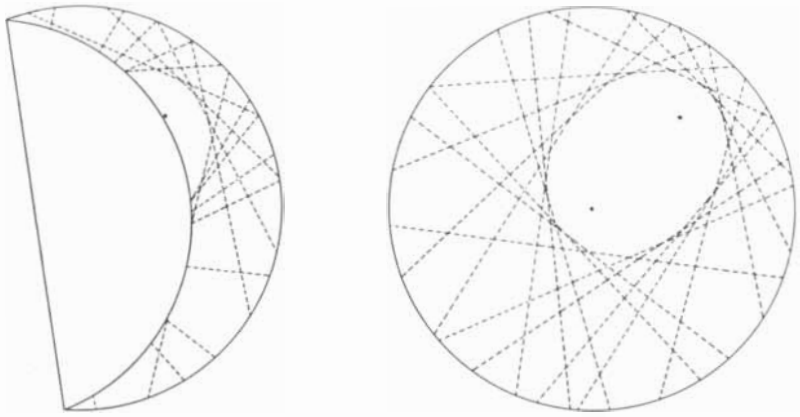
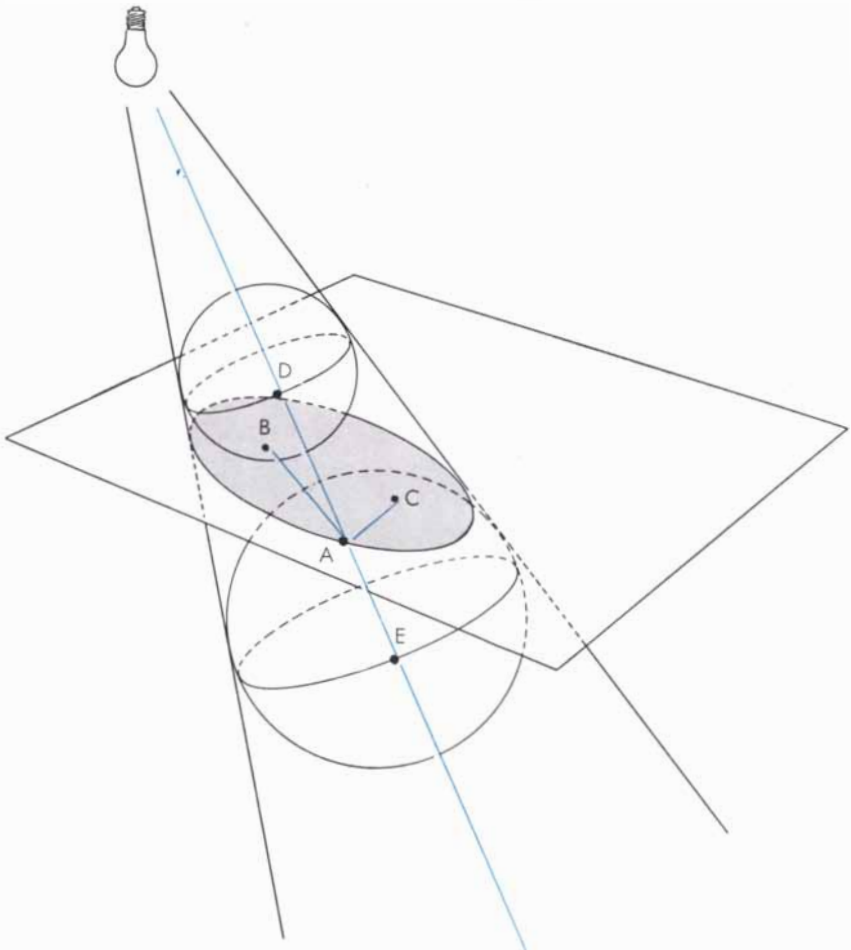


Folding a paper circle so that its edge falls on an off-center spot makes an ellipse

tration] that passes through A and the apex of the cone. This line will be tangent to the spheres at points D and E. Draw a line from A to point B, where the small sphere touches the shadow, and a similar line from A to C where the large sphere touches the shadow. AB is equal to AD because both lines are tangents to a sphere from the same fixed point. AE equals AC for the same reason. Adding equals to equals:

$$AD + AE = AB + AC$$

Now AD + AE is the same as the straight line DE. Because of the symmetry of cone and spheres, this line has a constant length regardless of where



By means of larger sphere it can be shown that shadow of smaller sphere is an ellipse

Inventiveness: indispensable ingredient of **S**pace **T**echnology **L**eadership

In the achievement of Space Technology Leadership, on-the-shelf hardware and the existing state-of-the-art are not always equal to the requirements of advanced missile and space systems. In such challenging situations Space Technology Laboratories responds with the full breadth of its resources ● In response to the need for time compression, STL inventiveness produced devices answering urgent requirements of advanced space programs conducted for the Air Force Ballistic Missile Division, National Aeronautics and Space Administration, and Advanced Research Projects Agency. Among these: Telebit, first digital computer to enter space; the first multi-million-mile space communications system of Pioneer V; a continuous-wave radio guidance system and lightweight autopilots for Able-series space vehicles; and a low-thrust multi-start space engine for maneuverable satellites ● On this foundation of inventiveness STL continues to broaden in scope, translating creative concept into accomplishment for Space Technology Leadership ● Outstanding scientists and engineers seeking such an environment are invited to investigate opportunities available at STL. Resumes and inquiries will receive meticulous attention.

SPACE TECHNOLOGY LABORATORIES, INC. P.O. BOX 95005V, LOS ANGELES 45, CALIFORNIA

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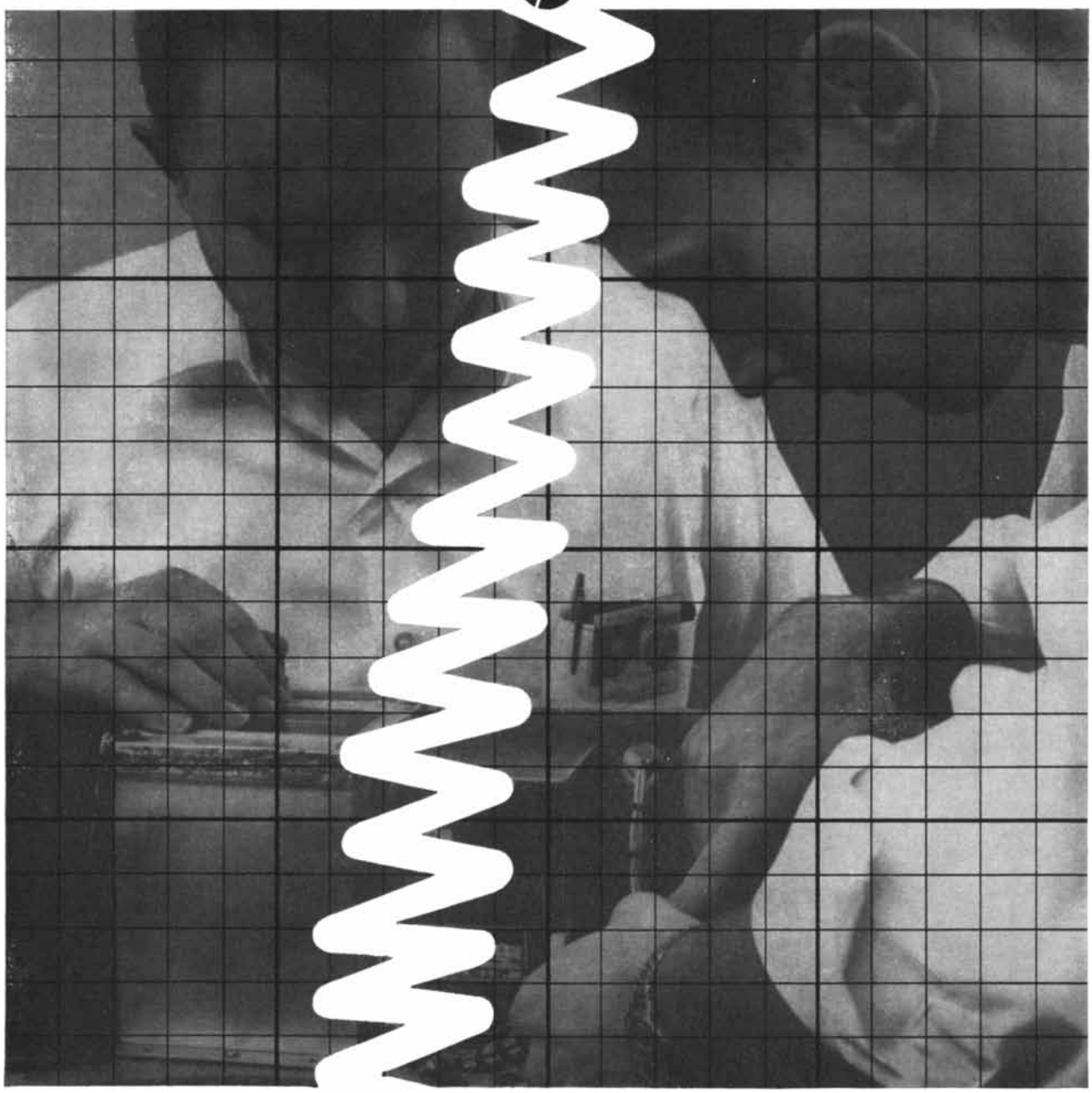
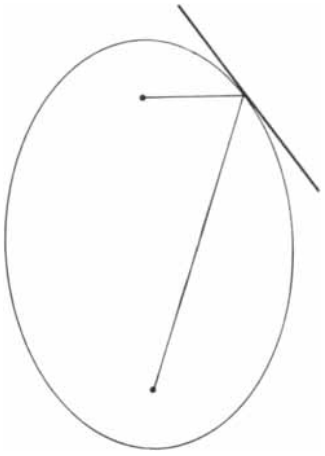
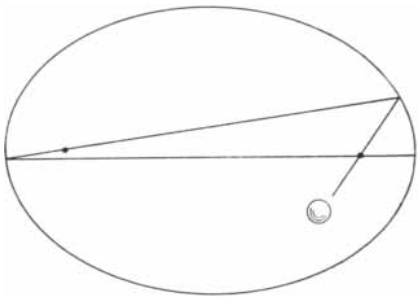
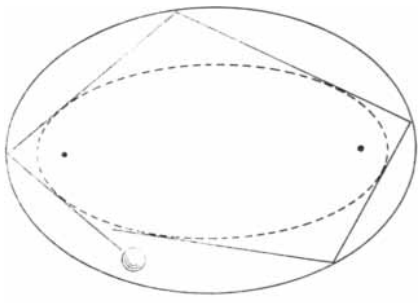




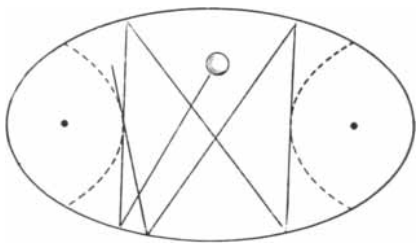
Tangent makes equal angles with two lines



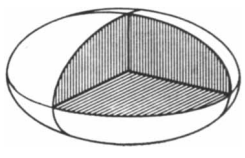
Path of ball driven over focus of ellipse



Path of ball that does not go between foci



Path of ball that does pass between foci



Each section of ellipsoid is elliptical

point A is chosen on the ellipse. If the sum of AD and AE is constant, then the above equation makes the sum of AB and AC a constant also. Since AB and AC are the distances of point A from two fixed points, the locus of A must be an ellipse with B and C as its two foci.

In physics the ellipse turns up most often as the path of an object moving in a closed orbit under the influence of a central force that varies inversely with the square of the distance. Planets and satellites, for example, have elliptical orbits with the center of gravity of the parent body at one of the foci. When Kepler first announced his great discovery that planets move in ellipses [see "The Celestial Palace of Tycho Brahe," page 118], it ran so counter to the general belief that God would not permit the paths of heavenly bodies to be less perfect than circles that Kepler found it necessary to apologize. He spoke of his ellipses as dung that he had been forced to introduce in order to sweep from astronomy the larger amount of dung that had accumulated around attempts to preserve circular orbits. Kepler himself never discovered why the orbits were elliptical; it remained for Newton to deduce this from the nature of gravity. Even the great Galileo to his dying day refused to believe, in the face of mounting evidence, that the orbits were not circular.

An important reflection property of the ellipse is made clear in the top illustration at left. Draw a straight line that is tangent to the ellipse at any point. Lines from that point to the foci make equal angles with the tangent. If we think of the ellipse as a vertical strip of metal on a flat surface, then any body or wave pulse, moving in a straight line from one focus, will strike the boundary and rebound directly toward the other focus. Moreover, if the body or wave is moving toward the boundary at a uniform rate, regardless of the direction it takes when it leaves one focus, it is sure to rebound to the other focus after the same time interval (since the two distances have a constant sum). Imagine a shallow elliptical tank filled with water. We start a circular wave pulse by dipping a finger into the water at one focus of the ellipse. A moment later there is a convergence of circular waves at the other focus.

Lewis Carroll invented and published a pamphlet about a circular billiard table. I know of no serious proposal for an elliptical billiard table, but Hugo Steinhaus (in his book *Mathematical Snapshots*, recently reissued in a revised edition by the Oxford University Press) gives a surprising threefold analysis of how a ball on such a table would behave. Placed at one focus and shot (without English) in any direction, the ball will rebound and pass over the other focus. Assuming that there is no friction to retard the motion of the ball, it continues to pass over a focus with each rebound [*see second illustration at left*]. However, after only a few trips the path becomes indistinguishable from the ellipse's major axis. If the ball is not placed on a focus, then driven so that it does not pass between the foci, it continues forever along paths tangent to a smaller ellipse with the same foci [*see third illustration at left*]. If the ball is driven between the foci [*see fourth illustration at left*], it travels endlessly along paths that never get closer to the foci than a hyperbola with the same foci.

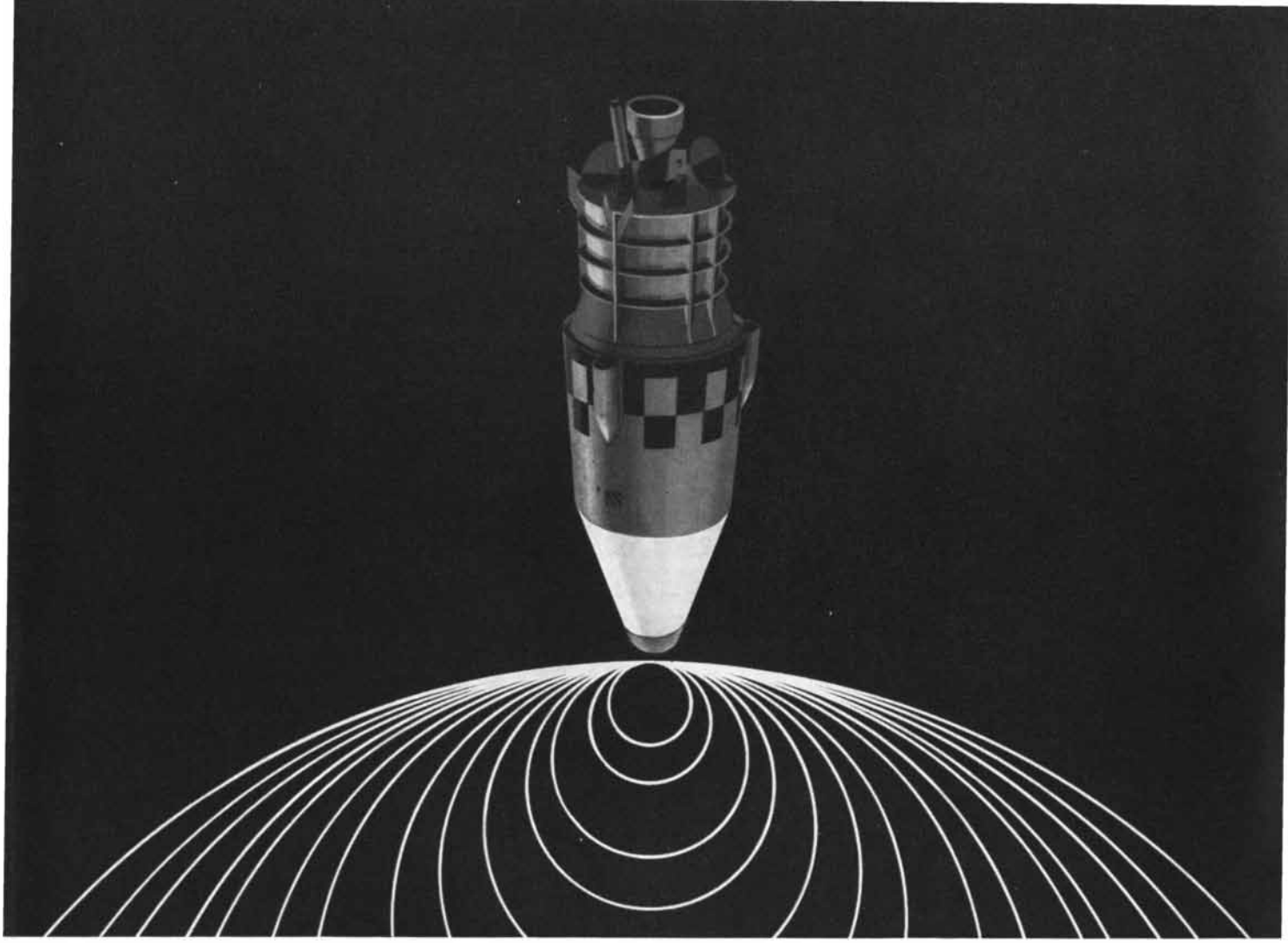
In *The Mikado* there are lines about a billiard player forced to play

On a cloth untrue
With a twisted cue,
And elliptical billiard balls!

In *A Portrait of the Artist as a Young Man* James Joyce has a teacher quote these lines, then explain that by "elliptical" W. S. Gilbert really meant "ellipsoidal." What is an ellipsoid? There are three principal types. An ellipsoid of rotation, more properly called a spheroid, is the surface of a solid obtained by rotating an ellipse around either axis. If the rotation is around the minor axis, it generates an oblate spheroid, which is flattened at the poles like the earth. Rotation around the major axis generates the football-shaped prolate spheroid. Imagine a prolate spheroid surface that is a mirror on the inside. If a candle is lighted at one focus, a piece of paper at the other focus will burst into flames.

Whisper chambers are rooms with spheroidal ceilings. Faint sounds originating at one focus can be heard clearly at the other focus. In the U. S. the best-known whispering gallery is in Statuary Hall of the Capitol in Washington, D.C. (No guided tour is complete without a demonstration.) A smaller but excellent whisper chamber is a square area just outside the entrance to the Oyster Bar on the lower level of New York's Grand Central Station. Two people standing in diagonally opposite corners, facing the wall, can hear each other distinctly even when the square area bustles with activity.

Both the oblate and prolate spheroids have circular cross sections if sliced by planes perpendicular to one of the three co-ordinate axes. When all three axes are



"MIDAS" REPORTS

through communications equipment by Philco

MIDAS II, the experimental "sentry in space," is the forerunner of a series of satellites that will detect the launching of ballistic missiles anywhere on earth and instantly relay the warning. Its entire communications system was designed and produced by Philco's Western Development Laboratories for the U.S. Air Force, as associate contractor with Lockheed.

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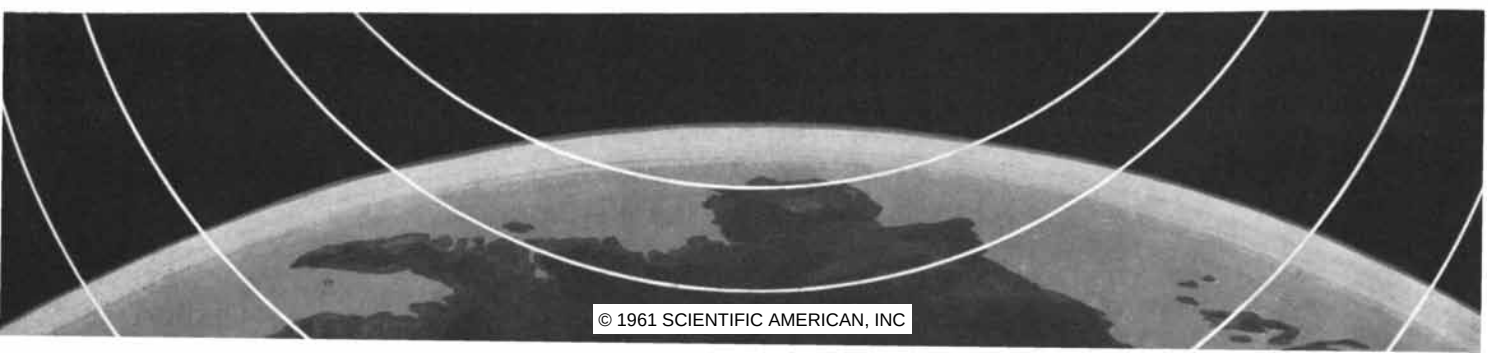


unequal in length, and sections perpendicular to each are ellipses, the shape is a true ellipsoid [*see bottom illustration on page 152*]. This is the shape that pebbles on a beach tend to assume after long periods of being jostled by the waves.

Elliptical "brain teasers" are rare. Here are two easy ones that will be answered in this space next month:

1. Prove that no regular polygon having more sides than a square can be drawn on a noncircular ellipse so that each corner is on the perimeter of the ellipse.

2. In the paper-folding method of constructing an ellipse, explained earlier, the center of the circle and the spot on the circle are the two foci. Prove that the curve outlined by the creases is really an ellipse.

The problem posed last month by Dr. Matrix was to determine the longest chain that can be constructed with three digits without having two identical patterns (of one or more digits) side by side. The answer is that there is no limit to such a chain. Several proofs have been published; the following by John Leech appeared in the *Mathematical Gazette* for December, 1957.

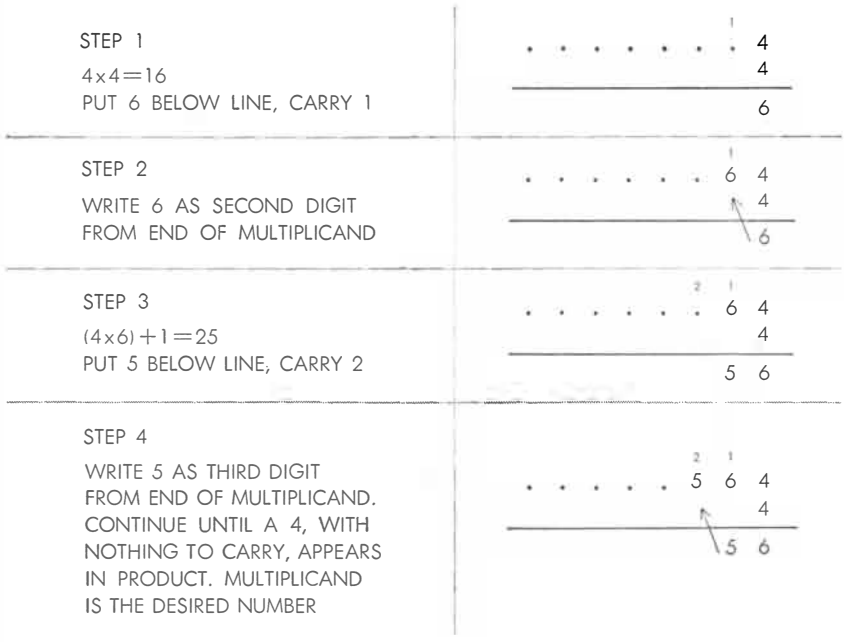
Consider the following three blocks of digits:

0 1 2 1 0 2 1 2 0 1 2 1 0
1 2 0 2 1 0 2 0 1 2 0 2 1
2 0 1 0 2 1 0 1 2 0 1 0 2

The digits in these blocks are so arranged that if we substitute the three blocks for the three digits (replacing 1 with one block, 2 with another, 3 with the third) in any patternless chain (*e.g.*, any one of the three blocks), the resulting chain will also be patternless. In this longer chain we can now substitute blocks for digits once more to obtain a still longer chain, and so on ad infinitum. It is not possible to construct shorter blocks that can be used in this way, but there are blocks other than the three given here.

Miss Toshiyori's phone number is 1-02564. The problem was to find a number ending in 4 that quadruples in size when the 4 is moved from the end to the front. Puzzles of this type are easily solved by a kind of multiply-as-you-go technique explained in the illustration below.

After mastering this method, readers may wish to tackle the following three problems (not to be answered next month): (1) What is the smallest number ending in 6 that becomes six times larger when the 6 is shifted from the end to the front? (Warning: The number has 58 digits!) (2) Find the smallest number *beginning* with 2 that triples when the 2 is moved to the end. (3) Prove that there is no number beginning with the digit n that increases n times when the first digit is moved from the front to the end, except in the trivial case where n is 1.

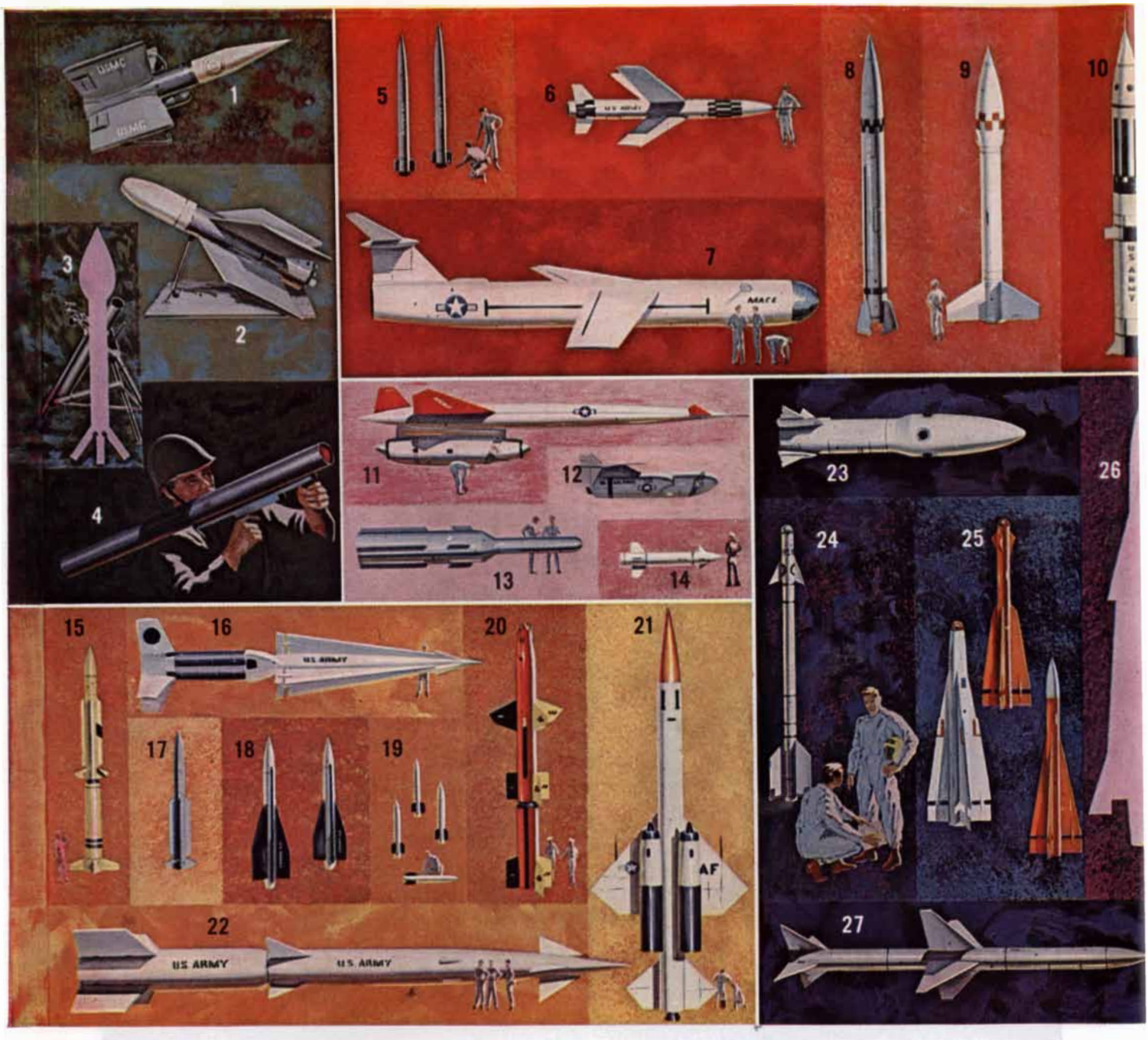


How to solve the problem of Miss Toshiyori's telephone number

Official Air Force Photograph at Cape Canaveral, Florida

CAPE CANAVERAL

CAPE CANAVERAL is a part of the complex of the Atlantic Missile Range extending 10,000 miles southeast into the Indian Ocean. Developing the vast network of essential island outposts devoted to the defense effort was a task uniquely suited to Pan Am's world-wide experience, staff and facilities. Planning the instrumentation and tracking systems for the Air Force Missile Test Center is a continuing space age challenge. Qualified electronics and systems engineers and physicists are invited to inquire about career advantages with Pan Am. Address Manager, Technical Employment, Pan American World Airways, Inc., Guided Missiles Range Division, Patrick AFB, Florida.



FACTS AND FIGURES ON . . .

MISSILES AND MISSIONS

Do you know the big names in this missile who's who?

Check your missile I.Q. and see. Correct answers are on reverse page.

A. Identify the one-man missiles in the "camouflage green" panel (No. 3 is an artist's impression):

1. ..... 3. .....
2. ..... 4. .....

B. Which of these missile metals are most subject to attack by corrosion: aluminum • magnesium • zinc • cadmium • silver • cuprous alloys • galvanized steel?

C. Identify the tactical surface-to-surface missiles in the bright red panel:

5. ..... 8. .....
6. ..... 9. .....
7. ..... 10. .....

D. Who is designer and builder of the U.S. Army's LARC-15, all-aluminum vehicle in ground support?

E. Identify the air-to-surface missiles in the pink panel — No. 13 is an artist's impression:

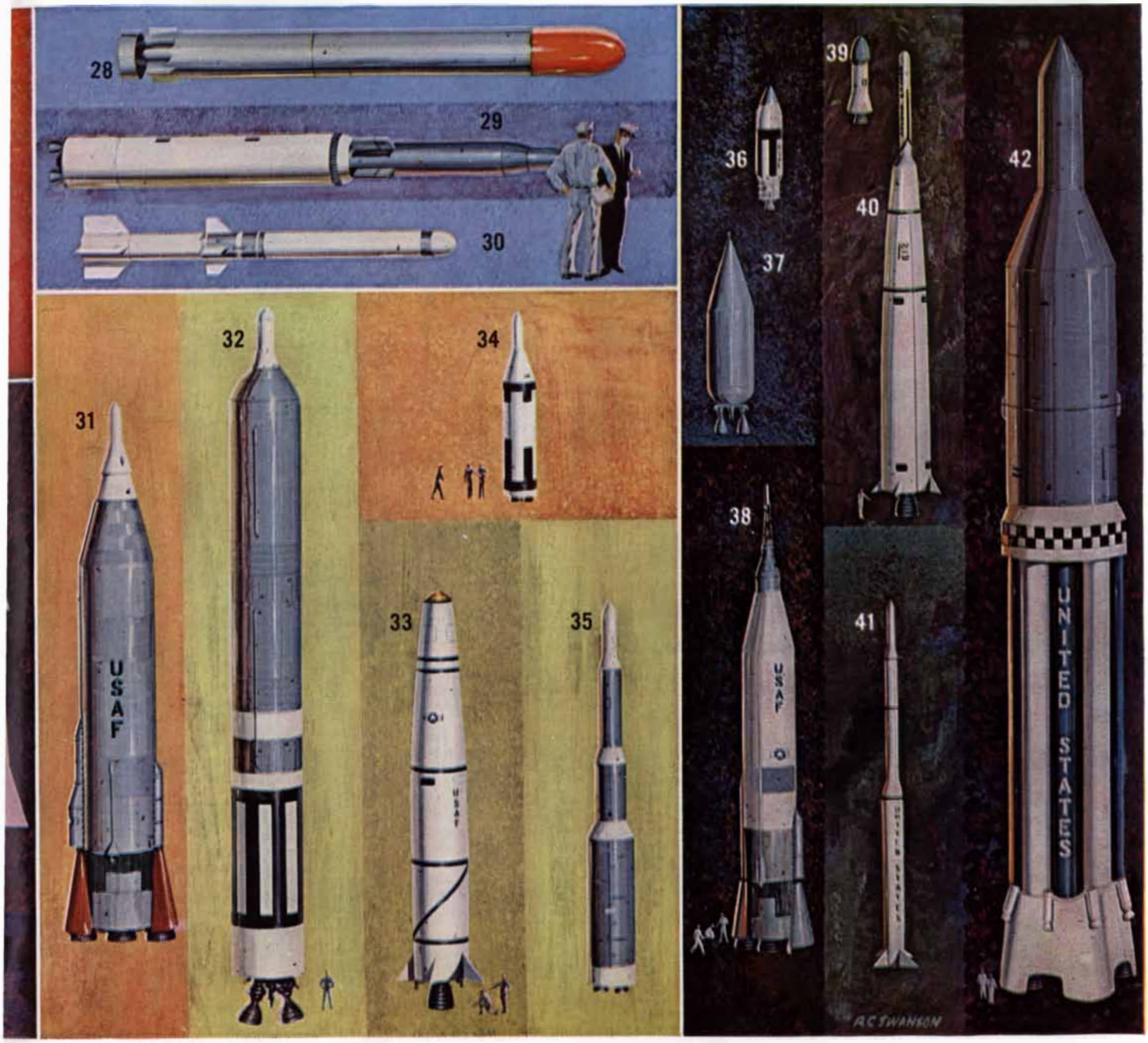
11. ..... 13. .....
12. ..... 14. .....

F. How do missile-makers control moisture, temperature and pressure in airborne electronics and ground support systems?

G. Identify the ground-to-air missiles in the tan panel:

15. ..... 19. .....
16. ..... 20. .....
17. ..... 21. .....
18. ..... 22. .....

H. What synthetic liquid fuel has been used in the greatest number and variety of operational rocket programs?



I. Identify the air-to-air missiles in the purple panel. (No. 26 is an artist's impression):

23. ..... 26. .....
24. ....
25. ..... 27. .....

J. Can exotic metals used in missiles be drilled like conventional materials?

K. Identify the undersea missiles in the light blue panel:

28. ..... 29. .....
30. .....

L. Why are the newest missiles making greater use of chemically tailored fluids?

M. Identify the long-range surface-to-surface missiles in the yellow panel:

31. ..... 33. .....
32. ..... 34. .....
35. .....

N. What kind of filters were chosen to protect support equipment for most of America's operational missiles?

O. Identify these *second-stage* spacecraft boosters in the blackish panel:

36. ..... 37. .....
39. .....

P. Missile fasteners (bolts and companion locknuts) are vital to the success of a mission. How many pounds per square inch of tensile strength do current missile superbolts possess? To what maximum temperature (Fahrenheit) are they operational? What materials are used to obtain high strength to weight ratio?

Q. Why can a titanium component be actually stiffer than steel, even though titanium's modulus is lower?

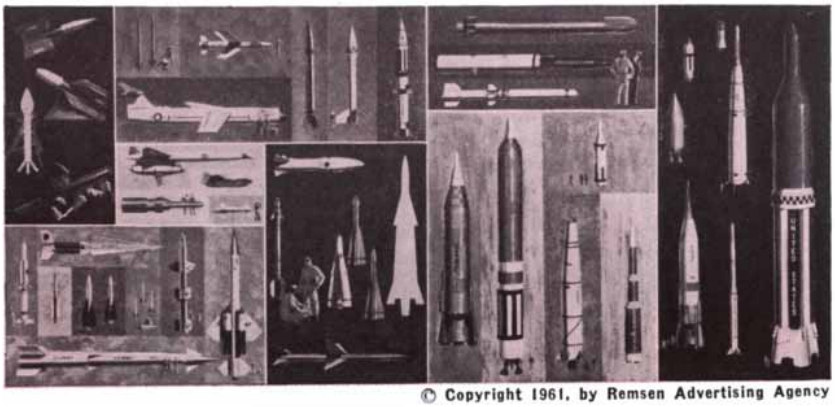
R. Identify these spacecraft boosters in the blackish panel:

38. ..... 40. .....
41. .....

S I. What is the most compact high-capacity bearing used in such applications as missile elevons, aircraft control surfaces, jet engine auxiliary equipment, flaps, and bell cranks?

S II. How large are bearings made for radar antenna mounts? What special features can be provided?

T. Almost anyone knows No. 42 as Saturn, the United States' biggest spacecraft booster. What payloads can it push into a low orbit (300 miles)? ..... Into very high, 22,000 miles orbit? ..... Into moon landing? .....



Free, full color reprints of this panorama will be sent to you on request. Oversized 35" x 18" full color framing prints without advertising copy are available on heavy stock for $1.00 each. Send all requests to: Remsen Advertising Agency, Inc., 155 Whitney Ave., New Haven 9, Conn.

ANSWERS TO MISSILE & MISSIONS QUIZ

The key to the test on the preceding pages appears below. Also, look for some mighty important names in defense technology — each one has the answer to vital problems in missile system design and performance.

A. The one-man missiles in the "camouflage green" panel are: 1. Cobra; 2. SS 11; 3. Davy Crockett; 4. Redeye.

B. All these metals are vulnerable to corrosion — by fuels, exhaust fumes, and moisture. And IRIDITE chromate conversion coatings by Allied Research Products protects them all: in missiles, aircraft, ground support equipment. See your Allied Field Engineer for assistance on your conversion problems. He's listed under Plating Supplies in the yellow pages. Or, send for free technical data on chemicals, processes, and equipment for metal finishing.

ALLIED RESEARCH PRODUCTS, INC. • 4004-06 East Monument Street • Baltimore 5, Maryland Branch Plant: 400 Midland Avenue • Detroit 3, Michigan

C. The tactical surface-to-surface missiles in the bright red panel are: 5. Little John; 6. LaCrosse; 7. Mace; 8. Sergeant; 9. Honest John; 10. Pershing.

D. The creator of the LARC-15 is Borg-Warner Corporation, a family of defense-oriented divisions with major systems capabilities in fuel control, ground support checkout, enemy detection, power systems, meteorological analysis, and advanced research.

BORG-WARNER CORPORATION, 200 S. Michigan Ave., Chicago 4, Illinois

E. The air-to-surface missiles in the pink panel are: 11. Hound Dog; 12. Quail; 13. Skybolt; 14. Bullpup.

F. They call on Eastern *liquid cooling* or *refrigeration cooling* systems to dissipate heat from electronic tubes or components — in anything from 50 to 50,000 watts dissipation rates. They protect radar wave guides from moist ambient air by Eastern *pressurizer/dehydrator* units — a controlled stream of dry air under pressure prevents moisture from condensing inside and causing arc-overs. Finally, Eastern components — *hydraulic pumps, quick disconnect valves,* and *servo units* keep space age systems on the job, up to the job in any environment.

EASTERN INDUSTRIES., 100 Skiff Street, Hamden 14, Conn., West Coast Office: 4203 Spencer St., Torrance, Calif.

G. The ground-to-air in the tan panel are: 15. Terrier; 16. Nike-Hercules; 17. Tartar; 18. Hawk; 19. Mauler; 20. Talos; 21. Bomarc; 22. Nike-Zeus.

H. Unsymmetrical dimethylhydrazine. This versatile synthetic fuel, manufactured by FMC under the trade name, DIMAZINE has contributed importantly to the success of more than a dozen major rocket programs for defense and space exploration because it offers a remarkably well-balanced combination of advantages in stability, storability, handling, and virtually all aspects of engine performance.

FOOD MACHINERY & CHEMICAL CORPORATION, CHLOR-ALKALI DIVISION, General Sales Office: 161 East 42nd Street, New York 17, N.Y.

I. The air-to-air missiles in the purple panel are: 23. Genie; 24. Sidewinder; 25. Three Falcons: late model with nuclear warhead (white finish): IR guided Falcon (blunt-nosed orange finish); and radar guided model (white pointed nose); 26. Eagle; 27. Sparrow III.

J. All missile metals — any substance which can be machined, in fact — can be deep-hole drilled with Hi-Standard gun drills. And it takes but a single pass to produce holes to 10 feet in depth — mirror smooth, accurate to micrometric measurements. In equivalent miles, Hi-Standard has just about drilled its way to the moon — through some of the toughest materials man and nature can create.

THE HIGH STANDARD MANUFACTURING COMPANY, HAMDEN, CONNECTICUT

K. The undersea missiles in the light blue panel: 28. Astor; 29. SUBROC; 30. ASROC.

L. *Functional fluids* by Monsanto help advance missile performance in all these applications: high temperature hydraulic fluids that stay on the job in missile environments; *jet engine lubricants* to extend the performance of cruise missiles by performing at 700° F. to 900°F.; *coolant-dielectrics* by Monsanto that permit miniaturizing of high-power electronic systems. In the future, Monsanto *radiation-resistant heat transfer fluids* and *moderator coolants for nuclear reactors* may roam the solar system aboard spacecraft with nuclear propulsion or auxiliary power.

MONSANTO CHEMICAL COMPANY, Aviation Fluids Dept. 1, 800 North Lindbergh Boulevard, St. Louis 66, Missouri

M. The long-range surface-to-surface missiles in the yellow panel are: 31. Atlas; 32. Titan II; 33. Thor; 34. Polaris; 35. Minuteman.

N. Those manufactured by the pioneer of the filter industry . . . Purolator Products, Inc. . . . whose present position is so aptly expressed by the slogan "Filtration for every known fluid" . . . the reasons are clear . . . Purolator can filter all fluids essential for the proper operation of aircraft, rockets or other equipment vital to America today.

The world's largest and most diversified makers of filters offers a choice of over 2,000 types to do the job and do it well.

PUROLATOR PRODUCTS, INC., Rahway, N.J. and Toronto, Canada

O. The *second-stage* spacecraft boosters in the blackish panel are: 36. Agena B; 37. Centaur; 39. Thor AbleStar.

P. Tension fasteners are currently manufactured to 300,000 psi tensile. Many of the superbolts and companion locknuts produced by Standard Pressed Steel Company are operational to 1600°F. High strength to weight (psi/density) is achieved through the use of exotic metals such as titanium or beryllium.

AIRCRAFT/MISSILE DIVISION SPS, Jenkintown, Pennsylvania • Santa Ana, California

Q. Stiffness, or buckling resistance, in compression-loaded structures (such as structural forgings or airframe sheet paneling), is more a function of the moment of inertia or geometry of the cross-section of the part, than simply the elastic modulus of the basic material. Titanium's density — about 40 per cent less than steel — thus permits use of greater thickness or cross-section in component design for a given weight. Therefore, in compression, titanium is actually more efficient than steel over a wide range of temperatures and load intensities.

TITANIUM METALS CORPORATION OF AMERICA, 233 Broadway, New York 7, N.Y.

R. The spacecraft boosters in the blackish panel are: 38. Atlas-Mercury; 40. Thor Able; 41. Scout.

S I. Torrington aircraft series bearings, made by the Torrington Company. Torrington also produces self-aligning ball bushings and spherical roller bearings for missile support equipment.

S II. Torrington has made precision ball bearings for radar antenna mounts with outside diameters up to 165 inches. Integral gear teeth can be supplied on either the inner or outer ring.

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THE AMATEUR SCIENTIST

Concerning periscopes, high vacuums, microprojection and photomicrography

Conducted by C. L. Stong

Poking about underwater with self-contained breathing apparatus, or simply with face mask and flippers, is surely one of the fastest growing diversions. In the midst of all this activity it is sometimes forgotten that amateurs can look into the underwater world without getting wet. As a contribution toward dry-shod submarine study this department explained last October how to build an inexpensive hydrophone for picking up underwater sounds. Now Paul B. Archibald, a chemist at the Lawrence Radiation Laboratory in Livermore, Calif., suggests a simple instrument for adding a picture to the sound:

"Build an underwater periscope," he writes. "Then you can see as well as hear. My interest in these fascinating devices was first aroused when I was asked to develop a means for inspecting the performance of swimmers to assist in the prevention of drownings. While considering the problem, a wider and more interesting use for the instrument suggested itself. Why not design an underwater periscope for observing fish and other forms of marine life in their natural surroundings? I visualized a watertight tube about four feet in length and 1½ inches in diameter with the line of sight bent 90 degrees at the bottom end. I considered unit magnification adequate, although some magnification would doubtless improve the performance.

"If one examines a diagram of the optical system of a submarine periscope, the impression is one of a large array of special lenses and prisms that, needless to say, are expensive and difficult to get. Moreover, the assembly and adjustment of such a system in a watertight tube present many problems that, even if not insurmountable, are difficult enough to discourage amateur effort.

"The lens system of a periscope can be regarded as two telescopes in series pointing toward each other. If the telescopes are of the same power, objects are seen in their normal size. In effect the optical system moves the eye to a position nearer the far end of the tube, and a proportionately larger field of view is observed in comparison with the field that could be seen through a simple tube (one without lenses) of the same length. The prism or mirror for bending the light at a right angle can be either inside or outside the lens system.

"While the above is a qualitative description of a periscope, it does not answer the questions of what focal length and of what quality the lenses should be. One might hazard a guess that if the magnification of the two telescopes comprising the system was fairly low (not over four times), the quality of the lenses would not need to be very high.

"The most inexpensive lenses I could locate turned out to have a diameter of 1¼ inches and a focal length of 7½ inches. They were bought at a local variety store for five cents each. Their optical quality proved to be satisfactory, and I found that a remarkably good low-power telescope could be made by combining several lenses for the eyepiece and using a single one for the objective. This trick of changing the focal length of a lens by putting several lenses together is well enough known to those engaged in professional optics, but as an amateur I had to discover it for myself.

"Thus relieved of the problem of obtaining a variety of lenses, the construction of a periscope of the sort that I wished to investigate became practical. My first impulse was to buy for the body of the periscope an aluminum tube that matched the diameter of the lenses and to equip each end with some sort of smooth-fitting ell. Such tubing was not readily available; further study indicated that the construction would present problems of machining that I was not equipped to solve. The most straightforward construction I could think of was a simple box 1¼ inches square (inside dimensions) by 50 inches long made of quarter-inch plywood.

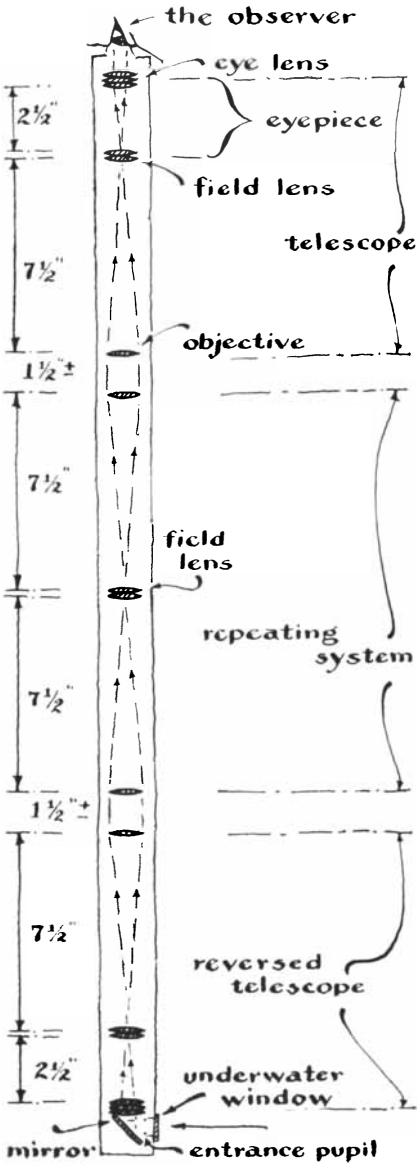
"Three sides of the box were first glued together to form a U-shaped trough into which the lenses would fit snugly. The box was made several inches longer than the anticipated length of the periscope to allow for adjustment of the lenses. Leaving the ends of the box open greatly simplified the adjustment. A mirror was used for bending the light at one end. It was inserted outside the lens system after the lenses were adjusted.

"While the assumption is reasonably correct that a periscope is two telescopes in series, a marked improvement in performance can be made by the insertion of additional lenses. After some experimentation, I hit on this final arrangement: Three of the lenses were combined to make the objective and were placed two inches from the end of the trough, then two lenses were combined and placed at the focal point of the objective (about 2½ inches farther down the trough). These served as a condensing lens to conserve light. Then a single lens was placed 7½ inches down the trough from the condensing lens. The seventh lens was placed 1½ inches from the sixth lens. This distance is not critical for the center of the field, where the light is parallel to the axis. If the spacing is made much greater than 1½ inches, however, increased vignetting, or loss of light at the edges of the field, will be apparent. The eighth and ninth lenses, which form a doublet, were placed at the focal point of the seventh lens, as shown in the accompanying drawing [*next page*]. This is the center of the symmetrical optical train. To complete the system the remaining lenses are installed in reverse order.

"The focal length of the lenses was determined by supporting a lens in a cardboard bracket and bringing the image of a distant object (the sun) to focus on a cardboard screen. The focal length is equal to the distance between the center of the lens and the screen. The lenses had been made up into magnifying glasses and were supported in a black plastic ring. The handle, attached to this rim, was easily broken off. The

rims were left in place, however, to steady the lenses in the tube. In the absence of such a rim one could cut a ring from cardboard tubing and cement the lens to it. The interior of the trough should be painted flat black to minimize internal reflections.

"The trough was placed on a table in a darkened room and pointed at a source of light some 20 feet away. The lenses were placed in the trough in their approximate positions. A small piece of white paper was inserted into the trough at a right angle to the optical axis and moved back and forth. The lenses were then adjusted one by one, starting at one end and working down the trough. Where the light is converging into a lens, an image will be formed, and the lens should be adjusted to this position.



Optical train of an underwater periscope

Where the light is diverging or parallel entering a lens, no image will be formed, and the adjustment is made by moving the piece of paper to the next focal point and adjusting the intermediate lenses.

"After adjustment the lenses were glued in place with a few drops of quick-drying cement. The fourth side of the trough was then glued on, completing the tube. The end window was cut and the 45-degree mirror inserted. The tube was cut off to a suitable length. One end was closed by a plain square of plywood and the other by a similar piece fitted with a small piece of Lucite. A Lucite window was also provided over the windows in front of the mirror. Finally the joints of the box were calked with wood filler and the wooden parts given several coats of waterproof paint.

"Some sort of eyeshield should be attached to the upper end of the instrument to aid in keeping the eye centered at a correct distance from the first lens. The shield also minimizes external light and thus enables the eye to adjust to the relatively weak light that comes through the periscope.

"The completed periscope is about 43 inches long and the field of view is 20 degrees. The system includes 16 lenses. The light loss is accordingly high: 5 per cent per surface is the figure commonly quoted, or a total loss of about 60 per cent. This is not fatal, however, and on a bright day is not particularly noticeable after one waits for a few seconds for the eye to compensate. In clear water such as a mountain lake's the range of vision is about 30 feet. (It is possible to make out a four-inch white post at this distance.) If the water contains suspended matter, the range is considerably reduced. The turbidity of the water limits the range more than light intensity.

"The periscope has advantages other than keeping the user dry. It is especially suited for observing in small, shallow bodies of water where a swimmer would disturb the environment. One of the most beautiful places I have found is the depths of a lily pond high in the mountains. The light filtering through the green leaves, the strangely shaped white roots and the small fish and insects present not only a fascinating cross section of marine biology but an unforgettable picture—in natural color."

A number of amateurs who built the high-vacuum system described in this department last March have asked for tips on how to cope with leaks in vacuum systems. The following letter from Edward L. Bonacci, a production engineer at the Machlett Laboratories in Springdale, Conn., suggests a number of practical antileak techniques:

"The pressure that can ultimately be reached by a pumping system," he writes, "and the speed at which this pressure is attained are determined by three factors: the volume of the system, the quantity of gas leaked or evolved into the system and the effective speed of the pumping system. Since it is obviously easier to evacuate a small container than a big one, the volume of the vacuum system and experimental chamber should be kept reasonably small. The leak situation can be divided into two parts, the first being leaks as we normally think of them, that is, holes in the system. These leaks are apt to be extremely small and hard to detect by normal methods. As an example, a leak that can just barely be detected by submerging the object in water and maintaining pressure inside so that air bubbles will appear at the leak would be regarded as enormous in a vacuum system, and the equipment would probably be inoperable.

"The second type of leak is the 'virtual leak' and is due to the continual evolution of gas from materials contained within the system. This can be corrected by the proper choice of materials, cleanliness and operating procedures. Since a vacuum system is limited by the speed at which a gas can be removed, the effective pumping speed is of great concern. The word 'effective' is important because we are interested in the pumping speed at the chamber to be evacuated and not the pump's rated speed. One of the faults I have noticed in earlier articles presented in 'The Amateur Scientist' was the use of long, small-diameter tubing to connect the pump to the experimental chamber. This tubing presents a resistance to the flow of gas molecules that varies directly with the tube length and inversely with the cube of the tube diameter. It is most important to use short, large-diameter tubing between components.

"The traditional material for vacuum systems is glass. For the average amateur, however, this material makes construction very difficult. The professional often uses two alternate building materials—copper and stainless steel. These materials are not only easier to handle but do not shatter. Generally the choice between these two will depend on the facilities available. Stainless steel is usually welded, and copper is usually brazed or soldered. Copper offers the additional advantage of availability to the experimenter. A good, dependable vacuum system is easily constructed from

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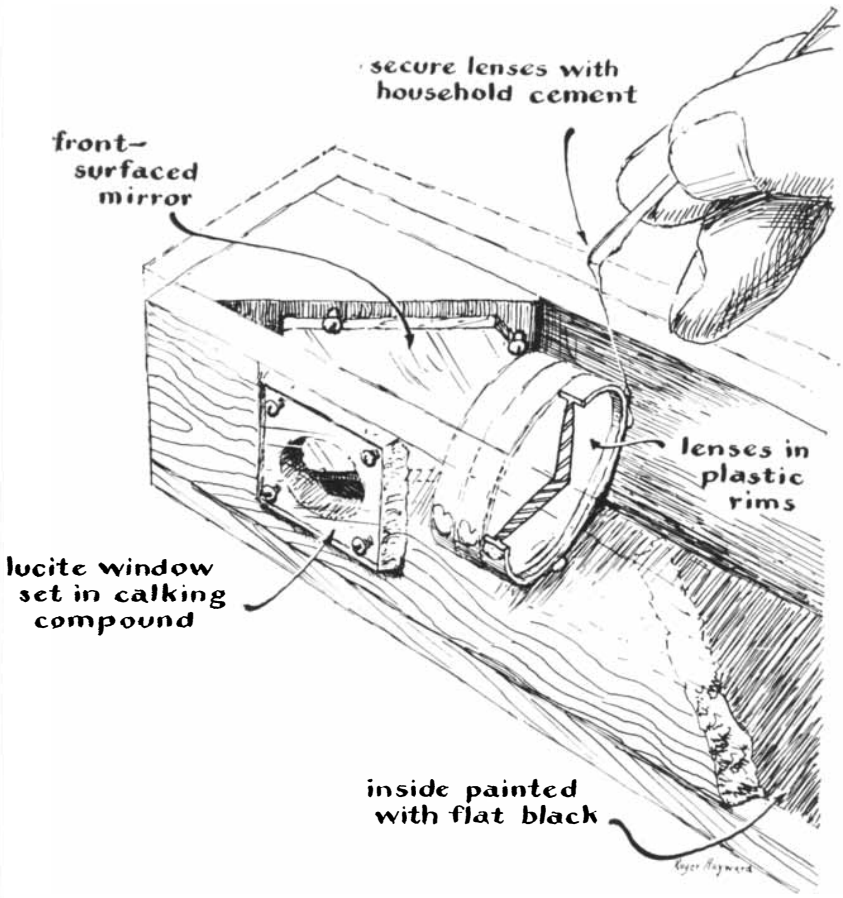

Details of a window and a mirror for an underwater periscope

standard copper tubing (usually the rigid type), and solder fittings are available at any plumbing supply house. The tubing is cut to length, and the ends are thoroughly cleaned with steel wool. Flux is then painted on the area to be soldered. The copper fittings are similarly prepared, the tubing is inserted and is carefully seated in preparation for soldering. All joints must be soldered carefully so that the solder flows evenly through the entire joint. We usually use hard (silver) solder and a borax-base flux; however, a fluxless type of solder or high-tin-content soft solder can be used with the understanding that the ultimate pressure, speed and highest temperature that can be reached will be limited by the type of solder and flux used. After applying flux to the area to be soldered, the torch (either household gas and air or propane) is played on the fitting and tubing to heat the general area thoroughly. As the flux bubbles and fluffs up, the torch is gradually moved closer to the area of the joint. The solder wire is frequently touched to the joint to determine when the work is hot enough for soldering. Solder is then fed into the joint (usually from the outside) while the torch is directed onto the fitting.

"The solder should flow freely into the fitting. Since it will follow the heat, it is possible to pull the solder completely through the joint merely by directing the heat from the torch to the opposite side. As soon as the solder has solidified the hot joint is plunged under running water to break off the flux. Soldering technique is most important, not only because poor solder joints are susceptible to leaks but also because such leaks are exceptionally difficult to find. A good solder joint will show a smooth, even fillet on both sides, indicating that solder has run completely through the joint.

"Most of the vacuum system can be built of copper tubing. This construction is recommended. Two problems still exist for the amateur. The first is that of temporary or semipermanent joints. These can be made of flanges that can be purchased. Flanges are sealed by rubber or Teflon 'O' rings. The manufacturers of O rings will also usually supply flange design data from which the amateur can make flanges to meet his needs. We have found from experience

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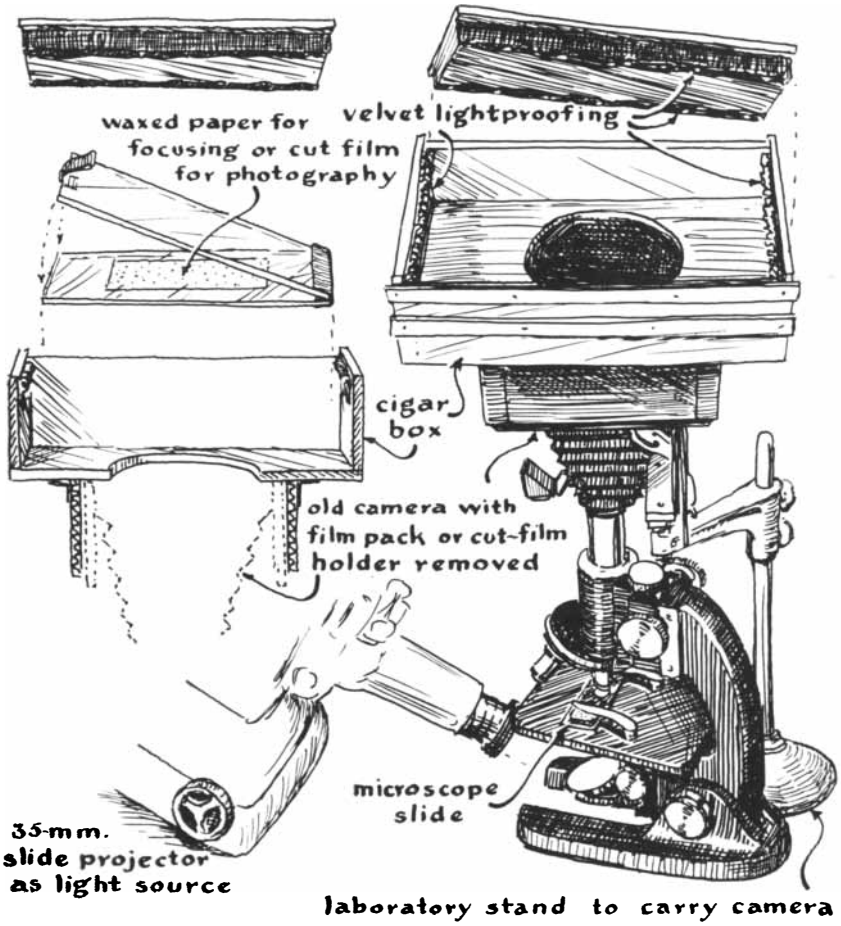
that the machining of a 45-degree bevel about ⅛ inch deep around the hole into which the tubing is soldered will ease the job of soldering the flange to the vacuum system. A second way of joining components is the use of compression fittings that are available from vacuum-equipment manufacturers. The third (but least satisfactory) way is to join the components with a short length of vacuum hose, using vacuum grease and radiator hose clamps.

"The second problem that is likely to trouble the amateur is the selection of valves. In general we try to avoid the use of valves altogether. If they are necessary, then several solutions are possible. For small applications (*e.g.*, the admission of gases) standard Hoke valves will usually do the job. Larger valves are best purchased from vacuum-equipment manufacturers; however, conversions can be made to other types. A Hills McCanna valve, for example, can be modified by first removing all paint inside, polishing the inside sealing surface with fine emery cloth and finally thoroughly cleaning all inner surfaces.

"Consideration should also be given to the system design. All vacuum lines should be kept as short and as large in diameter as possible, with a minimum of valves, obstructions and unsoldered joints. A 1-inch or 1½-inch inside-diameter tube will usually provide adequate conductances for the high-vacuum manifold, while ½-inch to ¾-inch inside-diameter tubing is usually sufficient for roughing lines. If oil or mercury systems are used, a cold trap may be desirable, and this can be obtained by refrigerating part of the high-vacuum line. Small electrical connections can be made by sawing off the bulb of an old metal radio tube and soldering this into the vacuum system. The tube connection pins can be used to make electrical connections to parts inside the vacuum.

"When the construction is completed, the parts should be thoroughly cleaned, with copper parts bright-dipped and thoroughly rinsed, then dipped in or rinsed with alcohol (or acetone) and dried. An effective dipping solution can be made by combining the following ingredients in the order listed (by volume): distilled water 13 per cent, sulfuric acid 61 per cent and nitric acid 26



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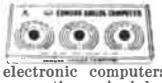

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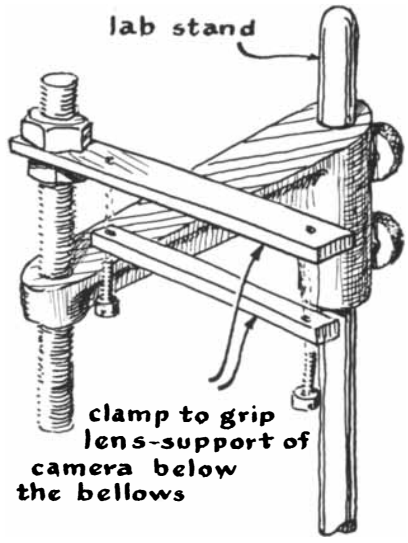
per cent. If a bright finish is desired, add 10 drops of hydrochloric acid per quart of solution.

"The parts should then be assembled and the vacuum system started. Gentle heating of the tubing with a torch or even a hair drier will help in removing water vapor and other gases from the inner surfaces of the system and thus will aid greatly in improving the vacuum that will eventually be obtained. Patience is essential. Outgassing of a new system may take a few hours or several days. Experience has shown that it does no good to rush the process. Don't panic if the vacuum is poor when the system is first started. Things will gradually improve. Such a system should easily reach a pressure of 10^{-6} millimeter of mercury. We usually design equipment (using this type of construction) for pressures of 1×10^{-7} millimeter if valves are used and 2×10^{-8} millimeter if no valves are used.

"A final word of caution concerning the selection of materials to be used in the vacuum: Glass, ceramics and metals with low vapor pressure such as copper, tungsten, tantalum, titanium, stainless steel, tin, Nichrome, gold and silver will give no trouble. High vapor-pressure metals such as zinc, mercury and brass should be avoided. Organic substances, oils and plastics generally are totally unsuitable; however, if plastics must be used, then Teflon is as good a material as any. If in doubt, consult vapor-pressure data *before* using a material. The use of some high-vapor-pressure substances may contaminate the system and necessitate its complete disassembly and cleaning."

The ordinary microscope is obviously a one-man instrument. Viewers must take turns at the eyepiece, a handicap that seriously limits the collaborative study of specimens. With the addition of a few simple accessories, however, even inexpensive instruments can be adapted for microprojection and photomicrography. Both living protozoa and permanent slides can be enlarged to the proportions of a home-movie screen. Similar adaptations enable you to make large-scale photographs of slides, either in black and white or color. Gene Udell, associate professor of education at Temple University in Philadelphia, explains how to proceed:

"Microprojection," he writes, "consists essentially in 'backfiring' light through the microscope. To be effective, the image must emerge through the eyepiece with sufficient intensity to be visible as a projected image upon a screen.



A clamp for a photomicrographic camera

"A 35-millimeter slide projector affords a good source of illumination for the experimenter. So also does an 8-mm. or 16-mm. motion picture projector. The projector is angled down to send its light beam as directly as possible onto the reflecting mirror of the microscope. A slip of ordinary writing paper is placed upon the microscope stage; the mirror, light source, diaphragm and substage condenser, if any, are adjusted until the paper over the stage aperture shows the most intense light. The paper is then replaced with a slide and the light beam proceeds through the optical system of the microscope. Careful focusing by bringing the microscope objective close to the slide and then backing it off will provide a clear image on the ceiling.

"The image can be diverted at a right angle for screen viewing by resting a 90-degree prism directly upon the microscope ocular. Alternatively a small first-surface mirror, such as the No. 40,242 that is distributed by the Edmund Scientific Company of Barrington, N.J., can be substituted for the prism. It makes a brighter image than a prism and costs about 50 cents. A bracket to support the mirror can be made of any convenient sheet metal.

"Stray light from the projection lens and the air-circulation vents of the projector can be masked from the screen by putting the complete setup in a cardboard box. A hole is made in the top of the box for the lens tube of the microscope and a door in one side provides access for changing slides and focusing. For extended projection the cardboard box can be vented and baffled to provide air circulation.

"Several refinements can be added as

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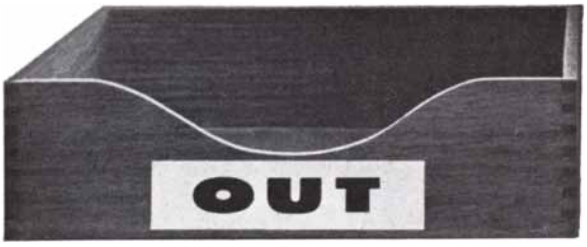

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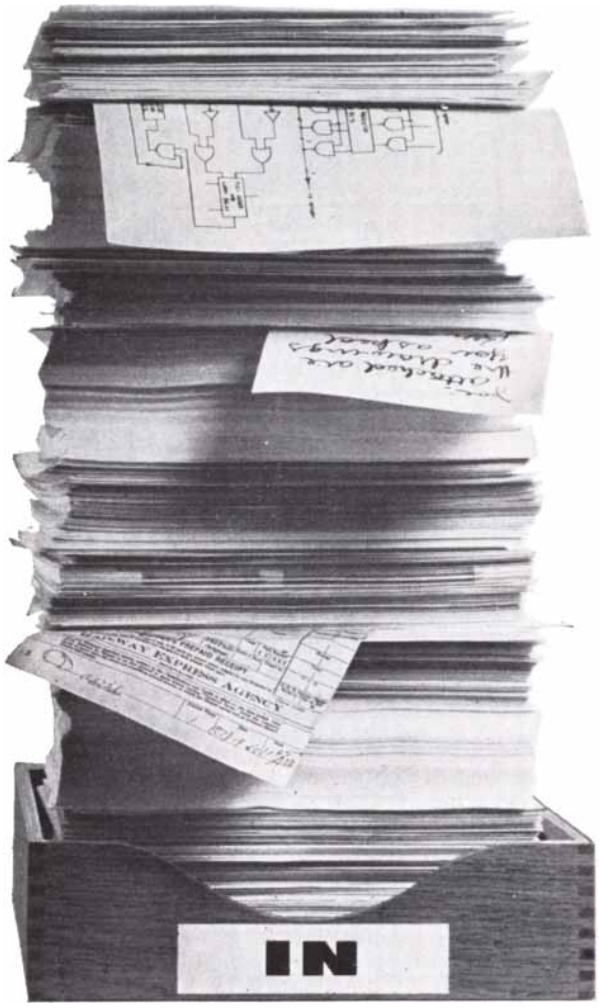

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desired. A simple condenser lens, installed between the light source and the reflecting mirror of the microscope, will direct additional light into the optical system and increase the screen illumination. A cell of copper-sulfate solution in the path of the light source will absorb much of the heat and so prolong the active period of living cultures. The copper-sulfate solution will not noticeably reduce the illumination.

"Up to this point the assumption has been that the projection will be directed onto a standard reflective screen surface. When this is the case in a room capable of being completely darkened (using a light source of 300 watts to 500 watts), a clear image at least four feet in diameter can be achieved. Should stray light be a problem, an excellent image can still be obtained by utilizing rear-screen projection. Cardboard sections cut in the form of a square-sided trumpet or megaphone, with a piece of sturdy milky plastic or plain window glass backed with waxed paper set in the large opening, will provide unusually effective viewing. Properly supported, the screen can be swung in an arc to include all viewers. This setup can also be used as a tracing surface for tracing outlines of still subjects. Tracing paper placed against the glass or plastic screen will show a clear picture of the projected slide. The light emerges from behind the pencil or pen without complicating shadows.

"Living specimens are dramatically conveyed to the screen. A hydra will seek out a water flea, grasp it with a tentacle, paralyze it and begin the ingestion process. Paramecia in a drop of rich culture will swarm over the screen. Strands of absorbent cotton will impede motion to permit examination of single specimens. Among the algae, spirogyra shows its delicate internal structure clearly. The experimenter is directed to standard texts for methods of establishing cultures of microorganisms.

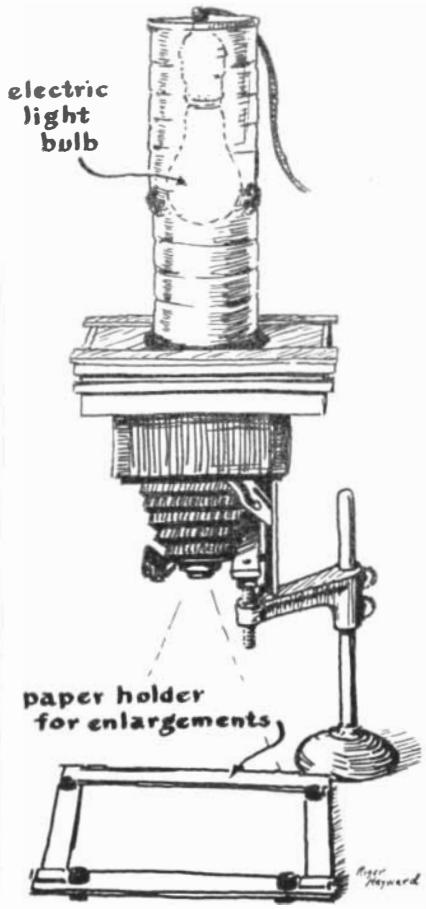
"A word should be added concerning the effects of magnification upon projection. As is evident, best projection, in terms of illumination, is obtained at low magnification. Oculars of three-diameter and five-diameter magnification are available at moderate cost should the existing ocular of the microscope provide too much magnification for successful illumination. At close range even oil-immersion magnification will be seen brightly with the arrangements described.

"Now to photomicrography. This means of recording the contents of slides on film and paper utilizes the same basic arrangement of backfired light.

"In the simplest case the projected image is cast upon a piece of photographic projection paper in a totally dark room. Since the microscope and light source are enclosed, there should be no difficulty. Limited amounts of stray light can be tolerated in the room if slow emulsions are used, such as projection paper emulsions.

"Often a paper negative will be fully as clear as a black-and-white standard print. Sometimes it is even more useful. If a positive print is desired, the paper-negative image can be placed in contact with the emulsion side of another piece of paper and exposure made through the paper negative. This yields a positive paper print. Incidentally, I cut my costs during my early experiments by buying slightly overage paper.

"To make film negatives and photographic enlargements, the light source and microscope are set up in the same way. A folding camera with lens removed and back opened is set on time exposure and placed over the microscope ocular so that the light path



A camera adapted as an enlarger

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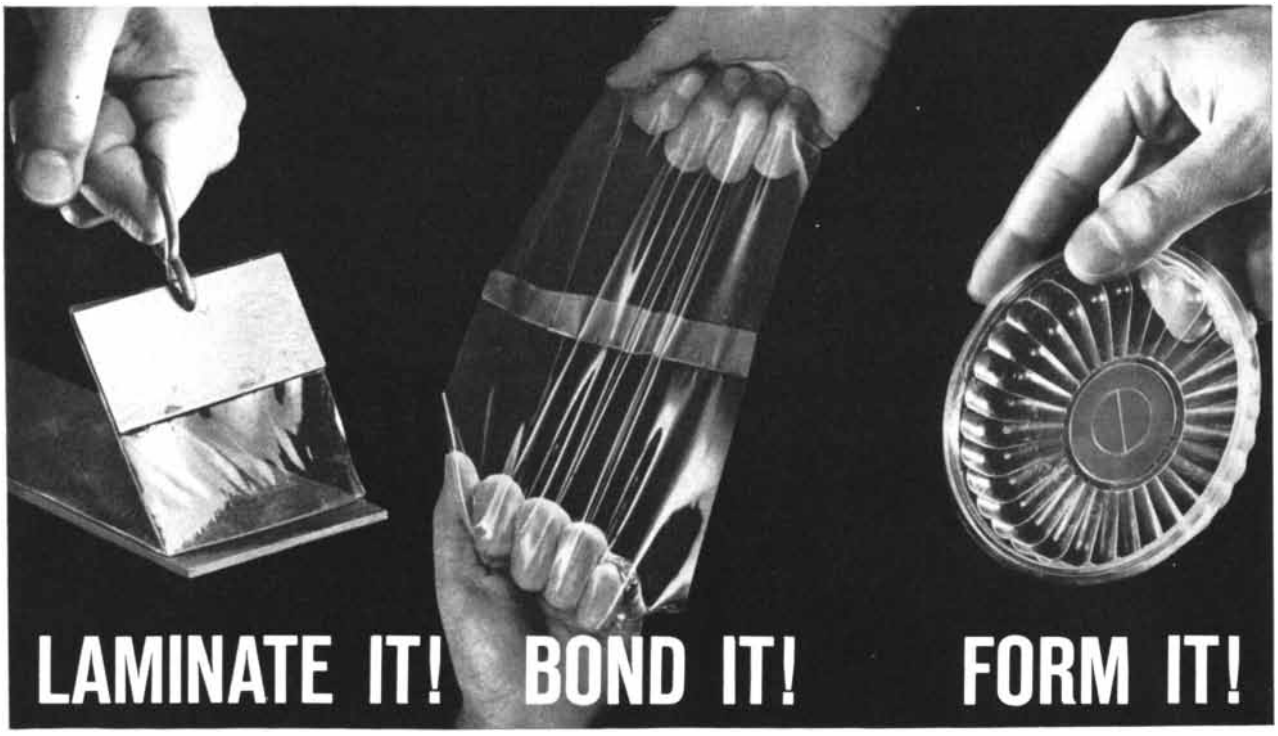

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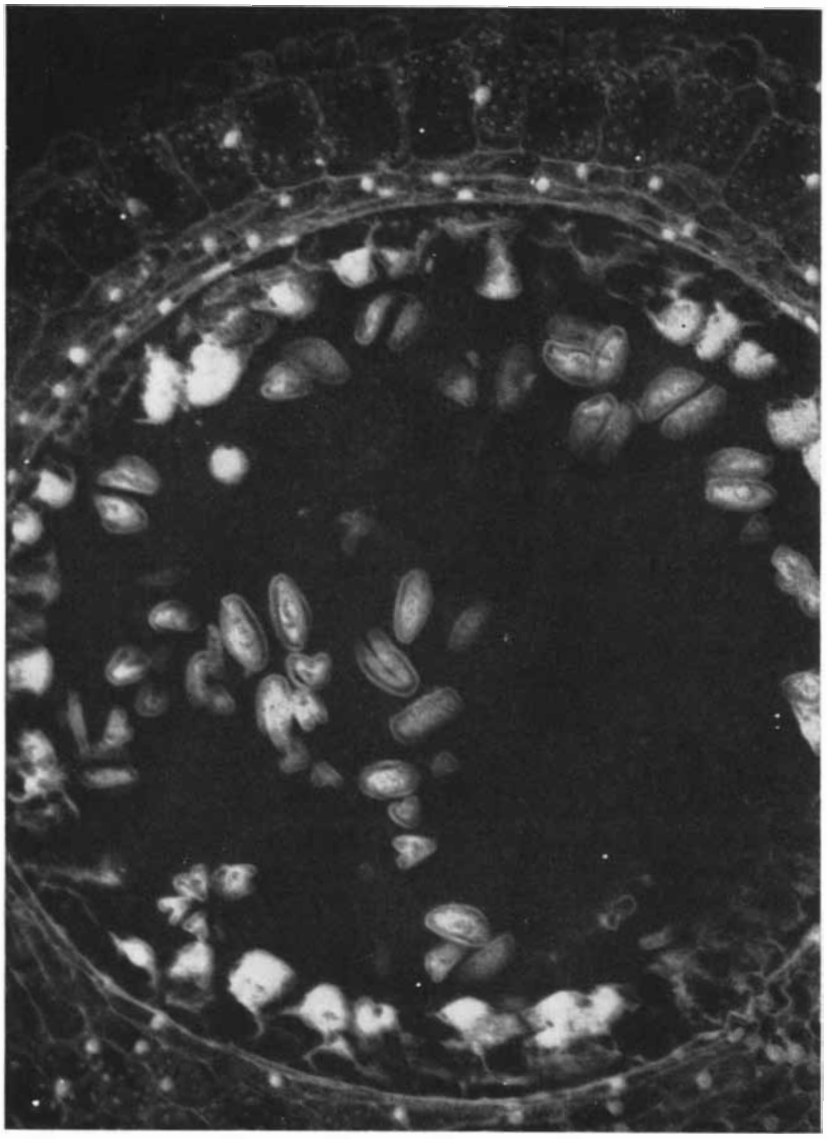
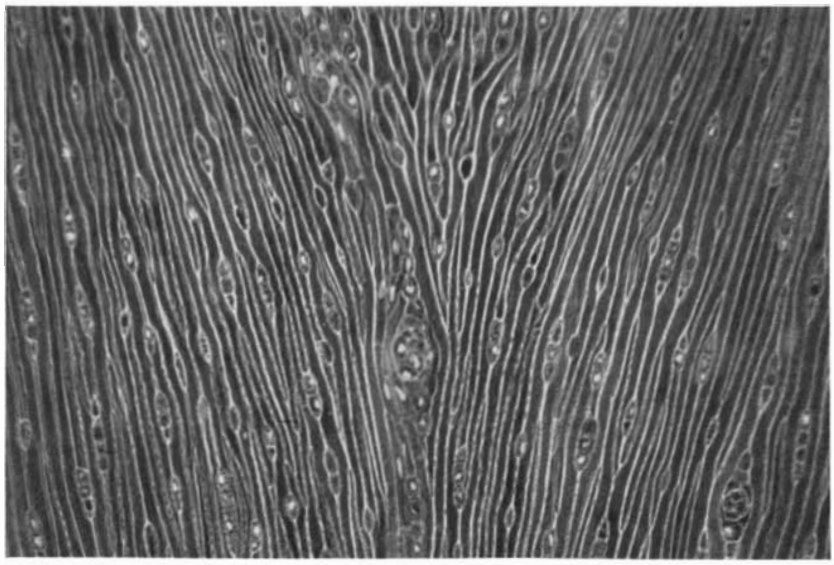


Mature pollen magnified 400 diameters



A longitudinal section of plant fibers, magnified 50 diameters

continues on through the camera as shown in the accompanying illustration [*page 164*]. Appropriate supports can be improvised for the camera. Across the open back of the camera two sheets of glass are laid, sandwiching a piece of waxed paper. The image is focused on the translucent paper. The light is then turned off, and a piece of cut film is substituted for the waxed paper. The light source is flicked on and off; the film is removed and developed. Exposure times are a matter of test, light intensity being regulated by the camera diaphragm.

"A different way to approach film exposure is by using a dummy camera. The dummy camera is a box with a piece of etched glass serving as its back. Since the eyepiece of the microscope serves as a lens, no lens is needed for either the regular camera or the dummy viewing camera. So long as both are adjusted to give a sharp image under the same conditions, focusing can be done with the dummy camera, which is then replaced by the real camera. The focusing of the latter is done by substituting waxed paper or etched glass for the film. Once the focuses of the two cameras are matched, the real camera can be loaded. This eliminates the need for a dark room.

"If the back of the real camera opens fully or can be removed, the instrument can be made to do double duty as an enlarger. Cut a hole in the bottom of a cigar box to match the open back of the camera and tack two wooden strips (shelf supports) inside the box about an inch above the bottom. Two clear glass panes, hinged with tape along one edge, rest on the supports. A circular hole is cut in the lid and is fitted with a tin can equipped with a socket and a photoflood bulb (No. 211 or No. 212). The top of the can must of course be closed to prevent stray light from shining into the room. It may be necessary to fit the lower hole with a frame (to serve as a light trap) that fits into the back of the camera. To use this arrangement as an enlarger make a vertically adjustable support for the assembly that can center the lens over a piece of white cardboard. Insert a negative between the panes of glass, turn on the light and operate the focusing adjustment of the camera so that a sharp image of the negative is projected onto the cardboard. Then turn off the light, replace the cardboard with a piece of projection paper and make an exposure. Exposure time must be determined experimentally. The accompanying photographs [*at left*] show the quality of the results that can be achieved."

Photo by Frank Cowan

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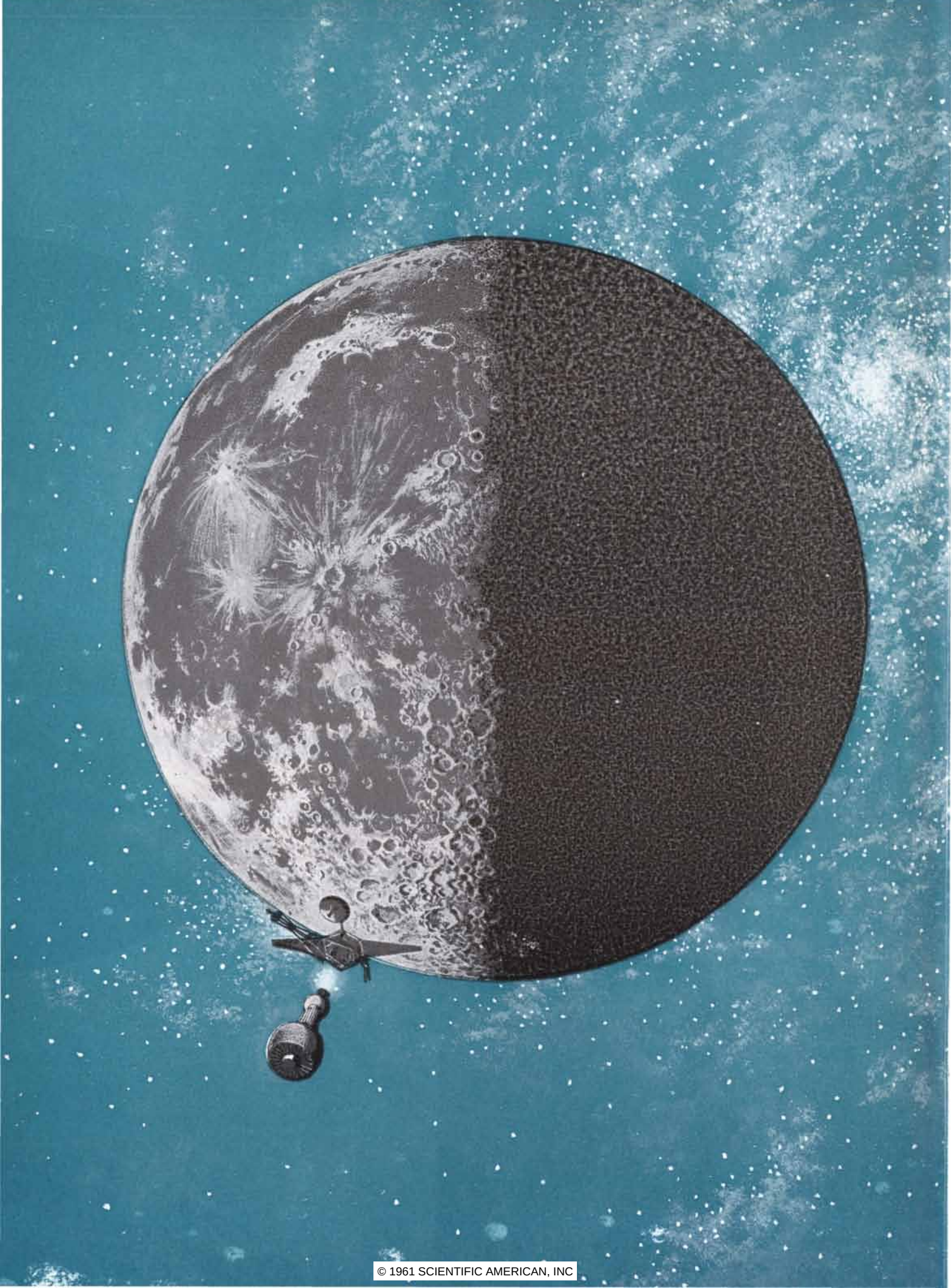

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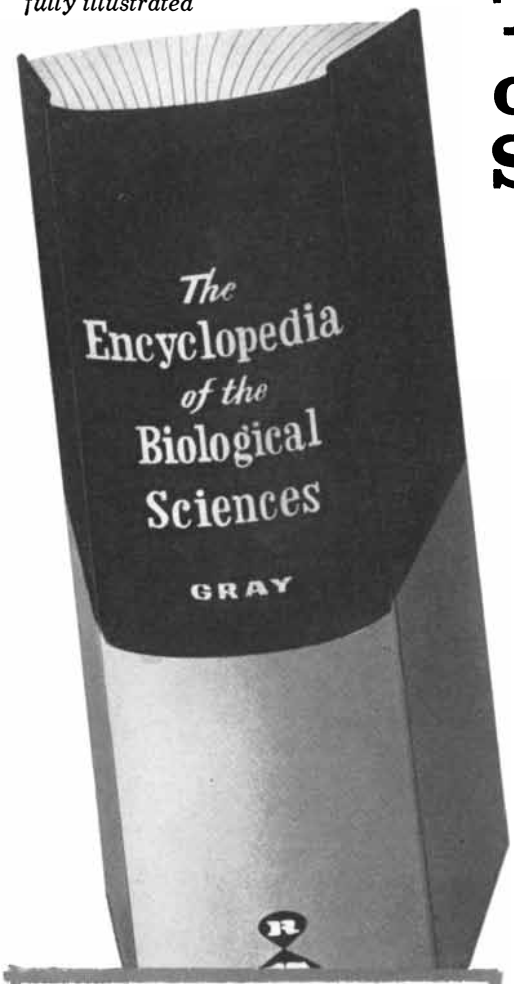

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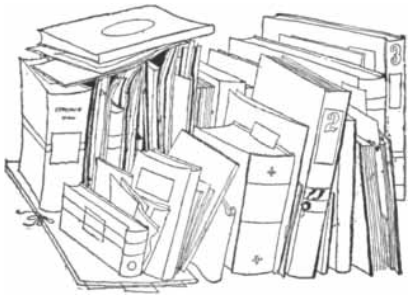

BOOKS

On problems of the idea of cause, not only in physics but also in science as a whole

by Sidney Morgenbesser

CAUSALITY: THE PLACE OF THE CAUSAL PRINCIPLE IN MODERN SCIENCE, by Mario Bunge. Harvard University Press ($7.50).

Mario Bunge has written a lively, informed book on a topical issue. Fifteen years ago the subject of causality could not have been described as topical. At that time many philosophers and scientists saw no need for a philosophical investigation of the status of causality in science. To be sure, some granted that philosophers might with profit investigate problems of causation in the realm of quantum mechanics. But it was argued that outside this realm there were no problems concerning the scientific employment of the term "cause." Today there is more interest in the scientific role of causality, and a review of some of the factors that have occasioned this shift in attitude may heighten the reader's appreciation of Bunge's work.

In support of the view that there was no cause to inquire into "cause" a number of arguments were adduced, of which we will mention three. First, it was affirmed that the term "cause" rarely, if ever, appears within the literature of the advanced sciences in general and of physics in particular. "Cause" was therefore characterized as harmless and fated for extinction when the sciences reached a higher stage of development.

Second, those who persisted in hunting down the problem of cause were advised to reread David Hume. The regularity theory developed by the great 18th-century thinker and his followers was widely considered to have exhausted the subject. According to this analysis a singular causal statement—for example, "The pulling of the trigger of this rifle caused the resulting noise"—is replaceable by a general law: "Whenever we pull the trigger of a loaded rifle in working order, there follows a loud noise," and the subsidiary statement that we pulled the trigger of this particular rifle. Since the term "cause" does not appear in the general statement, and the terms that are in it seem perfectly clear, the defenders of the Humean view concluded that there is no problem inherent in the term "cause."

Finally, it was suggested that general questions about causality are not really relevant to science. A statement such as "Every event has a cause," it was said, is not factual and therefore is not subject to empirical test. From the standpoint of the practice of science the statement is not a law but simply a maxim or a rule of procedure.

During the past 10 years or so an increasing number of philosophers have grown disturbed by the position we have reviewed here. As to the avoidance of the word "cause" by physicists, no very extensive search of the literature is required to show that it does appear, and not only, nor even primarily, in elementary textbooks. And even if the word were actually absent from physics, we might still need to use it in describing and assessing the results of physical theory.

The Humean analysis, dear to the hearts of empiricists, now seems something less than the last word on causality in science, even to its adherents. Thus physicians who specify the causes of individual deaths or economists who discuss the causes of a particular depression may be tacitly appealing to general laws. But it is doubtful whether they can put forth a set of general laws and initial conditions from which the specific events can be deduced. This is what the strict Humean position requires.

Again, to describe statements about causality as mere rules or maxims is not to bar them from investigation. Rules of procedure are subject to critical review in the light of empirical findings. If they are not themselves laws whose truth can be tested or questioned, they can still be judged by their success in leading to such laws.

So questions about causality are being reopened, and the moment and its mood are appropriate to Bunge's new book. But we do not welcome it primarily because of shift in the intellectual weather. The author's competence as physicist and philosopher (he is professor of theoretical physics and philosophy of science at Buenos Aires University) has enabled him to write a doubly enriched book. *Causality* offers not only a stimulating discussion of philosophic issues but also interesting and illuminating insights into scientific laws and principles. Moreover, Bunge has approached his subject historically. Even those who may be dubious of the success of Bunge's enterprise cannot deny that he is a well-stocked entrepreneur whose goods are worthy of detailed examination.

The author poses three main problems: to specify the nature of causality; to specify a sense for the term "cause" and its derivative, "causal sequence"; and to discover the status of the causal principle in science. Bunge's conclusions are: that causality is an ontological category (*i.e.*, "an ultimate mode of being," in the language of classical philosophy); that any satisfactory interpretation of the term "cause" must refer to the term "produce"; and that not all scientific laws are causal ones, and hence that the principle of causality has only limited applicability in the sciences.

Bunge's opposition to the Humean doctrine of causality is at once apparent. Hume and his followers were especially concerned about removing references to "production"; Bunge is most concerned to reintroduce it. His disagreement here is not a minor one, for he interweaves his dissent from Hume with a critique of empiricism in general. His own philosophy is not easy to specify, but fortunately his main conclusions, listed above, are independent of his general philosophical orientation. In addition to these conclusions he enunciates four principles about the nature of science, which also stand on their own feet: (1) that science is to be identified with the attempt to discover laws; (2) that the terms in these laws

must apply to, or name, natural entities or processes; (3) that nothing can arise out of nothing (the "genetic principle"); (4) that a still-unborn future cannot act upon the present. These principles would in fact be accepted by many, if not all, the contemporary empiricists Bunge criticizes.

Turning now to his analysis of cause, we seem to find more than one point of view. At one point he argues: "Countless hypotheses concerning causal connections have been empirically verified to within experimental error, millions and millions of times." Yet later he concludes that "strict and pure causation works nowhere and never." This is not necessarily a contradiction; Bunge may be distinguishing between causal hypotheses in general and those dealing with "strict and pure" causation. Nevertheless, these and other passages suggest either a variety of views about "cause" or a view that is qualified differently in divergent contexts. Perhaps arbitrarily, I shall distinguish between two extreme views.

Early in the book the author offers the following analysis: "Causation, far from being a relation, is a category of genetic connection, hence of change; that is, a way of producing things." He adds that this dynamic character is expressed in the following proposition: If C happens, then and only then E is always produced by it. This I shall call the constant-productivity view. The other may be termed the agent-patient view. According to it a process is considered causal if: (I) The process consists in the change of an entity, the patient P, from state L_1 to state L_2, a change that results when agent A acts upon P. A pushing P, P falling would be an obvious illustration. (II) The change in P from L_1 to L_2 is accounted for solely by reference to A; nothing else in the world is relevant but the action of A. To illustrate the force of this restriction Bunge points out that the expansion of a rod on being heated is not a causal process. For to specify the exact amount of expansion we must refer not merely to the rise in temperature but also to the thermal coefficient of expansion of the material. (III) The change in P from L_1 to L_2 at time t did not produce any change in A at t; at t, P did not act upon A. As a result of this condition "the connection between two gravitating masses is typically noncausal, for it consists in an interaction, not in a one-sided action." (IV) If A had acted slightly differently on P than it had, then P would have changed not from L_1 to L_2 but from L_1 to L_3, where L_2 and L_3 differ slightly. This is, I think, the intent of Bunge's observation that a process is a causal one if a small change in the cause introduces a small change in the effect.

With due modification these two definitions of the term "cause" can be shown to conform with each other, especially if we put enough restrictions upon what can be substituted for C and E in the formula expressing the constant-productivity view. In this discussion, however, I shall consider them as distinct. Bunge would most likely demur and insist that "cause" has only one meaning, which is most clearly revealed by examination of cases where we specify the causes between specific events. But I think it important to note that he does not, for the most part, vindicate his definition by referring to ordinary or scientific use of the term "cause." Rather he appeals to a theory of efficient causation (*i.e.*, a theory emphasizing the immediate agent that produces an effect) and tries to deduce what the term "cause" must mean if that theory is right. Bunge has proved that there are few or, strictly speaking, no causal sequences if we appeal to the theory of efficient causation to define "cause." But why we should use that theory as the starting point for discussion is never made explicit.

Whatever its genesis and a priori plausibility, let us now ask how the author's doctrine of causality compares with others as a tool for understanding scientific discourse and scientific problems. One of the difficulties with the Humean doctrine has already been noted. It requires the replacement of every singular statement about cause by a general statement of the following form: Whenever A obtains, B follows. The constant-productivity view involves an even more stringent demand; it requires a statement both of necessary and sufficient conditions: If C, then *and only then* E is produced. To be sure, Bunge admits that the statement can be modified to: If C, then E is produced. Now the requirement is merely for sufficient conditions, but this does not leave us any better off than under the Humean analysis.

Here Bunge might refer us to the agent-patient view. If so, I think his difficulties become even more direct. For example, I doubt that most of his conditions are met when we assert that a man fell because he slipped on a banana peel. We cannot clearly specify one agent that alone affects the patient. We can say that the slip caused the fall and that the fall did not cause the slip, but what would we answer if asked whether the man was acting on the peel or vice versa?

A closer inspection of Bunge's exposition of the agent-patient interpretation discloses some further ambiguities. At the end of his book there is an interesting discussion of the behavior of the elementary physical system comprising an electrical conductor fed by a direct-current source, such as a battery. The author analyzes the behavior of the current into three stages, only the middle one of which is a causal sequence and is described by Ohm's law. (This law states that the current flowing through a conductor is proportional directly to the voltage across it and inversely to its resistance.) Now first of all it appears that whether we can consider a process causal or not depends on how we look at it. In the example the process or sequence as a whole is not causal, whereas the middle section of it is. But it is we who decide to consider it as one long noncausal process or two noncausal and one causal. The process itself does not announce its nature.

Secondly, in order to prove that the second stage of the process is a causal one, Bunge appeals to Ohm's law. This, however, violates condition II, which requires a single agent. Current depends both on voltage and resistance. Still more significant is the fact that Ohm's law does not speak about causes and effects but about the interdependence between magnitudes. To know, therefore, that a given sequence is causal we must appeal to the truth of a statement that, by Bunge's standards, is not causal.

This dialectic could go on, for nothing I have said proves that the behavior of the current is not a causal sequence. But I hope I have shown that the classification may well be considered artificial and that, in any case, to explain it we must refer to general laws. Hence we must turn to Bunge's treatment of such laws and inquire whether his approach offers any major advantages over others that are current.

On the Humean analysis a statement such as "B is caused by A" is replaced by a certain type of general statement. We can invert the procedure and suggest that any general law of the form "If A at time t, then B at t or t', where t' is later than t" is a causal law. In adopting this view of causal law we will agree with Bunge that "cause" is connected with change. Moreover, we are able to derive most of his important conclusions. In particular we find that not all laws of science are causal, and

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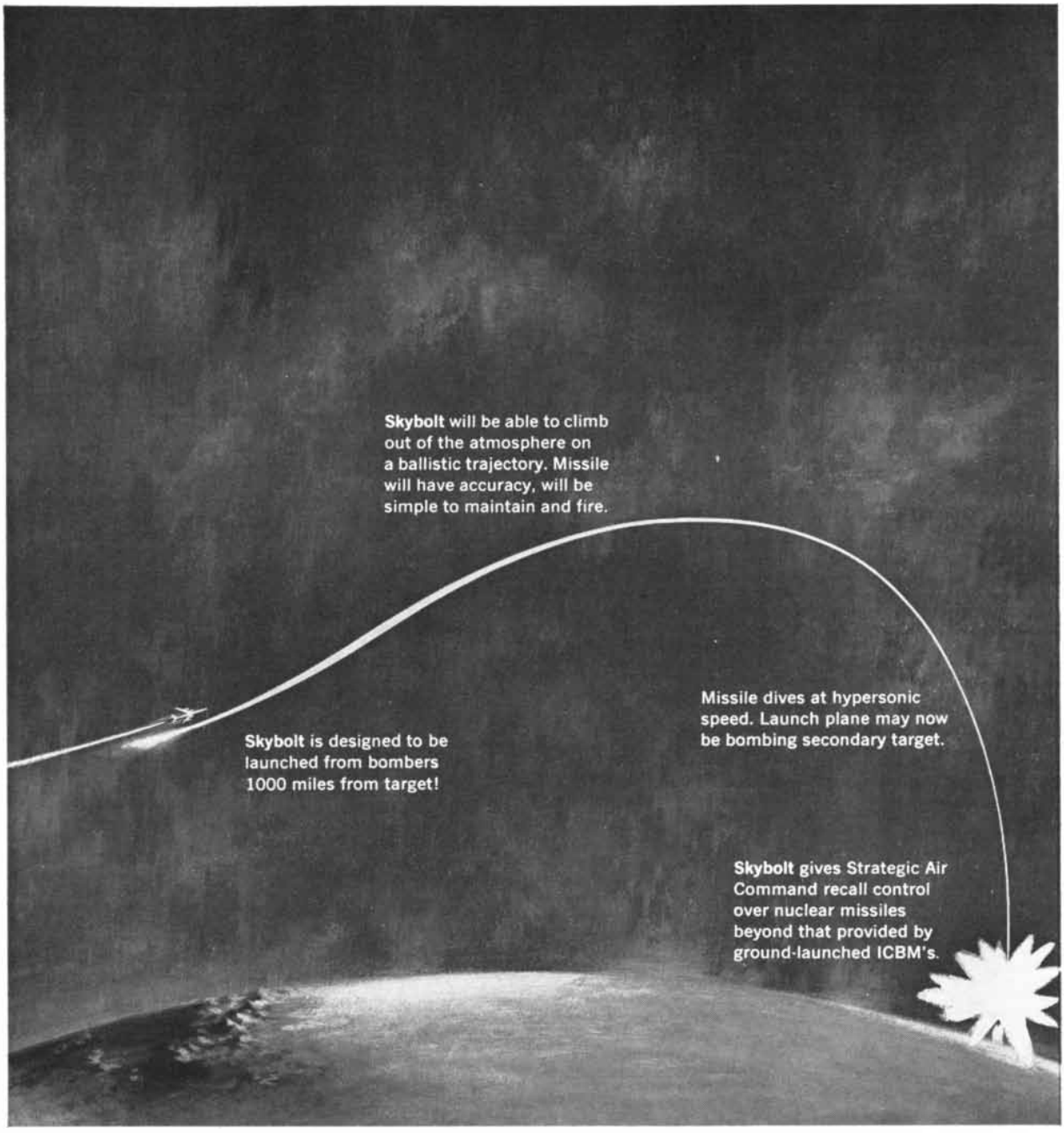

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hence that the causal principle has limited applicability in science.

Bunge objects to this approach on two grounds: it does not refer to the notion of production and it violates some ordinarily accepted assumptions about causality. Of the two the first is more significant, since the acceptability of his own theory turns on it. We expect the author to give us a long, patient analysis of the term "produce," but he fails to do so and mysteriously assumes that it is clearer than the term "cause."

It is not only the Humean, or constant-succession, analysis of cause and causal law that Bunge is rejecting. He is also opposed to the other popular view that defines causal law as a deterministic law. By the latter is meant a law that says that the rates of change of certain state quantities with respect to time are functions of the quantities themselves, and perhaps their spatial derivatives, but not of time itself. (Time is excluded out of deference to a common version of the law of causality that has long been a maxim in physical science. As James Clerk Maxwell put it: "The difference between one event and another does not depend on the mere difference of the times at which they occur.") It is easy to see why both the deterministic type and the constant-succession type of law have been called causal. Both refer to and can be used to describe changes over time. On the other hand, deterministic laws, unlike the constant-succession type, require measurable properties or magnitudes, and in most of them the temporal sequence is reversible.

The deterministic definition is the one that arises in what has become the most familiar argument about causality in science—the one concerning the causal nature of quantum mechanics. Most often this controversy has revolved around the question of whether Erwin Schrödinger's celebrated wave equation is deterministic. The vitality of the discussion might indicate that something essential is at stake, but Bunge is not overly concerned with it. As we have already indicated, Bunge does not identify the limitations on causality in science with a decline of determinism. In his analysis many of the scientific laws formulated before the 20th century were noncausal. Ohm's law has been mentioned. In Bunge's sense of the term we can add Newton's laws of motion.

Although not primarily concerned with the deterministic view of causal law, the author does direct some of his argument specifically against it. In adopting it, he claims, we are required to say that one state of a system caused the next one. In Bunge's analysis this is equivalent to saying that one state produced the next. Insisting that it is against intuition to speak of states producing others, he concludes that the deterministic approach to causal laws is irrelevant. The discussion is not completely persuasive. We need not refer to one state as causing another, even if we adopt the deterministic view of causal law. But if we agree that this is necessary, nothing (except prior acceptance of Bunge's thesis) demands that we talk of states of the system producing others. The argument, therefore, rests ultimately on the ostensible violence to language of referring to one state of a system as causing another. However, since a state is an event, and we ordinarily talk of one event causing another, nothing barbaric has been introduced.

Nevertheless, Bunge is still armed with the objection that deterministic laws do not meet his requirement of externality. He insists, it will be recalled, that we can refer to A as causing a change in P only if A and P are different entities. Since deterministic laws can be applied to a system as a whole, the requirement of externality is not always satisfied. Here Bunge is not alone. Others agree that a law is causal only if it explains changes in the behavior of members of a class, A, by reference to changes in the behavior of members of a different class, P.

The fact that other analyses of the causal status of physical laws involve difficulties does not mean that Bunge's approach is free of them. To mention just one instance, he does not consider it necessary that causes and effects be spatially contiguous. Yet many scientists have insisted that laws that postulate action at a distance violate the notion of causality.

And so we might go on, using one theory to knock down another, and vice versa. But the time has come to look more closely into this possibility of perpetual disagreement.

So-called laws of causality are not truths reached by induction but rather are rules in accordance with which we interpret the world. About the origin of these rules or habits we know very little. They may have come from primitive, unlearned reactions to the world that even animals exhibit. These unlearned reactions are soon changed and modified as we acquire general beliefs about the nature of the world by cultural transmission. Some of these beliefs come packaged together as theories of causation, which are ultimately theories about the world and which may conflict with physical theories. Given this conflict we can either redefine "cause" and "causal" so that they apply to some physical theories and to the regularities they describe, or insist that physical theories are not causal.

If I understand Bunge correctly, he has accepted one theory: the theory of efficient cause. By applying it he has classified many physical laws as noncausal. He is not satisfied with drawing negative conclusions, however, but seeks to replace laws of causality with the four principles to which we have referred.

While his discussion of these principles is frequently illuminating, their status and even their meaning is not always apparent. Some scientists are inclined to admit solutions to their equations that imply an influence of the future upon the present. Again, those who espouse a cosmology that involves the continuous creation of matter deny the genetic principle that nothing can come from nothing. As to the remaining pair of principles, we might reasonably ask that they be clarified. The meanings of "natural" and "law" are not much more obvious than the meaning of "cause."

Short Reviews

THE CORRESPONDENCE OF ISAAC NEWTON: VOLUME II, 1676–1687, edited by H. W. Turnbull. Cambridge University Press ($25). The second volume of this splendid edition of Newton's correspondence contains some 160 documents—letters, memoranda and manuscripts—covering the years 1676–1687. During this period Newton was in residence at Trinity College, Cambridge. He was in the fullness of his powers and already at the height of his fame, though his crowning achievement, the *Principia*, was not published until 1687. Through the letters, which every student of the history of science will treasure, we are able to follow the main lines of his mathematical thinking, his wide interest in astronomy, optics and other branches of natural philosophy, the beginnings of his controversies with Leibniz and Hooke, and the preparations for the *Principia*. The great letters are here and the trivia as well; every item sheds light on the man. To the major category belongs the famous *Epistola Prior*, the letter written in 1676 to Leibniz via Henry Oldenburg, the secretary of the Royal Society, which answers certain of Leibniz' inquiries as to infinite series, describes Newton's work on the binomial

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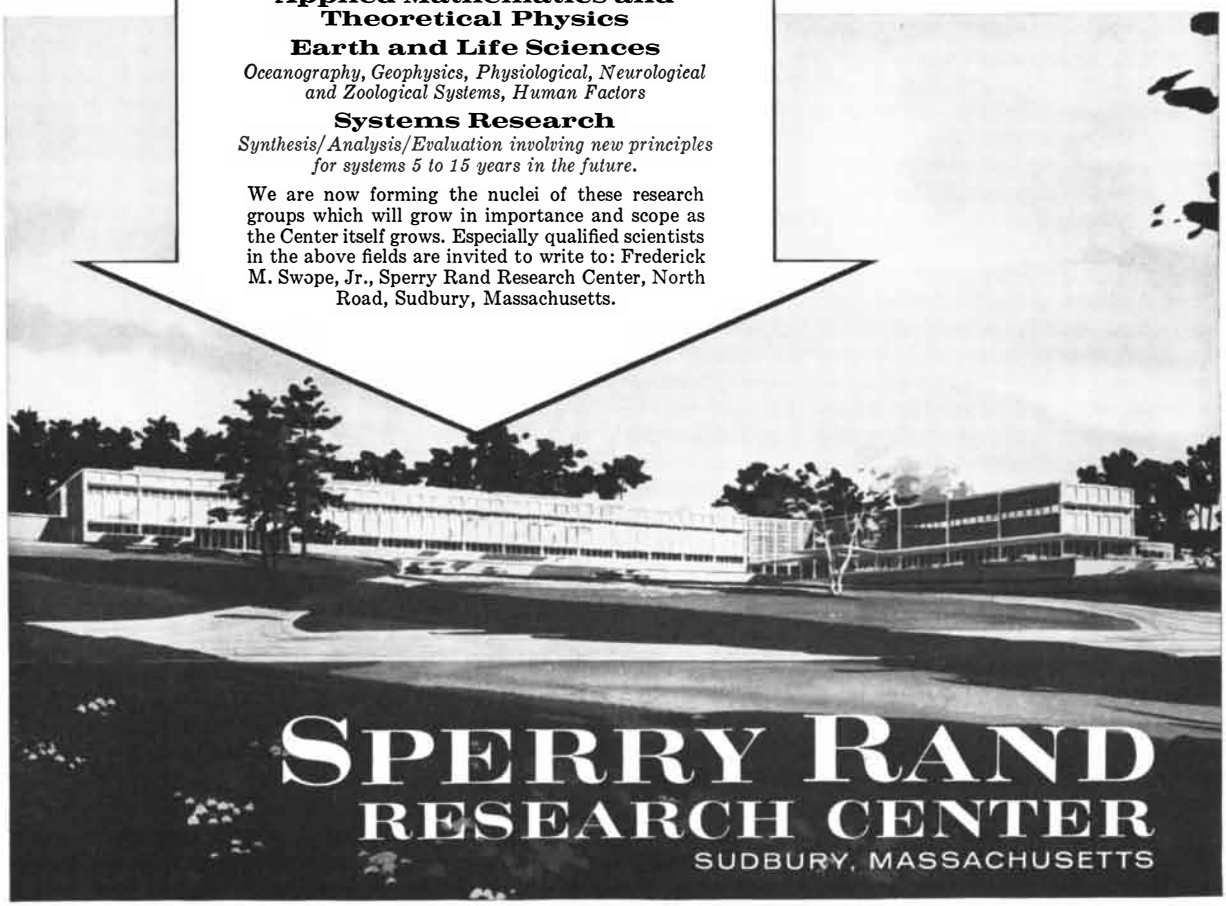


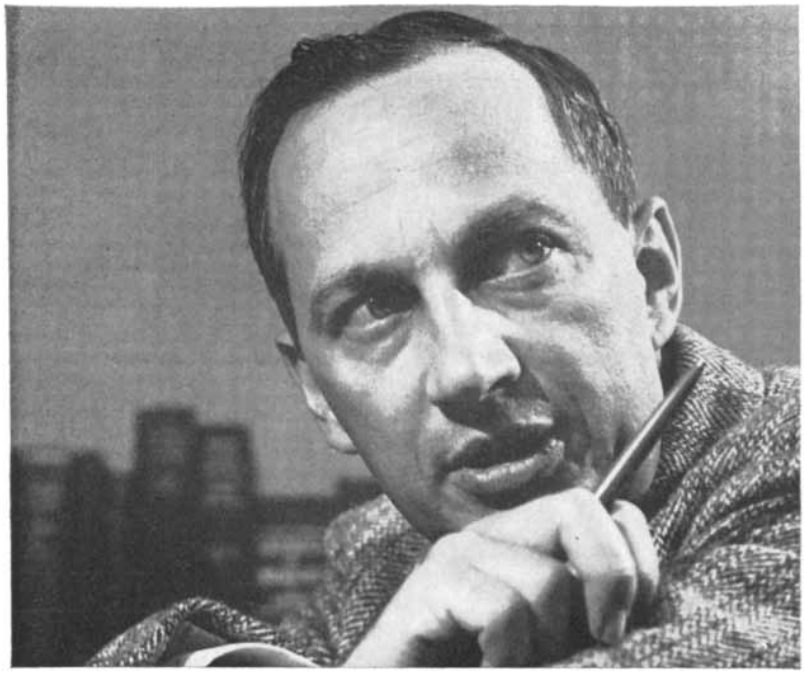
theorem (which he had discovered in 1664 or early 1665) and refers with apparently deliberate vagueness to his studies in the calculus. Leibniz in his reply (reprinted in this volume) asked for further details on the binomial theorem and on Newton's method of fluxions; this letter in turn evoked the equally celebrated *Epistola Posterior* ("as mighty in argument as it is copious in expression"), which gave all the information requested, *except* as to the method of fluxions. "The foundations of these operations," wrote Newton, "is evident enough, in fact; but because I cannot proceed with the explanation of it now, I have preferred to conceal it thus: *6accdæ13eff7i3l9n4o4qrr4s8t12vx.*" This was a combined Latin anagram and cipher, which decoded and translated reads: "Given an equation involving any number of fluent quantities to find the fluxions, and conversely." The concealment and secrecy were to lead later to the bitter and essentially absurd dispute as to which of the two men invented the calculus. There is another interesting point about the Leibniz correspondence. At the beginning of his letter Leibniz apologized for the delay in replying, explaining that this was due to the fact that he received Newton's letter of June 13 only on August 26, when he chanced to pass the shop of a German chemist who said that Leibniz' house had been looked for in vain. But in forwarding a copy of Leibniz' letter to Newton, someone—perhaps the copyist—omitted the first sentence, which contained the apology and explanation. Always touchy and inclined to be suspicious, Newton may well have been put out by the delay in Leibniz' reply.

The exchanges with Hooke, which began sweetly enough, soon foreshadowed friction between the two men. Hooke, who was Oldenburg's successor at the Royal Society, pressed Newton on certain problems concerning the earth's diurnal motion. The questions prompted Newton to pursue his researches on central orbits. Stimulated by the appearance of the great comet of 1680, Newton initiated an extensive correspondence with the astronomer John Flamsteed, the results of which helped Newton arrive at his views on trajectory. Later came Halley's famous visit, during which Halley learned that Newton had proved relationship between an elliptical path and the inverse-square law. This is the heart of the law of universal gravitation. Soon thereafter Halley persuaded Newton to write out his theories, a labor that took shape in less than two years as the *Principia*. No sooner was the manuscript in the hands of the Royal Society than Hooke asserted that it was he who had suggested the inverse-square law to Newton.

Other letters include Newton to Oldenburg ("at his house about the middle of ye old Pal-Maill in Westminster London") on the subject of stocking up with trees from whose fruit "cyder" that is not "harsh and churlish" can be had; Horne, a "pupill" of Newton's, asking help on the solution of certain equations with which he has difficulties—partly because of the novelty of setting an equation to zero, though the Nürnberg mathematician Michael Stifel first used the device as early as 1544 ("I know," writes Horne, "you are to[o] good and wise to deride me"); Newton to John North on the transmission of sound; Newton to Robert Boyle on the nature of the ether; Newton, at great length, repeatedly and very patiently, to a chuff-headed Jesuit theologian who insists that his experiments on light disprove Newton's theories of refraction; Newton to Hooke, telling him "I have long grutched the time spent in yt study [philosophy] unless it be perhaps at idle hours sometimes for a diversion"; and Newton to Halley, after Hooke's charges, proposing to suppress the third part of the *Principia*, relating to celestial motions, and justifying his impulse with the often quoted sentence: "Philosophy is such an impertinently litigious Lady that a man had as good be engaged in Law suits as to have to do with her." The only criticism of this volume is that it lacks a general introduction to guide the reader to the most important letters. But the editing is impeccable. The volume is a rich source of information for specialist and general reader alike, and the book itself is a noble production, a proper tribute by the Royal Society to the incomparable Newton.

McGRAW-HILL ENCYCLOPEDIA OF SCIENCE AND TECHNOLOGY, edited by William H. Crouse and others. McGraw-Hill Book Co., Inc. ($175). The vital statistics are: 15 stoutly made, clearly printed volumes; 9,712 pages bearing six million words; 7,283 articles on topics in all the physical and biological sciences, mathematics, diverse branches of engineering, communications, conservation, forestry, graphic arts, naval architecture; 2,000 contributors; maps, charts, diagrams, drawings, photographs; a comprehensive 548-page index. Within the limits the editors and publishers have set, this is a first-class tool without substitute. The limits are: no biographical or historical material, no philosophical assay of concepts, no consideration of the growth of scientific ideas or the web of scientific thought, no coverage of social studies or medicine or related disciplines (with the exception of physiological and experimental psychology). An admirable effort has been made to give a succinct account of every topic from astigmatism, ablastin, abnormal behavior, abrasive and absolute zero to West Indies, xenon, the Wurtz-Fittig reaction, Yagi antenna, yaws, zipper and that important family of fungi of the order Sphaeropsidales, the Zythiaceae. The introductory parts of the great majority of articles are simple, interesting and often deceptively inviting; thereafter the discourse gets much more detailed and addresses itself to the technically trained reader. The encyclopedia offers something to the person of general education, the college undergraduate, even the high school student. But it is not their book and it was not meant for them. It is the book for the specialist looking for information outside his specialty. To use this encyclopedia is a pleasure, a source of intellectual satisfaction; to use it is to learn to respect it and depend upon it. That it has its shortcomings and its errors is both true and a reviewer's cliché, but this reviewer has found so little that is faulty and so much that is good that he can recommend the work without qualification to all who have need of a truly professional encyclopedia of science.

THE INTELLIGENT MAN'S GUIDE TO SCIENCE by Isaac Asimov. Basic Books, Inc. ($15). Asimov is a prolific popularizer of science whose work sometimes appears to suffer from haste. Thus the appearance of another of his surveys in the form of an expensive two-volume boxed set could not have been expected to make a reviewer overflow with joyous anticipation. The agreeable surprise is that this is an enjoyable and competent guide, the best thing the author has yet done and one of the best available overall reports for the layman of the growth and state of scientific knowledge. The book deals with both the physical and the biological sciences, sketching the history of important concepts and describing the place each holds in the structure of contemporary scientific thought. There is a section on the size and birth of the universe, the old and new theories of cosmology, the methods and instruments that man uses to bring the remotest stars and galaxies within the reach of his senses; on the birth of the solar system, the nature of the planets,



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LIQUID PROPELLANT ROCKETS, by David Altman, James M. Carter, S. S. Penner and Martin Summerfield ($2.95); SOLID PROPELLANT ROCKETS, by Clayton Huggett, C. E. Bartley and Mark M. Mills ($2.45); GASDYNAMIC DISCONTINUITIES, by Wallace D. Hayes ($1.45); SMALL PERTURBATION THEORY, by W. R. Sears ($1.45); HIGHER APPROXIMATIONS IN AERODYNAMIC THEORY, by M. J. Lighthill ($1.95); HIGH SPEED WING THEORY, by Robert T. Jones and Doris Cohen ($2.95). Princeton University Press. These six volumes initiate a new series, Princeton Aeronautical Paperbacks, each consisting of a contribution already included in the larger volumes of the Princeton Series on High Speed Aerodynamics and Jet Propulsion. Papers have been selected which form a more or less complete entity within themselves; thus students will be able to purchase useful monographs at moderate prices and not be forced to acquire the large, expensive books in which the monographs first appeared.

COSMIC RADIO WAVES, by I. S. Shklovsky. Harvard University Press ($12.50). A translation by Richard B. Rodman and Carlos M. Varsavsky of an up-to-date Russian monograph on radio emission from objects located far beyond the solar system. Shklovsky, a distinguished Soviet radio astronomer, insists on the intimate connection between sources of cosmic radio waves and the origin of cosmic rays, with "the supernovae playing a major role in producing the needed plasma clouds with associated interstellar magnetic fields." An important scientific work.

STRUCTURE AND FUNCTION OF MUSCLE: VOL. I, STRUCTURE, edited by G. H. Bourne. Academic Press, Inc. ($14). The first volume of a co-operative treatise dealing with all aspects of current knowledge of muscle tissue. Included are articles on the anatomy and microanatomy of muscle, development of striated muscle, histochemistry of developing skeletal and cardiac muscle, skeletal muscle tissue in culture, structure of striated muscle as seen by the electron microscope, the molecular basis of contraction in cross-striated muscle, molecular structure and function of smooth muscle, muscle spindles and other muscle receptors. Two further volumes are promised.

TRENDS IN ATOMIC PHYSICS, edited by O. R. Frisch, F. A. Paneth, F. Laves and P. Rosbaud. Interscience Publishers, Inc. ($7.50). A collection of essays by various physicists and dedicated to Lise Meitner, Otto Hahn and Max von Laue on the occasion of their 80th birthdays. The volume consists of personal reminiscences and historical reviews of physical researches to which the principals made contributions, including gamma rays (W. Heitler), beta decay (C. S. Wu), crystallography (N. Riehl), radiochemistry of plutonium (Glenn Seaborg), scintillation spectroscopy (B. Karlik), X-ray diffraction (W. L. Bragg), nuclear structure (R. Hosemann), magnetic spectra of alpha particles (S. Rosenblum), vibrating atoms in crystals (Kathleen Lonsdale). A much better than average *Festschrift*.

PROBLÈMES PLAISANTS ET DÉLECTABLES: QUI SE FONT PAR LES NOMBRES, by Claude-Gaspar Bachet, Sieur de Meziriac (nine francs); RÉCRÉATIONS

MATHÉMATIQUES, by Édouard Lucas. (16 francs) Albert Blanchard. Reissues of two French classics of mathematics in the field of number theory, puzzles and recreations. Bachet's famous book on number problems, first published in 1612 in Lyons, presented the first solution of the first-degree equation of two unknowns in integers. The work was reprinted many times, gained high praise from Lagrange and now appears with a foreword by J. Itard. Lucas's collection covers a variety of games—including dominoes, parquet, Hamilton's icosahedron game, chess problems, solitaire, the "15" puzzle. A desirable brace of reprints.

DISEASE AND THE ADVANCEMENT OF BASIC SCIENCE, edited by Henry K. Beecher. Harvard University Press ($12.50). The Lowell Lectures of 1958, here rather opulently recorded, seek to substantiate the not very startling thesis that certain advances in scientific knowledge arise out of the study of disease. In other words, the abnormalities of structure and function that come under the eyes of the physician and surgeon have sometimes provided clues for research in physiology, biochemistry, biology, microbiology, psychology and other sciences. A few of the individual papers are of considerable interest; for example, Linus Pauling's discussion of researches in molecular structure suggested by the peculiar shape of the red blood corpuscles found in patients suffering from sickle-cell anemia; Paul Weiss's lecture on deformities as clues to understanding development of form; Carl F. Cori's paper on progress in knowledge of carbohydrate metabolism; Hallowell Davis' examination of what the study of deafness has added to neurophysiology and psychology. Other lectures, however, are less to the point and often consist of nothing more than rather meandering discourses on sequences in the history of medicine. A mixed and pretty high-priced bag.

A HISTORY OF POLAR EXPLORATION, by L. P. Kirwan. W. W. Norton & Company, Inc. ($5.95). By far the best history of its kind, this book by the director of the Royal Geographic Society presents a complete account of polar exploration, arctic and antarctic, from the first ventures of Greeks and Norsemen to the highly mechanized, almost too efficient and methodical expeditions of our own time. Kirwan writes with admirable clarity, ease and economy, so that he succeeds in compressing into a relatively brief compass, without losing any of

its color and excitement, a most remarkable story of courage and endurance, of careful planning and recklessness, of personal ambition and national pride, of suffering, tragedy and brilliant success. Scholarly and enthralling.

THE EDDYSTONE LIGHT, by Fred Majdalany. Houghton Mifflin Company ($4). A little to the southwest of Plymouth, in the "fairway" of the English Channel, is a jagged triple reef of rust-red rocks called Eddystone. Westerly winds, the currents of the Atlantic, the local tides combine to churn the waters around this wall of rocks into "a permanent chaos" of huge, plunging waves, immense curtains of spray, powerful currents and eddies. Even when the sea is calm the waters swirl violently around the reef, thus it got its name; and from the earliest times "a legend of dread" grew up around the Eddystone. As Plymouth grew in importance as a port, the legend grew. There was reason for it: every year more and more ships were wrecked on the reef. In the late 17th century the first lighthouse was set upon the rocks by Henry Winstanley in a heroic four-year labor. Four years later, while he was visiting the light, the greatest recorded storm in the history of the eastern Atlantic swept away the builder and his work. A few years after that a wooden tower took its place; this lasted for 47 years, to be destroyed by fire. In 1759 a massive, wonderfully designed stone structure was put up by John Smeaton; this outlasted its own foundation as the sea gnawed away at the rock. In 1882 the tower was replaced by the one still in use. The builders, the keepers, the engineering feats, the towers all are the subjects of this fascinating book by Fred Majdalany. It is a story of heroism, perseverance and ingenuity—a completely engrossing tale.

DYNAMICS IN PSYCHOLOGY, by Wolfgang Köhler. Grove Press ($1.75). Paperback reissue of lectures on psychological theory and its function in psychological work by a pioneer of Gestalt psychology. Köhler's aim in these Page-Barbour Lectures (University of Virginia, 1938) is to show by experimental evidence and theoretical inference that the laws governing psychological processes are the same as the basic laws of physics.

KINO, A HISTORY OF THE RUSSIAN AND SOVIET FILM, by Jay Leyda. The Macmillan Co. ($9.50). Beginning with the filming of the last Csar's coronation in 1896, this is a well-written, fully documented history of the Russian film industry, describing its products, its leading studios, directors and actors, the transformations both in the industry and the pictures brought about by the 1917 revolution, and the development of the present Soviet film. Apart from the uncommon interest of the story itself, Leyda's book presents a remarkable record of how an artistic activity reflects changes in social and political thought and circumstances. Excellent illustrations.

THE SPACE ENCYCLOPAEDIA, edited by M. T. Bizony. E. P. Dutton & Co., Inc. ($8.95). New, revised edition of a sound, plainly written reference book for the general reader, covering satellites, missiles, upper-atmosphere research and many topics of general astronomy. The contributors are Sir Harold Spencer Jones, A. C. B. Lovell, Hubertus Strughold, J. G. Porter, Homer E. Newell, Jr., R. H. Garstang, Patrick Moore, Eric Burgess. Good illustrations.

AN INTRODUCTION TO THE PHYSICS OF MASS, LENGTH AND TIME, by Norman Feather. Quadrangle Books, Inc. ($5). This text, the first in a series of Edinburgh University Publications, is an introduction to the bases of measurement of the fundamental physical quantities: mass, length and time. This leads to considerations of the mechanical properties of matter in bulk, of motion, force, gravitation, energy, heat, kinetic theory, elasticity, surface tension. One of the novel features is that the exposition covers soundly and thoroughly such a large area without making any use of the calculus that the concepts can be introduced at an earlier stage of physics teaching than is usually held possible.

HORNS, STRINGS AND HARMONY, by Arthur H. Benade. Doubleday & Company, Inc. (95 cents). An essay on the physics of music, which explains how sounds are formed by pianos, violins, trumpets, oboes, clarinets, saxophones and many other instruments. There is also a chapter on homemade wind instruments. A pleasant volume in the Science Study Series.

ROME, by M. Rostovtzeff. Oxford University Press, Inc. ($2.25). Rostovtzeff's history of the ancient world is a brilliant work long out of print and very difficult to get in secondhand book stores. The present book reprints Volume II of Rostovtzeff's survey and makes it available at low cost. The maps have been redrawn and 23 of the plates from

the original edition have been retained. A paperback in the publisher's Galaxy Book series.

GREECE: BYZANTINE MOSAICS, preface by André Grabar, introduction by Manolis Chatzidakis; ISRAEL: ANCIENT MOSAICS, preface by Meyer Schapiro, introduction by Michael Avi-Yonah. New York Graphic Society ($18 each). Two further volumes in the beautiful UNESCO World Art Series. Each volume has 32 full-page colored reproductions and prefatory material which, though brief, gives some notion not only of the place of these mosaics in the development of art but also of their relation to the society that produced them.

AMERICAN CHRISTIANITY, VOL. I, 1607–1820, by H. Shelton Smith, Robert T. Handy and Lefferts A. Loetscher. Charles Scribner's Sons ($10). The first volume of a historical interpretation of the development of Christianity from the Colonial beginnings, mainly told through representative documents. Each document is preceded by the authors' analysis and commentary and there are extensive references for further study of each topic.

CHEMISTRY IN THE SERVICE OF MAN, by Alexander Findlay ($1.75); A SHORT HISTORY OF CHEMISTRY, by J. R. Partington ($1.95); A DIRECT ENTRY TO ORGANIC CHEMISTRY, by John Read ($1.50). Harper & Brothers. Soft-cover reprints of three well-established volumes on chemistry. Findlay's book, now in its eighth edition, is an excellent introduction to the basic theories and their applications in research, agriculture, manufacture of dyes, production of artificial fibers and plastics, and other branches of technology. The Partington history is the best short work of its kind. Written by a leading student of the subject, it is clear and readable, useful both as a general survey and as a reference work. Read's popularization is simple, lucid and authoritative; it is the most agreeable brief excursion into the formidable thickets of organic chemistry.

THE ORIGIN OF LIFE ON THE EARTH, edited for the Academy of Sciences of the U.S.S.R. by A. I. Oparin, A. G. Pasynskii, A. E. Braunshtein, T. E. Pavlovskaya; and for the International Union of Biochemistry by F. Clark and R. L. M. Synge. Pergamon Press, Inc. ($15). An English-French-German edition of the proceedings of the First International Symposium on the Origin of Life on the Earth held at

Moscow in August, 1957. The subject is treated under five headings: primary formation of primitive organic compounds on the earth, transformation of these compounds, the origin of proteins, nucleoproteins and enzymes, the origin of structure and metabolism, the evolution of metabolism. An engrossing collection of ingenious speculations and high-powered scientific detective exercises.

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EMOTION AND PERSONALITY, by Magda B. Arnold. Columbia University Press ($15). This two-volume study examines previous work that has been done in emotional theory and then formulates the author's own theory in its psychological, neurological and physiological aspects.

DILEMMAS, by Gilbert Ryle. Cambridge University Press ($1.75). Softcover reprint of Ryle's 1953 Tarner Lectures, which discuss in penetrating but disarmingly readable fashion some of the subtlest puzzles of philosophy.

TRANSCENDENTAL AND ALGEBRAIC NUMBERS, by A. O. Gelfond. Dover Publications, Inc. ($1.75). This paperback presents the first English translation (by Leo F. Boron) of a leading Soviet mathematician's important contribution to the modern theory of transcendental numbers.

BEHAVIOR GENETICS, by John L. Fuller and W. Robert Thompson. John Wiley & Sons, Inc. ($8.95). A biologist and a psychologist review the literature on the influence of heredity and behavior, offer a synthesis of current knowledge and propose a theoretical framework for future research.

DESIGN FOR A BRAIN, by W. R. Ashby. John Wiley & Sons, Inc. ($6.50). A second and substantially revised edition of this most interesting book on the working of the brain, reviewed at length in SCIENTIFIC AMERICAN in 1952.

MATHEMATICAL SNAPSHOTS, by H. Steinhaus. Oxford University Press, Inc. ($6.75). New edition, revised and enlarged, of an entertaining sampler whose chief purpose is to explain mathematical ideas by pictures and to show that mathematics is connected with the physical world and not with "purely artificial inquiries." Steinhaus' snapshots illustrate, among other things, arithmetic and geometric puzzles, topological problems, probability, set theory.

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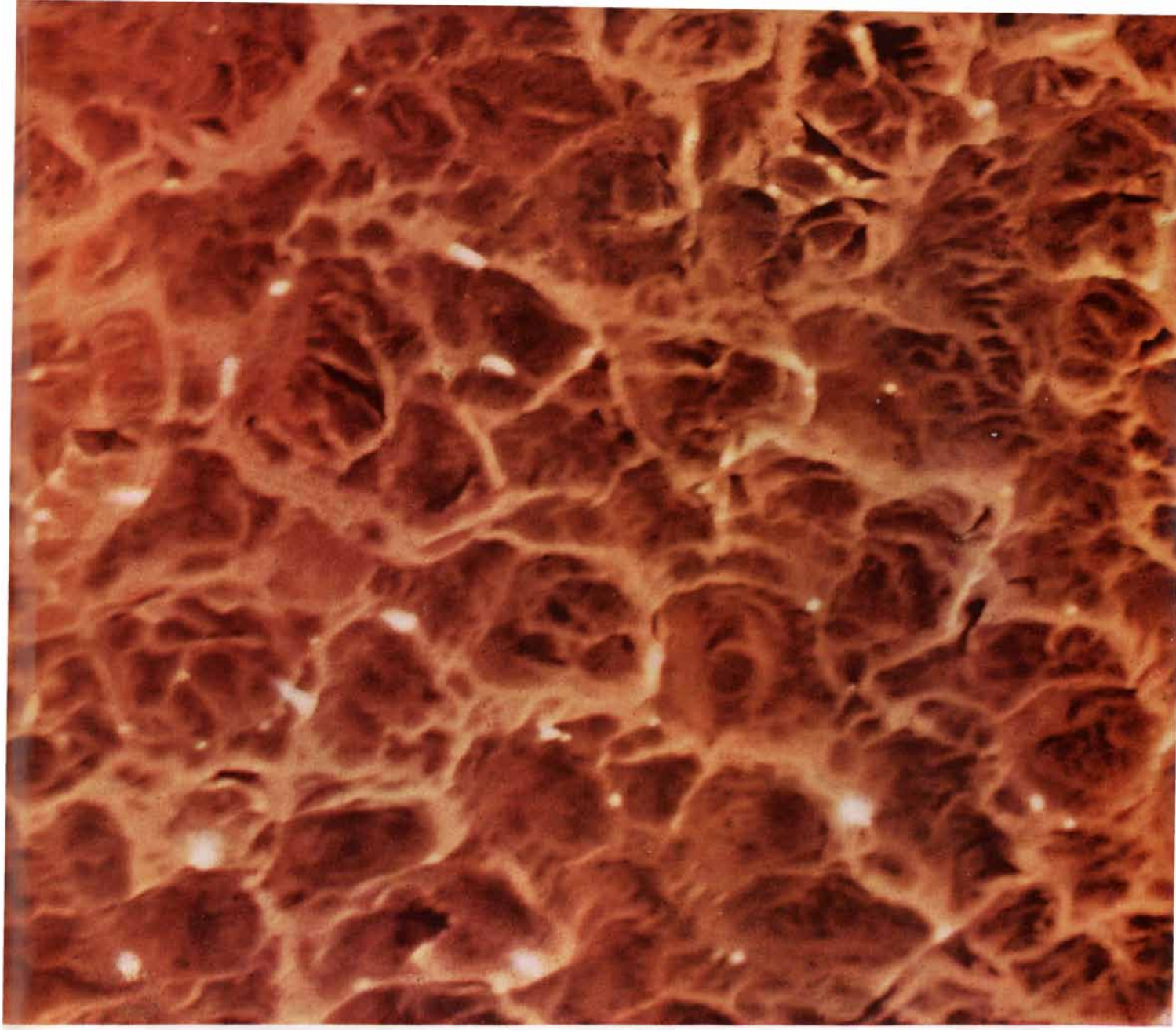

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