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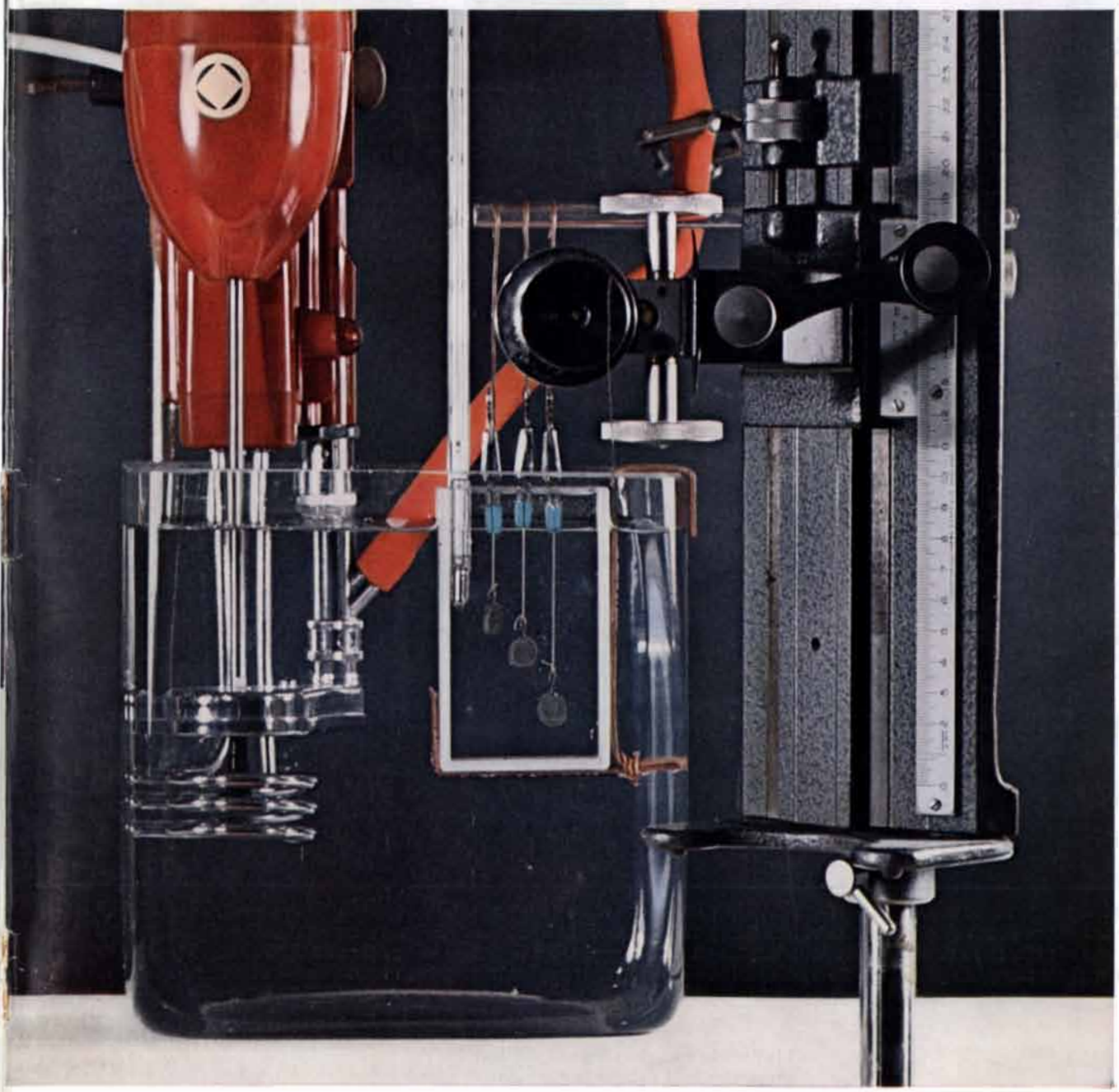

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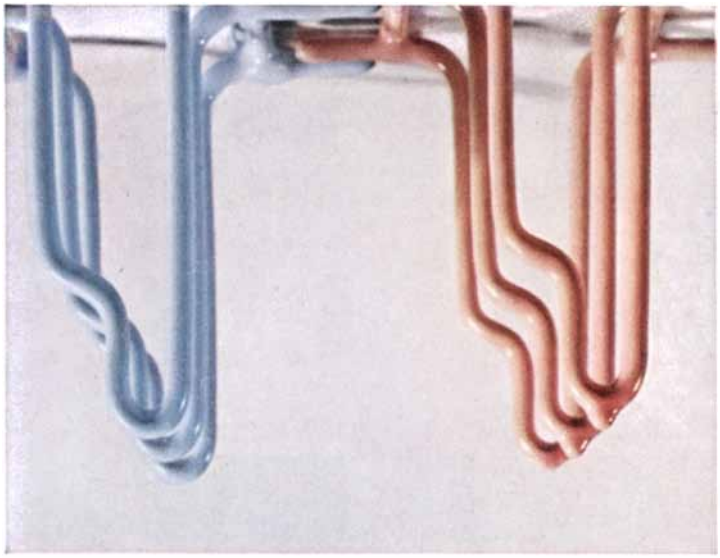

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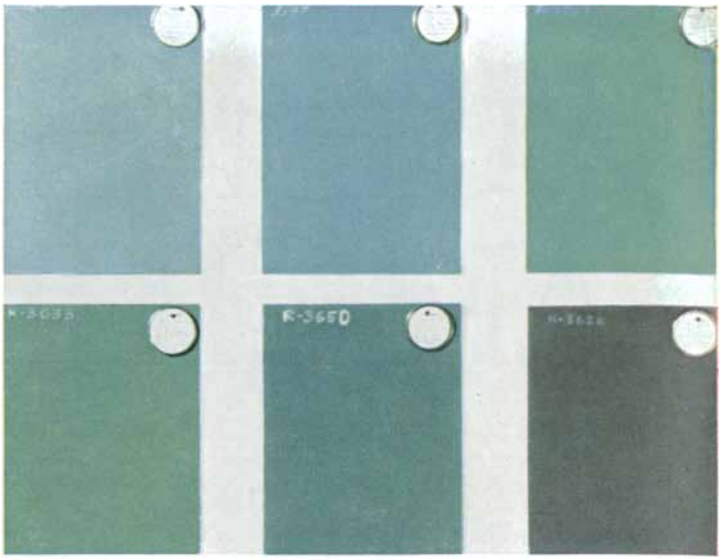

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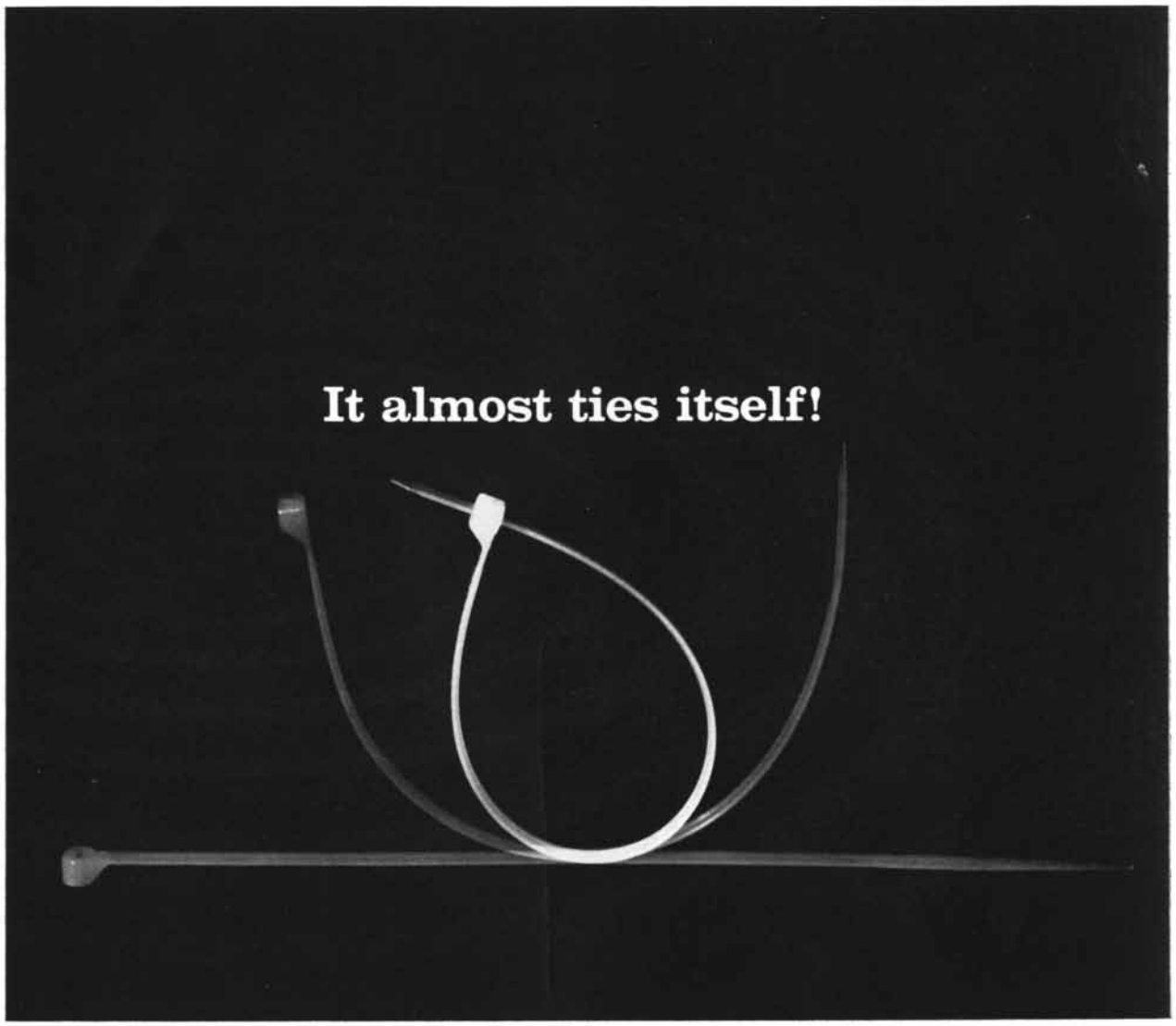

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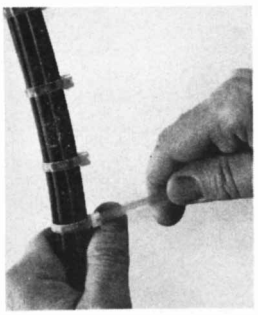

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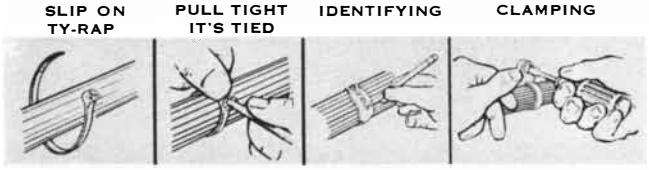

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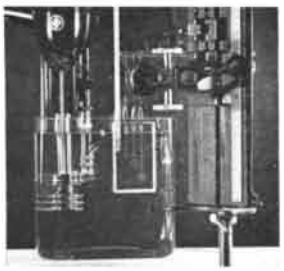

THE COVER

The photograph on the cover shows an experimental apparatus for measuring the contraction of collagen fibers at varying temperatures (see "The Aging of Collagen," page 104). The fibers, with weights attached (*center*), are immersed in a bath of Ringer's solution, which in turn rests in a heating bath. The object at lower left is a heating coil. The extent of contraction is measured by means of the microscope and scale arrangement at right.

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by Emil Schulthess

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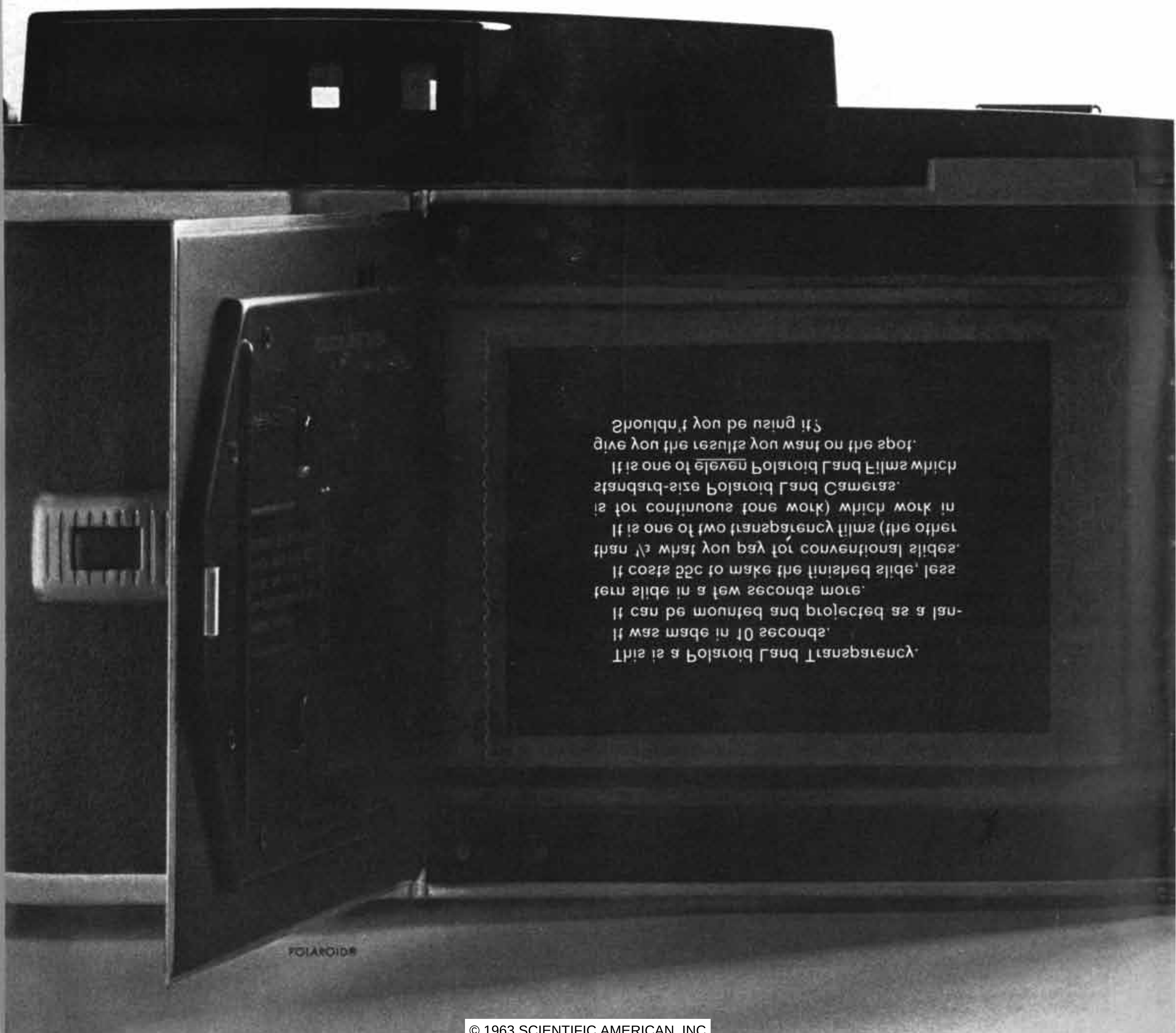

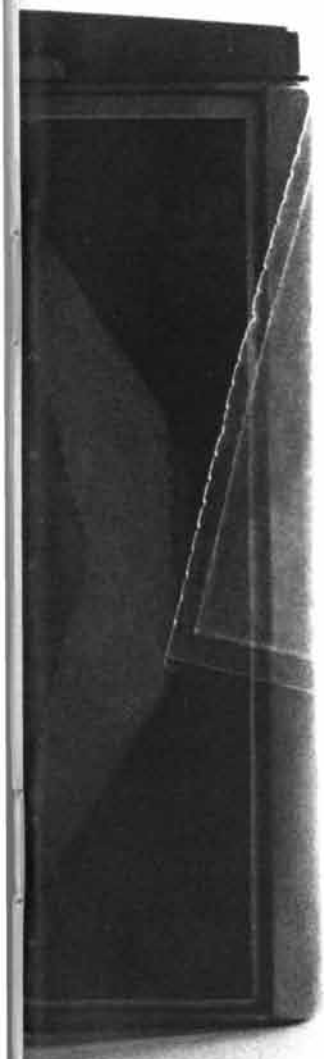

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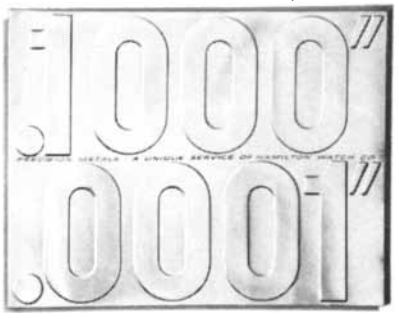

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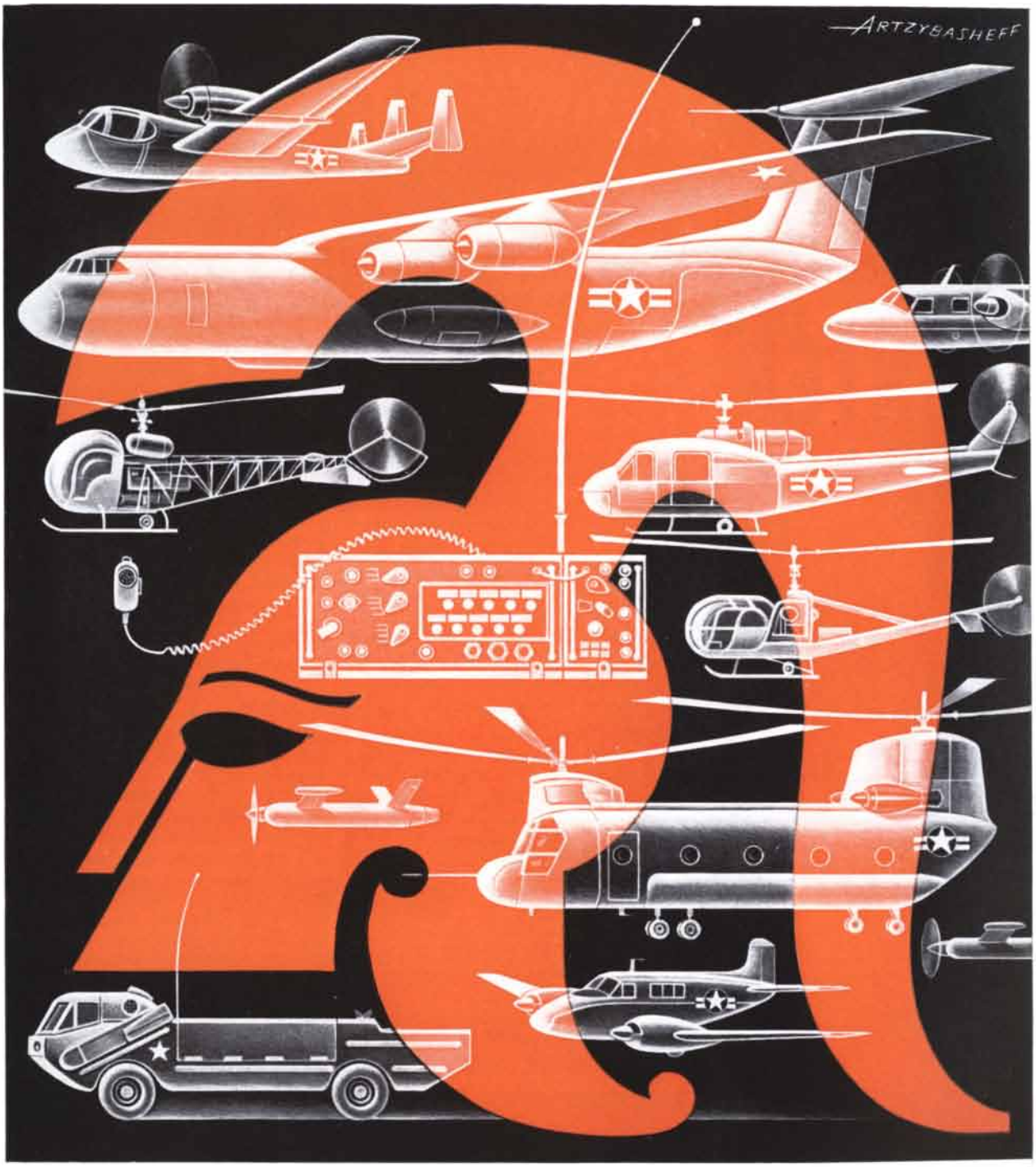

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LETTERS

Sirs:

In commenting on Dobzhansky's review of my book, *The Origin of Races*, in the February *Scientific American*, space does not allow me to answer him point by point. I shall ignore his dislike of my style and his godlike strictures—unbecoming to a scientist—about the immorality of telling the truth and shall concentrate my remarks on a few key points.

Had he read my first chapter carefully he would have seen that I discussed the problem of peripheral gene flow as being a mechanism of transforming, from one population to another, the critical genetic innovation that gradually transferred *Homo erectus* into *Homo sapiens*. I consider it very likely that this is exactly what happened, and said so. However, not being a professional geneticist, I am not so sure of it as he is, nor am I sure that all similar phenotypical effects can be attributed to the same gene locus, or that we really know the mutation rates of all racially important changes.

But I am, as he is not, a physical anthropologist of 40 years' experience, and I consider his rejection, without detail, of my criteria of grades and lines as being professionally incompetent.

Scientific American, April, 1963; Vol. 208, No. 4. Published monthly by Scientific American, Inc., 115 Madison Avenue, New York 17, N.Y.; Gerard Piel, president; Dennis Flanagan, vice-president; Donald H. Miller, Jr., vice-president and treasurer.

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Dobzhansky challenges the idea that a population bearing genes for the *sapiens* condition could interbreed with one lacking them, but he admits that anagenesis is a continuous process. Paleontology provides no evidence to support his view. Dobzhansky seems to be thinking of cladogenetically differentiated, contemporaneous species, which is all that a laboratory geneticist has to work with. That is an entirely different kettle of fish from a genetic sequence in time. Furthermore, he seems not to have realized that nearly all, if not all, the differences between *Homo erectus* and *Homo sapiens* could have been produced by minor changes in endocrine balance and in the growth sequence, changes that would have required relatively little chromosomal innovation.

As for the lag in time between the races in crossing the *erectus-sapiens* threshold, Dobzhansky should note that, unlike his fruit flies, human beings do not mate at random but are kept apart to a large extent and quite effectively by cultural barriers such as language and religion, and by such other customs as feelings about integration and segregation. These cultural roadblocks help geography to prolong periods of separation and impede, but do not prevent, gene flow.

CARLETON S. COON

West Gloucester, Mass.

Sirs:

Far from disliking Dr. Coon's style of writing, I find it admirable. The fact I have felt compelled to point out is that Dr. Coon uses his writing ability in such a way that his book is being utilized by racists in support of their propaganda. Dr. Coon has not seen fit to disavow these misuses of his book. If, on the other hand, his book is being used with his consent, he should have the courage to say so openly. A scientist cannot assume a pose of disdain and unconcern when what he believes to be truth is being misrepresented. There is no need for me to criticize in detail his criteria for delimiting what he calls *Homo sapiens* and *Homo erectus* because, first, this is too technical a matter for a review such as mine and, second, because this has been done by anthropologists who are Coon's peers in professional competence. His belief that *sapiens* evolved from *erectus* five times independently involves, however, a serious misconception of the mechanisms of evolution. And, contrary

to Coon, this misconception happens to be particularly serious exactly because human evolution involved a combination of anagenesis and cladogenesis, with a predominance of the former. Neither humans nor, I can assure Dr. Coon, fruit flies mate at random. Human culture and human mobility may not only impede but also promote the gene flow. If, as Dr. Coon seems to suggest, *erectus* differed from *sapiens* in only one or a few genes, then they were not different species at all; it is far more likely that the transition from *erectus* to *sapiens* involved rebuilding of the whole genetic system, and if so, this transition could not have happened five times independently. It is chiefly this misconception that opens Dr. Coon's work to misuse for racist propaganda.

THEODOSIUS DOBZHANSKY

The Rockefeller Institute
New York, N.Y.

Sirs:

The very interesting letter by John Bardeen and A. H. Taub in the February issue of *Scientific American*, which describes notes written in 1953 by John von Neumann relating to the possibility of using stimulated emission from recombination of electrons and holes in semiconductors to make a light amplifier, shows once more the great ingenuity and versatility of von Neumann. The account is somewhat misleading, however, when it says: "The basic principle was used later by [Charles H.] Townes and by [Nicolaas] Bloembergen in the MASER (Microwave Amplification by Stimulated Emission of Radiation) . . ." In fact, the possibility of negative absorption or amplification had been pointed out in print by Willis Lamb in 1950 and was discussed by Joseph Weber in 1953. Moreover, the great obstacles that remained to its actual realization had been analyzed and overcome by Townes in the spring of 1951. He not only found a suitable medium, the ammonia beam, in which a population inversion could actually be obtained, but he also found a way to increase the interaction of the excited ammonia molecules and the electromagnetic wave by enclosing them in a cavity resonator. Not only did Townes's use of a cavity resonator make possible useful amounts of amplification, it also provided a means of synchronizing the emissions of the individual atoms. Thus coherent radiation was obtained from

independently excited atoms or molecules.

I can testify from my own knowledge that Townes's concept of the maser, complete with source of excited atoms and resonator, was essentially complete in the spring of 1951. It was described in a widely distributed and unclassified progress report later that year. So when von Neumann first began to think of stimulated emission in 1953, the first maser built by J. P. Gordon, Herbert J. Zeiger and Townes was nearing operation. Bloembergen's important three-level solid-state maser did come later, but it involved a method of providing excited atoms different from the methods of both Townes and von Neumann.

ARTHUR L. SCHAWLOW

Department of Physics
Stanford University
Stanford, Calif.

Sirs:

Referring to the article "Surgical Stapling" by R. F. Mallina *et al.* in your October 1962 issue, I would like to point out a historical error.

The history of surgical stapling goes back to 1906, when Professor Hümér Hültl of the University of Budapest in collaboration with an engineer named Fischer designed a stapling instrument expressly for gastrointestinal tract surgery. This instrument was shown at the International Surgical Congress in Budapest in 1908. Dr. Hültl reported 30 consecutive cases of gastric resection for cancer of the stomach without a single fatality, which he attributed to this instrument.

This stapler has four rows of fine silver staples, therefore in that respect is superior to the Petz instrument currently in use. Inasmuch as the first Hültl-Fischer instrument was covered by an international patent for 17 years, Petz could not publish his simplified model until 1922.

I would like to add that the Hültl machine was used in large surgical centers in the U.S. as well as in Europe. It has the same drawback as the Russian instrument, namely that charging of the instrument is somewhat cumbersome, requiring a binocular loop and special training.

STEPHAN S. ROSENAK

Albert Einstein College of Medicine
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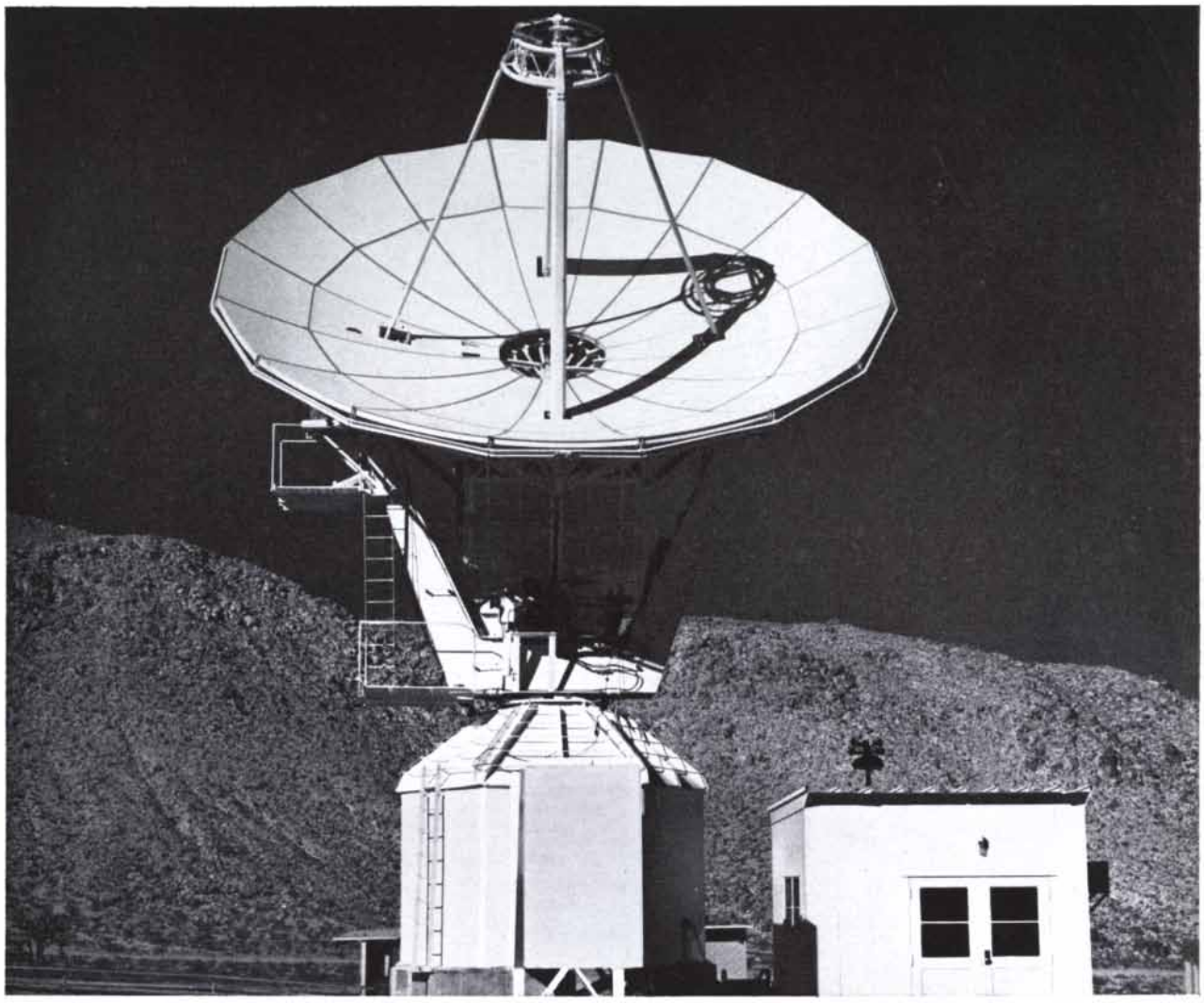

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Symmetry of the elevation bearings to the azimuth axis of rotation	Within 0.125 inches	0.090 inches
Elevation wheel radial runout	0.010 inches peak to peak	0.007 inches peak to peak
Reflector Panels Accuracy	0.030 inches RMS Manufacturing Tolerance	0.008 inches RMS
Reflector Face & Reflector Structure Accuracy	0.087 inches ($\frac{\lambda}{16}$ at 8.45 KMC)	0.030 inches

Rohr Offers the Complete Antenna Package from Design Through Manufacturing, Quality Control, Field Installation and Field Performance

A unique antenna concept at Rohr means complete systems responsibility from design through field test to meet customer requirements anywhere in the world . . . the antenna service now strengthened even more by proof of performance far exceeding customer specifications on Rohr-designed and Rohr-built 30-foot and 85-foot antennas. The Rohr antenna concept further includes the preference to be fully responsible for servo and control systems from the outset . . . allowing for full consideration and integration through design and fabrication. Basically, our philosophy has been one of introducing a new standard of precision to meet the ever-growing need for greater levels of accuracy in antenna operations. The fact that new precision standards have been achieved is proven through Rohr conducted test performance data now available. Rohr has designed, built and erected 5 antennas of widely varying sizes and configurations—for 4 customers—in 5 widely varying environmental conditions around the world. And other antennas of even more accuracy are being designed and fabricated at Rohr today.

Shown under construction is 85 foot Az/El antenna designed and built by Rohr for Radiation Corporation for Atlantic Missile Range

Rohr Antenna Research, Design and Engineering

Rohr's Antenna Systems Engineering Group was formed by recruiting from leading firms throughout the country and integrating these top antenna men with veteran Rohr aircraft engineers. This engineering group builds antenna design concepts on a broad base of knowledge acquired through the years . . . supported by intensive Rohr research in areas such as wind tests, vibration analysis, contour measuring tests, environmental studies, surface panel tests and truss evaluations.

Rohr Precision Antenna Fabrication Capabilities

Rohr's manufacturing facilities and know-how are, we believe, unmatched in the field of antenna fabrication. Our inventory of machines includes some of the world's largest presses and forming machines, numerically controlled machine tools, a battery of big bonding autoclaves, large processing tanks for chemical and heat treating, all types of automatic welding equipment, plus our tremendous, unique "antenna manufacture and assembly area" supported by huge traveling cranes and other strategic machinery. These modern antenna machines plus trained and talented antenna supervision and crews with a wealth of knowledge and experience in tooling and metal forming provide a full, seldom-found antenna fabrication capability. New Rohr-developed fabrication techniques such as use of large, structural weldments vs. bolted connections, and magnaflux and x-ray-controlled welding offer fabrication procedures for building in antenna accuracy levels not possible before.

Antenna Quality Control

Special quality control techniques are common procedure at Rohr. For instance, the unique, Rohr-developed contour measurement system which lends a more economical and precise method of verifying specified surface tolerances. The optical theodolite used in this measuring process operates in all reflector attitudes and requires only one origin to check the relationship of the feed support and reflector surface to the antenna axis. A fully equipped and fully staffed Quality Process Control Laboratory verifies materials and certifies all applicable equipment. In addition to these and other quality control techniques at Rohr, many of the critical antenna components are test assembled in plant prior to shipment, providing factory controlled accuracy that means savings in time and money in field installation.

Antenna Field Erection

Full, follow-through on-site erection service is another important part of the complete Rohr antenna package. Today Rohr has trained, experienced, erection crews ready to provide full field installation service anywhere in the world. For instance, Rohr is erecting three antennas simultaneously in three widespread locations. Rohr maintains a high degree of coordination with other contractors—servo, electronics and others—who may be associated with a project.

Rohr Antenna Field Test

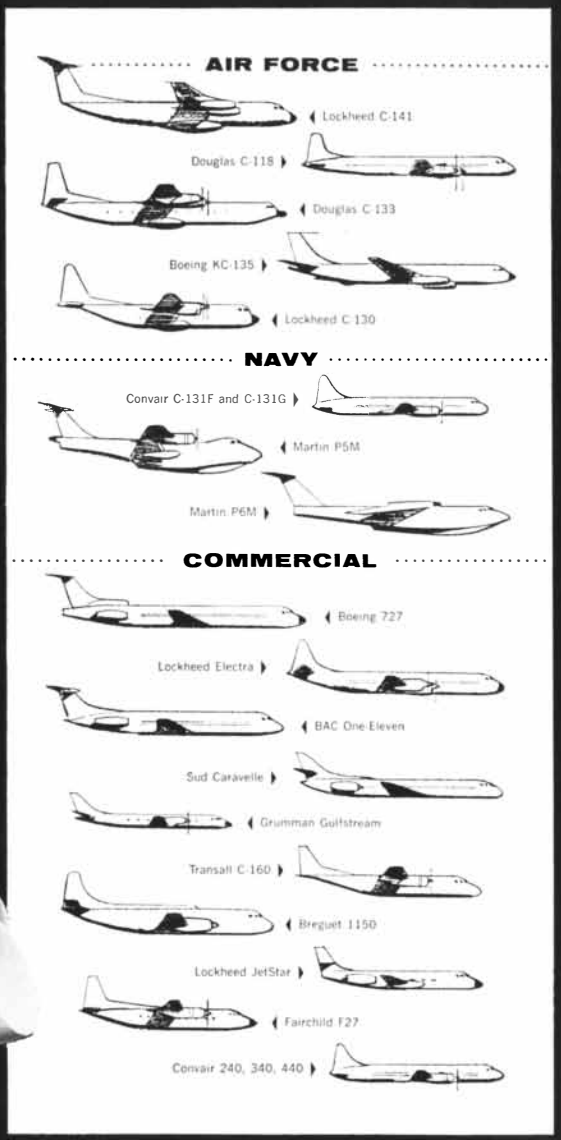
Rohr's trained field crews work with the customer in on-site operational check-out of every antenna installation. This service extends the company's quality control responsibility through to operational readiness and assures accurate antenna performance in every attitude.

For the Complete Rohr Antenna Story Write to:

Marketing Manager, Dept. 14, Rohr Corporation, Chula Vista, Calif. Rohr Sales Offices in Washington, D.C.; Huntsville, Ala.; Houston, Texas and Dayton, Ohio. Main Plant and Headquarters: Chula Vista, Calif. / Plant: Riverside, Calif. / Assembly Plants: Winder, Ga.; Auburn, Wash.

ROHR CORPORATION

Major aircraft rely upon AiResearch Gas Turbine experience



• Shaft, bleed, or combination units • 60 to 400 horsepower; up to 225 lbs. air / minute • DC or AC power; 400 cycle • Use aircraft fuel; instant starting in all weather • AiResearch support services at all major operating centers • Commercial turbines guaranteed to operate with normal maintenance to warranty life • Turbines qualified to military specifications • FAA approval on all units

Garrett-AiResearch on-board gas turbines provide an economical and reliable source of auxiliary power to make airline, corporate and military aircraft independent from ground power services.

These lightweight, compact units can furnish: either electrical or pneumatic main engine starting; air conditioning and heating; continuous or auxiliary power for operation or checkout of pneumatic, hydraulic, electrical and electronic systems; emergency power while airborne.

This means greater comfort on the ground, utilization of underdeveloped or isolated airstrips and an extra margin of safety in the air for the corporate and airline operator. The on-board gas turbine also provides needed additional power for electronic systems aboard military aircraft.

A wide range of units is immediately available for retrofit of existing aircraft and for new aircraft presently in production. Applications for future aircraft now in the design stage are under development.

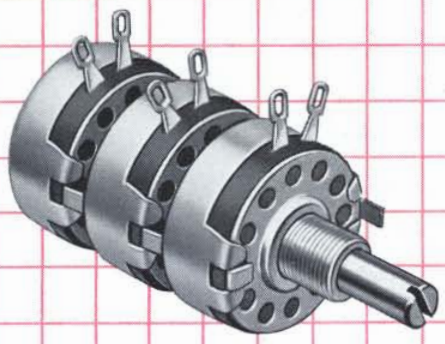
GARRETT

AIRESEARCH MANUFACTURING DIVISIONS • *Los Angeles 9, California • Phoenix, Arizona*

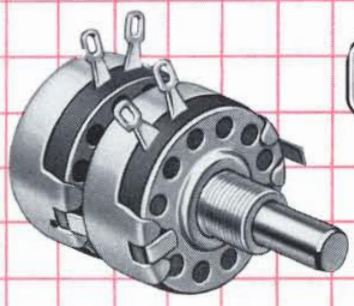
Systems and Components for:

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

Allen-Bradley Type J Variable Resistors used in constant impedance attenuators provide quiet, smooth control...at low cost!

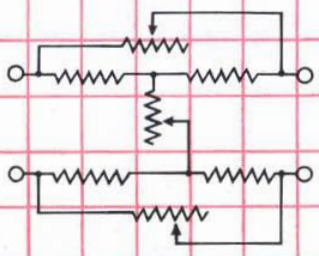


Type JJJ
Actual Size

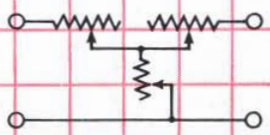


Type JJ
Actual Size

A-B QUALITY

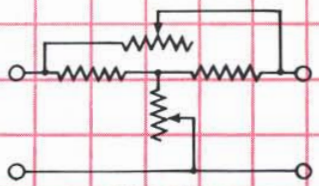


Bridged H



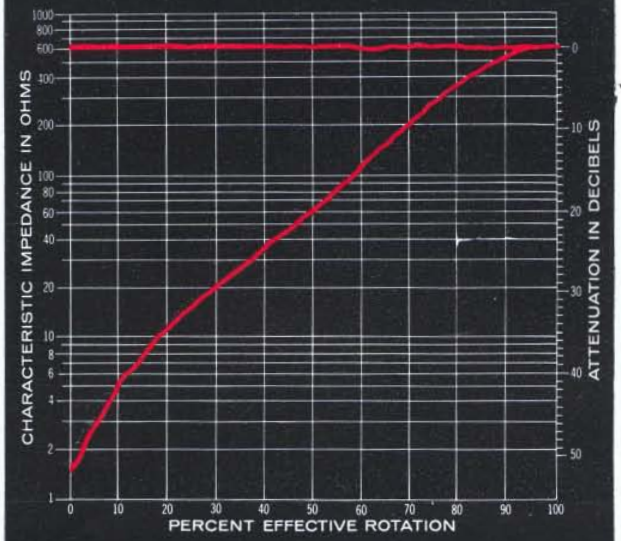
Straight T

Standard L



Bridged T

Reproduction of actual machine plot of Allen-Bradley 600 ohm Bridged-T attenuator, showing the uniform attenuation and constant characteristic impedance obtainable with such Type J variable resistors.



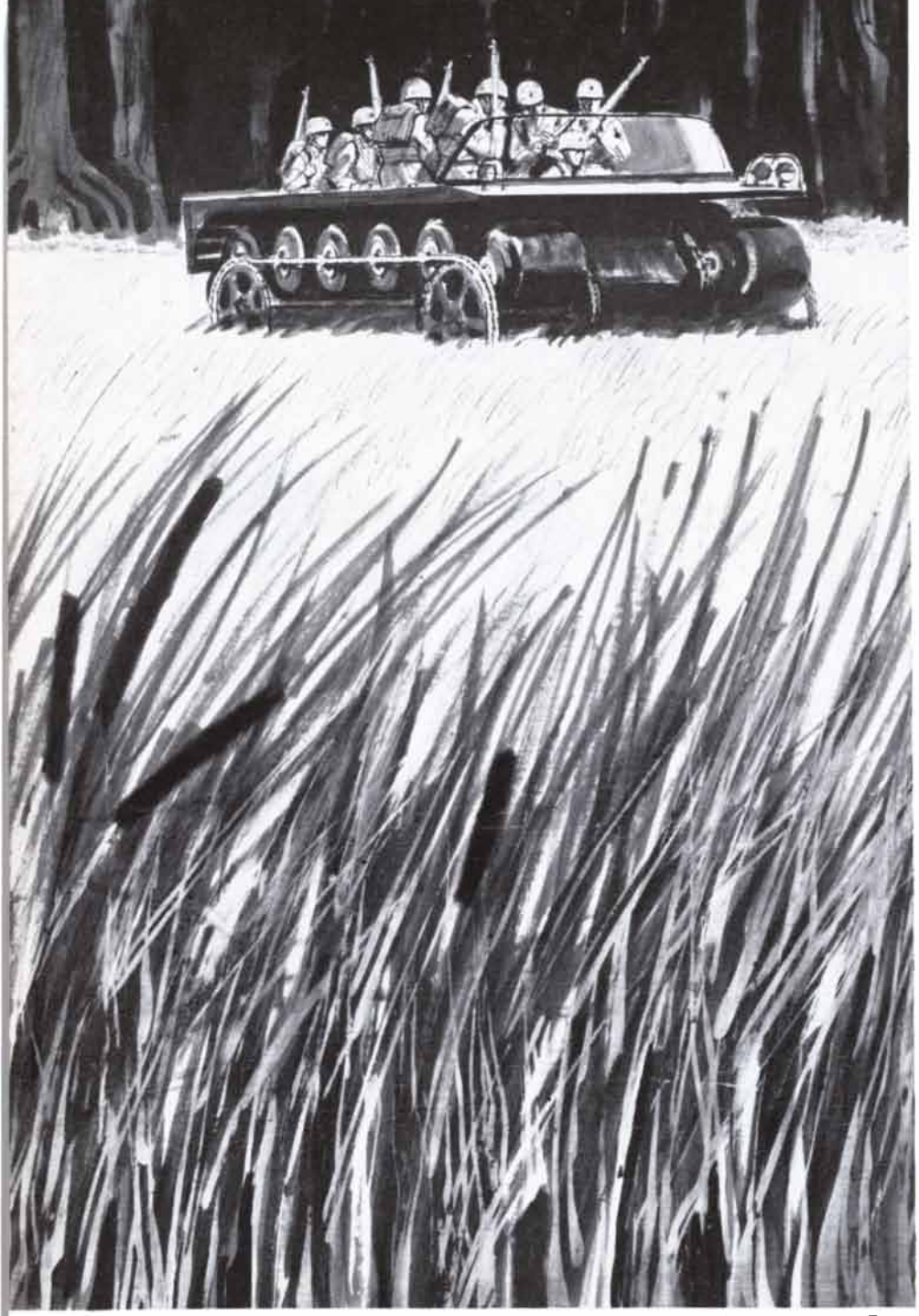
■ In attenuators, which of these characteristics is most important to you—stability, or smooth control, or constant impedance? Not only will Allen-Bradley Type J variable resistors give you all of these . . . but also long life and a high wattage rating in a remarkably compact structure.

The famous Type J solid resistance element—made by A-B's exclusive hot molding process—provides smooth control at all times—you'll never experience an abrupt change in impedance or attenuation during adjustment.

Allen-Bradley's control of the resistance-rotation characteristics during production assures the desired attenuation—approaching calibration accuracy. And, the characteristic impedance can be held to 10% *throughout* rotation—end to end! The discrete steps inherent in all wire-wound units are eliminated. Don't forget—freedom from inductance insures excellent high-frequency response.

The Allen-Bradley Type J variable resistors are available in dual or triple units for use in attenuators rated up to 5 watts. For more complete information on these Type J controls, please send for Technical Bulletin B5200B. Write: Allen-Bradley Co., 1204 S. Third Street, Milwaukee 4, Wis. In Canada: Allen-Bradley Canada Ltd., Galt, Ontario.

QUALITY ELECTRONIC COMPONENTS | ALLEN-BRADLEY



How do you make a vehicle that can run nature's

©1963, B-W Corp.

obstacle course? Borg-Warner knows how!

Borg-Warner's revolutionary Airoll military transport doesn't let desert sand, arctic snow, bottomless mud, jungle swamps, deep rivers or lakes get in its way. It rolls right over them . . . puts men and equipment into action instantly, anywhere. It can help us fight . . . and win . . . *limited* wars where *unlimited* mobility is needed.

Combining the best features of tracked, wheeled and jumbo-tire vehicles, Airoll moves easily over terrain that would stop other transports dead in their tracks. In a brushfire war it could mean the difference between victory and defeat.

This versatile amphibian was developed for the Marines by the Ingersoll Kalamazoo Division of Borg-Warner. It's a dramatic example of how Borg-Warner's unique engineering and research skills help our armed forces meet the needs of national security. Borg-Warner Corporation, 200 South Michigan Avenue, Chicago 4, Illinois.

B-W

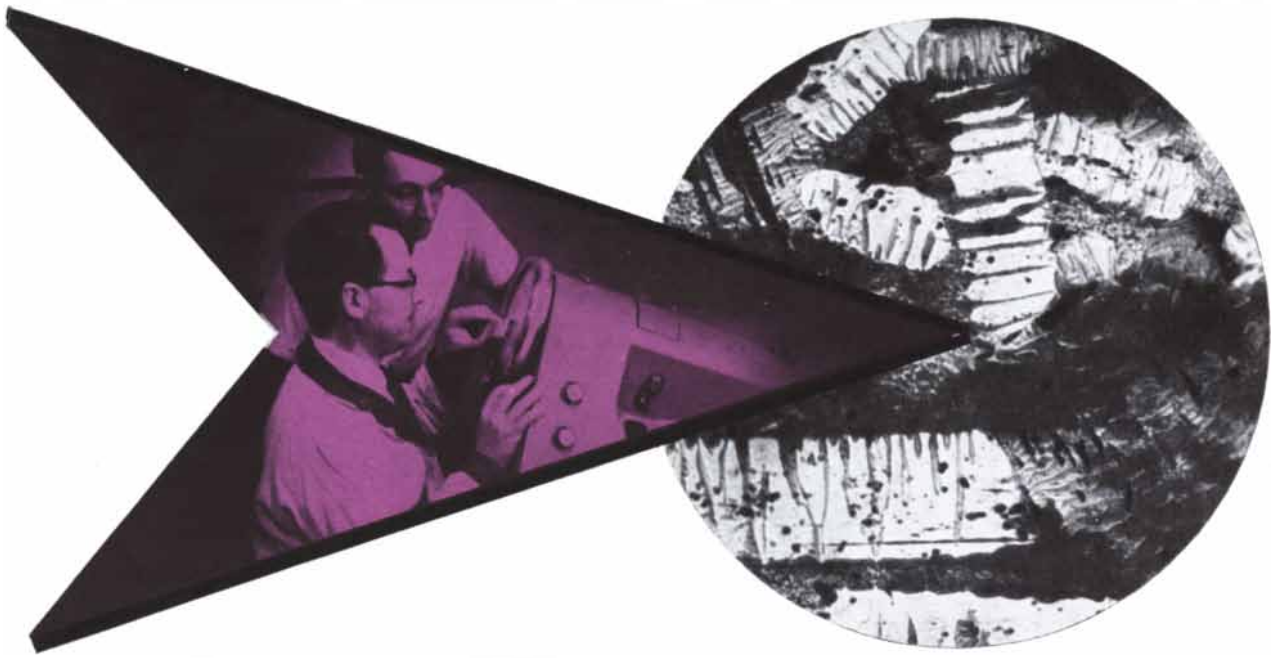
BORG-WARNER

where research and engineering work wonders for you

we probe magnetic domains . . .

because magnetism is our business

Analyzing magnetic materials is an essential facet of our continuing research in the broad field of applied magnetics. Take the microscopic magnetic domains, for example, created when magnetic moments of electrons are oriented in the same direction. They vary with different materials and with the magnetic force applied. By applying a suspension of iron oxide to a sample, and observing through the microscope how the particles line up in domain patterns (as illustrated here), we can draw definite conclusions about the material's magnetic characteristics. ■ Micro-motion pictures of these "powder patterns," taken as the magnetic field is varied, show us how a material goes through a complete hysteresis loop traverse. In modern, high-quality permanent magnet materials, the structures are of such an extremely fine dispersion, we often apply an electron microscope to reveal the details. ■ In practical application, such materials research was extremely valuable in developing our INDOX® ceramic magnets. If you would like to read more about this subject, **write today for "Magnetic Domains,"** to Indiana General Corporation, Valparaiso, Indiana.



INDIANA GENERAL

The Honeywell Visicorder oscillograph & GUNPOWDER records forces in circuit breaker bushings

Wham! Forces imposed by the operation of oil-filled circuit breakers—especially during short-circuit interruption—are destructive enough to damage bushings. Engineers at the Ohio Brass Company have devised an ingenious method of simulating this explosive force in order to analyze bushing loads.

On a typical bushing, they mounted a dummy interrupter, in which they exploded gunpowder to propel from the interrupter fist-sized metal projectiles.

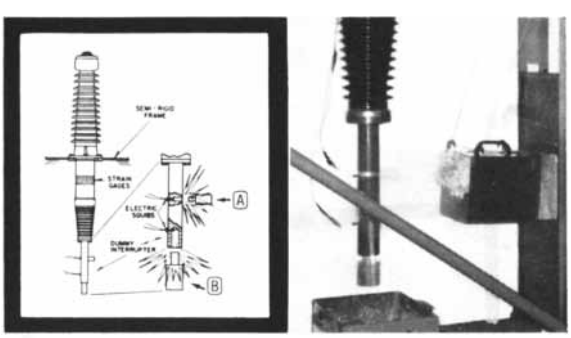
Strain gages, installed on the bushing ground sleeve, were connected to a Honeywell 119 Amplifier.

A Honeywell 906 Visicorder oscillograph was chosen to record the test data because of the extremely high speed and transient nature of the signals to be measured.

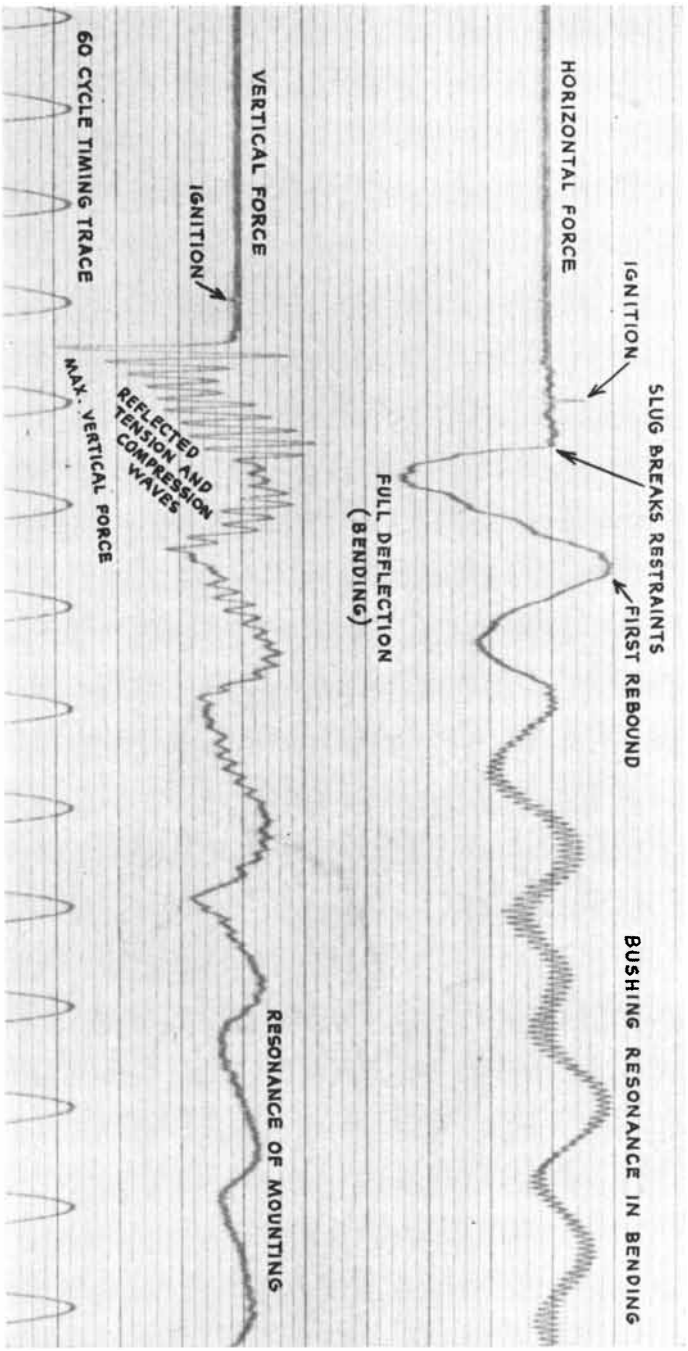
A typical record of this test, shown at right, was made at a record speed of 50″/second.

These Ohio Brass tests have opened the way to the development of standards for the mechanical performance of bushings (AIEE papers 62-153, 60-107).

This application is only one of thousands where the Visicorder is called upon daily as a basic research, test, and development tool. One of the six different Visicorder models should be a basic instrument in the management of your data acquisition.



Schematic at left diagrams method for duplicating bushing loads during short-circuit interruptions. Projectile (A) produces lateral forces at right angles to bushing axis; projectile (B) produces axial load on bushing terminal. At right, squibs have just detonated charges propelling projectiles from dummy interrupter. Below, Honeywell Model 906 Visicorder Oscillograph records circuit breaker bushing test for Ohio Brass.

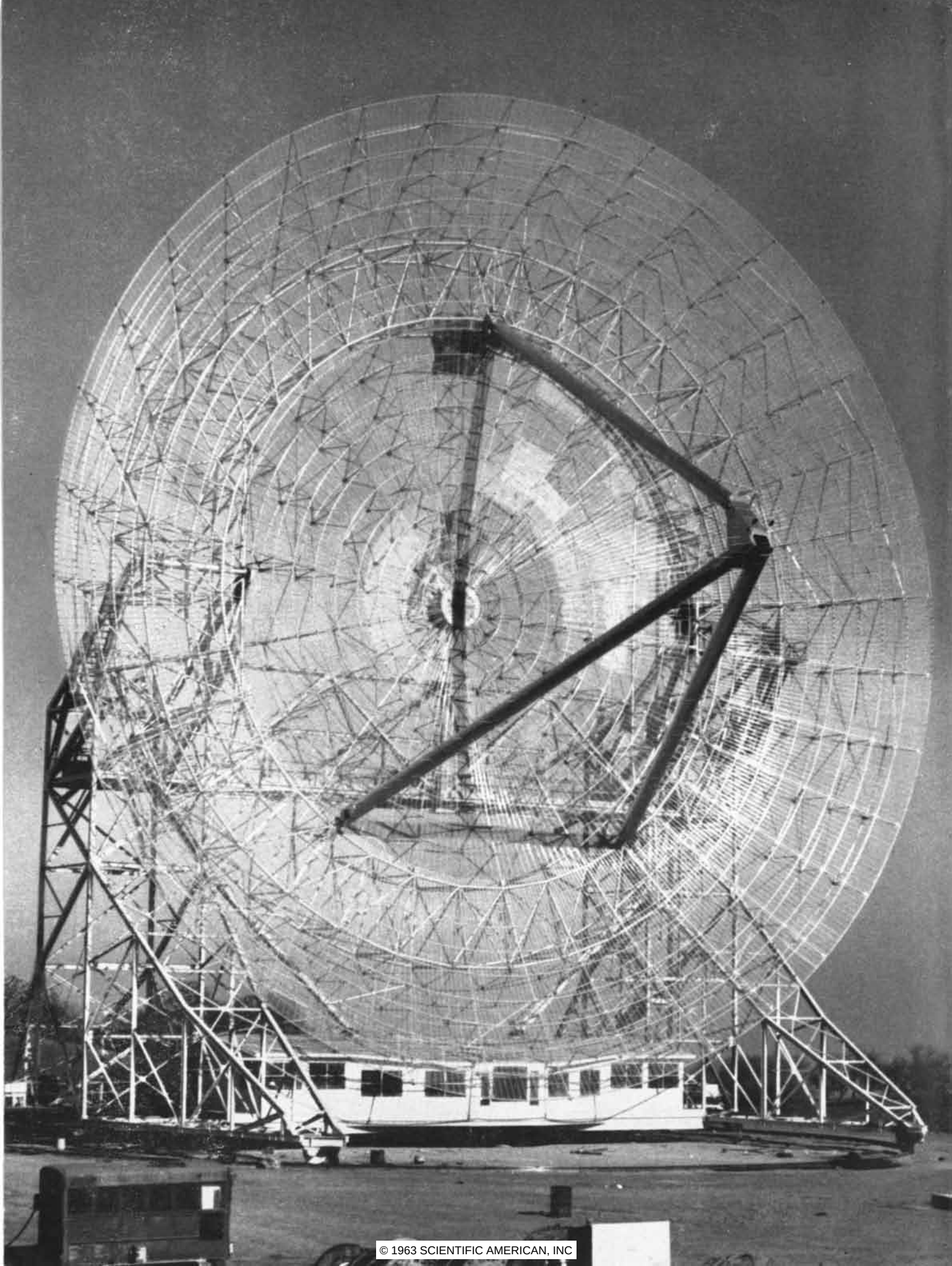


The Honeywell Model 906 Visicorder Oscillograph—with a Honeywell Model 119 Amplifier—record circuit bushing tests for Ohio Brass.

For full details on all Visicorder Oscillographs, tape systems, and signal conditioning equipment, write to Honeywell, Denver Division, Denver 10, Colorado, or phone 303-794-4311.

DATA HANDLING SYSTEMS

Honeywell



Where no metal but Platinum will do the job as well...

Giant Stanford telescope uses platinum-clad grid wire to help control signals from 160-ft. antenna

Radar astronomers at Stanford University and Stanford Research Institute have an exciting new tool for the exploration of space. It's a giant telescope with a 160-foot parabolic antenna that operates in the 20 to 55 megacycle range. Its transmitter, powered in part by Eitel-McCullough 4W20,000A tetrodes, supplies an input of 1,000,000 watts!

To insure dependable performance, engineers at Eitel-McCullough Corporation, San Carlos, California, selected platinum-clad wire for the grids in these power tetrodes because of its outstanding ability to suppress electron emission. In addition to this vital characteristic, this platinum-clad wire has high strength and remarkable heat resistance.

It could pay you to use a Platinum Metal

Your problem might be readily and economically solved with a Platinum Metal—where superior electrical properties are required, such as in grid wires...where high temperature corrosion and spark erosion are involved, such as in aircraft sparkplugs...where wear-resisting, non-tarnishing surfaces are required, such as for printed electrical circuits ...where a combination of severe corrosion and erosion must be met, as in the case of spinnerettes for rayon production...where peak catalytic efficiency is required, as in the refining of high octane gasoline...or where product purity must be retained despite high temperatures, as in the case of lens glasses... the Platinum Metals have proved to be the most economical for certain critical equipment.

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

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

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

CAN THESE PROPERTIES OF THE PLATINUM METALS HELP YOU?
High Temperature Stability
Exceptional Chemical Inertness
Superior Wear Resistance
Peak Catalytic Activity
Low Vapor Pressure

The six Platinum Metals are:

PLATINUM • PALLADIUM • RHODIUM
RUTHENIUM • IRIDIUM • OSMIUM

INCO TRADE MARK

PLATINUM METALS DIVISION
The International Nickel Company, Inc., 67 Wall Street, New York 5, New York

50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

APRIL, 1913: "The latest plans of the German Admiralty for a huge aerial fleet to accompany the warships have recently been made public. These call for an appropriation of $12,500,000 to be spent during the next five years, while the appropriation for army aviation and aeronautics is to be nearly $25,000,000. In a bill introduced into the Reichstag on March 29 a large appropriation was made for 10 naval dirigible balloons of the largest size, eight of which are to be put in service and two held in reserve. Fifty aeroplanes (36 for active use and 14 for reserve) are to be built and are to be manned by a special corps of 1,452 officers and men."

"The floods in the upper watershed of the Ohio, with their tragic accompaniment of suffering and widespread ruin, will have carried with them a large compensation if they prove to this nation that the question of the control of the Mississippi River and its tributaries is broader than any state or community and that it must be faced and mastered by the nation at large. If anyone asks why the Federal Government should be urged to take hold of this problem on a national scale and assume full responsibility for the time and labor and great cost involved in obtaining complete control of the Mississippi River, surely it is sufficient to remind him that the drainage area of this great river covers 41 per cent of the total area of the United States."

"The idea of carrying out surveys in the Sahara and elsewhere with the aid of airships and aeroplanes has often been suggested, and it seems likely that many blanks on our maps, where ordinary surveying methods are difficult or impossible, will ultimately be filled up in this manner. A German writer calls attention to the fact that the first demonstration of the feasibility of such undertakings was furnished by the Italian military aeronauts during the recent war with Turkey. A large tract of country around the city of Tripoli was mapped from overhead. The data thus obtained enabled the general staff to construct a series of charts on a scale of 1:40,000."

"The power-driven vehicle can no longer depend on its present fuel. The demand for gasoline has overtaken production. During the last decade the oil market has been readjusting itself to radically new conditions. This has been brought about by many new applications of oil products for developing heat and power. Crude oil was formerly looked on as the raw material for the production of illuminating and lubricating oils."

"Capt. Amundsen has received a grant of $20,000 from the National Geographic Society toward his coming north polar expedition. In voting this grant the research committee of the society desired especially to increase the scientific possibilities of the undertaking as to oceanographic research, meteorological and magnetic observations, etc. Amundsen expects to start north from the Pacific coast sometime in the summer of 1914. His ship, the *Fram*, which now lies at Buenos Aires, will be sent through the Panama Canal sometime this summer or autumn, and it is understood that the authorities have arranged that she shall be the first vessel, other than a man-of-war, to pass through the big cut."

Scientific American.

APRIL, 1863: "All the harbors of our large cities are skirted round by forts that, in the present improved state of ordnance and by the adoption of ironclads, are rendered of very little use. This is saying a great deal, but the statement can be substantiated by facts. It is fresh in the minds of all persons that our ironclads have repeatedly run the batteries at Vicksburg, and that our fleet of wooden ships passed up to New Orleans in spite of Forts Philip and Jackson; disregarding the storm of iron that these works belched forth, they boldly and successfully dared the passage. They accomplished their purpose and obtained the surrender of the city by appearing before it with open ports and guns yawning from them. Such has been the experience at that point, and other cases might be cited in proof of the assertion that ordinary forts are not only incapable of arresting the passage of an enemy's vessel or fleet but also that they themselves

What was Bell Telephone Laboratories doing on Monday, October 1, 1962?

Murray Hill Laboratory, N. J. The search continued for new materials exhibiting superconductivity. Some of these materials have been used to produce very strong magnetic fields with the expenditure of very little electrical energy.

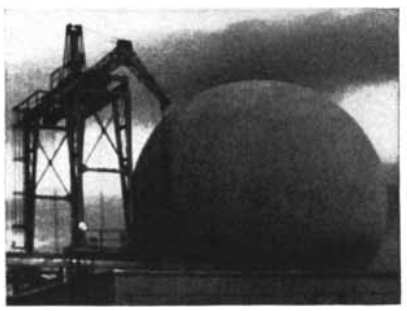
Allentown Laboratory, Pa. We were working with engineers of Western Electric, manufacturing unit of the Bell System, on the manufacture of long-life electron tubes for a new deep sea cable system.

Merrimack Valley Laboratory, Mass. We were increasing the capabilities of a new microwave system designed for low-cost telephone and television communications over distances up to 200 miles. This system is based on advances in solid state technology.

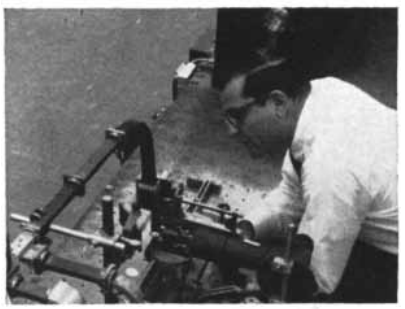
Holmdel Laboratory, N. J. We were developing an electronic switching system using new solid state devices. It will bring telephone customers a whole new range of services.

Indianapolis Laboratory, Ind. We were perfecting improved automatic dialer telephones. One model will permit the customer himself to rec]50 frequently called names and numbers and then dial by simply selecting a name and pressing a button.

New York Laboratory, N. Y. We were studying the performance of a new data set which converts teletypewriter pulses into tones for transmission over regular voice circuits. Transmitting teletypewriter messages over voice circuits was introduced on August 31, 1962.



Whippany Laboratory, N. J. We were evaluating new radar technology for the NIKE-ZEUS antimissile missile system under development for the Army. Significant improvements are further tested at four other ZEUS test sites ranging halfway around the world.



Crawford Hill Laboratory, N. J. We were experimenting with the microwave modulation of light from a helium-neon gaseous optical maser. Modulated light may someday be used to carry large volumes of information.

Cape Canaveral, Fla. We were preparing for the 102nd successful use of Bell Laboratories-developed Radio Command Guidance System. On July 10, it was used in the NASA launching of the Bell System's Telstar. This guidance system was originally developed for the Air Force and is operational on the Titan I ICBM.

These were some of the highlights of one day. Engineers and scientists at Bell Laboratories work in every field that can benefit communications and further improve Bell System services. Their inquiries range from atomic physics to new telephone sets, from the tiny transistor to transcontinental radio systems, from the ocean floor to outer space.

BELL TELEPHONE LABORATORIES

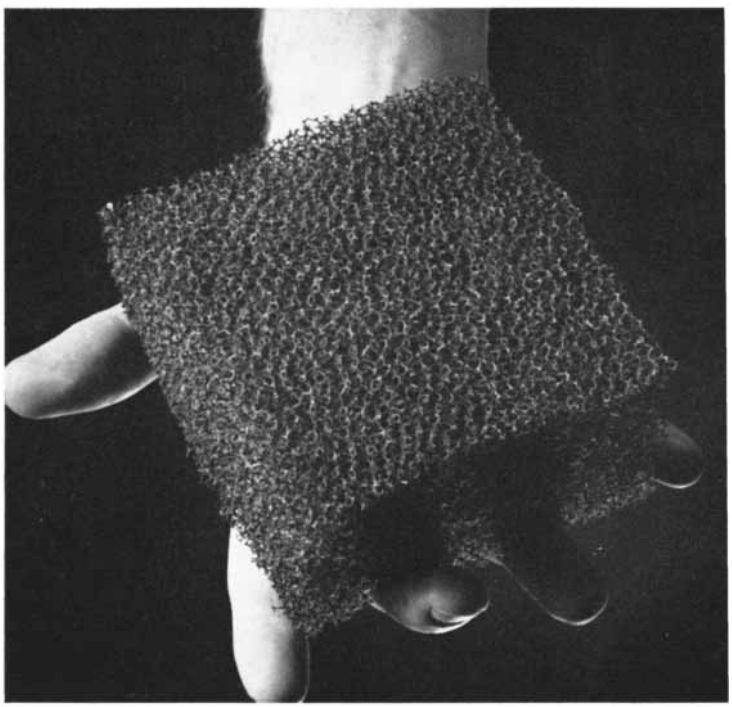
World center of communications research and development

are far from being any protection to the forces within."

"A lecture on the subject of radiation through the earth's atmosphere lately read before the Royal Institution by Prof. Tyndall contains much original information of an interesting character and a clear explanation of the reason why dry clear nights are always colder than those that are cloudy. Moisture in the atmosphere is compared to a blanket for preventing the radiation of heat from the surface of the earth, and an explanation is given of the phenomena of heat. Prof. Tyndall also believes that there is a subtile ether pervading all space. He says: 'Within our atmosphere exists a second and a finer atmosphere in which the atoms of oxygen and nitrogen hang like suspended grains. This finer atmosphere unites not only atom with atom but star with star; and the light of all suns and of all stars is in reality a kind of music propagated through this interstellar air.' The phenomena of heat is attributed to the vibrations of this ether. He says: 'We must not only figure our atoms suspended in this medium, but also we must figure them vibrating in it. In this motion of the atoms consists what we call their heat. Well, we must figure this motion communicated to the medium in which the atoms swing, and are sent in ripples through it with inconceivable velocity to the bounds of space. Motion in this form, unconnected with ordinary matter but speeding through the interstellar medium, receives the name of radiant heat; and if it is competent to excite the nerves of vision, we call it light.' "

"It is generally believed by men of science that the interior of the earth is a mass of molten matter, the heat of which is intense beyond that which can be produced by known artificial modes. Many of the rocks that form the crust of the earth appear to have been once in a fluid condition. Dr. Siljeström, a Swedish astronomer, expresses it as his belief that the interior of the earth is occupied by currents of various degrees of heat, which mix with each other and attain a certain degree of temperature in the same manner as substances subjected to all the physical influences of the earth's exterior. In other words, the theory is that a mass of fluid, possessing different temperatures in different parts of its interior, must be subjected to a process of convection. The result is usually a change of volume in the entire mass of circulating fluid, causing eruptions like those of volcanoes."

Think what you might do with a material



that's 97% nothing.

Scott industrial foam isn't like other foams. It has open pores, no windows. And it's 97 per cent void. What's left is a three-dimensional structure of polyurethane strands. Cell size is closely controlled, ranging from 10 to 115 pores per linear inch.

Scott industrial foam has special properties that make it useful in all sorts of applications.

It's a great filter, for instance—traps dust and dirt without using messy oil. And you can clean it easily by washing or vacuuming. (Special additives are available to give it flame-retardant or anti-bacterial properties.)

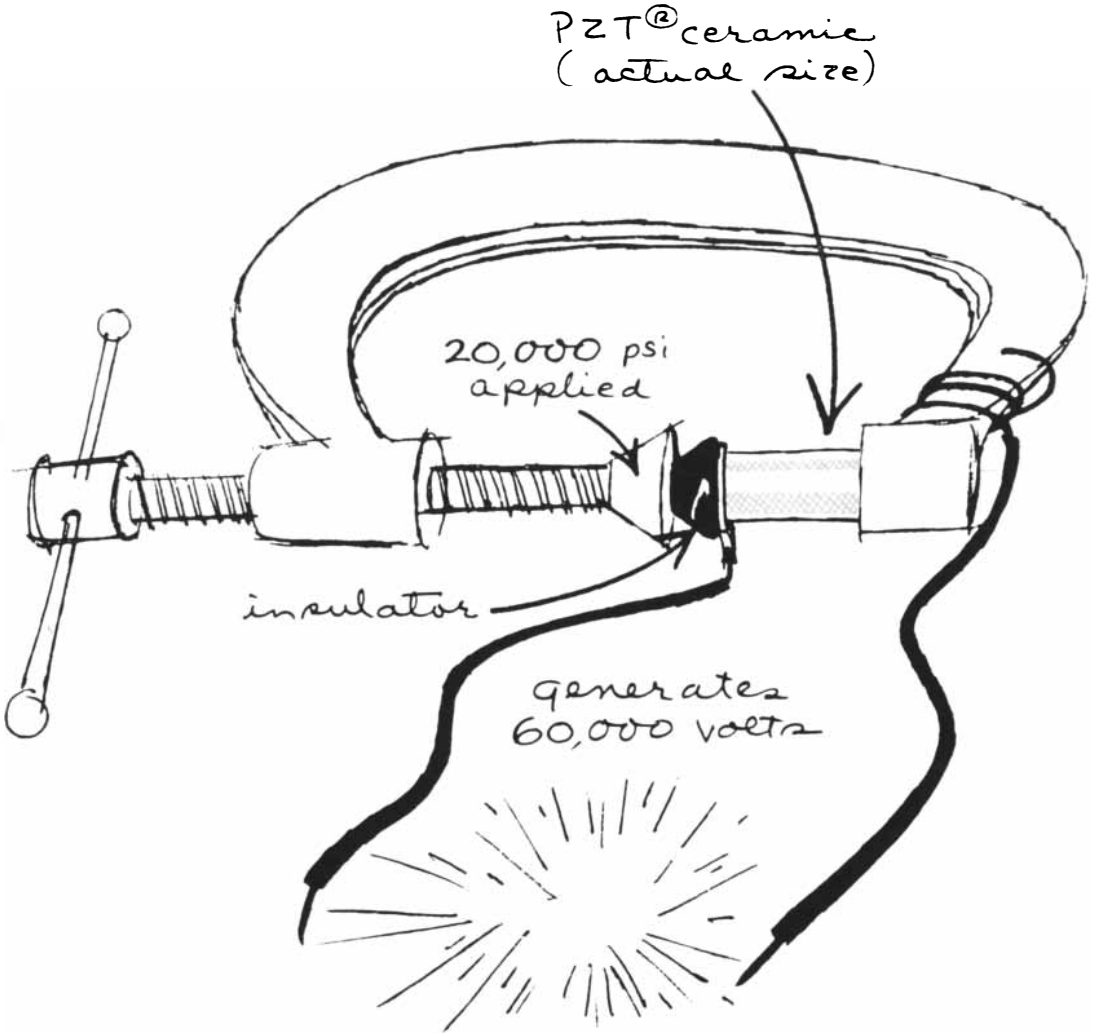
Good for demisting or mist agglomeration, too. Air passes freely through the open pores as the network of strands traps the moisture.

It makes an excellent humidifier pad. Water is readily dispersed on the skeletal structure where the freely-moving air picks it up.

It's fine for coalescing. You can choose surface areas from 150 square feet per cubic foot (10-pore foam) to 2000 square feet per cubic foot (115-pore foam).

Light, easy to work with, Scott industrial foam can be glued, grommeted, stapled or sewn. Designers have found many new uses for it. Maybe you will, too. Write for samples and more facts: Edgar C. Mack, Manager Industrial Sales, Foam Division, Dept. A, Scott Paper Company, Chester, Pa.

SCOTT MAKES IT BETTER FOR YOU

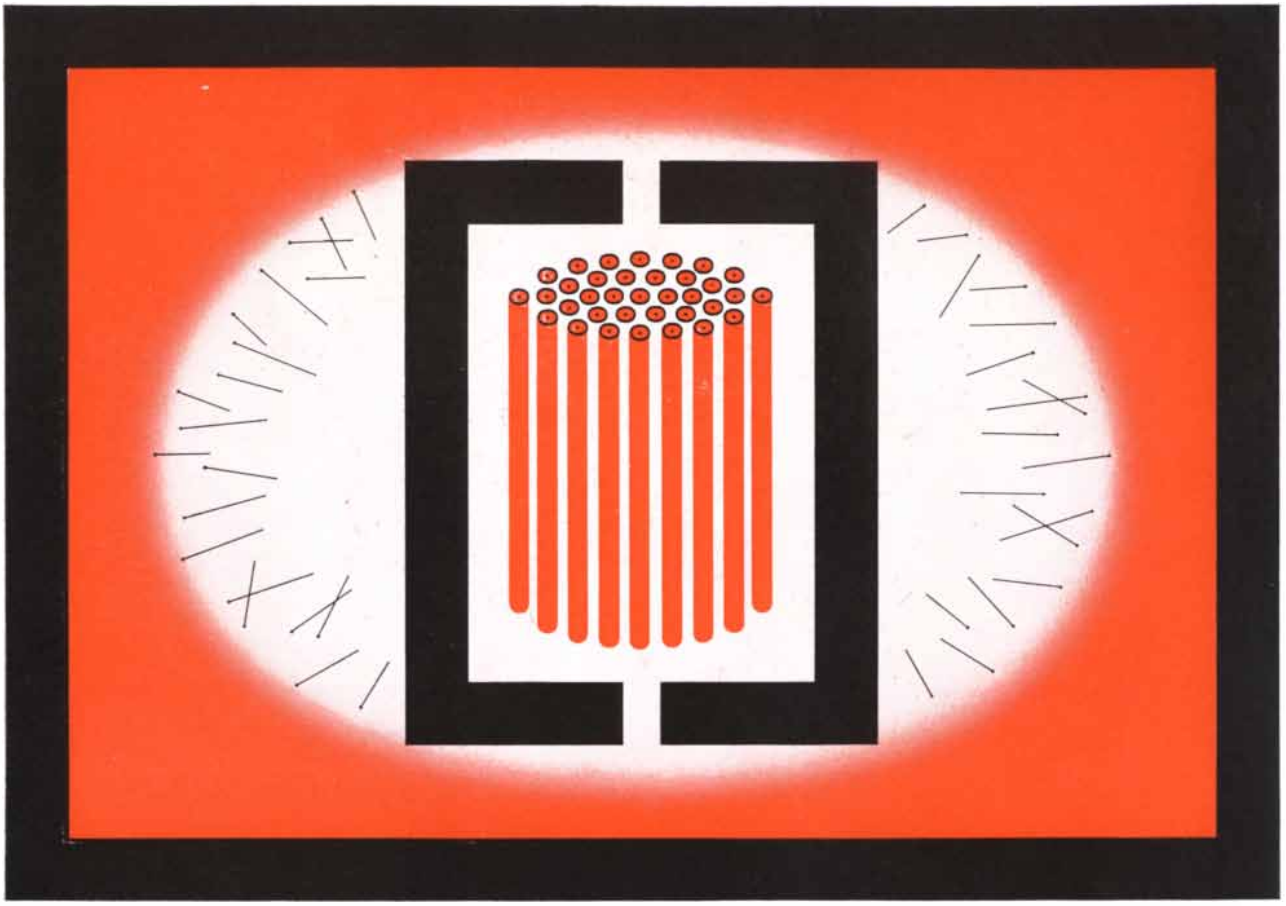


Why are piezoelectric transducers practical?

Piezoelectric ceramics are providing new solutions to electromechanical transducer design problems in applications ranging from satellite sensing devices and interstellar navigation to household appliances. Although the requirements of these transducers differ widely, they have one common tie. The particular specifications of each happen to be very well suited to the nature and characteristics of piezoelectric ceramic transducers.

Unfortunately, there is no general rule of thumb that tells the designer in twenty five words or less whether or not some piezoelectric ceramic transducers will be an efficient, economical answer to his electromechanical design requirement. Like most successful designs, the practical piezoelectric transducers now in use are the sum of hard work and inventive imagination. If you are interested in applying either to an electromechanical transducer design problem, we will send you our new bulletin #9248, "Piezoelectric Ceramic Design Data."

PIEZOELECTRIC
DIVISION/CLEVITE
232 FORBES ROAD, BEDFORD, OHIO



ACHIEVEMENTS IN HIGH TEMPERATURE REACTOR TECHNOLOGY

1250°F LONG-DURATION FUEL ELEMENTS—AnAGN BeO-UO_2 element has been successfully tested for 10,000 hours at 1250°F. Demonstrating long-term endurance for the ML-1 gas-cooled reactor, this run broke all temperature-time records.

1850°F MATERIALS FOR COMPACT LIQUID-METAL REACTORS—AGN has pumped cesium through a columbium loop for over 2,000 continuous hours of unattended operation at 1850°F.

2260°F FEASIBILITY OF LIGHTWEIGHT SPACE POWER SYSTEMS—AGN has successfully generated 74 watts of electricity from a thermionic cell using lithium at 2260°F pumped through a columbium loop.

4500°F SPACE PROPULSION REACTOR FUEL ELEMENTS—Economical manufacturing processes by extrusion for graphite and tungsten fuel elements capable of 4500°F operation have been reduced to practice—an AGN first.

For further information on advances in the field of nuclear materials, write for AGN Active File No. 6:

AGN

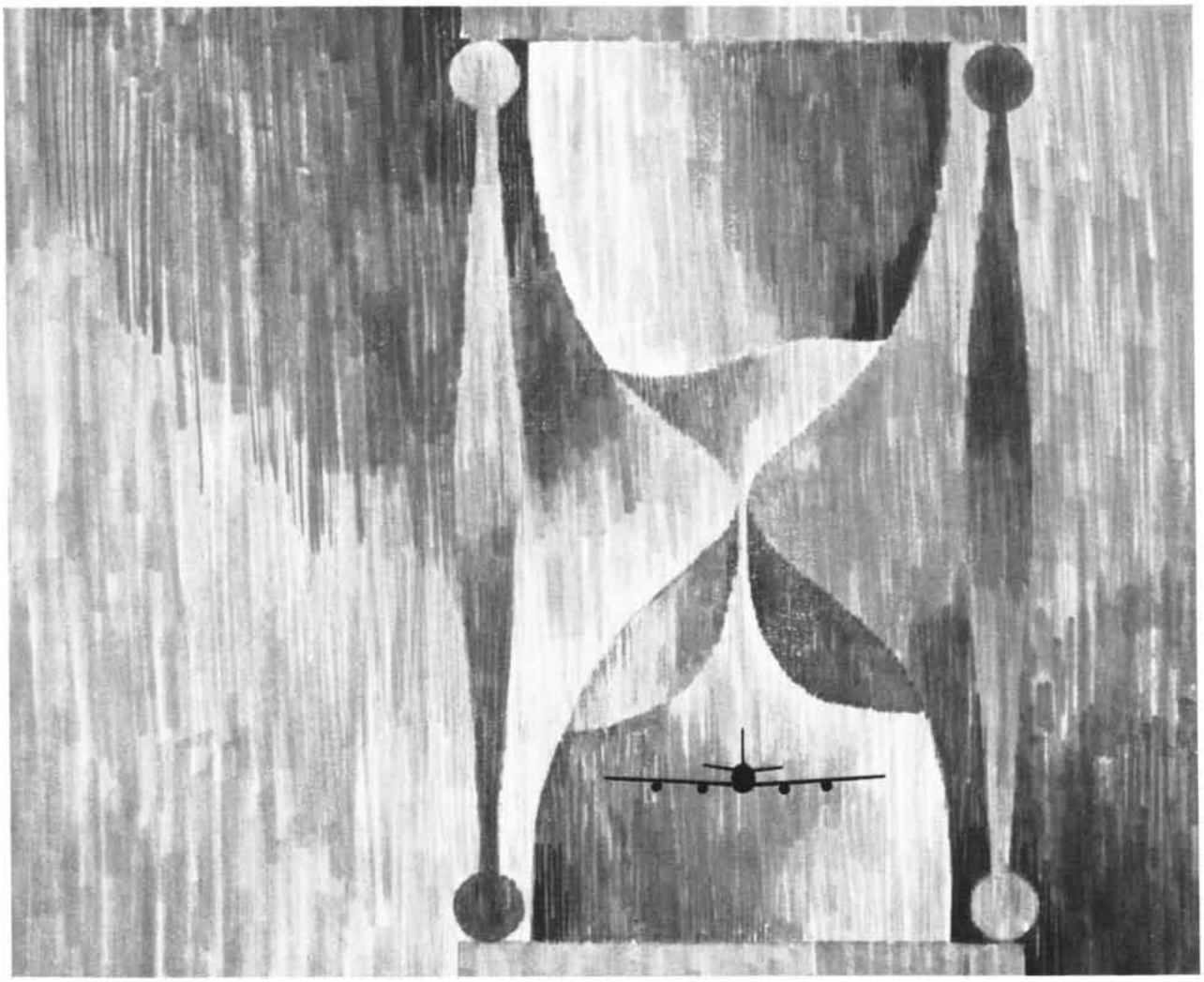
AEROJET-GENERAL NUCLEONICS/San Ramon, California

GENERAL TIRE T.M.

AEROSPACE GERIATRICS

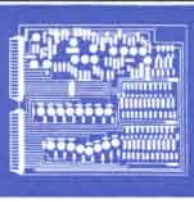
...AND WHAT DOUGLAS IS DOING ABOUT IT

In aircraft parts, as in men, excessive stress accelerates the aging process. And stress aging per hour varies for each aircraft. Yet the present way of determining servicing schedules is based primarily on hours flown. □ Now Douglas researchers have developed a device which, when installed on an aircraft, provides a more positive method of determining check-up times for aircraft parts. □ Called a "Service Meter," and weighing less than 1½ pounds, the Douglas unit computes the accelerations encountered by its aircraft in relation both to number and severity. It allows servicing to be performed on the basis of the true *work age* of parts, and will be an important aid to maintenance procedures that keep aircraft young. □ Research like the foregoing has helped build the Douglas reputation for producing the world's most reliable aircraft.



The "Service Meter" is the result of one of the more than 500 research programs under way at Douglas. Some relate to present programs like SATURN S-IVB, ZEUS, DELTA, DC-8F and SKYHAWK. Others are oriented on great aerospace developments of the future.

DOUGLAS

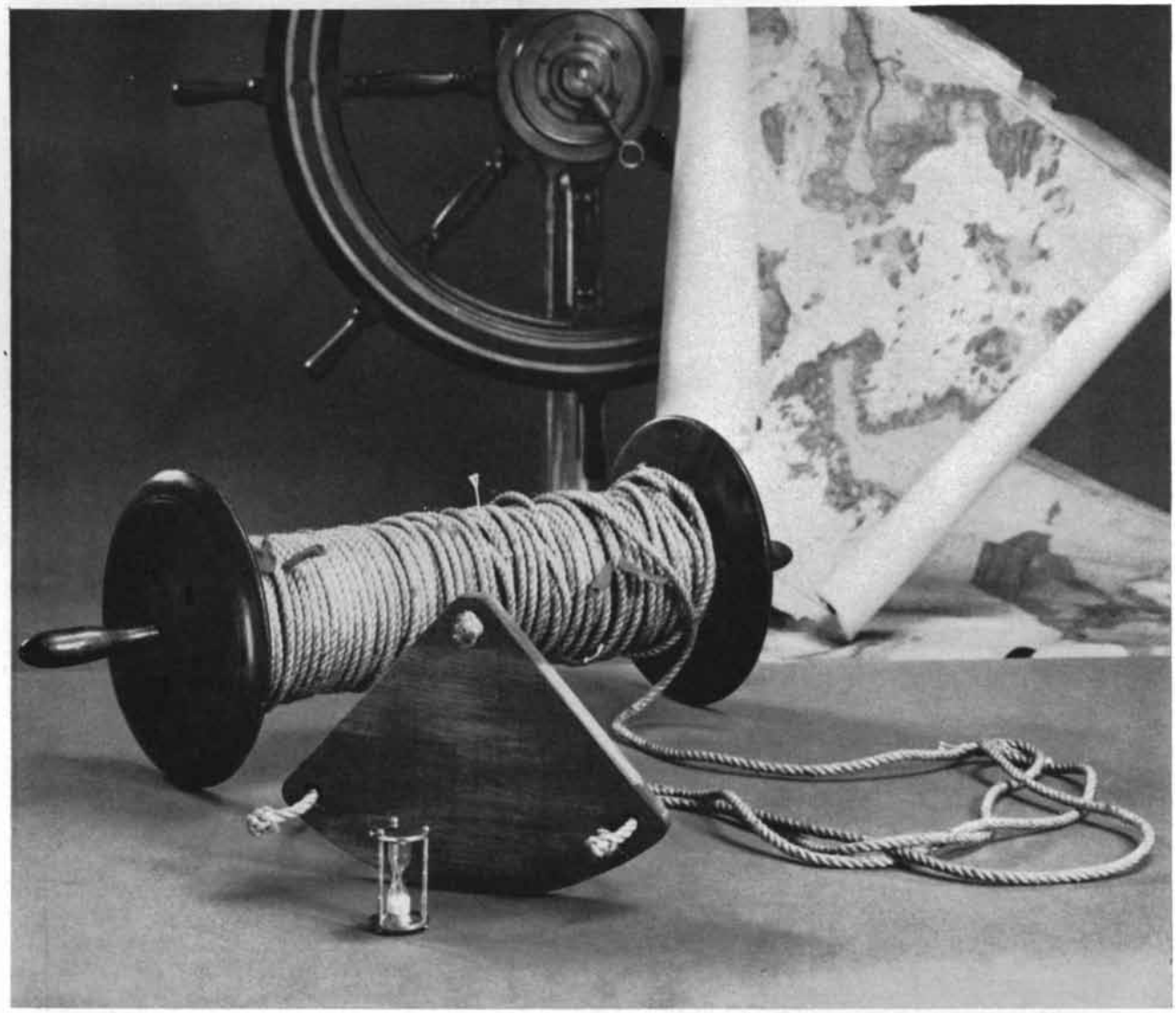


FOR SERVICE BEYOND THE CALL

The telephone, your obedient servant, is learning new ways to assist you. Many conveniences, available today in private automatic exchanges for business, may soon be introduced to telephone users generally. Call Forwarding, for example, permits you to instruct your exchange to transfer your calls—just by dialing a code and any desired transfer number. Calls to busy lines will be completed automatically—as soon as the lines are free. You'll be able to set up conference calls, or tie in to paging systems, by dialing appropriate codes. / These and other new services are provided for by a new electronic switching system developed by an ITT company. All solid-state, with printed circuit modules, a file-cabinet-sized unit replaces a roomful of conventional equipment. / This major advance in telephony typifies ITT's pioneering approach to communication techniques. ITT introduced long distance subscriber-to-subscriber dialing in Morocco as early as 1932. Today this service is widely implemented in Europe and the U.S. ITT is credited with basic development work in TV...radar...microwave ...data communications...mobile, maritime, airborne and spaceborne communications. Through this work, ITT has earned its position as the world's largest international supplier of electronics and telecommunications./ International Telephone and Telegraph Corporation. World Headquarters: 320 Park Avenue, New York 22, N.Y.

worldwide electronics and telecommunications ITT

FROM CHIP LOG TO ACCELEROMETER



Chip Log (19th Century)—The earliest device known to measure a ship's speed. The chip was attached to a line knotted at specific intervals and drawn through the water during a measured 30 seconds. The knots were then counted, indicating the nautical miles per hour the ship was making. (Dossin Museum)

ACCURATE, RELIABLE COMPONENTS DELIVERED ON TIME, AT LOW COST

AC develops and produces guidance and navigational components as well as complete navigation systems. AC aided in the development of, and is now producing, pendulous integrating gyroscopes and inertial reference integrating gyroscopes for the Navy's POLARIS Missile Program. In addition, AC-produced gyros and accelerometers have provided the heart for each AC-guidance system, including the All-Inertial Guidance Systems for the TITAN II, THOR and MACE. AC-produced instruments will be used in the development of an inertial platform for the APOLLO spacecraft and a guidance system for the TITAN III.

Our record proves our ability to develop and produce precision guidance system components, and to deliver them on time, at low cost. We welcome the challenge to prove our capabilities and solve your guidance problems. Contact Director of Sales, AC-Milwaukee.

AC ACCELEROMETERS—These instruments measure the linear acceleration of missiles, aircraft, space vehicles and ocean vessels and convert this information into velocity data. This and other computed data are compared to the vehicle's predetermined course, sensing any deviation from the intended line of motion.

MASTER NAVIGATORS THROUGH TIME AND SPACE

AC SPARK PLUG • THE ELECTRONICS DIVISION OF GENERAL MOTORS

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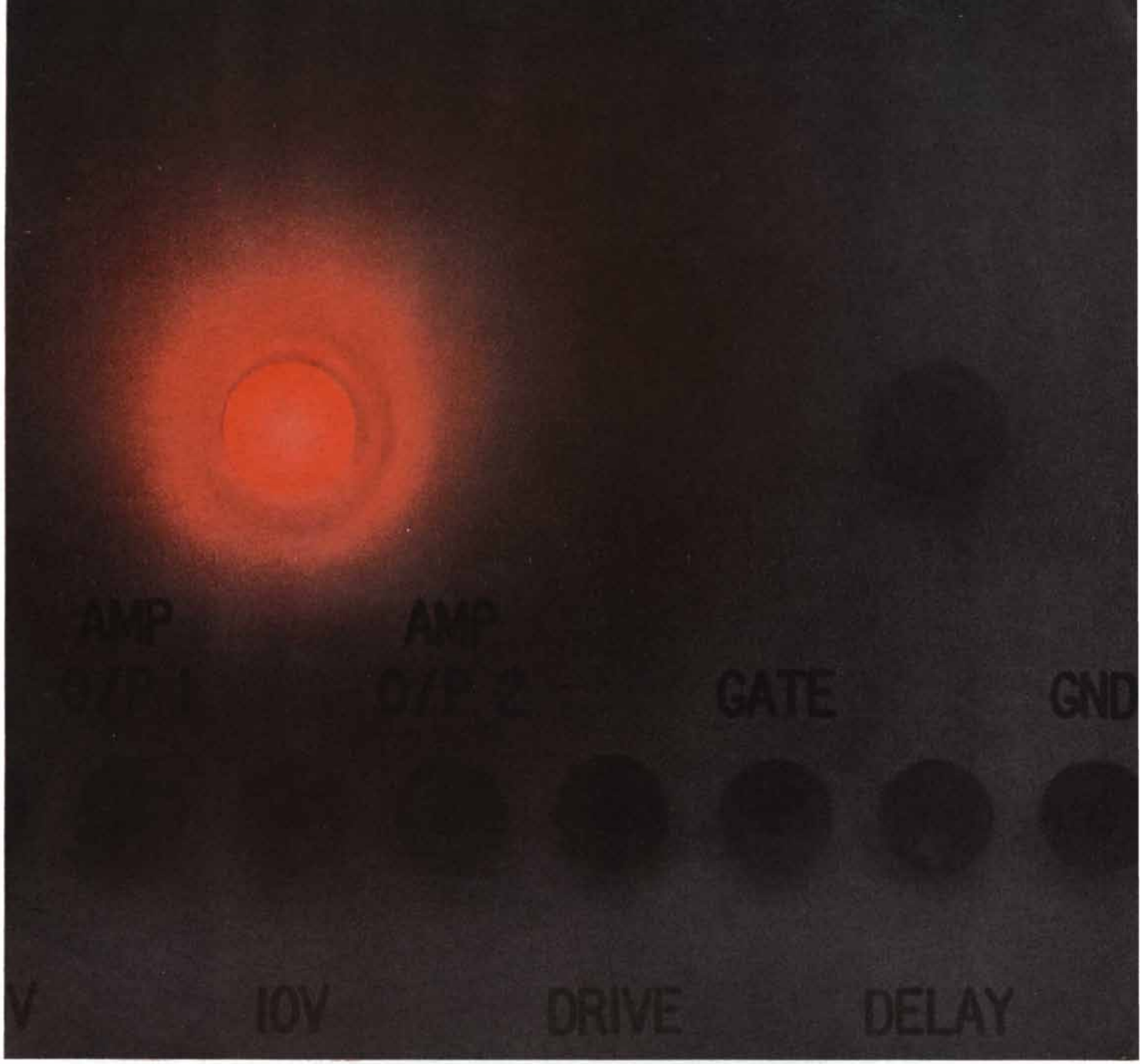
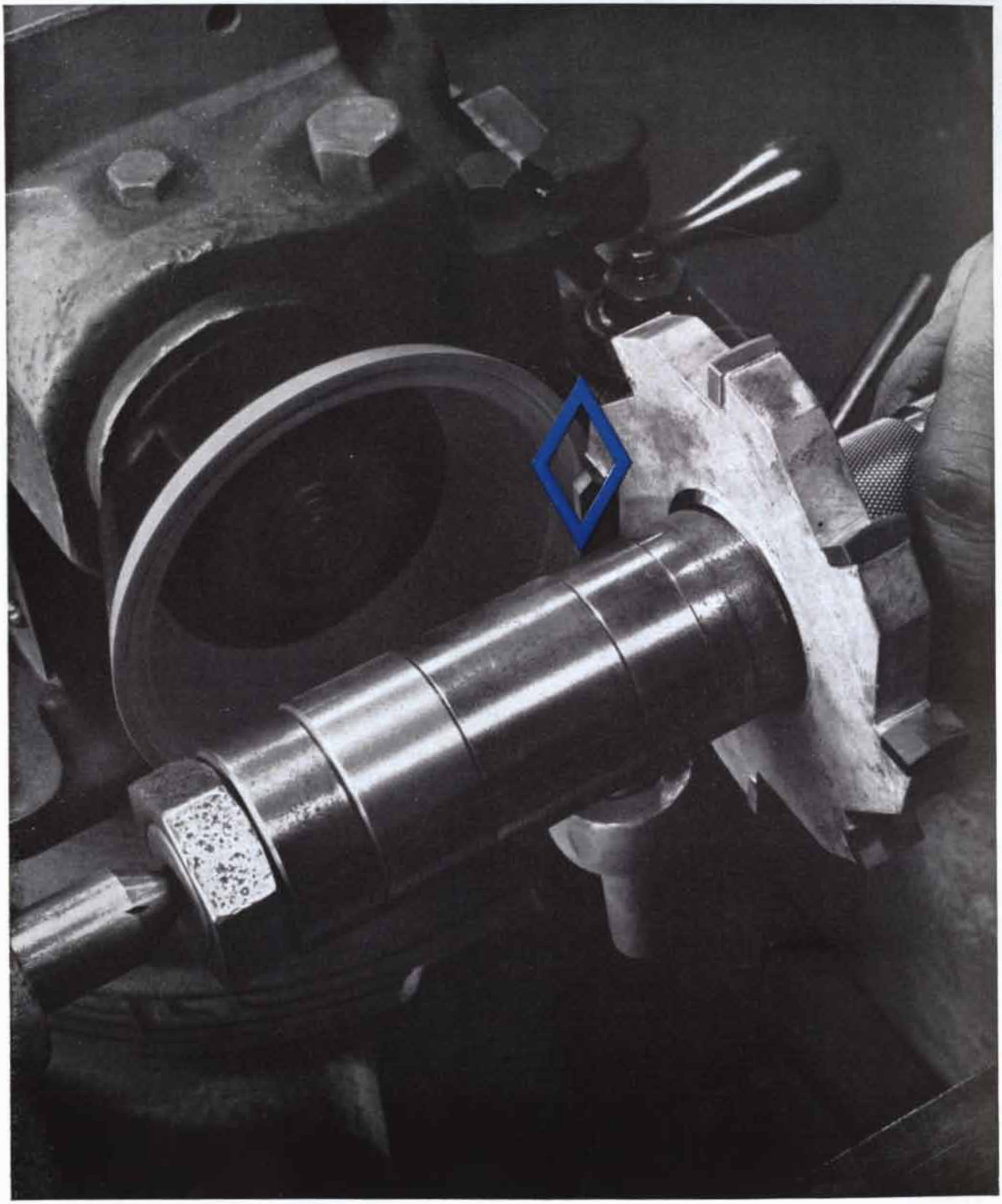


We see red over next to nothing.

You are looking at the most sensitive machine ever developed for the measurement of electrical leakage in transistors. It's Fairchild's new low-leakage tester . . . and it lights up when it detects a flaw as small as *one-trillionth* of an amp. (That's one-trillionth of the current you'd need to light an ordinary house bulb!) We designed this new device to spot the smallest deviation from standard in Fairchild transistors – and we made it a hundred times more sensitive than any other such machine. The reason? As long as we see red over the tiniest imperfection – no one else will.

FAIRCHILD
SEMICONDUCTOR

FAIRCHILD SEMICONDUCTOR/545 WHISMAN RD., MOUNTAIN VIEW, CALIF./YORKSHIRE 8-8161/TWX: MN VW CAL 853/A DIVISION OF FAIRCHILD CAMERA AND INSTRUMENT CORPORATION



Diamond grinding wheel finishes carbide-tipped milling cutter to exact specifications at Nelco Tool Co., Manchester, Conn. Finishing is performed dry with resin-bonded wheel containing 130-mesh natural-diamond grit. One such diamond wheel will outlast grinding wheels containing other abrasives by at least 25 to 1 with far higher standards of precision. Diamond wheels are also used to form and finish end mills, counterbores, drills and other carbide cutting tools.

EACH OF THESE JOBS IS DONE BETTER WITH NATURAL DIAMONDS

The grinding and finishing jobs shown on these pages are being performed on abrasive wheels, laminated plastic, and carbide tools. Yet they share one important detail: in every instance, natural diamonds are doing the job quickly—and economically.

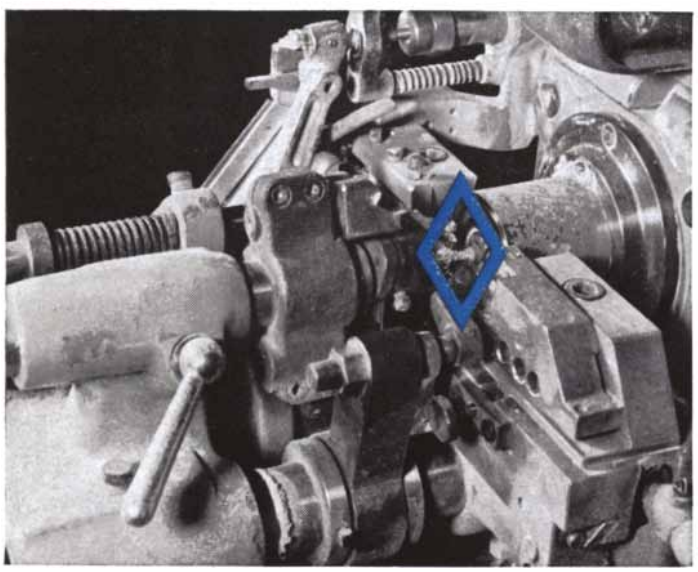
When you use diamonds, you get the unique combination of excellent cutting ability linked with fantastic endurance. Result: your diamond tools last longer than any other tools you can use. Your people spend more time producing, less time changing tools.

If you cut, sharpen or smooth anything in your business, you can probably use natural diamonds to advantage. Test them against the method you're using now. You'll see how efficient—and economical—a diamond tool can be.

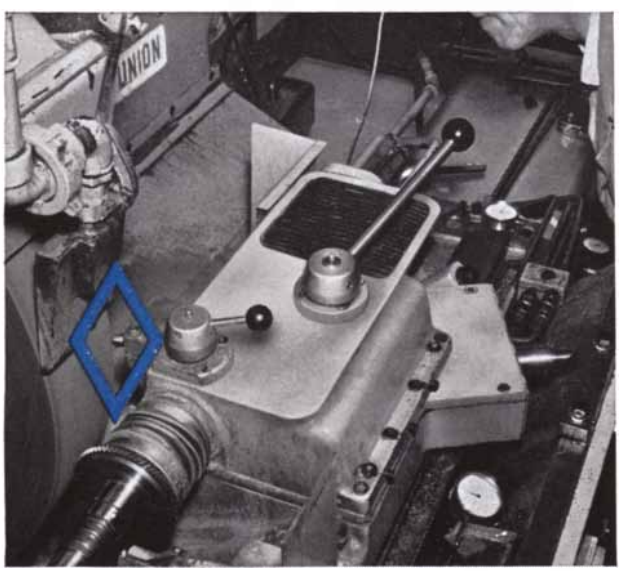
BEST GRIT FOR METAL-BOND WHEELS DEVELOPED BY THE DIAMOND RESEARCH LABORATORY IN JOHANNESBURG

A special impact crushing method for natural diamonds is producing the strongest and most durable grit ever obtained for metal-bond wheels. Your tool and wheel manufacturer is ready to help you select the diamond tool that's right for your job.

Diamond-tipped reamers bore inside diameters of automotive distributor-arm bushings at Synthane Corp., Oaks, Pa. Natural diamonds make the ideal cutting edge for long production runs and close tolerance required to produce these tough laminated plastic bushings. Wide range of reamer sizes is used in the manufacture of more than 18 million bushings annually.



By combining one wide-faced wheel with a cam-guided natural-diamond dressing tool, Borg-Warner, Letchworth, England, simultaneously grinds four diameters on output shaft of new transmissions for smaller cars. Four diameters are ground to .0005-inch accuracy and about 20-micro-inch finish in one operation. Carbide-tipped tracer (right) follows profile of cam and guides diamond tool (left) across face of aluminum oxide grinding wheel.



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THE AUTHORS

GILBERT F. WHITE ("The Mekong River Plan"), professor of geography at the University of Chicago, is a student of water resources problems, including the social and economic aspects of floods and of river development. He received a B.S., an M.S. and a Ph.D. from Chicago and worked on water conservation and development problems for the U.S. Mississippi Valley Committee, the National Resources Planning Board and the U.S. Bureau of the Budget. White has been an adviser to a number of national and international water and power development commissions and study groups, and during 1961 and 1962 was a consultant to the co-ordinating committee planning the vast river development of which he writes in this issue. A Quaker, he served with the American Friends Service Committee from 1942 to 1946 and was president of Haverford College from 1946 to 1955. He went to the University of Chicago the following year. This year he is in England, lecturing at the University of Oxford and other institutions.

MARTHA and WILLIAM LILLER ("Planetary Nebulae") are respectively lecturer in astronomy at Wellesley College and Robert Wheeler Willson Professor of Applied Astronomy at Harvard University. Martha Liller, who is also a Research Fellow at the Harvard College Observatory, took an A.B. at Mount Holyoke College and an M.A. and a Ph.D. at the University of Michigan. It was as a beginning graduate student at Michigan that she met her future husband, who was at that time instructor in astronomy. William Liller, who is currently chairman of the department of astronomy at Harvard, received an A.B. at Harvard and an M.A. and a Ph.D. at Michigan. Following their marriage in 1959, the Lillers remained at Michigan for a year before taking their present jobs.

GLENN T. SEABORG and ARNOLD R. FRITSCH ("The Synthetic Elements: III") are respectively chairman of the U.S. Atomic Energy Commission and technical assistant to the chairman. Seaborg is best known for his work in synthesizing elements heavier than uranium. Following the identification of element 93 (neptunium) by E. M. McMillan at the University of California at Berkeley in 1940, Seaborg and his co-workers proceeded to synthesize elements 94 (plutonium) through 98 (californium), the last in 1950. For this work he shared with McMillan the 1951 Nobel prize for chemistry. Since then Seaborg and his co-workers have synthesized five more transuranium elements. The synthesis of the last two is described in the present article. All of this work was done at Berkeley, where Seaborg obtained a Ph.D. in 1937. During World War II he was chiefly responsible for the development of the chemical-separation procedures used in the manufacture of plutonium. Returning to Berkeley in 1946, he served as chancellor of the University of California from 1958 until his appointment as chairman of the AEC in 1961. Fritsch, who took a Ph.D. in chemistry at Berkeley in 1957, had served as an AEC assistant in nuclear energy at Berkeley, as a senior engineer in nuclear physics for the Westinghouse Electric Corporation and as chief of the Technical Branch of the AEC's Division of International Affairs before going to his present job in 1961.

J. TUZO WILSON ("Continental Drift") is professor of geophysics and director of the Institute of Earth Sciences at the University of Toronto. Wilson first studied at Toronto, taking an A.B. there in 1930, and then at the University of Cambridge, where he received an A.B. and M.A. in 1932. In 1936 he acquired a Ph.D. from Princeton University and for the next three years was an assistant geologist with the Geological Survey of Canada. His service with the Royal Canadian Engineers for the duration of World War II brought him an Order of the British Empire and the Legion of Merit. He became professor of geophysics at Toronto in 1946 and director of the Institute in 1960. From 1957 to 1960 Wilson was president of the International Union of Geodesy and Geophysics. A traveler on seven continents, Wilson is the author of *One Chinese Moon,* an account of his month's visit to China in 1958 for the purpose of studying the state of geophysics there.

FREDERIC VERZÁR ("The Aging of Collagen") has taught and done research in physiology since 1914. He was born and educated in Budapest, lectured in physiology before World War I and in 1918 became professor at the medical school of the University of Debrecen in Hungary. In 1930 he went to the University of Basel in Switzerland, where he taught until his retirement in 1956 to found the Institute for Experimental

Nitrogen at work!

TODAY . . . bringing "space" down to earth to test satellite components

TOMORROW . . . sheltering laser beams carrying telephone conversations, TV programs or data transmissions cross-country

Think of it . . . tens of thousands of telephone conversations transmitted simultaneously on a single laser beam! But the required straight-line transmission must be protected from refraction by moisture . . . must be sheltered by a dry, inert nitrogen atmosphere. Other Divisions of General Dynamics are now crossing the threshold of the Laser Age—and Liquid has the capability of providing the nitrogen that can bring the laser out of the laboratory into the practical world of communications.

Dept. SCA, 135 South LaSalle Street, Chicago 3, Illinois
In Canada: Liquid Carbonic Canadian Corporation, Limited, 8375 Mayrand Street Montreal 9, Quebec

A Major Supplier of Cryogenic Gases

Liquid 75th year

LIQUID CARBONIC
DIVISION OF **GENERAL DYNAMICS**

Gerontology in that city. Verzár's research has been concentrated in three major areas: absorption from the intestine, the physiology of the adrenal cortex and the aging process.

MARTIN SCHEERER ("Problem-solving") was professor of psychology at the University of Kansas when he died in 1961. The article presented under his name was assembled from his writings by his friend and former colleague Irvin Rock, professor of psychology at Yeshiva University. Scheerer was graduated from the University of Berlin and received a Ph.D. from the University of Hamburg, where he taught psychology from 1930 to 1933. After coming to this country he taught psychology at the University of Louisville, practiced clinical psychology at Montefiore Hospital in New York and taught at Wells College, Brooklyn College, the College of the City of New York and the New School for Social Research. He went to the University of Kansas in 1948.

ROBERT S. WOODBURY ("The Origins of the Lathe") is professor of the history of technology at the Massachusetts Institute of Technology. Woodbury was graduated from M.I.T. in 1928 and studied mathematics there while teaching English literature and history. In 1936 he received an M.A. from Harvard University, where he studied the history of ideas and the history of science for two more years while teaching both subjects at M.I.T. During World War II Woodbury was on active duty with the Navy and later served on the staff of the Smithsonian Institution before returning to M.I.T.

HOWARD E. EVANS ("Predatory Wasps") is associate curator of insects in the Museum of Comparative Zoölogy at Harvard University. Evans received a B.A. from the University of Connecticut in 1940, an M.S. from Cornell University in 1941 and a Ph.D. from the latter institution in 1949, having served in the Army from 1942 to 1945. From 1949 to 1952 he taught at Kansas State College. For the next eight years he was on the faculty at Cornell, going to his present job in 1960. He was a Guggenheim Fellow in 1959. His work on the ethology of wasps has been supported by grants from the National Science Foundation.

DENNIS H. WRONG, who in this issue reviews Philippe Ariès' *Centuries of Childhood,* is associate professor of sociology on the graduate faculty of the New School for Social Research.

This car won't do 150. It just looks like it will.

But it will do an honest 106 mph. And for $3995* the Volvo P1800 gives you the Gran Turismo features that 150 mph cars give you for $10,000: disc brakes, 4-speed synchromesh gearbox, complete instrumentation including tachometer and electric clock, independent front suspension, precise steering, European styling and coach work. As Road & Track magazine wrote, "The P1800 is a very civilized touring car for people who want to travel rapidly in style, a Gran Turismo car of the type much in the news these days—but at a price that many people who cannot afford a Ferrari or Aston Martin will be able to pay." One more thing. The P1800 is at your dealers now and you can take it home for a test drive. Alone. Try *that* with one of those $10,000 jobs. Unh-uh.

VOLVO

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Be fussy

Two things determine whether or not a particular printed circuit connector is "right" for your application:

1. How the printed circuit board mates with the connector, and

2. How the connector connects to the rest of the system.

Take mating, for example. Besides having the correct number of contacts, a printed circuit connector must hold the board securely whether the board happens to fall at the high or low end of thickness tolerances.

IT TAKES THREE

These considerations convinced Amphenol engineers that no single contact design could satisfy the requirements of a wide range of applications. So they designed three contacts that will.

One, used in Prin-Cir* connectors, looks a lot like a tuning fork with lips. The circle lip design makes contact overstressing or "setting" impossible —even after repeated insertions. The contact's long spring base also enables it to accommodate boards that range in thickness from .055″ to .073″, while doing an excellent "wiping" job.

EASY DOES IT

But not every application requires the Prin-Cir "bite." For this reason, Amphenol engineers designed connectors with ribbon contacts that mate with a gradual wedge-like force. In blind mating applications, gradual mating makes the feeling of *correct* mating unmistakable. (Just the thing when your equipment may eventually be maintained by less-skilled and less-concerned personnel.) Ribbon contact wedge action also makes it possible for connectors using these contacts to accept the same wide range (.055″ to .073″) of board thicknesses as do Prin-Cir connectors.

Finally, advances in micro-miniaturization (like Amphenol-Borg's Intercon® pre-fabricated circuitry) meant that tinier-than-ever-before connectors were needed. Amphenol's answer was the Micro-Min® receptacle and printed circuit board adapter. Micro-Min contacts are actually tiny springs of beryllium copper wire, formed in a precisely designed arc to assure firm circuit board retention. This unique design makes it possible to space contacts on .050″ centers and crowd 19 connections into a little more than an inch of space.

TERMINATIONS COUNT, TOO

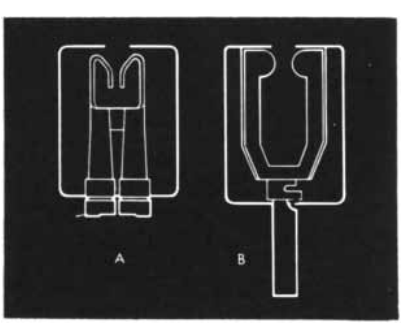
"How to connect connectors to the rest of the system" also merits a good deal of consideration. In some cases, hand soldered terminations will do just fine. In others, higher volume requirements call for high production rate methods like dip soldering and wire-wrapping. Some engineers prefer taper pin terminations.

Our printed circuit connectors are available with contact tails designed for each of these termination methods. In addition, adapters are available for use in connecting printed circuit boards at right angles to each other or in modular arrangements. We make printed circuit connectors with hermetically sealed contacts — still others with coaxial contacts.

Take your choice.

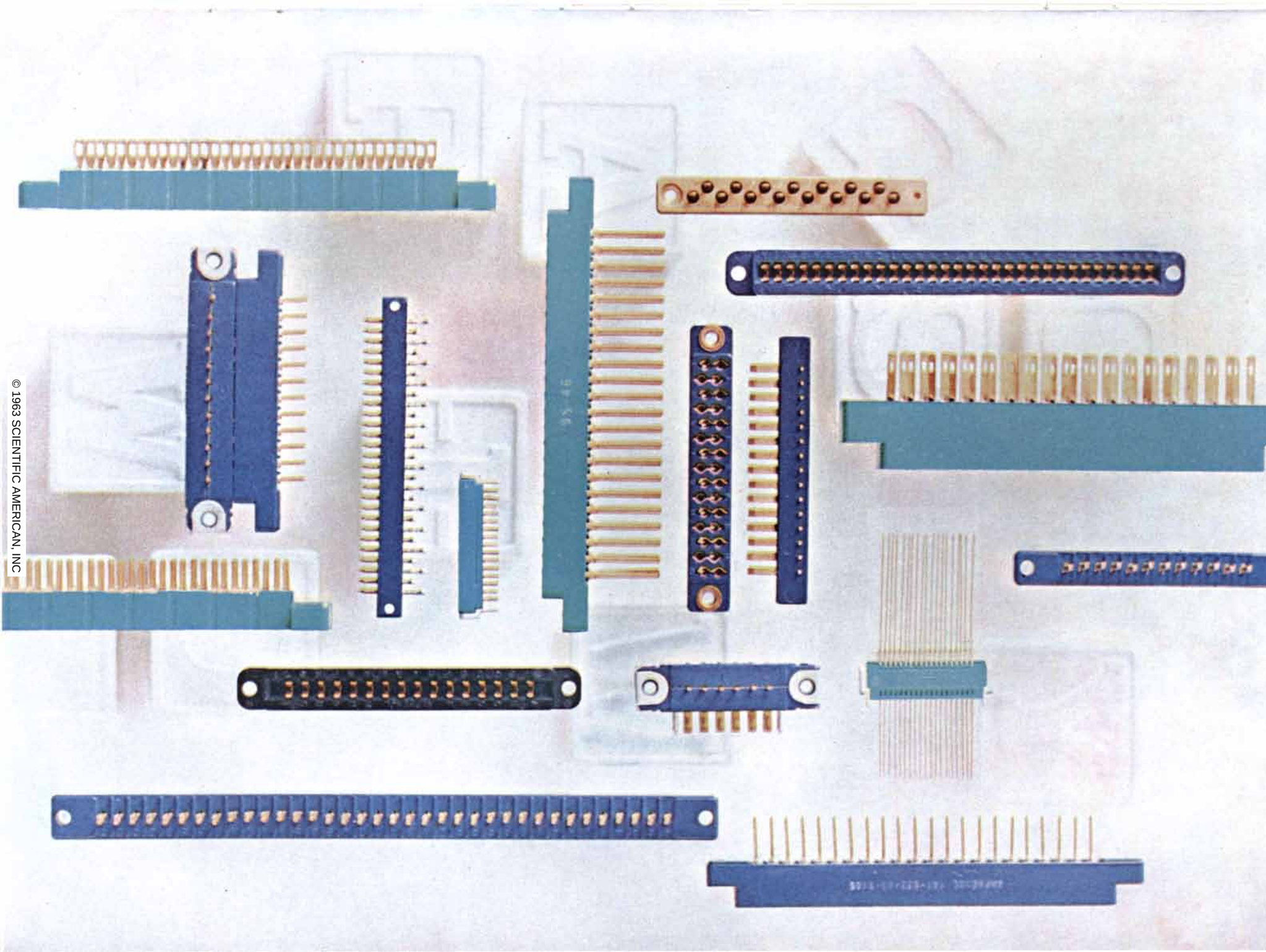
Any Amphenol Sales Engineer or authorized Amphenol Industrial Distributor will be happy to discuss printed circuit connectors (ours) with you. Or, if you prefer, write directly to Dick Hall, Vice President, Marketing, Amphenol Connector Division, 1830 S. 54th Avenue, Chicago 50, Illinois.

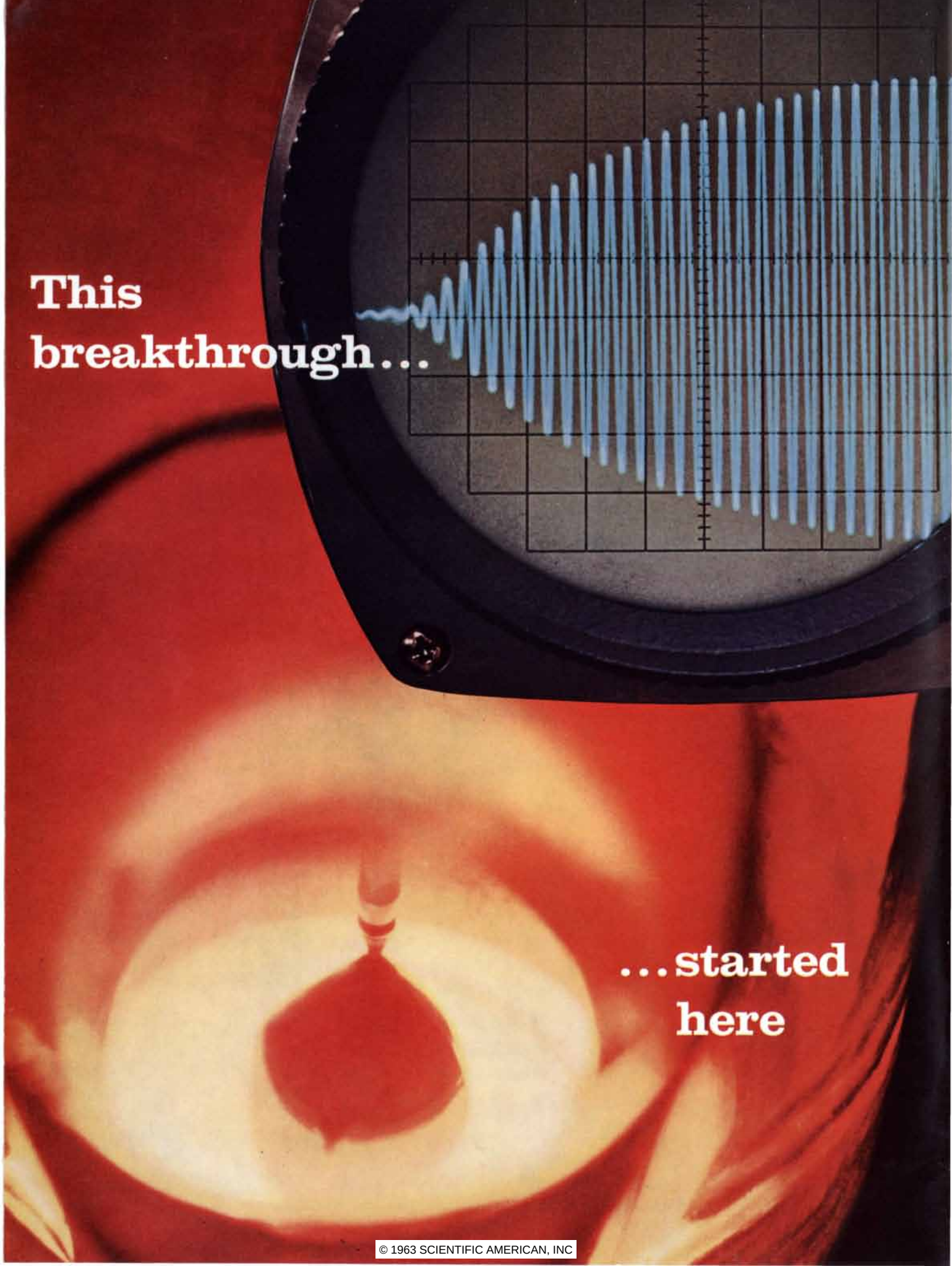
*T.M. Amphenol-Borg Electronics Corp.



Wedging action of Amphenol ribbon-type (A) and long spring base of Amphenol Prin-Cir connectors (B) assure firm printed circuit board retention, whether board happens to fall at low (.055″) or high (.073″) end of thickness tolerance.

AMPHENOL **Connector Division** / Amphenol-Borg Electronics Corporation





PROGRESS

in radio communication depends on continuing improvement in microwave technology. Despite steady advances in the generation and reception of microwave signals, the techniques for modulating these signals have remained relatively undeveloped.

Modulating, or varying the signal so that useful intelligence is carried, has been extremely difficult because of the nature of the klystron oscillator, the usual source of microwave signals.

Under previous conditions, for example, attempts to amplitude modulate the output of a klystron with a sine wave have resulted in major changes in the output signal's frequency. Attempts to pulse modulate klystron output also result in poor frequency stability of the modulated signal.

Now Hewlett-Packard, with a four-year research program, has developed a unique proprietary PIN (positive-intrinsic-negative) diode which permits, for the first time, normal amplitude and pulse modulation of high frequency signals without affecting the rf frequency. Where previous attempts to modulate klystrons involved changing the potentials on the klystron itself, the PIN diode affects only the *output* signal; the rf signal source is completely undisturbed during modulation.

The diode consists of a minute chip from a specially diffused silicon wafer in which the diffused P and N surfaces are separated by a layer of intrinsic silicon. At low frequencies this device operates as a typical diode rectifier, but at high frequencies it behaves as a high-speed voltage-programmable absorption-type attenuator, essentially as a linear microwave resistor whose resistance changes according to a bias potential. This bias potential is the modulating signal, the intelligence that varies the effective resistance of the diode. This, in turn, varies the amplitude of the output from the klystron by absorbing varying amounts of the rf energy.

Modulation of carrier signals is important both from the standpoint of transmitted information and from the standpoint of testing the performance of high frequency instruments and systems in the laboratory, to be sure their characteristics are such that they will be useful when finally given the supreme test—that of reaching areas as yet unexplored by man.

Hewlett-Packard's PIN diode, then, is a true contribution to the state of the art. Applications for high frequency modulation challenge the imagination. Incorporated in hp instruments, the PIN diode and its accompanying circuitry provide a practical innovation, a totally new capability in measurement.

The oscilloscope trace shows a 1000 mc uhf signal being pulse modulated by the new Hewlett-Packard PIN diode modulator. The twenty nanosecond rise time shown, completely freed from FM and jitter, has been impossible to achieve until now. The bottom area of the photograph shows one of the first stages in the manufacture of a PIN diode, the "growing" of the silicon wafer.

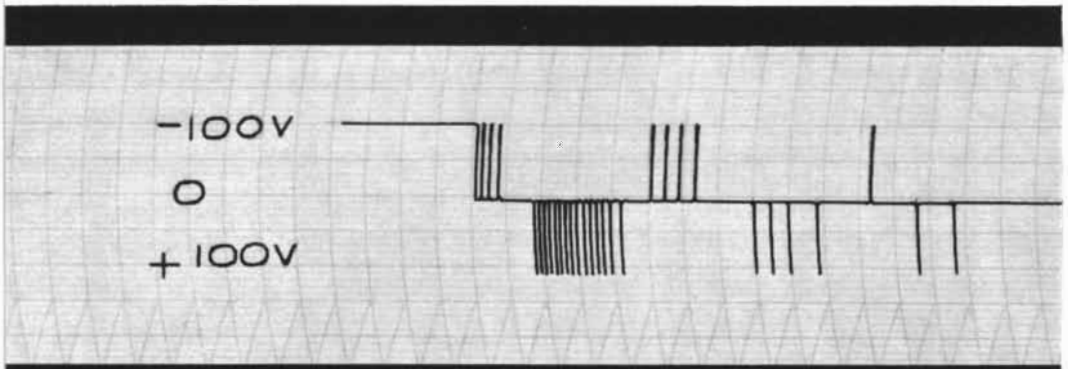
The Hewlett-Packard 8614A Signal Generator, which employs the PIN diode modulator, delivers precision uhf signals from 800 to 2400 mc and permits amplitude modulation of these signals from dc to 1 mc. Other modulation capabilities include signal leveling across the band, internal square wave, 800 to 1200 cps, and 0.5 μsec rise time. It features an output of at least 10 mw or a leveled output flat within ± 0.5 db. Price, $1650.

HEWLETT-PACKARD COMPANY

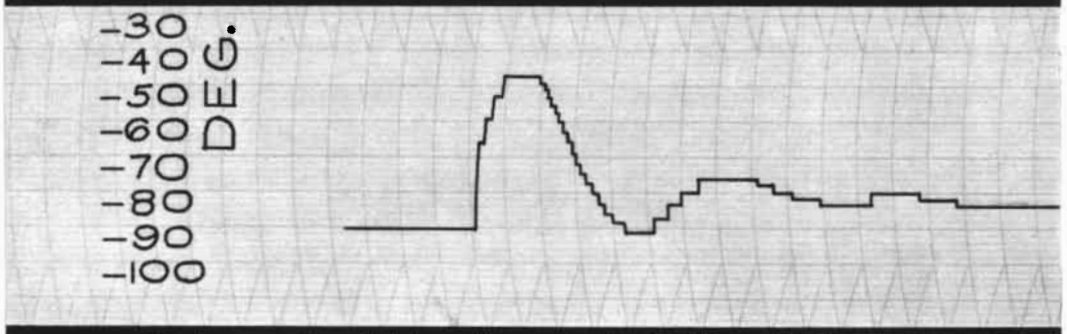
1501 Page Mill Road, Palo Alto, California

Divisions and Affiliates: Hewlett-Packard S.A., Geneva; Hewlett-Packard (Canada) Ltd., Montreal, Quebec; Boonton Radio Company, Dymec Division, Harrison Laboratories Division, HP Associates, F. L. Moseley Co., Sanborn Company. **Plants:** California, Colorado, Massachusetts, New Jersey; England, Germany.

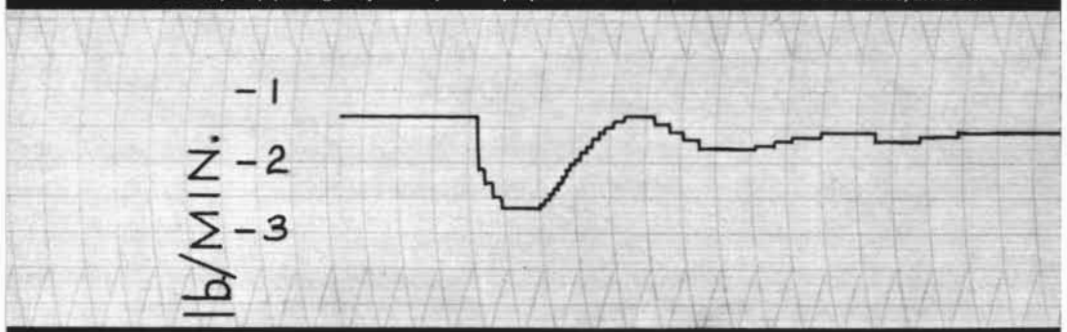
How can a "bargain" temperature control system perform like this?



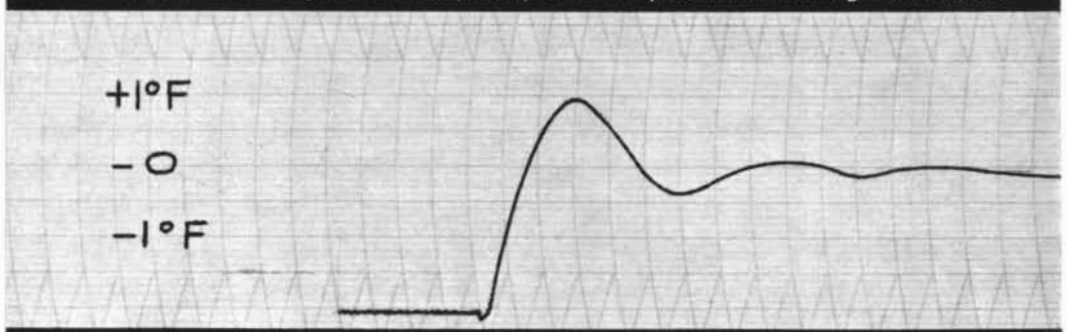
Command impulses to valve correct high temperature condition in critical area during initial cool down.



Valve in pump package adjusts to provide proper flow of coolant. Time scale is 60 seconds/division.

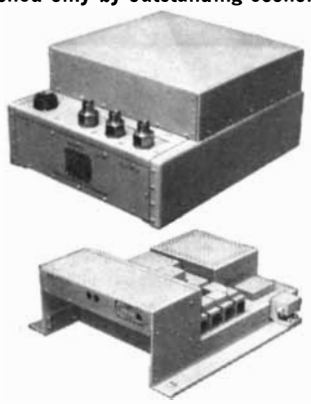


Coolant flow is directly related to valve position; "overshoots" present to overcome large thermal inertia.



Temperature at thermistor in critical area stabilizes at pre-set figure ±0.2° F. less than 9 minutes after start-up.

Chalk it up to experience. Since 1947, United Control has designed and manufactured a variety of reliable aerospace and industrial temperature control systems, proving them in the field, the laboratory, and with analog computer studies even before prototypes are produced. Today, nobody knows temperature control like United Control: each fresh requirement can be satisfied quickly and efficiently; after-delivery service is greatly simplified; and unsurpassed reliability is matched only by outstanding economy.



The dependable **1793-1 Temperature Control System,** used to regulate guidance compartment temperature in the newest of America's silo-stored ICBM's, was put through its paces by United Control's analog computer. The compact, lightweight system, consisting of a controller and a pump package, established the pre-set temperature with operating tolerance ±0.2°F. in less than 9 minutes (far better than required)... and is capable of maintaining this accuracy for full life. This system also provides many vital auxiliary functions: for example, an alarm signal if temperature errors exceed ±0.45 ±0.05°F. ...stoppage of non-system processes if temperature varies by over ±17°F. ...and constant readout for split-second determination of guidance compartment temperature. Both instruments can be stored for up to 5 years after delivery, then put in continuous, trouble-free service for 3 years ...a total life of 8 years!

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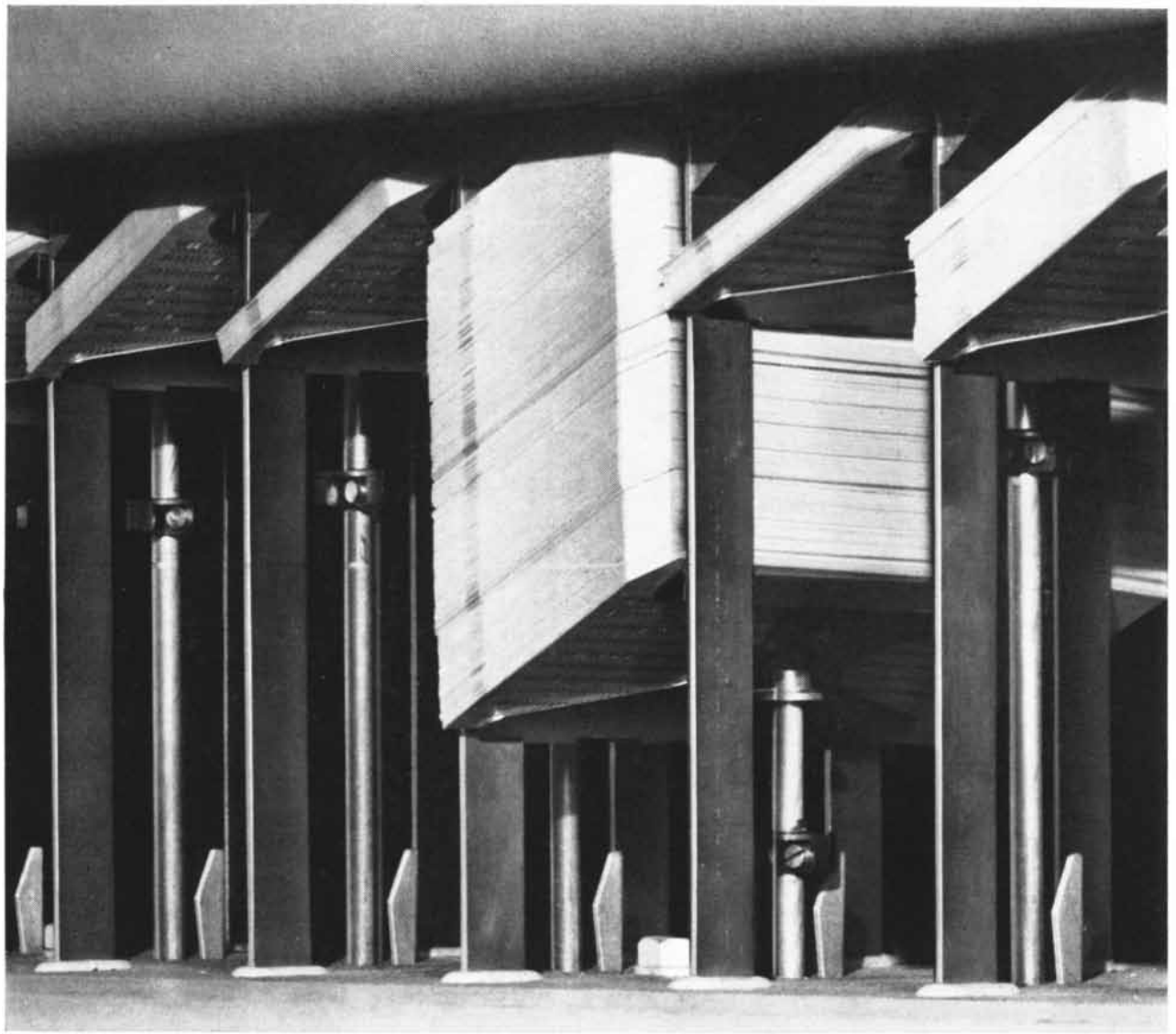

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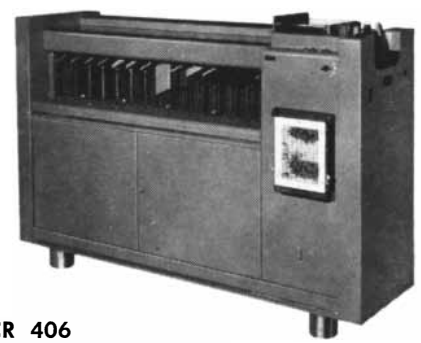

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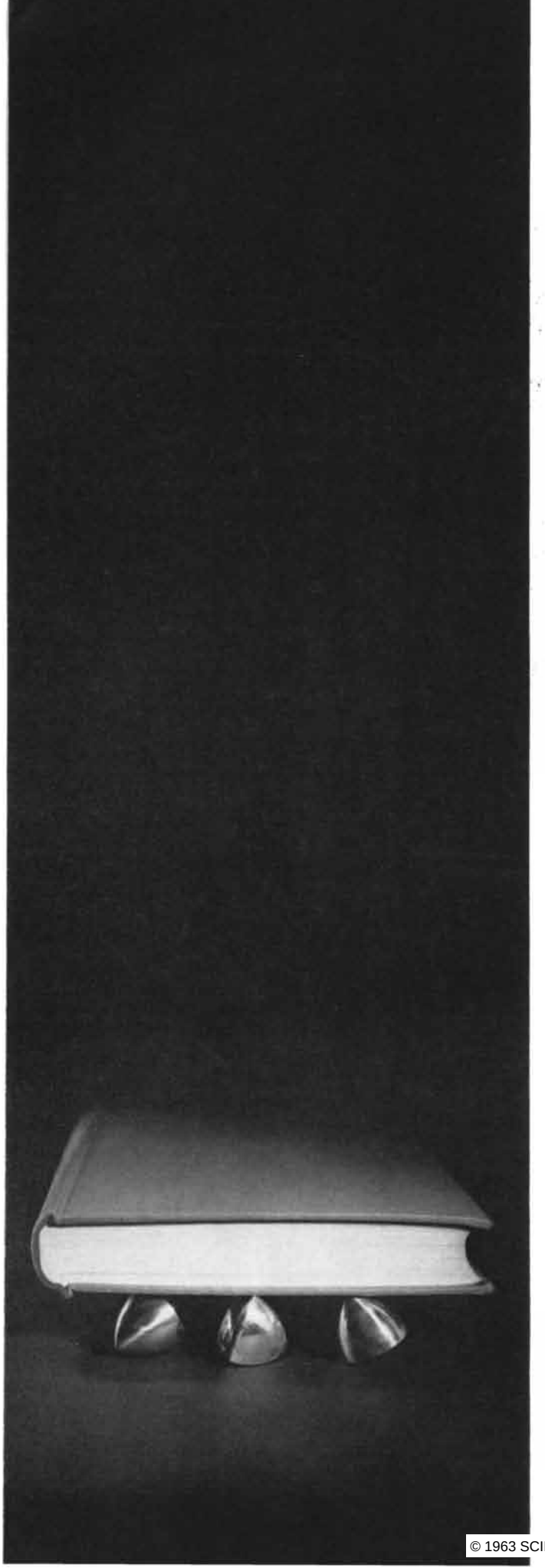

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The Mekong River Plan

In spite of many political obstacles, four southeast Asian nations helped by 14 others under UN auspices are engaged in thorough advance planning for a historic experiment in river development

by Gilbert F. White

The winding yellow streams of the lower Mekong River system in southeast Asia are currently the scene of a historic international experiment in river development. Some 20 million citizens of four nations—Cambodia, Laos, Thailand and Vietnam—live within this watershed. Their numbers are bound to double in the next 25 years. The dominant rhythm of their economic life is the annual cycle of monsoon rains and dry season, of flood and drought on their land. To advance the welfare of these peoples and help them to build stable societies, 14 nations and the United Nations are assisting the four countries in a co-operative undertaking to realize the abundance of the waters of the lower Mekong. This venture is unique in three respects. It is the first such effort in the UN family. It is the first to marshal knowledge from the social as well as the natural sciences on such a large scale in setting the aims, priorities and methods of river-basin management before the moving of earth or the pouring of concrete. It exacts international co-operation in a region where political relations are unstable and where an untoward turn of events—or the mistakes of administrators—could destroy the enterprise overnight.

The Mekong is one of the world's great rivers. Exclusive of its reaches beyond the Chinese frontier, it drains an area of 307,000 square miles, a watershed greater than that of the Tigris-Euphrates of the Middle East or the Columbia of the northwestern U.S. In its volume of flow at low water it ranks with the Irrawaddy of Burma, and it is several times larger than the Indus of India and Pakistan and the Yellow River of China. Man has tampered only a little with it. A few small dams have been built on tributaries in Thailand; there are bits of levees along the main stem; the flatlands of the alluvial valleys below Sambor have been cut here and there with channels for irrigation and drainage or for navigation. Nowhere is the main channel yet crossed by a bridge; nowhere is it curbed by a dam. The great bulk of its water flows from source to sea without human use.

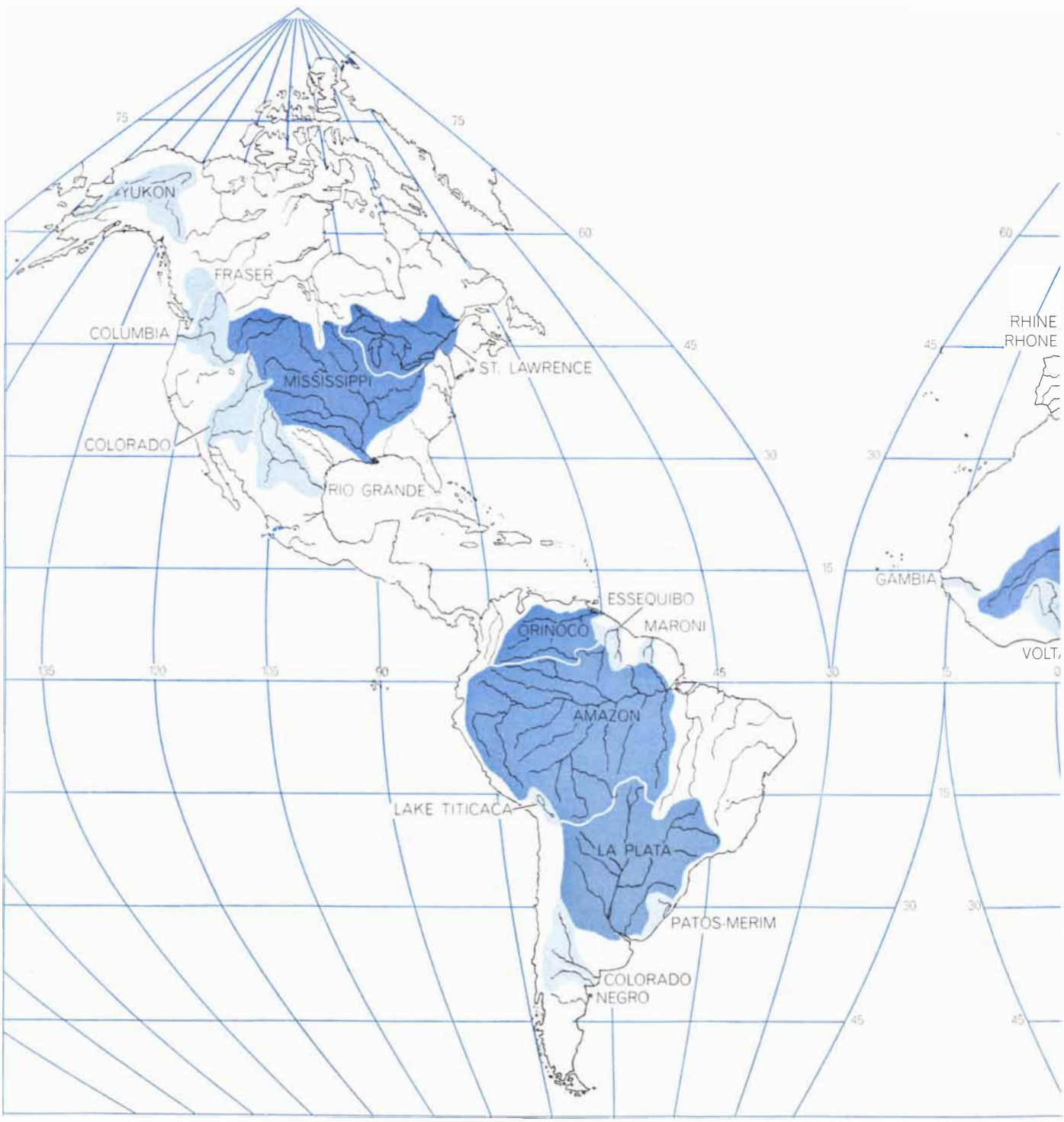
The present studies and the vision that inspire them had their origin in a pioneering appraisal made by P. T. Tan and his associates in the flood control bureau of the UN Economic Commission for Asia and the Far East (ECAFE). In its major outline the work reflects the findings of a reconnaissance conducted for ECAFE by the Bureau of Reclamation of the U.S. Department of the Interior and the recommendations of a UN engineering mission headed by Lieutenant General Raymond A. Wheeler, who had been deputy commander of the Allied bases in this region during World War II and was later chief of the U.S. Army Corps of Engineers. The Wheeler Mission recommended in particular that a series of detailed studies precede any construction. The four nations had signed an agreement on September 17, 1957, authorizing the work under an international co-ordinating committee operating with staff aid and sponsorship supplied by ECAFE.

During 1961 and 1962 I joined with three colleagues (Egbert de Vries, Harold B. Dunkerley and John V. Krutilla) in a study supported by the Ford Foundation of the economic and social aspects of the undertaking that we have now filed with the co-ordinating committee. This experience provides much of the factual material for the present article. It should be understood, however, that my comments on emerging problems and their political implications go beyond the committee's authority and our assignment as its consultants and are made on my personal responsibility.

Confidence in the central premise of the enterprise—that the long-run social development of the region requires the management and distribution of the lower Mekong waters on a basis that comprehends the lower basin as a whole—has grown stronger as the work has gone forward over the past half decade. Given the political history of the region during this period, the continuation of the work seems incredible. Twice since the formal planning for the Mekong began, Cambodia and Thailand have broken off diplomatic relations; Laos and Vietnam have each been divided by civil war. Even now parts of the Annamite plateau country and the delta lands of Vietnam are controlled by guerrillas. This is hardly the setting for internation-

al collaboration in resource management. Yet for the present the work is going forward, setting administrative precedents, engaging the energies of devoted people in the four nations and drawing on the human and material resources of 14 other nations.

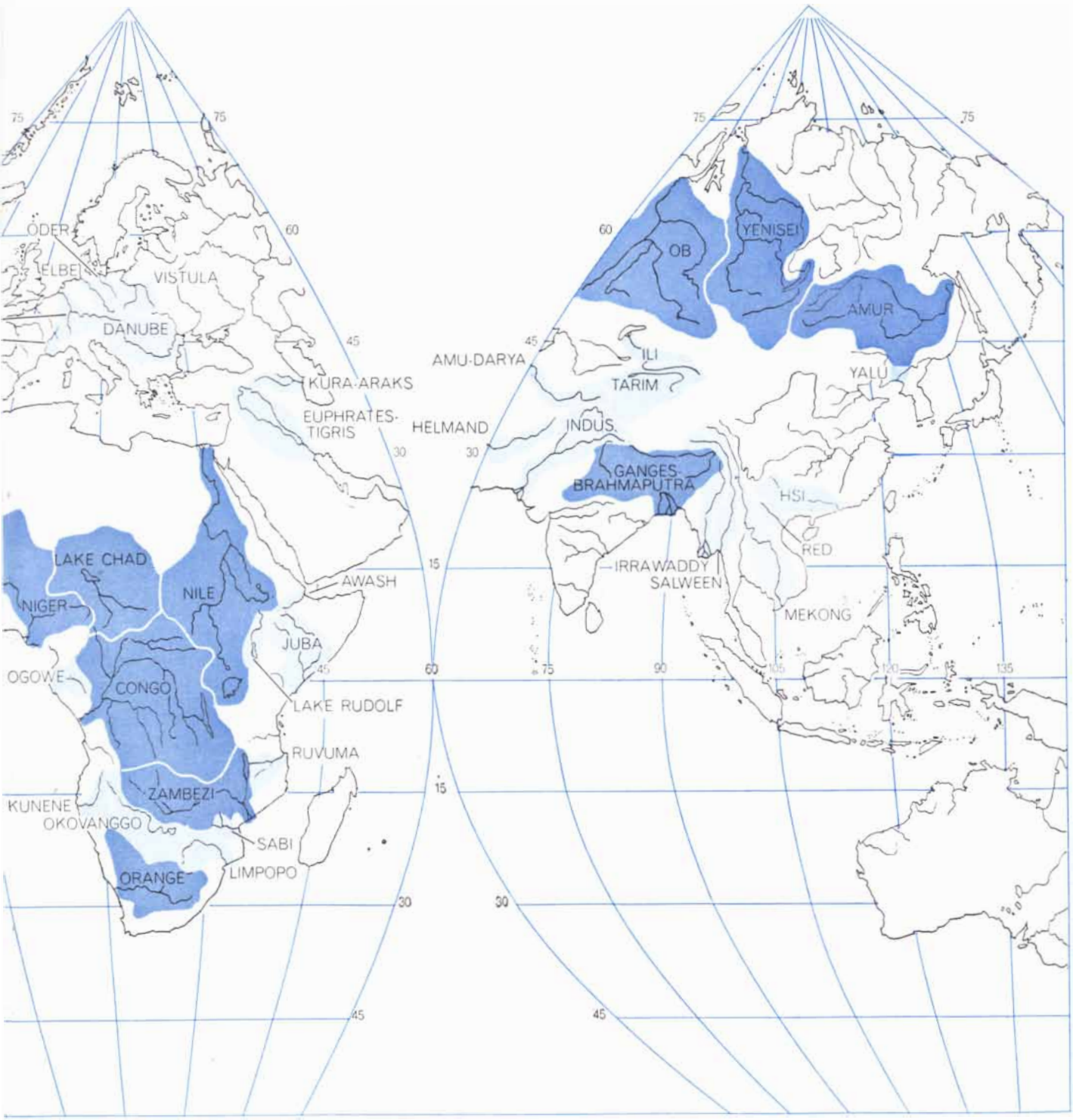
Politics has excluded the upper basin, which lies within the People's Republic of China, from the planning to date; China, not being a member of the UN, does not participate in the activities of ECAFE. This removes from consideration 74,000 square miles of the total drainage area, all of it lying in the high, rugged Tibetan plateau and in the long, precipitous gorge cutting down through the Yunnan Plateau from altitudes of 10,000 to 5,000 feet, paralleling the upper gorges of the Salween and Yangtze rivers. Ideally the entire stretch of the river should be embraced in the planning, but for two reasons the division at the present line does not seem crippling. The excluded territory is so high and dissected that it offers little opportunity for agriculture or dense settle-



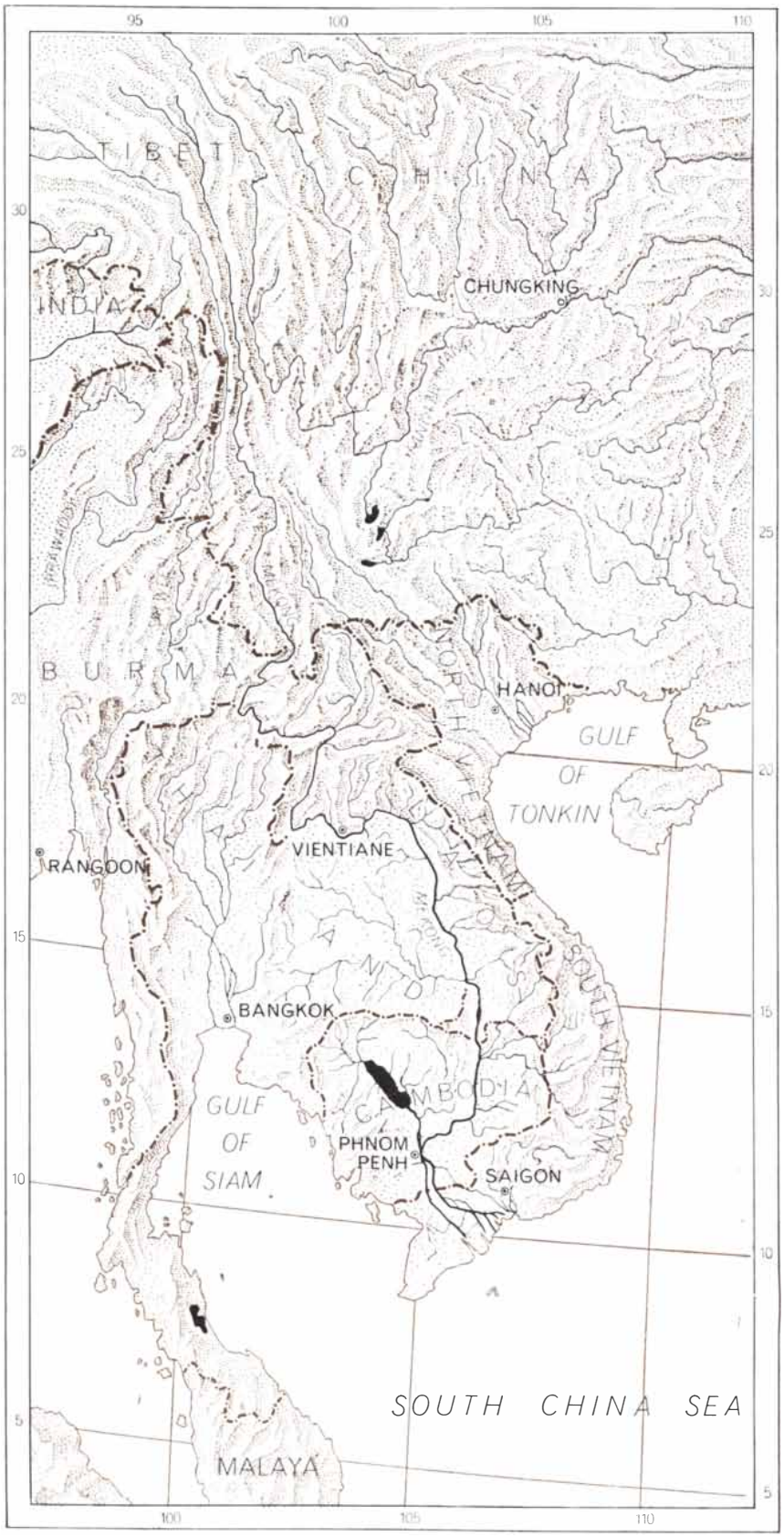
BASIN OF MEKONG RIVER (*white hatching at far right*) **in southeast Asia is one of 55 international river basins that include more than 100,000 square kilometers. Its total area of 987,000 square kilometers (381,000 square miles) makes the basin the 25th in size**

ment and is therefore unlikely to make heavy demand on the flow of water. There are sites for large-scale hydroelectric power installations, but if these did not involve diversion of water, they would affect the river regimen chiefly by storage during periods of high flow and thus would be helpful to water management downstream.

The major portion of the Mekong waters is gathered in the lower basin, where the mean annual rainfall ranges from 40 to 150 inches a year. In 1960, a near-average year, more than 100 million acre-feet (an acre-foot of water covers one acre to a depth of one foot) flowed past Pa Mong on the Thailand-Laos border, 1,000 miles from the mouth; here is a site for a storage reservoir with a capacity three times that of Lake Mead, the reservoir behind Hoover Dam on the Colorado River. Without holdover from flood seasons and even in the driest years, the flow at this point is expected to be sufficient to irrigate more than a million acres without encroaching on flow requirements in the lower reaches.



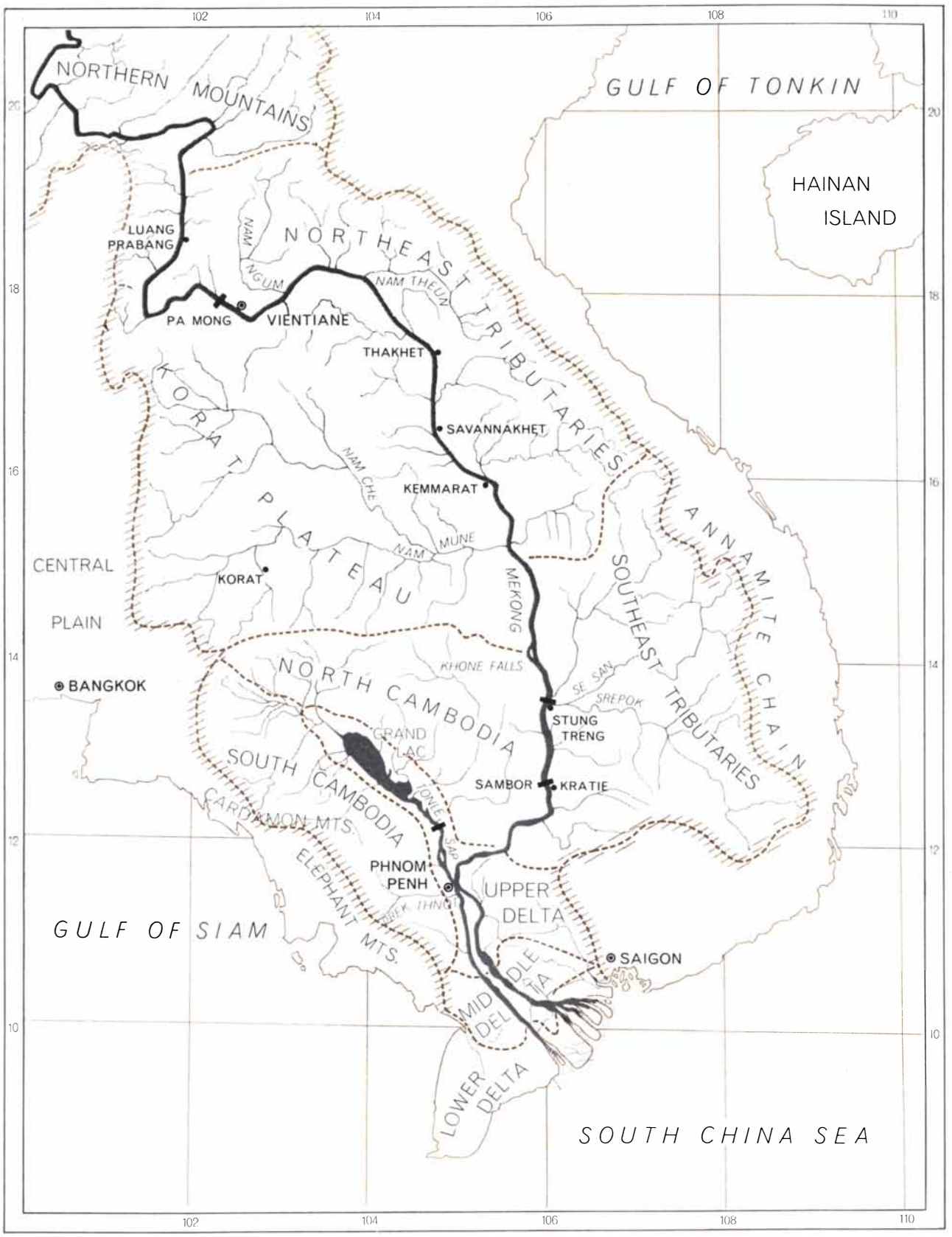
in the world, but even in the dry season the Mekong carries more water than many rivers that have larger basins. Basins of 100,000 to a million square kilometers are in lighter color; those of more than a million square kilometers are designated by darker color.



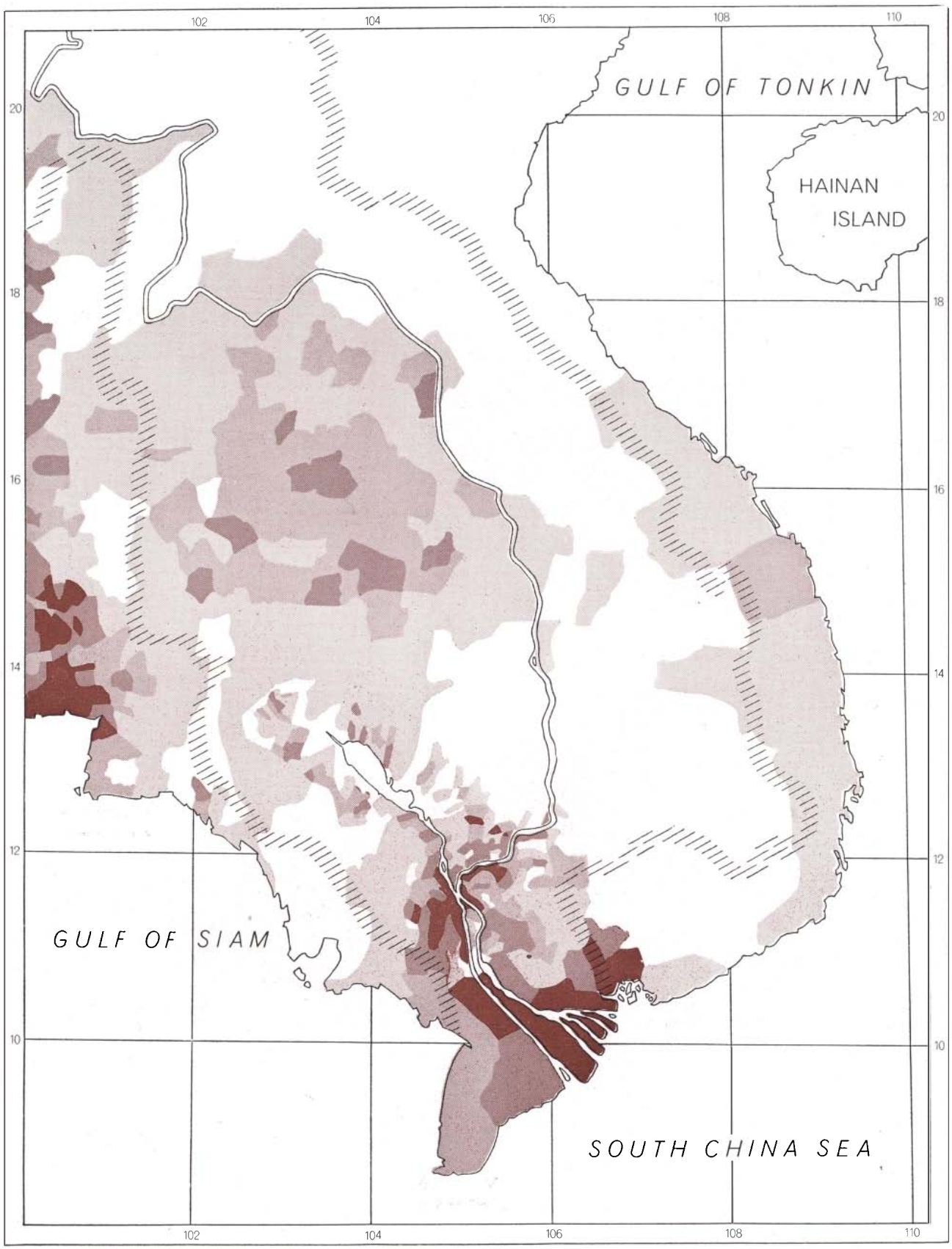
PARTS OF SIX COUNTRIES are drained by the Mekong River, which flows out of heights of the Tibetan plateau in China. The area of the proposed lower Mekong development includes most of Cambodia and Laos, about half of Vietnam and a third of Thailand. The small portions of the river basin lying in China and Burma have not been included in the plan.

Most parts of the basin have a pronounced wet season in the summer and early fall and a dry season in the winter and spring months of the year. Rice is the dominant crop everywhere. Its cultivation in paddy fields, with water supplied by seasonal inundation, crowds a major portion of the population into the alluvial lands of the delta and the lowlands of the main stream and its numerous tributaries. In terms of area, on the other hand, more of the land in the basin is covered by the shifting cultivation of upland rice and associated crops; the forest is burned, the land is cleared and cropped for two to five years and is then abandoned for a longer period, during which regrowth of the forest restores the depleted soil. Under this primitive mode of agriculture, which prevails over much of the tropical regions of the world, it can be said that there is land to spare in the basin, in contrast to many other parts of Asia. There is little land, however, that could be claimed for intensive use without destruction of the soil or elaborate measures of conservation and improvement. Farming practice throughout the basin is adapted to the arrival, duration and volume of the monsoon rains and to the rise and fall of the rivers. In general it can be said that from season to season and year to year there is either too much water or too little. The task of water management calls at once for drainage and for irrigation—for measures that will carry over the water from the wet season to the dry and distribute it more evenly in time and on the land.

Over so vast a territory, of course, such generalizations do not hold without amendment and qualification with respect to specific local conditions. The gross patterns of present and potential water use that have emerged from the project studies divide the basin into nine regions, each with a somewhat homogeneous combination of annual water balance and water-management opportunities [*see illustration on opposite page*]. In the densely populated lower delta region the flat land is beyond the reach of floods but is subject to the hazard of intruding salty water; drainage is required for intensive rice and vegetable cultivation, and irrigation is possible where the flow in the distributary streams is sufficient to prevent salt intrusion during dry periods. In the middle-delta and upper-delta—Grand Lac regions the annual flood hazard is serious, and relief will ultimately involve the entire complex of dams and storage reservoirs in the distant reaches of the main



LOWER MEKONG AREA is divided into nine water-management regions, each with its own geographic, hydrographic and climatic characteristics. The map also shows cities and the proposed sites of four major dams. Flood control, irrigation and drainage would make cultivation possible in new lands and would allow second-cropping in several regions. Ultimately river could be made navigable from mouth to Vientiane, opening Laos to shipments from overseas. Most tributaries could furnish hydroelectric power.



POPULATION OF MEKONG REGION is largely rural. White areas have fewer than 13 people per square kilometer. The four color gradations denote, from the lightest to the darkest, concentrations of 13 to 49 people per square kilometer, 50 to 99, 100 to 199 and more than 200. Hatching marks boundary of Mekong valley. More than 20 million people live in the region of the lower Mekong, grouped largely on the Korat Plateau and in the upper and middle delta. The map is based largely on population estimates.

stream and tributaries. At the height of flood in the main stream the water actually flows upstream in the Tonle Sap into Grand Lac; project investigators are looking into the possibility of controlling the lake as a reservoir. In the streams that drain the forested Cardamon and Elephant mountains small heads of water for electric-power generation can be captured by dams and the water impounded for dry-season irrigation of the lands in the South Cambodia region. Harnessing of the flow in the main stream at the several promising sites between Sambor and Khone Falls would supply water to irrigate certain of the thin soils of the North Cambodia region, and the improvement in navigation would make the rough and sparsely settled terrain of the southeast-tributaries region more accessible to development.

In the heavily populated Korat Plateau region much of the alluvial bottom land is flooded so deep each year as to go uncultivated; yet in the dry season this area suffers the greatest water deficiency in the entire basin. Here flood control and irrigation must go hand in hand. There are only a few substantial power sites in the low-gradient tributary streams, but the Pa Mong site to the north offers a huge block of power and of water for diversion southward on the plateau. In the rugged northeast tributary and northern mountain regions the steeply falling streams provide many sites for cheap power and for the storage of water to irrigate the lands on the gentler slopes and lower plains where these streams join the main stream.

The major cities of southeast Asia—the Vietnamese capital Saigon-Cholon on the eastern edge of the Mekong delta (with a population of a million) and the Thai capital Bangkok at the mouth of the Chao Phraya (with a population of similar size)—are outside the basin. Except for the 500,000 in the Cambodian capital Phnom Penh and the 100,000 in the Laotian capital Vientiane, the population in the basin is largely rural. Although for the great majority labor in the rice paddies and upland fields yields little more than subsistence, the region depends on agricultural surplus for export. Rice, rubber, teak and a few other products of field and forest constitute the principal commodities that enter the monetary economies of the four countries and move in the channels of trade among them and with the world outside. During the past 10 years great numbers of refugees have moved from the north to the delta in Vietnam, the hill tribes of Laos have suffered displacement and there has been a steady emigration from the Korat Plateau into the central plain of Thailand and the city of Bangkok.

Estimates of present and future needs for purposes of planning development are heavily conditioned by uncertainty of data, including such basic data as population statistics. It does appear, however, that the population of the four countries now totals about 48 million. A conservative projection, assuming a continuing decline in maternal and infant death rates in a population now strongly grouped in the younger age brackets, and assuming that birth rates will be high even if birth control spreads and living levels rise, indicates that the population may grow at the rate of 3 per cent per year for the next 25 years. At that rate the population of the four countries will exceed 90 million by the last decade of this century.

To secure the food requirements for that number of people and a surplus for the foreign exchange necessary to generate a modest—50 per cent—increase in income from other economic activities will require an increase in production of milled rice from a present total of eight million tons to 17 million tons. Current exports of rice from Cambodia, Thailand and Vietnam run at about two million tons; in the interest of foreign exchange it will be desirable to increase this figure. There is reason to think that in recent years rice production in the three countries has been increasing at about 2 per cent per year; at this rate population growth will soon overtake production and eat up the surplus. It is apparent that the rate of increase in rice production must be accelerated to 3.5 or 4 per cent per year. Forecasts and plans must also reckon with concomitant increases in secondary crops and livestock products in response to changes in food habits and nutritional needs. Toward the support of economic growth, external demand for the forest products of the basin and for rubber may be expected to grow.

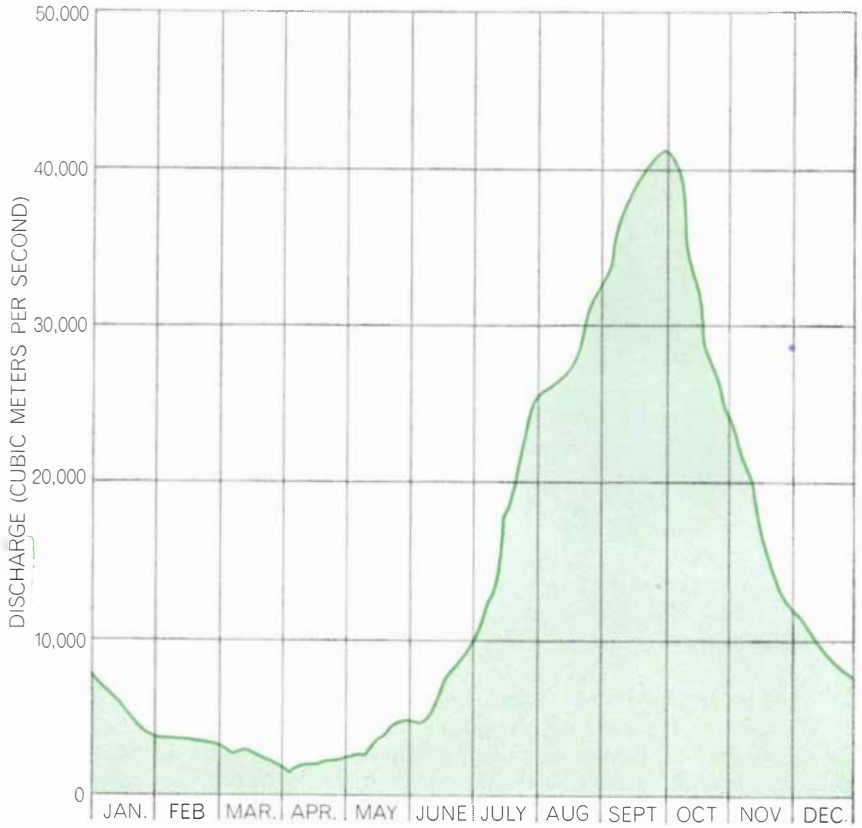
If the 50-per-cent improvement in income per capita is to be achieved, industrial output will have to grow at the rate of 6 or 7 per cent per year. A substantial portion of this activity is likely to be in the processing of agricultural and forest products. Without assuming the building of large industry serving regional or world markets, it appears that electric-power demand might increase five- to sevenfold.

Still another major item on the agenda of the future is transportation. At present the lack of adequate transportation routes and facilities presents a major obstacle to economic growth. Improvement is essential to the shift to monetized economy and efficient use of resources.

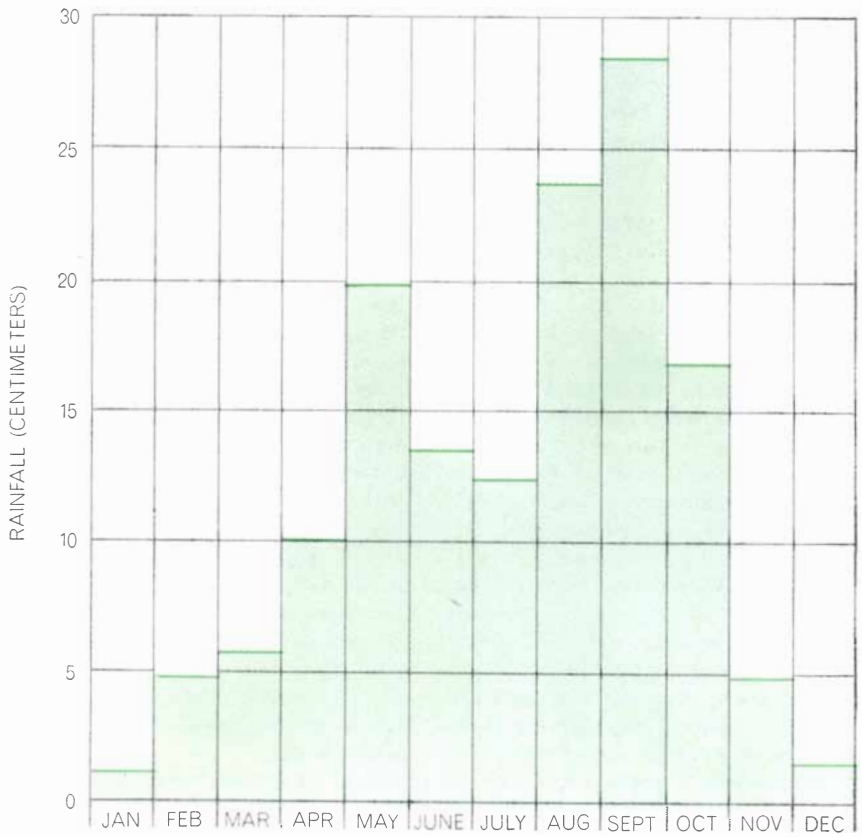
It is apparent that water management has a central role to play in the attainment of all of these objectives. Major increases in agricultural production, in the first place, require the balancing of the water surplus and the water deficiency that present such hazards to agriculture today. Irrigation will make possible the cultivation of a second crop of rice over large areas of the basin; drainage will improve yields from the regular wet-season crop; and flood control will reduce the risks that now discourage the investment of seed, fertilizer and labor in the single crop that is raised. In many of the tributaries and along the main stream the regulation of high and low flows will involve dams and reservoirs, because the concentration of high runoff in the valleys is little affected by small local works. Individual dams on the upper tributaries will have to be operated in conjunction with others in the same system before substantial reduction of floods can be assured in the principal valleys, and only very large installations on the main stream of the Mekong can affect flood heights appreciably in the alluvial areas below Sambor. Over large regions where slash-and-burn agriculture is now practiced, irrigation combined with careful soil management can stabilize yields and make possible the diversification of crops. As my colleague De Vries likes to put it, water may here replace fire as an agricultural tool.

Since prospecting in the sedimentary basins and plateaus has not so far revealed any major deposits of fossil fuels, the stream system offers the chief means of generating electric energy. The great opportunities are on the main stream, where there are likely dam sites that command flows the size of that on the lower Columbia River and heads of 60 to 180 feet. Virtually all the tributaries have some hydroelectric potential. The conspicuously attractive sites are in the Nam Theun and other east-bank tributaries in middle Laos that drain the heavy plateau runoff through steep, short valleys.

Dams built for water storage and power will help to open the main stream as a transportation route. In the reaches of the distributaries in the delta country below Phnom Penh the maintenance of



ESTIMATED DISCHARGE of the Mekong River at Phnom Penh in a wet year shows the typical long dry season and the flood period. Change is so great that Tonle Sap reverses flow.



MEAN MONTHLY RAINFALL at station on the Korat Plateau in Thailand also shows wet and dry seasons. The plateau suffers from both heavy floods and severe shortages of water.

stable, well-marked deep channels would encourage coastal and overseas shipping. Upstream there can be improvement of channels between the stretches of rapids for seasonal navigation. Conversion of the Mekong into a year-round deep-water channel to Vientiane—1,000 miles from the sea—would open up the land-locked areas of the basin to bulk shipments by water. The necessary engineering works would be too costly, however, if they were not combined in power and flood-control structures with savings from joint purpose and large scale.

Although the inhabitants of the country below Sambor have learned to live with floods—cultivating, for example, special varieties of floating rice that survive rising waters and give a harvest—the river in some years can bring catastrophe to farm and village. A number of towns, such as Phnom Penh, are built on natural levees or are protected by natural levees that may be overtopped by the rare great floods. Certainly flood control will become increasingly imperative as farming is extended and urban life spreads into new areas.

If the full array of possible measures to put the river to human use were to be applied over a period of perhaps 100 years, the total investment might run to $7 billion at current prices. Even with generous external aid, heavy local contributions would be required. To maintain such a rate of investment would call for expansion of total economic activity to levels not yet attained by any of the countries but not beyond the realm of possibility.

As of today it can be said that the first $14 million of investment in this vision has been committed. The figure is a small one, but it is larger than any previously assembled for a multilateral international enterprise under the auspices of the UN. The money has gone to finance the surveying and engineering work that must precede construction. Since this work involves skills that are still rare in the populations of the four nations of the Mekong basin, the personnel supplied by the other participating nations and by international agencies have helped to gain precious lead time.

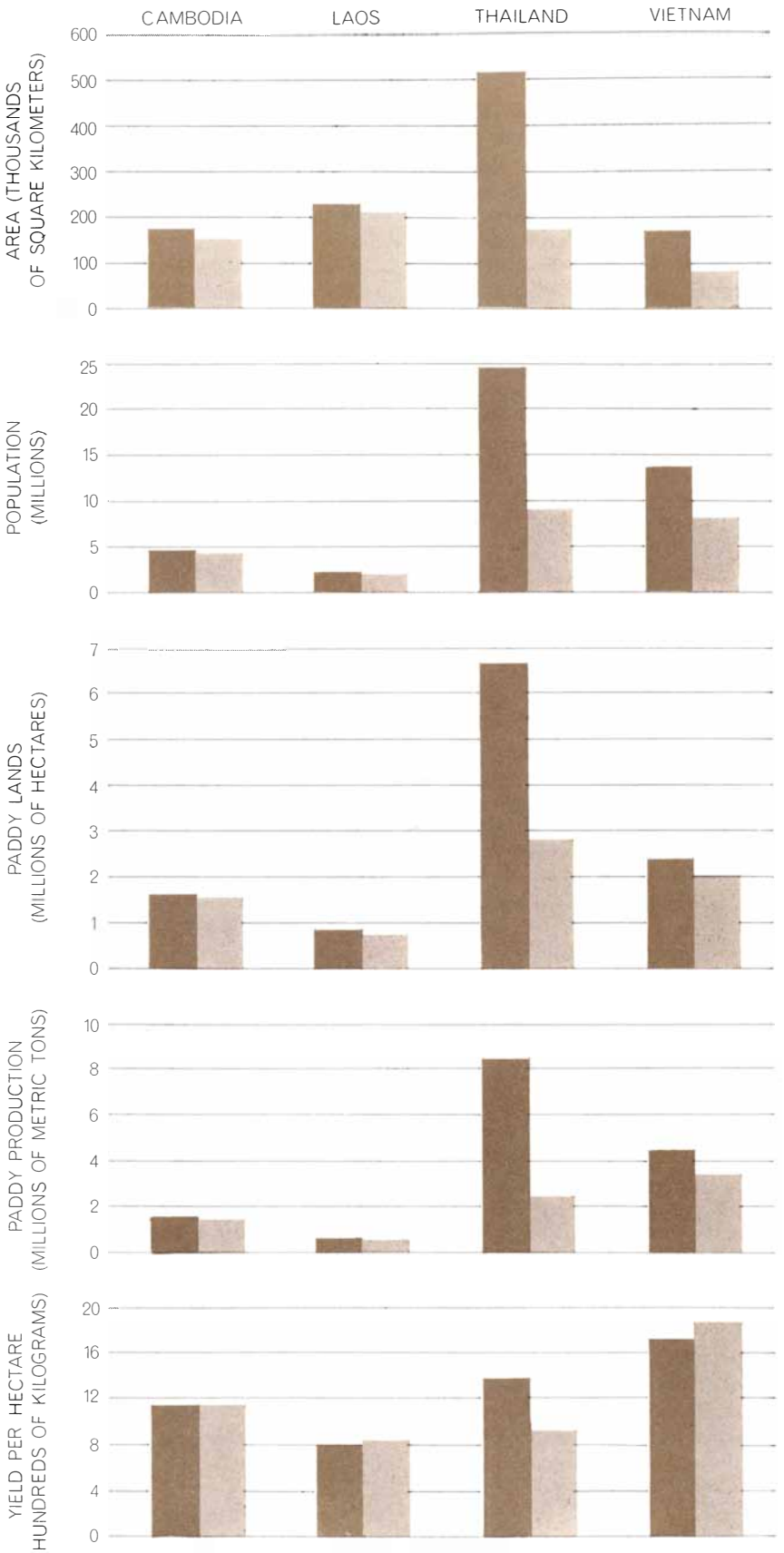
By 1964, with Canadian and U.S. assistance, the project's planners will have at their disposal topographic maps of the basin on a scale of 1:50,000. Meanwhile the Canadians, with aid from the Filipinos, are completing large-scale maps of selected river reaches for use in dam-site and irrigation-project studies; to estab-

lish ground control for aerial photography precise levels have been run along the main line of the river. Geological investigation of the dam sites for several of the likely major projects has been handled by the Australians, not without personal hazard from unfriendly guerrillas. The fundamental observations of precipitation and stream flow are going forward on a network established by a U.S. engineering firm and now maintained by local personnel with assistance from the World Meteorological Organization. Improvement in navigation has been supported by the United Kingdom and New Zealand, with a hydrographic survey under a grant from the UN Special Fund for International Development.

A heavy part of the work has centered on engineering and associated studies looking to preliminary plans for dams on the main stream and on the tributaries. Three main stream sites are receiving attention at present. At Sambor in Cambodia a Japanese team is at work; engineers from the U.S. have made a preliminary examination of the Pa Mong site, and Indian engineers are preparing a comprehensive report for the Tonle Sap project in Cambodia. The last, with its possible effects on water, sediment and fish life in the Grand Lac area, requires examination of silt and fisheries data collected by French workers, and it would have major effects downstream in the delta. In that area there is a small experiment in reclamation of the land through drainage and irrigation, and a mathematical model of water volume and density is being prepared under a UNESCO contract supported by the UN Special Fund.

A Japanese group has completed a reconnaissance survey of all the tributaries, and more detailed surveys are being conducted by Japanese, French and U.S. engineers at seven sites. All of these involve irrigation and power development. At or near four of these sites the Special Fund, in collaboration with the UN Food and Agriculture Organization, is setting up experimental farms. Other countries are also taking part in the tributary studies: Pakistan is planning the irrigation-distribution system at the Nam Pong site in Thailand and Israel is helping with irrigation design and project review for the Prek Thnot in Cambodia.

Israel and the Republic of China have contributed cement. Iran has donated the petroleum for use in the land and water transport of the survey teams. The World Health Organization, the Interna-



COMPARISONS are made for area, population and rice-paddy cultivation in the four Mekong countries. The light bars are for the Mekong region alone; the dark bars give totals for each country as a whole. There are 2.47 hectares to an acre and 2.2 kilograms to a pound.

tional Atomic Energy Agency, the International Labor Organization and UNESCO have sent experts to deal with special problems.

Large-scale construction of dams, canals and channels does not in itself guarantee solution to the long-term needs of the rapidly growing population in this region. Experience with several score small-scale projects built on the Korat Plateau during the past decade shows that, even though the dams, spillways and outlet works were soundly designed, the water is little used and does not reach all the paddies that ought to have benefited. There has been difficulty or delay in getting proper canals built, in laying out the distributary ditches and drains, in advising farmers on methods and seeds and in managing suitable transport, credit and market facilities for the hopefully enlarged harvest. By the same token any extensive growth in manufacturing would depend in large measure on revision of conditions and institutions, habits and outlook among people of all classes. Near the heart of the problem is education. With adult literacy at about 50 per cent in Thailand and 20 per cent in Cambodia, Laos and Vietnam and with something like the same percentages of school-age children in school in each country, the expansion of elementary and secondary schools ought to have high priority in the national development plans. Technical and physical works have highly significant roles to play, but they must be evaluated in the broader context of the less visible and tangible social transformations that must accompany them if they are to serve their purpose.

The most urgent question confronting the Mekong planners, my colleagues and I found, is to decide when the basic studies have reached a stage that warrants embarking on construction. Administrators and citizens alike yearn to see earth move, concrete structures rise and power lines make their giant strides across the green terrain. The engineer and the economist directly responsible for the study are subject to pressure not only from above and below but from all sides—from agencies competing for investigation and investment funds. As the reports from engineering teams pile up on the table of the co-ordinating committee, its members will face extremely difficult problems of choice in terms of internal feasibility and the relation of projects to one another within the basin and to other forms of national development activity. Our mission urged that the collection and analysis of social and economic data be advanced promptly to catch up with the lengthening shelves of technical and physical reports. Power markets should be assessed, agricultural measures should be appraised, land capability should be inventoried and a systems analysis should be carried out. Certain of the needed studies are already under way.

Some data of this kind cannot be assembled from archives, questionnaires or head counts. We recommended that the experimental and demonstration effort be pushed on a larger scale than that of the experimental farms. The complete village setting is necessary to test and predict the effects of some measures. It would be desirable to get a project of at least 6,000 acres in operation in connection with one of the tributary dams.

Perhaps the most urgent need is for the training of agricultural advisers to work in the villages and provincial centers. Without competent and devoted workers who are ready to get their feet wet in the paddy fields, the benefits of much engineering investment might never be developed. To train as many as 6,000 village workers and 1,000 more for service out of the provincial centers over the next 10 or 15 years would in itself be a tremendous task. Their training might be initiated at the pilot farms now being organized.

An equally critical need is for a relatively few highly educated individuals in the agencies of the governments who are qualified to prepare, review and revise the schemes for water management in relation to the scheme for the basin as a whole and the economic policies of their countries. An expert from the outside cannot acquit responsibilities of this kind. Nor can a central lower Mekong staff, however competent and enlightened, be charged with essentially national decisions.

Some of the other personnel requirements seem easier to meet. The training of workers to handle and maintain earth-moving equipment can be accomplished in a matter of 18 to 24 months. The engineering skills are demanding, but the Royal Irrigation Department in Thailand has shown that a competent engineering office can be set up in the region. Until these skills are more widely established in the population, however, personnel equipped with them can be imported. At present the start-up of four projects on the tributary rivers would call for more professional workers than the four countries now have in their employ.

In setting human and cultural demands of this kind the program for water management in the Mekong basin becomes the organizing force behind more subtle aspects of social change. Since one cannot wait for the other and both water management and social change must go forward together, our mission recommended that the four countries should proceed forthwith on the specifications

INTENSIVE CULTIVATION of rice in Cambodia is shown in this aerial photo-

for and construction of a few tributary projects. We did so in the belief that the values of early experience and action—in the management of agricultural development as well as dam-building—would outweigh the possible social costs of undertaking a less fruitful project or one that would later hamper optimum development downstream.

Within recent weeks commitments have been made for financing the first multipurpose dam on the tributaries. The West German government has agreed to lend Thailand the equivalent of $11 million for the Nam Pong project. If political conditions are favorable and if reason and vision can find their way into the construction and administration of the lower Mekong program to the same degree that they have emerged in the study stage, this program may become the first genuinely international and peaceful venture in river-basin development. It may thereby help to remove the obstacles that stand in the way of the development of international rivers elsewhere in the world.

graph made by Hunting Survey Corporation Limited for the Canadian government under the Colombo Plan program. North is at bottom. Small town (*lower right*) is Sambor, where a large dam may be built on the Mekong. Shape of fields is typical of rice paddies.

PLANETARY NEBULAE

These peculiar celestial objects consist of a hot, dense star surrounded by a sphere of luminous gas. The comparison of old and new astronomical photographs elucidates their mechanism

by Martha and William Liller

The 18th-century French astronomer Charles Messier, searching the sky for comets, located 103 diffusely luminous objects that remained fixed among the pinpoints of light that are stars. Of these "nebulae," 34 have been identified as island universes, now called galaxies; 57 as clusters of stars within our own Milky Way galaxy; seven as diffuse nebulae, or clouds of interstellar material lighted by stars; and four as planetary nebulae. (One object has never been confirmed; it was presumably a telescopic "ghost" but may have been a comet that the comet-hunter Messier missed.) The adjective "planetary" was attached to this class of nebulae when more of them were discovered, around the middle of the last century, in the same telescopes that had disclosed the existence of the trans-Saturnian planets Uranus and Neptune. The new planets and the planetary nebulae both appeared as faint greenish disks of about the same size. The resemblance was striking and suggestive but in each case a few nights of observation showed that the unknown objects did not move against the background of the stars.

Modern reflecting telescopes have now catalogued more than 500 planetary nebulae. Characteristically they are faintly green in color; many are circular in outline, with a sharply defined outer perimeter, and the forms of others range from slightly elliptical "smoke rings" to confused arrays of knots and loops. In almost every instance a star can be seen at the precise center of whatever symmetry there may be. If this central star is not reddened appreciably by interstellar dust or by the earth's atmosphere, it inevitably appears steely blue, suggesting at once to the astronomer a temperature measured in the tens of thousands of degrees Kelvin (degrees centigrade above absolute zero); estimates in some cases place the temperature above 100,000 degrees K., making the central stars possibly the hottest reasonably permanent stars in our galaxy. Spectroscopic examination of the greenish nebulosity surrounding these stars confirms such estimates.

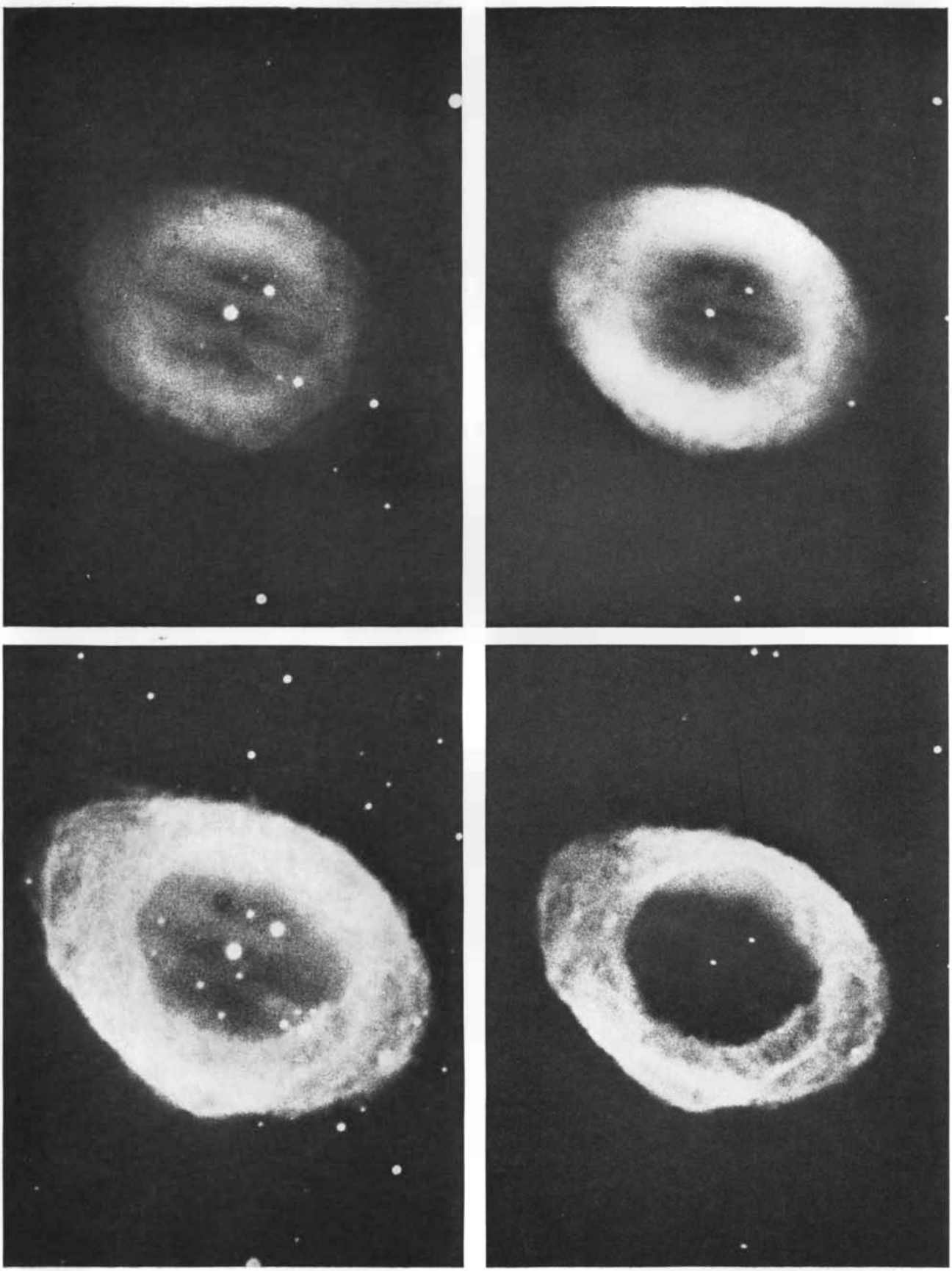
Dominating that part of the spectrum over which the eye is sensitive are two bright emission lines at wavelengths of 5,007 and 4,959 angstrom units, nearly at the center of the green region. These lines, never seen in terrestrial laboratories, were at first attributed to an undiscovered element, appropriately named "nebulium." Ira S. Bowen, now director of the Mount Wilson and Palomar Observatories, showed in 1928 that the radiations are emitted by oxygen atoms doubly ionized (that is, stripped of two outer electrons) by the intense radiation from the star and persisting in this state because they are present at a density far below that attained in the best vacuums produced on earth.

That there is a physical connection between the hot central star and the immensely large surrounding envelope of extremely tenuous gas is obvious. The precisely central location of the star suggests that either the gas was once ejected by the star (or continues to be ejected by it) or that the gas is falling into the star, becoming visible as it comes within range of ionization by the energy radiating from the stellar surface. Spectrograms of the light from the cloud show that the gas is indeed in motion and even give a precise measurement of its velocity. But the spectrogram does not tell whether the gas cloud is expanding or contracting. Curiously, the answer to this question has come from the transparently simple procedure of making a direct comparison of the size of the gas clouds as shown in recent photographs with the size shown in photographs taken by the same telescope more than 60 years ago. In terms of astronomical time, of course, 60 years is an exceedingly brief interval. What is extraordinary—as a reflection of the dynamism of the processes in these stars and their gas clouds—is that this elementary stratagem showed significant results.

The distance of the planetary nebulae from the sun makes it difficult to translate their "apparent" features, as seen by the observer, into quantitative information about their "absolute," or actual, size, brightness and so on by means of the standard procedures of astronomy. For example, since the image of the nebula subtends a measurable angle on the photographic plate, it should be possible to compute the actual dimensions of the gas cloud by straightforward trigonometry. This requires an accurate measurement of the distance, however, and the measurement is uncertain by a factor of at least two for all but a few of the planetary nebulae. One of them is just close enough to the solar system for its distance to be derived by the triangulation method that uses the diameter of the earth's orbit as its base line. This object is number 7293 in the New General Catalogue of galaxies, star clusters and nebulae, which replaced Messier's catalogue in 1888. Triangulation shows that NGC 7293 lies about 300 light-years away in the direction of the constellation Aquarius. Its apparent diameter is 15 minutes of arc, half that of the full moon; its absolute diameter must therefore be 1.3 light-years. Another rather small planetary nebula is a member of a globular cluster, for which the distance is reliably established by methods appropriate to these objects. A

RING NEBULA in Lyra (*above*) is a typical planetary nebula. Although the outer shell consists almost entirely of hydrogen, its predominantly green light is emitted by doubly ionized oxygen atoms. The blueness of the central star indicates that it is very hot.

DUMBBELL NEBULA in Vulpecula (*below*) was photographed on film with low sensitivity to green wavelengths. As a result blue wavelengths of ionized hydrogen predominate. Both photographs were made with the 200-inch telescope on Palomar Mountain.



DISTRIBUTION OF LIGHT AND MATTER in the Ring Nebula is shown in this series of photographs made in four different wavelengths with the 200-inch telescope. Light from highly ionized neon (*top left*) and helium (*bottom left*) tends to fill the "hollow" center of the shell, whereas doubly ionized oxygen (*top right*) and neutral hydrogen (*bottom right*) are detectable only around the perimeter. Radiation from the hot central star strips away all but the most tenacious electrons from the atoms of the inert gases.

more average-looking planetary nebula, NGC 246, has a central star about which can be seen revolving (within the nebula) a second star with characteristics typical of stars found relatively close to the sun. Knowledge of the absolute brightness of such stars, combined with measurement of the apparent brightness of this star, enables one to calculate the distance to this system with some confidence.

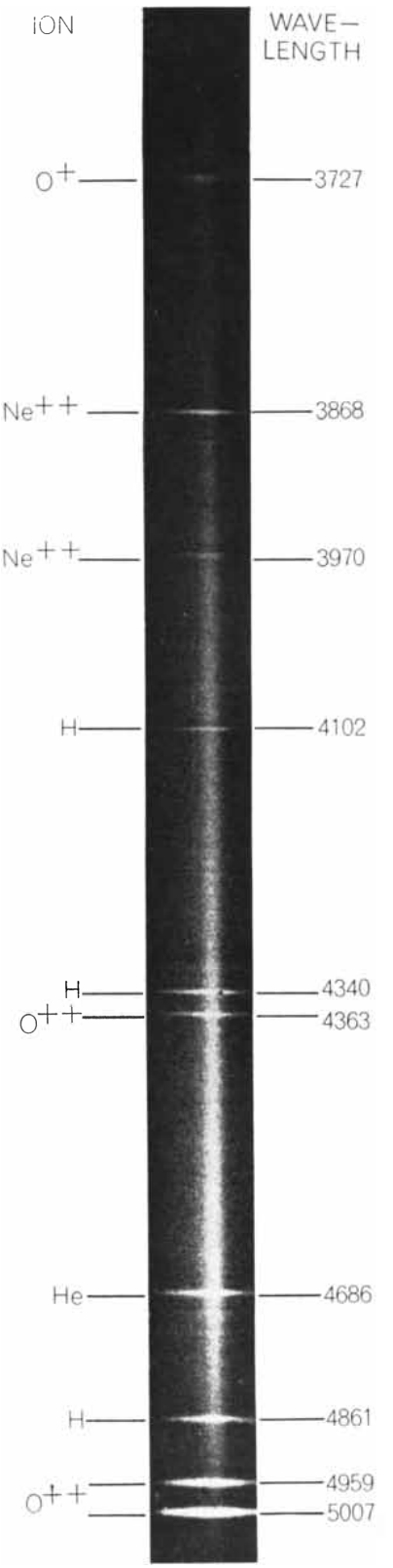
For the class of planetary nebulae as a whole, however, there is no basis for estimating the absolute brightness of either the central star or the nebulosity surrounding it. The brightness "yardstick" that measures distances to other stars by comparison of their known or estimated absolute brightness with their measured apparent brightness cannot therefore be applied to planetary nebulae. About the best astronomers can do is to make a guess as to true size and brightness and combine this with angular size and apparent brightness to derive a crude estimate of distance to a given nebula.

Arguing back and forth, from size to distance and from distance to size, and taking a sufficient number of cases, one can arrive at some brave generalizations. The largest planetary nebulae would seem to be as much as a few light-years in diameter and the more typical a half light-year in diameter. Since the larger nebulae generally have a lower surface brightness they become more difficult to see at greater distances, particularly in those regions of the sky closer to the Milky Way (the central plane of the galaxy), where there are greater concentrations of stars, dust and gas; the larger nebulae nonetheless show a tendency to be located near or in the spiral arms of the galaxy. The more compact and brighter nebulae also tend to lie in the galactic plane, but with a particular concentration in the direction of the nucleus of the galaxy near the constellation Sagittarius, the most distant being about 30,000 light-years away. In the great nearby spiral galaxy in Andromeda those planetary nebulae that can be resolved by the big reflecting telescopes show the same general distribution.

The central stars that generate the diffuse luminosity of the nebulae show varying luminosities up to 100 times that of the sun. Luminosity is here used in its special sense as an index of the total energy radiated from the star and represents the intrinsic brightness as measured by a detector equally sensitive to all wavelengths. Unlike the sun, one of these "blue-hot" stars radiates most of its energy in the ultraviolet and so does not give out as much visible light. Because the amount of energy radiated by each unit area of the star's surface depends solely on the fourth power of the temperature, it is possible to calculate the radius of a star, given its luminosity and its temperature as indicated by the distribution of the luminosity across the spectrum. A typical central star of a planetary nebula, with a luminosity of 10 suns and a surface temperature of 35,000 degrees K., would have a diameter of only 73,000 miles—close to that of the planet Saturn and a twelfth that of the sun. Because stars vary relatively little in mass, such a star must have a mean density 2,400 times the density of water and 1,800 times the mean density of the sun.

Such a star, according to the currently accepted scheme of stellar evolution, is very likely an old star. This is borne out by the fact that one planetary nebula appears in a globular cluster, the stars of which were formed more than 10 billion years ago. It is not supposed, however, that the central star of a typical planetary nebula was always so dense. Rather, it is thought that recently—perhaps as recently as 100,000 years ago—the star was an enormous red giant or supergiant star that shucked its outer layers and contracted to an extremely hot core of a star. This crisis in the evolution of a star is set off by the exhaustion of the star's nuclear fuel; the sudden failure in the output of energy from within is followed by the gravitational collapse of the star. In what amounts to a milder version of the process that supposedly produces the star-annihilating explosion of a nova or supernova, the star ejects a shell of gas into space. The existence of double- and triple-shelled planetary nebulae suggests that these eruptions may be repeated two or three times in the life of a single star. Sometimes the gas is released locally from the star's surface and the rotation of the star spirals it out into space. If the star is embedded in an appreciable magnetic field, the gas may stream along the lines of force in the field and distort the appearance of the nebula.

In other words, if the shell of gas in a planetary nebula is found to be expanding, this may be evidence that the star within has come close to the end of its life. It is destined soon to become a white dwarf, the last stage before it disappears from view altogether [see "Dying Stars," by Jesse L. Greenstein; SCIENTIFIC AMERICAN, January, 1959]. Indeed, it seems that the faintest nebular stars known are no more luminous than a typical white dwarf. If, in fact, these stars



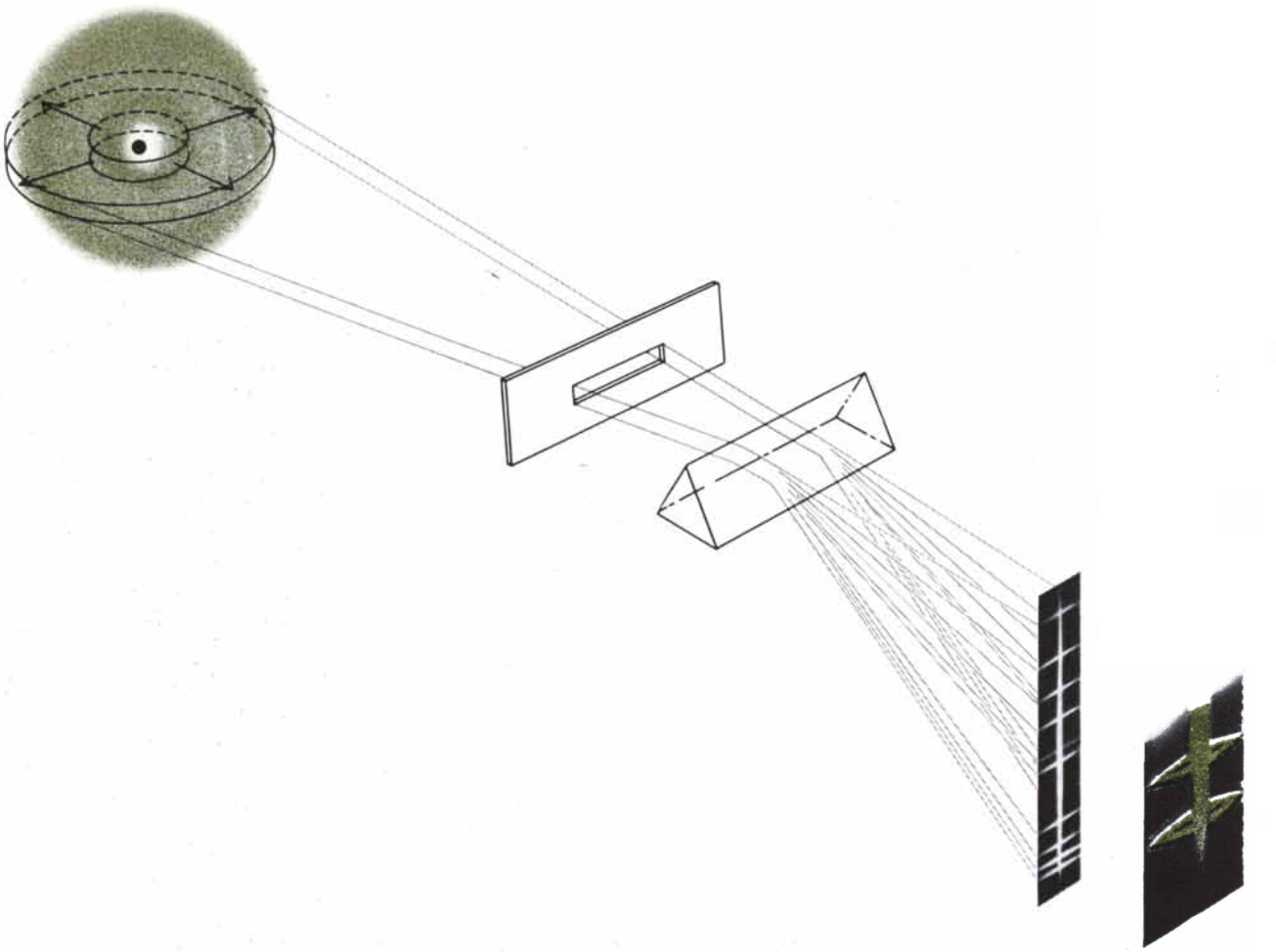
SPECTROGRAM of planetary nebula NGC 2392 shows the characteristic bowed emission lines of several nebular elements, particularly doubly ionized oxygen. Vertical streak down the center is the continuous spectrum of the central star. Wavelengths in this small section of a full spectrum run from violet (*top*) to green (*bottom*).

can be classified as white dwarfs, they represent the hottest of this class of stars.

The evidence that the gas is moving with high velocity shows up unequivocally in high-resolution spectrograms. The emission lines of ordinary stars—produced by passing the star's light through a thin rectangular slit and then refracting it through a prism or diffracting it from a grating—register on the spectrogram as images of the slit, that is, as thin straight lines. In the spectrogram of a planetary nebula the emission lines from the gas shell split in a curious manner as they approach the streak across the center of the film that is the spectrum of the star; the lines bend apart and rejoin on the other side of the stellar spectrum, forming a pattern like the eye of a needle [*see illustration below*]. It is of course the familiar Doppler wavelength shift, which shows up so often in astronomical spectrograms, that explains this pattern. The Doppler effect shifts the wavelength of radiation from a receding source to the longer-wavelength, or red, end of the spectrum, and that from an approaching source to the shorter-wavelength, or violet, end. Thus in the spectrogram of an expanding gas cloud the radiation from the far side of the cloud would be shifted toward the red and that from the near side toward the violet. The effect would be most pronounced at the center of the cloud, where the motion of the gas is most nearly in the line of sight, and this would account for the bending of the lines.

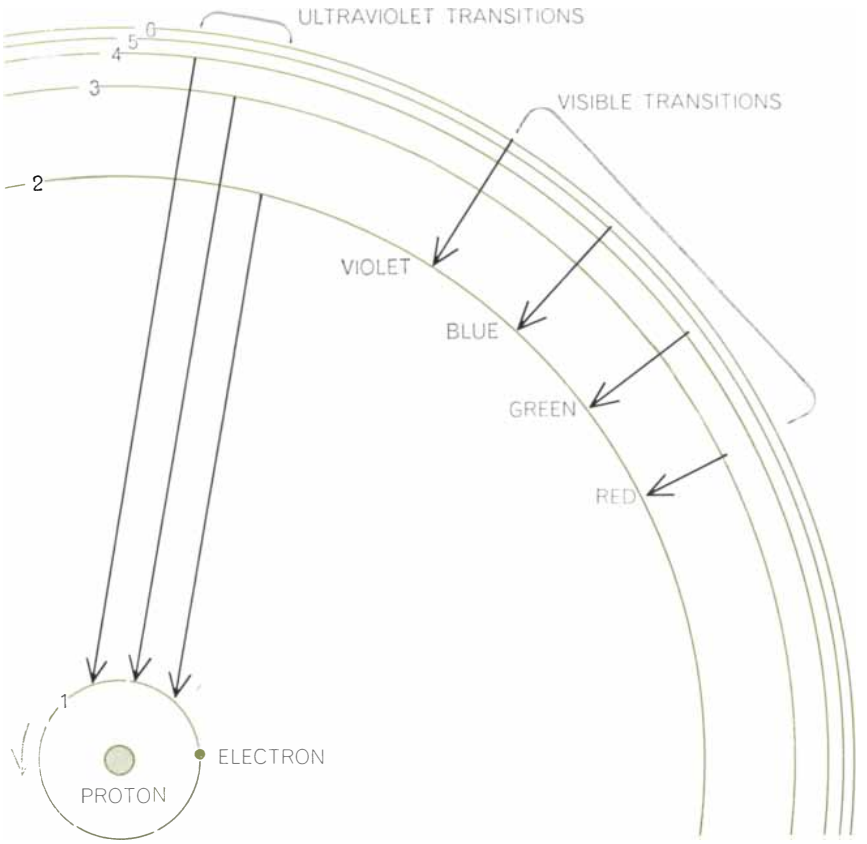
What appears to be a satisfactory explanation of the spectrogram and a proof that the planetary nebulosities are expanding is marred, however, by the fact that the same spectrograms would be produced by a collapsing gas cloud. The red shift, in this case, would come from the gas on the near side of the cloud and the violet shift from the far side. Whereas the spectrograms, combined with what is known about stellar evolution, strongly indicate the ejection of the gas from the stars, it is not yet possible to show, by independent evidence, that the clouds are expanding.

The spectrograms have much else to tell about the strange state of matter in these gas clouds, and this has helped considerably to point the way out of the dilemma. In addition to the green lines of doubly ionized oxygen, they show emission lines from helium, carbon, nitrogen, neon and sulfur, usually in several stages of ionization, and from hydrogen, which is the most abundant element here as elsewhere in the universe. A weak continuous emission along the spectrum could conceivably be due in part to the presence of molecular hydrogen (H_2); confirmation of this conjecture would be the first evidence for the existence of molecular hydrogen anywhere outside the solar system.



BOWING OF SPECTRAL LINES occurs when the gaseous envelope of a planetary nebula is expanding. Light emitted from the approaching gas is shifted toward shorter wavelengths; that from the receding gas, toward longer wavelengths. Motion perpendicular to the line of sight produces normal wavelengths, which are represented by the pinched ends of the emission lines. Enlarged section of nebular spectrogram at right shows two bright green lines of doubly ionized oxygen split into longer and shorter wavelength components.

All of this indicates that the gas cloud has an extremely low density. As a result a molecule, an atom or a subatomic particle in the cloud remains undisturbed for long periods of time. The central star, perhaps a tenth of a light-year away, is a point of light no brighter than the moon in the earth's sky. Around the atom, space glows faintly, some of the light coming from distant stars but most of it from other atoms in the nebula. The color of the "sky" glow is strongly ultraviolet, the color of 1,216 angstroms to be exact. This is the wavelength of the radiation emitted by the most probable quantum jumps of an electron as it rejoins the central proton of a hydrogen atom and settles in its "ground" state, or lowest-energy orbit. From the earth's surface the emission at 1,216 angstroms is invisible because it is blocked by the earth's atmosphere. Its presence and brightness can be deduced, however, from the intensity of hydrogen emissions at other wavelengths.



LIGHT IS RADIATED from a hydrogen atom when the electron "jumps" from a higher to a lower orbit. Some transitions are shown by arrows. Orbit separations are in energy units; the longer the transition, the more energy released and the shorter the wavelength.

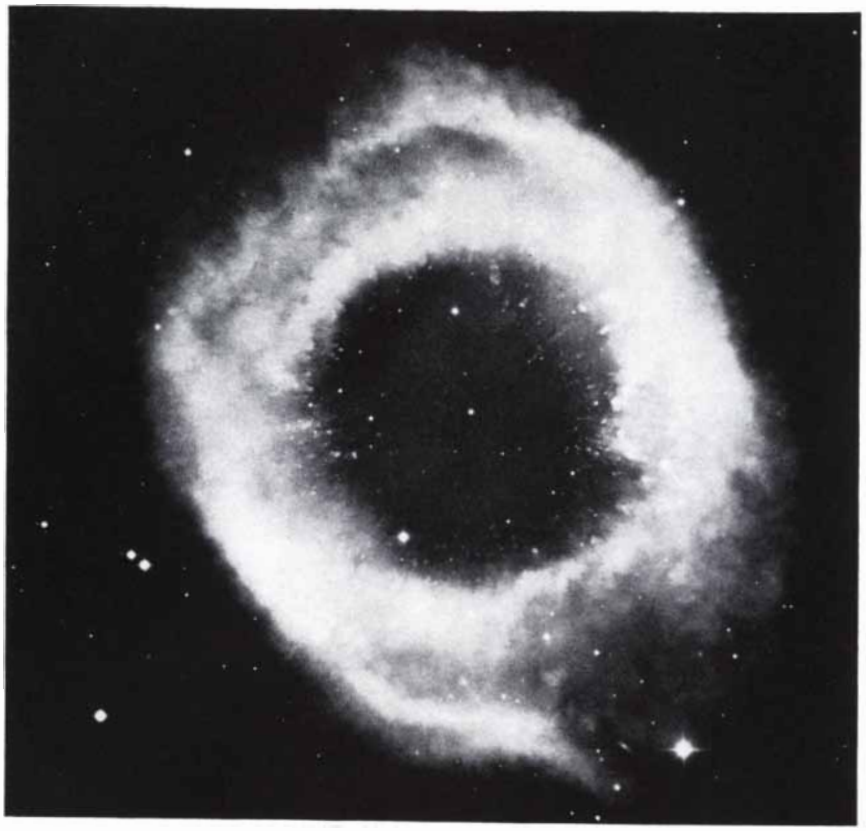
In decoding the information that is contained in these emissions, it is necessary to disentangle the effects of the density of electrons per cubic centimeter and the velocity, or "temperature," of the electrons. If the gas clouds were composed exclusively of hydrogen, it would not be possible to do this very accurately and the intensity of emissions could be attributed as well to density as to temperature. Fortunately the "impurities," particularly oxygen, in the nebula provide the means to make this discrimination. In addition to supplying most of the light that reaches the spectrogram, therefore, the impurities also make it possible to measure the true density of the nebula and the high excitation to which the matter in the gas cloud is boosted by the energetic radiation from the star.

Like the hydrogen, three-quarters of which remains ionized at all times, most of the oxygen is ionized. From their ground states the outer electrons of singly or doubly ionized oxygen atoms move most easily into metastable states; spontaneous, downward return from these states is virtually "forbidden" according to the equations of quantum physics. Provided that they are left undisturbed, the electrons will persist in these states for several seconds, which in the context of atomic processes is a long time. When at last they return to their ground states, they emit a photon of radiation corresponding to the energy difference between the two states. For doubly ionized oxygen the wavelengths of these transitions are those of the "nebulium" lines at 5,007 and 4,959 angstroms; singly ionized oxygen produces a pair of lines at 3,727 angstroms, just outside the visible spectrum. In the laboratory these forbidden lines are almost never seen; in a second's time an atom undergoes so many collisions with other atoms that electrons are de-excited from metastable states without the release of radiation. The radiations at these wavelengths, therefore, provide a measure of the density of the gas. In effect the simultaneous solution of the equation for the forbidden-line intensities and for the hydrogen-line intensities yields the electron density and the electron temperature as separate quantities.

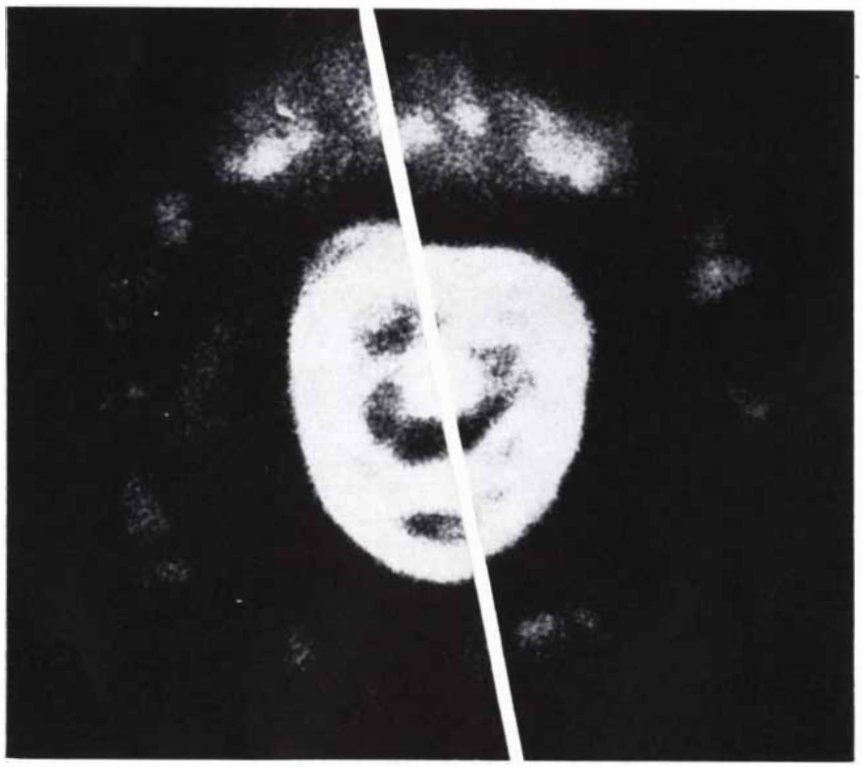
From one nebula to the next the answers prove to be surprisingly uniform. According to Lawrence H. Aller of the University of California at Los Angeles a typical planetary nebula has 10,000 electrons per cubic centimeter and an electron temperature of 10,000 degrees K., corresponding to a mean electron velocity of 675 kilometers per second. This compares to a particle density of 10 million per cubic centimeter in an excellent laboratory vacuum and an average velocity of half a kilometer per second for an oxygen molecule at room temperature.

Many nebulae appear as rings, as if they are shells of gas "visible" to the photographic film only around their circumference, where the shell is seen, as it were, edge on. To determine if there is any gas within the shell one can take advantage of the fact that the higher intensity of radiation closer to the star must strip all but the most tenacious electrons from the atoms there. Only the very-hard-to-ionize inert gases will be left with any electrons at all. A survey of the spectrograms for lines from helium, neon and argon has shown that some ring nebulae are indeed empty shells. If their nebulosity represents gas ejected from the star, it must have been ejected discontinuously, in a "puff." Other ring nebulae, however, show faint radiations of inert gases from within—radiations that indicate material does exist there. The Ring Nebula in Lyra (No. 67 in Messier's catalogue) shows such radiations [*see illustration on page 62*].

The next question that comes to mind is whether or not there is any gas outside the sphere of ionization. Is space



HELICAL NEBULA in Aquarius is the only planetary close enough to the earth for its distance (about 300 light-years) to be measured trigonometrically. The comet-like shapes around the inner edge are caused by the pressure of light radiated from the central star.



ANTICIPATED EXPANSION of the Eskimo Nebula, NGC 2392, is about four seconds of arc in 100 years, as shown in this composite made from a photograph taken recently with the 200-inch telescope. In spite of the large value indicated by its Doppler measurements, no actual expansion of NGC 2392 was detected in photographs made 47 years apart.

empty there? Or is gas present and invisible because it does not shine? As long ago as 1938 Bengt Strömgren, then at the University of Copenhagen, framed these questions in a more fruitful way: Why does the sphere of ionization show such a sharp outer boundary? His theoretical answer provided the clue that prompted us to make the comparison of the before-and-after pictures of the planetary nebulae. Strömgren found that the radius of the sphere of ionization depends on the density of the gas as well as the luminosity of the star. He showed that the ionizing power of the radiation not only varies inversely as the square of the distance from the star, as might be expected, but also varies inversely with the density of the gas. This follows from the fact that the radiation is more strongly absorbed by the gas at higher densities. The thinner the gas, therefore, the longer the reach of the radiation, even though its ionizing power dies away with distance. At a given distance from a particular star the curves for these two variables intersect and ionization ceases quite suddenly, giving the ionization sphere its sharp definition.

If the gas of a planetary nebula is expanding and so growing less dense, Strömgren's model showed that the ionization sphere should also expand in size. In fact, the velocity of the expansion of the ionization sphere, according to his equation, must be equal to twice the velocity of the expansion of the gas, multiplied by the ratio of the radii of the ionization and the gas spheres [*see illustration on opposite page*]. Since the velocity of the motion of the gas is known from Doppler measurements on the spectrograms, an increase in the size of the ionization sphere would yield a measurement of the size of the gas sphere in relation to that of the ionization sphere.

With Barbara Welther, our associate at the Harvard College Observatory, we decided to see if comparison of recent and old photographs of planetary nebulae would show any detectable increase in the size of their ionization spheres. Albert E. Whitford, director of the Lick Observatory of the University of California, allowed us to use for this purpose the 36-inch Crossley reflecting telescope at that observatory, the first in the world designed for high-resolution astronomical photography. Many excellent photographs of planetary nebulae were made with this telescope before 1900 and are available in the extensive negative collection of the Lick Observatory. By comparing these with new negatives, made under as nearly identical conditions as

possible, we could eliminate systematic errors.

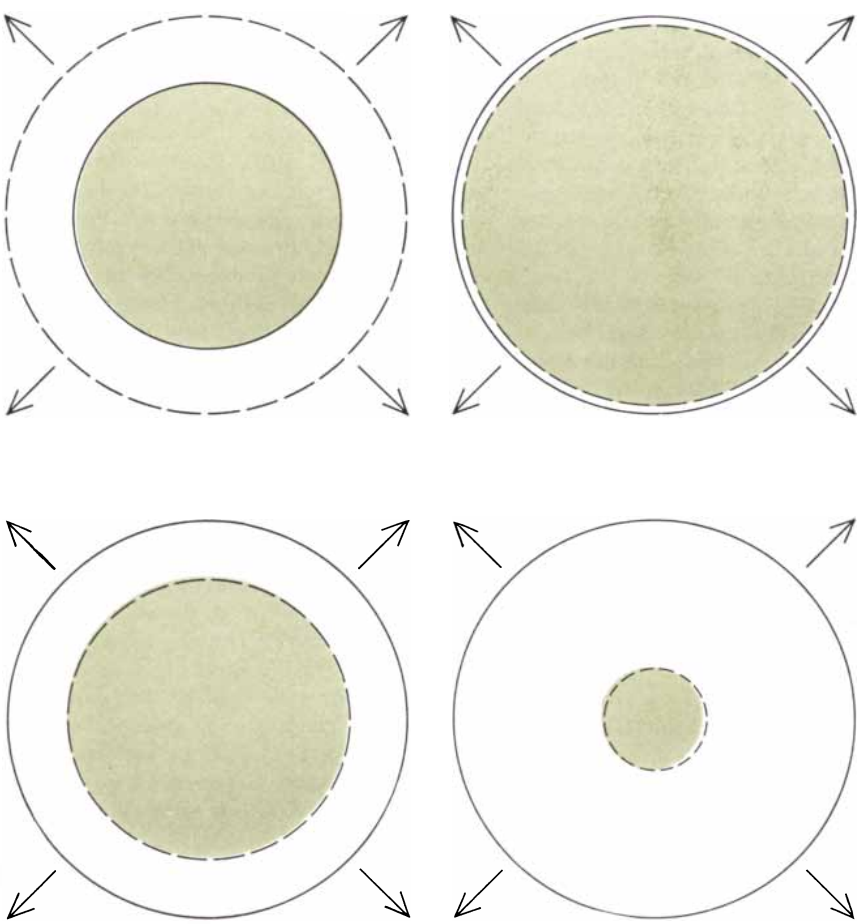
The results of our efforts are quite fascinating. Our picture of the Ring Nebula in Lyra, for example, showed a radial expansion of .3 second of arc—just outside the range of possible error of plus or minus .2 second of arc—when compared with the 1900 photograph. This result agrees quite well with measurements of the Ring Nebula made by the Soviet astronomer A. A. Latypov. The rate of expansion of the gas, based on Doppler measurements made by Olin C. Wilson of the Mount Wilson and Palomar Observatories, indicated that the increase in the radius of the gas sphere over the 60-year period might come to as much as one second of arc. The conclusion to be drawn from this finding is qualified by uncertainty as to the distance to the nebula, but it seems unlikely that the nebula is three or four times more distant than has been estimated. Instead, according to the Strömgren equation, it would appear that the ionization sphere has a radius only about a sixth that of the gas sphere and is expanding at about a third of the velocity of the gas sphere. There is thus a great deal of gas in space around the outside of the visible ionization sphere. That there is also gas within is indicated by the observed emissions from the inert gases inside the sphere.

In the case of the Dumbbell Nebula (Messier 27) in the constellation Vulpecula, Wilson's Doppler measurements showed that the gas moves away from the star with a velocity of 28 kilometers per second. If the distance to the Dumbbell Nebula is 1,200 light-years, as estimated, then the gas sphere should have expanded 2.1 seconds of arc in diameter in the 62 years separating the two sets of photographs. The expansion of the visible nebula observed in our comparison of the photographs came to .62 second of arc, plus or minus .18 second. This is again a small increase in size and strongly supports the case for the expansion of an ionized sphere.

A precise coincidence in the rate of expansion of the visible nebula and the gas spheres, however, would present a special case of the equation that relates them. The conclusion would then be that the ionizing power of the radiation from the star outreaches the gas sphere or that the radius of the gas sphere is just twice as large as that of the ionization sphere. So far we have not found a planetary nebula existing in this special state.

The Eskimo Nebula (NGC 2392) presents still another special case. Here no expansion whatever is detectable in a comparison of the two sets of photographs. The Doppler measurements show a rate of expansion in the gas sphere, however, that is equivalent to an expansion of two seconds of arc over the 60-year period. This must be a nebula in which the central star is still ejecting material; with the density of the gas sphere thereby held constant, the ionization sphere would remain constant in size. Independent confirmation of this conclusion comes from a study of the spectrum of the central star, reported by Wilson in 1948, which shows that it is truly releasing material into space.

Although we have so far measured only a relatively few nebulae, there does not yet seem to be any tendency for these objects to show angular expansions equal to the expansion of the gas predicted from Doppler measurements. Very possibly, then, all planetary nebulae are ionization spheres, with the gas extending into space out beyond the visible edge of the nebulosity. Our preliminary results can be improved on when larger telescopes have been in operation for a sufficiently long period of time—and perhaps they may be improved on even sooner by the higher resolving power of telescopes placed in orbit about the earth.



RATE OF EXPANSION of the visible portion of a planetary nebula (*colored area*) depends on the relation between the extent of the gas sphere (*solid line*) and the extent of the ionization sphere (*broken line*) as well as on the relative rates of expansion of these two spheres. In the first case (*top left*) the ionization sphere is larger than the gas sphere and the rate of visible expansion equals the Doppler rate of radial expansion of the gas. In the second case (*top right*) the ionization sphere almost fills the gas sphere and the visible nebula expands twice as fast as the Doppler prediction. In the third case (*bottom left*) the radius of the ionization sphere is two-thirds that of the gas sphere and the visible nebula expands at four-thirds the predicted rate. In the fourth case (*bottom right*) radius of gas sphere is four times that of ionization sphere and visible nebula expands half as fast as Doppler prediction. In all four cases central star is assumed to have stopped ejecting gas.

The Synthetic Elements: III

Two earlier articles in this magazine described the synthesis of elements up to element 101. The list now extends to element 103, and plans are afoot to make some of the rarer elements in quantity

by Glenn T. Seaborg and Arnold R. Fritsch

Since 1940, 11 radioactive elements heavier than uranium have been created by man. This works out to one new transuranium element every two years. Two of the transuranium elements, neptunium and plutonium, are now manufactured by the ton; neptunium is of course made because it decays into plutonium. Of the remaining transuranium elements, five have been produced in visible quantities and four have never actually been seen. Two of the elements were unexpectedly discovered in the radioactive debris of a thermonuclear explosion; both have since been made in the laboratory. All 11 transuranium elements were identified either in whole or in part by workers associated with the Radiation Laboratory of the University of California at Berkeley.

The 11 elements occupy positions 93 through 103 in the periodic table of elements, which begins with hydrogen, with an atomic number of 1. The atomic number of an element tells how many protons, or positively charged particles, it has in its nucleus. All elements, except for the lightest member of the hydrogen family, also contain one or more neutrons, or neutral particles, in their nuclei. The sum of the protons and neutrons defines the mass number of a nuclear species. The mass numbers of the 11 transuranium elements range from 231 to 257. In order of atomic number the 11 transuranium elements have been given the following names: 93, neptunium; 94, plutonium; 95, americium; 96, curium; 97, berkelium; 98, californium; 99, einsteinium; 100, fermium; 101, mendelevium; 102, no accepted name; 103, lawrencium. Each of the 11 has several isotopes, or nuclear species, that differ in their number of neutrons. Plutonium 238, for example, has 94 protons and 144 neutrons; plutonium 239 has the same number of protons and 145 neutrons. The two isotopes can respectively be written $_{94}Pu^{238}$ and $_{94}Pu^{239}$. All told, nearly 100 isotopes of the transuranium elements have been created and studied.

Two earlier articles in *Scientific American*, one in April, 1950, and the other in December, 1956, have recounted the discovery of elements 93 through 101. This article will describe the discovery of elements 102 and 103 and will discuss the effort to produce elements of still higher atomic number. The general procedure for creating a new heavy element is to add one or more protons to the nucleus of an already existing element. This can be done by driving one or more protons into the nucleus with the help of a particle accelerator such as a cyclotron or linear accelerator. Another method is to add one or more neutrons to an existing nucleus. By a radioactive decay process a neutron inside a nucleus can emit an electron, thereby becoming a proton and raising the atomic number by one. Since neutrons have no charge they can easily enter the positively charged nucleus of an atom and do not need, like protons, to be accelerated to high energies. The neutrons can be obtained from a nuclear reactor or a nuclear explosion.

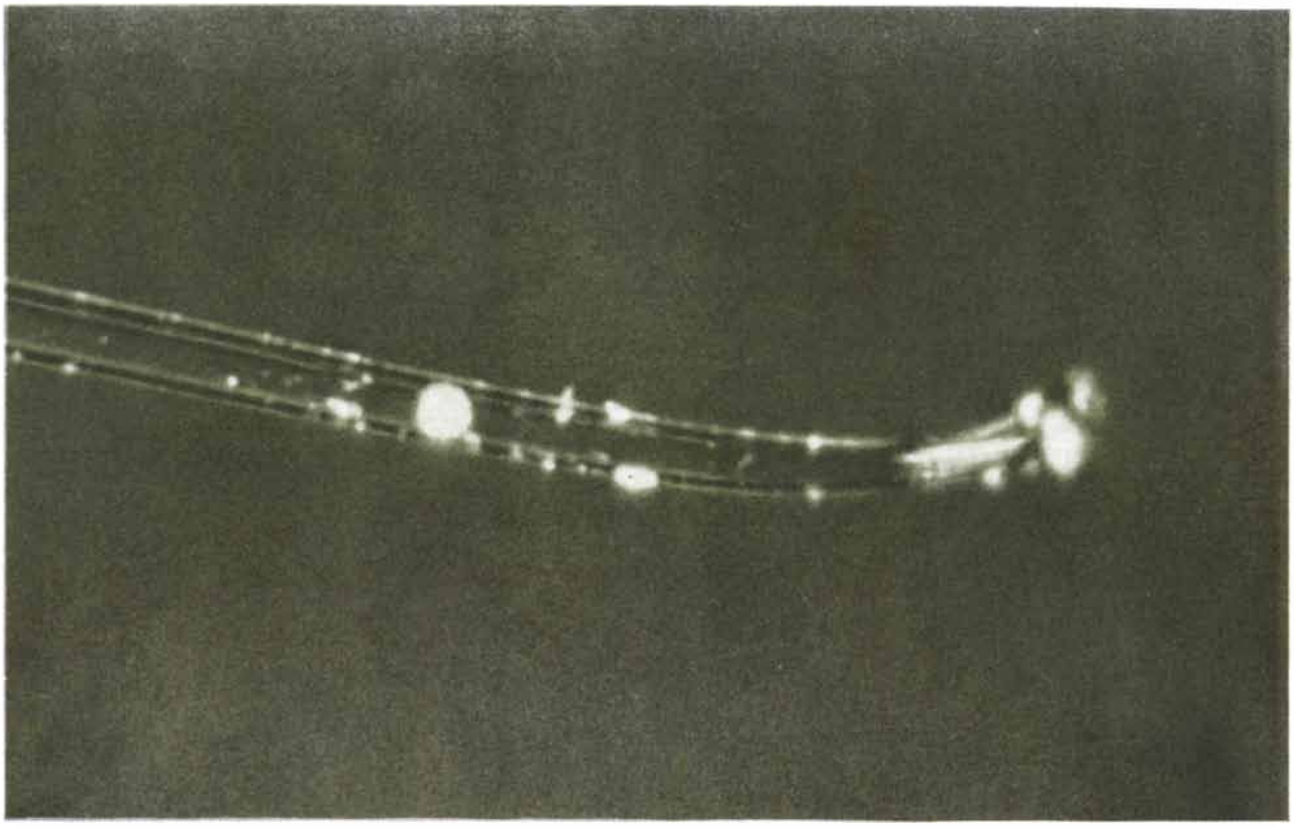
Neptunium and its decay product plutonium (of mass number 239) are made in large quantities in nuclear reactors. Americium (95) was first made in a reactor. Einsteinium (99) and fermium (100) were first found 11 years ago in the debris of the first thermonuclear explosion, having been produced by the intense neutron irradiation of uranium.

Six of the transuranium elements—93, 94, 96, 97, 98 and 101—were first created with the help of one remarkable machine: the 60-inch cyclotron at the University of California at Berkeley. Built in 1939 by Ernest O. Lawrence, inventor of the cyclotron, the machine was finally retired last June. It had produced most of the six new elements by bombarding the heaviest available transuranium elements with alpha particles (the nuclei of helium atoms), which contain two protons and two neutrons. Depending on the target nucleus and the energy of collision, one or both protons may remain lodged in the target, and in some cases one of the neutrons may also remain. The 60-inch cyclotron had also assisted in the production of a host of additional transuranium isotopes.

Before its retirement the 60-inch cyclotron had been superseded in usefulness by the powerful heavy-ion linear accelerator (HILAC), finished in 1957, and by a more versatile 88-inch cyclotron, finished in 1962. The HILAC was specifically designed to accelerate nuclei heavier than alpha particles, with the objective of creating elements beyond mendelevium (element 101).

As we have moved up the atomic scale the problem of identifying the new elements has increased in difficulty with the problem of creating them. The chemical separation of these new elements has depended almost entirely on the ion-exchange method. In this method the mixture of elements to be separated is passed through a tube packed with a granular ion-exchange resin. Each element travels through the tube at a characteristic rate, as its ions repeatedly associate and disassociate with the resin. In general elements of higher atomic number travel faster than elements of a lower number. The outflow of the tube is collected drop by drop and analyzed by its chemistry and radioactivity.

Advances in ultramicrochemistry have enabled workers at Berkeley and else-



BERKELIUM, element 97, was discovered in 1949. One of the first visible bits of a pure berkelium compound, berkelium chloride, was this speck (*round dot within tube*) obtained in 1962. It weighed approximately three nanograms (billionths of a gram).

CALIFORNIUM, element 98, discovered in 1950, was obtained in a compound in visible quantity in 1960. The speck of californium oxychloride in the tube weighed .3 microgram (millionth of a gram). This material was used for macroscopic measurements.

where to study the properties of seemingly infinitesimal quantities of compounds of the transuranium elements. With samples weighing as little as a few nanograms (billionths of a gram) the Berkeley investigators have measured the magnetic properties of the compounds and have even conducted X-ray diffraction studies of them to determine their crystal structure. All the transuranium elements through einsteinium (99) have now been subjected to some macroscopic chemical and physical analysis. The task has been complicated because many of the elements have short half lives, making them very radioactive. As an example the isotope of einsteinium (Es-253), studied at Berkeley by Burris B. Cunningham, James C. Wallmann, Llad Phillips and Raymond C. Gatti, has a half life of only 20 days. The sample they worked with weighed about .01 microgram, less than a billionth of an ounce. Generally speaking the half life becomes shorter with increasing atomic number, which makes it practically impossible to undertake chemical or physical studies with macroscopic quantities of elements having atomic numbers greater than that of einsteinium.

The production and identification of mendelevium (element 101), named after the great originator of the periodic table, Dmitri Mendeleev, was literally accomplished atom by atom. After its production in the 60-inch cyclotron, it was separated by ion exchange, an atom or two at a time, from all other known elements. The separation and identification had to be done at high speed because the half life of the isotope being studied was about 1.5 hours.

When the search began for element 102, it was clear that nature had not relented after mendelevium but had become even more obdurate. The predicted half life for the isotopes of element 102 that could be successfully produced ranged from a few seconds to several minutes. Chemical separation, the classical test for a new element, appeared out of the question. It seemed that the identification would have to rest at least in part on physical evidence.

In the summer of 1957 a group of workers from the Argonne National Laboratory near Chicago, the Atomic Energy Research Establishment at Harwell in England and the Nobel Institute for Physics in Stockholm announced the discovery of an isotope of element 102 as a result of research done at the Nobel Institute. The isotope was reportedly produced by bombarding curium 244 with carbon 13 nuclei in the Nobel Institute's cyclotron. This isotope of element 102 was said to have a half life of about 10 minutes and to decay by emitting alpha particles with an energy of 8.5 million electron volts (Mev). This is a surprisingly long half life for an isotope that emits such energetic particles.

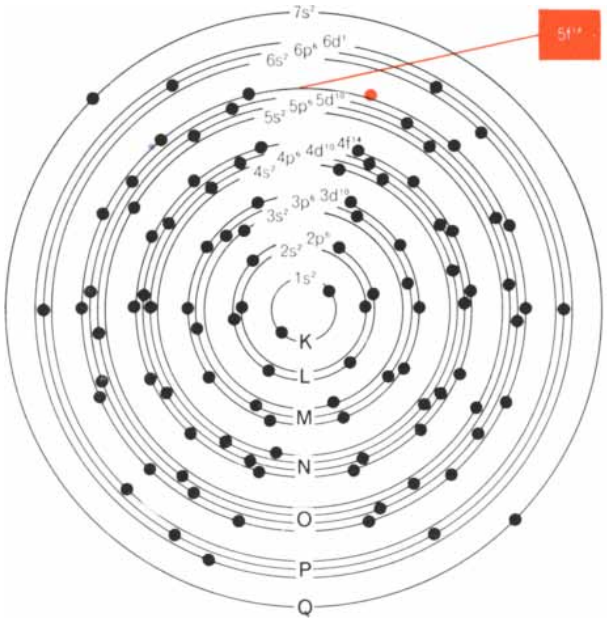
The investigators proposed the name "nobelium" and the symbol "No" for element 102, and the name was accepted by the Commission on Atomic Weights of the International Union of Pure and Applied Chemistry. The acceptance turned out to be premature. All attempts both in the U.S. and in the U.S.S.R. to duplicate the Stockholm experiment have failed, in spite of the use of research tools many times more sensitive than those used in Stockholm.

Less than a year later, in April, 1958, an isotope of element 102 having a mass number of 254 (102^{254}) was unambiguously identified at Berkeley by Albert Ghiorso, Torbjorn Sikkeland, John R. Walton and one of the authors of this article. The isotope was produced by bombarding curium 246 with carbon 12 nuclei accelerated in the HILAC. In this reaction the six protons in the carbon nucleus combine with 96 protons in the curium nucleus to produce a nucleus with 102 protons. In addition, neutrons from the carbon increase by two the number of neutrons in the target [*see upper illustration on page 72*]. Within about three seconds half of the 102^{254} nuclei decay into 100^{250} (fermium) nuclei, with the emission of an alpha particle in each decay.

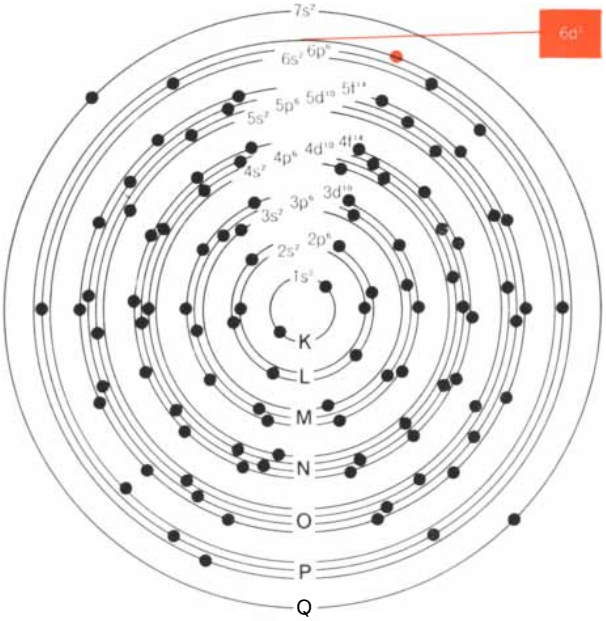
Fermium 250, in turn, has a half life of 30 minutes, releasing upon decay an alpha particle with an energy of 7.43 Mev. By chemical identification of fermium 250 one could be sure that the new element, 102^{254}, had been created. No attempt was planned or made to subject the new element to chemical manipulation because its half life is too short. The Berkeley workers will have the traditional privilege of suggesting the new name for element 102 to replace the name "nobelium."

The experimental arrangement for producing element 102 is diagramed at the top left on page 73. The target consisted of a mixture of curium isotopes, including curium 246, that had been produced by bombarding plutonium with neutrons over a period of years. The curium was deposited on a thin nickel foil and was placed in a container filled with helium. When the HILAC beam of carbon 12 nuclei struck the thin target, the newly created atoms of element 102 were knocked out of the target and into the surrounding helium. At this point the atoms of element 102 had not yet acquired a full complement of electrons and therefore still had a net positive charge; that is, they were positive ions. It was found that practically all the ions of element 102 could be attracted to a negatively charged moving metallic belt placed directly beneath the target. The belt then traveled under a "catcher" foil that was negatively charged with respect to the belt. Approximately half of the fermium daughter atoms produced by the alpha-particle decay of element 102 recoiled from the surface of the belt and, because they were still positively charged, were attracted to the catcher foil.

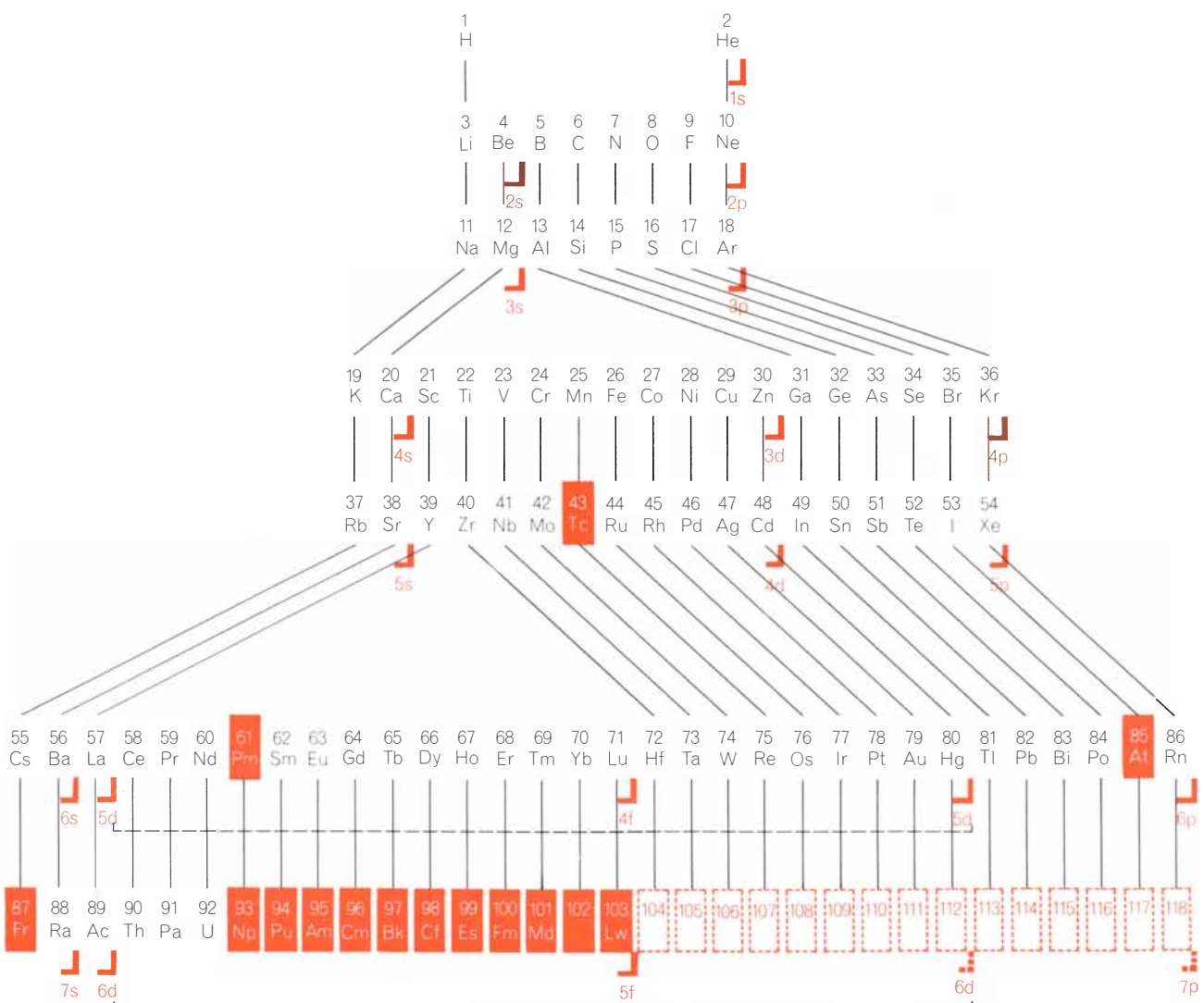
THE PERIODIC TABLE at the bottom of the opposite page presents the 103 natural and synthetic elements according to differences and similarities in their chemical properties. The 15 synthetic elements are indicated by the solid colored rectangles. Open colored rectangles indicate synthetic elements not yet discovered. Most elements in each horizontal row differ from one another in chemical properties. The lines running from top to bottom connect elements of similar chemical properties. Above the symbol for each element is its atomic number: the number of positive charges in its nucleus or the number of electrons bound by them. In each horizontal row the colored brackets designated *1s*, *2s*, *2p* and so on denote the filling of subshells of electrons, and it is largely the number of electrons in the outer shell that determines the chemical properties. The electron-shell structure of lawrencium, the latest element to be synthesized, and of element 104, which will probably be created next, are given in the schematic drawings at the top of the page. In X-ray terminology the shells are designated K, L, M, N, O, P and Q. In spectrographic terminology they are 1, 2, 3, 4, 5, 6 and 7. The spectrographic subshells are s, p, d and f. The maximum number of electrons (*dots*) in any s subshell is two, in any p subshell six, in any d subshell 10 and in any f subshell 14. For each subshell the number of electrons is indicated by a superscript figure. In most elements all the inner subshells are filled, and electrons add to the outer shell with increasing atomic number. In the "lanthanide" rare-earth elements (numbers 58 through 71) the number of 5d and 6s electrons remains approximately the same and electrons in successive elements are added to the 4f subshell. The transuranium elements through lawrencium are part of another group of rare earths, the "actinides," in which 5f subshell fills up. Element 104 will be first element above actinide series. Colored dot in each atom is last electron added; large colored rectangles mark changed subshells.



ELEMENT 103
(LAWRENCIUM)



ELEMENT 104



After a time of bombardment suited to the half life of the daughter atom to be examined, the catcher foil was cut into five equal sections at right angles to the motion of the belt. Each section was analyzed simultaneously in radiation counters. It was found that fermium 250 recoiling from the moving belt could be collected on the stationary catcher foils in accordance with a three-second half life for the parent isotope 102^{254}.

The chemical identification of the daughter fermium 250 was accomplished by dissolving the radioactive material from the catcher foil and separating it by ion exchange. The tiny fraction of liquid containing fermium 250 produced nine radioactive decays, recorded by instrument, showing that nine fermium atoms were present. The identification of the fermium-containing fraction was aided by adding tracers to the sample before it was put into the ion-exchange column. Two of the tracers were radioactive isotopes of thulium and yttrium, which in such an ion-exchange column behave somewhat as elements 102 and 101 are expected to. That is, they should emerge from the column just slightly before a fraction containing fermium (element 100). Two other tracers, californium (element 98) and einsteinium (element 99), were added to define positions immediately behind fermium. Thus the radioactivity found in a fraction just before einsteinium should be due to fermium; the matching of these radioactive properties (half life and energy) with the known properties of fermium 250 completes the identification.

In later, more direct, experiments the positively charged atoms of element 102 that had been knocked out of the curium target were caught on a negatively charged belt. The belt was then quickly pulled inside an alpha-particle counter in order to measure directly the half life of the element and the energy of its alpha particles. The values obtained were again three seconds for the half life and, in addition, 8.3 Mev for the alpha-particle energy. It was also discovered that this isotope of element 102 decays in part by spontaneous fission.

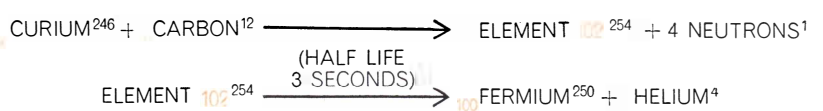
In the spring of 1961, after almost three years of work begun shortly following the discovery of element 102, Ghiorso, Sikkeland, Almon E. Larsh and Robert M. Latimer of Berkeley found an isotope of element 103 with a half life of about eight seconds. The discoverers suggested the name "lawrencium" in honor of the man who was not only the inventor of the cyclotron but also the founder and longtime director of the Radiation Laboratory at Berkeley. As in the case of element 102, it has not been possible to obtain a chemical identification of element 103, and the discovery rests solely on physical evidence.

The method used to produce and identify lawrencium is similar to that used in the later direct studies of element 102 and is depicted schematically at the top right on the opposite page. Three micrograms of a mixture of californium isotopes (californium 250, 251 and 252) were bombarded in the HILAC with ions of boron 10 or boron 11. All five protons and an additional number of neutrons equal to about half of the neutrons in the boron nucleus remained with the californium nucleus [*see lower illustration below*]. The positively charged atoms of lawrencium recoiled from the target into an atmosphere of helium and were then collected on a negatively charged copper tape. This tape was automatically placed before solid-state radiation detectors every few seconds to measure the rate of decay of the lawrencium isotope and the energy of the alpha particles being emitted.

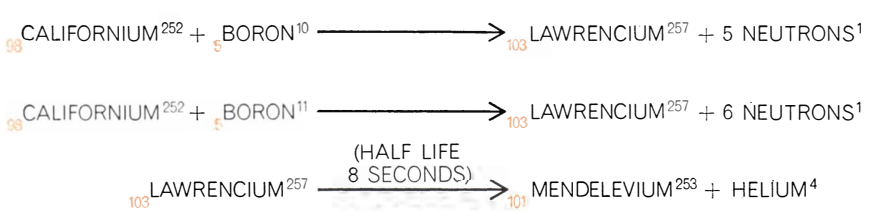
By this means it was possible to identify the lawrencium isotope; it was lawrencium 257, with a half life of eight seconds. This isotope decays through the emission of alpha particles with an energy of 8.6 Mev. Many "cross bombardment" experiments were made with various target elements and different bombarding particles of various energies to show that the isotope emitting 8.6-Mev alpha particles was produced only when the californium target was bombarded with boron particles of the appropriate energy. The complete elimination of lead and bismuth impurities from the californium target was of particular importance because these yield radioactive isotopes with properties similar to that of the isotope of element 103.

So far we have spoken only of the nuclear constituents of the transuranium elements. The chemical properties of an element, however, depend not on its nuclear constitution but almost entirely on the electrons outside the nucleus and their particular arrangement in a shell-like structure. The electrons in the transuranium elements are arranged in seven shells, which are labeled simply 1, 2, 3, 4, 5, 6 and 7, reading from the nucleus outward. The shells are further subdivided into subshells designated s, p, d and f [*see illustration on preceding page*]. The chemical behavior of the transuranium elements was predicted by one of the authors in 1944, when only neptunium and plutonium had as yet been discovered. The prediction was that the transuranium elements through element 103 would behave very much like the series of rare-earth elements from element 58 to element 71, which had been termed the lanthanide series because they have chemical properties similar to those of the immediately preceding element, lanthanum (element 57). By analogy the transuranium series through element 103 was called the actinide series after actinium (element 89), which immediately precedes the first element (thorium) in this series.

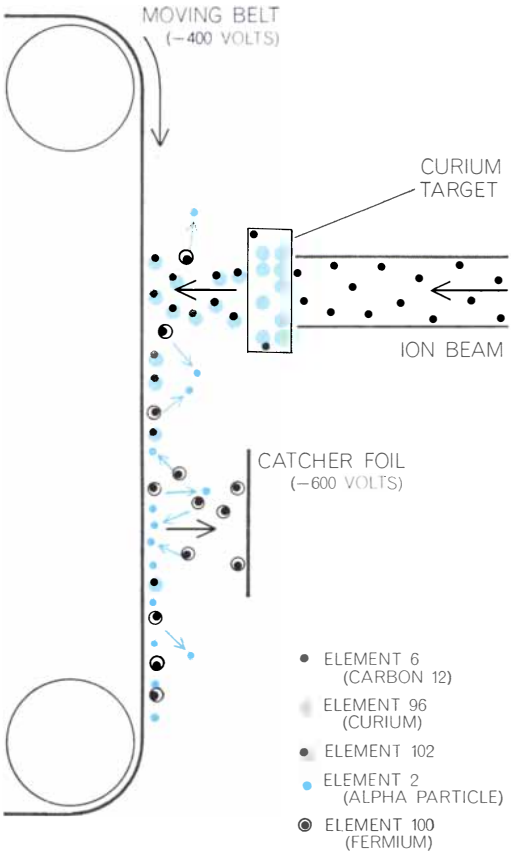
The two series share the following peculiarity of electron arrangement. The lanthanide series is built up by the addition of electrons entirely to the 4f subshell of the atom. The highest member of the series, lutetium, therefore has 14 electrons in the 4f shell. By the same token the actinide series is built up by



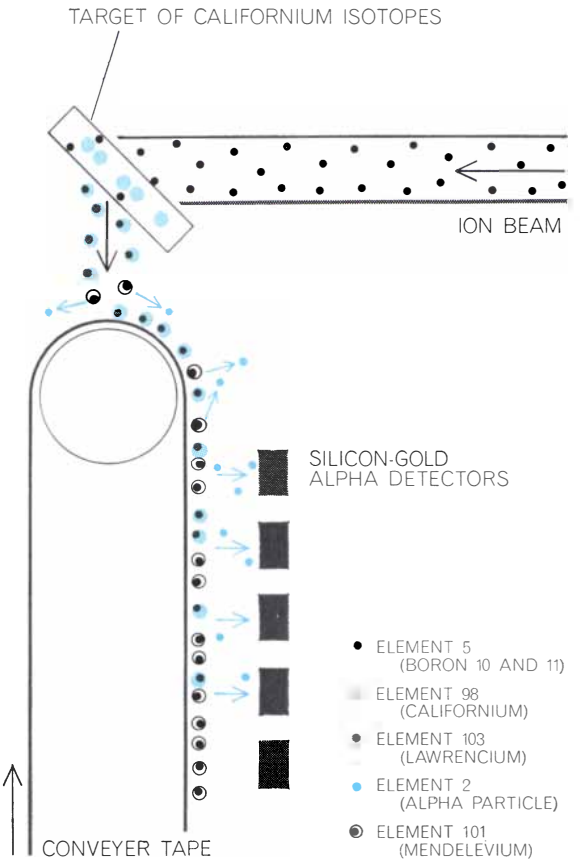
PRODUCTION OF ELEMENT 102 was achieved in 1958 through the nuclear reaction given in the upper line. It was identified through the decay reaction shown in the lower line. The figures in color are atomic numbers; the superscript figures are mass numbers.



PRODUCTION OF ELEMENT 103, lawrencium, was accomplished in 1961. The upper lines indicate two of the reactions in which lawrencium was created. Helium nucleus (alpha particle) emitted in decay (*bottom line*) was the key to the identification of the element.



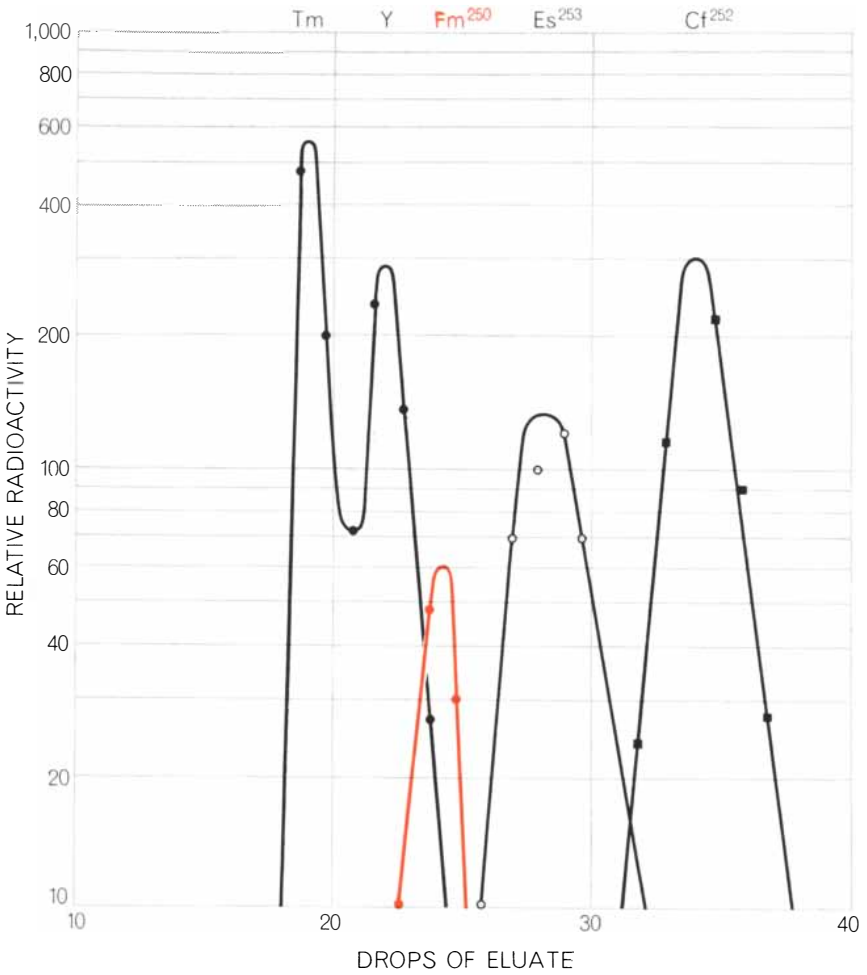
ELEMENT 102 was created and identified in this experimental arrangement. Beam of carbon 12 ions from accelerator made curium into a positive ion of 102 that decayed in three seconds by emitting an alpha particle. When particle was emitted toward belt, resulting charged fermium atom recoiled toward catcher foil. If particle flew away from belt, recoil embedded fermium atom in belt.



LAWRENCIUM, 103, was produced in similar apparatus. A target of californium was bombarded with ions of boron, creating positively charged ions of lawrencium, which were collected on negatively charged moving copper tape. Radiation detectors measured rate of decay of the lawrencium isotope and the energy of the alpha particles that it emitted in decaying to mendelevium.

ATOMIC NUMBER	NAME	SYMBOL	YEAR DISCOVERED	SOURCE OF FIRST PREPARATION	FIRST ISOTOPE IDENTIFIED	HALF LIFE OF FIRST ISOTOPE IDENTIFIED
93	NEPTUNIUM	Np	1940	Irradiation of uranium 238 with neutrons	Np^{239}	2.35 DAYS
94	PLUTONIUM	Pu	1941	Bombardment of uranium 238 with deuterons	Pu^{238}	86.4 YEARS
95	AMERICIUM	Am	1945	Irradiation of plutonium 239 with neutrons	Am^{241}	458 YEARS
96	CURIUM	Cm	1944	Bombardment of plutonium 239 with helium ions	Cm^{242}	162.5 DAYS
97	BERKELIUM	Bk	1949	Bombardment of americium 241 with helium ions	Bk^{243}	4.5 HOURS
98	CALIFORNIUM	Cf	1950	Bombardment of curium 242 with helium ions	Cf^{245}	44 MINUTES
99	EINSTEINIUM	Es	1952	Irradiation of uranium 238 with neutrons in first thermonuclear explosion	Es^{253}	20 DAYS
100	FERMIUM	Fm	1953	Irradiation of uranium 238 with neutrons in first thermonuclear explosion	Fm^{255}	22 HOURS
101	MENDELEVIUM	Md	1955	Bombardment of einsteinium 253 with helium ions	Md^{256}	1.5 HOURS
102			1958	Bombardment of curium 246 with carbon ions	102^{254}	3 SECONDS
103	LAWRENCIUM	Lw	1961	Bombardment of californium 252 with boron ions	Lw^{257}	8 SECONDS

TABLE OF TRANSURANIUM ELEMENTS lists atomic numbers, names, symbols, year of discovery, how they were first created, the first isotope identified and the half life of that isotope. The group at Berkeley that discovered element 102 has not yet named it.



CHEMICAL IDENTIFICATION of element 102 was accomplished through detection of its decay product, element 100 (fermium), in ion-exchange reaction. The other four elements (thulium, yttrium, einsteinium and californium) were placed in the exchange column because it was known that the first two should emerge just before and the second pair just after element 100. Nine atoms of fermium were detected in the liquid emerging from column.

successive additions of electrons to the 5f subshell. Lawrencium, with 14 electrons in the 5f subshell, is therefore the last member of the actinide series.

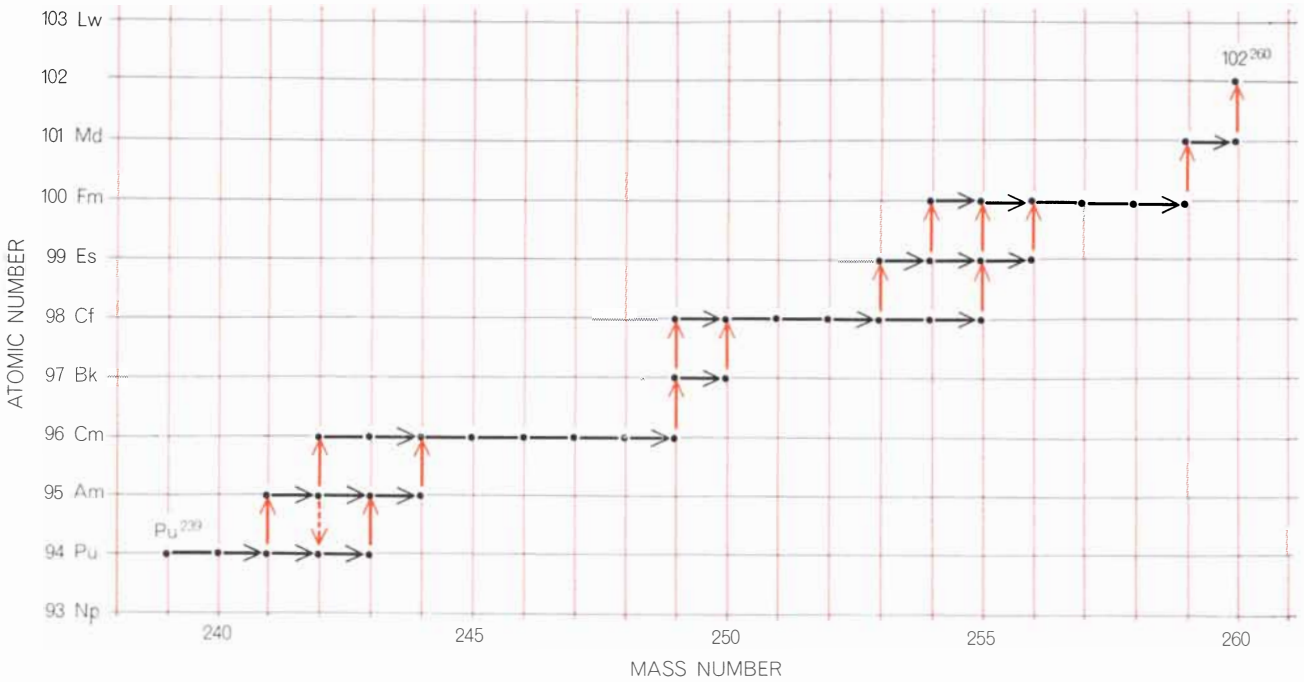
Element 104, when it is discovered, should be a most interesting element: it will be the first transactinide element. It should be chemically similar to hafnium (element 72), according to the predictions of the periodic table. Similarly, element 105 should resemble tantalum (element 73); element 106 should resemble tungsten (element 74), and so on. The expected half lives, however, decrease with increasing atomic number at such a rate that it will apparently not be possible to synthesize and detect new elements beyond about element 110, and the study of their chemical properties may become impossible long before this atomic number is reached.

It is disappointing, of course, that there seems to be little possibility of producing still heavier elements. If the limit of half lives did not exist, one might hope to produce ultimately a wholly new kind of "transition" series of 18 elements containing a fifth major electron subshell, 5g, beyond the 5f subshell of the actinide series. To study the properties of these elements would be fascinating, but unfortunately this seems to be impossible because the series probably would not begin before element 120 or thereabouts.

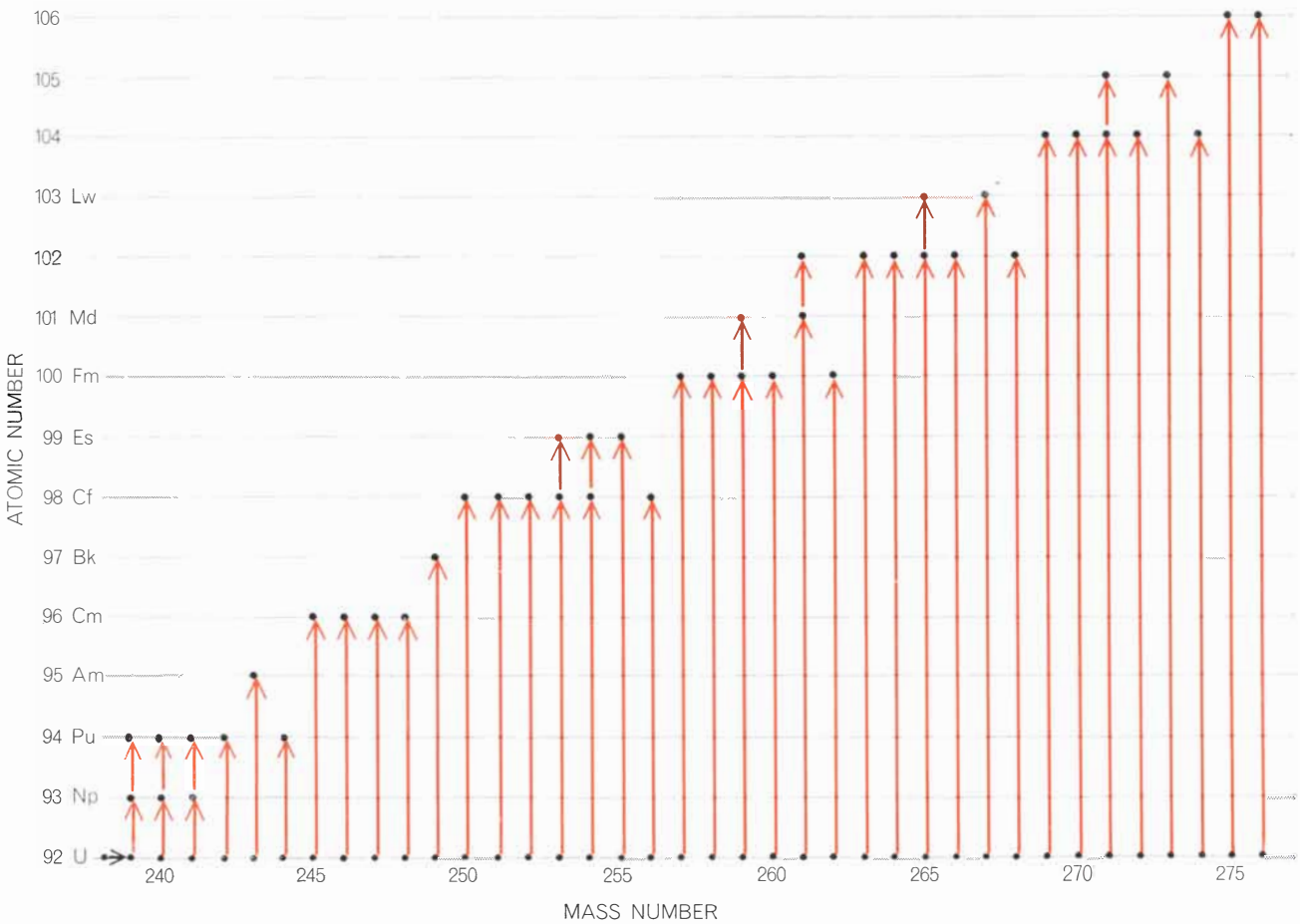
Efforts to produce and identify element 104 have been under way at Berkeley since shortly after the discovery of lawrencium. It is expected that element 104 can be created by bombarding a californium target with carbon ions in the HILAC. Predictions of the half lives of the isotopes of element 104 that may be produced in this manner indicate that they will probably be very short and perhaps on the border line of the tape-transport system used in the identification of lawrencium. To overcome this possible difficulty the Berkeley workers are developing even faster and more sensitive separation systems. One system employs a mass spectrograph, the device that projects ionized molecules or atoms into a magnetic field, in which they trace paths of different curvatures depending on their mass. The device might provide a quick and direct measure of the mass of the heaviest isotopes. Other techniques are being refined for rapidly collecting the decay products of element 104 and measuring their radioactivity. These techniques, if successful, may also be applicable to the synthesis and detection of elements beyond element 104. An important limitation, however, in using accelerators such as the HILAC is that they tend to produce transuranium isotopes with less than the optimum ratio of neutrons to protons. Isotopes thus deficient in neutrons usually have much shorter half lives than isotopes that contain a somewhat higher ratio.

A general principle to be observed in trying to create heavy elements by heavy-ion bombardment is that of using the heaviest available isotope as a target material and the lightest bombarding ion that will do the job. The search for element 104 uses element 98, californium, as a target material out of necessity. If element 99, einsteinium, were available in adequate quantity as a target material, the bombarding ion could be boron, which has only five protons, instead of carbon, which has six. As the number of protons in the bombarding ion increases, so does the energy required to get it past the barrier of positive charges carried by the target nucleus. This is important, because the energy carried by the bombarding ion contributes to the over-all excitation energy of the new nucleus formed. In the heavy-element region the higher the excitation energy is, the more likely it is that the excited, or compound, nucleus initially formed will undergo almost instantaneous fission and not yield the heavy nucleus being sought.

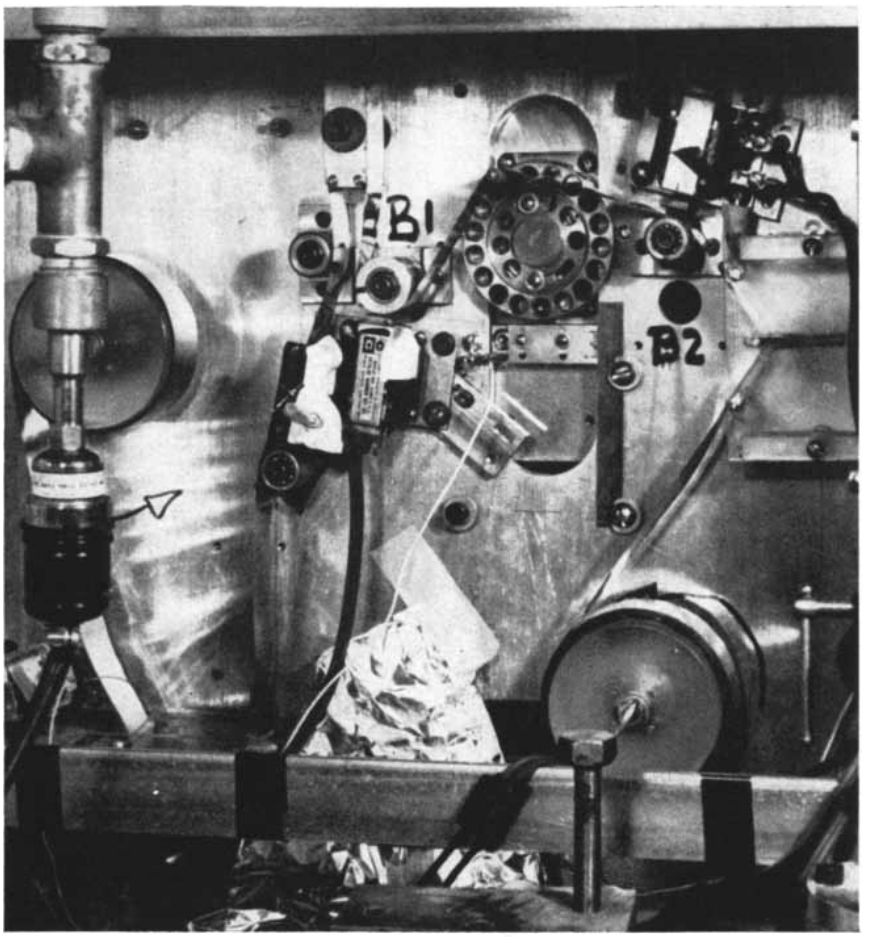
To provide adequate amounts of heavy nuclei to serve as target material, and for other purposes, the Atomic Energy Commission has initiated a "national transplutonium production program." The first step in the program, now well under way, is the irradiation of some 20 kilograms of plutonium 239 in a large production reactor at the AEC's Savannah River Plant near Aiken, S.C., to produce plutonium 242, americium 243, curium 244 and smaller amounts of heavier isotopes. Of the initial 20 kilograms of plutonium 239, about two kilo-



NUCLEAR REACTIONS that produce transuranium elements result from intense irradiation by slow neutrons. Each neutron capture (*black arrows*) adds one unit of mass and each beta decay (*colored arrows*) converts a neutron into a proton, increasing atomic number one unit. The broken colored arrow denotes capture of an orbital electron, which converts a proton into a neutron.



MULTIPLE NEUTRON CAPTURES occur virtually instantaneously in thermonuclear explosion, increasing mass number of atoms of original uranium 238 by various amounts. This occurs along horizontal line at bottom of graph. Subsequent beta decays (*vertical arrows*) produce the elements and isotopes of them indicated by dots. Reactions beyond element 100 (fermium) are hypothetical.



EXPERIMENTAL ARRANGEMENT used for the discovery and identification of lawrencium, element 103, is shown in this photograph. Apparatus was placed at end of accelerator.

grams will be recovered eventually in the form of useful heavier isotopes; 18 kilograms will be consumed in the fission reactions. At periodic intervals several hundred grams of the plutonium, americium and curium isotopes will be discharged from the reactor, chemically separated from the associated fission products and shipped to the Oak Ridge National Laboratory near Oak Ridge, Tenn.

At Oak Ridge the separated plutonium 242, americium 243 and curium 244 will be irradiated further in a specially designed reactor, the High Flux Isotope Reactor (HFIR), which is now under construction. After appropriate irradiation of the target materials in the HFIR, it will be possible to recover gram quantities of californium, hundreds of milligrams of berkelium, tens of milligrams of einsteinium and about a milligram of fermium, in addition to almost 100 grams of heavy curium isotopes (predominantly curium 246 and curium 248). To process the highly radioactive products of the HFIR, a special chemical plant, called the Transuranium Processing Facility (TPF), is also under construction at Oak Ridge.

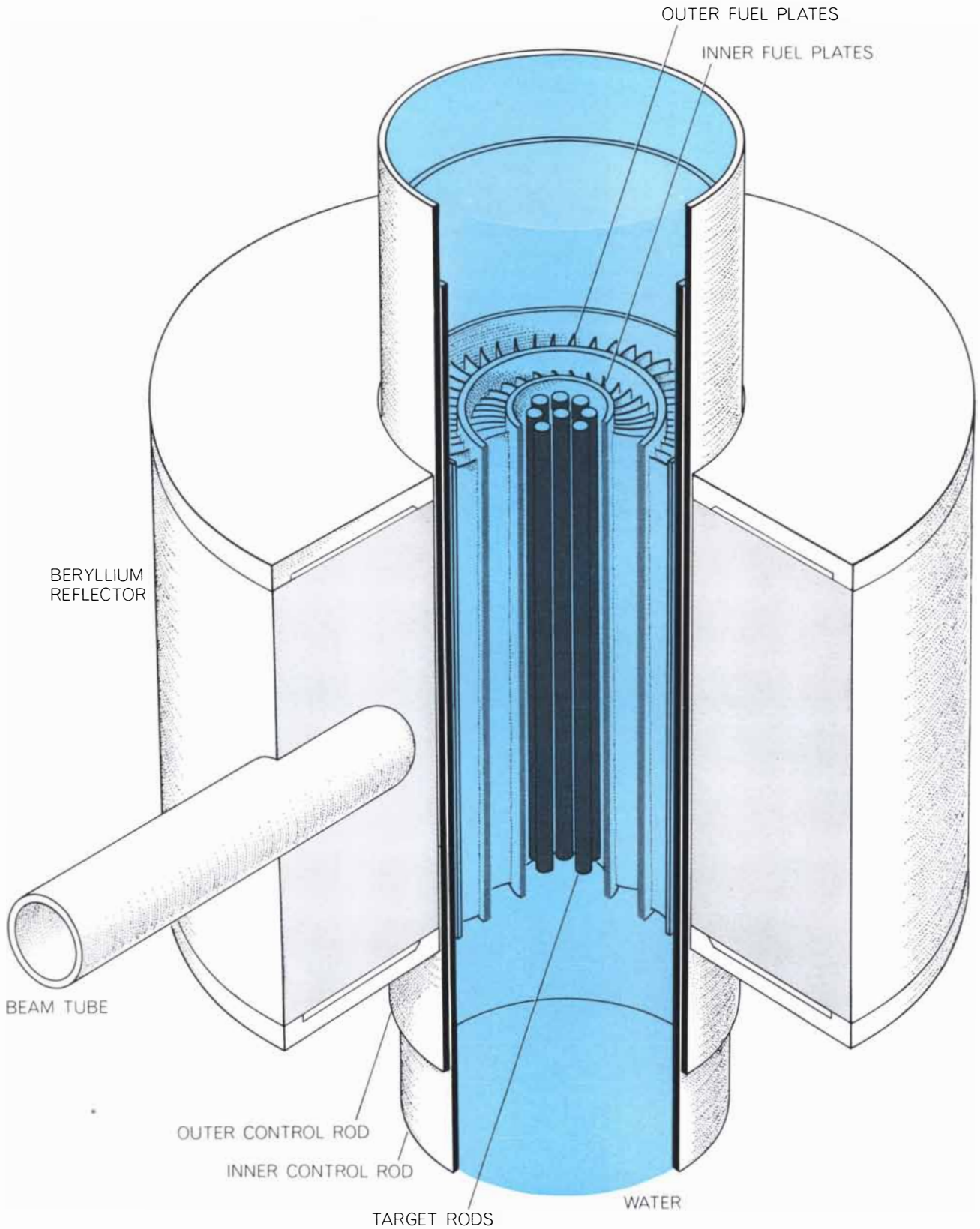
At full power the HFIR reactor will generate 100,000 kilowatts of heat, comparable to the heat produced in a good-sized power station. The useful neutron flux in the central region of the reactor, where the transplutonium isotopes are irradiated, will be between 3×10^{15} and 5×10^{15} neutrons per square centimeter per second. This is almost 10 times greater than the flux in the best existing research reactors in the U.S. and will improve on the present rate of production of californium isotopes by a factor of about a million.

The HFIR will be ready for operation late in 1964. The TPF facility is scheduled to begin processing target material late in 1965. The initial quantities of californium (a few hundred milligrams), and lesser quantities of berkelium, einsteinium and fermium will not be ready until early 1966. This is not surprising when one recognizes that it will require 13 successive neutron captures to transmute plutonium 239 to californium 252, and that the ultimate yield will be only about .3 per cent because of the large losses due to the competing fission reactions in plutonium 239 and other intermediate isotopes. It will probably not be possible to produce any new elements with these intense neutron irradiations, because in the region of elements 100 to 102 new, short-lived isotopes, produced by the successive neutron captures, decay either by the emission of an alpha particle or by spontaneous fission as fast as they are formed.

In addition to the national transplutonium program the AEC hopes to produce heavy elements in underground thermonuclear explosions. Experiments will be carried out under the AEC's Project Plowshare, the aim of which is to develop the peaceful uses of nuclear explosives. The plan calls for a special nuclear device to be exploded in a natural salt formation near Carlsbad, N.M. The total time-integrated neutron flux in such an explosion would be about 10^{24} neutrons per square centimeter or more, all set free within a few microseconds, compared with the 3×10^{15} to 5×10^{15} neutrons per square centimeter per second in the HFIR. Techniques are being developed to obtain samples of the radioactive debris within seconds after the explosion. The samples may contain new elements as well as new isotopes of known elements. The advantage of a thermonuclear explosion over a nuclear reactor for making heavy elements is that neutron capture proceeds so rapidly that short-lived isotopes in the vicinity of elements 100 to 102 do not break the production chain.

Isotopes produced in such an explosion are comparatively rich in neutrons, and it is quite possible that they will have longer half lives than those that can be manufactured in any other way. As a dividend the program will provide a source of longer-lived transplutonium isotopes that can be mined and recovered after the initial radioactivity has subsided. The mining may produce gram amounts of curium and milligram amounts of californium.

As a result of these efforts many interesting isotopes will be available for the first time in almost pure form and in substantial quantities. For example, it will be possible to separate multimilligram amounts, and perhaps later gram amounts, of pure californium 249, produced by the decay of its parent, berkelium 249. This will allow the chemical and physical study of californium in the form of a pure isotope with a half life of about 360 years. The isotopes of californium so far available (particularly those



HIGH FLUX ISOTOPE REACTOR, now being built at Oak Ridge National Laboratory, will produce several of the transuranium elements in significant quantity for chemical experiments and for creation of elements beyond element 103. Target rods in center will contain the chemical elements to be irradiated by neutrons emitted in the fission of uranium 235 contained in the fuel plates. Control rods will move up and down to regulate neutron flux. The beam tube is an opening to obtain neutrons for experiments.

of mass numbers 252 and 254) are intensely radioactive and hard to handle because they decay in appreciable part by spontaneous fission, a process that releases penetrating neutrons.

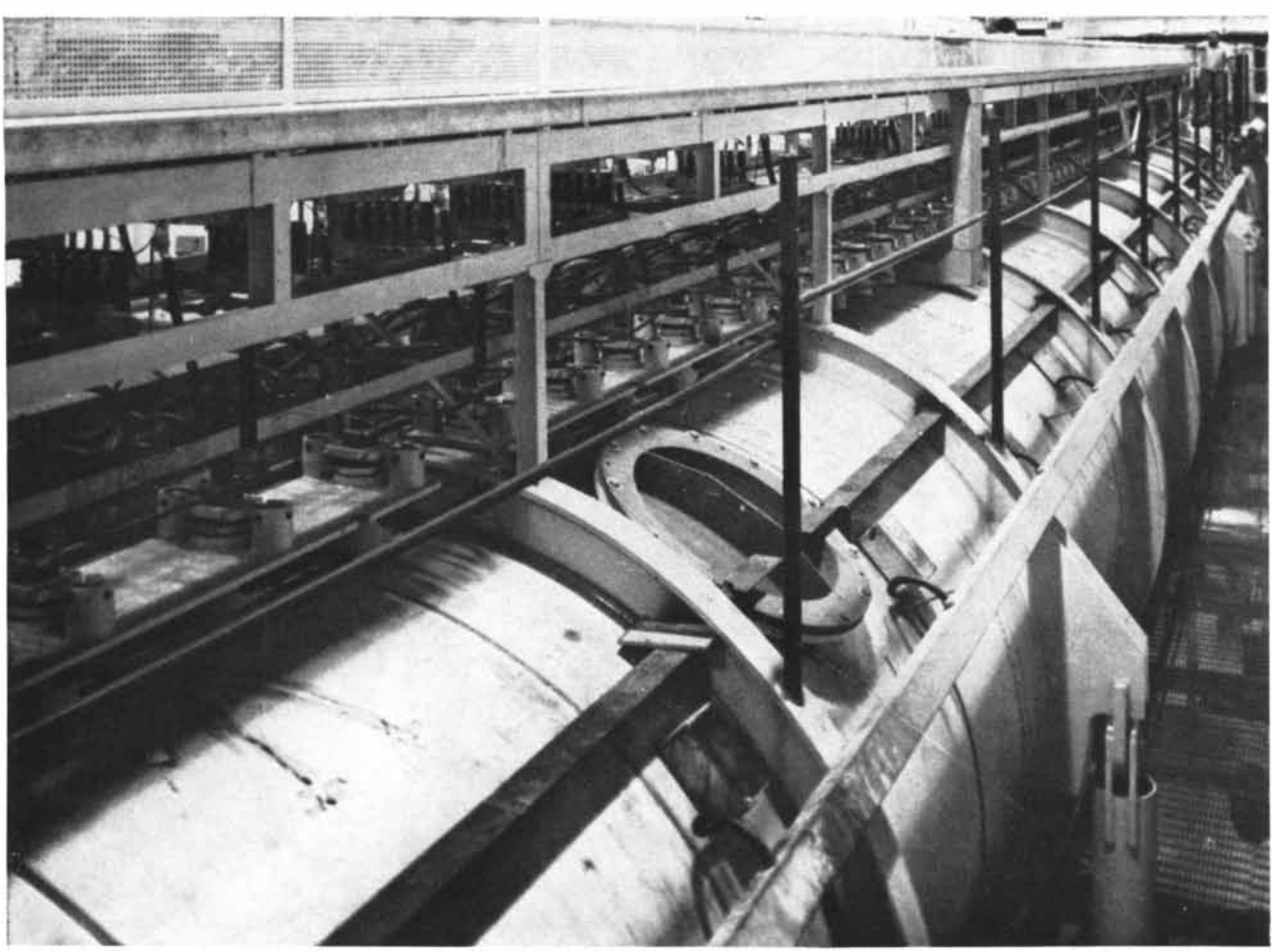
It will also be possible to produce einsteinium 254, with a half life of 250 days, permitting many more direct physical and chemical studies than can now be made with the scarce, short-lived isotope einsteinium 253 (half life, 20 days). Similarly, the long-lived curium 248, with a half life of almost half a million years, could be produced in an almost pure form through the relatively rapid alpha decay of its parent, californium 252.

We have every reason to believe that half lives will continue to decrease with increasing atomic number, barring the discovery of new isotopes with unexpected stability. In any event, the longest half lives are to be found in isotopes that have an odd number of neutrons or protons or both.

Some of the practical consequences of the discovery of transuranium elements are too well known to need repeating. In years to come plutonium will almost certainly become an important fuel for generating electric power. Present power reactors employ the fissionable uranium isotope uranium 235, which represents only one part in 140 of natural uranium. If nuclear energy depended solely on this rare isotope, a significant limit would be set on the reserves of nuclear fuel. Fortunately it is possible to build highly efficient breeder reactors that can convert uranium 238—the relatively stable isotope that makes up the other 139 parts of natural uranium—into fissionable plutonium 239. The development of breeder reactors will not only increase the energy resources available in present economic deposits of uranium ores by about a factor of 100 but also make possible the economic recovery of uranium from dilute low-grade ores (perhaps even granite), providing a nuclear-energy reserve that should last for centuries.

Moreover, plutonium 238, curium 242 and curium 244 can provide a compact source of heat energy without fission. These isotopes emit highly energetic alpha particles, the kinetic energy of which is converted into heat when they are stopped in a surrounding mass. This heat can be converted directly into electricity, without moving parts, by thermoelectric or thermionic devices. Plutonium 238 has already served as a power source in the Navy's *Transit IV-A* navigational satellite, launched on June 29, 1961, and further space missions are contemplated. Still heavier elements, such as californium 252 and 254, may someday serve as concentrated neutron sources in research and industry.

The discovery of almost a dozen transuranium elements and nearly 100 transuranium isotopes has been immensely stimulating to the entire field of inorganic chemistry. The new substances have enriched our understanding of the periodic table and of the structure of both atoms and nuclei.

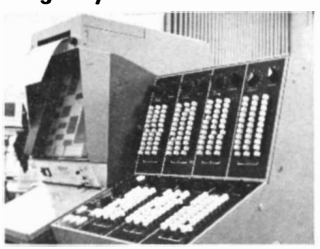


PORTION OF HILAC (heavy-ion linear accelerator) is shown here. It was specially designed to accelerate nuclei heavier than alpha particles in order to create elements beyond californium (element 98). Machine was completed at Berkeley, Calif., in 1957.

Kodak reports on:

"that new coding system" . . . Mr. Gibson's pictures . . . the awful consequences of the soldering ladies' retirement

Microfilm that responds intelligently



It will be like playing the piano or the typewriter. The mind works through the fingers. The hand never touches the microfilm. The roll carrying thousands of page-images is inside a cartridge. The player will pick a cartridge and insert it. He will spell out his instructions on the keyboard: "Show me everything you have that is coded '116' in the first field *and also* carries the concept 'beryllium' in the fourth field *but only if* dated earlier than 4/15/58. Then deliver me a full-size paper copy of all pages of each document so specified. Correction: copy only the first page of each such document. Go." And it will go, and the copies will fall out of the slot at the top, and then the microfilm will retreat back into its cartridge.

It is already working for one large customer. The whole outfit, including the camera that microfilms the documents and encodes the film, will sell right off the shelf for about the annual cost of two or three well-trained secretaries.

For details, write Recordak Corp. (Subsidiary of Eastman Kodak Company), 770 Broadway, New York 3, N. Y., or phone John Eager there and when he asks why you are calling, reply "that new coding system."

Fluorescence in the infrared

Here is an ordinary photograph of gallstones

and here they are by fluorescence in the near infrared:

Here are some plant fragments and a chunk of greenockite by infrared fluorescence,

infrared reflection,

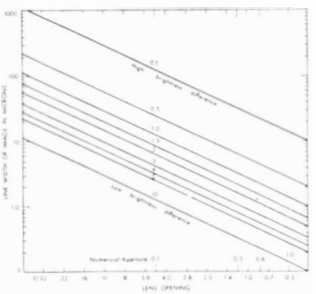
and visible.

Illumination for the fluorescence shots was blue-green light with all the infrared filtered out. In front of the KODAK RETINA Reflex Camera loaded with KODAK High Speed Infrared Film, a KODAK WRATTEN No. 87 Filter passed only radiation longer than 740mμ. To record infrared reflection instead of infrared fluorescence, we removed the blue-green-passing, infrared-absorbing filter from the lamp, left everything else the same, and cut exposure time 20,000 times.

A man at Eastman Kodak Company, X-ray Sales Division, Rochester 4, N. Y. is the expert on this. His name is H. Lou Gibson. Write him if you like.

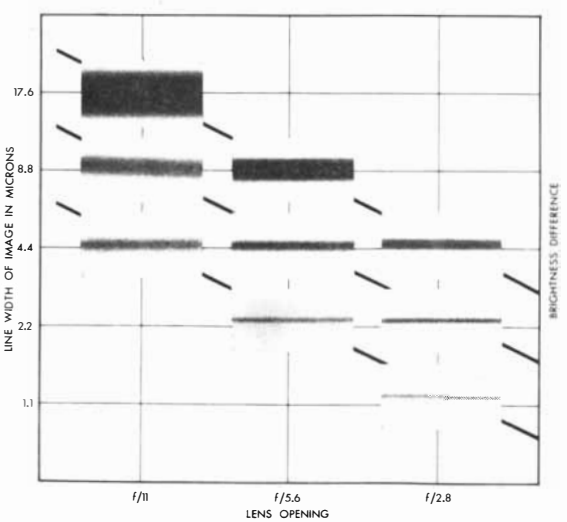
Microphotography for microelectronics

The optics of microscopy, the fabrication of electronic circuitry, and the techniques of the graphic arts are now all entwined. Girls who once lived by the soldering gun now devote themselves to baking bread and planning P.-T.A. carnivals. To manufacture a thin-film circuit or a micromodule, one carefully draws it all up (perhaps 200 times actual size) and then converts the drawing into the thing drawn. Incredible to the incredulous. Very difficult. Requires an understanding of

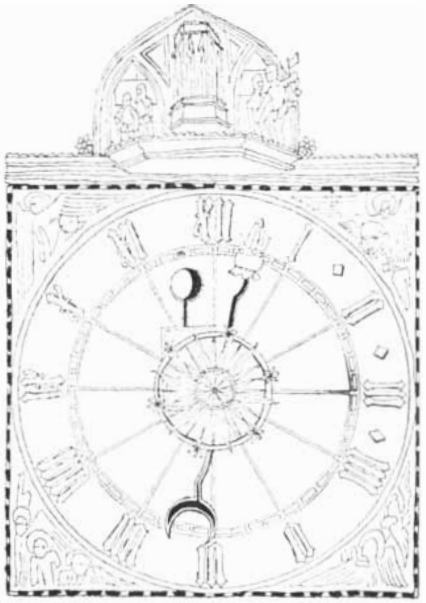


which tells how wide a lens opening is required at the very least when photographically reducing a white line on a black background down to the width represented on the ordinate. Each diagonal plot represents a quality level.* "1.0" indicates quality so good that for practical purposes you'd never need it any better; "0.1" is ten times as good and "10" is ten times as bad. This scale is arbitrary and is for the benefit of those who have to know stuff like this but who are too tired in the evening to study the literature on modulation transfer concepts in photography and therefore send for a how-to-do-it booklet entitled "Techniques of Microphotography" to Eastman Kodak Company, Special Sensitized Products Division, Rochester 4, N. Y. It covers much more than what lens apertures to use.

*Perhaps this will help show what the oblique lines connect:



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

Power Politics and Nuclear Power

Nuclear power has become inextricably tangled with power politics, and last month the combination of the two dominated the international scene and even played a large role in the domestic politics of several countries. In Geneva the U.S. and the U.S.S.R. were still wrestling with the old and difficult issue of safeguards against clandestine underground testing. The U.S.S.R., having agreed to the principle of inspection, stood on its offer of two or three inspections a year. The U.S., having come down from its 12 to 20 a year to seven, tried in vain to get the Soviet representatives to bargain away the difference. The U.S. indicated that a spelling out of inspection procedures and the details of a "black box" automatic detection system would facilitate such bargaining; the Russians demanded initial agreement on a specific number of inspections.

While the two sides in the cold war debated how to stop testing the bomb, the Western allies were arguing among themselves about how to deploy it. France is shaping its own nuclear force, and President de Gaulle's close relation with West Germany has raised fears of a Bonn-Paris axis armed with the bomb. Under the Nassau plan agreed to by President Kennedy and Prime Minister Macmillan, Great Britain is expected to buy Polaris submarines and use them as the basis of its own nuclear deterrent. In an effort to prevent the Balkanization of Europe into rival nuclear powers, the U.S. last month proposed the formation of a NATO deterrent force armed with Polaris-bearing surface ships and submarines. Even if the plan is accepted by the NATO governments, it seems likely to run into political difficulties within many of the countries: in Canada and Great Britain it is a hot political issue.

While it negotiates in Geneva and the NATO capitals, the Kennedy Administration is having trouble protecting its rear in Washington. Republican opposition to test-ban concessions was formalized by a House "Republican Conference Committee on Nuclear Testing" report accusing the Administration of endangering U.S. security by moving toward an inadequately policed test suspension. As for the NATO force, it too seemed likely to run up against Congressional objections on the ground that it would place too many fingers on the nuclear trigger and would violate the Atomic Energy Act.

Venus Confirmed

Instruments aboard *Mariner II*, which passed to within about 21,000 miles of Venus on December 14, 1962, indicated that temperature measurements made previously by earth-bound instruments were remarkably good. Terrestrial instruments had indicated surface temperatures of about 600 degrees Fahrenheit, averaged over the whole planet. *Mariner II* took three sets of readings, one on the sunlit side of Venus, one on the dark side and one across the terminator (the line separating the sunlit and dark sides). The temperatures for the three regions were respectively 260, 370 and 570 degrees F.

Since most objects are not ideal radiators it can be assumed that the actual Venusian temperatures are somewhat higher than the values given. A preliminary estimate is that the actual temperature at the terminator is about 800 degrees. The terminator value is considered to be more indicative of the true surface temperature than values obtained for either the sunlit or the dark side. When *Mariner II*'s instruments viewed the sunlit and dark sides, an effect known as limb darkening came into play and reduced the temperature readings. This simply means that when the planet was viewed obliquely, the instruments responded to a greater thickness of the cold Venusian atmosphere.

The observation of limb darkening

was in itself important: it set to rest the speculation that the Venusian ionosphere might have an electron density thousands of times that of the earth. A dense shell of electrons would have produced limb brightening.

Mariner II carried two microwave radiometers, which operated at wavelengths of 13.5 and 19 millimeters. If there were much water vapor in the atmosphere of Venus, 13.5-mm. radiation emanating from the surface of the planet would be absorbed, whereas 19-mm. radiation would not. A comparison of the two readings showed that the atmosphere contains very little water vapor.

The temperature near the top of the Venusian atmosphere was determined by infrared radiometers that measured the emission at wavelengths of 8.4 and 10.4 microns (thousandths of a millimeter). The two wavelengths were chosen in the hope of detecting breaks in the cloud cover of Venus. In the 10-micron region the lower atmosphere of the planet is masked by carbon dioxide. In the eight-micron region the atmosphere is transparent except for clouds. If there had been breaks in the cloud mass, the eight-micron detector would have seen down to a deeper, hotter region than the 10-micron detector. The actual data show no significant differences between the two readings. At the center of the planet's disk the cloud-layer temperature was about −30 degrees F. This too agrees closely with values measured from the earth.

The one anomaly in the temperature data was the finding of a spot in the cloud cover that was about 20 degrees cooler than elsewhere. This means that the clouds in this region are higher or more opaque or both. Conceivably the cold spot aloft is associated with some hidden feature of the surface.

Lost Scientists

The richest country in the world is absorbing scientists from other countries at a rate that is causing increasing concern in underdeveloped nations and in Great Britain, one of the most highly developed. Between 1957 and 1961, according to a National Science Foundation report last year, more than 24,000 scientists and engineers immigrated to the U.S. In addition 2,400 students from

abroad received doctorates in the physical and biological sciences here between 1957 and 1960, and many of these students settled in the U.S. instead of returning home. From this country's point of view the influx is a good thing. As the NSF report pointed out, "domestic institutions of higher education do not yet provide the country's needed annual aggregate of scientists."

But the drift of scientists to the U.S. does not seem so beneficent to their home countries. In recent years there have been complaints that the new nations and others attempting to build their scientific and technical man-power resources are providing a form of "foreign aid" they can least afford by exporting trained men or promising students to this country. Last month Britain's Royal Society reported that 518 scientists with doctorates, most of them physicists and chemists, left Britain for the U.S. between 1952 and 1962, at an annual rate that doubled during the 10-year period. Britain is now losing about one out of eight of its best scientists by emigration each year, half of them to the U.S. Quoting the report, Viscount Hailsham, Britain's Minister of Science, complained to the House of Lords of "a recruiting drive systematically and deliberately undertaken by American business, by American universities and, to a lesser extent, by American government . . . to buy British brains and pre-empt them for the service of the U.S.A." Lord Hailsham suggested that the U.S. has to "live parasitically on other people's brains" because of the inadequacies of its high school system, and he said that, pending the reform of U.S. schools, Britain can stem the flow only by providing better research facilities and opportunities at home.

Conserved Current

A new conservation law in physics, first stated in 1958, has now been demonstrated to hold true. Miss C. S. Wu of Columbia University, who performed the crucial experiment on the nonconservation of parity in the weak interactions, has made measurements showing that a quantity called vector current is conserved in these interactions. Her work was done with the radioactive isotopes boron 12 and nitrogen 12, both of which decay into carbon 12 through the weak interaction of beta decay. She compared the energy spectra of the electron given off by boron and the positron emitted in the decay of nitrogen and obtained a result closely equal to that predicted four years ago.

At that time Richard P. Feynman and Murray Gell-Mann of the California Institute of Technology enunciated the conservation law in trying to account for a peculiarity in the behavior of the weak interactions. A mathematical quantity called the vector coupling constant is the same for the decay of the mu meson (muon) and the beta decay of the neutron, even though neutrons spend much of their lives surrounded by a "virtual" cloud of pi mesons (pions) and muons do not interact with pions at all.

Feynman and Gell-Mann reasoned by analogy from the electromagnetic situation, where the charge on the nucleon (proton or neutron) is conserved through its conversion into meson clouds and back again to the "bare" particle. They said that similarly a vector current must be conserved in the case of the neutron-pion mixture in the weak interactions. Vector current gives the vector coupling constant for any weak decay such as that of the muon, the nucleon or the pion itself. Out of the theory came a specific prediction about the form of the beta decay of boron 12 and nitrogen 12 to carbon 12.

Many experimenters had tried to check the prediction, but their work was not sufficiently accurate to uncover the small effect being looked for. Now Miss Wu has succeeded, and has put the conservation of vector current on a firm footing. By implication this means that pions as well as nucleons and muons can decay through weak interaction.

Wet Electron

Knowledge of the high-speed chemical events that take place when water is exposed to ionizing radiation is of great interest to workers in many fields, particularly designers of nuclear reactors and cancer investigators. It has now been discovered that much of the chemical reactivity of irradiated water can be traced to a highly transient chemical fragment consisting of an electron feebly bound to a group of water molecules. An electron trapped in this manner is termed a hydrated, or wet, electron. Evidence for its existence is reported by Edwin J. Hart of the Argonne National Laboratory and Jack W. Boag of Mount Vernon Hospital in Northwood, England, where the work was done.

Recent studies have shown that the first effect of irradiation is to set free an electron (e^-), leaving a positively charged water molecule (H_2O^+). Ultimately the free electron reacts with water, setting free a hydrogen atom, but how this took place was obscure. About

10 years ago Robert L. Platzman, a physicist at the Argonne Laboratory, suggested that the electron would have to become hydrated before it could react with water. It had been known for many years that electrons can become "solvated" under certain conditions—for example, in liquid-ammonia solutions of alkali metals such as sodium—but the effect had not been demonstrated when water was the solvent. In ammonia the solvated electron strongly absorbs red and infrared radiation with a peak absorption at a wavelength of about 14,500 angstrom units. Moreover, the ammonia-solvated electron is extremely stable.

A number of workers looked for the hydrated electron without success. Hart and Boag found it while studying the effects on aqueous solutions of brief pulses of high-speed electrons. The solutions were irradiated in a small quartz cell with electron pulses lasting two microseconds (millionths of a second). Simultaneously the cell was illuminated with a bright flash of light lasting four microseconds. After passing through the cell the light entered a spectrograph, where it was separated into its component wavelengths. Chemical fragments formed in the cell could be identified by their absorption spectra. An intense absorption band, never before seen, turned up with a peak around 7,000 angstroms. Subsequent experiments showed that the absorption was due to the wet electron. Its estimated lifetime in pure water is between 10 microseconds and 100 microseconds. In this brief period it can initiate a great variety of chemical reactions, now being explored in detail.

Water-breathing Rodents

Rats and mice can survive for many hours while breathing water, it has been independently ascertained by a team of investigators in the Netherlands and three students at the University of California Medical Center in San Francisco. To bring about this seeming reversal of evolution, two conditions must be met. The water must contain salts in isotonic, or physiological, concentration and oxygen must be led into it under pressure to raise the dissolved oxygen content well above normal levels.

The Dutch investigators, J. A. Klystra and his associates at the University of Leiden, were led to their experiments by a study of the mechanics of drowning. Mice were submerged in a tank and observed until respiratory movements stopped. When the tank was filled with ordinary sea water or tap water, the mice

died quickly. When it was filled with an isotonic solution and oxygen was bubbled into it at a pressure of eight atmospheres (120 pounds per square inch), mice survived for as long as four hours. And when the temperature was held at 20 degrees C. and an agent was added to improve carbon dioxide exchange, survivals increased to a maximum of nearly 18 hours.

The California students—Terence L. Horner, John H. Pegg and Eric A. Wahrenbrock—became interested in the water-breathing problem through skin diving. In their study, carried out under the supervision of John W. Severinghaus of the medical school faculty, rats were anesthetized and a tracheotomy tube was inserted to assure a clear "waterway" to the lungs. The rats were then placed for up to four hours in a tank filled with an isotonic solution, buffered to aid carbon dioxide exchange; oxygen was bubbled into the tank under 10 atmospheres of pressure. When they were removed from the tank and their lungs were drained, they were alert and scampered about. They soon died of lung collapse, however.

The most significant question raised by the experiments is not why the submerged rodents lived so long, since water under eight to 10 atmospheres of pressure will hold as much free oxygen as the same volume of air, but why they died. Several possible explanations have been advanced, including damage to the lining of the lungs and exhaustion from the mechanical work of moving water in and out of them. In any event, notes Severinghaus, the water-breathing rodents may provide a means of studying respiratory problems in newborn infants, whose habitat up to the moment of birth is a fluid-filled womb.

Optical Transistor

Gallium arsenide, the crystal that has recently come into prominence for making the light-amplifying devices called lasers, has now been used to make an optical analogue of the junction transistor, a device for amplifying or switching electric signals. In a conventional transistor the incoming signal stimulates an internal flow of electric charges, which may be carried by either electrons or "holes" (sites vacated by electrons). In the new optical transistor some of the incoming electric signal stimulates the emission of light in the first layer of a three-layer structure. The light carries the signal across a middle, or base, layer and is absorbed in the third layer, releasing electrons that constitute the output current. The advantage of the optical transistor is that light can cross the base region much faster than electrons or holes can. To obtain high-speed (or high-frequency) operation in a conventional transistor the base must be made extremely thin to minimize signal travel time, and thinness is difficult and costly to achieve. In the optical transistor extreme thinness is unnecessary.

The optical transistor was devised by Richard F. Rutz of the International Business Machines Corporation. Although somewhat similar devices have recently been proposed by workers at the Lincoln Laboratory of the Massachusetts Institute of Technology, Rutz's device is evidently the first of its kind to be reduced to practice.

Petroleum Mulch

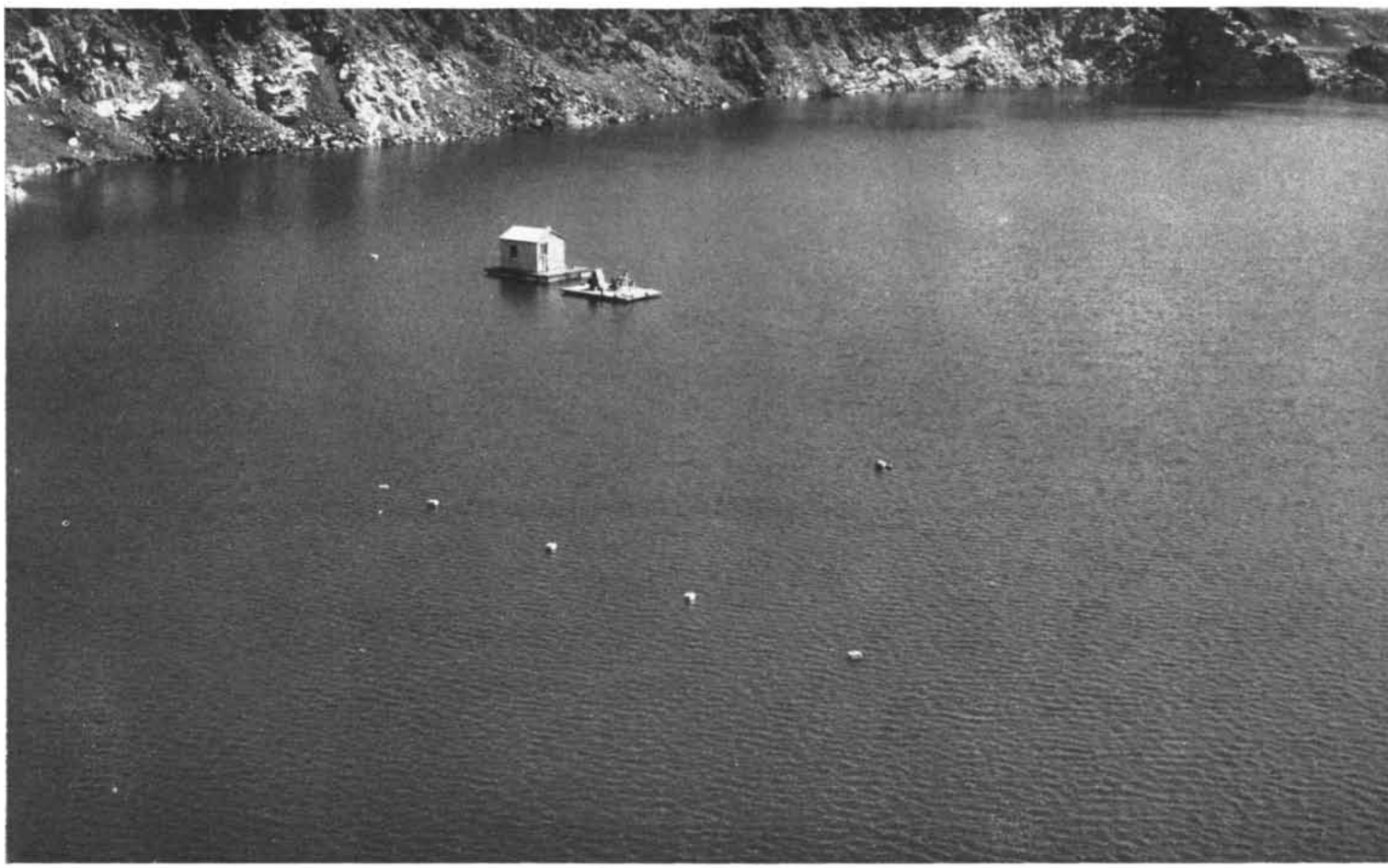
Gardeners and farmers sometimes spread a mulch of straw, leaves, sawdust, paper, dead moss or a similar substance to protect the roots of young plants from cold and drought. Now the firm Esso Research has developed a mulch of inexpensive petroleum resins that does the job far more effectively than traditional materials, producing large increases in crop yields.

The substance performs four functions. Because it is dark it absorbs heat from the sun, warming the soil by as much as 20 degrees Fahrenheit and speeding germination. It reduces evaporation of water from the soil. It holds the soil, thereby decreasing erosion, and it prevents water and other agents from dispersing mineral and chemical fertility factors in the soil.

Esso has been testing the mulch in various parts of the world for the past three years. After a field is planted with a row crop the emulsion is sprayed on in bands from three to 10 inches wide. It forms a thin, continuous film that clings but does not penetrate deeply and that lasts from four to 10 weeks.

The new mulch has proved particularly effective in arid climates. Arizona cotton fields sprayed with the mulch produced 121,900 plants per acre 12 days after planting, compared with only 8,710 plants in the unsprayed field. After 21 days the mulched field had 139,000 plants as against 112,000 in the control field. The final yield of the mulched field was 2.22 bales per acre, compared with 1.65 for the control field, an increase of 34 per cent. The material apparently does no harm to the soil. One field was covered with a 20-year supply of mulch, then plowed and planted; it produced a normal crop.

the house on submarine alley...



The water ripples lightly. It laps at a line of buoys, and at the moorings of a floating shack nearby. Then an underwater charge explodes, hurling the surface upwards in a plume...an anti-submarine warfare run has begun at Daystrom Electric.

This is "submarine alley": our private land-locked lagoon, 160 feet deep, ⅓ mile long, and holding approximately 1½ billion gallons of water. The "shack" is a highly-instrumented electronics laboratory. Here, our oceanographers, engineers, and other scientists have carried out countless studies in underwater technology; studies resulting in new devices and equipment for the whole field of oceanography, as well as applications special to anti-submarine warfare. We have designed and developed underwater acoustic and measurement systems, shipboard instruments, airborne instruments, transducers, support equipment, ordnance and other devices.

Undersea technology has been the specific province of Daystrom Electric for many years. We have accumulated our knowledge in the actual underwater environment, where theory meets its rudest test. In addition, we regularly utilize our own ocean-going research vessel for further full-scale studies in marine phenomena. With these facilities constantly available, our staff has acquired first-hand, practical experience that is reflected in all our researches. Have you a problem for the house on submarine alley?

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CONTINENTAL DRIFT

In 1912 Alfred Wegener proposed that the continents had originated in the breakup of one supercontinent. His idea has not been widely accepted, but new evidence suggests that the principle is correct

by J. Tuzo Wilson

Geology has reconstructed with great success the events that lie behind the present appearance of much of the earth's landscape. It has explained many of the observed features, such as folded mountains, fractures in the crust and marine deposits high on the surface of continents. Unfortunately, when it comes to fundamental processes—those that formed the continents and ocean basins, that set the major periods of mountain-building in motion, that began and ended the ice ages—geology has been less successful. On these questions there is no agreement, in spite of much speculation. The range of opinion divides most sharply between the position that the earth has been rigid throughout its history, with fixed ocean basins and continents, and the idea that the earth is slightly plastic, with the continents slowly drifting over its surface, fracturing and reuniting and perhaps growing in the process. Whereas the first of these ideas has been more widely accepted, interest in continental drift is currently on the rise. In this article I shall explore the reasons why.

The subject is large and full of pitfalls. The reader should be warned that I am not presenting an accepted or even a complete theory but one man's view of fragments of a subject to which many are contributing and about which ideas are rapidly changing and developing. If it is conceded that much of this is speculation, then it should also be added that many of the accepted ideas have in fact been speculations also.

In the past several different theories of continental drift have been advanced and each has been shown to be wrong in some respects. Until it is indisputably established that such movements in the earth's crust are impossible, however, a multitude of theories of continental drift remain to be considered. Although there is only one pattern for fixed continents and a rigid earth, many patterns of continental migration are conceivable.

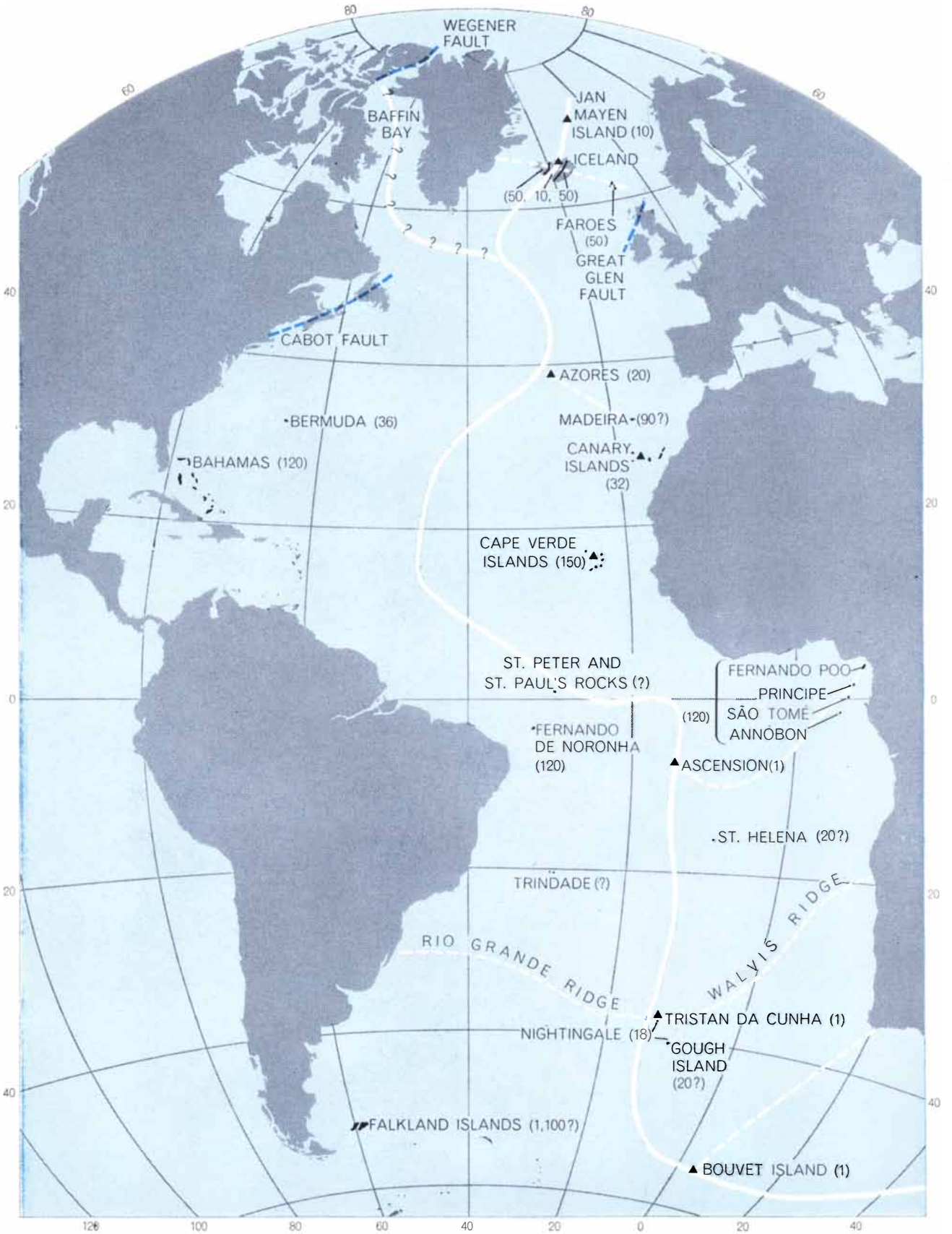
The traditional rigid-earth theory holds that the earth, once hot, is now cooling, that it became rigid at an early date and that the contraction attendant on the cooling process creates compressive forces that, at intervals, squeeze up mountains along the weak margins of continents or in deep basins filled with soft sediments. This view, first suggested by Isaac Newton, was quantitatively established during the 19th century to suit ideas then prevailing. It was found that an initially hot, molten earth would cool to its present temperature in about 100 million years and that, in so doing, its circumference would contract by at least tens and perhaps hundreds of miles. The irregular shape and distribution of continents presented a puzzle but, setting this aside, it was thought that the granitic blocks of the continents had differentiated from the rest of the crustal rock and had frozen in place at the close of the first, fluid chapter of the earth's history. Since then they had been modified *in situ,* without migrating.

This hypothesis, in its essentials, still has many adherents. They include most geologists, with notable exceptions among those who work around the margins of the southern continents. The validity of the underlying physical theory is defended by some physicists. On the other hand, a number of formidable objections have been raised by those who have studied radioactivity, ancient climates, terrestrial magnetism and, most recently, submarine geology. Many biologists have also thought that, although the evolution and migration of later forms of life—particularly since the advent of mammals—could be satisfactorily traced on the existing pattern of continents, the distribution of earlier forms required either land bridges across the oceans—the origin and disappearance of which are difficult to explain—or a different arrangement of the continents.

The discovery of radioactivity altered the original concept of the contraction theory without absolutely invalidating it. In the first place, the age of the earth could be reliably determined from knowledge of the rate at which the unstable isotopes of various elements decay and by measurement of the ratios of daughter to parent isotopes present in the rocks. These studies showed the earth to be much older than had been imagined, perhaps 4.5 billion years old. Dating of the rocks indicated that the continents are zoned and have apparently grown by accretion over the ages. Finally, it was found that the decay of uranium, thorium and one isotope of potassium generates a large but unknown supply of heat that must have slowed, although it did not necessarily stop, the cooling of the earth.

The rigid earth now appeared to be less rigid. It became possible to explain the knowledge, already a century old, that great continental ice sheets had depressed the earth's crust, just as the loads of ice that cover Greenland and Antarctica depress the crust in those regions today. Observation showed that central Scandinavia and northern Canada, which had been covered with glacial ice until it melted 11,000 years ago, were still rising at the rate of about a centimeter a year. Calculations of the viscosity of the interior based on these studies led to the realization that the earth as a whole behaves as though a cool and brittle upper layer, perhaps 100 kilometers thick, rests on a hot and plastic interior. All the large topographical features—continents, ocean basins, mountain ranges and even individual volcanoes—slowly seek a rough hydro-

ROBESON CHANNEL separating northwestern Greenland (*upper right*) from Ellesmere Island (*foreground*) marks the Wegener Fault. The latter was named by the author for the German meteorologist who 50 years ago predicted the existence of such a fault and of a great lateral displacement along the length of the channel. Not yet fully mapped, it probably joins a known fault farther southwest.



AGE OF ATLANTIC ISLANDS, as indicated by the age of the oldest rocks found on them, apparently tends to increase with increasing distance from the Mid-Atlantic Ridge. The numbers associated with the islands give these ages in millions of years. Geologists divide Iceland into three areas of different ages, the central one being the youngest. The Rio Grande and Walvis ridges are lateral ridges that may have formed as a result of the drifting apart of Africa and South America. Other lateral ridges along the Mid-Atlantic Ridge are also represented. Islands that have active volcanoes are represented by black triangles; most of these islands lie on or near the Mid-Atlantic Ridge. The extension of the ridge into Baffin Bay is postulated. Broken colored lines are faults.

static equilibrium with one another on the exterior. Precise local measurements of gravity showed that the reason some features remain higher than others is that they have deeper, lighter roots than those that are low. The continents were seen to float like great tabular icebergs on a frozen sea.

Everyone could agree that in response to vertical forces the outer crustal layer moved up and down, causing flow in the interior. The crux of the argument between the proponents of fixed and of drifting continents became the question of whether the outer crust must remain rigid under horizontal forces or whether it could respond to such forces by slow lateral movements.

Gondwanaland and "Pangaea"

Suggestions that the continents might have moved had been advanced on various grounds for centuries. The remarkable jigsaw-puzzle fit of the Atlantic coasts of Africa and South America provoked the imagination of explorers almost as soon as the continental outlines appeared opposite each other on the world map. In the late 19th century geologists of the Southern Hemisphere were moved to push the continents of that hemisphere together in one or another combination in order to explain the parallel formations they found, and by the turn of the century the Austrian geologist Eduard Suess had reassembled them all in a single giant land mass that he called Gondwanaland (after Gondwana, a key geological province in east central India).

The first comprehensive theory of continental drift was put forward by the German meteorologist Alfred Wegener in 1912. He argued that if the earth could flow vertically in response to vertical forces, it could also flow laterally. In support of a different primeval arrangement of land masses he was able to point to an astonishing number of close affinities of fossils, rocks and structures on opposite sides of the Atlantic that, he suggested, ran evenly across, like lines of print when the ragged edges of two pieces of a torn newspaper are fitted together again. According to Wegener all the continents had been joined in a single supercontinent about 200 million years ago, with the Western Hemisphere continents moved eastward and butted against the western shores of Europe and Africa and with the Southern Hemisphere continents nestled together on the southern flank of this "Pangaea." Under the action of forces

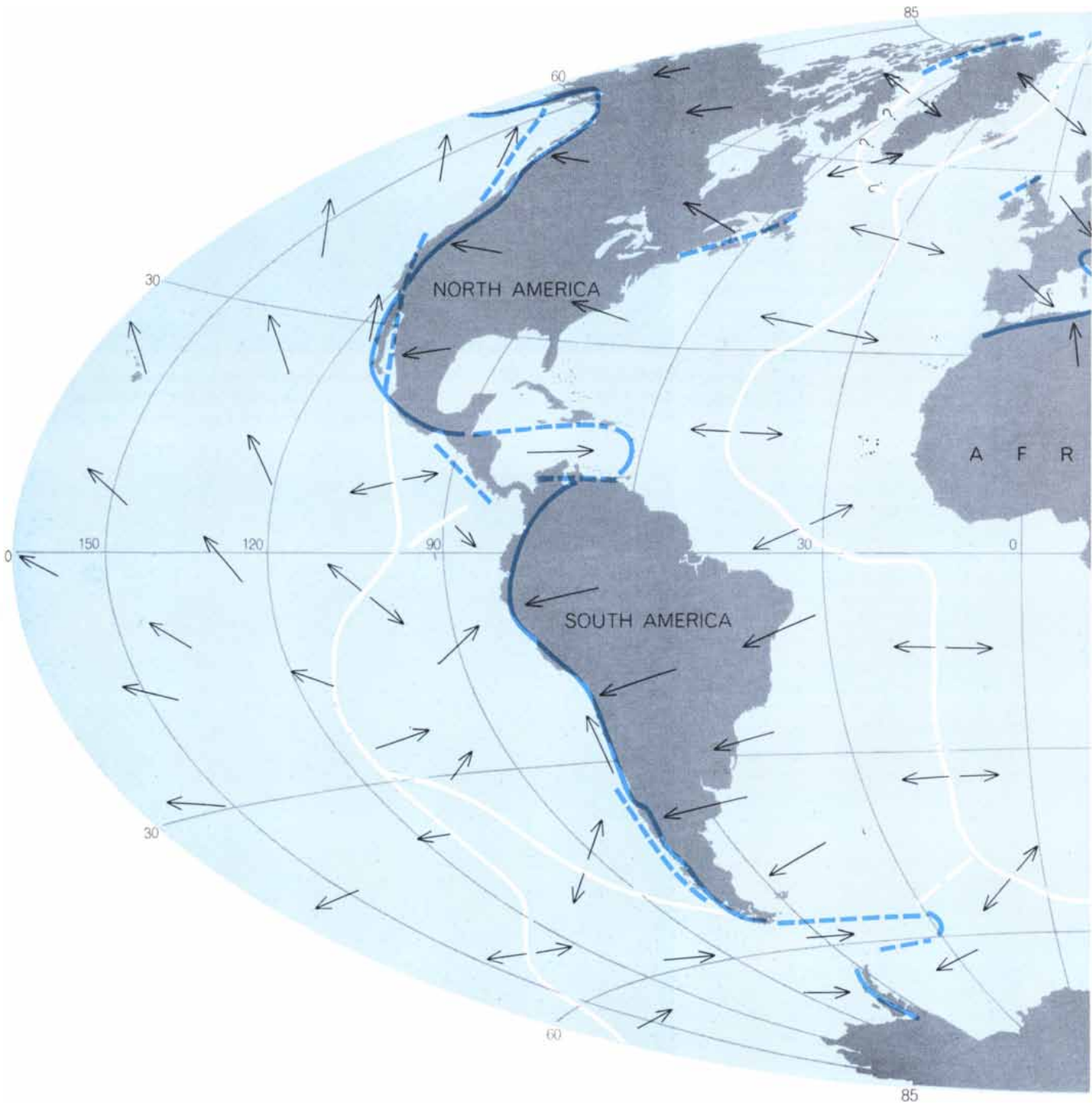
GREAT GLEN FAULT in Scotland is named for a valley resulting from erosion along the line of the fault. About 350 million years ago the northern part of Scotland was slowly moved some 60 miles to the southwest along this line (*see illustration on opposite page*).

ASPY FAULT in northern Nova Scotia is marked by several cliffs like the one seen here. The fault is part of the Cabot Fault system extending from Boston to Newfoundland (*see illustration on opposite page*) and may represent an extension of the Great Glen Fault.

associated with the rotation of the earth, the continents had broken apart, opening up the Atlantic and Indian oceans.

Between 1920 and 1930 Wegener's hypothesis excited great controversy. Physicists found the mechanism he had proposed inadequate and expressed doubt that the continents could move laterally in any case. Geologists showed that some of Wegener's suggestions for reassembling the continents into a single continent were certainly wrong and that drift was unnecessary to explain the coincidences of geology in many areas. They could not, however, dispute the validity of most of the transatlantic connections. Indeed, more such connections have been steadily added.

It was the discovery of one of these connections that prompted my own recent inquiries into the subject of continental drift. A huge fault of great age bisects Scotland along the Great Glen in the Caledonian Mountains. On the western side of the Atlantic, I was able to show, a string of well-known faults of the same great age connect up into another huge fault, the "Cabot Fault" extending from Boston to northern Newfoundland. These two great faults are much older than the submarine ridge and rift recently discovered on the floor of the mid-Atlantic and shown to be a

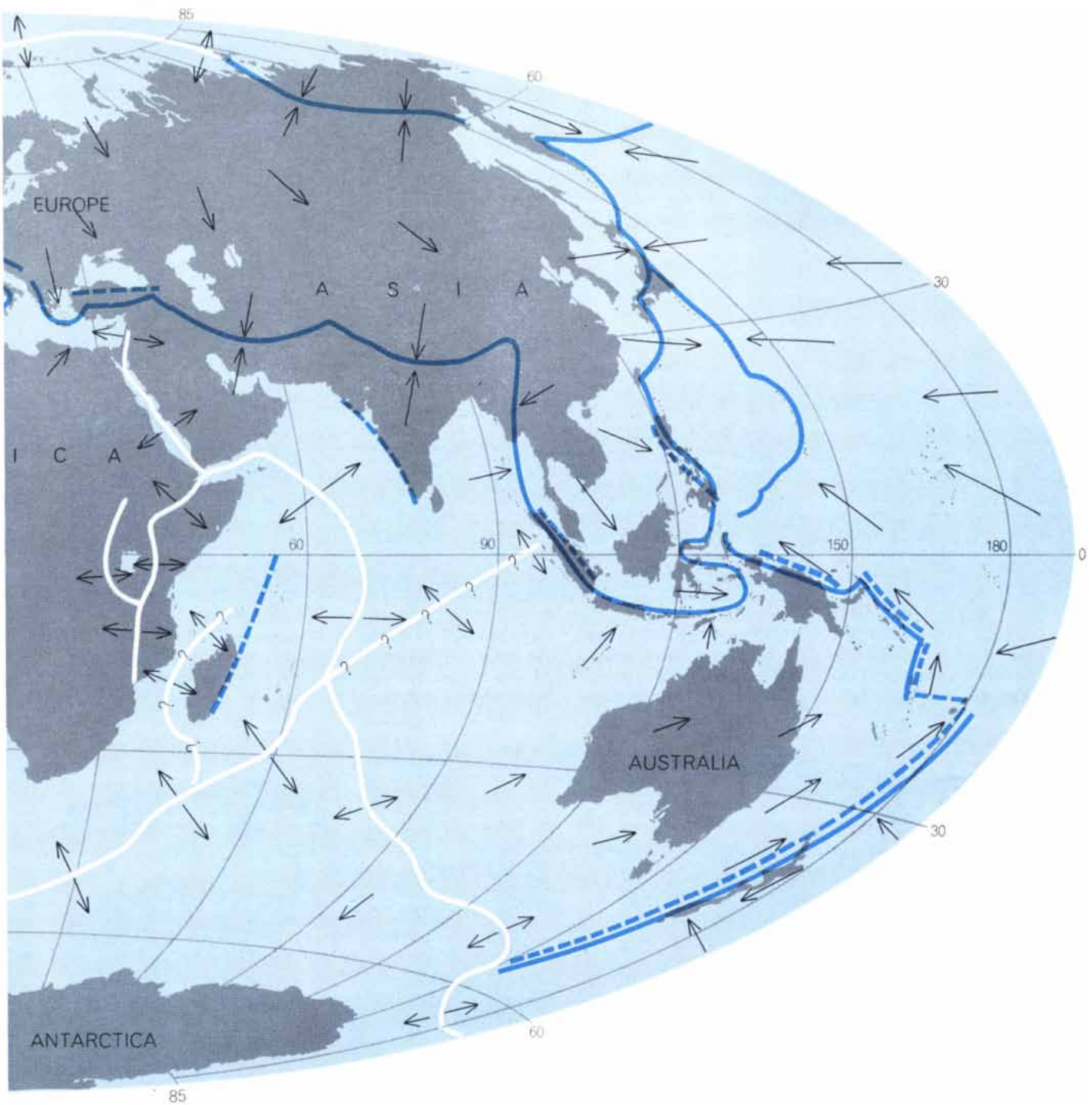


CONVECTION CURRENTS in the earth's mantle may move blocks of crustal material with different effects. Continental mountain chains and island arcs could form where currents sink and blocks meet; mid-ocean ridges, where currents rise and blocks are torn

young formation. The two faults would be one if Wegener's reconstruction or something like it were correct. Wegener also thought that Greenland (where he died in 1930) and Ellesmere Island in the Canadian Arctic had been torn apart by a great lateral displacement along the Robeson Channel. The Geological Survey of Canada has since discovered that the Canadian coast is faulted there.

Many geologists of the Southern Hemisphere, led by Alex. L. Du Toit of South Africa, welcomed Wegener's views. They sought to explain the mounting evidence that an ice age of 200 million years ago had spread a glacier over the now scattered continents of the Southern Hemisphere. At the same time, according to the geological record, the great coal deposits of the Northern Hemisphere were being formed in tropical forests as far north as Spitsbergen. To resolve this climatic paradox Du Toit proposed a different reconstruction of the continent. He brought the southern continents together at the South Pole and the northern coal forests toward the Equator. Later, he thought, the southern continent had broken up and its component subcontinents had drifted northward.

The compelling evidence for the existence of a Gondwanaland during the



apart. On this assumption arrows indicate directions of horizontal flow of currents at the present time. Solid colored lines represent mountain chains and island arcs; heavy white lines, the worldwide system of mid-ocean ridges; and broken colored lines, faults.

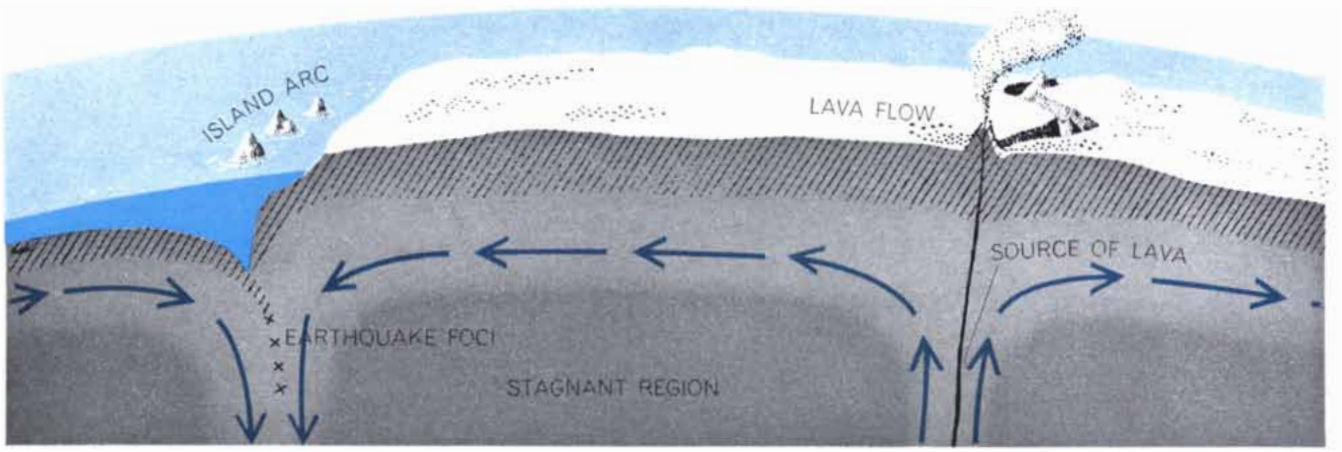
Mesozoic era—the "Age of Reptiles"—has been reinforced by the findings made in Antarctica since the intensive study of that continent began in 1955. The ice-free outcrops on the continent, although few, not only show the record of the earlier ice age that gripped the rest of the land masses in the Southern Hemisphere but also bear deposits of a low-grade coal laid down in a still earlier age of verdure that covered all the same land masses with the peculiar big-leafed *Glossopteris* flora found in their coal beds as well.

Many suggestions have been made as to how to create and destroy the land bridges needed to explain the biological evidence without moving the continents. Some involve isthmuses and some involve whole continents that have subsided below the surface of the ocean. But the chemistry and density of continents and ocean floors are now known to be so different that it seems even more difficult today to raise and lower ocean floors than it is to cause continents to migrate.

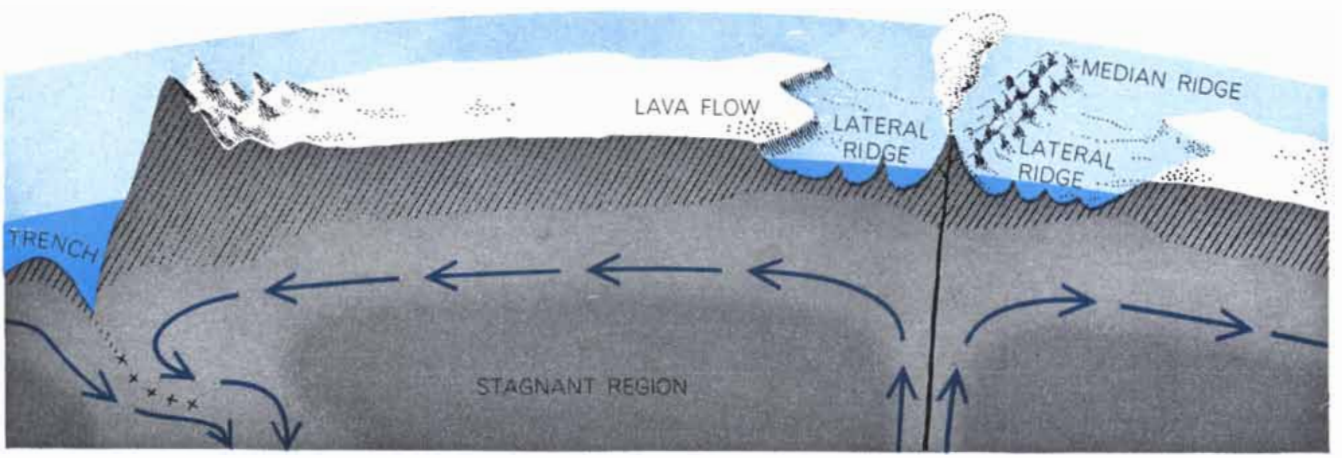
Convection in the Mantle

One of the first leads to a mechanism that would move continents came more than 30 years ago from the extension to the ocean floor of the sensitive techniques of gravimetry that had established the rule of hydrostatic equilibrium, or isostasy, ashore. The Dutch geophysicist Felix A. Vening Meinesz demonstrated that a submerged submarine would provide a sufficiently stable platform to allow the use of a gravimeter at sea. Over the abyssal trenches in the sea floor that are associated with the island arcs of Indonesia and the western side of the Pacific he found some of the largest deficiencies in gravity ever recorded. It was clear that isostasy does not hold in the trenches. Some force at work there pulls the crust into the depths of the trenches more strongly than the pull of gravity does.

Arthur Holmes of the University of Edinburgh and D. T. Griggs, now at the University of California at Los Angeles, were stimulated by these observations to re-examine and restate in modern terms an old idea of geophysics: that the interior of the earth is in a state of extremely sluggish thermal convection, turning over the way water does when it is heated in a pan. They showed that convection currents were necessary to account in full for the transfer of heat flowing from the earth's interior through the poorly conductive material of the mantle: the region that lies between the core and the crust. The trenches, they said, mark the places where currents in



EFFECTS OF CONVECTION CURRENTS, schematized in the two illustrations on this page, provide one possible means of accounting for the formation of median ridges, lateral ridges, mountain ranges and earthquake belts. Rising and separating currents (*arrows at right*) could break the crustal rock and pull it apart; the rift would be filled by altered mantle material (as suggested by H. H. Hess of Princeton University) and lava flows, forming a median ridge. Sinking currents (*left*) could pull the ocean floor down.



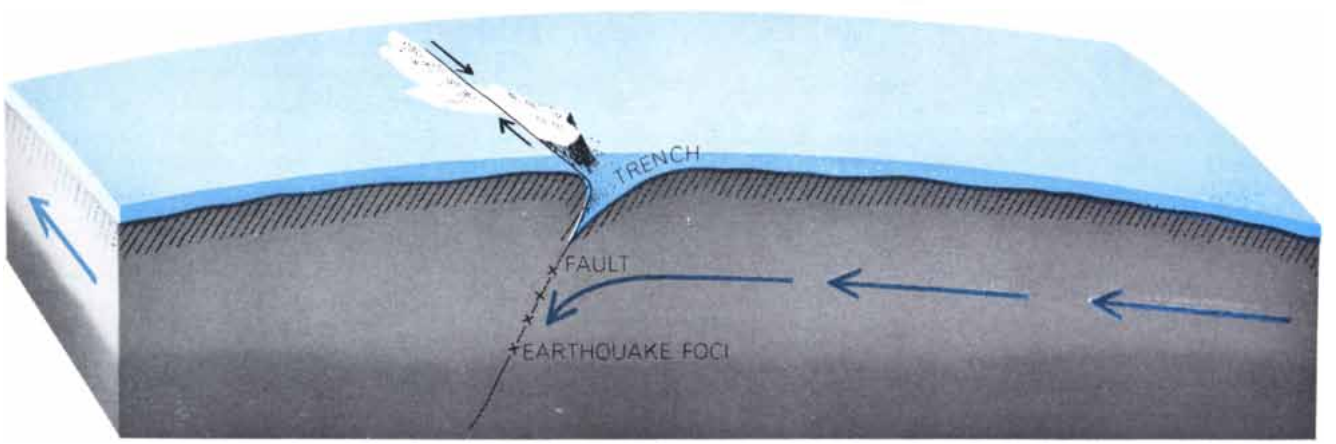
DRIFTING CONTINENT may be "piled up," where it meets sinking currents, to form mountains like those of the Andes (*left*). Since continents are lighter than the mantle material of the ocean floor, they cannot sink but tend to be pushed over sinking currents, which are marked by deep earthquakes. Active volcanoes continue to form over rising currents (*right*), but drift may carry these volcanic piles away to either side of the median ridge. Separated from their source, the inactive cones form one or two lateral ridges.

the mantle descend again into the interior of the earth, pulling down the ocean floor.

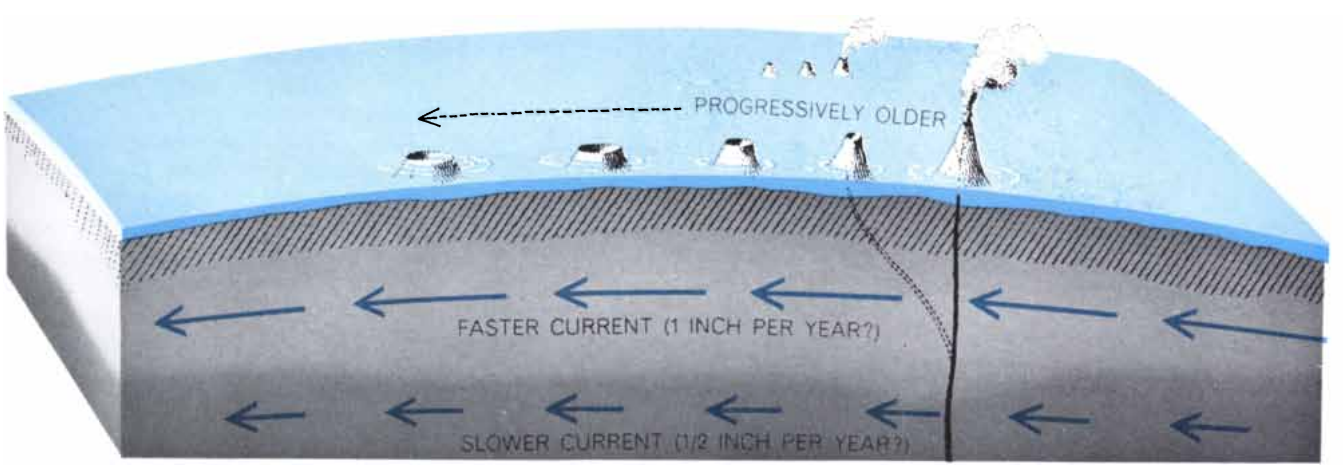
Convection currents in the mantle now play the leading role in every discussion of the large-scale and long-term processes that go on in the earth. It is true that the evidence for their existence is indirect; they flow too deep in the earth and too slowly—a few centimeters a year—for direct observation. Nonetheless their presence is supported by an increasing body of independently established evidence and by a more rigorous statement of the theory of their behavior. Recently, for example, S. K. Runcorn of Durham University has shown that to stop convection the mantle material would have to be 10,000 times more viscous than the rate of postglacial recoil indicates. It is, therefore, highly probable that convection currents are flowing in the earth.

Perhaps the strongest confirmation has come with the discovery of the regions where these currents appear to ascend toward the earth's surface. This is the major discovery of the recent period of extraordinary progress in the exploration of the ocean bottom, and it involves a feature of the earth's topography as grand in scale as the continents themselves. Across the floors of all the oceans, for a distance of 40,000 miles, there runs a continuous system of ridges. Over long stretches, as in the mid-Atlantic, the ridge is faulted and rifted under the tension of forces acting at right angles to the axis of the ridge. Measurements first undertaken by Sir Edward Bullard of the University of Cambridge show that the flow of heat is unusually great along these ridges, exceeding by two to eight times the average flow of a millionth of a calorie per square centimeter per second observed on the continents and elsewhere on the ocean floor. Such measurements also show that the flow of heat in the trenches, as in the Acapulco Trench off the Pacific coast of Central America, falls to as little as a tenth of the average.

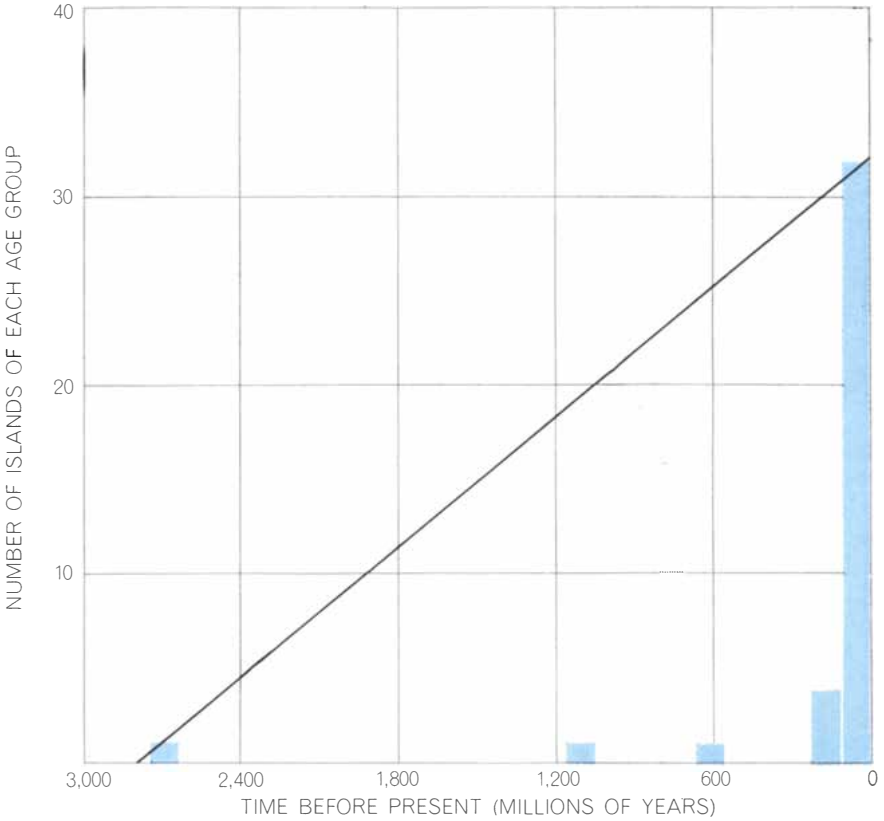
Most oceanographers now agree that the ridges form where convection currents rise in the earth's mantle and that the trenches are pulled down by the descent of these currents into the mantle. The possibility of lateral movement of the currents in between is supported by evidence for a slightly plastic layer—called the asthenosphere—below the brittle shell of the earth. Seismic observations show that the speed of sound in this layer suddenly becomes slower, indicating that the rock is less dense, hotter and more plastic. These observations have also yielded evidence that the asthenosphere is a few hundred kilometers thick, somewhat thicker than



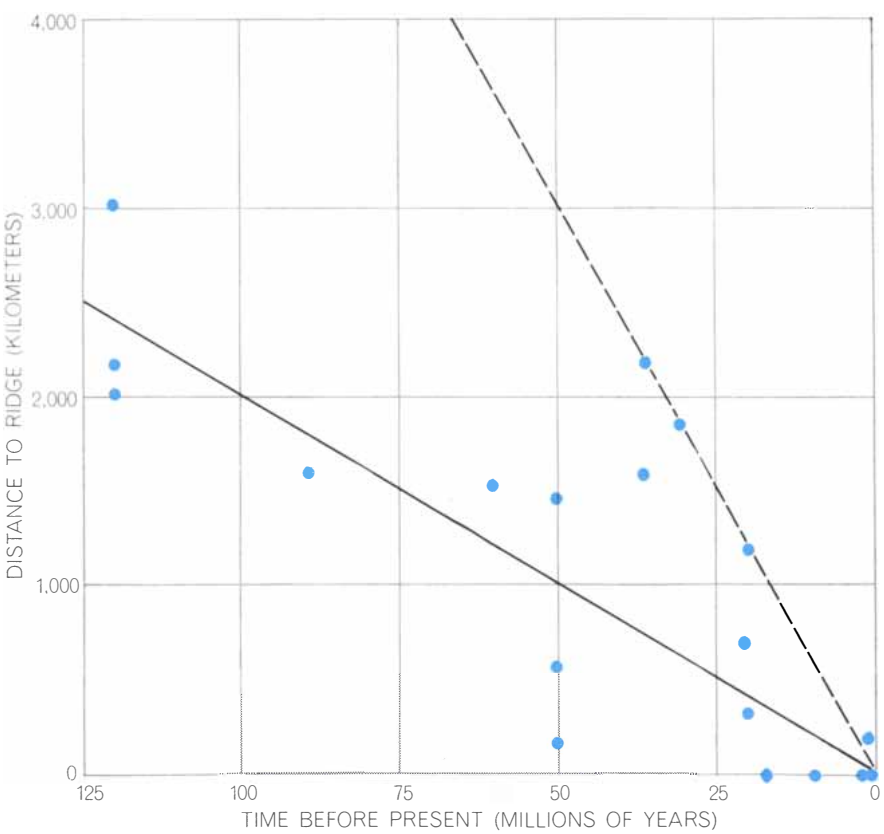
TWO CONVECTION CURRENTS perpendicular to each other suggest a mechanism for producing large horizontal faults such as the one that has offset western New Zealand 300 miles northward. The two convection currents (*arrows indicate direction*) would produce a fault. One current would be forced downward, producing a trench and earthquakes along the sloping surface. Continued flow of the second current would result in a sliding motion, or lateral displacement, along the plane of the fault, shearing the island in two.



VOLCANIC-ISLAND CHAINS like the Hawaiian Islands must have originated in a process slightly different from that which formed pairs of lateral ridges. The source of lava flow does not lie on a mid-ocean ridge; it is considered that the source may be deep (100 miles or more) in the slower moving part of convection currents. The differential motion carries old volcanoes away from the source, while new volcanoes form over the source. The length of the island chain depends on how long the source has been active.



FREQUENCY DIAGRAM shows the age distribution of about 40 islands (in main ocean basins) dated older than "recent" (the number of very young islands is vastly greater). The diagonal line shows the corresponding curve for continental rock ages over equivalent areas.



DISTANCE FROM MID-OCEAN RIDGE of some islands in Atlantic and Indian oceans is plotted against age. If all originated over the ridge, their average rate of motion has been two centimeters a year (*solid line*); maximum rate, six centimeters a year (*broken line*).

the crust, and that below it the viscosity increases again.

Here, then, is a mechanism, in harmony with physical theory and much geological and geophysical observation, that provides a means for disrupting and moving continents. It is easy to believe that where the convection currents rise and separate, the surface rocks are broken by tension and pulled apart, the rift being filled by the altered top of the mantle and by the flow of basalt lavas. In contrast to earlier theories of continental drift that required the continents to be driven through the crust like ships through a frozen sea, this mechanism conveys them passively by the lateral movement of the crust from the source of a convection current to its sink. The continents, having been built up by the accumulation of lighter and more siliceous materials brought up from below, are not dragged down at the trenches where the currents descend but pile up there in mountains. The ocean floor, being essentially altered mantle, can be carried downward; such sediments as have accumulated in the trenches descend also and, by complicated processes, may add new mountains to the continents. Since the material near the surface is chilled and brittle, it fractures, causing earthquakes until it is heated by its descent.

From the physical point of view, the convection cells in the mantle that drive these currents can assume a variety of sizes and configurations, starting up and slowing down from time to time, expanding and contracting. The flow of the currents on the world map may therefore follow a single pattern for a time, but the pattern should also change occasionally owing to changes in the output and transfer of heat from within. It is thus possible to explain the periodicity of mountain-building, the random and asymmetrical distribution of the continents and the abrupt breakup of an ancient continent.

Some geophysicists consider that isostatic processes set up by gravitational forces may suffice to cause the outer shell to fracture and to slip laterally over the plastic layer of the asthenosphere. This mechanism would not require the intervention of convection currents. Both mechanisms could explain large horizontal displacements of the crust.

Evidence from Terrestrial Magnetism

Fresh evidence that such great movements have indeed been taking place has been provided by two lines of study in

the field of terrestrial magnetism. On the one hand, surveys of the earth's magnetic field off the coast of California show a pattern of local anomalies in the ocean floor running parallel to the axis of a now inactive oceanic ridge that underlies the edge of the continent. The pattern bears a persuasive resemblance to the "photoelastic" strain patterns revealed by polarized light in plastics placed under stress. More important, the pattern shows that the ocean floor is faulted at right angles to the axis of the ridge, with great slabs of the crust displaced laterally to the west by as much as 750 miles. These are apparently ancient and inactive fractures; now the active faults run northwesterly, as is indicated by the earthquakes along California's San Andreas Fault.

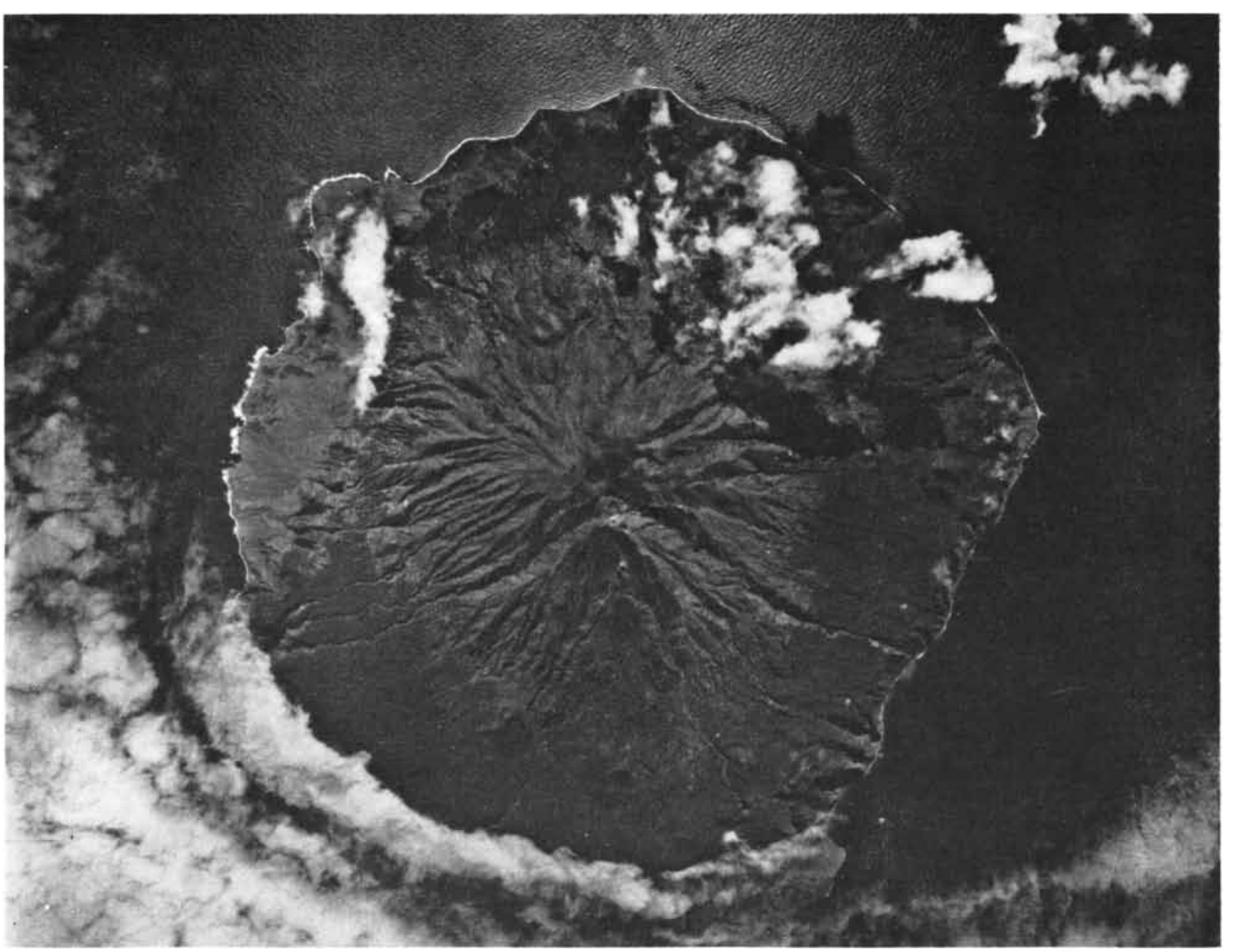
Evidence of a more general nature in favor of continental drift comes from the studies of the "remanent" magnetism of the rocks, to which Runcorn, P. M. S. Blackett of the University of London and Emil Thellier of the University of Paris have made significant contributions. Their investigations have shown that rocks can be weakly magnetized at the time of formation—during cooling in the case of lavas and during deposition in the case of sediments—and that their polarity is aligned with the direction of the earth's magnetic field at the place and time of their formation. The present orientation of the rocks of various ages on the continents indicates that they must have been formed in different latitudes. The rocks of any one continent show consistent trends in change of orientation with age; those from other continents show different shifts. Continental drift offers the only explanation of these findings that has withstood analysis.

Some physicists and biologists are now prepared to accept continental drift, but many geologists still have no use for the hypothesis. This is to be expected. Continents are so large that much geology would be the same whether drift had occurred or not. It is the geology of the ocean floors that promises to settle the question, but the real study of that two-thirds of the earth's surface has just begun.

The Oceanic Islands

One decisive test turns on the age of the ocean floor. If the continents have been fixed, the ocean basins should all be as old as the continents. If drift has occurred, some regions of the ocean floor should be younger than the time of drift.

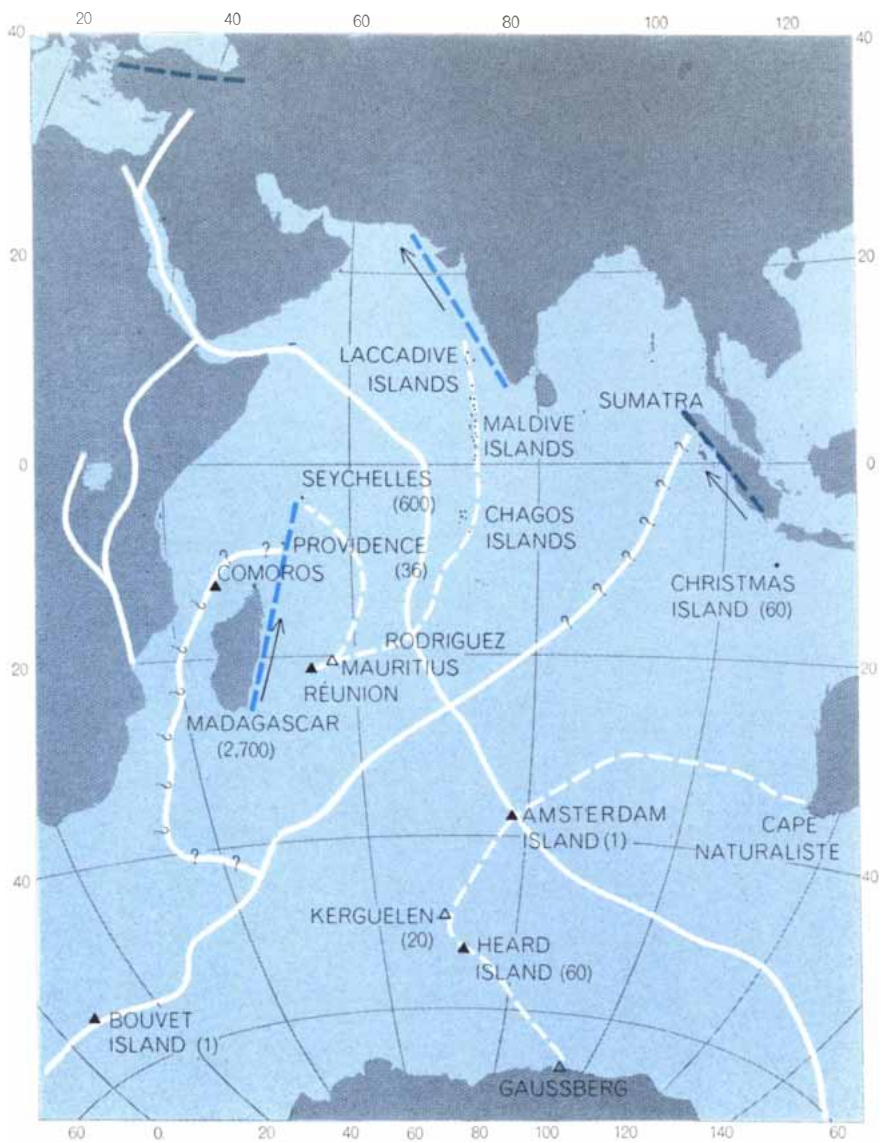
A survey of the scattered and by no means complete literature on the oceanic islands conducted by our group at the University of Toronto shows that of all the islands in the main ocean basins only about 40 have rocks that have been dated older than the Recent epoch. Only three of these—Madagascar and the Seychelles of the Indian Ocean and the



TRISTAN DA CUNHA ISLAND in the South Atlantic lies on the Mid-Atlantic Ridge. At center are the lava beds and partially filled crater of the main cone, which has not erupted for several centuries. Along the perimeter of the island secondary cones are just discernible, as is the settlement on the island's northeastern promontory (*upper left*). Several months after this aerial photograph was made in 1961 a volcanic eruption took place about 300 yards east (*to right*) of the settlement. The island is eight miles at its widest.

Falklands of the South Atlantic—have very old rocks; all the others are less than 150 million years old. If one regards the exceptions as fragments of the nearby continents, the youth of the others suggests that either the ocean basins are young or that islands are not representative samples of the rock of the ocean floor.

Significantly, it turns out that the age of the islands in the Atlantic Ocean tends to increase with their distance from the mid-ocean ridge. In this reckoning one need not count the island arcs of the West Indies or the South Sandwich Islands, which belong to the Cordilleran system—that is, the spine of mountains running the entire length of North and South America—and so have a continental origin. At least six of the islands on the ridge or very close to it have on them active volcanoes that have had recent eruptions; the most recent was the eruption of Tristan da Cunha, which is located squarely on the ridge in the South Atlantic. Only two of the islands far from the ridge have active volcanoes. If the hot convection currents of the mantle rise under the mid-ocean ridge, it is easy to understand why the ridge is the locus of active volcanoes and earthquakes. The increase in age with distance from the ridge suggests that if the more distant islands had a volcanic origin on the ridge, lateral movement of the ocean floor has carried them away from the ridge. Their ages and distances from the ridge indicate movement at the rate of two to six centimeters a year on the average, in keeping with the estimated velocity of the convection currents.



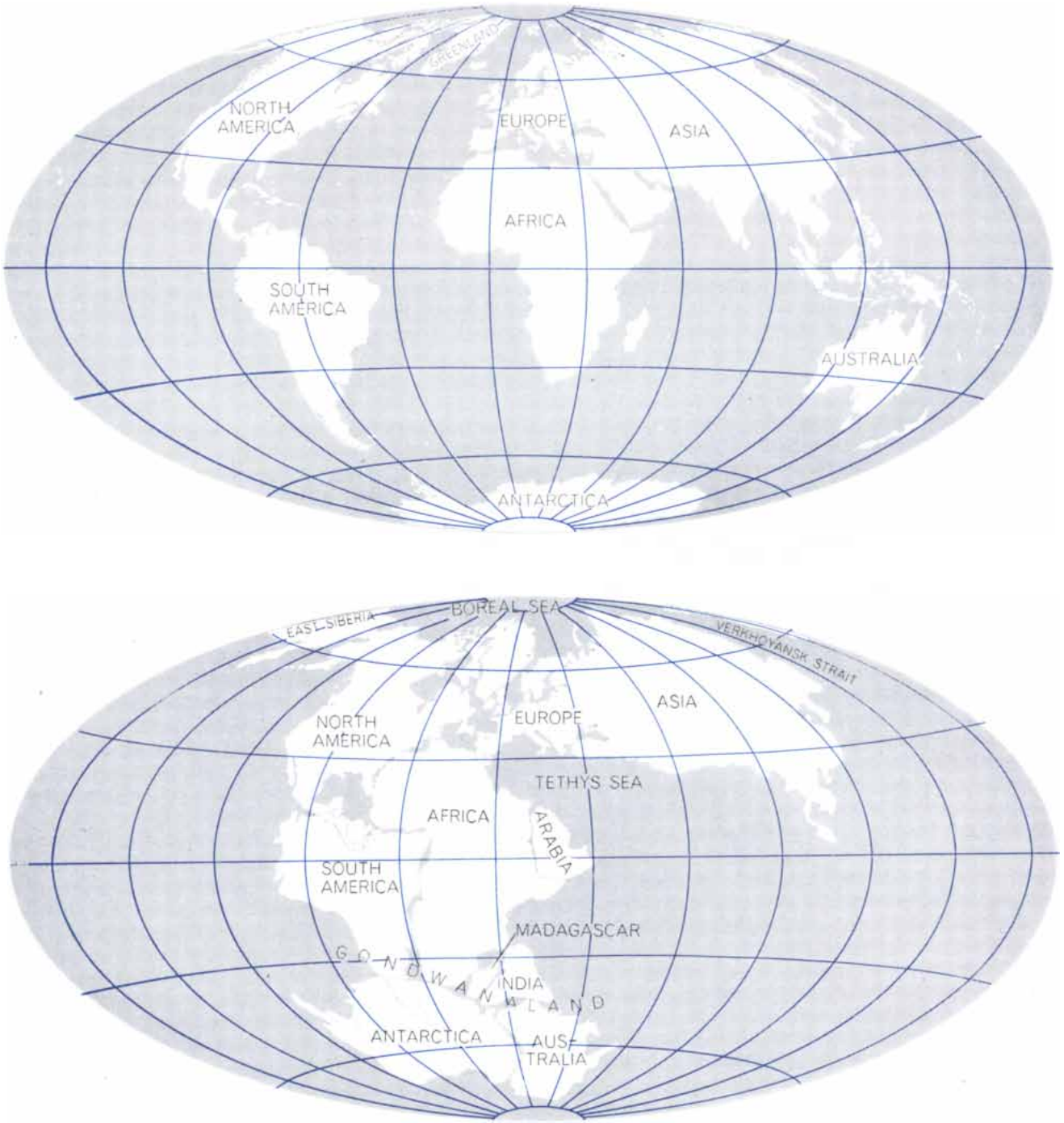
INDIAN OCEAN possibly formed as the result of four continents drifting apart. If so, four median ridges would have formed midway between continents, with pairs of lateral ridges connecting them. Heavy white lines show three known median ridges; there is evidence for one running to Sumatra. Broken white lines are lateral ridges; broken colored lines, faults; open triangles, inactive volcanoes. Numbers give ages in millions of years.

Of great significance in connection with the mechanism postulated here are the two lateral ridges that run east and west from Tristan da Cunha to Africa on the one hand and to South America on the other. It is reasonable to suppose that these ridges had their origin in a succession of volcanoes that erupted and grew into mountains on the site of the present volcano and were carried off east and west to form a row of progressively older, extinct and drowned volcanoes [*see illustration on page 88*]. There are no earthquakes along the lateral ridges and so they are distinctly different in character from the mid-ocean ridge. These ridges meet the continental margins at places that would fit together on the quite independent criterion of the match of their shore lines. One explanation of this coincidence is that the continents were indeed joined together and have moved apart, with the lateral ridges forming trails that record the motion. The two ridges are roughly mirror images of each other, showing that the motion was uniform on each side. Another similar pair of ridges connects Iceland—where the mid-ocean ridge comes to the surface and where the great tension rift is visible in the Icelandic Graben—to Greenland and the shelf of the European continent.

A Double Hypothesis

We have therefore advanced two related hypotheses: first, that where adjacent continents were once joined a median ridge should now lie between them; second, that where such continents are connected by lateral ridges they were once butted together in such a manner that points marked by the shoreward ends of these ridges coincided. If this is correct, it provides a unique method for reassembling continents that have drifted apart. One of the major troubles with theories of drift has been that the possibilities are so numerous no such precise criterion existed for putting the poorly fitting jigsaw puzzle together.

Without doubt the most severe test of this double hypothesis is presented by the Indian Ocean. Here four continents—Africa, India, Australia and Antarctica—may be assumed on geological and paleomagnetic evidence to have drifted apart. The collision of India with the Asian land mass could have thrown up the Himalaya mountains at their



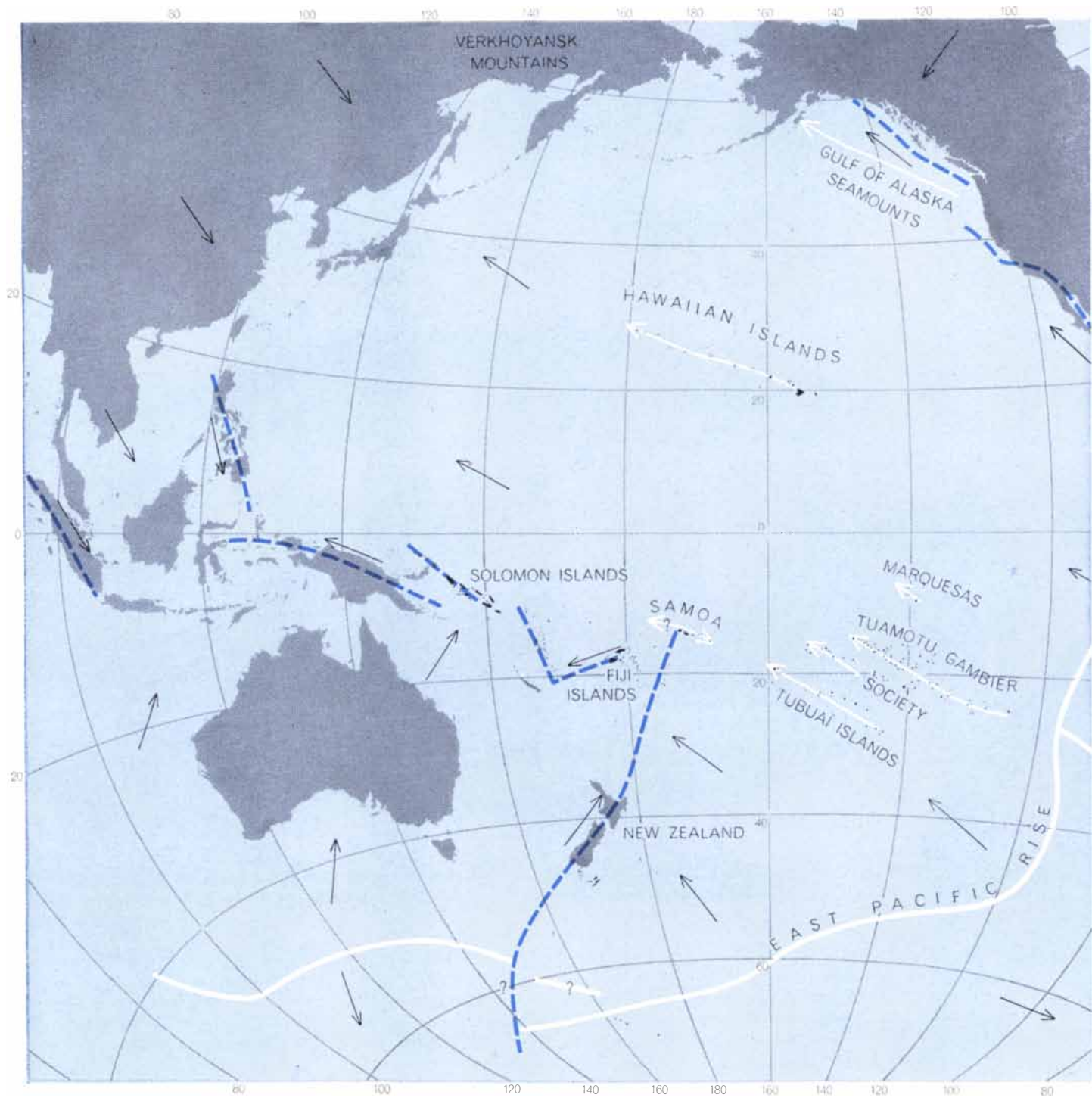
SINGLE SUPERCONTINENT, presumed to have existed some 150 million years ago, would have resembled that depicted in the map at bottom. A present-day map appears at top. In both maps the distortion of the continents is a result of the projection employed.

junction. These continents should accordingly be separated by four mid-ocean ridges. Three such ridges have already been well established by surveys of the Indian Ocean, and there is evidence for the existence of the fourth. In each quadrant marked off by the ridges there is also, it happens, a lateral ridge! These submarine trails may be presumed to be records of the motion of the continents as they receded from one another. From Amsterdam Island one of these lateral ridges runs through Kerguelen Island to Gaussberg Mountain on the coast of Antarctica; a mirror image of this ridge runs from Amsterdam Island to Cape Naturaliste on Australia. The corresponding ridges connecting Africa and India are distorted by lateral faults running along the coasts of Madagascar and India. Thus in each quadrant there exists a lateral ridge to show how points on Madagascar, India, Australia and Antarctica once lay close together. What is remarkable is not that there is some irregularity in the present configuration of these ridges but that the floor of the Indian Ocean should show such a symmetrical pattern.

The mid-ocean ridge separating Australia from Antarctica has been traced by Henry W. Menard of the Scripps Institution of Oceanography across the eastern Pacific to connect with the great East Pacific Rise. From the topography of the Pacific floor it can be deduced

that this ridge once extended through the rise marked by Cocos Island off Central America and formed the rifted ridge that moved North and South America apart. Another branch of this ridge, running across the southern latitudes, suggests the cause of the separation of South America from Antarctica. The oceanic islands in this broad region of the Pacific form lines that extend at right angles down the flanks of the East Pacific Rise; geologists long ago established that these islands grow progressively older with distance from the top of the rise. Unlike the rest of the continuous belt of mid-ocean ridges to which it is connected, the East Pacific Rise tends to run along the margins of the Pacific Ocean; it has rifted an older ocean apart rather than a continent. The floor of the western Pacific is believed to be a remnant of that older floor.

There are therefore enough connections to draw all the continents together, reversing the trends of motion indicated by the mid-ocean ridges and using the continental ends of pairs of lateral ridges as the means of matching the coast lines together. The ages of the islands and of the coastal formations suggest that about



AGE OF PACIFIC ISLANDS appears to increase with increasing distance from the mid-ocean ridge. This is compatible with the idea that the eastern half of the Pacific Ocean has been spreading from the East Pacific Rise (as has been suggested by Robert S. Dietz of the U.S. Navy Electronics Laboratory). Broken colored lines represent faults; the associated arrows indicate the direction of horizontal motion, where known, along the fault. Other arrows show the probable directions of convection flow. Island arcs of the kind

150 million years ago, in mid-Mesozoic time, all the continents were joined in one land mass and that there was only one great ocean [*see illustration on page 97*]. The supercontinent that emerges from this reconstruction is not the same as those proposed by Wegener, Du Toit and other geologists, although all have features in common. The widespread desert conditions of the mid-Mesozoic may have been a consequence of the unusual circumstance that produced a single continent and a single ocean at that time. Since its approximate location with respect to latitude is known, along with the location of its major mountain systems, the climate in various regions might be reconstructed and compared with geological evidence.

represented by Japan develop where the forces associated with such flow are directly opposed; great horizontal faults, where these forces meet at right angles.

It is not suggested that this continent was primeval. That it was in fact assembled from still older fragments is suggested by two junction lines: the ancient mountain chain of the Urals and the chain formed by the union of the Appalachian, Caledonian and Scandinavian mountains may have been thrown up in the collisions of older continental blocks. Before that there had presumably been a long history of periodic assembly and disassembly of continents and fracturing and spreading of ocean floors, as convection cells in the mantle proceeded to turn over in different configurations. At present it is impossible even to speculate about the details.

Breakup of the Supercontinent

If it can be assumed that the proposed Mesozoic continent did exist and spread apart, geology provides some guide to the history of its fragmentation. The present system of convection currents has apparently been constant in general configuration ever since the Mesozoic, but not all parts of it have been equally active all of that time. Shortly before the start of the Cretaceous period, about 120 million years ago, the continent developed a rift that opened up to form the Atlantic Ocean. The rift spread more widely in the south, with the result that the continents must have rotated slightly about a fulcrum near the New Siberian Islands [*see illustration on next page*]. Soviet geologists have found that the compression and uplift that raised the Verkhoyansk Mountains across eastern Siberia began at about that time. To the south a continuation of the rifting separated Africa from Antarctica and spread diagonally across the Indian Ocean, opening the northeasterly rift. Africa and India were thus moved northward, away from the still intact Australian-Antarctic land mass.

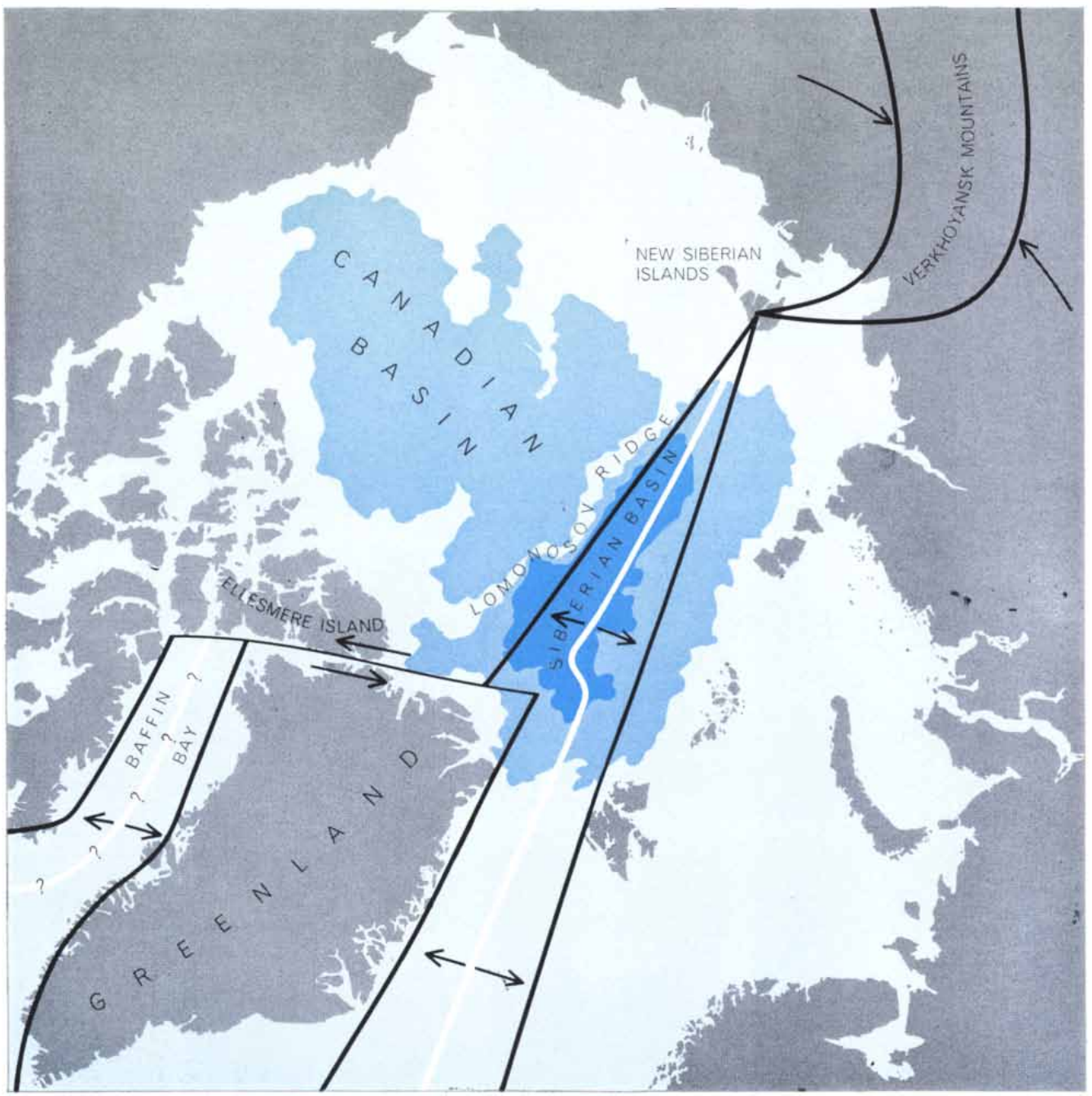
It seems reasonable to suggest, particularly from the geology of the Verkhoyansk Mountains and of Iceland, that at the start of Tertiary time, about 60 million years ago, this convection system became less active and that rifting started up elsewhere. A new rift opened up along the other, northwesterly, diagonal of the Indian Ocean, separating Africa from India and Australia and separating Australia from Antarctica. With the collision of the Indian subcontinent against the southern shelf of the Asiatic land mass, the uplift of the Himalaya mountains began. The proposed succession of activity in the two main ridges of the Indian Ocean would explain why India has moved twice as far north with relation to Antarctica as Australia or Africa has and why the older northeast ridge is now a somewhat indistinct feature of the ocean floor. The younger rift in the Indian Ocean seems to have extended along the East Pacific Rise and Cocos Ridge to cross the Caribbean. A branch also passed south of South America. As these median ridges have continued to widen they have been forced by this growth to migrate northward, forming great shears or faults off the coast of Chile and through California. Indeed, a case can be made out for the idea that every mid-ocean ridge normally ends at a great fault or at a pivot point, as in the New Siberian Islands.

A few million years ago activity in this system decreased, allowing the North and South American continents to be joined by the Isthmus of Panama. The Atlantic rift now became more active again, producing renewed uplift in the Verkhoyansk Mountains and active volcanoes in Iceland and the five other still active volcanic islands down the Atlantic. Again the pattern of rifting in the Indian Ocean was altered. The distribution of recent earthquakes shows that the greatest activity extends along the western half of each diagonal ridge from the South Atlantic to the entrance of the Red Sea and thence by two arms along the rift valley of the Jordan River and through the African rift valleys, where the breakup of a continent has apparently begun.

The presently expanding rifts run mostly north and south or northeasterly so that dominant easterly and westerly compression of the outer crust is absorbed by overthrusting and sinking of the crust along the eastern and western sides of the "ring of fire" around the Pacific. For this reason East Asia, Oceania and the Andes are the most active regions of the world. The westward-driving pressure of the South Atlantic portion of the Mid-Atlantic Ridge has forced the continental block of South America against and over the downward-plunging oceanic trench along its Pacific coast. The northwest-trending currents below the Pacific floor have pulled down trenches under the eight island arcs around the western

and northern Pacific from the Philippines north to the Aleutians. Even at the surface of the Pacific, the direction of the subcrustal movement is indicated by the strike of several parallel chains of volcanic islands, such as the Hawaiians, which may be thought to have risen like bubbles in a stream from the slower moving deep interior [*see lower illustration on page 93*]. These chains run parallel with the seismically active shearing faults that border each side of the Pacific, along the coast of North America and from Samoa to the Philippines. The compression exerted by the mid-ocean ridge through the southern seas is absorbed, with less seismic activity, along a line from New Zealand, through Indonesia and the Himalaya highlands to the European Alps. In all cases, the angle at which the loci of deep-focus earthquakes dip into the earth seems to follow the direction of subsurface flow—eastward and downward, for example under the Pacific coast of South America; westward and downward under the island arcs on the opposite side of the Pacific.

The theory I have outlined may be highly speculative, but it is indicative of current trends in thought about the earth's behavior. The older theories of the earth's history and behavior have proved inadequate to meet the new findings, particularly those from studies of terrestrial magnetism and oceanography. In favor of the specific details suggested here is the fact that they fit observations and are precise enough to be tested.



RIFTING OF SUPERCONTINENT to form the Atlantic Ocean could have produced the Verkhoyansk Mountains in eastern Siberia. As shown on this map of the Arctic, the rift spread more widely to the south. The opening of the Atlantic Ocean and Baffin Bay separated Greenland from both North America and Europe. The continents were rotated slightly about a fulcrum near the New Siberian Islands. The resulting compression and uplift would create a mountain range. Opposing arrows mark the Wegener Fault.

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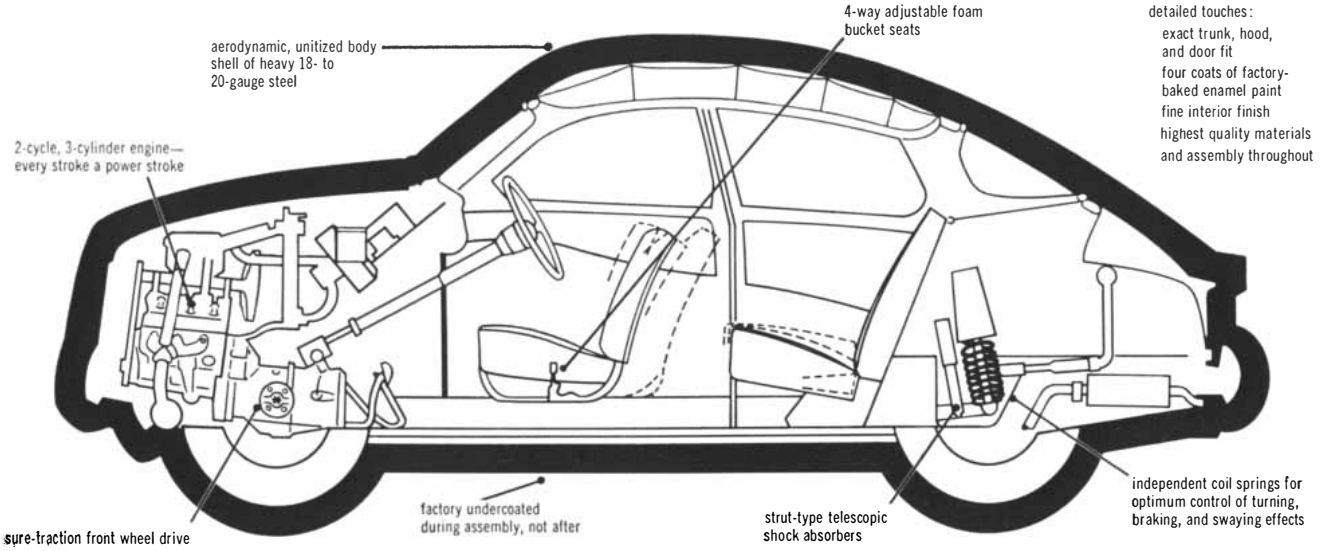

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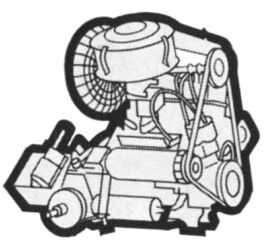

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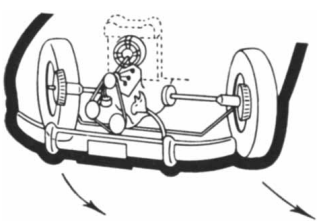

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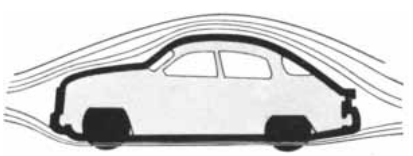

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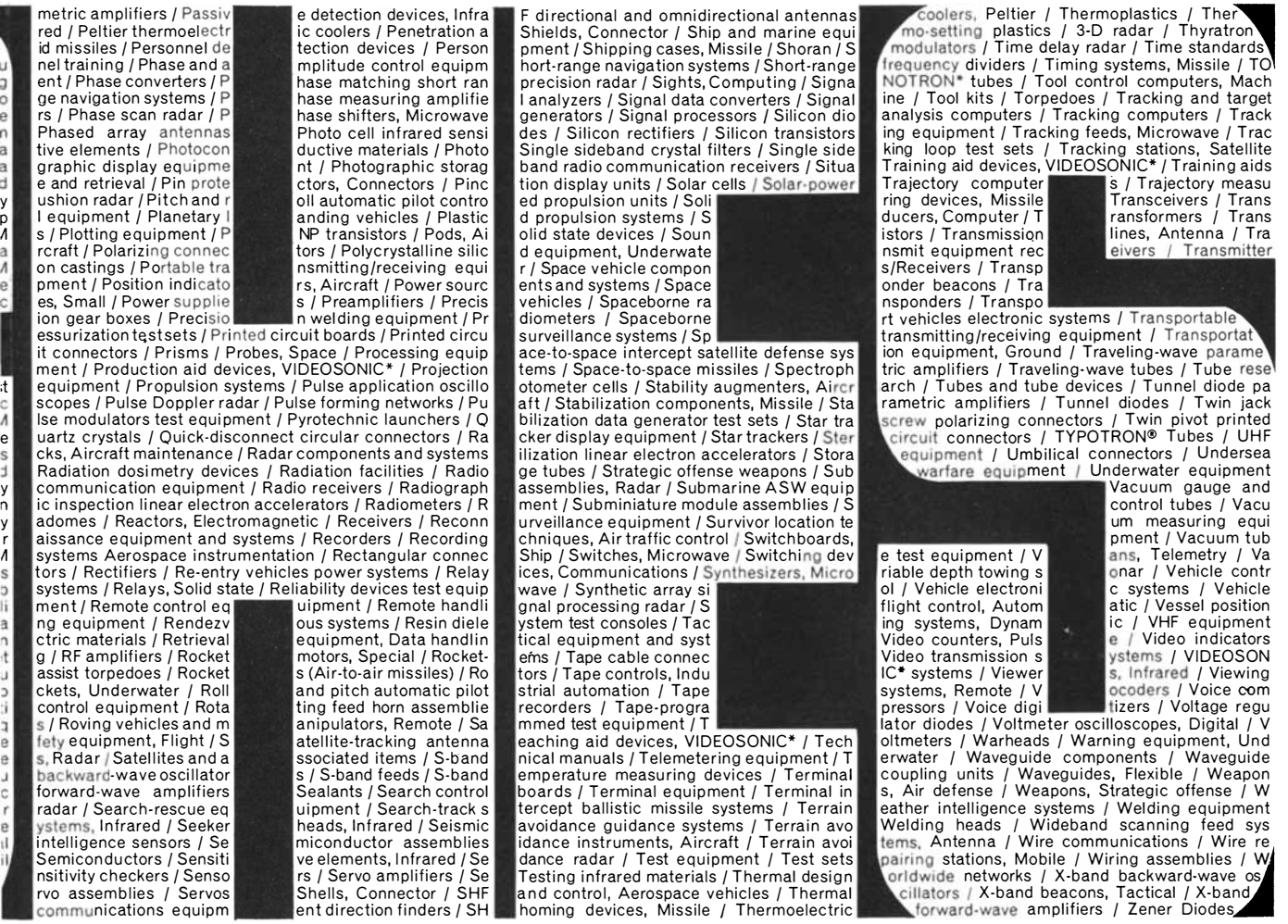

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The Aging of Collagen

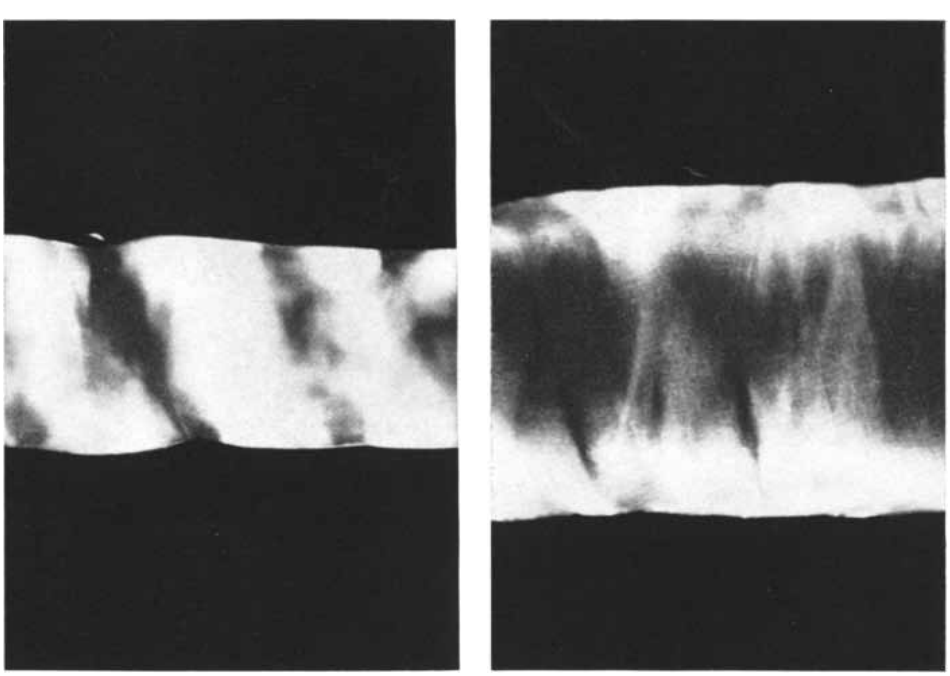
Simple tests of this protein provide objective measurements of the biological age, as distinct from the calendar age, of an animal. They also clarify the molecular basis of aging

by Frederic Verzár

The process of aging—the progressive decline in all the vital capacities of the organism that terminates in death—goes on at different rates in animals of different species and in different individuals of the same species. At 16 months the laboratory white rat has already lost sexual competence, and by 24 months half of the members of a colony have died. Some people appear "old" beyond their years and others remain "younger" than their age. It is clear that the advance of age cannot be measured by chronology alone. Investigators no longer suppose that the inactivity of any one organ, such as the pituitary gland or the sex glands, determines the duration of life for the organism as a whole. On the contrary, they seek clues to the underlying process in changes that proceed continuously throughout the body in the molecular constituents of its tissues. The work in my laboratory at the Institute for Experimental Gerontology in Basel, Switzerland, has recently centered on collagen, the protein that constitutes 40 per cent of all the protein in the body. Samples of the material, subjected to a simple mechanical or chemical test, reveal that the collagen accumulates changes in its molecular structure that affect its integrity and function. The aging of the collagen, as measured by these tests, may now provide an objective index for determining the "biological age," as distinguished from the "calendar age," of men and other animals.

In subjective terms one can say that this aging of the collagen is not unrelated to the stiffness of joints and leatheriness of skin suffered by and observed in the elderly. Collagen supplies the matrix in which the calcium salts that give the bones their hardness are deposited. Collagen is the substance of cartilage and tendon; it fills up the spaces between muscle fibers and between the cells of many organs, serving as the stabilizing fiber of connective tissue. In the skin a thick matting of collagen fibers forms the "corium" that gives the skin its toughness and plasticity. This corium layer in the hide of animals becomes the substance of leather after tanning. It is no accident that the investigations of leather chemists have made significant contributions to gerontology, the science of the aging process.

Once the fibers of collagen are laid down in the body they cannot be renewed. Studies using substances labeled with radioactive atoms show that the collagen molecules in the tendons of a rat, for example, take no further part in the metabolism of the animal after the tendons have matured. The long chains of amino acid units that make up collagen are synthesized in the fibroblast cells of the connective tissue; the chains consist to the extent of about a third of the amino acids proline and glycine in the ratio of about two to one. Extruded from the cells into the "ground substance" of the connective tissue (made up chiefly of mucopolysaccharides and mucoproteins), the primary precollagen chains undergo a unique transformation. The proline is partly transformed to hydroxyproline by the attachment of a hydroxyl (OH) side group. These side groups play an important part in the next step in the maturation of collagen, in which the chain assumes the configuration of the left-handed alpha helix,



RAT TENDON FIBERS magnified 55 diameters appear at various stages of contraction in the five photomicrographs on these two pages. A normal fiber in water at 25 degrees

found universally in proteins, and coils with two other such chains to form a right-handed triple helix. Many such "tropocollagen" molecules now join end to end and coil one around the other to form the typical collagen fibril.

In electron micrographs all the collagen fibers of the body show a rhythmically repetitive pattern of striation. This is a reflection of the high degree of order with which the tropocollagen molecules are built up from their constituents. From every 10 triple helices a superhelix is formed and, as in the spinning of a cable, the pattern is repeated until the basic helical structure attains microscopic visibility. Thus even under low magnification in the light microscope one can discern a beautifully regular helical pattern: the continuation into microscopic dimensions of the helical structure of the tropocollagen filaments.

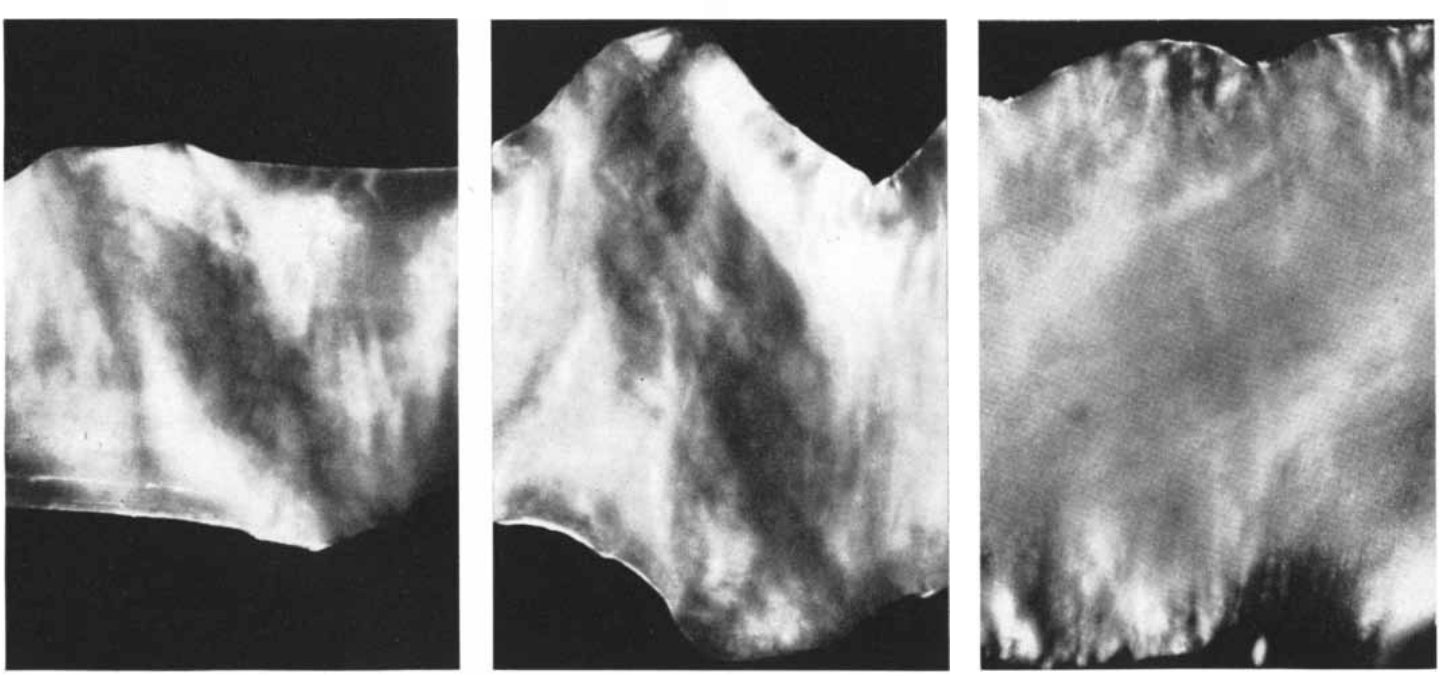
This structure develops its ultimate mechanical properties on the macroscopic scale in the tendons of the body. The function of the tendons is to transfer muscular contractions across the articulations of the joints. The collagen fibers of the tendons must be inelastic if they are to transfer these contractions with the precision of the commands issued by the nervous system—as in the finger movements of an expert pianist. Such precision requires that the tendons stretch no more than .01 millimeter at each contraction of the muscles. The collagen fiber is, in fact, so inelastic that a weight 10,000 times its own weight will not stretch it.

Every cook knows that the tendons that attach meat to bone shrink when they are immersed in hot water. Anatomists first took note of this fact about 100 years ago, and physiologists described the phenomenon in detail some 50 years later. It came vividly to my mind when, about 10 years ago, I became interested in the aging of collagen as a possible index of the aging of the body as a whole. Some preliminary experiments with skin showed that its shrinkage upon being heated might be related to changes that come with age. Because the collagen fibers in the corium are randomly oriented I decided that a single tendon fiber, with its collagen fibers and fibrils all uniformly aligned in one direction, would make a better subject for such tests. Tendons of just the right size—10 centimeters long and .015 centimeter in diameter—are provided by the tail of the laboratory rat; these tendons are so extremely fine and strong that surgeons once used them as sutures for small-scale operations on the eye. From a single tail one can dissect several fibers of the same diameter for comparative and control experiments. With these fibers as our experimental subjects we set out to determine if collagen of different age would show differences in the force with which it contracts when it is heated.

In our first experiment we immersed four equal lengths of tendon, taken from a five-month-old rat, in a neutral salt solution; the fibers were stretched taut with weights of .1 gram, one, two and three grams respectively suspended from them. When the water bath was heated to 60 degrees centigrade (140 degrees Fahrenheit), the fiber with the .1-gram weight contracted to 25 per cent of its original length; upon being heated further, the fiber with the one-gram weight proceeded to shrink; at a still higher temperature, the third fiber contracted to about 25 per cent of its length against the pull of the two-gram weight. The fiber with the three-gram weight did not contract even when the temperature was raised to 65 degrees C., at which point the fiber broke.

When we repeated this experiment with fibers of the same dimensions and weight taken from the tail of a relatively senile 30-month-old rat, we found that the inhibiting weight—the weight against which the tendon could not contract at maximum temperature before breaking—was 10 grams. In general we found that the older the rat, the greater the weight required to inhibit contraction completely. The experimental results showed a certain amount of scatter. As we perfected our technique, however, and learned to conduct our experiments with more nearly uniform material and under more accurately controlled conditions, we obtained more consistent results [*see top illustration on page 108*].

The varying force of "isotonic" contraction thus grossly measured could be taken as being an expression of tension



centigrade (*left*) begins to contract at 58 degrees C. (*second from left*). The contraction continues to completion (*right*) at a rate dependent on the temperature. The micrographs were made by Harry R. Elden of the Howard Hughes Medical Institute in Miami, Fla.

liberated in the collagen fiber by heating. We accordingly undertook to measure the tension directly by an arrangement that allowed no shortening of the fiber and that transferred the tension to a strain gauge or similar arrangement. This "isometric" contraction of the fiber allows more precise determination of the maximum tension that can be developed by the fiber as the temperature of the water bath is raised. If the maximum tension is reached, the fiber starts to relax. If this temperature is maintained, the fiber ultimately breaks; if the temperature is somewhat lowered, the fiber "relaxes" completely and the tension returns to its original zero value. Our results with this method matched and confirmed our experiments with isotonic contraction.

With the isometric method we could work with pieces of fiber only one centimeter in length; we could thereby study age differences in *Xenopus laevis,* a South African frog that has been standardized as a laboratory animal. Fibers taken from the fingers of frogs ranging in age from one to 12 years indicated that the collagen of these cold-blooded animals shows the same age effects as that of the rat. The frog ages slower than the rat, but its tendons register a parallel increase in tension with age. Aging is independent of the rate of growth; fibers from old male frogs weighing 60 grams and from old females weighing 150 grams showed the same biological age.

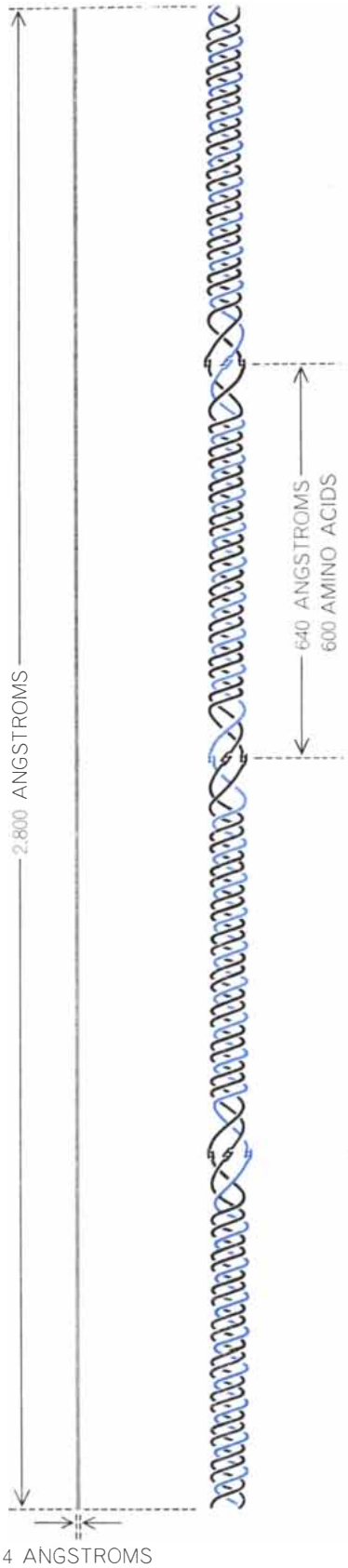
In observing the relaxation of the fibers we noted that in general young fibers relax more quickly than old fibers. It might, in fact, be possible to correlate the time of relaxation—from maximum tension—with age. Seemingly there is also a relation between age and the temperature at which the fiber develops maximum tension. This has led some authors into the error of reporting that in the older animal a higher temperature is needed to produce the shrinkage, or contraction. At a higher temperature, it is true, the contraction of an older fiber will lift a heavy weight against which a younger fiber will not contract at all. On the other hand, the fibers of both old and young animals begin to contract immediately at 58 degrees C., as can be observed with the isometric method and also with the isotonic method, provided that the fibers are not loaded.

With these methods for measuring biological age at hand, it occurred to us to make a test of the alleged rejuvenating effects of the analgesic drug procaine, which are still occasionally claimed in "procaine therapy." After treatment with the drug for an entire year, however, the tendons of the treated rats showed them to be just as old biologically as their control fellows were by the calendar. We were somewhat surprised, on the other hand, to find that ionizing radiation, which undoubtedly does shorten life, does not affect the aging of the collagen of the body. Rats that died several months after whole-body irradiation with X rays had tendons of the same biological age as those of the control rats. The locus of damage by irradiation may be elsewhere in the body.

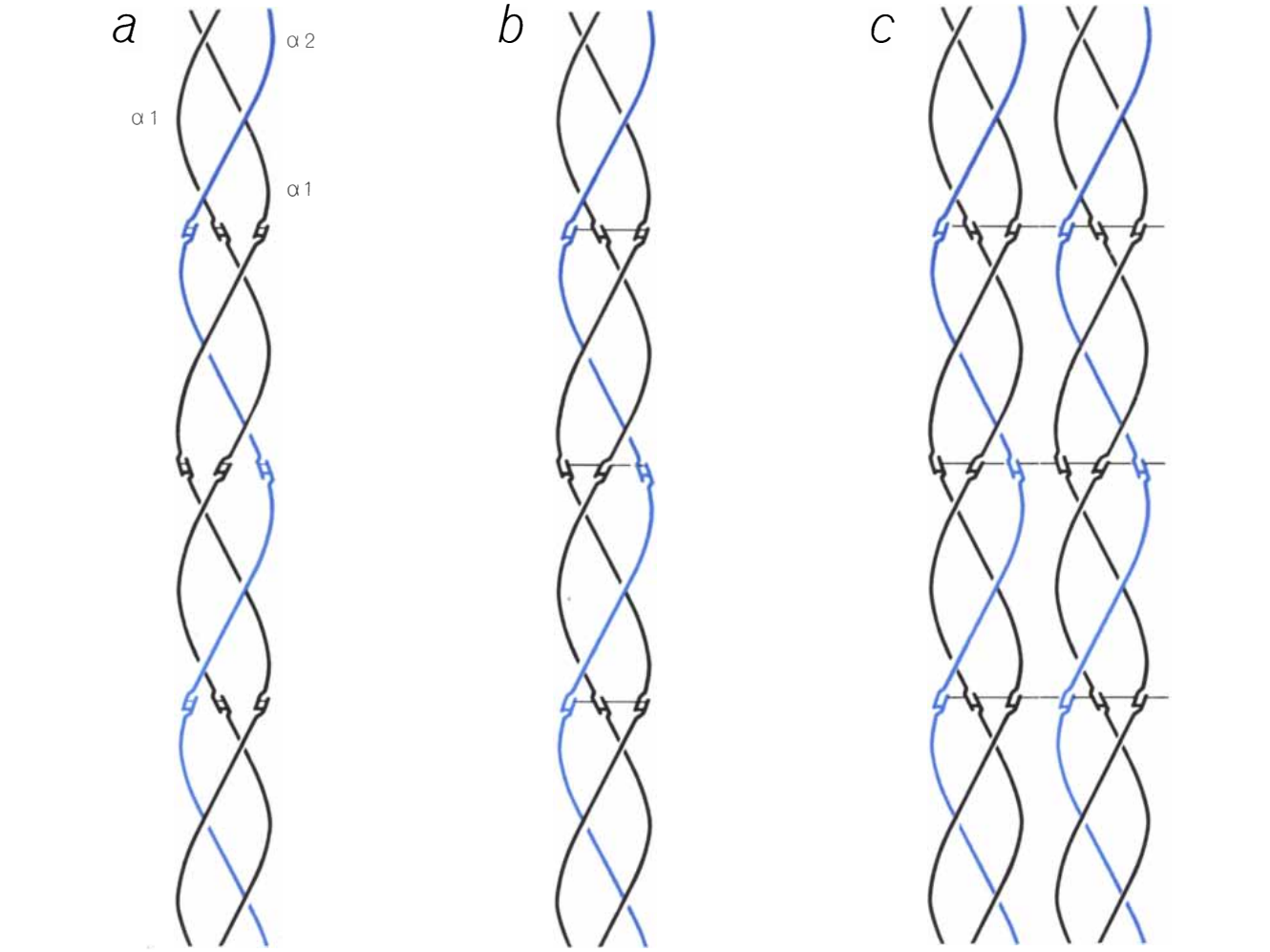
The addition of certain substances to tendons enhances the tension liberated with heating. Among these formaldehyde produced by far the greatest effect —increasing the maximum weight lifted by isotonic contraction from four to 40 grams and elevating the temperature of maximum contraction to within one degree C. of the boiling point of water without breaking the fiber. Formaldehyde is a standard tanning agent, and other tanning agents show similar effects.

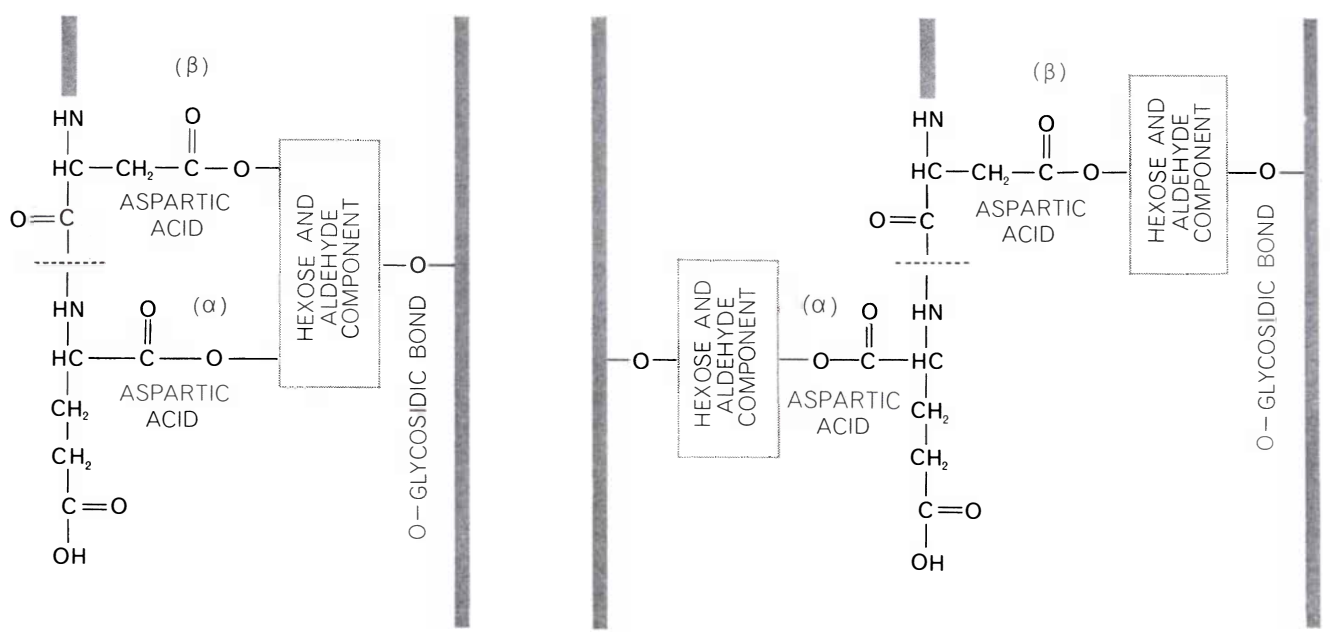
Other investigators have demonstrated that contractions induced by chemicals alone can be used to measure biological age. J. Banga of the Medical University of Budapest has calibrated the effects of potassium iodide (KI), and M. Chvapil of the Institute of Industrial Hygiene in Prague has done the same with sodium perchlorate ($NaClO_4$). In suitable concentrations either one of these substances will induce greater tension at room temperature, measured by the isometric method, than heating will. The effect of formaldehyde after heating is enhanced still further if the fibers are pretreated with potassium iodide or sodium perchlorate. Chvapil uses the measurement of the speed of relaxation after chemically induced contraction as an index of biological age. This agrees with our own observations of the relaxation of fibers after contraction induced by heat; the fiber must, however, be lightly loaded. By this method Chvapil has demonstrated a real case of prolongation of youth. As Clive M. McCay of Cornell University showed in 1939, animals kept on a restricted diet live longer. In the tendons of such animals this age test showed a biological age younger than their calendar age.

The question of what causes the higher tension in the biologically older collagen calls for the explanation of what causes the collagen fibers to contract in the first place. From experience with in-

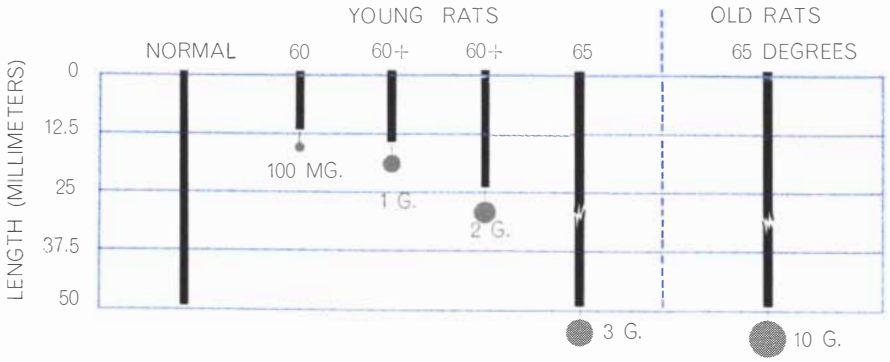


COLLAGEN MOLECULE (*left*) consists of three strands wound around one another in helices. The investigations of Karl A. Piez and his co-workers at the National Dental Institute suggest that the amino acid composition of one strand differs somewhat

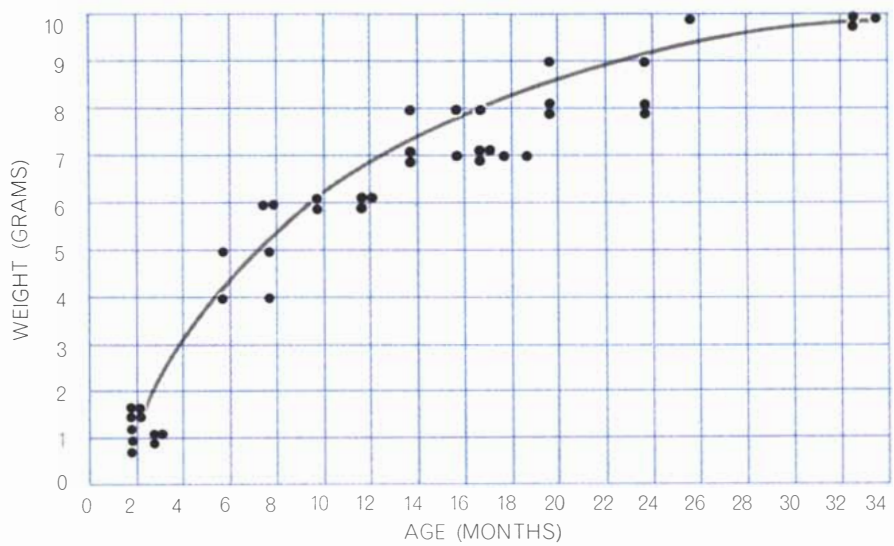




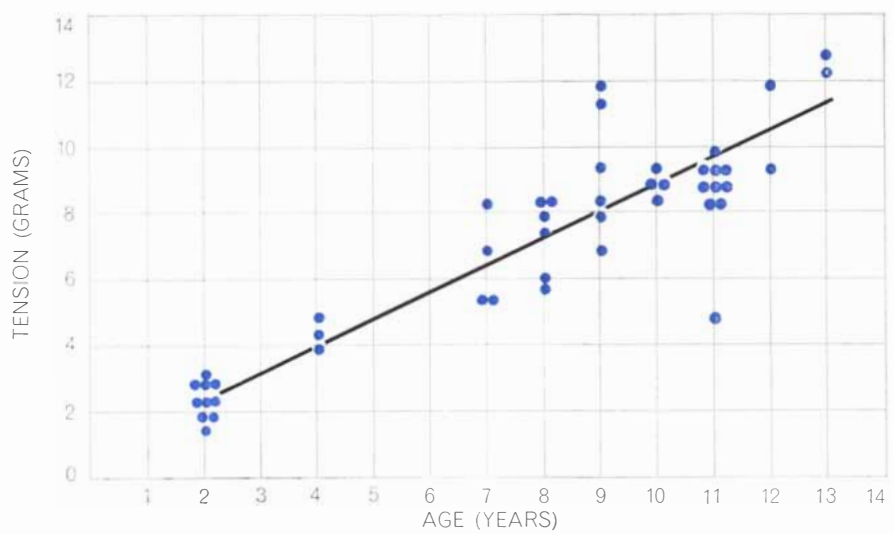
from that of the other two. The work of Paul M. Gallop, Olga O. Blumenfeld, C. Franzblau and Sam Seifter of the Albert Einstein College of Medicine indicates that each strand consists of four subunits connected by pairs of ester bonds (*"a" at top*). One bond may be capable of shifting to connect two strands (*b*) or two molecules (*c*). The nature of these bonds is not completely known. Alpha (*α*) and beta (*β*) ester bonds between subunits (*left-hand drawing at bottom right*) are no more than seven amino acid units apart (*broken line*). The unknown component apparently consists of a hexose (suggested also by W. Grassmann and H. Hörmann) and an aldehyde. The connection between two strands (*right-hand drawing*) may involve the shift of one of these bonds.



ISOTONIC CONTRACTION of collagen fibers from the tail tendon of five-month-old rats is considerably less than it is in 30-month-old rats. When the water bath (*see cover*) is heated to 60 degrees C., the most lightly weighted fiber contracts to about 25 per cent of its original length. Further heating is required before fibers with one- and two-gram weights begin to contract. The minimum weight required to prevent contraction is three grams for young fibers and 10 grams for old fibers. Thus weighted, the fibers break at 65 degrees C.



AGE OF RAT TENDON and the weight it can lift upon contraction when heated show a definite correlation. The tensile strength (or strength of contraction) steadily increases with age. Rats are adult at five months. Twenty per cent, at most, survive beyond 35 months.

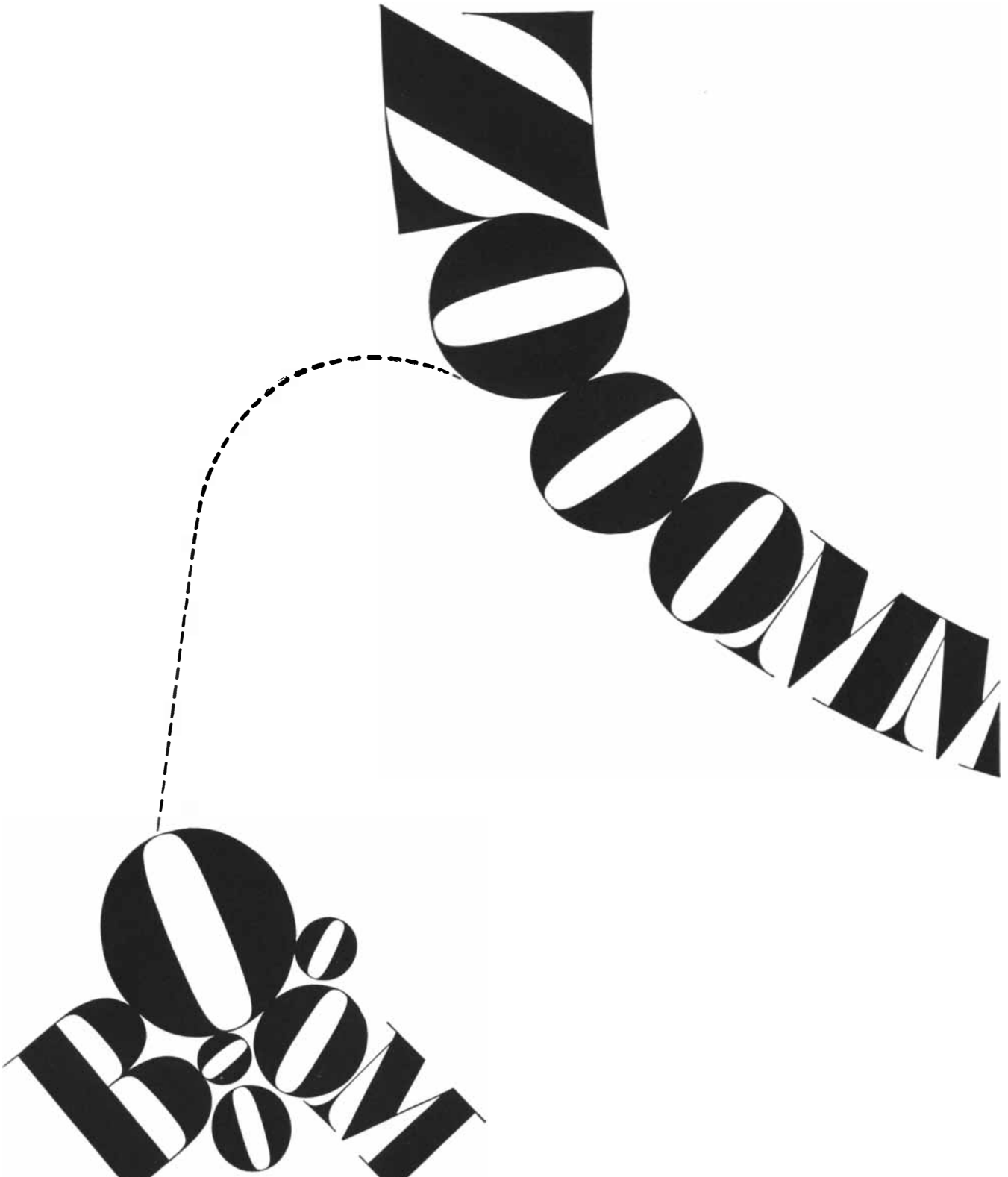


ISOMETRIC CONTRACTION of fibers from the frog *Xenopus laevis* showed the same correlation between age and weight lifted that appeared in the isotonic contraction of rat fibers. Frogs age slower than rats, but increase of tension with age is about the same in both.

organic materials one might expect heat to cause expansion. Contraction as a result of heating is an effect that is well known, however, to investigators and engineers engaged in the synthesis and application of high polymers: the ubiquitous and useful long-chain molecules analogous to those synthesized by the living cell. Even the public has been acquiring some experience with plastics that contract upon being heated.

Perhaps the most familiar example is the rubber band. Whether it is made of synthetic or natural rubber, it is composed of long-chain molecules that are entangled in a disordered array and that are chemically cross-linked to one another only at infrequent intervals along their lengths. The internal molecular constitution of rubber is therefore more like that of a gas than of a solid. Like the molecules of a gas, the molecules of rubber are in constant diffusional (Brownian) movement, tending always to reach maximum entropy, that is, the state of most random disorder. As a result the rubber band contracts and resists extension. Stretching restrains the random diffusional motion of the molecules, brings them into ordered alignment with one another and correspondingly reduces their entropy. If the rubber band is heated in this state, the input of energy stirs the molecules to larger amplitude of motion and toward corresponding increase of entropy; the result is that the elastic band tends to contract more strongly and exerts increased tension.

The rigorously ordered structure of the collagen molecule presents a diametrically opposed picture. Hydrogen bonds tie the long molecular chains of collagen together all along their lengths, forming cross links that run between the hydroxyproline or hydroxylysine units and hold the chains in the triple-helix configuration. These bonds are sensitive to heat. In fact, like the hydrogen bonds that hold molecules of water together in an ice crystal, they have a precise "melting point." They let go all at once at about 58 degrees C. It is the melting of these bonds that accounts for the first primary contraction—or release of tension—that shows up in old as well as young collagen fibers when they are heated to that temperature. Under the microscope it can be seen that the fibers have lost their ordered crystalline structure. They have become instead glassy and transparent, and their polypeptide chains have fallen into the same random and amorphous disorder as the squirming molecules of rubber. Because the hydrogen bonds are also sensitive to



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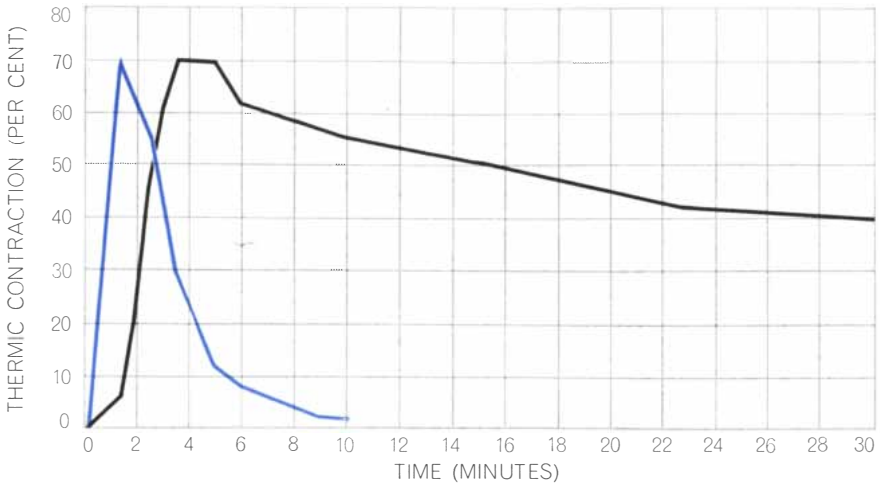


RELAXATION TIME required for a rat tendon fiber (with a light weight attached) to regain its original length following contraction is less for young rats (*colored curve*) than for old rats (*black curve*). These curves represent results obtained by the isometric method.

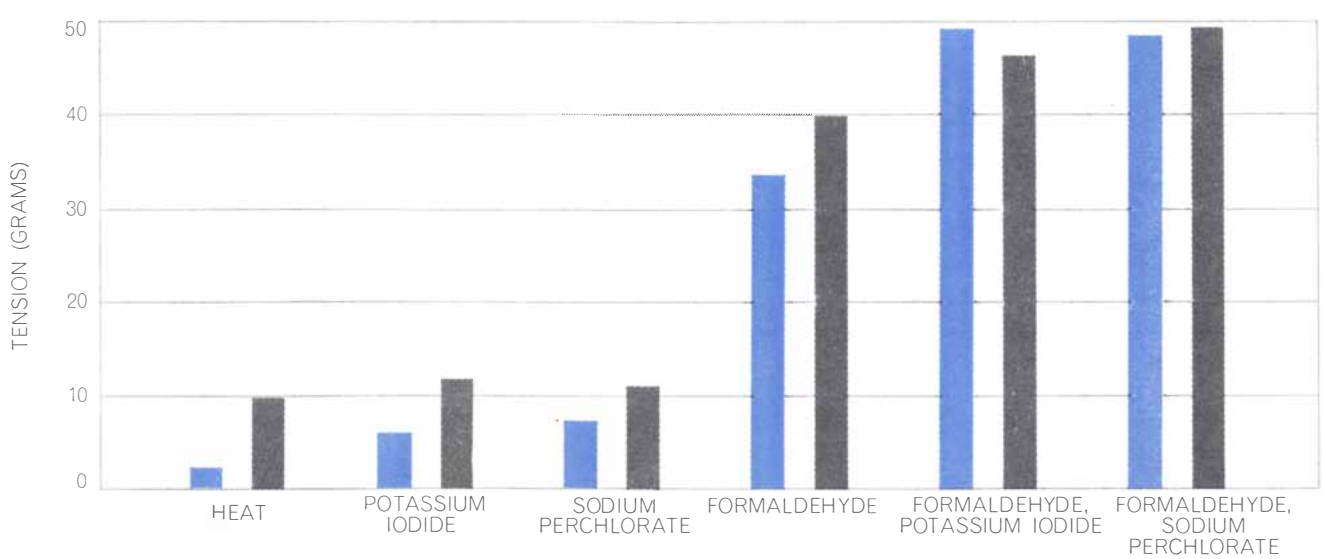
chemical action, the chemical induction of contraction brings the internal structure of the fibers into the same disarray.

The analogy of the collagen fiber after thermally or chemically induced contraction to a rubber band is supported further by the fact that the contracted collagen fiber shows a rubbery elasticity. From contraction to 25 per cent of its original length it can be extended again to its original length by loading it with a small weight; when it is unloaded, it will contract again to 25 per cent of its length. The operation can be repeated as often as one wishes. A fiber re-extended to its original length and cooled down to 15 or 20 degrees C. will remain extended. If it is then heated to 58 degrees C., it will immediately contract again. If the fiber has spontaneously relaxed or is heated above its temperature of maximum contraction, it becomes inelastic. Any fiber that has spontaneously relaxed to its original length loses its capacity to contract again upon being heated. These observations all hold in the case of chemically as well as thermally treated fibers. (Most of them also apply to the behavior of a rubber band, although at widely different points on the thermometer.)

Since it is the cross-linking by hydrogen bonds or other bonds that keeps the native collagen fiber extended to its proper length (under tension!), one is naturally prompted to explain the higher tension exhibited by a biologically older fiber as the result of an increase in the number of cross links among its constituent tropocollagen molecules. I first put this idea forward as an explanation of our tendon experiments in 1956. A similar idea occurred independently to Johan Bjorksten of the Bjorksten Research Laboratories in Houston, Tex., who mentioned in this connection the action of tanning agents as factors in the aging of proteins in general.

At our laboratory in 1957 we began to look for evidence of increase in cross-linkage with age by studying the chemical changes that take place during heat-induced contraction in young and old fibers. One of our first observations showed that, with the substitution of distilled water for the customary neutral saline solution, contraction occurs at higher temperatures. Distilled water extracts sodium, potassium and calcium from the fibers. Evidently the removal of these electrically charged ions frees chemical energy in the fiber for the formation of an increased number of cross links. This may serve as a sort of general confirmation of the cross-linkage hypothesis.

Our analyses showed that other substances also pass into solution from the contracting and relaxing fiber. Among these are collagen itself and shorter chains of amino acid units with a high hydroxyproline content, plus some mucopolysaccharides. The difference in the quantity of the material released by young and old tendons was sufficiently pronounced and consistent to enable us to establish a chemical test for the biological age of collagen, which we have called the hydroxyproline test. The method itself, reflecting the lower solubility of aging collagen during thermally induced contraction at 65 degrees C.,



EFFECT ON CONTRACTION of rat tendon fibers from three-month-old (*color*) and 30-month-old rats (*gray*) varied greatly when the fibers were placed in solutions of different substances. The variations in the effects are discussed in detail in the text

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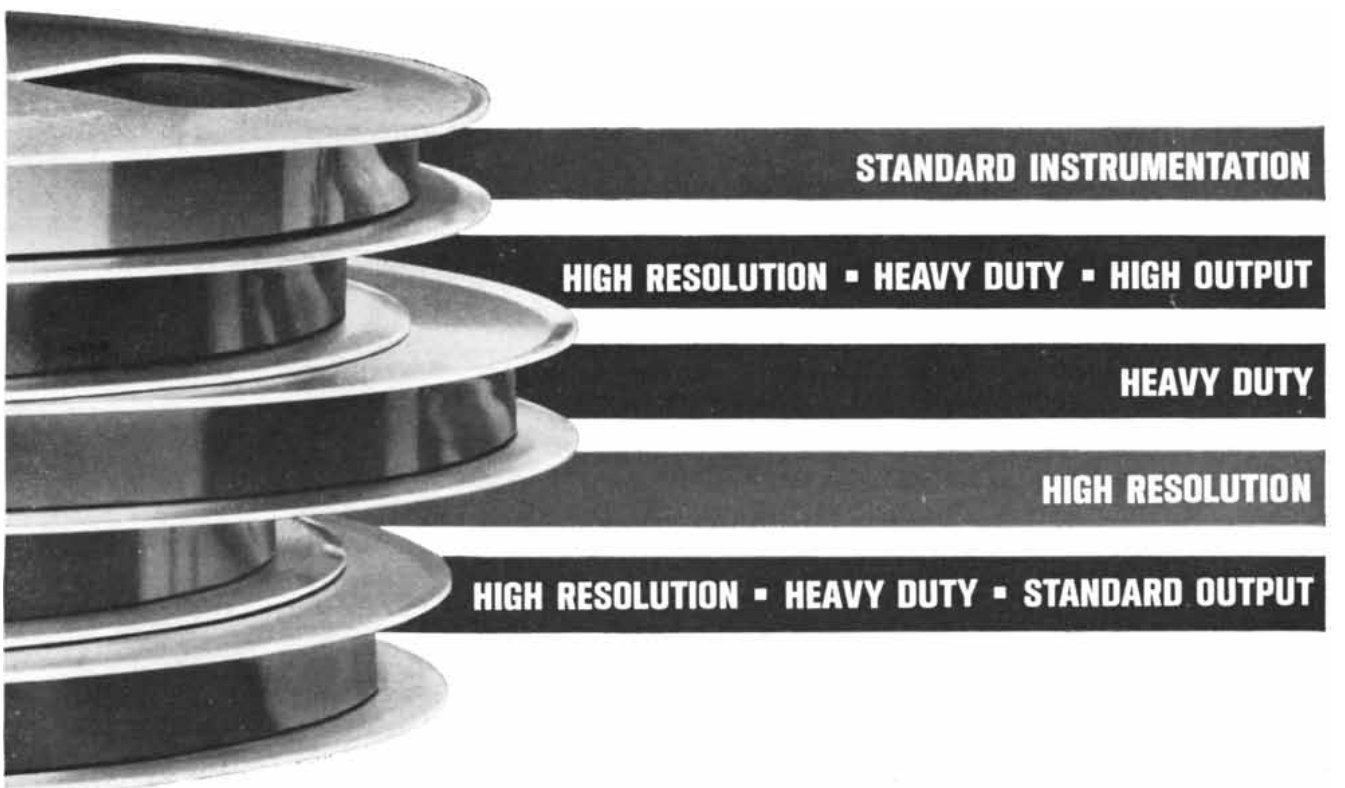

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testifies to an increase in the number of cross links in the older fibers.

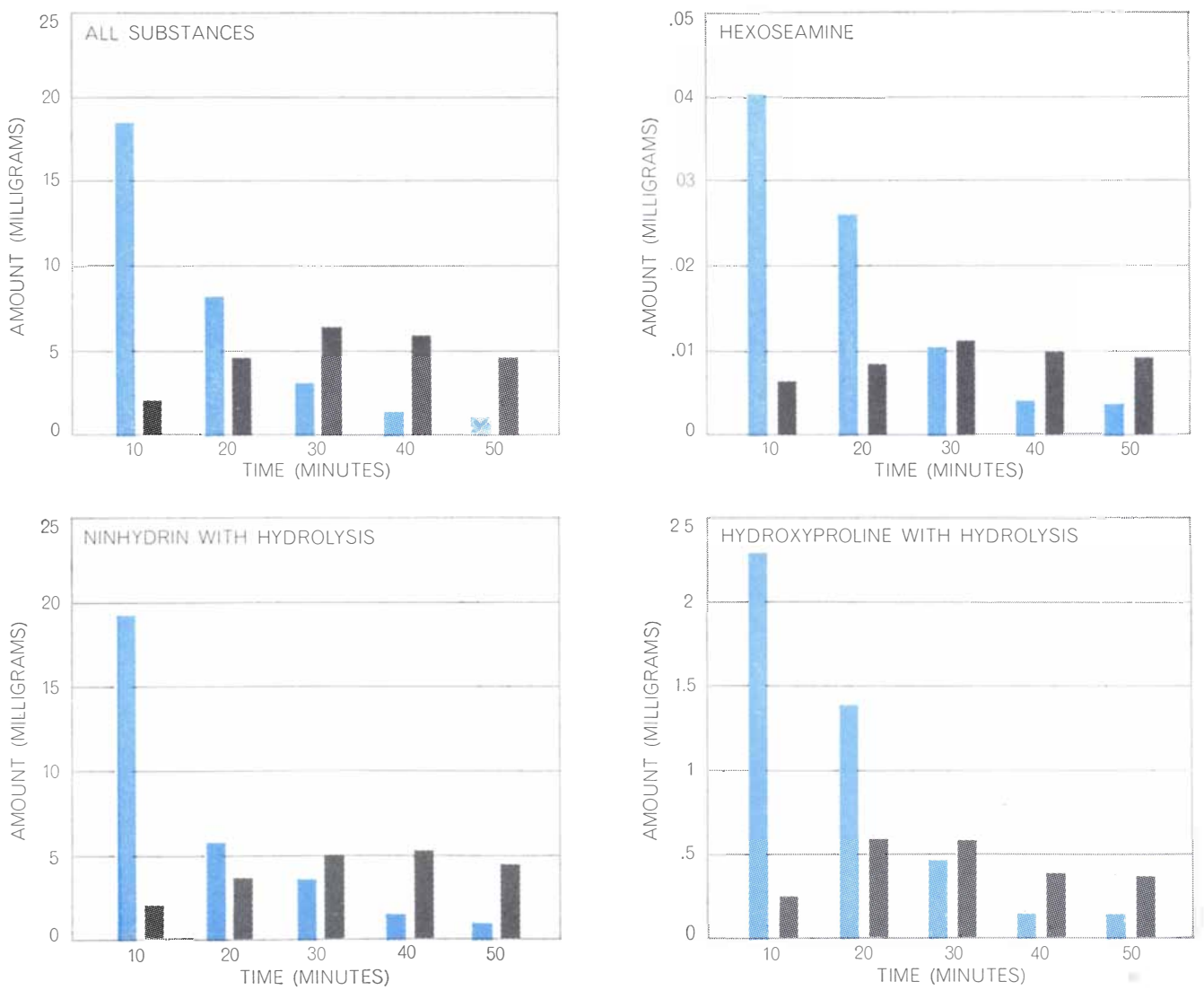
One virtue of this test is that it can be used to study the aging of collagen in organs from which no long fibers can be dissected for testing by the mechanical methods. We are able, for example, to assay the biological age of skin; we used the method first on bovine skin, then on rat skin and finally on human skin. The age relation is less marked than that shown by the tension measurements, but the difference between young and old animals is unmistakable. By closer regulation of the experimental conditions the method may be perfected in the future.

The collagen fibers in the corium layer of the skin are richly convoluted. Single fibers teased out of the corium under the microscope with the help of a needle show the same helical structure as the larger tendon fibers. Upon being heated to 58 degrees C. the fiber can be seen to contract, lose its helical pattern and become transparent, just as in the case of the tendon fiber.

Marcus Schaub in our laboratory has used the hydroxyproline method to study the aging of the collagen that lies between the muscle fibers; he finds that it ages in the same way as the collagen in the tendon and skin. In collaboration with H. Willenegger we have also used the method to make the interesting finding that the new collagen in the scar tissue of a healing wound is young collagen, even when the wound is in a very old individual. After it has formed, this collagen proceeds to age the way other collagen does. In the near future we expect to assay the biological age of collagen under pathological conditions, which would seem to be promising territory.

What causes the increase in the number of cross links in aging collagen? The answer to this question rests in part on the determination of what kind of cross links exist at all. A number of investigators have been attracted to work on this still unsolved problem. As for the cause, however, one may hazard the preliminary guess that the Brownian movement of the collagen molecules brings them into random contact with one another. When denatured collagen is allowed to stand in vitro, it becomes increasingly insoluble through the formation of hydrogen cross links established spontaneously in this manner. In the body, bathed with fluids containing ions and such substances as mucopolysaccharides and mucoproteins, the collagen molecules could be expected to form a variety of bonds as they are shuttled about. Over a lifetime, during which the collagen is not renewed or replaced, the molecules would tend to accumulate cross links in increasing numbers.

Since the primary hydrogen bonds that hold together the triple helix of the tropocollagen molecule melt out at 58



HYDROXYPROLINE METHOD described in the text measures age by the amount of material released by contracting and relaxing collagen. Young rat tendons (*color*) release more material (particularly hydroxyproline, a constituent of collagen) than do old ones.

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degrees C., the bonds that remain must be stronger "covalent bonds," those that tie the molecules together in fibrils and fibers. These would also include the bonds that accumulate during the lifetime of the collagen. The rubbery elasticity of the contracted fiber suggests the presence of ester bonds, which are considerably more energetic than hydrogen bonds and therefore more resistant to heat and solvents. The high strength of these bonds would account for the increase in tension observed in older collagen; that they are few in number is indicated by the ease with which the contracted fiber can be elongated.

Paul M. Gallop and his associates at the Albert Einstein College of Medicine in New York have treated collagen with reagents specific to ester bonds and arrived at the estimate that there are two such bonds per 600 amino acid units in the polypeptide chains [*see illustration on pages 106 and 107*]. By a somewhat different procedure W. Grassmann and H. Hörmann of the Max Planck Institute of Protein Chemistry in Munich have found evidence for a similar frequency of ester bonds.

The hexose (sugar) molecules necessary to the formation of such bonds might be supplied by the mucopolysaccharides contained in the ground substance of the connective tissue. In support of this possibility a number of investigators have shown that mucopolysaccharides can promote the reconstitution of collagen molecules from solutions of denatured collagen. K. Kühn of the Max Planck Institute of Biochemistry in Heidelberg has used connective-tissue extract to reconstitute collagen fibrils with normal striations from collagen that had been completely denatured by the digestive enzymes pepsin and trypsin. It is not known what active substance brings about this result; it may be an enzyme that initiates ester cross links. This has been called a true rejuvenation in vitro—the only exploit of its kind achieved so far—but since it requires the complete dissolution of the collagen, it might more aptly be termed a resurrection.

The new knowledge of collagen chemistry may open the way to discovery of substances that promote the cross-linking and thus the aging of collagen in the body. R. A. Milch of Johns Hopkins University has undertaken studies of this kind in connection with pathological metabolic disturbances associated with arthritic changes. It may therefore be possible in the future to find the means to prevent the premature aging of at least one important constituent of the tissues in the body.

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Hydroxyproline of Primary Cell Walls. Lamport, D. T. A. Federation of American Scientists for Experimental Biology, 46th Annual Meeting.

The Electron Microscope in Metallurgy. Otto, H.

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Photosynthetic Electron Transport. Kok, B., University of Minnesota.

Light Conversion in Photosynthesis. Kok, B. Wright Patterson Air Force Base.

Experimental Evidence for Cyclic and Spontaneous Migration of Cesium on Rhenium and Tungsten. Gumnick, J. L. Symposium on Thermionic Power Conversion. Colorado Springs.

Structure of the Photochemical Apparatus in Photosynthesis. Schidlovsky. Symposium on Biologistics for Space Systems. Dayton.

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Space Charge Limited Photoconductivity in Alkali Halide Crystals. Kahn, D. Conference on Space Charge in Dielectrics. Westhampton Beach, Long Island.

Experimental Studies of Cesium on Refractory Metals. Gumnick, J. L. University of Notre Dame.

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Pneumatic Guidance and Control. Frantz, W. SAE, April.

Development of Jet vanes for Solid Propellant Missiles. Ahearn, R. SAE, April.

High Temperature Materials for Solid Rocket Blast Deflectors. Locke, S., Chandler, H., Sayer, P. and Wheelahan, E. SAE, Oct.

Design and Performance of a Ground Effect Machine Using Recirculation. Martin, G. and Ortell, A. SAE, Oct.

Control Contamination With Components. Frantz, W. SAE, Oct.

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Point Target, Circular and Ellyptical Area Coverage, Boyce, R. Symposium on Effectiveness Analysis Techniques for Non-Nuclear Warheads Against Surface Targets. Dahlgren, Va., Nov.

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Electron Beam Phenomena Associated With Perforated Wall Hollow Cathode Discharges. van Paassen, H., Muly, E. and Allen, R. IRE, Oct.

Cold Hollow Cathode Discharge Welding. van Paassen, H., Muly, E. and Allen, R. IRE, Oct.

Recent Advances in Infrared Detectors for the 8.5-13.5 Micron Spectral Band. Lennard, J. IRE, Oct.

Use of Integrated Circuitry in a Digital System. Thayne, L. IRE, Oct.

Using Decision Theory Technique for Optimum Selection of Thin Film Concepts. Poisendine, D. IRE, Oct.

Optimal Bang-Bang Guidance System. Harmon, Kent and Purcell. IRE WESCON, August.

Experimental Studies of Reflected Ion Beam Recording. Bittman, L. NAECON, May.

Searching Out new Inertial Guidance Techniques. Chyba, H. NAECON, May.

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Propagation of Information-Bearing Signals Through Space. Leach, R. IRE, Oct.

Martin-Denver Auto QC. Bennett, R.A. 8th National Symposium on Reliability and Quality Control, Washington, D. C., January.

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An Approach to Environmental Control System Weight Estimation in Advanced Design. Harris, J. and Frahm, J. SAWE, May.

Some Design and Economic Considerations of Minimum Stage Launch Vehicles for Earth Orbital and Lunar Missions. Cox, R.L. IAS, Oct.

Vibration Prediction Techniques for Space Launch Vehicles. Cordos, F.M. IAS, Oct.

Basic Data for Large Booster Programs. Rosenthal. R.I. IAS, Oct.

A Discussion of the Factors Contributing to the Structural Design of 624A (Titan III). Thompson, E.D. IAS, Oct.

Human Control Performance and Tolerance Under Severe Complex Wave Form Vibration. Clark, C.C. IAS/NASA, April & May.

A New Optical Radar. Johnson, R.E., Ticen, J.E. and Sheppard, A.P. IRE, February.

Individuality in Small-Plant Reliability. Bearer, I. IRE, March.

Thermal Characteristics of Potted Electronic Modules. Gonzales, J.I. and Waugh, C.E. IRE, March.

Gimballess Inertial Reference System. Lanzkron, R., Byrne, B. and Murphy, W. IRE, March.

Test Fixture Variance and Reliability. Reynolds, L. IRE, March.

An Experimental Study of Missile Control System Parameters. Seider, J. and Williams, H. IRE, March.

A Digital Data Telemetry System for an Atomic-Powered Automatic Weather Station. Sullivan, A. IRE, March.

Vapor Jet Control of Space Vehicles. Vaeth, J. IRE, March.

The Company and Engineering Communication. Logan, S.C. IRE, Sept.

Some Electronics Problems in Infrared Systems Design. Whelan, F. IRE, Oct.

Ion Beam Formation and Control for Reflected Ion Beam Deposition. Bittman, L. and Litton, J. IRE, Oct.

Pattern Gain of Phased Arrays Using Non-Isotropic Elements. Thomas, R. IRE, Oct.

Human Factors Engineering in Electronics. Bauer, H. A. IRE SPEAKER, June.

Junk-Box Current Limiter Protects Breadboard Equipment, Ideas for Design. Boelter, D. A. ELECTRONIC DESIGN, June.

Experimental Studies of Reflected Ion Beam Recording. Bittman, L., Dr. Ire/Ias 14th Naecon, May, Dayton. Proceedings of the National Aerospace Electronics Conference, July.

Zerner, Diode Bridge Form Double-Ended Clipper. Boelter, D. A. ELECTRONIC DESIGN, Ideas for Design, March.

Transistor Voltage Regulator. Del Giorno, D. ELECTRONIC EQUIPMENT ENGINEERING, March.

P-C Boards are Precision Rubber Stamped. Duman, G. (co-author George Franz). Electronic Packaging and Production, Sept., Oct.

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Optimal Attitude Control of Space Vehicles. Foy, W. 9th Annual East Coast Conf. on Aerospace & Navigational Electronics, Oct. Proceedings of the 9th Annual East Coast Conf. on Aerospace & Navigational Electronics, Oct.

Infrared Ovens Permanently Mark Teflon Wire. Franz, G. B. ELECTRONICS, Feb.

Precision Rubber Stamps Used on Printed-Circuit Boards. Franz, G. B. PRINTING MAGAZINE, April.

AN/MSQ-45 ASW Test and Training Central. Friese, W. DIGEST, published by the Naval Aviation Engineering Service Unit, May.

Wide Band D.C. Power Amplifier. Higginbotham, J. W. SEMICONDUCTOR PRODUCTS, March.

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Interaction of Information Displays With Control System Dynamics and Course Frequency in Continuous Tracking. Obermayer, R. PERCEPTUAL AND MOTOR SKILLS, June.

The Interaction of Information Displays With Control System Dynamics in Continuous Tracking. Obermayer, R. W. JOURNAL OF APPLIED PSYCHOLOGY, Dec.

The Effects of Hypnosis on Performance on the H-T-P and MPS. Webster, R. B. JOURNAL OF CLINICAL AND EXPERIMENTAL HYPNOSIS, July.

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Simple Test Anticipates Transistor Failures in Complex Equipment. Foerster, R. P. ELECTRONIC EQUIPMENT ENGINEERING, Nov.

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Far-Field Wide-Band Distortion Patterns of Antennas. Lewinski, D. J. Proceedings of the IRE 8th National Communications Symposium, Oct.

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Use of Target Cost Program. Sauter, F. J. Proceedings of the 3rd Electronic Industries Assoc. Conf. on Value Eng.

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Radiative Heat Transfer to Hemispheric Noses. Wing, L. D. ARS JOURNAL, Jan.

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Evaluation of Space Radiation Doses Received Within a Typical Spacecraft. Beck, A. J. ARS JOURNAL, Nov.

Roll Control Problem of Finned Rocket Vehicles With Winged Payload. Decker, J. L. AEROSPACE ENGINEERING, Nov.

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Weibull Distribution Analysis, a Short Method. Ruzicka, R. K. JOURNAL OF THE ELECTRONICS DIVISION, ASQC, Nov.

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Pattern Gain of Phased Arrays Using Non-Isotropic Elements. Thomas, R. K. PROCEEDINGS OF THE NATIONAL ELECTRONICS CONFERENCE, Oct.

Design Parameters for Elliptical Toroidal Pressure Vessels. Turner, H. M. AEROSPACE ENGINEERING, Nov.

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Instability of a Vortex Sheet in Nonequilibrium Flows. Wang, Juo Chang. THE PHYSICS OF FLUIDS, Nov.

Environmental Problems With Acoustic and Vibration Measurement System Components. Peverley, R., Grabbe, A. and Nunley, J. 64th Meeting Acoustical Society of America. Seattle, Nov.

Ambient Sea Noise Directivity. Forster, C. 64th Meeting Acoustical Society of America. Seattle, Nov.

Analysis of the Sound in the First Surface Shadow Zone of a Deep Point Source by Use of the WKB Approximation. Leach, R. 64th Meeting Acoustical Society of America. Seattle, Nov.

The Electro-Acoustic Sensitivity of Pressure Equalized Spherical and Cylindrical Hydrophones. Lukman, F. 64th Meeting Acoustical Society of America. Seattle, Nov.

Deep Ocean Noise Model Determined by a Deep Line Array. Watson, J. 64th Meeting Acoustical Society of America. Seattle, Nov.

Comparison Between Observed and Theoretically Computed Values of Propagation Loss. Webb, D. and Pipkin, R. 20th U. S. Navy Symposium on Underwater Acoustics. San Diego, Nov.

Radiation Dosages From Electrons and Bremsstrahling in the Van Allen Belts. Russak, S. Symposium on Protection Against Radiation Hazards in Space. Gatlinburg, Tenn., Nov.

Research on Thin Film Triode-Electron Injection. McNeill, D. 9th National Vacuum Symposium. Los Angeles, Oct.-Nov.

Use of Target Cost Programs. Sauter, F. J. 3rd EIA Conference on Value Engineering, St. Louis, Oct.

The Structural and Heat Transfer Characteristics of Resin-Impregnated Porous Ceramics During Simulated Re-Entry Exposures. Strauss, E. American Ceramics Society Fall Meeting. Bedford, Pa., Oct.

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The Use of Measured Data for Establishing Hardware Design Criteria for Primary Ground Support Structures. Benfield, W., Cox, H. and Winter, R. 31st Symposium on Shock, Vibration and Associated Environments, Oct.

NUCLEAR POWER

Power Sources for Nuclear Space Instruments. Corliss, W. R. NUCLEONICS, Oct.

Corrosion by Liquid Metals and Aqueous Solutions. Eisenberg, P.H. Metals for Nuclear Reactors, American Society for Metals, Cleveland.

The Integration of Isotopic Power Supplies with Space Vehicles. Harvey, D. G. ASTRONAUTICS, May.

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Radioisotope Fuel Thermoelectric Generators. Kershaw, W. L. 16th Annual Power Sources Conf., N. J., Accepted. ELECTROTECHNOLOGY Magazine, July; WEEKLY SCIENCE DIARY, June.

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Mechanical Design of the MH-IA Reactor, Pickering, R., ANS Transactions, Nov.

A Nuclear Auxiliary Power Unit for Lunar Exploration. Streb, A. J. Proceedings of the International Symposium on Aerospace Nuclear Propulsion, Oct.

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Laboratory Experiments on Reactor Core Thermal and Hydraulic Transients. Norin, M. P. ANS Transactions, Nov.

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PROBLEM-SOLVING

The intelligent solution of a problem seems to involve more than trial and error. Experiments show that it often requires a fresh insight based on a sudden shift in the way the problem is viewed

by Martin Scheerer

A cat is penned in a wooden cage, the door of which can be released by a tug on a latchstring. The cat has never seen a latchstring. In an effort to get out it tries to squeeze between the bars and claws and bites at them in a random fashion until, by pure chance, it happens to claw at a loop in the string and pull. After gaining its freedom the cat is put back in the cage. Again it squeezes and claws and bites and finally happens to pull the string. On repeated trials the cat gets to the string a little sooner each time, and eventually it pulls the loop as soon as it is placed in the cage.

A hungry chimpanzee confined in a cage sees a banana outside the bars just beyond its reach. After some futile attempts to get the banana by reaching through the bars the chimpanzee discovers a stick lying on the floor of the cage. In one swift action the ape picks up the stick and with it retrieves the banana.

The cat and the chimpanzee each faced a problem and solved it in a very different way. The manner in which a cat or a chimpanzee—or a human being—solves a problem is a fundamental characteristic of the animal or person. The behavior manifested in solving a problem, moreover, provides a convenient window through which to observe mental processes. Since the turn of the century the experimental investigation of problem-solving has been a fruitful source of information on how animals and men think and learn.

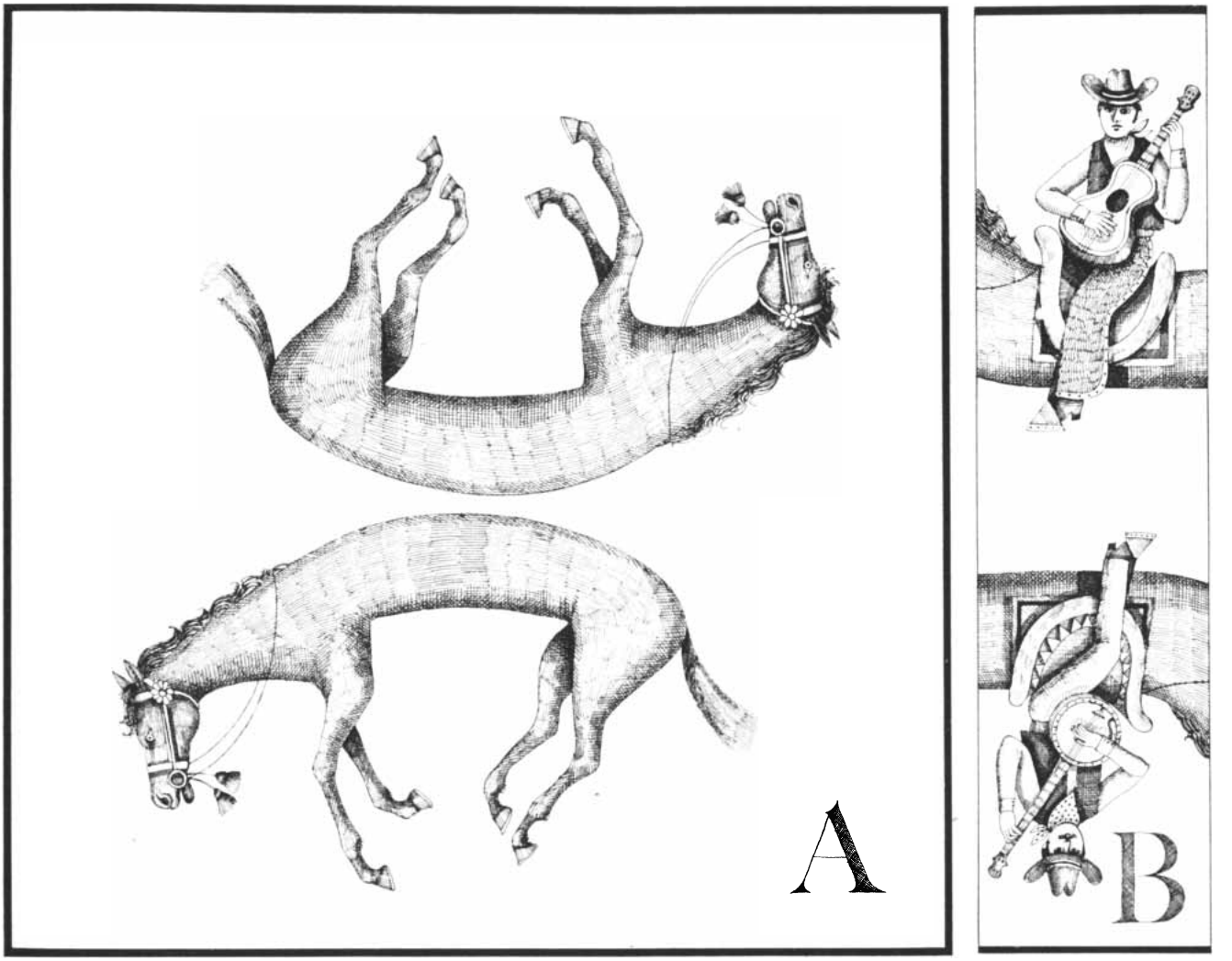
The course of this experimentation has been heavily influenced by a canon laid down by the British zoologist and comparative psychologist C. Lloyd Morgan: Never attribute behavior in an animal to a high level of thinking or knowing if the behavior can be explained in terms of lower processes; in other words, always explain behavior in terms of the simplest possible mechanism.

In 1898 the U.S. psychologist Edward Lee Thorndike undertook to apply this principle of psychological parsimony in a comprehensive study of problem-solving in the cat and other animals. Thorndike's definition of "problem" is still widely accepted: A problem exists when the goal that is sought is not directly attainable by the performance of a simple act available in the animal's repertory; the solution calls for either a novel action or a new integration of available actions. It was Thorndike who performed the cat-in-the-cage experiment described at the beginning of this article. He posed these questions: Is it necessary to assume that the cat has intelligence in the human meaning of the term? Does the solution—pulling the string—require any understanding or insight or can it be achieved quite mechanically?

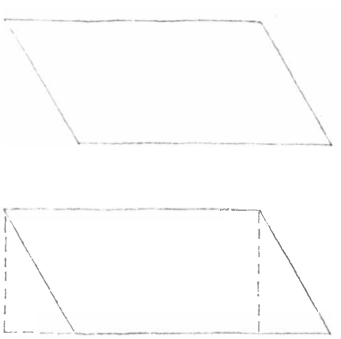
Thorndike noted that the cat pulled the string by chance and that the time it required to trip the latch declined gradually in successive trials. He concluded that the solution behavior could be explained quite simply: The string was a stimulus and the tugging was a response. The tugging was rewarded by escape. From this and similar experiments Thorndike derived his principle of learning: Whatever behavior is rewarded is "stamped in" and whatever behavior is not rewarded or is punished is "stamped out." This principle is at the heart of contemporary stimulus-response psychology, which was shaped not only by Thorndike but also by I. P. Pavlov, John B. Watson, Clark Hull and many others. In this view the tugging behavior is a learned habit, acquired through repeated "reinforcement," or reward. There is no need to assume that the cat has any understanding of why the tugging leads to escape; there is no need to assume any kind of intelligence other than a plasticity that allows the learning of new habits.

Then the Gestalt psychologists came on the scene. They emphasized the tendency of the mind to organize and integrate and to perceive situations, including problems, as total structures. They argued that more is involved in problem-solving than a sequence of stimuli and responses. One of the founders of Gestalt psychology, Wolfgang Köhler, objected specifically to Thorndike's test situations. The cat, he maintained, cannot possibly behave intelligently in the cage because the release mechanism is hidden and therefore not part of the perceived situation, and because its functioning is too complicated for an animal to unravel. Isolated on Tenerife in the Canary Islands during World War I, Köhler carried out a classic series of experiments with chimpanzees. One of his problem situations was the one involving the banana and the stick. In this case the chimpanzee's solution did not come gradually and was not the result of trial and error. It was intelligent behavior, Köhler said, based on a perception of what was required to solve the problem: some way of overcoming the distance barrier.

The insight that leads to a solution, in the Gestalt view, stems from this perception of the requirements of a problem. Max Wertheimer, another founder of Gestalt psychology, provided a good example to support this point of view. Suppose a child who already knows how to get the area of a rectangle is asked to find the formula for the area of a parallelogram. If the child thinks about it, Wertheimer said, he will be struck by the fact that a parallelogram would look like a rectangle were it not for the fact that

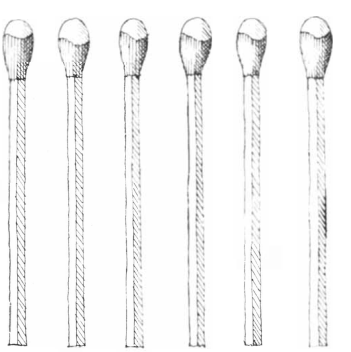


HORSE-AND-RIDER PUZZLE illustrates the power of fixation. The problem is to place drawing *B* on drawing *A* in such a way that the riders are properly astride the horses. This drawing is adapted from the original version. The correct solution is on page 126.



PARALLELOGRAM (*top*) is equal in area to a rectangle of the same base and altitude because the "protuberance" at one end is equal to the "gap" at the other (*bottom*).

NINE DOTS are arranged in a square. The problem is to connect them by drawing four continuous straight lines without lifting pencil from paper. Solution is on page 124.



SIX MATCHES must be assembled to form four congruent equilateral triangles each side of which is equal to the length of the matches. The solution appears on page 124.

one side has a "protuberance" and the other side has a "gap" [*see illustration above*]. He formulates the hypothesis: "Get rid of the protuberance and fill in the gap." Then he realizes that the protuberance is equivalent to the gap; if he moves the protruding corner to the indented side, the figure is converted into a rectangle of the same base and altitude. Hence the formula is the same as it is for a rectangle.

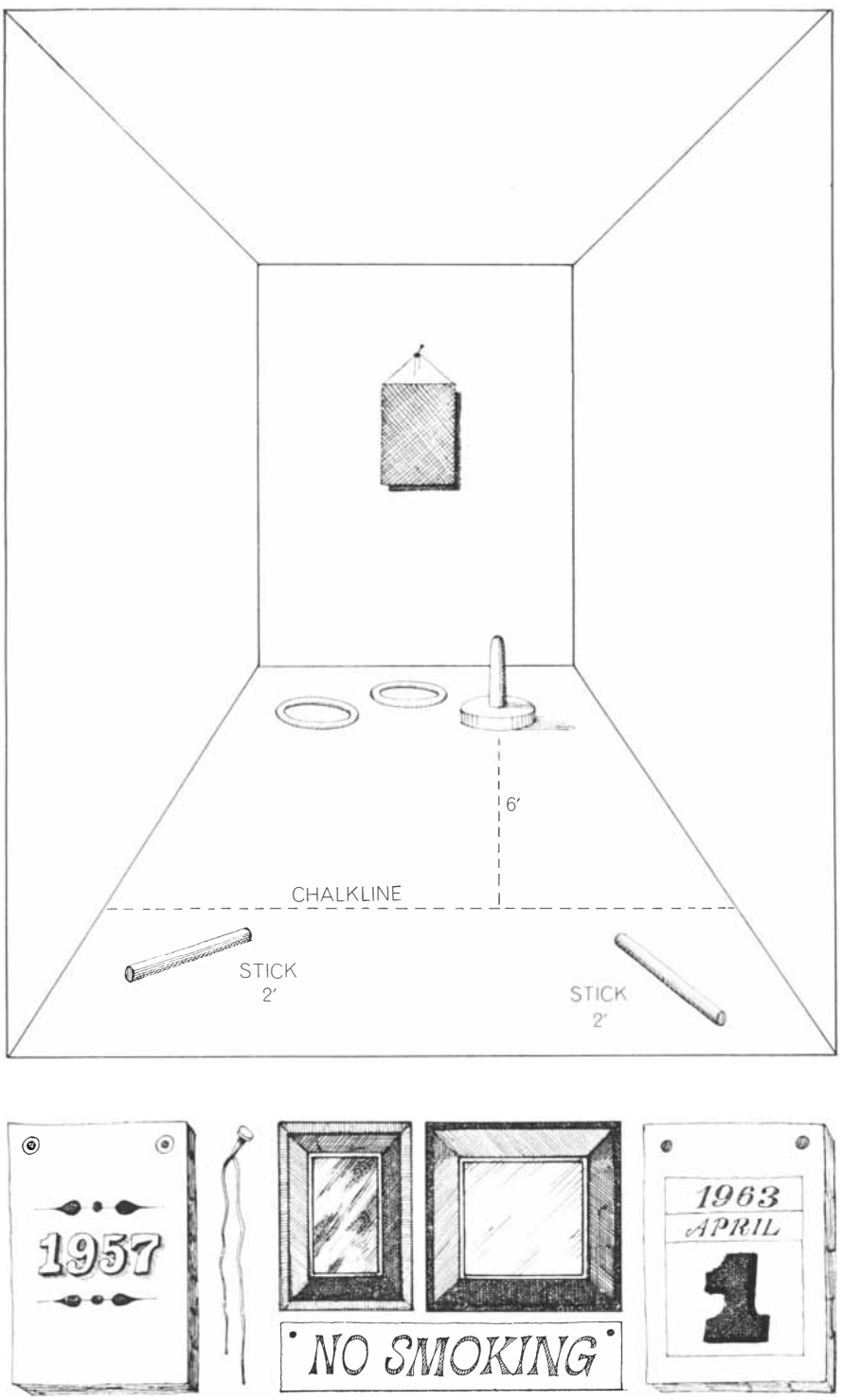
With Morgan's warning in mind one can ask at this point if it is necessary to assume that the child has done more than go through a process of trial and error and call on previously learned habits. The Gestalt answer is that although there may be trial and error it is not a blind, or random, sequence as Thorndike believed. Productive thinking is not accidental success or the mere application of bits of past experience. The problem has a structure of its own that points the way to its solution. Only within this

total framework, or context, does the problem-solver draw selectively on relevant knowledge.

This view of problem-solving has direct implications for theories of learning and teaching. It is interesting, in passing, to consider how the thought process outlined above differs from the way the formula for the area of a parallelogram is usually taught. A geometry teacher would probably give the formula $b \times a$ (base times altitude) and offer the following proof. He would extend the base line and drop perpendiculars to construct two triangles and then demonstrate that the triangles are congruent. But he would probably not have pointed out in advance the simple reason why one should want to prove the congruence of the triangles. A bright student might grasp the reason but others would never attain that insight. Fortunately, insight achieved in the solving of a problem can be explained to others, who should then have precisely the same understanding attained by the original problem-solver. This true understanding has two major advantages beyond the intrinsic pleasure of grasping something: it can be retained easily and it can be transferred to other, similar problems. Once a student understands the reason the area of a parallelogram is given by $b \times a$, he can figure out how to get the area of a triangle or a trapezoid.

Wertheimer and Karl Duncker, who was then at the University of Berlin, explored the nature of the process by which people gain or fail to gain insight into problems. They found that although men have the capacity for genuine insight and often attain it, not everyone gains insight into a problem in the same way or at the same stage—or ever. Insight is often delayed or thwarted by "fixation" on an inappropriate solution. If the chimpanzee fails to realize that it simply cannot get the banana without a tool and keeps reaching through the bars, it will not notice the stick; the fixation stands in the way of a correct solution.

The author's own work in problem-solving has been centered on this phenomenon of fixation. He found that it operates in many ways. Sometimes a person clings misguidedly to a false premise or assumption concerning the task before him. Consider two simple problems that are made difficult by this fixation [*see lower illustrations on preceding page*]. The first requires that nine dots be connected by four straight lines drawn without lifting the pencil from the paper. This cannot be done unless one extends the lines beyond the dots [*see illustration at bottom left on page 124*]. But almost everyone assumes—although it is not stated as a condition of the problem—that he must stay within the group of dots. The second problem, assembling six matches of equal length to form four equilateral triangles with sides equal to the length of the matches, cannot be solved as long as one assumes that the matches must lie in one plane, and virtually everyone who tries it assumes just that. The assumption is implicit; most people do not even know they have made it. The way to the correct solution —an equilateral tetrahedron, or pyramid

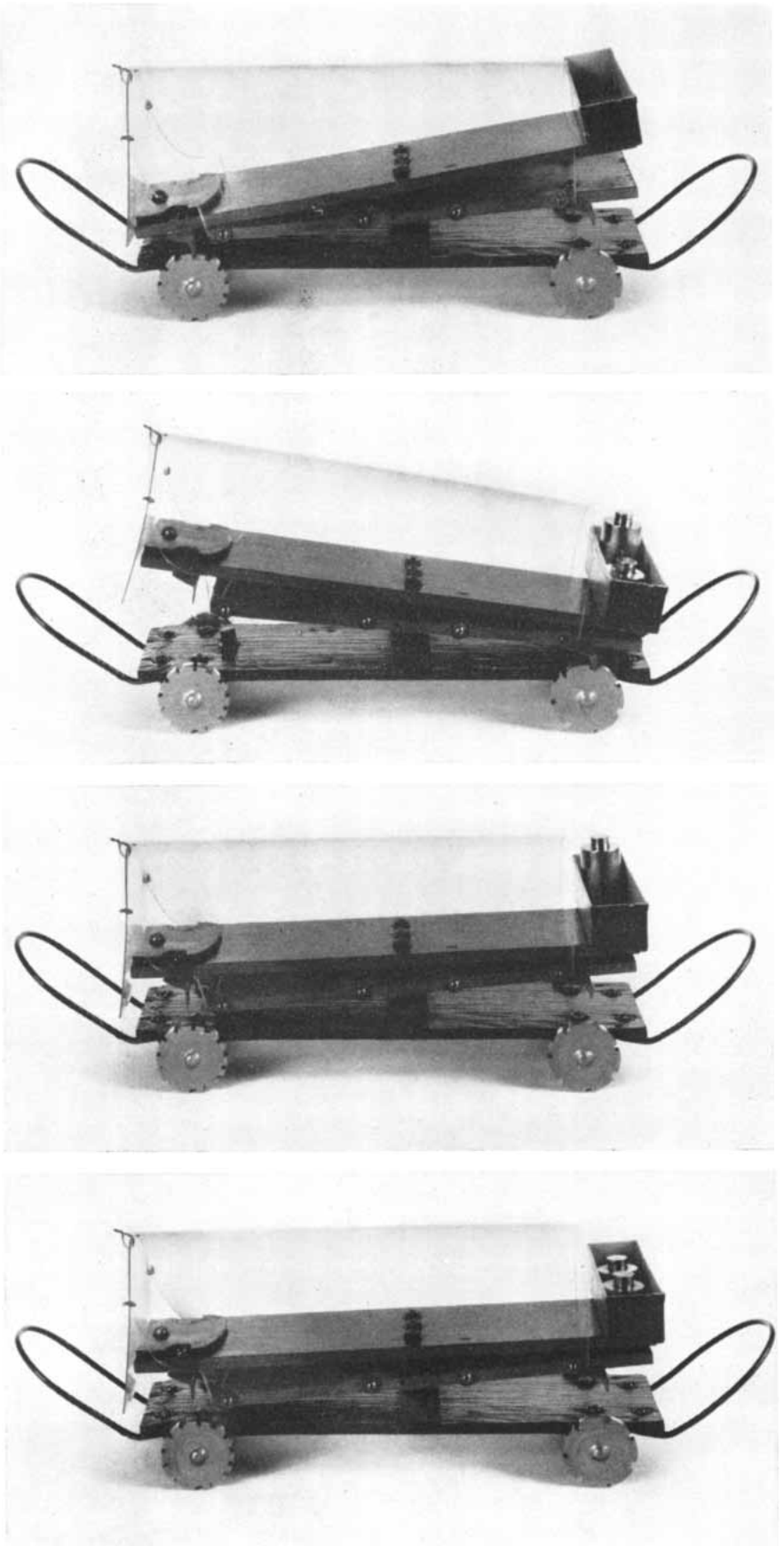


RING-AND-PEG PROBLEM could be solved with a piece of string with which to tie the two sticks together. The only string in the room hung on a nail on the wall. When it hung there alone, every subject solved the problem. When it was used to suspend a cardboard, an old calendar or a cloudy mirror, some people failed. When the string was a hanger for functional things such as a sign, a clear mirror or a current calendar, more than half failed.

—is opened as soon as one realizes that the matches need not lie flat. This shift from one premise to a new one is what Gestalt psychologists call a "reformulation," or "recentering," of one's thoughts.

The power of fixation and recentering is illustrated by a problem the author developed in collaboration with the neuropsychiatrist Kurt Goldstein and Edwin G. Boring of Harvard University. The puzzle, which the author first came upon in an advertisement, involves a drawing of two misshapen horses and a drawing of two riders [*see upper illustration on page 119*]. The problem is to place the drawing of the riders (*B*) on the other drawing (*A*) in such a way that the riders are properly astride the horses. (The reader can try this himself by tracing the two drawings on two strips of paper.) The overwhelming tendency is to try to place each rider on one of the horses drawn in *A*. It is quite clear that this will not work (the horses are back-to-back in *A* and belly-to-belly in *B*, and the space between the horses is much less than the distance between the two riders) but most people keep trying. The correct solution requires a complete recentering of one's perception of the elements of the puzzle. The two horses in *A* must be broken into parts, so to speak, after which the head and the hindquarters of one combine respectively with the hindquarters and the head of the other to form two new horses. Then, when one of the strips is turned 90 degrees with respect to the other, the riders fit nicely on the newly created horses [*see illustration on page 126*]. In this case a solution is inhibited by a fixation that arises from the perceptual make-up of the puzzle. Another puzzle presents a similar problem with more abstract shapes [*see top illustration on page 124*].

Duncker discovered that fixation often interferes when the solution of a test problem requires the use of a familiar object in a novel way. Suppose someone needs a screw driver and one is not available. He could make do with any thin and sufficiently hard object—a coin, for example. But to see this possibility he must shift from his usual idea of "coin as money" to the new functional concept of "coin as screw driver," and this is a difficult kind of shift for many people to make. (Substitution of a coin, to be sure, seems rather obvious because it is a familiar expedient, but a person who thinks of it independently should be credited with a truly creative insight.) Duncker found that it was particularly hard for a person to think of an object as adaptable for a novel



WAGON AND WEIGHTS were used in the author's analogue of the river-crossing problem. The wagon was constructed on a double-seesaw principle. Flanges at the ends locked the front wheels if no weight was placed in the container (*top*) and the rear wheels if too much weight was loaded (*second from top*). The wheels turned and the wagon rolled only when either one large weight or one or two small ones were loaded (*two lower pictures*).

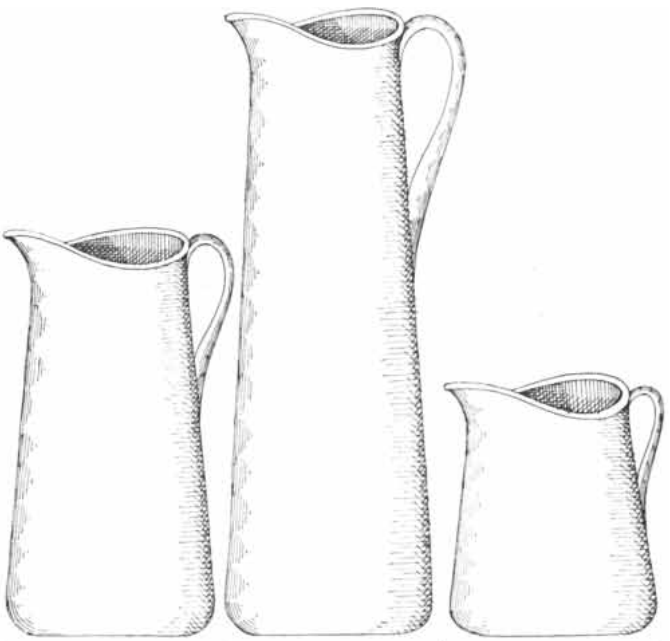
function if he had just put it to its conventional use. In one experiment the task was to suspend a piece of string from a wooden ledge. The subject had no hooks but he did have a gimlet; the solution was to screw the gimlet into the wood, leave it there and hang the string on it. Subjects given a preliminary task in which they employed the gimlet to make holes were less likely than others to think of using it as a peg.

The author sought to extend Duncker's investigation of "functional fixedness" in a series of experiments conducted with Maurice Huling of the University of Kansas. The problem, originally developed with Zelda S. Klapper and Herman Witkin of the State University of New York College of Medicine in Brooklyn, required the subject to put two rings on a peg from a position six feet from the rings and the peg. He could not do it without a tool to extend his reach. Except when he was picking up the rings and putting them on the peg, he was allowed to move about the room, and he could use anything he saw. There were two sticks in the room, but neither was long enough to bridge the gap alone; they had to be joined together. The only piece of string in the room was one by which an object hung from a nail on the wall [*see illustration on page 120*]. This string was in clear view but it was embedded in a meaningful context. It was predicted that it might not be seen as an available piece of string; although not hidden perceptually, it would prove to be psychologically inaccessible for anything but its present function.

At first 16 volunteers were given the problem with a piece of string hanging alone on the nail. All of them took down the string, tied the sticks together and with them placed the rings on the peg. The experimental series was then begun with the string holding things that had no real function: a piece of blank cardboard, an old calendar and a cloudy mirror. It was predicted that the string would still be psychologically available, and virtually everyone tested in these situations did indeed solve the problem. In the next phase the objects hung on the wall had definite functions: a current calendar, a clear mirror and a "No Smoking" sign. These could be expected to have a "stay put" quality. Fifty-six per cent of the subjects failed with the current calendar, 69 per cent with the intact mirror and 53 per cent with the "No Smoking" sign.

In each case the string had been tied with a square knot, which was placed in plain sight above the nail and looked eminently untieable. The subjects who failed to take down the string did not think they were forbidden to make use of it; they simply did not think to do so, as could be ascertained from their comments (they had been encouraged to think aloud) and follow-up interviews. Moreover, almost everyone decided quickly that he needed a string. This means that in this phase of the experiment more than half of the individuals sought a string for nearly the entire 20-minute test period but did not think of using for their purpose a string that was one of the most prominent things in their field of view.

In one situation the subject himself was asked to hang the object on the wall. While he was occupied with some unrelated written problems the departmental secretary came into the room, apologized for intruding and left a mirror on the table, explaining that mirrors were being put in all the laboratory cubicles "for an experiment next week." The experimenter said casually: "I suppose this should be hung up. Would you do



PROBLEM	*a*	*b*	*c*	GOAL
1	21	127	3	**100**
2	14	46	5	**22**
3	18	43	10	**5**
4	7	42	6	**23**
5	20	57	4	**29**
6	23	49	3	**20**
7	15	39	3	**18**

FIXATION because of habit is illustrated by this series of problems. In each a quantity of water (*right*) must be measured out; there is an unlimited supply of water but the only tools available are three pitchers, *a*, *b* and *c*, the volumes of which are specified for each problem. Once the subject hits on a successful pattern of filling and pouring ($b - a - 2c$) he tends to follow that pattern even when, in Problems 6 and 7, there is an easier solution.

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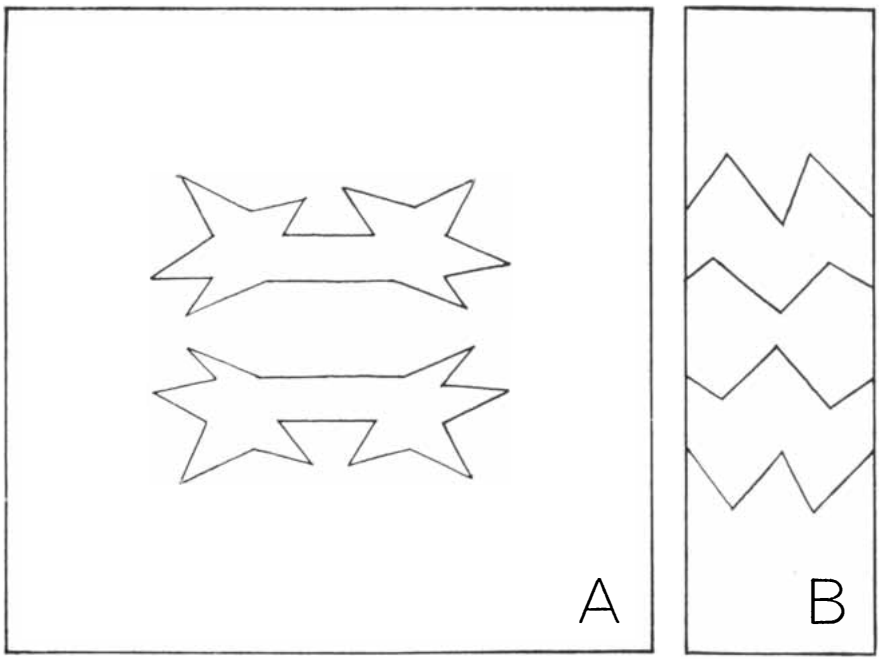


PERCEPTUAL FIXATION demonstrated by the horse-and-rider puzzle operates also with these abstract shapes. The problem here is to place element *B* on element *A* in such a way that two closed figures are formed. The solution to this problem appears on page 128.

it for me?" The subject hung the mirror on the nail (the only one in the room) and went back to his paper work. Fifteen minutes later he was given the ring-and-peg problem. In spite of the direct experience with the piece of string, the failure rate in this situation was 50 per cent.

The results were quite different when the string was handled ahead of time but was handled as "string." In what was called a "test of manual dexterity" we had a group of volunteers hang up the old calendar, the cardboard or the clear mirror using tweezers to tie the string. The object was left on the wall. When these subjects undertook the ring-and-peg problem after a 15-minute interval, only one out of 36 failed. Apparently even a functional mirror, if hung on the wall in the course of a "dexterity test," did not later take on the coloration of something that belonged on the wall. Instead the mirror and the string were perceived as two things left on the wall after fulfilling a specific but transient purpose. The string remained a string, not just a means of hanging things.

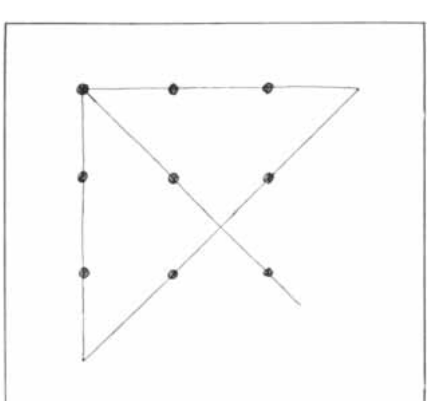
The follow-up interviews with people who had failed showed how persistent a fixation can be. The experimenter began by pointing in the general direction of the object on the wall and asking: "What about that?" The hint was enough for only five out of 47 people. When the experimenter then asked, "What about that mirror [or calendar and so on]?" only four more saw the solution. Many of the others responded: "What about it?" Still others suggested making the sign or mirror into a shovel-like tool with one of the sticks, wrapping the sticks in the sign or somehow employing the screw eyes in the back of the mirror. When the experimenter finally asked directly, "What about the string?" all 38 of the remaining subjects expressed surprise, chagrin and self-reproach as they admitted this was indeed a solution.

Fixation had been reported to be a function of involvement in a situation. To see if an increase in "psychological distance" would help to overcome it, some observers were allowed to watch as a "subject" ran through the motions of trying to solve the problem. The subject was excused when he reached the point of verbalizing the need for something with which to fasten the two sticks together. The observers were then asked to work out the problem in their minds. Only one out of seven of these observers failed, compared with the more than half of the deeply involved subjects who had tried to solve the same problem in action.

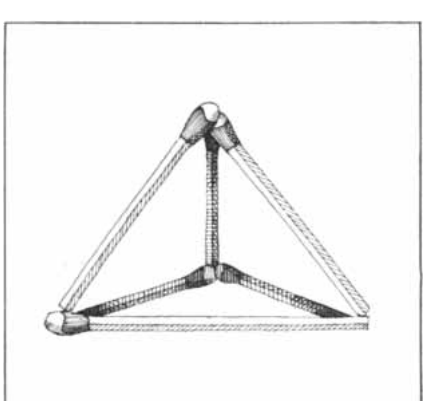
One of the difficulties in the study of problem-solving is that the experimenter can never be sure just what is going on in the subject's mind. He can ask after the experiment is over, but the subject may forget details or may reconstruct his thought processes incorrectly. Even when the person being tested thinks aloud in the course of the solution, he may not mention everything that occurs to him. It is desirable, therefore, to construct a problem that invites and encourages a running translation of thought into visible action. James M. Elliott and the author worked out such a situation in another experiment at the University of Kansas.

The problem chosen was essentially the familiar one of the river crossing. Eight soldiers have to cross a river. The only means of transportation is a small boat in which two little boys are playing; the boat can carry at most two boys or one soldier. How do the soldiers get across? If the reader will try to solve this problem before reading on, he will understand the difficulties our subjects faced.

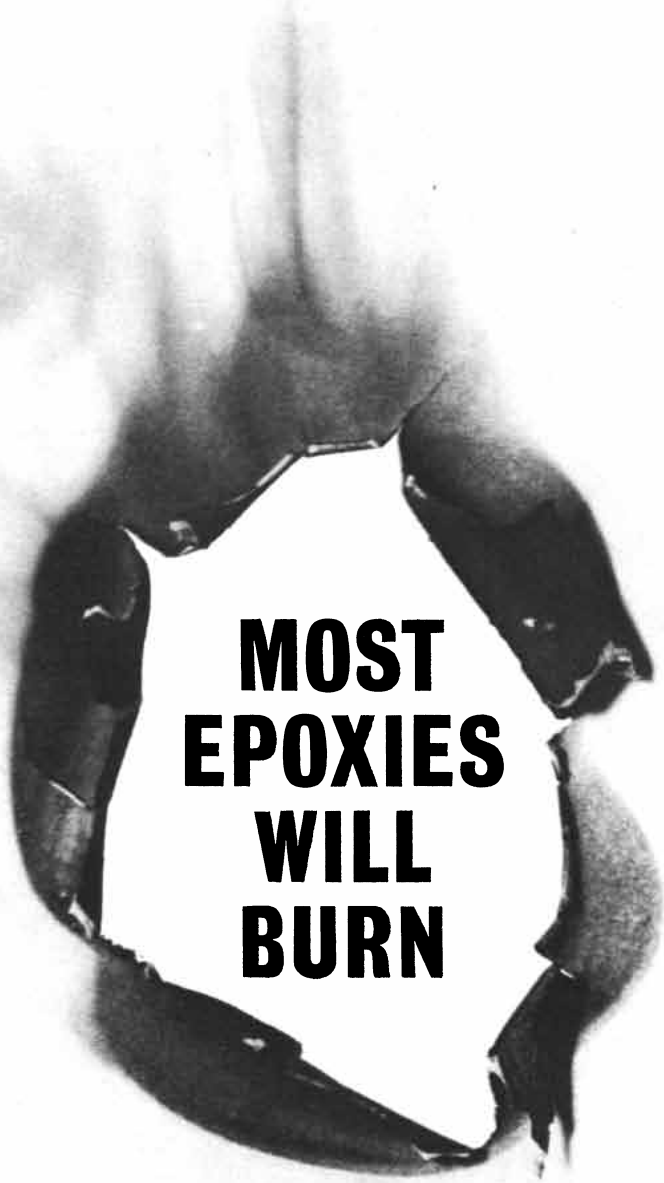
The river puzzle was converted into one involving physical objects and requiring a sequence of discrete moves on the part of the person attempting it. A crude wagon was substituted for the boat, and eight large weights and two small ones for the soldiers and the boys



DOT PROBLEM is solved by extending the lines beyond the dots. But most people assume incorrectly that they may not do this.



MATCH PROBLEM is solved by building a three-dimensional pyramid. Most people wrongly assume that matches must lie flat.



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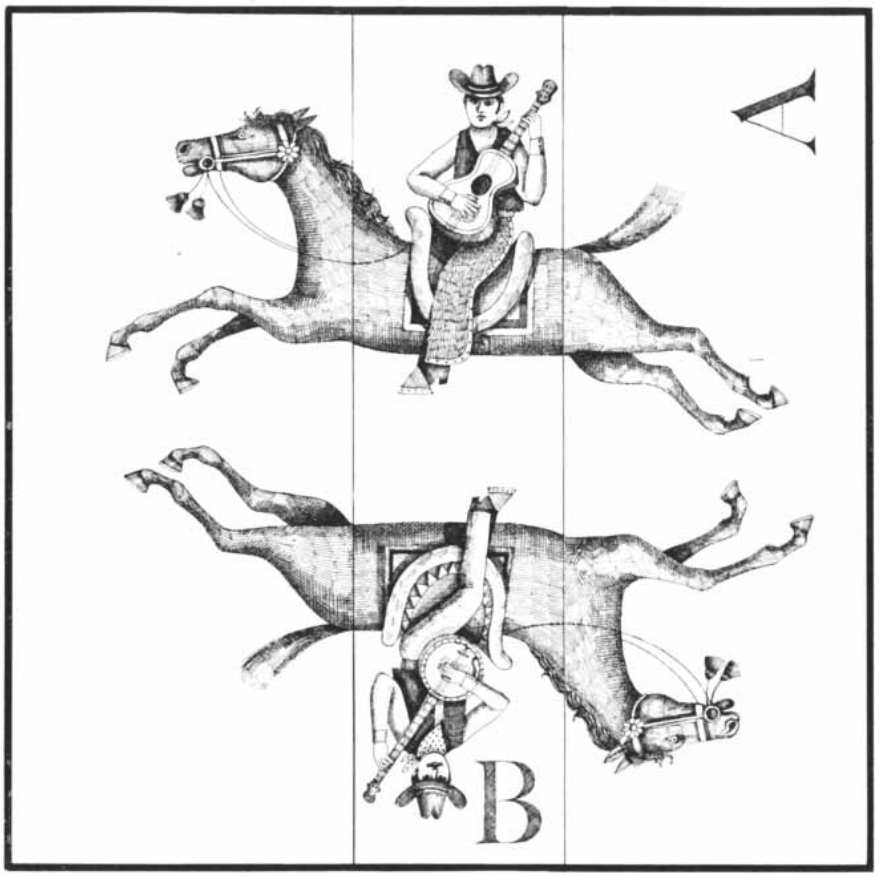

SOLUTION of the horse-and-rider puzzle requires a "recentering." The horses cannot be used as they are drawn in *A* but must be abstracted into their component parts and recombined into two new horses. Then, if drawing *A* is rotated 90 degrees, the riders fit properly.

[*see illustration on page 121*]. The wagon wheels locked if no weights were placed in it and also if more than one large weight or two small ones were loaded. Each subject was told that his task was to transport all the weights in the wagon from one side of a table ("Lawrence") to the other side ("Topeka"), that the wheels must roll freely, that he could make as many trips as he wished and that there were no hidden tricks or gadgets on the wagon—that its rolling was a function of the amount of weight in it.

The solution consists in realizing that a precondition for getting the large weights across is to have one small weight on each side. The way to achieve this is to begin by taking both small weights across to Topeka. After one of them has returned the wagon to Lawrence the first large one can make the trip to Topeka. Then the small weight originally left in Topeka serves its purpose, getting the wagon back to Lawrence. Now the entire cycle must be repeated, and so on until all the weights are across.

Two experiments were performed. In the first the problem was simply given to 49 individuals. In the second the subjects were divided into groups and interrupted at certain points in order to know what they were thinking or planning. In both cases the participants were asked to think aloud and were observed as their thoughts took the form of concrete behavior, recording each loading of a weight and each abortive or successful movement of the wagon.

No two individuals proceeded in exactly the same way but there were some striking similarities in the behavior of the volunteers. They began by exploring the various weight loadings that would allow the wagon to roll. They soon discovered that it would carry either one large weight or one or two small ones. After this discovery most of them formulated a hypothesis: "Take one weight over at a time, thus transporting them all in repeated trips." This hypothesis led 40 of the 49 into the error of promptly loading one large weight and taking it to Topeka—only to realize when they got there that it was impossible to get the wagon back without taking the weight back again.

Once they realized it did no good to start by transporting a large weight alone, most of the subjects decided: "Take at least two weights over in order to return the wagon with one." This "rider" hypothesis, combined with the knowledge that the wagon would not roll with too much weight, usually led to the idea of transporting one large and one small weight—a combination that accounted for 52 per cent of the trial loadings at this stage. Virtually all the subjects who made that attempt said they intended to get the wagon back from Topeka with the small weight—that it seemed the best "rider" for the purpose. And although the wagon would clearly not roll with a large and small weight aboard, they returned again and again to that combination. For 30 of the subjects who persevered at it, the mean number of repetitions was 6.1. Many of them tried to rationalize the fixation as an attempt to find some special way of placing the weights so that the wagon would roll.

The reason for the fixation is fairly clear. These subjects had decided that they needed to carry a rider, and that the small weight was a logical one because it was less of an extra load than a second large weight. Even the few subjects who considered taking the two small weights across together saw one as a rider for the other only on a preliminary trip; thereafter, they thought, it would be a rider for a large one—so they might as well face the small-plus-large problem at the outset. Some went so far as to load the two small weights and still failed to see that it was the essence of the solution. All of these subjects were fixating on what appeared to them to be the goal: transporting the large weights to Topeka. For them the small weights had lost the quality of weights to be transported and were seen as riders only. It was therefore a detour from the major goal to transport two small weights first to Topeka merely in order to leave one there. The solution required them to shift to the perception of both small weights as tools to be taken across on a preliminary trip.

When individuals loading a large and a small weight were interrupted and asked, as the experimenter pointed to the other small weight, "What about this one? Have you ever thought of using them together?" a few were able to solve the problem. But most of them said something like: "It looks the same... I could take these two [small ones] over, but after one trip I couldn't do any more... I'd still be faced with the problem of getting the large ones over."

Even as they finally hit on the correct

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first step of transporting the two small weights, many subjects failed to see the point. Some got back to Lawrence with a small weight and then tried once again to load a large and a small weight together. Even more of them got safely through the next steps of sending over one large weight and returning the waiting small one but failed to see that they had to start all over again at that point with the two small weights. In other words, they had not yet attained the second major insight: the cyclical nature of the solution.

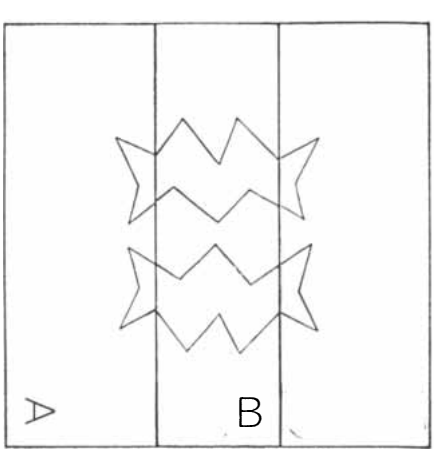
Eventually all the subjects did solve the problem and all but two of them understood the solution. On questioning later, 36 per cent of them expressed the underlying principle in spatial terms: "You need a small one on each side at all times." Another 41 per cent expressed it in temporal terms, reciting the required sequence of events in the cycle. The remaining 23 per cent were unable to verbalize the principle clearly.

The various problems discussed here illustrate several causes of fixation in problem-solving. A person may start with an implicit but incorrect premise. He may fail to perceive an object's suitability for a solution because it must be used in a novel way or because it is embedded in a conventional context. Or he may be unwilling to accept a detour that delays the achievement of his goal. Any type of fixation can be strengthened by too much motivation. Herbert D. Birch, now at the Albert Einstein College of Medicine, found that if a chimpanzee is too hungry it will not do as well at a problem requiring a detour—the Köhler banana problem, for example—as an animal that is only moderately hungry. The overly hungry chimpanzee fixates rigidly on the goal, striving to no avail to reach the banana. On the human level there is some evidence that strong ego-involvement in a problem makes for overmotivation and is detrimental to a solution.

One final factor affecting fixation is habituation. There is truth to William James's statement that habit is the "flywheel of society," but one might add that habit can also be the flypaper of society. The direct availability of a habitual mode of response may make it much harder to break with habit and approach a problem afresh. This effect was beautifully illustrated some years ago by Abraham S. Luchins, who was then associated with Wertheimer at the New School for Social Research. The subject is asked to measure out mentally a given quantity of water; the tools available to him are three pitchers of specified sizes [*see illustration on page 122*]. Take the first problem: With three pitchers that hold three, 21 and 127 quarts, and with an unlimited supply of water, measure out 100 quarts. The solution is to fill the 127-quart vessel (b), pour off enough to fill the 21-quart pitcher (a) and then enough to fill the three-quart pitcher (c) twice. This leaves the desired 100 quarts in the big pitcher (b). The reader is invited to do the whole series.

Most people solve Problem 6 by pouring water from the filled 49-quart vessel into the 23-quart vessel and then twice into the three-quart pitcher, and they follow the same routine in Problem 7. But both problems have much simpler solutions. Problem 6 can be solved by filling a and pouring from it into c once; Problem 7 can be solved by filling a and c and pouring them into an empty b. But because Problems 1 through 5 all call for the $b - a - 2c$ solution the subject becomes habituated to it, consciously or not, and holds to the same pattern even when it is inappropriate. This fixation is exploited in the traditional childhood game in which one child is called on to pronounce as the other spells out: "MAC DONALD...MAC HENRY...MAC MAHON...MAC HINERY." The victim is trapped into pronouncing the last "name" as "Mac Hinery" instead of "machinery."

If insight is the essential element in intelligent problem-solving, fixation is its archenemy. Fixation is overcome and insight attained by a sudden shift in the way the problem or the objects involved in it are viewed. The work described in this article has pointed to some of the factors that necessitate this sudden shift, but precisely what brings it about is still unknown. It remains the central problem of problem-solving.



RECENTERING also solves this problem. The abstract shapes of *A* are broken up and rotated 90 degrees. *B* then fits properly.

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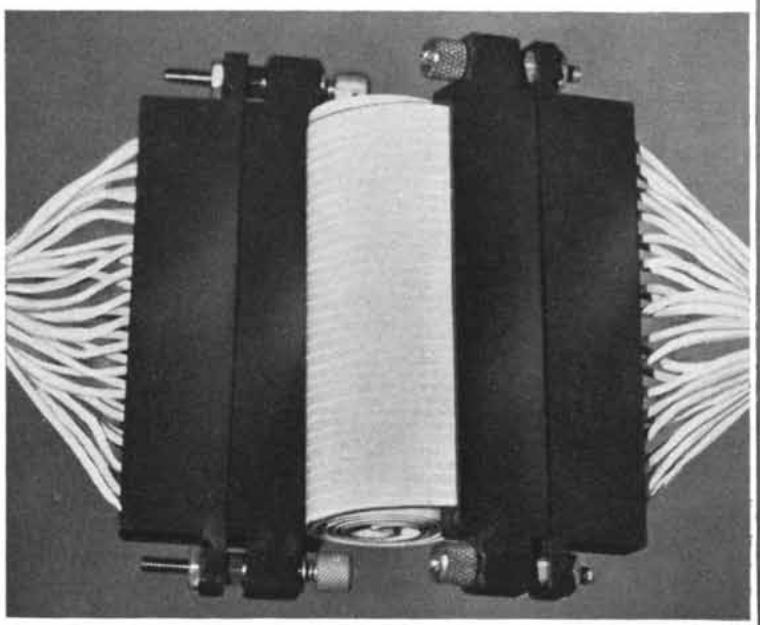

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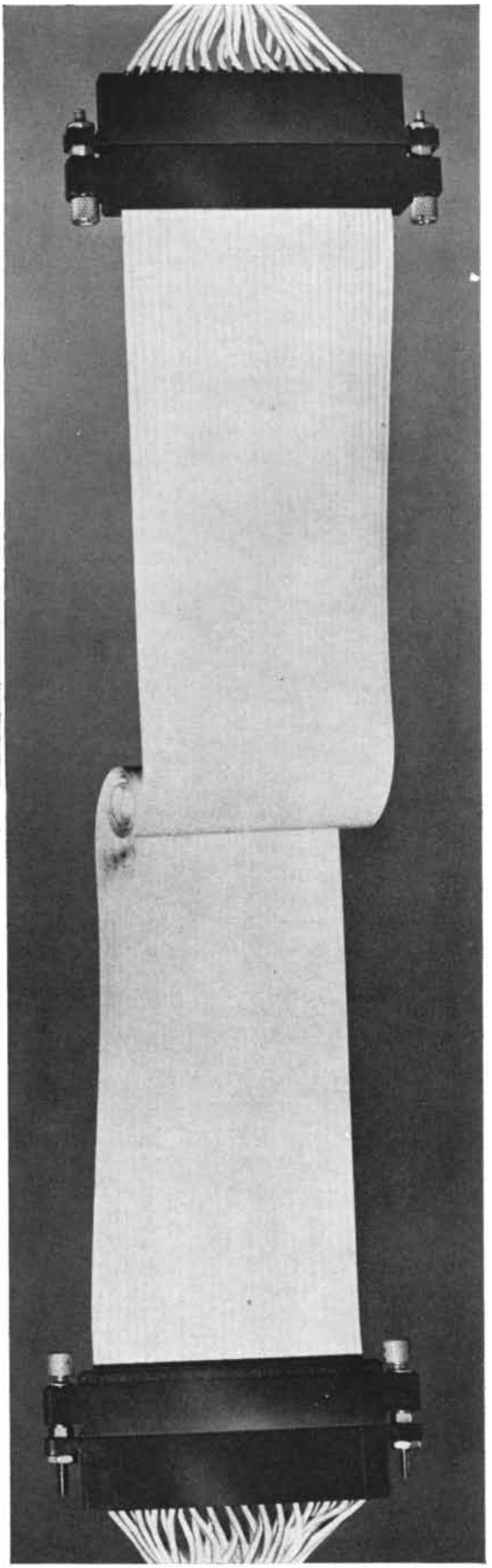

Rack-and-Panel Connector partially extended

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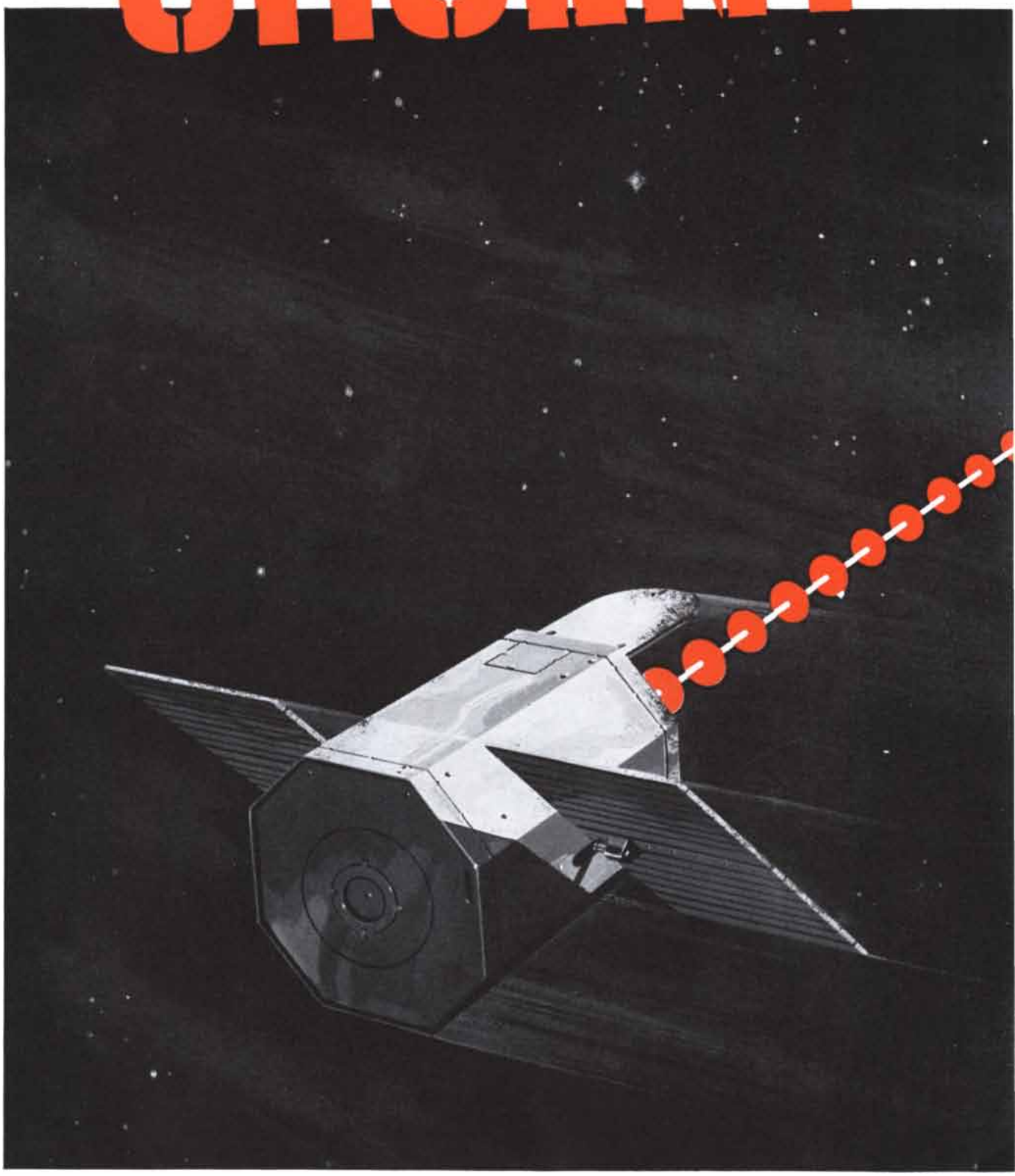

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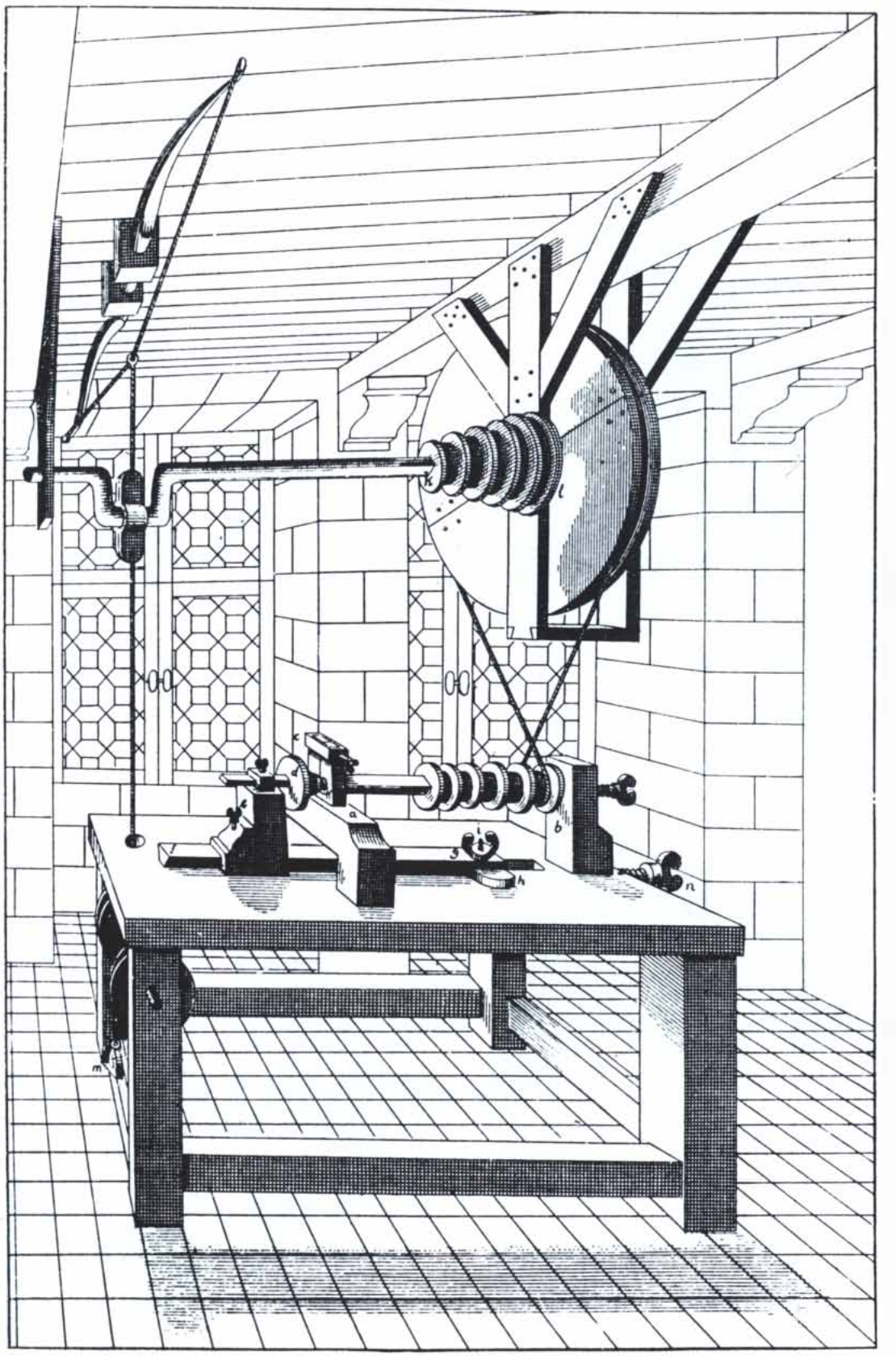


LATHE OF 1671 was remarkably advanced for its time. The bow drive was powered by an apprentice who placed his foot in a stirrup (*m*) and pumped. The crankshaft was turned by the combined action of foot and bow. A large flywheel kept the piece turning smoothly. The lathe, described by Cherubin d'Orleans, used pulleys of various sizes to provide various speeds of revolution.

The Origins of the Lathe

The importance of the iron-cutting lathe to the Industrial Revolution is rarely appreciated. A number of ingenious lathe mechanisms can be traced back to the Middle Ages

by Robert S. Woodbury

Machine tools lie at the heart of industrial production, and the acknowledged queen of machine tools is the lathe. Yet because the lathe originated in antiquity and has no single inventor it receives short shrift in most histories, which often describe the Industrial Revolution as if it had been evoked solely by the steam engine, the power loom and the cotton gin. Without major developments in the lathe between 1750 and 1830 the Industrial Revolution could not have taken place.

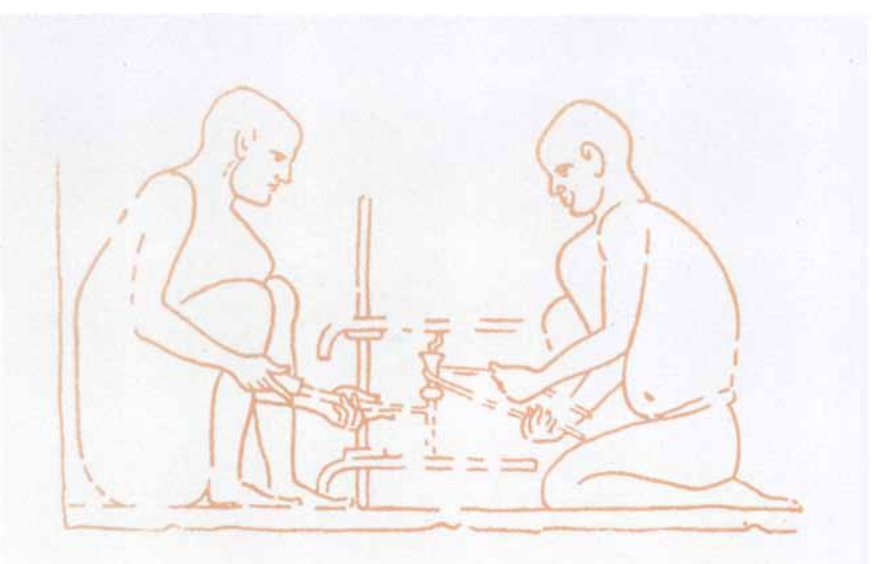
Nor were these developments anonymous. Until 1750 the lathe was used primarily for working in wood and pewter and for turning the brass components of clocks and instruments. By 1830 it had been transformed into a powerful factory tool capable of shaping iron and steel machine parts in industrial sizes and quantities. The man who stood at the center of this transformation was Henry Maudslay, an Englishman whose work climaxed a long history of development going back many centuries.

From various artifacts found in archaeological sites it can be inferred that the lathe was invented nearly 3,000 years ago. The history of invention strongly suggests that such an inspiration rarely depends on a solitary genius, and the idea of the lathe probably arose independently in several minds. By the fifth century B.C. the lathe was known to the Etruscans in Italy, to the Celts in England and to the inhabitants of the Crimean Peninsula. Three hundred years later turned products of wood and other material were to be found throughout the ancient world.

The earliest known picture of a lathe is one carved in low relief on the wall of an Egyptian grave of the third century B.C. [*see illustration at right*]. It shows the article to be shaped—the workpiece—being rotated between two fixed members, which would now be called the headstock and tailstock. (Although the workpiece appears to be held vertically, it was an Egyptian pictorial convention to rotate horizontal objects into the vertical plane for clarity.) The workpiece is being turned by a cord or thong wrapped around it, which an assistant is pulling back and forth. The skilled artisan is holding a cutting tool against the workpiece.

Somewhat later pictures show that the simple hand-held cord was often replaced by a cord stretched in a bow. The bow cord made a loop around the workpiece or around a spindle attached to the workpiece. The work was rotated by pulling the bow back and forth. The great advantage of the bow over the simple cord was that it allowed a man to work alone, using one hand to pull the bow and the other to hold the tool. The drawback of both methods was that the workpiece rotated first in one direction and then in the other, requiring that tool pressure be co-ordinated with the power stroke of the cord or bow.

The next major advance, which did not come until the Middle Ages, was the introduction of the spring-pole-and-treadle drive [*see illustration at top left on page 136*]. In this method a flexible pole was mounted above the lathe and a cord ran from the pole, around the lathe spindle and to a foot treadle. Sometimes a heavy bow replaced the flexible pole. In either case the workpiece rotated back and forth as the workman stepped on the treadle and released it. The treadle drive, which was in use by

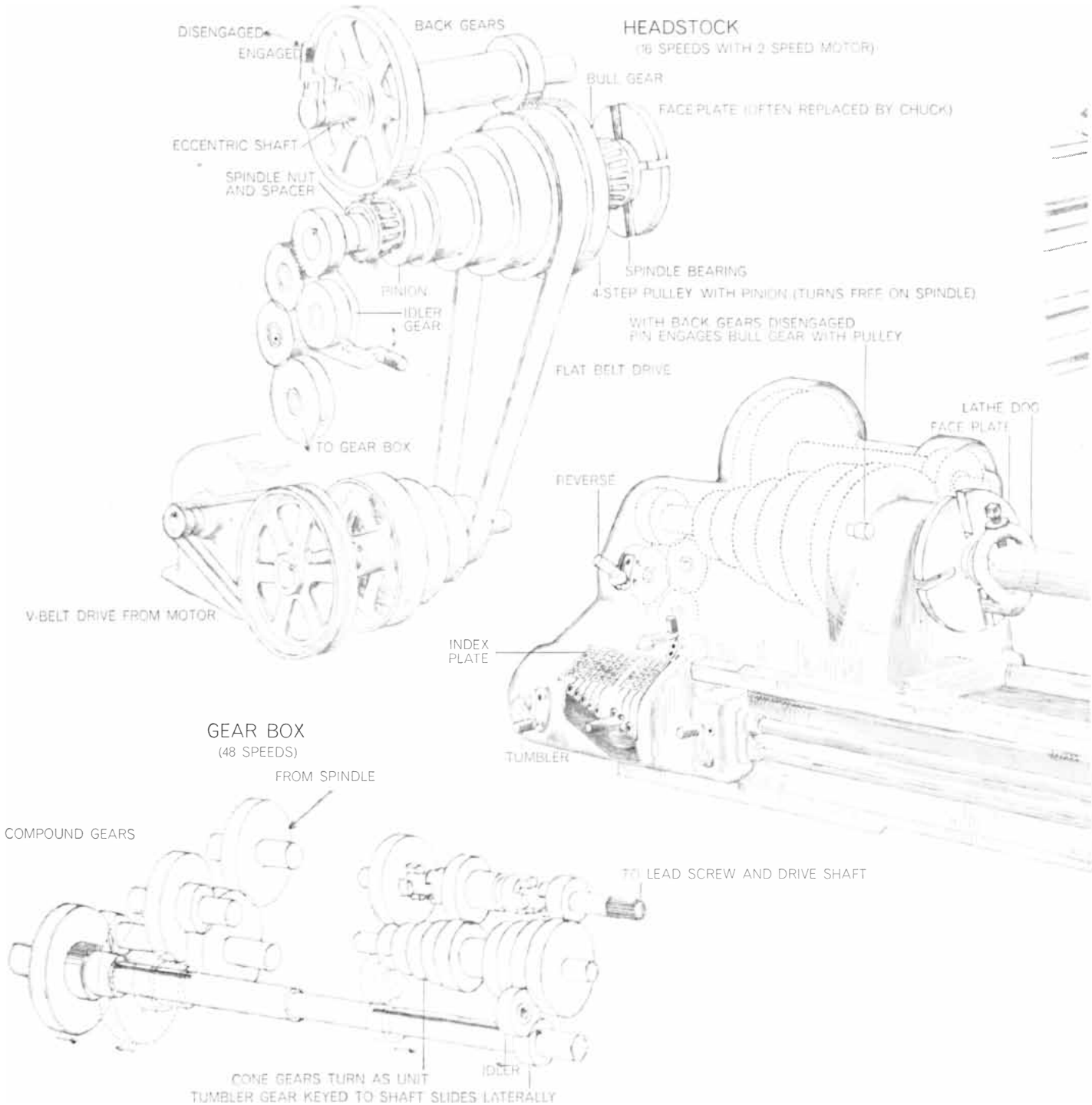


EARLIEST PICTURE OF A LATHE is one on the wall of an Egyptian grave of the third century B.C., shown here in a line drawing. The man at left is holding the cutting tool. The man at the right is making the workpiece rotate back and forth by pulling on a cord or thong.

A.D. 1400, gave the workman use of both hands for holding the cutting tool.

The bothersome back-and-forth rotation of the spindle became a serious problem when the lathe was used to turn heavy wooden pieces or nonferrous metals. The workman had all he could do to guide his cutting tool accurately without trying to generate the required foot power and co-ordinate the tool position at the same time. This problem was solved by adopting a continuous pulley drive, which again called for the help of an apprentice [*see illustration at top right on page 136*]. Old woodcuts and drawings show that many lathes were turned by hand in this way until 1800 and even later.

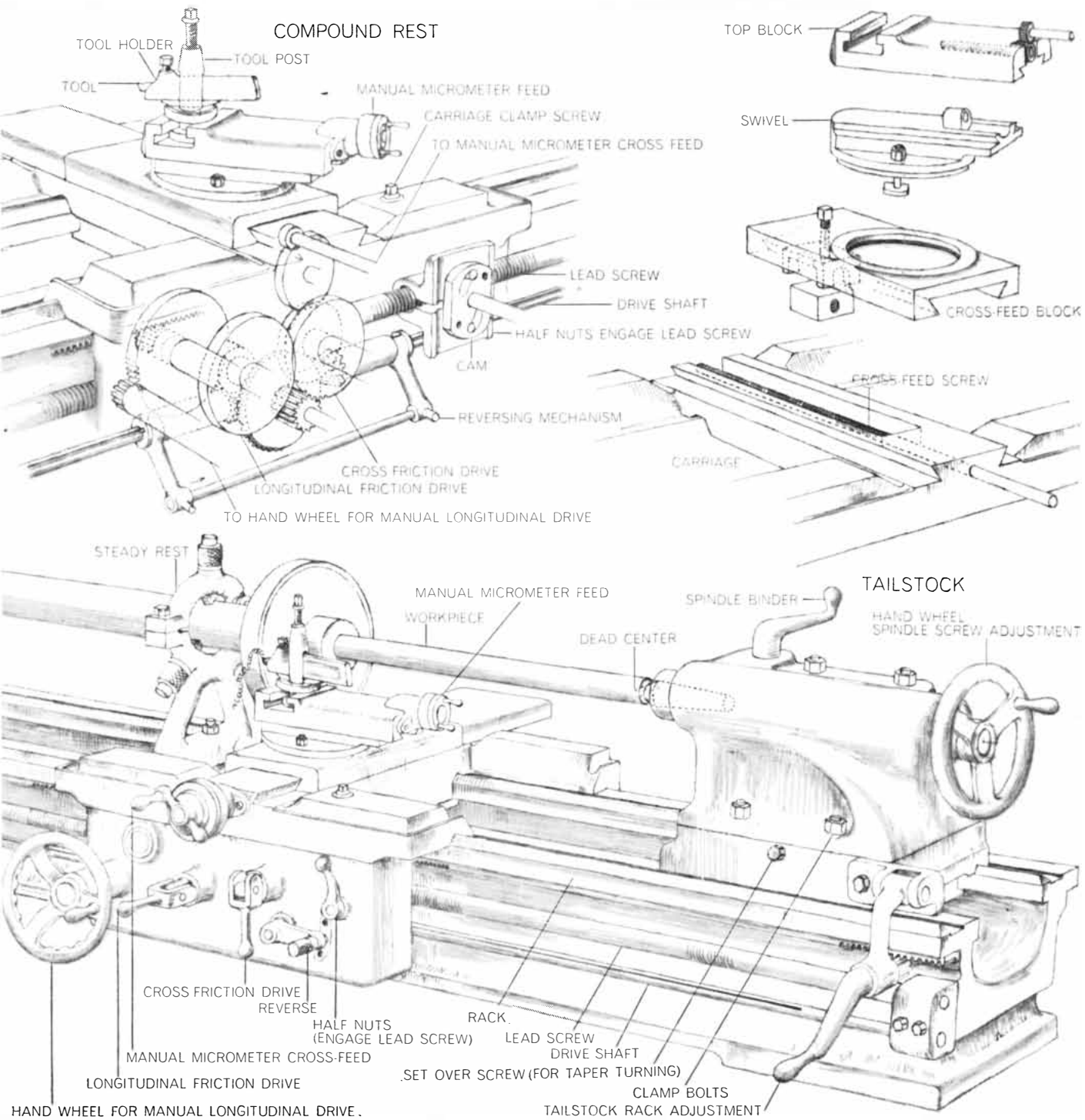
In the *Mittelalterlichen Hausbuch* of about 1480 there is a most important drawing. It shows a lathe in which for



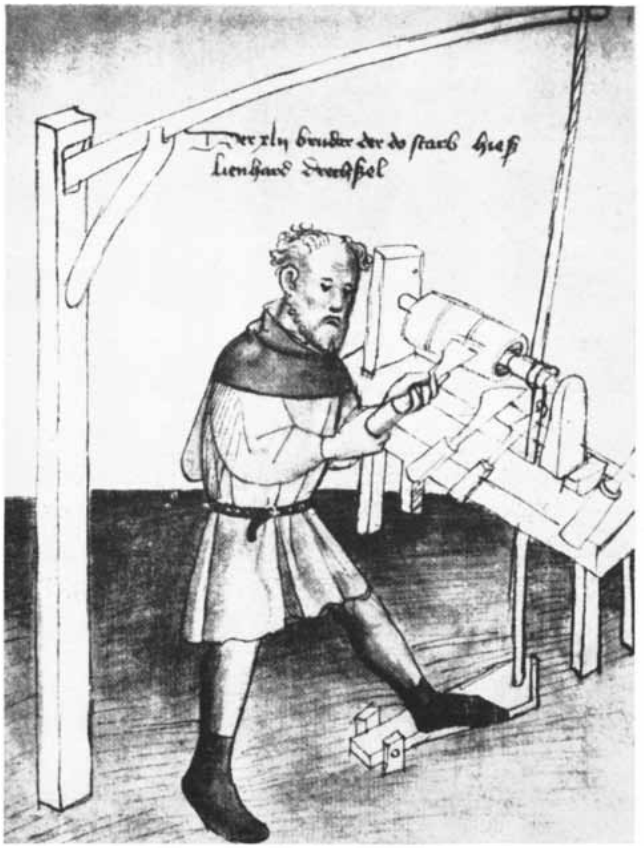
ANATOMY OF THE LATHE shows the location of the principal parts and mechanisms discussed in the text. The workpiece is held between the headstock and tailstock. The compound rest, a development of the simple slide rest, holds the cutting tool and, in mod-

the first time control of the cutting tool was taken from the skilled hands of the turner and put into a mechanical device today called a slide rest [*see bottom illustration on next page*]. The cutting tool was fed into the work by means of a screw mechanism much like modern cross-feed devices. Moreover, the toolholder was held fixed in the lateral direction, while the workpiece was moved past it by means of what is now known as a lead screw, turned by a crank. This combination of motions made it possible to cut screw threads into the workpiece. Thus all the elements of a screw-cutting lathe, including a fully developed cross slide, had appeared by the end of the 15th century.

In the late 16th century Leonardo da Vinci turned his attention to the lathe and sketched a number of mechanisms



ern lathes, is equipped with means for feeding the tool into the workpiece. The steady rest, a development of the back rest, keeps the workpiece from bending under the pressure of the tool. The lead screw provides the means for cutting threads in the workpiece.



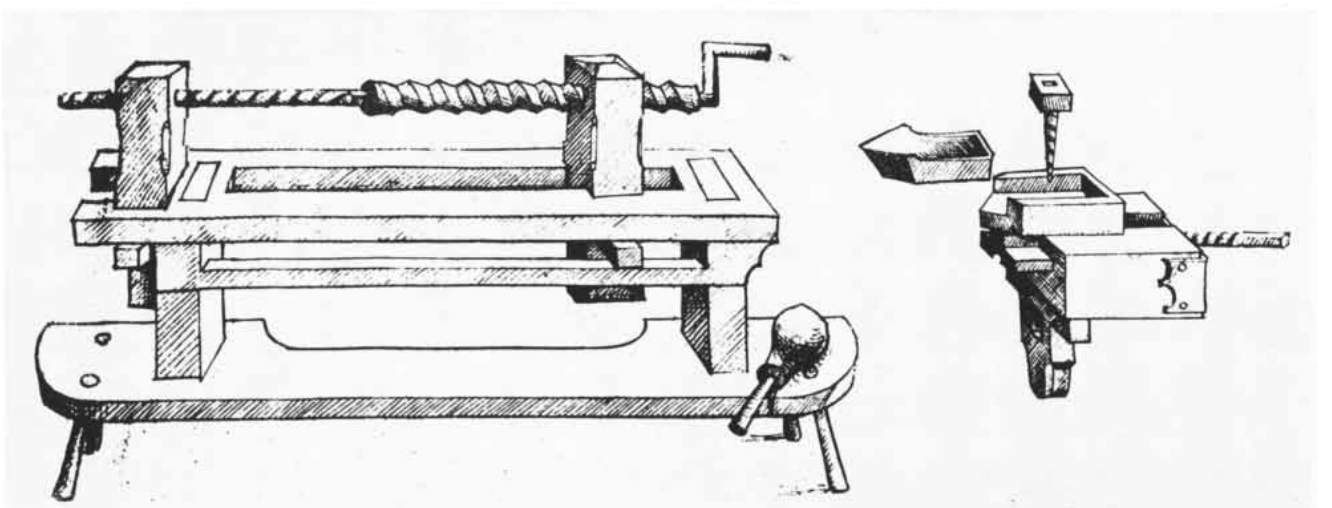
POLE LATHE OF 1395 enabled the workman to turn the workpiece by means of a foot treadle and freed both of his hands for holding the cutting tool. The workpiece rotated back and forth.

CONTINUOUS-DRIVE LATHE OF 1568 eliminated the back-and-forth rotation of the workpiece, produced by pole-and-treadle lathe, but required the services of a helper to turn a drive wheel.

not seen previously [*see top illustration on opposite page*], but whether or not his innovations were embodied in the machines of his day is not known. Leonardo showed one lathe driven by a treadle acting on a crankshaft. The crankshaft was attached directly to the lathe spindle and was mounted between two bearings—the first time this arrangement had been seen. A flywheel, supported by an additional bearing, kept the work turning smoothly. Finally, to hold workpieces of various lengths, Leonardo introduced an adjustable tailstock spindle.

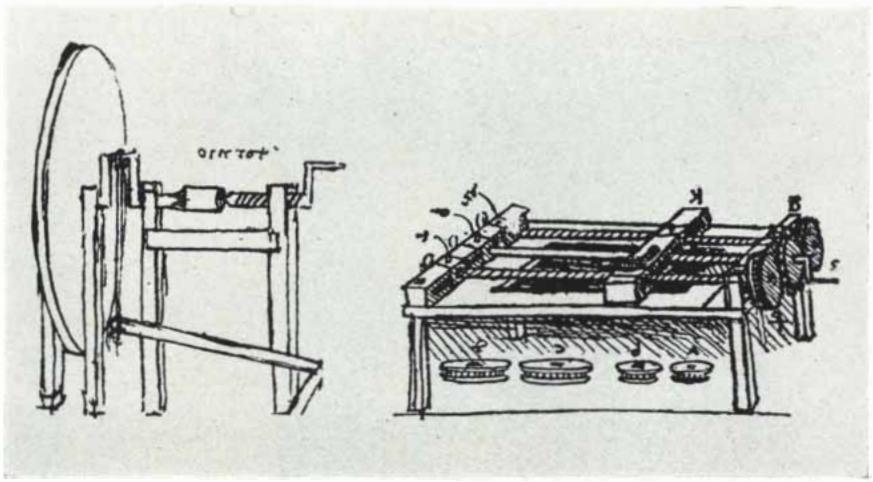
In another sketch Leonardo showed a screw-cutting machine (not strictly a lathe), in which he provided "change gears" to cut threads of various pitches. This was a significant advance over the screw-cutting lathe of 1480.

After Leonardo, lathe designers turned



SCREW-CUTTING LATHE OF 1480 was depicted in the *Mittelalterlichen Hausbuch*. For the first time control of the cutting tool was taken from the skilled worker and put in a mechanical device (*detail at right*), which today would be called a slide rest. The rest was held in a longitudinal guideway. The workpiece was moved below, and past, the cutting tool by means of a hand crank.

their attention increasingly to improving the controls with which the tool was brought to bear on the workpiece. Leonardo's successor as engineer to the French court, Jacques Besson, made several important advances. In a screw-cutting lathe designed about 1550 Besson cleverly co-ordinated the movement of the workpiece and the cutting tool [*see bottom illustration at right*]. In the 1480 screw-cutting lathe a lead screw moved the work past the tool; in Besson's lathe a lead screw moved the tool past the work. This marked the first use of a lead screw, held in a nut, for longitudinal feeding of a lathe tool, another important element of modern machines. It was also the first semi-automatic lathe, that is, a lathe in which the performance did not depend on the operator's skill but was built into the machine itself.

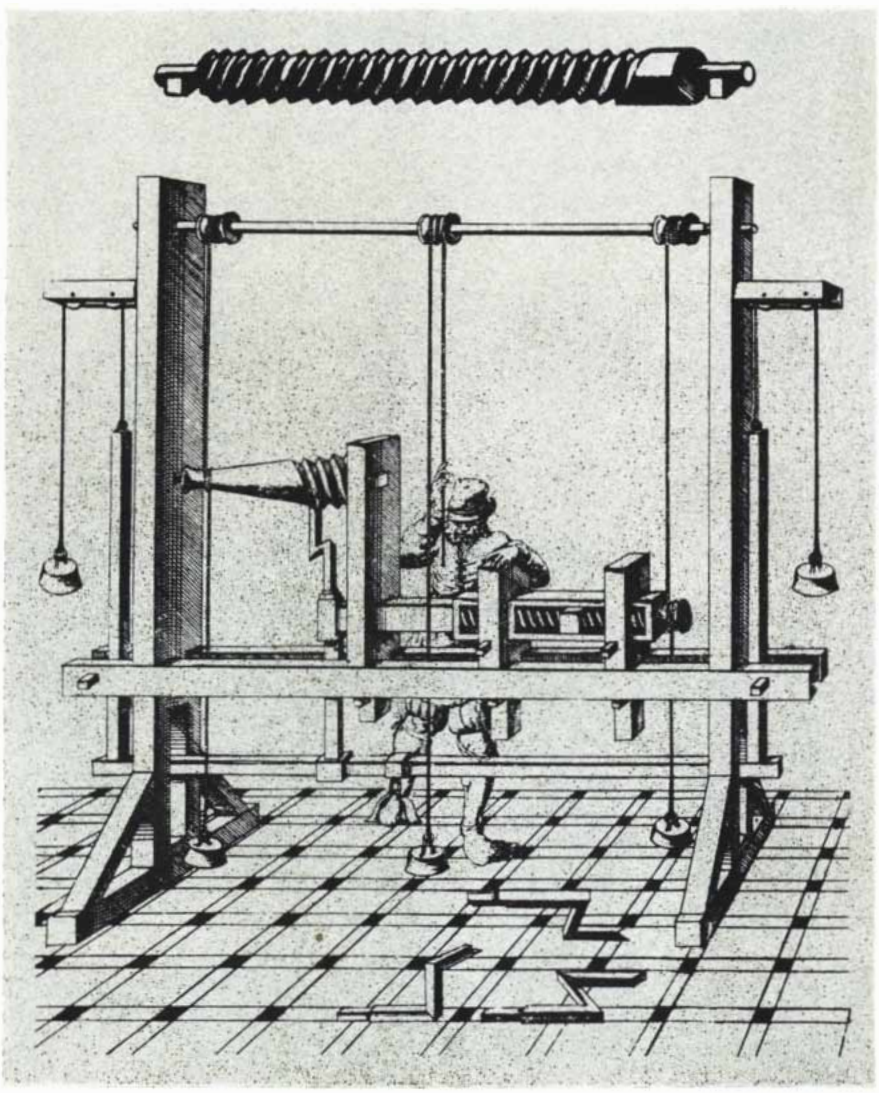


SKETCHES BY LEONARDO DA VINCI show several remarkable innovations in machine design. The lathe at left has a treadle, a crankshaft and a large flywheel. The tailstock spindle can be adjusted by a hand crank. The device at right is a screw-cutting machine (not strictly a lathe), which has a set of change gears for cutting threads of various pitches.

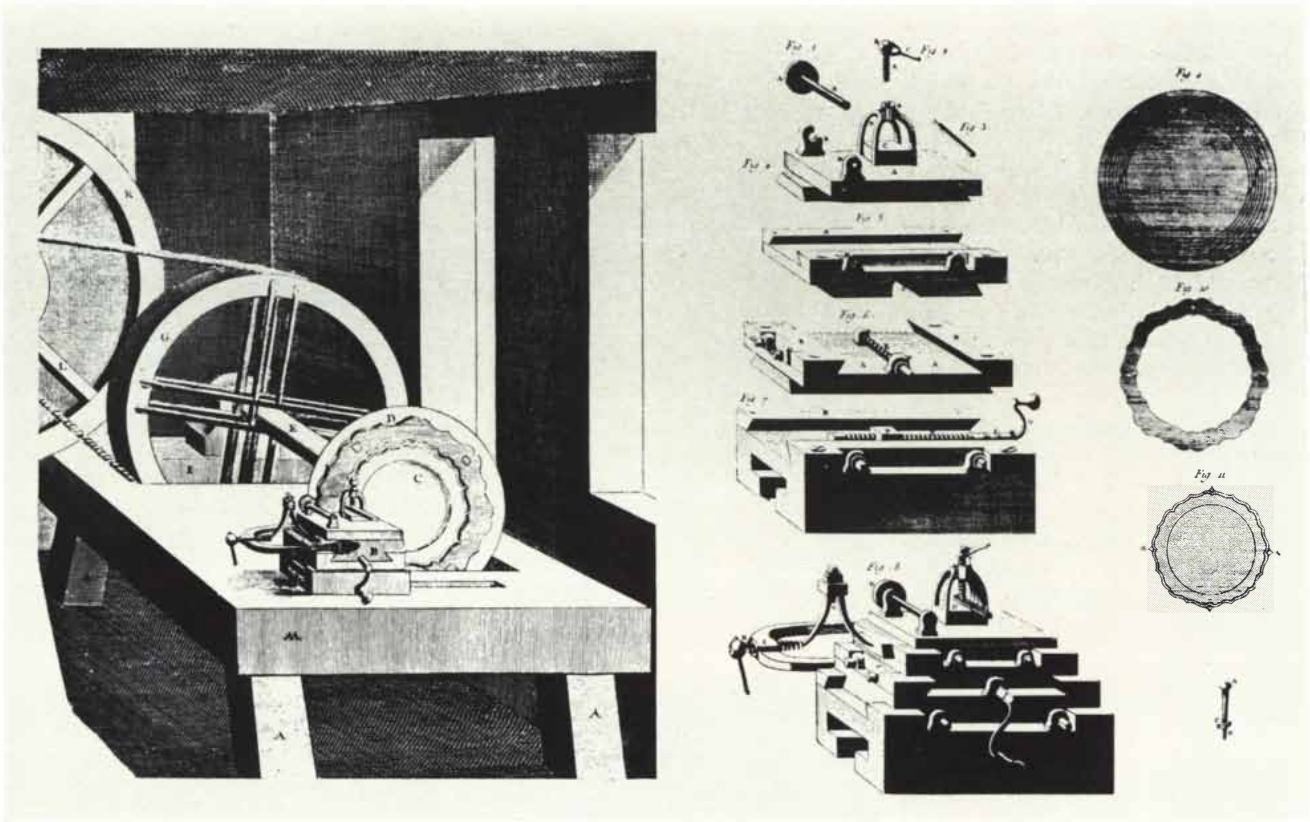
Between Besson's time and 1750 there was slow but significant progress in tool control and drive mechanisms. In 1671, about midway in this interval, Cherubin d'Orleans described a lathe with an interesting combination of bow-and-treadle drive and flywheel [*see illustration on page 132*]. The outstanding feature of the design was the use of several pulleys of different sizes mounted on an overhead shaft to provide different speeds of revolution. Much concerned with reducing friction and improving the precision of bearings, Cherubin was also the first to use a conical bearing in a machine tool. He also developed devices called gibbed slides to improve the accuracy and facility of holding the cutting tool. A century later such slides had become remarkably complex, as can be seen in a "rose engine" built in 1771. This was a specialized lathe named for its ability to cut roselike patterns [*see top illustration on next page*].

Early in the 18th century an important chapter in lathe design was contributed by clock- and instrument makers, many of them French. Although their workpieces were quite small and their lathes hardly what one would call industrial tools, these gifted artisans recognized that to turn out metal parts of precise dimensions lathes would have to be accurate and made entirely of metal. Instrument makers of course worked mainly with brass and other soft metals.

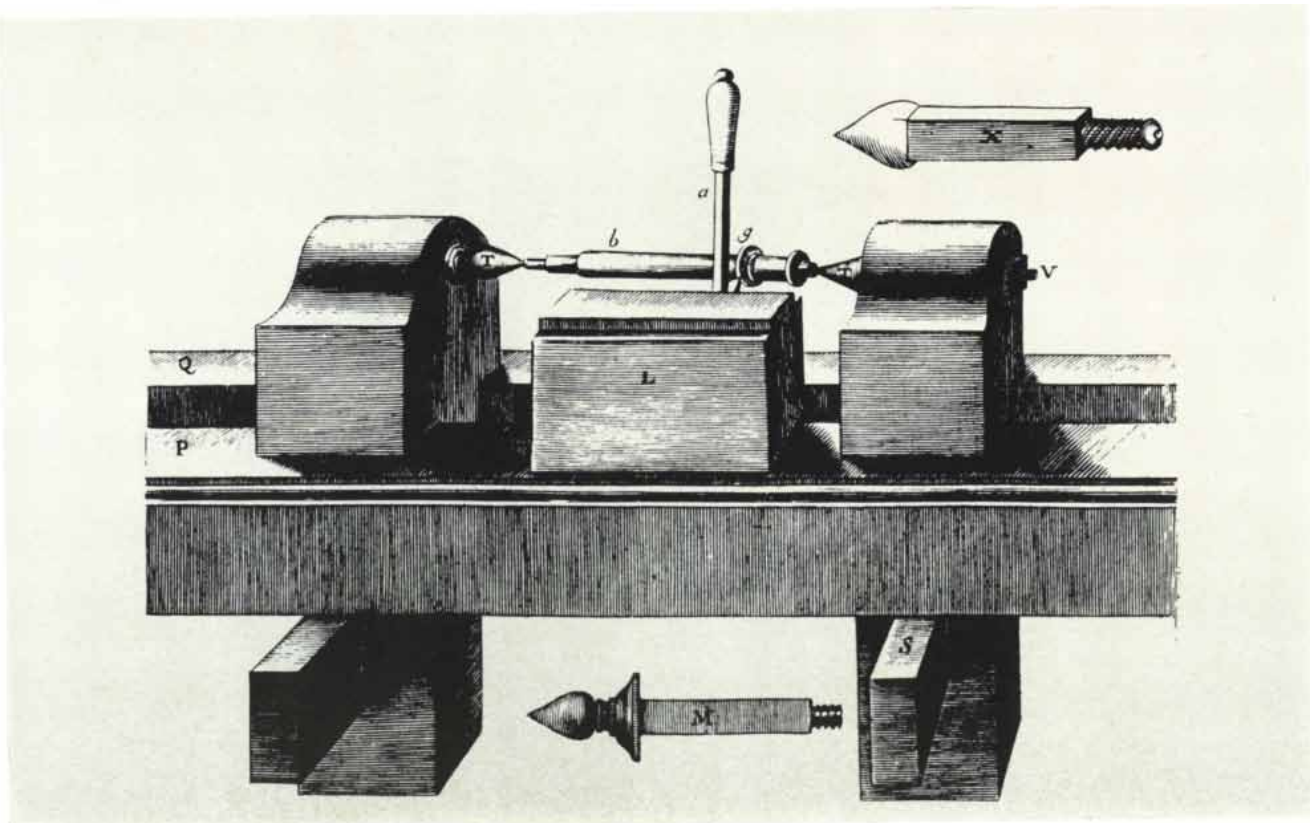
The first significant reference to cutting iron on a lathe appeared in 1701, in a treatise called *L'Art de Tourner* by Charles Plumier. He wrote that he knew of only two other men who could turn iron. In describing his own lathe for this



LATHE DESIGNED BY JACQUES BESSON, Leonardo's successor as engineer to the French court, incorporated a clever means for feeding the cutting tool longitudinally in co-ordination with the rotation of the workpiece. (Workpiece is the tapered screw being cut at the left.) The co-ordination of tool feed and workpiece rotation is achieved by pulleys.



"ROSE ENGINE" of 1771 was a specialized lathe for cutting rose-like and other ornamental designs in wood or soft metals such as pewter. A close-up of the compound slide rest is shown at the bottom right, with an "exploded" view of its parts directly above.



IRON-CUTTING LATHE OF 1701 was designed by Charles Plumier. The lathe was ruggedly built and had adjustable stocks. The cutting tool was supported by a heavy rest (*L*). Power was supplied by a large wheel (*not shown*) turned by two laborers.

work he emphasized strength, rigidity and finish of workmanship [*see bottom illustration on preceding page*]. Plumier's lathe had iron spindles held in bearings of cast tin or other soft metal, one of the earliest examples of this type of bearing construction, now widely used in machinery of all kinds.

Plumier's lathe was powered by two men, who turned a large wheel; an iron-working lathe built by Christopher Polhem in Sweden was powered by water. It seems likely that Polhem had his lathe in operation as early as 1710, but details are scanty. The lathe had a tool carriage driven by a lead screw and gears to move the cutting tool longitudinally. This lathe was evidently able to make accurate parts on an industrial scale, yet Polhem had little influence on machine-tool design even in Sweden. Why, one can only guess.

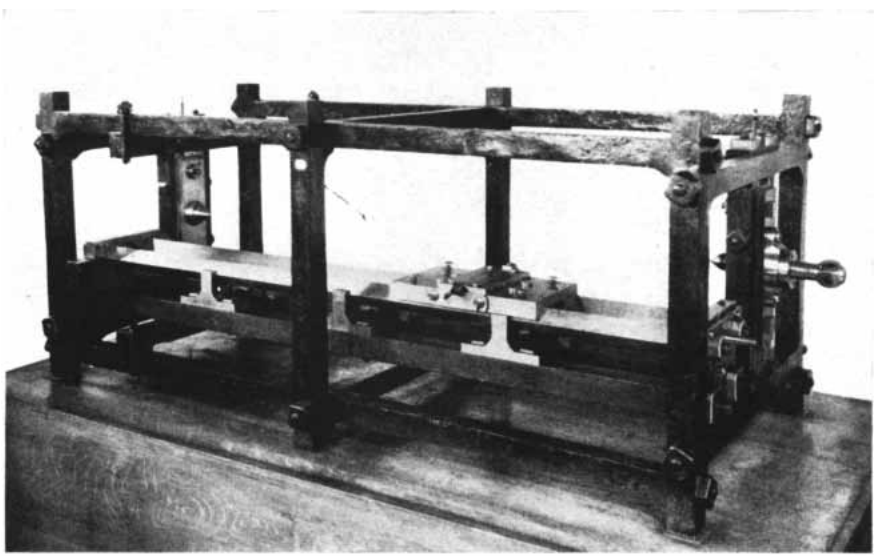
By 1760 a very fine iron-turning lathe appeared in France, built by Jacques de Vaucanson, a gifted machinist who also made important improvements in the loom. His lathe is preserved in the Conservatoire National des Arts et Métiers in Paris [*see upper illustration at right*]. It has a heavy framework of iron bars solidly bolted together, and it can take a workpiece about a meter in length and a third of a meter in diameter. An important innovation appears in the metal guideways that support the tool carriage. They are made of square bars mounted at an angle of 45 degrees. This made it simpler to get high precision guiding of the slide rest, and the surfaces, being sloped, easily shed dirt and chips. Guideways with these sloping surfaces are said to be prismatic and have been widely used in machine tools ever since.

Vaucanson's lathe must have been rather inconvenient to use. The apparent limitations in the workpiece drive mechanism and the use of brass instead of iron in the carriage must have sharply limited the rate of metal removal. It shows quite clearly, nevertheless, that French designers were at least a generation ahead of English lathe builders in producing a lathe capable of precision machining on parts of industrial size.

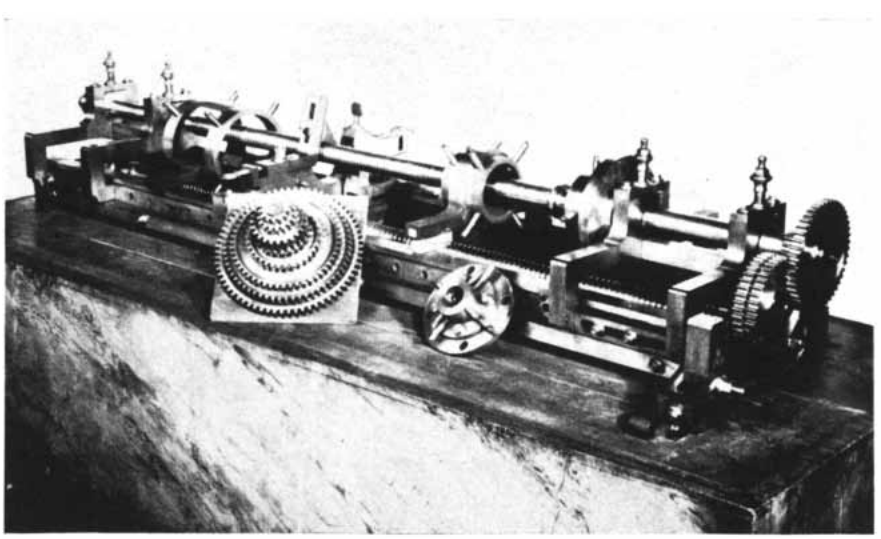
Also preserved in the Conservatoire National is a remarkable screw-cutting lathe built in 1795 by a machinist named Senot [*see lower illustration at right*]. It includes such features as change gears (for changing the pitch of the screws to be cut), fixed and following back rests (to keep the workpiece from bending while being cut), a simple set-screw chuck mounted on the headstock spindle (to accept workpieces of various diameters) and provision for lubricating the bearings and other critical parts. All in all, it was a rugged and precisely built machine capable of turning out accurate parts at a good rate.

It is indicative of the rapid spread of new technology that only three years later, in 1798, David Wilkinson in the U.S. was building a screw-cutting lathe that compared rather favorably with Senot's machine. By 1806 Wilkinson had built a general-purpose lathe that became very popular, particularly in Government arsenals, where more than 200 were in use by 1848. Curiously, the lathe was never patented, with the result that many details of its construction are unknown. In his busy shop in Pawtucket, R.I., Wilkinson trained a whole generation of machinists and machine-tool builders, laying the foundation of the U.S. machine-tool industry.

The man who grasped most clearly the need for a metal-cutting lathe of precision and large capacity and who had the genius to design, build and market it was Henry Maudslay. Born in 1771, Maudslay started work at the age of 12 in the Woolwich Arsenal. By 15 he was an expert metalworker in the arsenal's smithy. In 1797, at 26, he



IRON-TURNING LATHE OF 1760, built by Jacques de Vaucanson, is preserved in the Conservatoire National des Arts et Métiers in Paris. The heavy framework of solidly bolted bars provided great rigidity. The lathe could take a workpiece a meter in length.

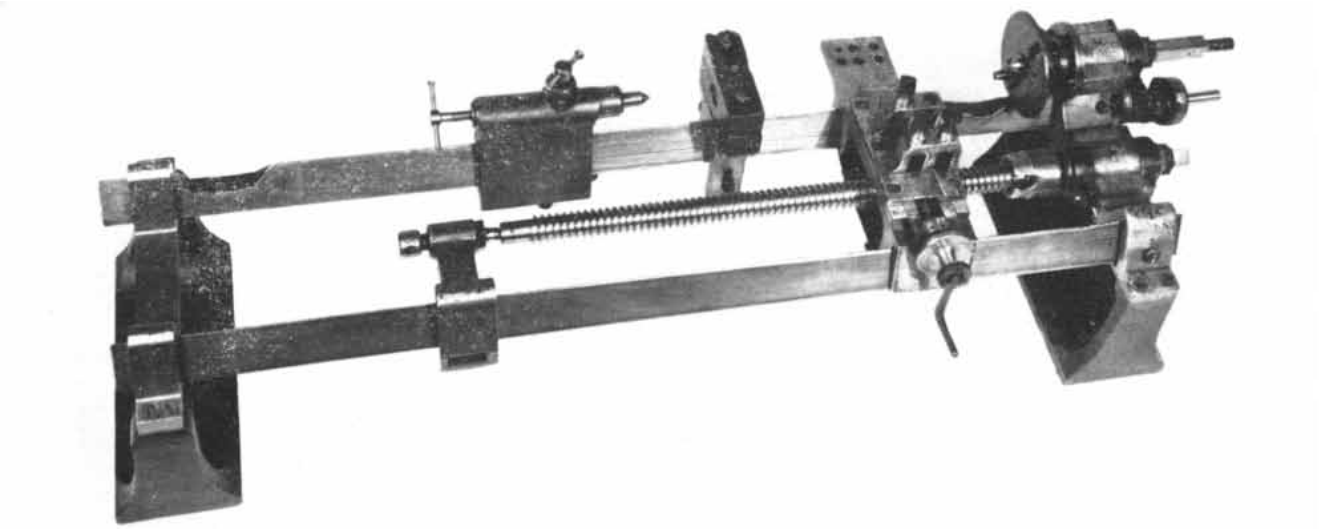


SCREW-CUTTING LATHE OF 1795, also in the Conservatoire National (which supplied these two photographs), was built by a machinist named Senot. The lathe includes change gears, fixed and following back rests and a set-screw chuck mounted on headstock spindle.

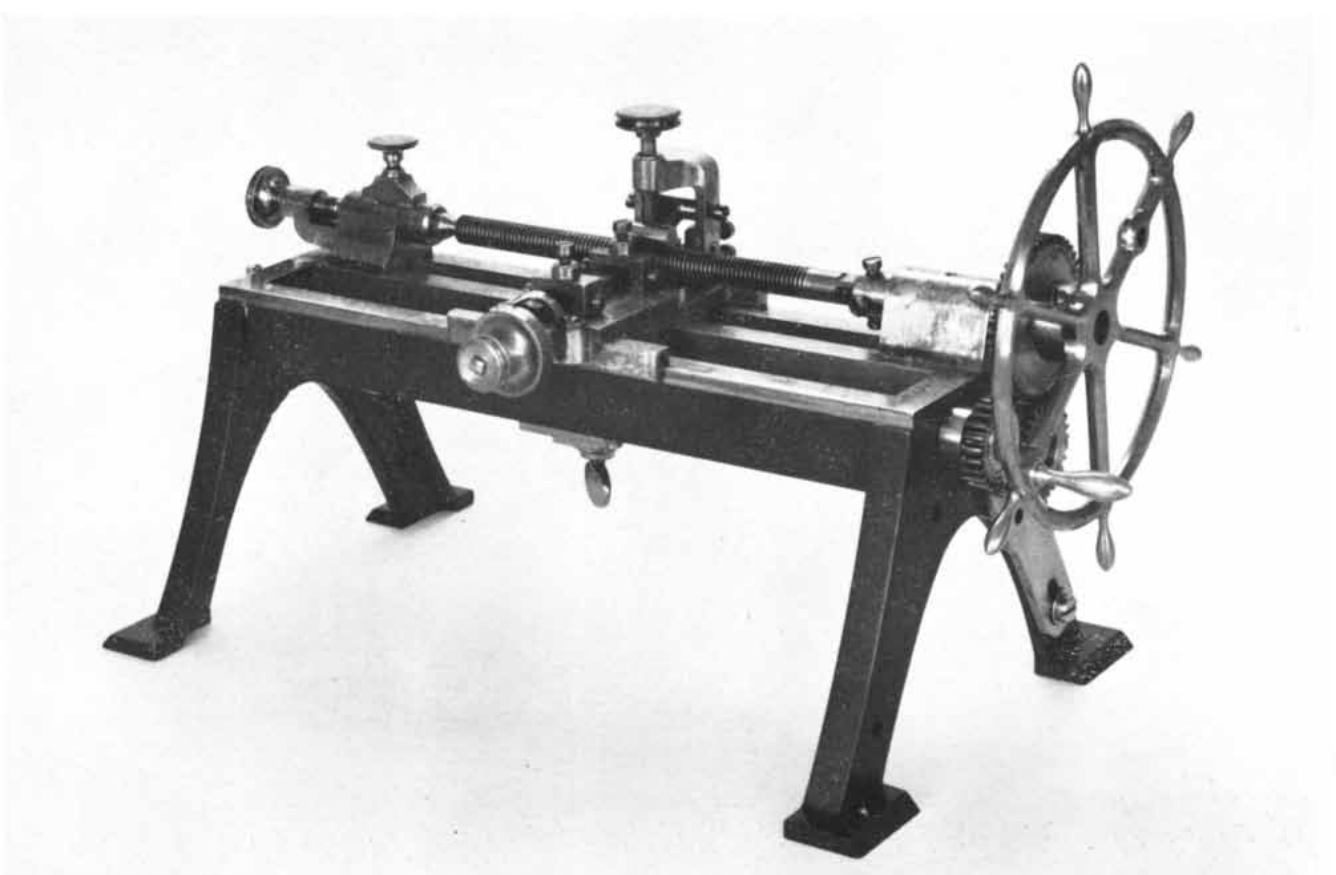
founded what became one of the great machinery works of England.

Maudslay approached the problem of improving the lathe just as the Industrial Revolution was creating a demand for machine parts produced in large quantities and to close specifications. He brought to the problem an intuitive sense of mechanical analysis that had been sharpened by close familiarity with metalworking techniques and the behavior of metals. He quickly recognized the importance of providing perfectly flat surfaces on which to mount the headand tailstocks and on which the tailstock and tool carriage were to slide. He saw that a precision lead screw was essential to accurate cutting. And he saw too the importance of accurately aligned spindle bearings and tailstock centers.

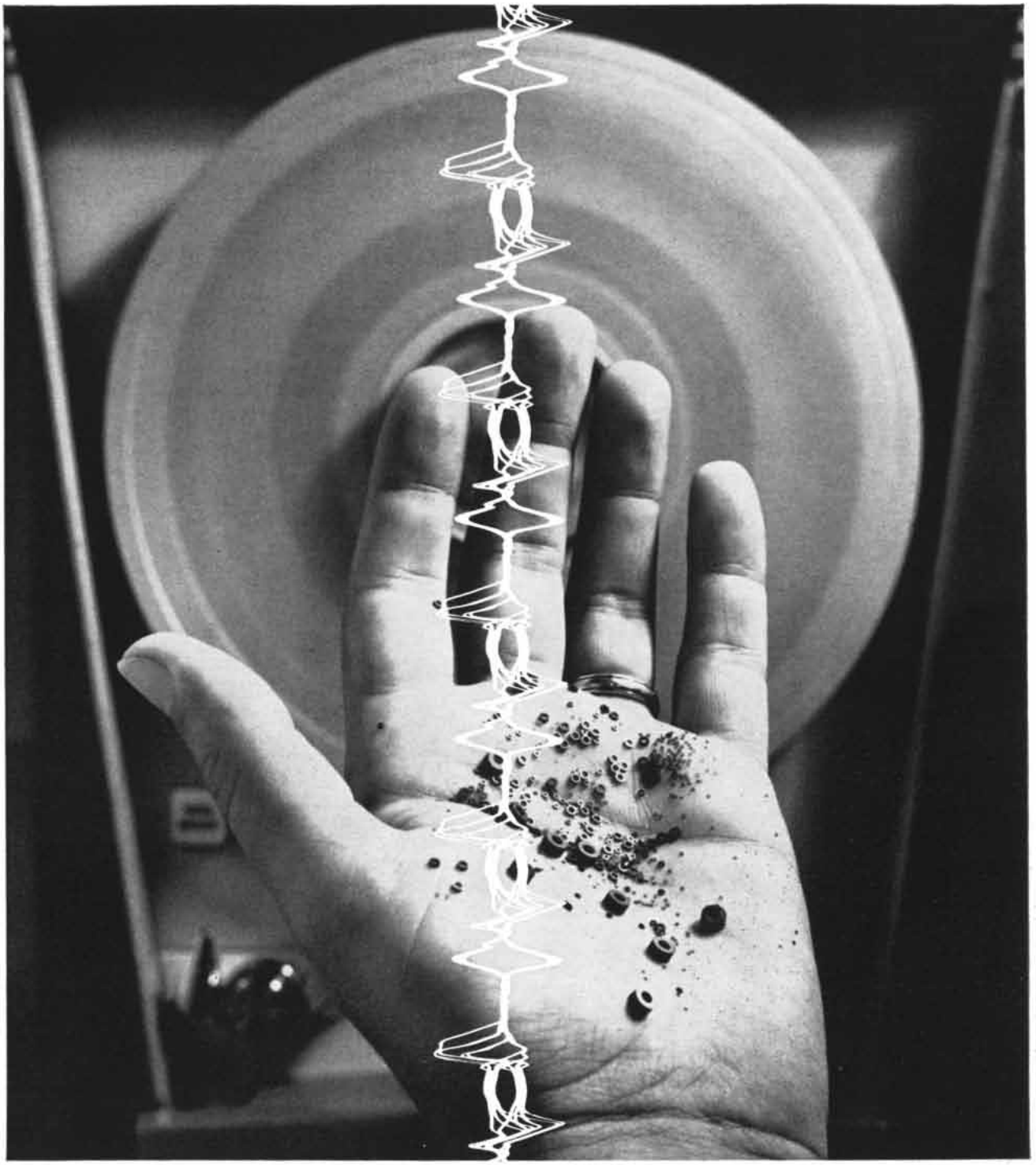
Maudslay began building lathes in



SCREW-CUTTING LATHE OF 1797 was built by the gifted English machinist Henry Maudslay when he started his own shop at the age of 26. He devoted great effort to producing true guideways, highly precise master screws and accurate, rugged bearings.



ANOTHER MAUDSLAY LATHE was this screw-cutting model built around 1800. The guideways are mounted on a separate cast-iron bed supported on solid legs. The machine shown is relatively small, but it foreshadows the design of larger industrial lathes.



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1794 and by 1797 had produced his first screw-cutting lathe [*see upper illustration on page 140*]. It could handle workpieces up to three feet long and six inches in diameter. The bed was formed by two triangular bars, which served as guideways for the tool carriage. It was the first lathe larger than instrument maker's size to have guideways with precise surfaces. In a screw-cutting lathe built about 1800, Maudslay incorporated still more features of the modern industrial lathe [*see lower illustration on page 140*]. For example, the headstock spindle had a simple set-screw chuck and the guideways were mounted on a separate cast-iron bed supported on solid legs.

Maudslay was particularly resourceful in obtaining master lead screws of high precision. He would begin by cutting a lead screw first in one direction and then in the other to smooth out defects in the lead screw used to guide the cutting. Selected sections of this new lead screw were used to cut a second screw. He also devised a mechanism in which two guide screws were linked so that their defects would be averaged out in guiding the cutting tool. After many efforts of this sort Maudslay had a splendid brass screw about seven feet long that was only one-sixteenth of an inch off from its computed length. This meant an error of about .002 inch per turn of the thread. He then invented a clever linkage by means of which even this small error could be corrected.

Maudslay put an equally great effort into the design of precision bearings. In one of his large lathes of 1830 he incorporated a split journal bearing of brass as a front bearing and a tapered rear bearing in which the spindle journal was held in tapered steel bushings. The lathe also had a remarkable feed mechanism, a forerunner of the famous Norton gear box, which did not appear until 1892. The drive consisted of three gears of different sizes mounted on the spindle and a small connecting gear, or pinion, mounted on a countershaft. The countershaft could be shifted so as to engage the pinion with any one of the three gears.

Beyond dispute Maudslay had put into one great synthesis all the elements of the lathe that had gone before. And he anticipated features that later were to be highly developed. Equally important was his great influence on a number of other toolbuilders—such as Richard Roberts and Joseph Whitworth—who learned their trade and their standards of workmanship in his shops.

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SOLITARY WASPS take prey, which they paralyze by stinging, primarily as food for their larvae. This great golden digger wasp, *Sphex ichneumoneus*, has taken a large katydid, which it grasps with its mandibles. In flight the wasp carries its prey with its legs.

BEMBIX PRUINOSA, having prepared a nest in a sand dune, approaches the nest carrying a flower fly with its middle legs. *Bembix* is one of the few solitary wasps that bring their larvae fresh prey daily. The photographs on this page were made by the author.

APHILANTHOPS LATICINCTUS, a highly evolved wasp, preys only on one species of harvester ant, which it carries on specialized segments on its abdomen. This *Aphilanthops* is standing on its middle and hind legs and using its front legs to reopen its nest.

PREDATORY WASPS

Solitary wasps prey on spiders and insects to feed their larvae. Their highly specific predatory behavior, including choice of prey and manner of carrying it, provides clues to the evolution of wasps

by Howard E. Evans

The sting of bees, wasps and certain ants gives these insects a formidable defense against predators. In the solitary wasps, however, the sting still serves primarily the function for which it originally evolved: the taking of prey. The solitary wasps are hunters. Most familiar in the "digger" or "mud dauber" forms, they have diversified into hundreds of genera and thousands of species in pursuit of their fellow insects and other arthropods, such as the spiders. Each species tends to specialize, hunting down a particular prey and disregarding others of similar size and more ready availability. Some restrict their predation to a single species or genus and only a few claim victims from more than one order of arthropods. The affinity of predator to prey is, in each case, as characteristic of the wasp as the anatomical features that distinguish it from other wasps. Such specialization of behavior is not surprising in view of the difference in strategy and tactics required for capturing a caterpillar, for example, compared with a fly. The consequent diversity in the behavioral repertories of the solitary wasps has invited increasing attention in recent years, as zoologists have turned to the study of the decisive role of behavior in the origin of species.

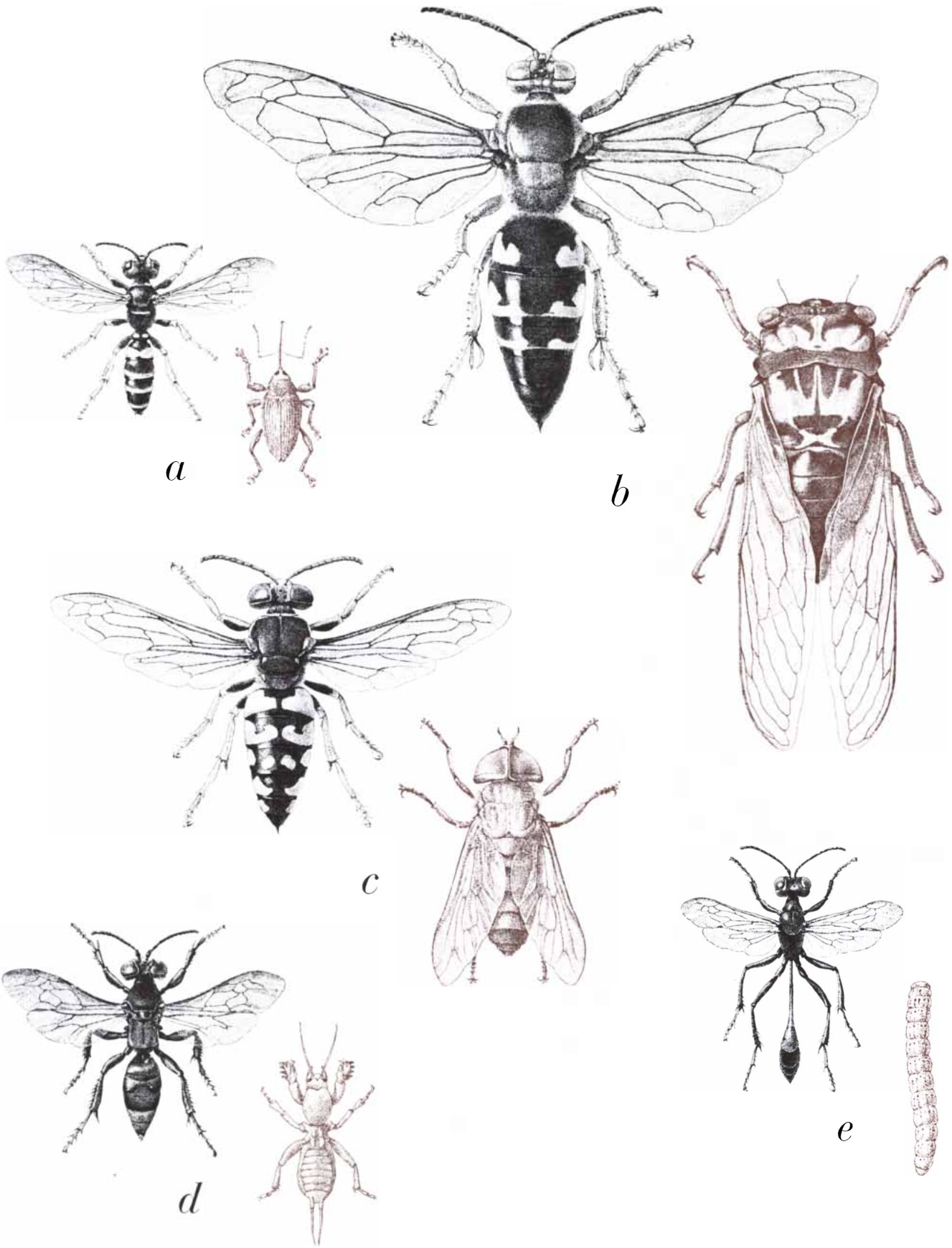
Solitary wasps are predators of a rather special sort. Only a few take prey as food for themselves; for the most part the adults of all species feed on sugars in solution, which they find in the nectar of flowers, in ripe fruit or in the honeydew secreted by aphids and other plant-sucking insects. The male wasps, in fact, are not predators at all and feed exclusively on plant exudates. It is the females that take prey, and they do so primarily to feed their larvae. In this remarkable plan of behavior the solitary wasps foreshadow the still more elaborate larva-nurturing of the social Hymenoptera—the ants, bees and social wasps—all of which apparently arose from certain long extinct groups of solitary wasps. (The termites arose from an entirely different stock, the cockroaches of the order Orthoptera.) The solitary wasps in turn have derived the elements of their behavior—their specificity as to prey, the restriction of the predatory habit to the female and the consignment of the prey to the nurture of the next generation—from their precursors in the Hymenoptera line.

The most primitive Hymenoptera, on the basis of many features of larval and adult structure, are the sawflies, and these first appear in the fossil record at the beginning of the Mesozoic era, some 200 million years ago. With its sawlike ovipositor the female deposits its eggs in plant tissue. Most species are highly host-specific. In the Jurassic, the second period of the Mesozoic, the parasitic Hymenoptera, including the ichneumon wasps, made their appearance. The female deposits its eggs on or in another arthropod (most commonly a plant feeder); the larvae feed on the host, causing its death only when they have completed their own development. These insects flourished almost immediately and even today form an enormous group of many thousands of species. Some are equipped with ovipositors twice the length of their bodies, with which they are able to plant their eggs on grubs burrowing deep in the trunks of trees.

For this unique form of parasitism O. M. Reuter of the University of Helsingfors many years ago coined the term "parasitoid." When the true wasps appeared toward the end of the Mesozoic, they inherited this manner of life; some living groups of primitive wasps still behave essentially like parasitoids. But most wasps paralyze their hosts (now called "prey") by stinging them, then store them in the nest where the egg is laid and larval development takes place. The true wasps are no more predators in the usual sense than the ichneumon wasps are parasites. One might perhaps use the term "predatoid" to epitomize the origins and gross behavior of these insects.

The adapatation of a particular wasp to its prey presents one of the most intriguing problems in the study of behavior. In two widely separated localities, the digger wasp *Aphilanthops laticinctus* has been found to prey exclusively on one species: the prairie mound-building ant *Pogonomyrmex occidentalis.* A related species, *A. haigi,* seems to confine its predation to another ant, *P. barbatus rugosus.* I have seen *haigi* hunting in areas where a closely related ant, *P. maricopa,* was more abundant, and I have seen these wasps approach a worker *maricopa,* back away and proceed to hunt *barbatus rugosus* workers. *Maricopa* appears, however, to be the normal prey of another species of *Aphilanthops,* called *A. sculleni.* Reports of such narrow specialization should be further documented; sometimes a wasp that appears highly host-specific in one region is found to prey on another species, although usually a related species, elsewhere.

One *Aphilanthops, A. frigidus,* a common species in the eastern U.S., is known to prey on queen ants instead of workers; in museums there are many specimens pinned with their prey. Curiously, this wasp takes only winged queens at the time of their nuptial flight and ignores the queens that have lost their wings and are seen at times running in numbers over the ground. The wasp removes the wings from the ant, however, before placing it in the brood cell. Without exception the victims belong to the species



FEMALE WASPS, members of the family Sphecidae, are depicted with some of the insects they prey on (*prey are shown in color*): *Cerceris halone* with a weevil (*a*), *Sphecius speciosus* with a cicada (*b*), *Stictia carolina* with a horsefly (*c*), *Larra analis* with an immature mole cricket (*d*) and *Ammophila arvensis* with a moth larva (*e*). The wasps and their prey are drawn about twice life size.

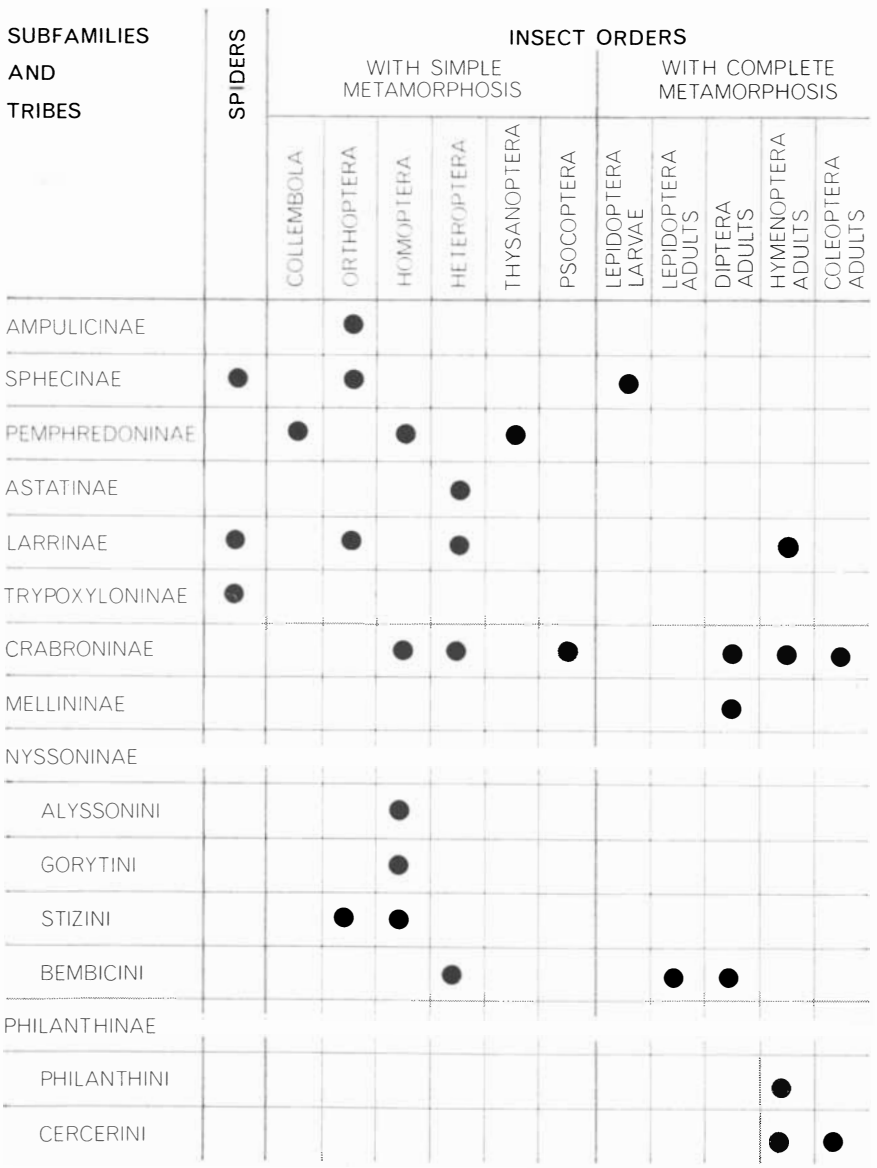
Formica fusca or one of two or three other closely related species of the genus *Formica*.

Wasps more commonly prey on several related species of a genus—*Cerceris halone*, for example, preys on the long-beaked weevils of the genus *Curculio*. Still more commonly, a given species of wasp will prey on several or even many genera of one family or several related families. The great golden digger, *Sphex ichneumoneus*, takes katydids and long-horned grasshoppers of several genera in at least two subfamilies; *Ochleroptera bipunctata*, a tiny wasp that sometimes nests in flowerpots, takes leaf hoppers and other plant-sucking insects (Homoptera) in five related families. Less commonly, a wasp may prey on a wide variety of insects of a given order. *Philanthus pacificus* has been found to take prey belonging to six different families of Hymenoptera, including bees, ichneumonids and even other wasps.

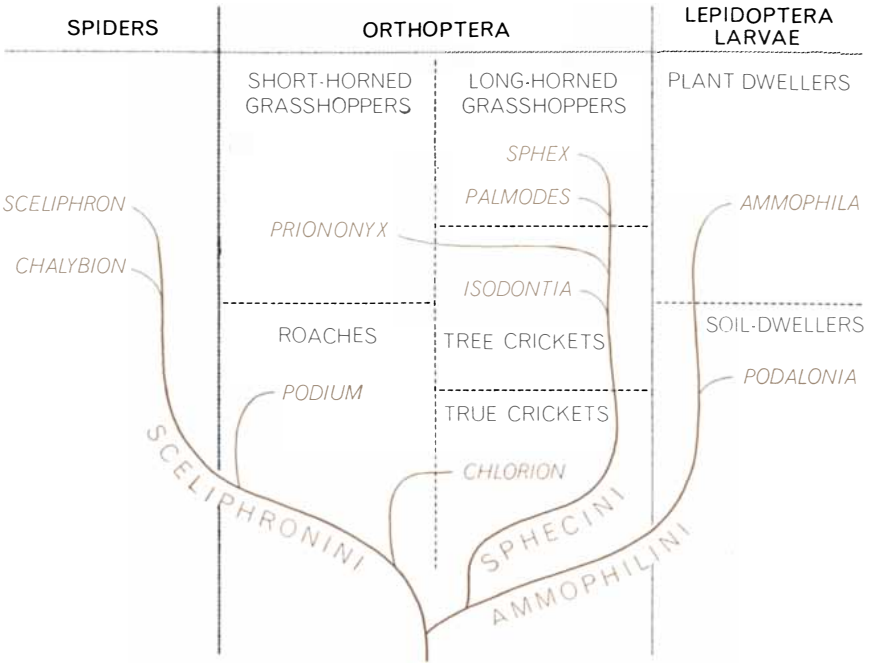
Such host-specificity is the more curious because the larvae of wasps can often be induced to develop normally on prey quite different from that provided by the mother. The French naturalist Jean Henri Fabre many years ago successfully reared *Bembix*, a predator of flies, on a diet of grasshoppers. Similar experiments have been performed by Fabre and other investigators on other species of wasps. The host must, of course, be paralyzed or freshly killed if it is to be acceptable.

For a wasp to take insects of more than one order is unusual, but several species are known to do so. *Crossocerus quadrimaculatus* preys on a wide variety of flies (Diptera) and also occasionally takes small moths (Lepidoptera) and caddis flies (Trichoptera). *Lindenius columbianus errans*, a minute wasp that happens to be quite common on a sandy road near my home in Lexington, Mass., fills its nest with a remarkable mixture of midges (Diptera), small parasitic wasps (Hymenoptera) and minute bugs (Hemiptera). Another unusual wasp is *Microbembex*, which is known to stock its brood cells with insects of 10 different orders as well as with spiders. The victims in this case, however, are picked up from the sand already dead or disabled; *Microbembex* is the only genus of digger wasps that has become a scavenger rather than a predator. If one wonders why this mode of life is not more prevalent among wasps, the answer may be that the scavenger's niche was amply filled at an earlier date by other Hymenoptera: the ants.

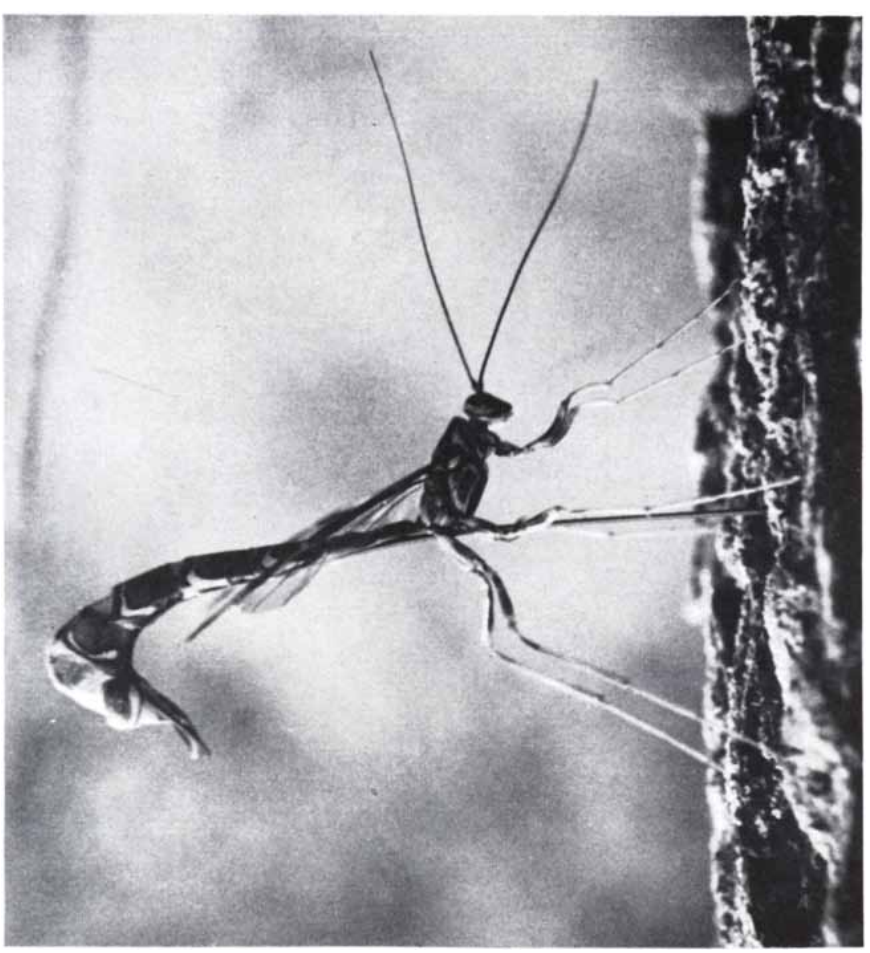
Many species of wasps take their prey in habitats quite different from and often distant from that in which the new adult emerges from the brood cell and where she eventually builds the brood cells of her offspring. Little is known about her initial hunting flights. These must often involve much random flying about before the wasp locates the source of prey appropriate to her species. Once she arrives in the proper habitat it is apparent that an assortment of cues direct her to her prey. In the case of the bee wolf, *Philanthus triangulum*, Nikolaas Tinbergen of the University of Oxford and his co-workers have observed that the wasp flies from one flower to another; when she sees a moving object on a flower about the size of a bee, she hovers a short distance downwind from it. At this point olfactory cues become important: if the object has the odor of a bee, the wasp pounces on it. But she does not actually sting it unless she finds it has the "feel" of a bee. Less thorough studies of a number of other digger wasps suggest that this succession of visual-olfactory-tactile cues may serve to guide wasps of many different species to their prey. The tendency to respond to appropriate cues in each of these sensory modalities is apparently part of the unlearned, genetically determined behavioral repertory of each



SPECIFICITY of prey choice is illustrated in this chart. The major subfamilies (in some cases subdivided into tribes) of the Sphecidae, or digger wasps, are arranged at left in approximate evolutionary sequence (*top to bottom*). Their prey, indicated by the colored disks, include spiders and many orders of insects. Aside from some exceptional cases that are not illustrated here, each subfamily preys on remarkably few different orders of insects.



EVOLUTIONARY SCHEME of the subfamily Sphecinae is based on larval and adult structure. Changes in type of prey (*shown in black*) are correlated with the development of wasp tribes and genera (*color*). In general the advanced wasps prey on advanced insects.



PARASITIC HYMENOPTERA, which may have been the evolutionary precursors of the solitary wasps, lay their eggs on or inside the bodies of other insects or spiders. This parasitic ichneumon wasp, *Megarrhyssa macrura,* has inserted its extremely long ovipositor through the bark of a tree in order to lay its egg on the larva of a sawfly, the pigeon horntail.

species. William Morton Wheeler of Harvard University many years ago suggested that the olfactory system of the wasp is conditioned in the larval stage when it consumes the specimens of its future prey captured for it by its mother. This seems improbable in view of what has already been said about the diversity of prey taken by some species; in any case, it suggests no corresponding way in which the visual components in this behavior might be "conditioned."

Wasps do not normally "make mistakes" with respect to prey. I have accumulated thousands of prey records of various North American species of *Bembix,* and not a single one involves an insect other than a fly (Diptera). Yet in different parts of its range any one species of *Bembix* will hunt in quite different habitats and take quite a different array of flies. Wheeler found an Australian *Bembix* preying on damsel flies—slender insects of the entirely different four-winged order Odonata—and postulated that in this region the wasps had turned to damsel flies because true flies were scarce. It is quite possible, however, that damsel flies provide the usual prey of this Australian *Bembix* and that the species has come to respond innately to damsel flies and not to true flies. This would represent a comparatively recent development in evolution.

In nesting aggregations of *Bembix* I have often found the brood cells of one individual stocked with nothing but horseflies; in the nests of others I have found mostly flies captured on flowers; in the nests of still others, flies taken on carcasses or dung. Apparently once a given wasp has located a rich source of prey it returns again and again to the same place. I have also observed the prey taken by a single wasp change in character as she built a series of nests, indicating that one source of prey had become exhausted and another had been found.

Many Diptera-hunters take their prey mainly from mammals and in their hunting flights apparently seek out mammals likely to harbor biting flies. *Stictia carolina,* a cousin of *Bembix,* is known as the "horse guard" because it is so frequently seen hovering about the flanks of horses and cattle, whence it snatches horseflies. Joseph C. Bequaert of Harvard University has observed small wasps of the genus *Oxybelus* pouncing on, stinging and carrying away black flies from the skin of human beings in Guatemala.

Although one is most likely to see wasps hunting in broad daylight in the

open air, this must not obscure the fact that important species do their hunting under entirely different circumstances. Wasps that prey on crickets and cockroaches do most of their hunting on the ground, creeping into crevices under stones and fallen timber and into holes in the ground. Diggers of the genus *Podalonia* unearth cutworms from the soil. One species of *Bembix* does all its hunting just at twilight, preying on Diptera that have come to rest for the night in vegetation. The members of the genus *Argogorytes* have a still stranger specialization: they extract immature spittle insects from their masses of supposedly protective froth on the stalks of plants.

The stinging of the prey that follows capture is a relatively stereotyped sequence of motions that differs from one major group of wasps to another in apparent adaptation to the anatomy and physiology of the prey. André Steiner of the University of Montpellier has observed that *Liris nigra* stings its cricket prey first in the vicinity of the nerve ganglion controlling the hind legs—the jumping legs—and then twice more in the vicinity of the ganglia controlling the other two pairs of legs. As Fabre first pointed out, the hunters of caterpillars sting their prey not only on the thorax but also several times along the underside of the abdomen. In caterpillars the "prolegs" on the abdominal segments of the body are as important in locomotion as the thoracic legs, if not more so, and the nervous system is not highly concentrated in the thorax. On the other hand, there is much evidence that the predators of leaf hoppers, cicadas and other Homoptera, in which the nerve ganglia are concentrated in a single large mass in the thorax, administer a single, prolonged sting in the vicinity of this nerve center. Wasps that prey on other members of the order Hymenoptera also generally insert the sting only once.

The extensive literature that explains the stinging behavior of wasps in terms of the neural anatomy of the victim may have to undergo revision as the result of the recent work of Werner Rathmayer of the University of Munich. He observed that the bee wolf inserts its sting into the honeybee only once, in the membrane around the coxae, or anchor segments, of the front legs on the underside of the thorax, and that the stinging lasts from 20 to 50 seconds. By careful dissection of the victims Rathmayer was able to show that the sting does not normally penetrate the ganglion. Instead the venom diffuses from the point of injection into the flight muscles and the muscles controlling the legs.

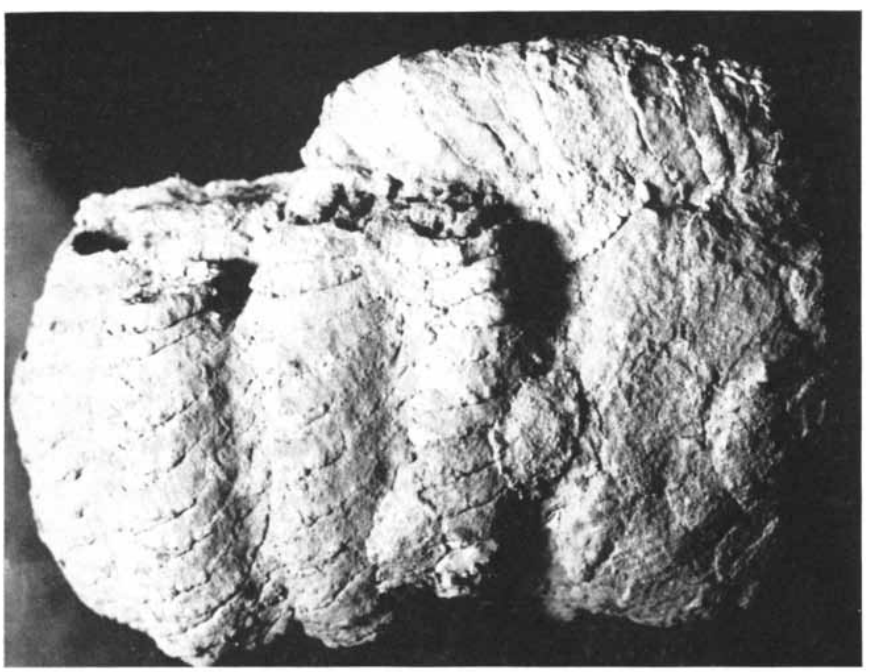
Rathmayer's finding that the venom does not act directly on or through the nervous system is well documented. It may be that the stings are inflicted through the underside of the thorax not because of the presence there of nerve ganglia but because "chinks in the armor" around the coxae give ready access to the muscles of locomotion. Rathmayer also found, incidentally, that a component in the blood of the bee wolf makes it immune to its own venom but that this does not protect it against injection of its venom directly into a ganglion. *Palarus variegatus*, a wasp that preys on other wasps, including the bee wolf, is also immune to wasp venom.

In the not yet completed task of classifying wasps, the study of behavior and particularly of prey selection has begun to shed light on difficult problems. Workers in our laboratory at Harvard University have recently divided one genus of

ADAPTIVE RADIATION of predatory behavior in the Sphecidae is illustrated in this chart. Characteristics of the behavior of the more primitive wasps are shown at the left with two examples (*black*) of wasps typical of this group. The arrows show how those characteristics have changed in the direction of more specialization and more advanced predatory techniques. This more advanced behavior is exhibited by many wasps; those listed at the right (*black*) are merely genera of which each behavioral item is typical.

the tribe Bembicini into two: *Stictiella*, which has been found to provision its nests exclusively with moths and butterflies, and *Glenostictia*, which feeds its larvae from day to day on flies. Father Aloys Adriaanse of Tilburg in the Netherlands has carried this kind of discrimination of the species level, separating *Ammophila campestris*, which preys on the larvae of sawflies, from its sibling species *A. pubescens*, which preys on the larvae of moths.

The major steps in the evolution of wasps were taken millions of years ago. Many of the wasps found in Baltic amber look much like contemporary wasps, and it is probably safe to assume that many of them behaved much the way their relatives do today. Hence it is not surprising to find that those groups of wasps that are ranked as primitive on the basis of their structure and generally simpler behavior patterns prey largely on orders of insects considered low on the evolutionary scale. The Ampulicinae, for example, are an isolated and probably relict group of digger wasps; they limit their predation to cockroaches, dominant insects of earlier geologic time. Other roach-hunters turn up in the relatively primitive subfamilies Sphecinae and Larrinae, most of whose members are adapted to the now more dominant groups of Orthoptera, such as crickets and grasshoppers. Spiders, an arthropod order of ancient origin, also serve as prey for certain Sphecinae and Larrinae and do not attract predation by more advanced digger wasps. Correspondingly, the more advanced wasps take as their prey more advanced insects, such as flies, bees and beetles, that go through complete metamorphosis. The higher flies underwent most of their radiation during the Tertiary period, which began some 60 million years ago, and several groups of structurally advanced wasps quickly took advantage of them.

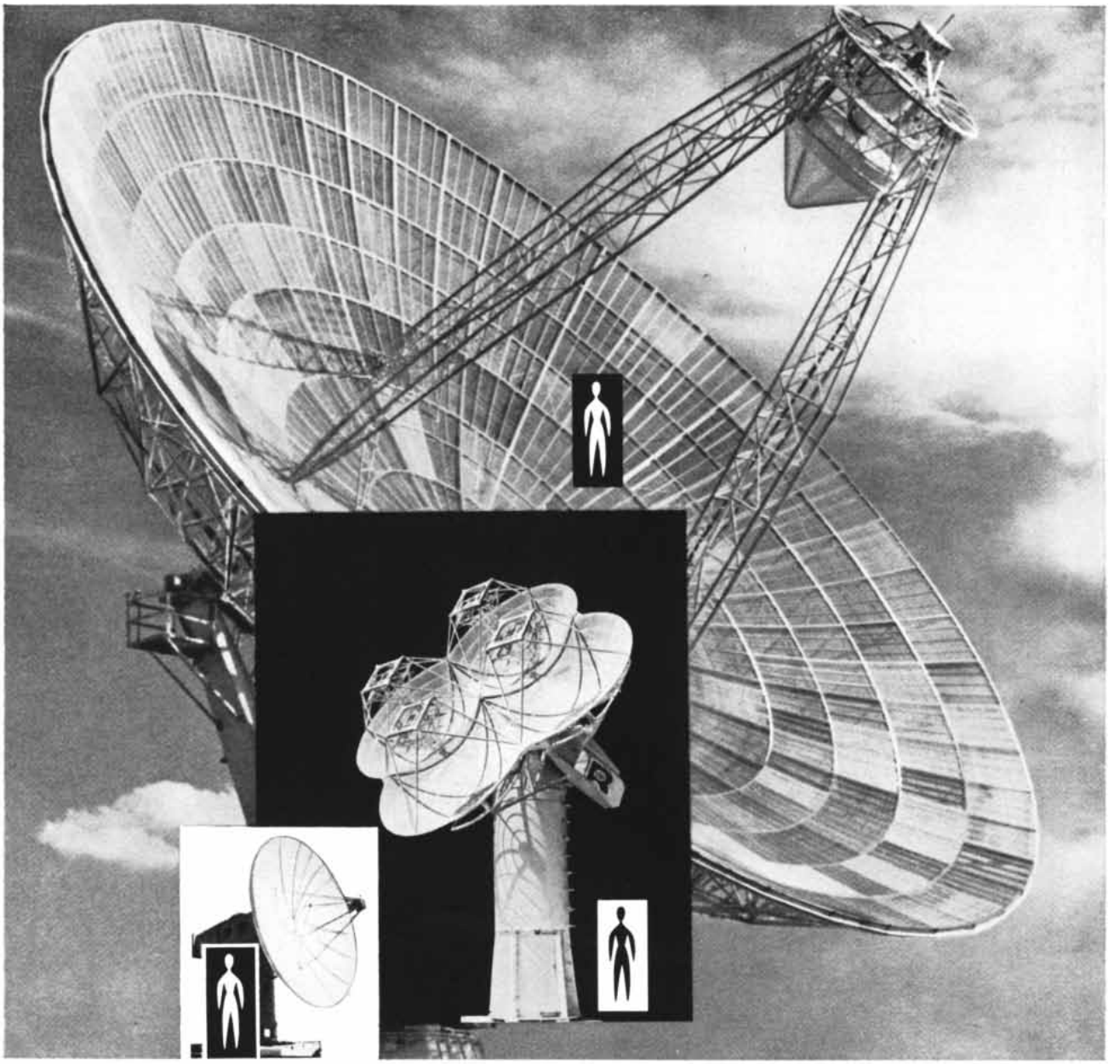


MUD DAUBER, *Sceliphron caementarium*, builds a substantial nest two or three inches across. The photographs on this page were made by William P. Nye and George E. Bohart.

NEST IS CUT OPEN, revealing parts of two separate cells stocked with paralyzed spiders to feed the larvae. The wasp's egg is the translucent ovoid object inside the white square.

In the sequence of evolutionary development that begins to emerge from study of these relations, the size of the prey compared with the size of the wasp emerges as a significant factor. Once the prey has been immobilized it must be carried back to the nest. Obviously the size of the prey must strongly influence the mode in which the wasp transports it. Since primitive wasps generally install only a single victim in each brood cell, they must take prey as large as or larger than themselves if their larvae are to have enough food to reach full size. In this they betray their more immediate derivation from the parasitoid Hymenoptera, which are invariably smaller than their hosts. The more primitive wasps accordingly drag their prey over the ground, grasping the victim in their mandibles. Some beat their wings to facilitate their progress and some drag their prey up on a high object and glide off with it. As might be expected, they cannot cover much ground by these methods, and they nest correspondingly close to the habitat of their prey. Wasps of the genus *Priononyx*, for example, nest in bare spots on the prairie, where their grasshopper prey abounds.

Wasps of the related genus *Sphex* illustrate the first stage of progress beyond this simple pattern of behavior. They hunt green meadow grasshoppers



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Example: Antennas of diversified design

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Thus, Radiation has developed more experience in automatic tracking antenna design and application of telemetry techniques than any other company. A 12-foot dish antenna, featuring new all solid-state tracking servo system and mode switching logic, is now under development for the X-20 (Dyna Soar) program. Two high-gain, wideband 85-foot antenna systems will soon be put into service on the Atlantic and Pacific Missile Ranges. Radiation quad-helix array antennas with phase monopulse tracking have been delivered for Bell's Telstar Project. And now, Radiation's broad-band "Telscom" antenna is available. Telscom *combines* acquisition and tracking operations for telemetry, surveillance and communications and operates from 200 to 2,300 Mc.

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in tall weeds and bushes, and yet they make their nests in bare sand and gravel. They are able to transport their victims considerable distances in flight because they take smaller prey. And because the grasshoppers are smaller the wasps must supply several of them to each larva. A species of the genus *Pemphredon* similarly may gather aphids in habitats far removed from the soft wood in which it constructs its galleries; this wasp flies back and forth between its hunting grounds and nest many times a day.

All of these species carry their prey in their mandibles. As a result they cannot dig while holding their prey, because it is held so far forward that it obstructs the use of their front legs. These wasps must leave their nests open or, if they close them, must put down the prey while they scrape open the entrance. Either of those actions exposes the prey or the contents of the nest to the attacks of a variety of parasites. The next breakthrough in the evolution of the digger wasps came, therefore, with the development of what I have called pedal prey-carrying mechanisms. Wasps that have made this advance grasp their prey in their middle and hind legs or in their middle or hind legs only, thereby leaving their front legs and mandibles free. They close the nest entrance when they leave and they are able to open it readily when they return while still holding their prey. Since the prey is carried well back beneath the body close to the center of equilibrium in flight, the pedal mechanisms greatly enhance the carrying efficiency of these wasps. Four subfamilies have made this breakthrough, and some members of two of those subfamilies have made the further advance to what I have called abdominal mechanisms, carrying the prey on their sting and, in one genus, on special modifications of the segments at the end of their abdomen.

This significant trend in the evolution of more advanced wasps would not have been possible without a parallel adaptation toward smaller prey. The more advanced prey-carrying mechanisms thus emerge as part of the great adaptive radiation in behavior that distinguishes the numerous advanced types of digger wasps, a radiation that was influenced

BEMBIX LARVA is seen in a rearing tin, feeding on flies of various kinds that have been supplied by the mother. A wasp of this genus stocks 20 to 40 flies in each cell of the nest.

AMMOPHILA URNARIA grasps a large leaf-eating caterpillar with its mandibles and front legs. The photograph, like most of those illustrating this article, was made by author.

not only by the availability of food niches but also by the pressure of parasites, by the independent evolution of complex nest-building behavior and by other factors that can be only dimly surmised.

A listing of the major groups of digger wasps in the probable order of their emergence as indicated by their morphology shows excellent concordance with changes in type of prey and in hunting and prey-carrying behavior. The crossing over of a line of wasps to a new type of prey clearly represents the invasion and occupation of a new adaptive zone. This has frequently resulted in diversification in the new zone and invasion of still further, previously inaccessible adaptive zones and subzones. Thus the emergence of new, successful groups of insects provided in the course of time a multitude of unoccupied or incompletely occupied niches into which most of the solitary wasps sooner or later moved.

What is remarkable about the solitary wasps is the thoroughness with which they pursued the evolutionary diversification of the arthropod phylum. Many of the arthropods preyed on are themselves predators; others exhibit protective coloration that appears to protect them from predators other than wasps; still others are mimics of stinging insects or are armed with chemical defense mechanisms that seem to hold other predators at bay. Preying mantids, those arch-predators of the insect world, are themselves the prey of at least two genera of wasps. The tree hoppers that look so remarkably like rose thorns and caterpillars that look like twigs are each preyed on by certain wasps. Diptera-hunters such as *Bembix* capture drone flies and other bee mimics, but bee-hunters such as *Philanthus* spurn bee mimics even under experimental conditions. The stink bugs, the defensive secretions of which are too well known to require comment, supply the brood cells of wasps of three separate and unrelated genera. Black widow spiders are frequently taken by blue mud daubers. Many formidable stingers, including worker harvester ants, bees of many kinds (not excluding bumblebees) and other wasps (not excluding social forms), are among the prey of solitary wasps. Evidently the various mechanisms of defense, deception and concealment elaborated by the insect world are primarily adapted to protect their possessors from predation by vertebrates, since they do not protect them from the solitary wasps.

The solitary wasps are esteemed by entomologists not only as subjects but also as colleagues of a sort. A small species of *Philanthus* nesting in my back yard a few years ago collected three new species of bees; these have since been described, one of them being named appropriately *philanthanus*. The prize example of this collaboration comes from the Congo. In 1915 Herbert Lang of the American Museum of Natural History trained several native assistants to collect flies being brought to their nests by *Bembix dira*. Among the nearly 1,000 flies brought in by the wasps there were more than 200 species belonging to 14 families. A great many thus collected were new to science, and several have not been rediscovered since!

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MATHEMATICAL GAMES

A bit of foolishness for April Fools' Day

by Martin Gardner

In keeping with the spirit of April Fools' Day, which is close to the day on which this issue goes to subscribers, a collection of 37 short problems is presented in the hope of "catching" as many readers as possible. Every problem conceals some sort of joke. None is mathematically significant. For this reason the answers are given at the end of this month's department instead of being withheld until next month. The reader is urged, however, not to peek until he has made at least a semiserious attempt to answer as many of the questions as possible.

1. Three Navaho women sit side by side on the ground. The first woman, who is sitting on a goatskin, has a son who weighs 140 pounds. The second woman, who is sitting on a deerskin, has a son who weighs 160 pounds. The third woman, who weighs 300 pounds, is sitting on a hippopotamus skin. What famous geometric theorem does this symbolize?

2. A tired physicist went to bed at 10 o'clock one night after setting his alarm clock for noon the following day. When the alarm woke him, how many hours had he slept?

3. Joe throws an ordinary die, then Moe throws the same die. What is the probability that Joe will throw a higher number than Moe?

4. What is the exact opposite of "not in"?

5. On level ground a 10-foot pole stands a certain distance from a 15-foot pole [*see top illustration on page 158*]. If lines are drawn from the top of each pole to the bottom of the other as shown, the lines intersect at a point six feet above the ground. What is the distance between the poles?

6. "How much will one cost?"

"Twenty cents," replied the clerk in the hardware store.

"And how much will twelve cost?"

"Forty cents."

"Okay. I'll take nine hundred and twelve."

"That will be sixty cents."

What was the customer buying?

7. A triangle has sides of 13, 18 and 31 inches. What is the triangle's area?

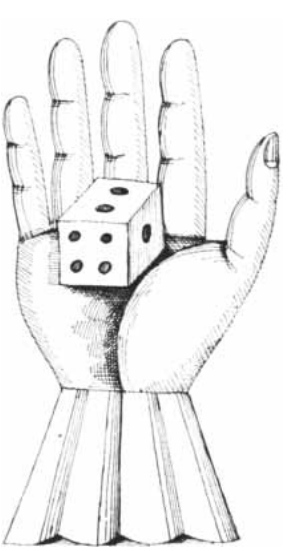
8. What familiar English word is invariably pronounced wrong by every mathematician at the Institute for Advanced Study in Princeton, N.J.?

9. John Kennedy was born in 1917. He became president in 1960. His age is 46 and he has been in office 3 years. The sum of these four numbers is 3,926. Charles de Gaulle was born in 1890. He became president of France in 1958. His age is 73 and he has been in office 5 years. The sum of these four numbers also is 3,926. Can you explain this remarkable coincidence?

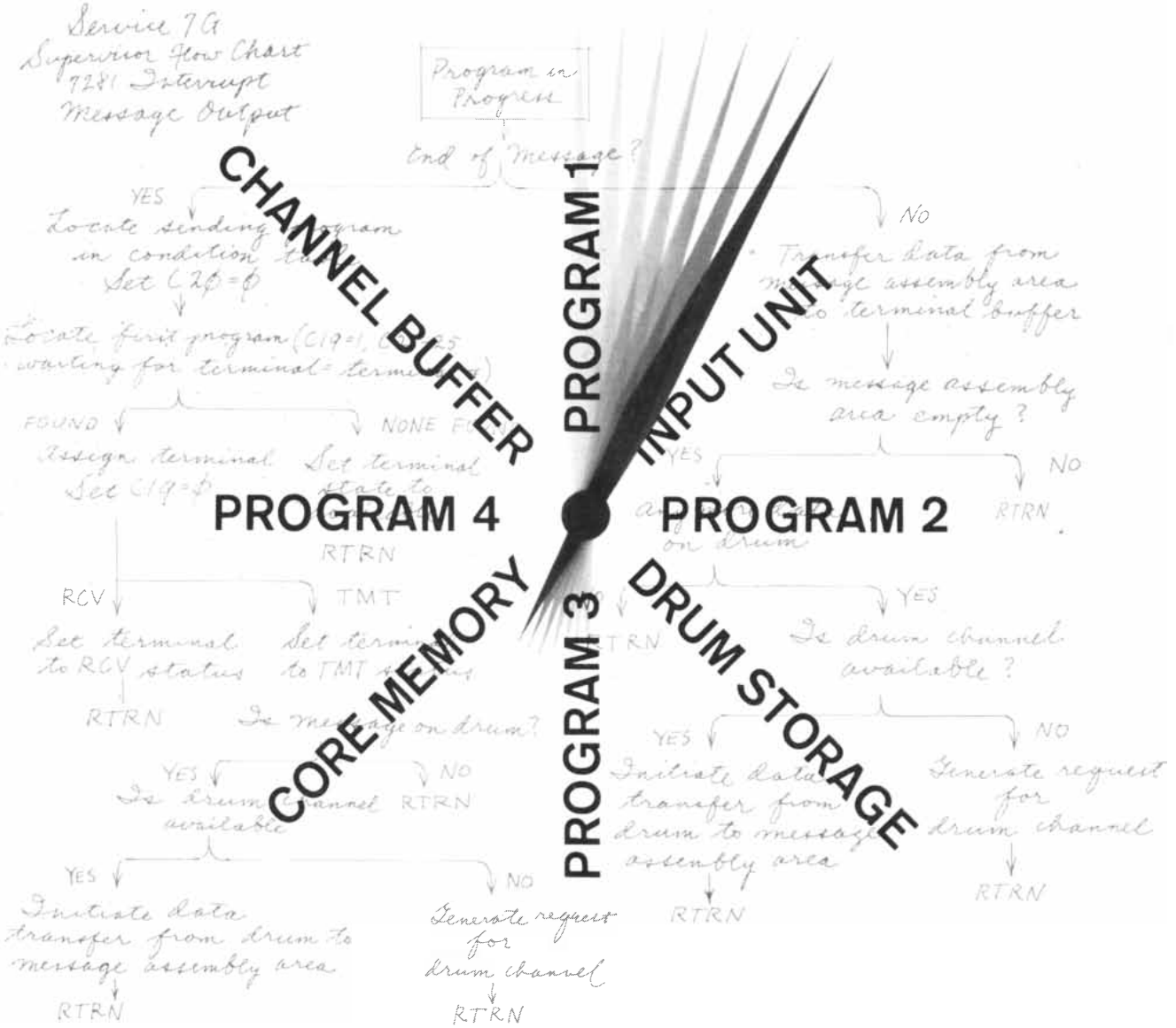
10. What angle is made by the two colored lines on the cube in the bottom illustration on page 158?

11. Rearrange the letters of NEW DOOR to make one word.

12. The edge of a reservoir is a perfect circle. A fish starts at a point on the edge and swims due north for 600 feet, which takes him to the edge again. He then swims due east, reaching the edge



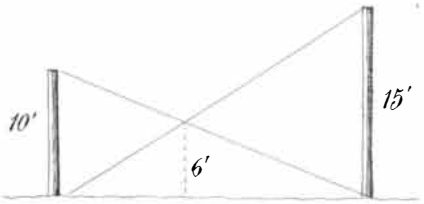
A die is thrown by Moe and Joe



How can we make computers more accessible?

Existing systems which process programs sequentially may take considerable time to return processed results. Therefore, IBM is exploring a theoretical system which would cycle several programs through the central processing unit (CPU) at extremely short intervals. This approach could achieve superior user response time by effectively giving each program immediate access to the CPU. The proposed system combines multiprocessing and multiprogramming techniques. It would use an IBM 7090, together with a programmed multiplexing system, to transfer messages in and out of core memory without bothering the CPU. Built-in protection would keep programs in memory from being destroyed by programs using the CPU. Drum storage units with fast access time would store partially executed programs with a disk file providing auxiliary storage.

Governed by a supervisory multiprogramming system, programs would cycle between memory and the drum storage, receiving a "slice" of processing time each time they reached the head of the queue. The supervisor would allocate memory space, maintain work schedules, assign vacated processing facilities, and monitor the interrupt system. By overlapping input-output operations and time-sharing the CPU, systems like this may make future computers more convenient to use as well as more efficient to operate. If you are interested in making important contributions in programming systems or other fields in which IBM scientists and engineers are finding answers to basic questions, write to: Manager of Employment, IBM Corporation, Department 659D, 590 Madison Avenue, New York 22, New York. IBM is an Equal Opportunity Employer.



What is the distance between the poles?

after going 800 feet. What is the reservoir's diameter?

13. A statistician gave mathematical tests to everyone who lived in a village of 6,000 people and at the same time measured the lengths of their feet. He found a strong correlation between mathematical ability and foot size. Explain.

14. Roy G. Biv, of Rainbow, Ore., wants to know what familiar continuum is expressed by the following words: flushed, New Jersey town, cowardly, naïve, depressed, dyestuff, shrinker.

15. Write a simple formula with only the one variable, x, such that when any positive integer is substituted for x, the formula is sure to give a prime number.

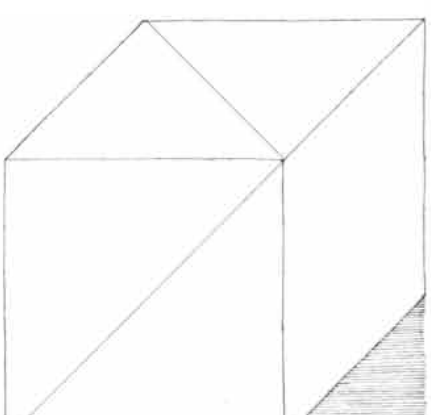
16. A man wishes to build a house on a large triangular plot of land, then to construct three straight roads, each leading from the house to a side of the triangle and each road perpendicular to the side. The triangle is equilateral. Where should he place his house in order to minimize the sum of the lengths of the three roads?

17. Divide 50 by 1/2 and add 3. What is the result?

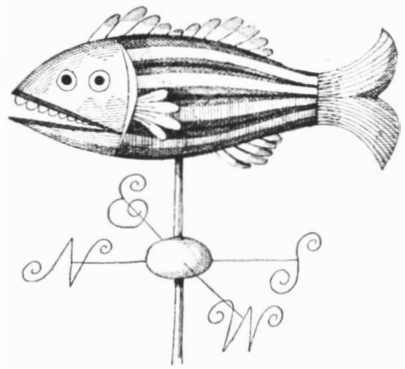
18. In the following line of letters cross out six letters so that the remaining letters, without altering their sequence, will spell a familiar English word:

B S A I N X L E A T N T E A R S

19. A topologist bought seven dough-



What angle is made by the colored lines?



How to measure diameter as the fish swims

nuts and ate all but three. How many were left?

20. In going over his books one day a bookkeeper for a toy company noticed that the word "balloon" had two sets of double letters, one following the other. "I wonder," he said to himself, "if there is an English word containing *three* sets of double letters, one right after the other." Such a word appears on this page. Can you find it?

21. The colored lines in the bottom illustration on page 163 are bisectors of the two base angles of a triangle. They intersect at right angles. Leo Moser of the University of Alberta asks: If the base of the triangle is 10 inches, what is its altitude?

22. How many months have 30 days?

23. Mrs. Smith wants to stop smoking after she finishes her last remaining nine cigarettes. She can make a new cigarette by wrapping three butts in a piece of cigarette paper. If she uses this technique as many times as she can, how many cigarettes can she smoke before she finally quits?

24. The following limerick was composed by Leigh Mercer of London. Can you read it correctly?

1,264,853,971.2758463

25. "Here are three pills," a doctor says to you. "Take one every half-hour." You comply. How long will your pills last?

26. One hundred and thirty-seven men have signed up for an elimination tennis tournament. All players are to be paired for the first round, but because 137 is an odd number one player gets a bye, which promotes him to the next round. The pairing continues on each round, with a bye to any player left over. If the schedule is planned so that a minimum number of matches is required to determine the champion, how many matches must be played?

27. Find a word of 10 letters that can

be typed by using only the top row of letters on a typewriter.

28. A box contains two U.S. coins that together total 55 cents. One is not a nickel. What are the coins?

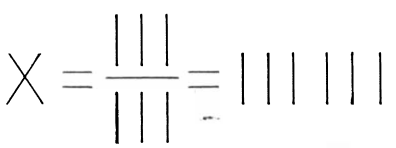
29. A fish weighs 20 pounds plus half its own weight. How much does it weigh?

30. The following telegram was recently composed by Roger Angell, a writer on the staff of *The New Yorker:*

"MARGE, LET DAM DOGS IN. AM ON SATIRE; VOW I AM CAIN, AM ON SPOT, AM A JAP SNIPER. RED, RAW MURDER ON GI! IGNORE DRUM . . . WARDER REPINS PAJAMA TOPS . . . NO MANIAC, MA! IWO VERITAS: NO MAN IS GOD.—MAD TELEGRAM."

What is so remarkable about this message?

31. D. G. Prinz, a mathematician with Ferranti Ltd. in Manchester, England, discovered the following symmetrical equation:



What is the value of x? (Hint: Each set of "III" can be interpreted in three different ways.)

32. Arrange six glasses in a row as shown in the top illustration on page 166. The first three glasses are filled with water, the last three are empty. By moving one glass only, change the arrangement so that the glasses alternate empty with full.

33. A wheel has 10 spokes. How many spaces does it have between spokes?

34. "The number of words in this sentence is nine." The sentence just quoted is obviously true. The opposite of a true statement is usually false. Give a sentence that says the exact opposite of the quoted sentence but is nevertheless true.

A house builder's triangular problem

The bookkeeper and his balloon

35. Two girls were born on the same day in the same year of the same parents, yet they were not twins. Explain.

36. If someone says to you, "I'll bet you a dollar that if you give me five dollars I'll give you a hundred dollars in exchange," would that be a good bet to take?

37. O. Henry's famous short story, "The Gift of the Magi," opens as follows: "One dollar and eighty-seven cents. That was all. And sixty cents of it was in pennies." Is there anything mathematically wrong here?

The answers to the above problems are as follows:

1. The squaw on the hippopotamus is equal to the sons of the squaws on the other two hides.

2. Two hours.

3. 5/12. The probability that both will throw the same number is 1/6, therefore the probability that one will throw higher than the other is 5/6 or 10/12. This is halved to give the probability that Joe will get a higher number than Moe.

4. "In."

5. Any distance. The height of the intersection is equal to the product of the heights of the two poles divided by their sum.

6. House numbers.

7. Zero.

8. "Wrong."

9. Any date added to the number of years since that date will total the cur-

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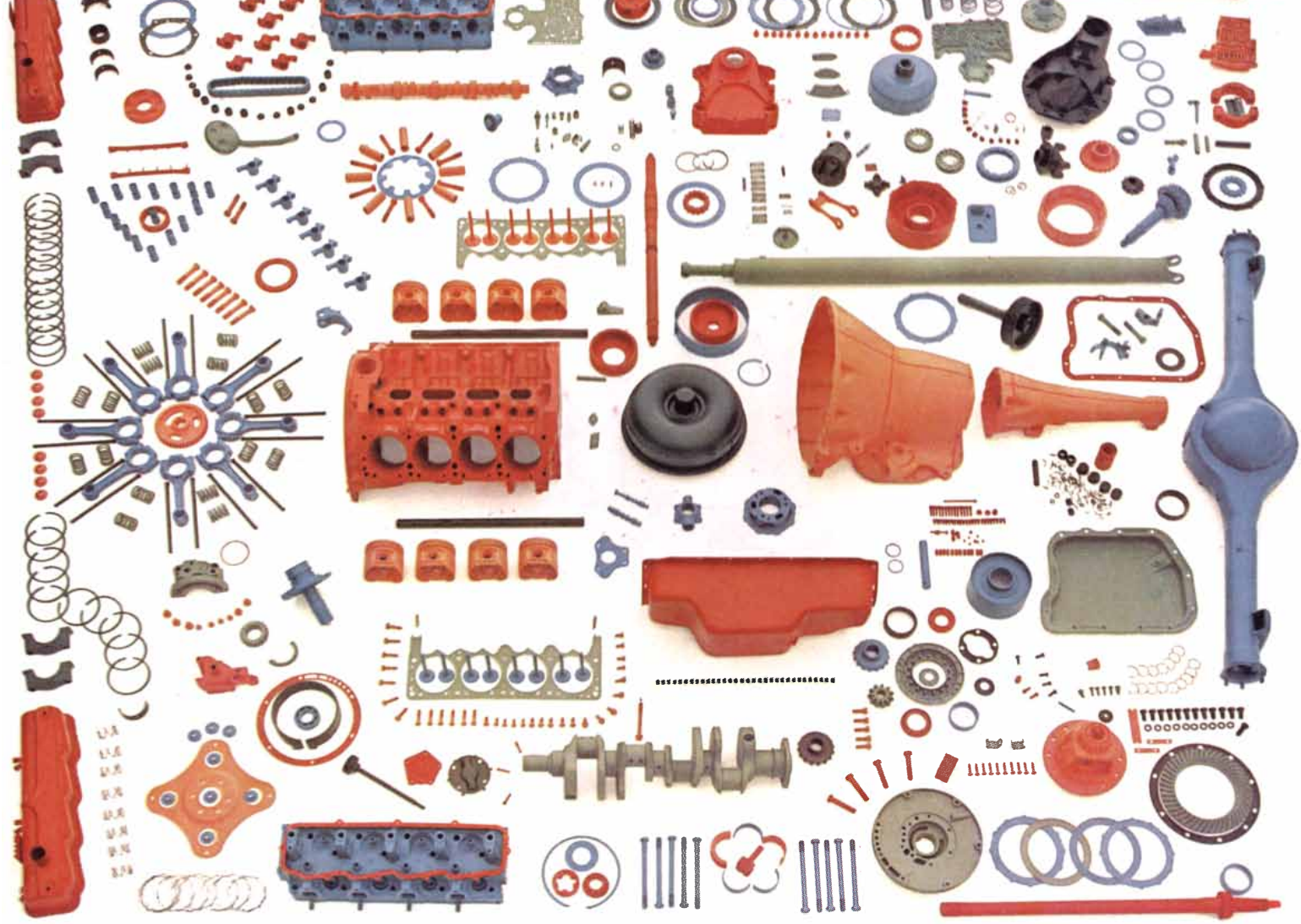

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rent year. Two such totals will be twice the current year.

10. Sixty degrees. Joining the ends of the red lines completes an equilateral triangle.

11. ONE WORD.

12. A thousand feet. The fish makes a right-angle turn. A right angle, with its vertex on the circumference of a circle, intersects the circumference at the end points of a diameter. The diameter is therefore the hypotenuse of a right triangle with sides of 600 and 800 feet.

13. "Everyone" included babies and children.

14. The spectrum of visible light: red, orange, yellow, green, blue, indigo, violet. Roy G. Biv, a mnemonic acronym for the spectrum, is really Stephen Barr of Woodstock, N.Y.

15. $2 + 1^x$.

16. Anywhere. The sum of the three paths is a constant equal to the triangle's altitude.

17. 103.

18. After crossing out SIX LETTERS, the remaining letters spell BANANA.

19. Three.

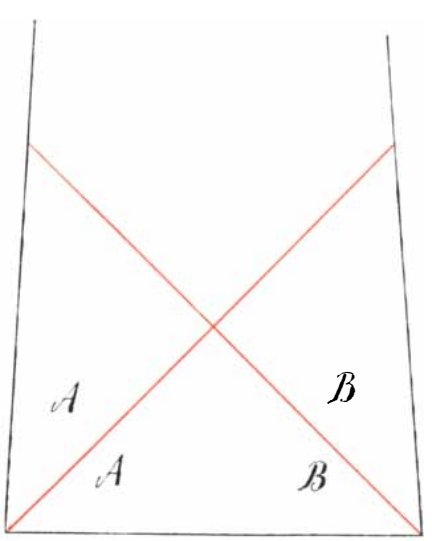
20. Bookkeeper.

21. Infinity. Angles *a* and *b* sum to 90 degrees. The two base angles of the triangle ($2a$ and $2b$) sum to 180 degrees. Therefore the top angle of the triangle must be 0 degrees, with the sides of the triangle parallel, meeting at infinity.

22. All but February.

23. Thirteen.

24. One thousand two hundred and
sixty-
Four million eight hundred and
fifty-
Three thousand nine hun-
Dred and seventy-one
Point two seven five eight four
six three.



What is the altitude of the triangle?

Mrs. Smith smokes her last cigarettes

25. One hour.

26. Because 136 players must be eliminated, there must be 136 matches.

27. Typewriter.

28. A 50-cent piece and a nickel. The 50-cent piece is not a nickel.

29. Forty pounds.

30. The telegram is a palindrome, reading the same backward and forward.

31. $$X = \frac{111}{3} = 37.$$

In the fraction, the III above the line is in the decimal system, the III below is a Roman numeral. The next III is also Roman and the last III is in the binary system.

32. Pick up the second glass, pour its contents into the fifth glass, replace the second glass.

33. Ten.

34. "The number of words in this sentence is not nine."

35. They were in a set of triplets.

36. No. He can take your $5, say "I lose" and hand you his $1. You win the bet but lose $4.

37. No. At the time O. Henry wrote this story the U.S. still had a two-cent coin.

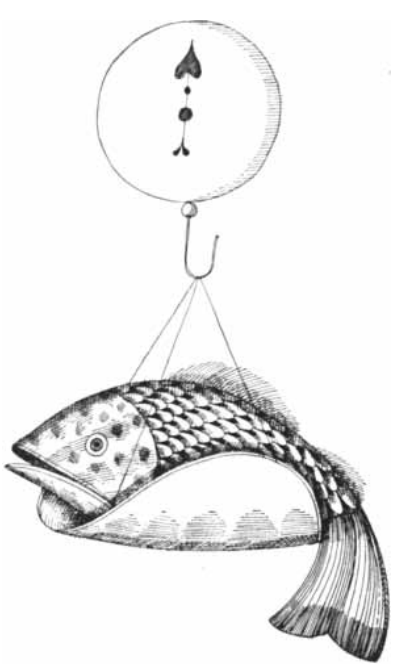
A famous unsolved problem, discussed in this department last November, has been solved. The problem: In how many different ways can the standard 8-by-8 checkerboard be cut into two congruent halves? Cutting must be along grid lines, and rotations and reflections are not considered different.

The first reader to report the solution was John McCarthy, who assigned the problem last November to his class of students at the Stanford Computation Center in Stanford, Calif. The computer found a total of 92,263 solutions. This was later confirmed by Bruce Fowler,

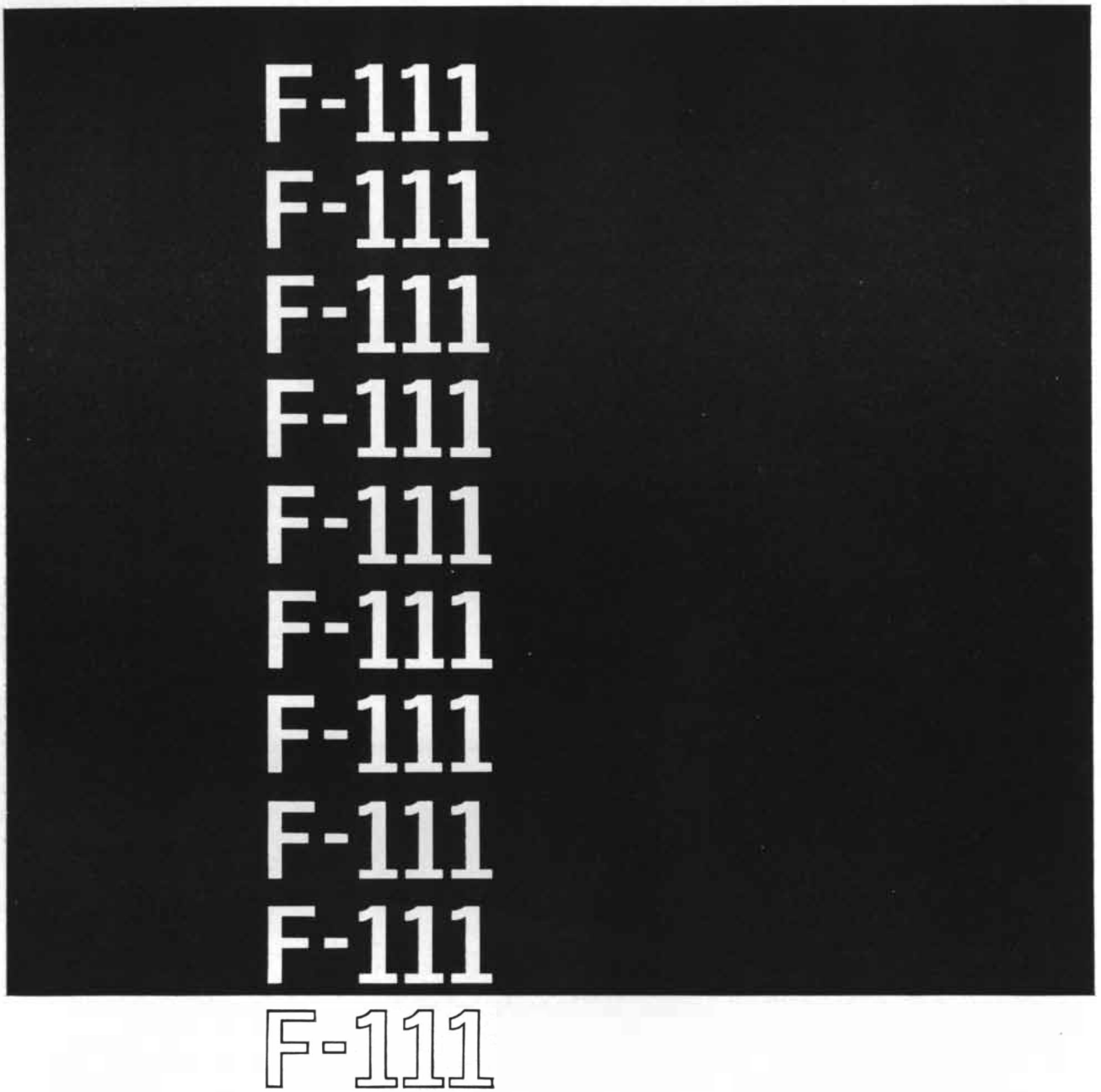
A tennis player moves to the next round

who made use of an IBM 1620 computer at the Newark College of Engineering in Newark, N.J. Running time: 26 minutes. Some notion of how rapidly the number of solutions increases as the size of the board increases can be gained from the fact that the 6-by-6 board has only 255 solutions. The IBM 1620 confirmed this in less than three seconds.

I have not yet learned the details of the Stanford program. Fowler reports that his program is based on the fact that any bisecting line must pass through the board's center, and that the two halves of the line are symmetrical with respect to the center. "The program works some-



A fish is weighed



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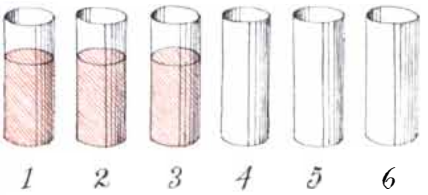

Move one glass to alternate empty and full

what like the mouse in a maze," he writes. "It starts at the center, moving one space at a time and making all possible right-hand turns. When it bumps into its previous path, it backs up one space, turns left 90 degrees and continues. When it reaches the edge of the board, it scores up one solution, backs up one space, turns left, and so on. In this way all possible solutions are obtained. The total is printed when it discovers the direct route to the edge, in the original starting direction."

The "backtrack" program just described applies only to the even-order boards. Odd-order boards, with center square removed, are more complicated. McCarthy's students found a total of 1,897 solutions for the 7-by-7 board, also previously unsolved, and this figure has also since been verified by Fowler. Fowler attempted the 9-by-9, but after an hour's running time the machine had found only 194,442 solutions, which represent only a small bite out of the total. He estimated the running time for the 9-by-9 to be about a week—and that was more time than the machine could spare.

How to lose $4

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THE AMATEUR SCIENTIST

How to construct a stream table to simulate geological processes

Conducted by C. L. Stong

Although the natural forces that build mountains, alter coast lines, carve river valleys and otherwise modify the landscape proceed at a pace and on a scale that usually rule out direct observation, many geological processes can be demonstrated realistically by means of a stream table, an apparatus that amounts to little more than a sophisticated version of a child's sandbox. The apparatus can take the form of a wide, flat-bottomed trough that is hinged in the middle so that the sand in one section can be raised or lowered to simulate slopes arising from vertical excursions of the earth's crust. At one end of the table is a source of water—a spray or a stream—and at the other is an outlet that can be adjusted in depth. The table is filled with sands of various colors and grain sizes, or sand mixed with pebbles or crushed ice, depending on the geological feature to be demonstrated. Colored sirups, molten lead, plastic sheeting and other materials can be used to create, identify and alter the direction of the forces of erosion. By embedding a sheet of plastic in the sand, for example, one can re-create the effects of underground water in the appearance of springs, lakes and swamps. In short, the stream table is a versatile means of simulating a miniature of large-scale geological processes and their consequent land forms. An apparatus particularly well suited to amateur experimentation has been constructed as a research project by Maurice Schwartz, a student of geology at Columbia University.

"My stream table," writes Schwartz, "is some three feet wide, 10 feet long and six inches deep. It is hinged so that either end can be raised and it holds 500 pounds of dry sand. The weight of the completed assembly when wet, together with accessories, approaches half a ton. I first made two boxes, each open at one end, of 20-gauge galvanized iron and after soldering the corners I etched the metal surface with dilute muriatic acid and applied two coats of epoxy resin paint. The sheet-metal boxes were then nested for support in close-fitting wooden boxes. Half-inch plywood was used for the bottoms. The ends and sides, which measure two by six inches in cross section, were made of Douglas fir. One box is about four feet long and the other about six feet long. The open end of the larger box was beveled at an angle of 20 degrees to allow the hinged sections to be folded. Three equally spaced cross cleats were spiked to the bottom of each box to give added strength and to provide air space so that water could not collect between the bottom and the supporting surface. One could reduce the cost somewhat by constructing the boxes of rough planks and lining the wood with plastic sheeting. The sand is shifted frequently, however, and thin plastic is not particularly durable. The end sections were joined by a heavy piano hinge and covered by a wide strip of heavy sheet rubber that extends across the bottom and over the sides. The strip was first cemented over the hinge and then secured at the edges by metal strips screwed to the wood. Ordinary door hinges, although not as strong, could be substituted and covered with a strip of opened automobile inner tube. In this case the crack in the bottom and the V-shaped openings at the sides should be covered with loose pieces of plywood to prevent the weight of the sand from pushing the rubber into the openings.

"The larger section of the stream table is equipped with pipe racks for supporting shower heads about two feet above the sand and with a clip on the upper edge of the end for holding a garden hose that leads to a water tap. Rain is simulated by the sprinkler system and stream sources by the open hose. An outlet at the bottom of the smaller section is fitted with a short length of garden hose that can be clipped to the end at various heights for adjusting the depth of accumulated water [*see illustration on opposite page*].

"Accessories include plastic sheeting, a cement trowel, a few pounds of dry sand and a wave generator. My wave generator was improvised from a small aquarium pump of the type that has a leather diaphragm for a piston. The cylinder, piston and connecting rod were disconnected and a metal rod about an eighth of an inch in diameter and five inches long, threaded at each end, was inserted in the end of the connecting rod to replace the screw that held the leather diaphragm. During reassembly the metal rod was passed through a hole drilled in the bottom of the cylinder and a small wooden block was attached to the free end of the rod to serve as a paddle. The completed mechanism was then mounted on a plywood base that is clamped to the side of the stream table where the paddle makes contact with the water. The speed of the motor, and hence the size of the waves, can be controlled by a rheostat.

"The apparatus rests on a sturdy platform that is about waist-high. The larger end is raised and lowered by means of an automobile jack and is supported in elevated positions on blocks. In most experiments the smaller end of the table remains level and the larger end is tilted to represent elevated terrain. Coast lines are formed by pushing sand away from the lower end of the table. Sand of any grade may be used, but I prefer the fine white variety used in hourglasses and known as Ottawa sand. This material is clean, flows readily and holds its shape nicely when wet. Ottawa sand can be procured from suppliers of building materials. It is currently priced at $5 per 100 pounds in the New York City area. Five hundred pounds fills the stream table to a depth of about four inches.

"The operation of the table makes some demand on the experimenter's manipulative skills because the production of realistic effects involves art as much as science. Most experiments are set up by first modeling wet sand to represent some combination of geological features such as mountains, valleys, plains or coast lines. The features are then subjected to erosion by streams, waves or mechanical forces. The investi-

gation of land erosion in rainy regions makes a nice introduction to the technique.

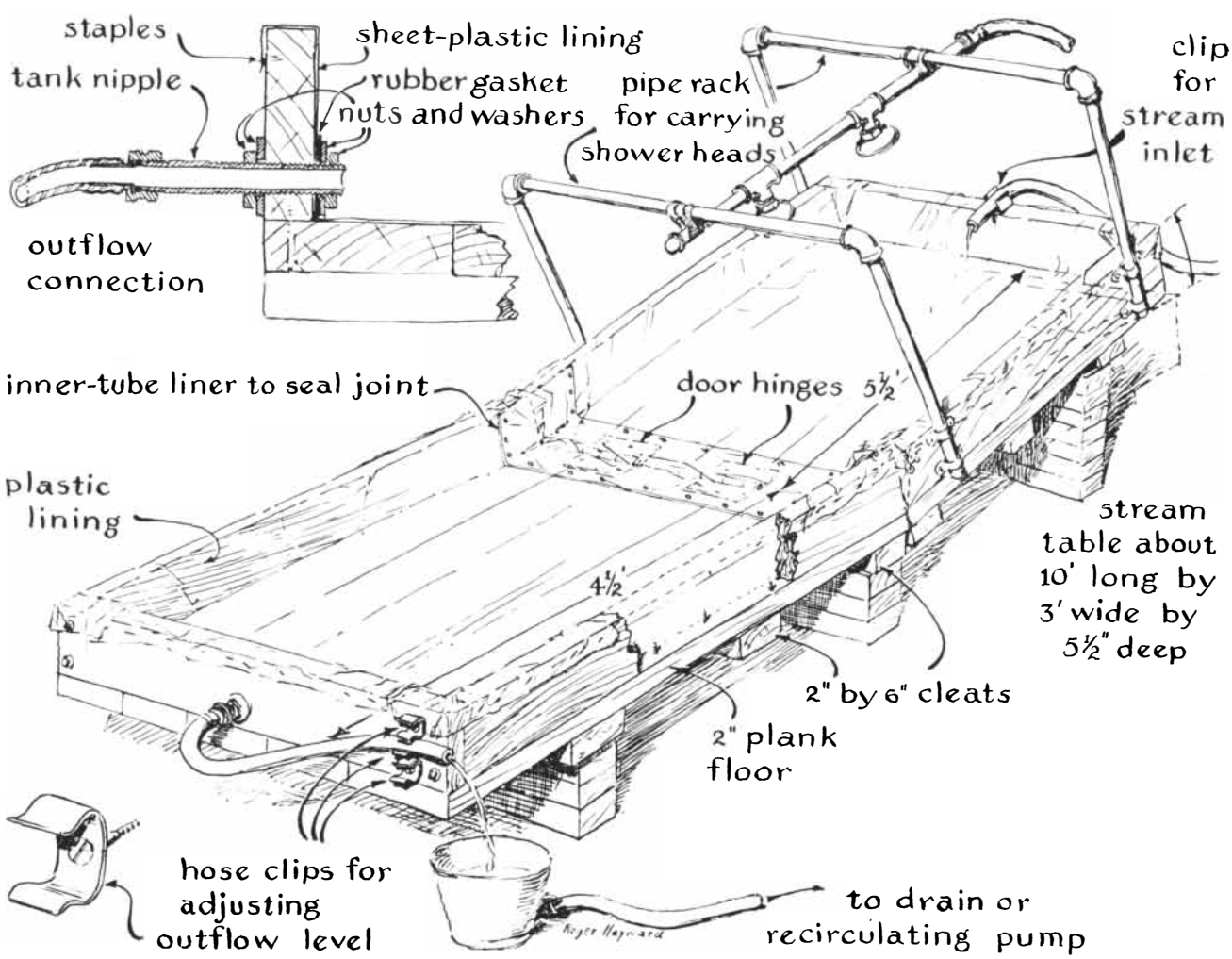
"The introductory series of experiments assumes a region that has recently been elevated above sea level by natural forces: a uniform, slightly rolling terrain that slopes gradually to the sea. First elevate the larger end of the table about 18 inches and block it in place. Place about half of the sand in the elevated section so that it extends slightly past the hinge into the lower section and cover it with plastic sheeting. The edges of the sheeting should be turned up about an inch on all sides. Place the remainder of the sand over the sheeting so that it extends to within about three feet of the lower end and make a few small piles of sand here and there in the empty area. Wet the sand thoroughly and smooth it from side to side to form a shallow curve down the middle with the edges about an inch above the center. Mold the lower end of the sand to form a steeply sloping beach and give the inland topography a bit of moderate relief here and there. Adjust the outlet tubing so that the water that accumulates in the smaller section will reach about half the depth of the sand and thus establish an initial shore line. Connect the inlet hose to the shower heads and open the tap to simulate a brisk rain.

"Initially the falling drops will merely smooth the surface and the water will soak into the sand. After a short interval, however, small gullies will form near the lower boundary of the rain belt and gradually become longer and deeper until they unite in a single, fast-running stream. As the rainfall continues, erosion will extend the gullies slowly upstream.

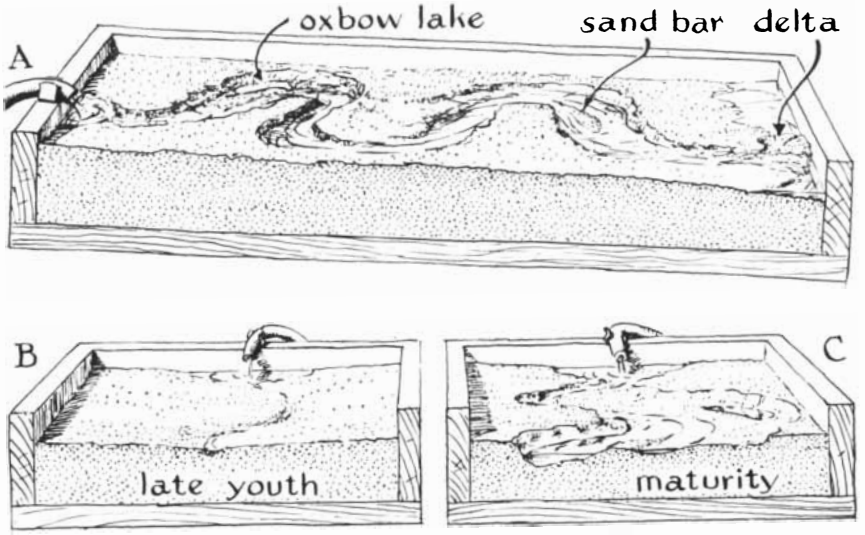
"In the meantime the main stream deepens rapidly and within a few minutes will have cut a relatively straight channel to the 'sea,' a channel with steep banks and few sand bars. The runoff accumulating at the lower end of the stream table gradually submerges the marine features; bays, peninsulas and islands appear, depending on the prearranged pattern of sand.

"After the basin fills note in particular the mechanism of delta formation at the mouth of the river. The current quickly loses its velocity when it encounters the still water, and it deposits a thin, fan-shaped pattern of sand on the bottom that extends a considerable distance beyond the mouth of the stream. Geologists refer to this initial deposit as the 'bottom set.' A second deposit, known as the 'fore set,' is characterized by a steep, straight edge that advances over the bottom set. As the top of the fore set approaches 'grade' (the average level of the stream), a thin, gently sloping deposit is laid down on top of the fore set. Thereafter erosion cuts a channel in the top set, and the velocity of the stream, now confined to the channel, increases and initiates a new cycle with the formation of bottom set at the mouth of the new channel. When this cycle has progressed through the stages of fore set and top set, still another channel forms. In this way the exposed surface of a mature delta becomes a fan-shaped patchwork of small islands interlaced by streams.

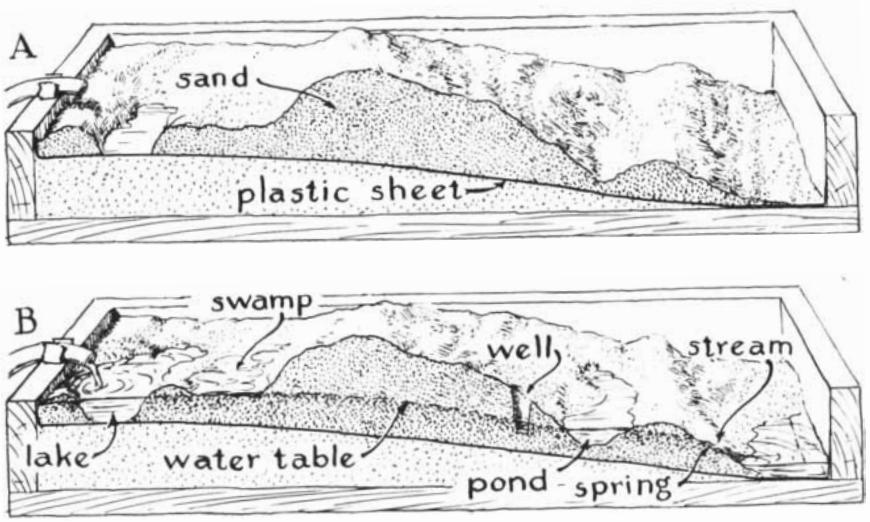
"When the delta has matured, lower



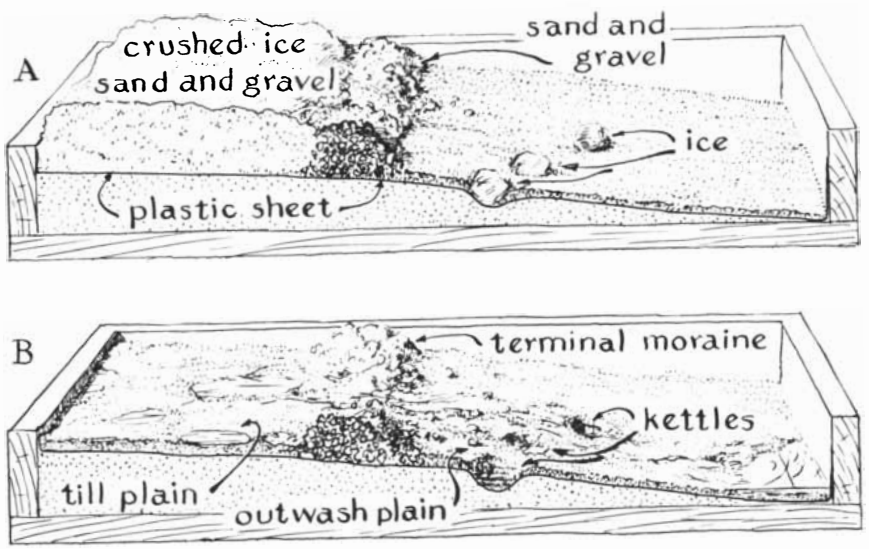
Construction of the stream table



River-valley demonstration and two stages in maturation



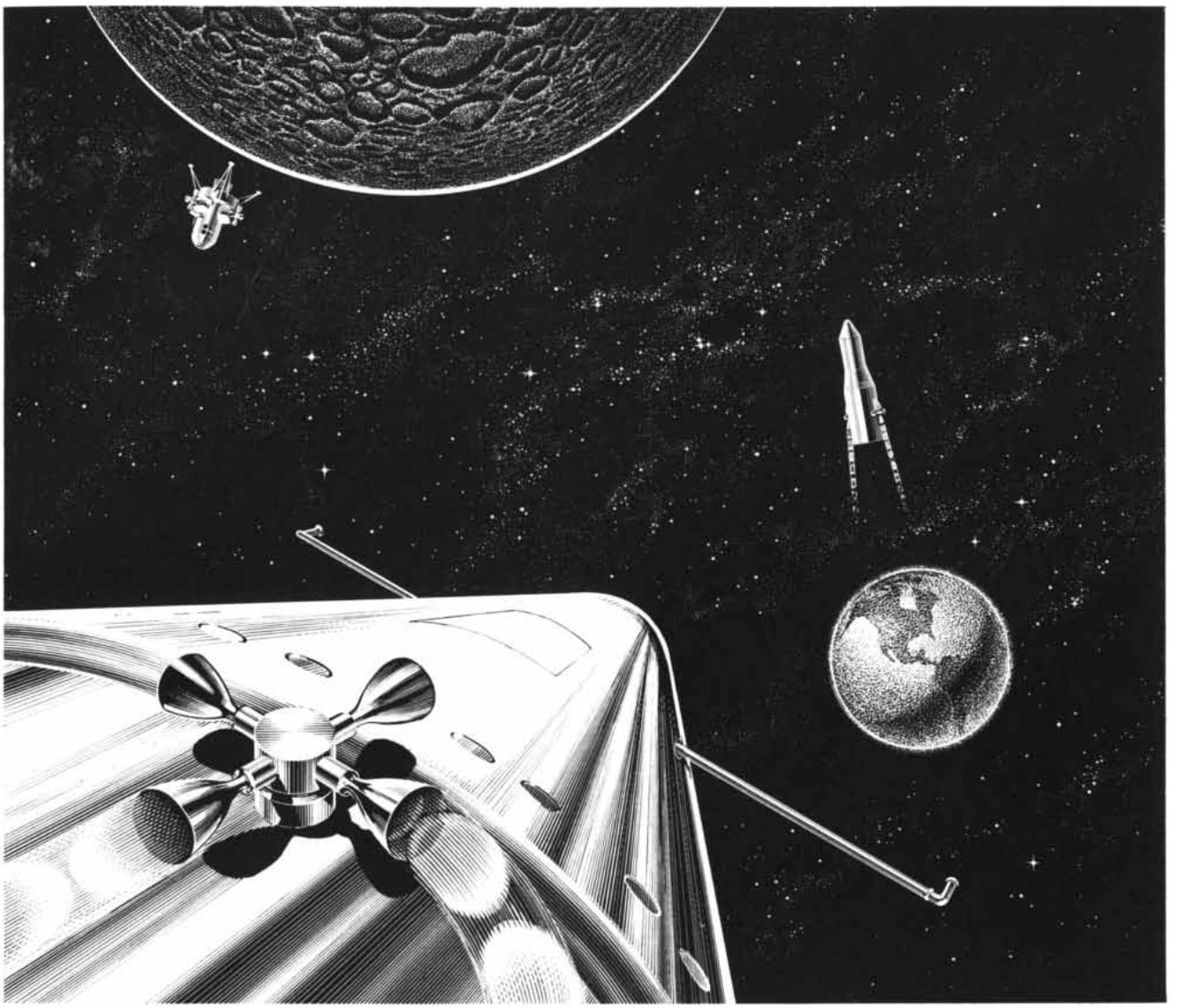
Ground-water setup (A) *and demonstration* (B)



Setup (A) *and demonstration* (B) *of glacial land forms*

the larger section of the stream table so that the terrain slopes about three inches from end to end. This simulates a later stage in the history of the stream's development, when erosion has leveled the uplands. Initially the gullies that appeared beneath the shower heads had joined to form a relatively narrow, fast-running stream that tended to deepen faster than it widened. After the straight channel reached a certain depth, however, its steep banks were undercut here and there. Material breaking free at these points was swept downstream. Other portions of the bank, where the sand was packed more densely, resisted the current for a time, and erosion proceeded fastest at the opposite bank. Slight bends therefore appeared along these stretches of the river. Such departures from straightness had the effect of directing the water still more forcefully against the points of weakness and accelerating erosion. With the simulated erosion of the uplands, the narrow, fast-running stream becomes a slow, meandering river. After some hours it will be observed that the meanders move slowly downstream and bends form near the mouth of the river. The result is a broad valley dotted here and there by former islands, sand bars and strange crescent-shaped lakes that mark channels originally occupied by the river.

"Other major features of rainy regions are induced by ground water that collects between the surface of the soil and a layer of relatively impervious material underneath. This layer is simulated by the plastic sheeting of the stream table. To set up a demonstration of ground water, first shut off the shower heads and drain the accumulated water. Then lower the larger section so that the sand is about six inches higher than it is at the outlet end. Mold a terrain that slopes gradually and, beginning at the high end, form in succession a lake bed, a lowland, a hill with gently sloping sides and a small basin behind a ridge near the coast line [*see middle illustration at left*]. Detach the garden hose from the shower heads, clip it to the elevated end of the stream table and open the tap. Regulate the flow so that seepage into the sand just balances the inflow and causes the level of the lake to remain constant. Within a matter of minutes the underground water table will form, seep into the lowland and create a swamp. Shortly thereafter a pond will form in the depression near the coast line and one or more springs will appear downgrade from the pond, if the edge of the plastic sheeting has been brought close to the surface. Runoff from the spring will



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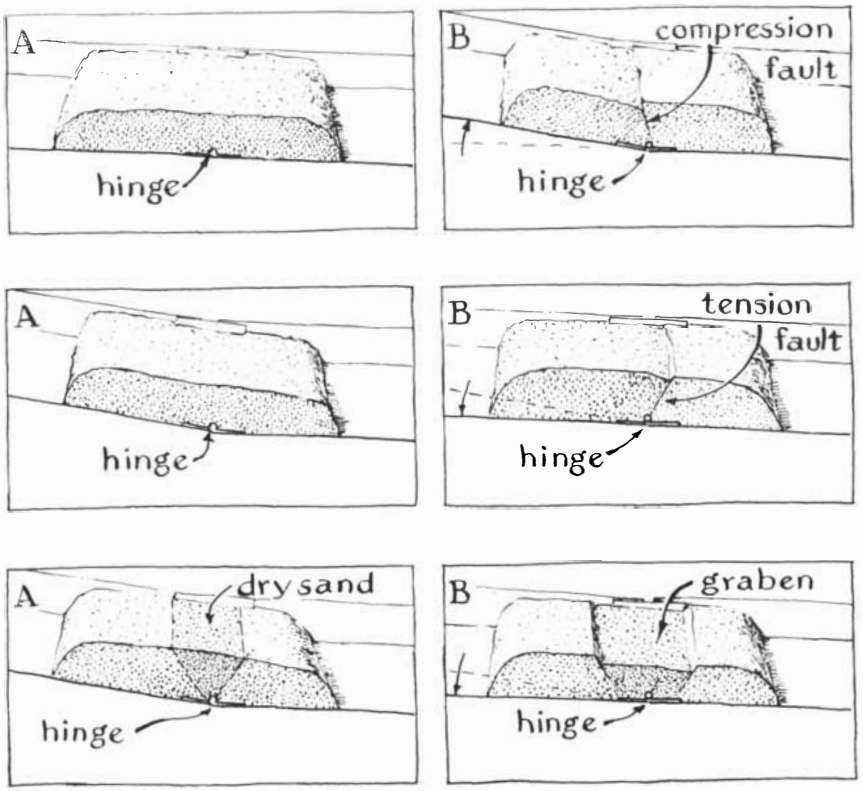
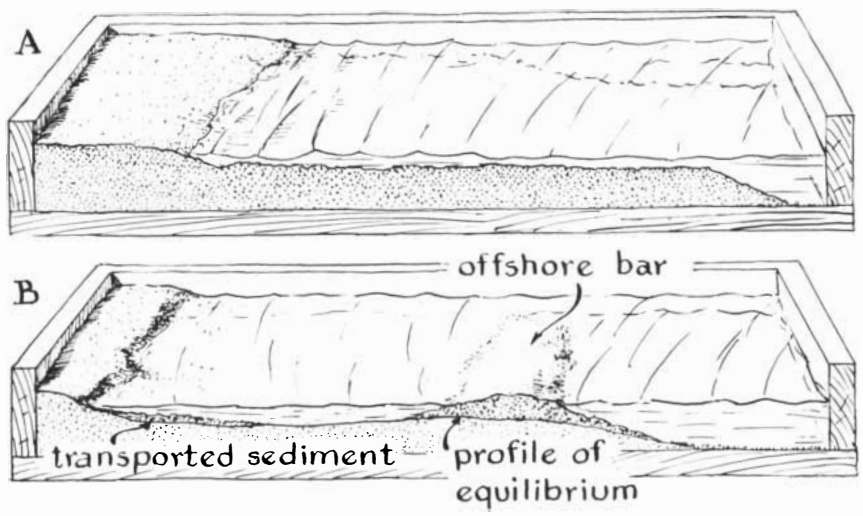
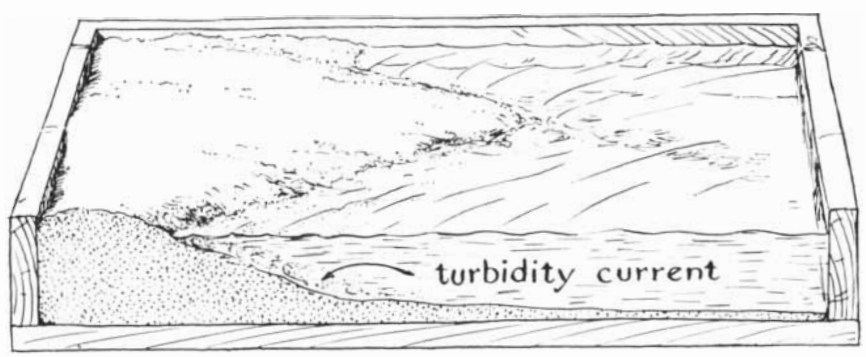


Three types of fault that result from vertical movement



Beginning (A) *and equilibrium stage* (B) *of sand-bar formation*



Demonstration of turbidity currents

gradually fill the basin at the outlet and form a beach. A well dug in the face of the hill above the pond will fill to the height of the water table.

"Of the several geological agencies responsible for large-scale alterations of the landscape none is more spectacular in its effect than the action of glaciers. So far I have discovered no way to simulate the slow deformation and flow of ice in the stream table. But it is easy to duplicate the effects of a glacier in the region of its most extreme advance—where the flow of ice has stopped. The glacier simply melts and deposits its burden of transported material. The associated runoff erodes the downward-sloping terrain.

"To perform this experiment drain the stream table, remove about 75 pounds of sand, lower the larger section so that it is level with the smaller section and embed the plastic sheeting about an inch below the surface of the remaining sand, which should slope gently from one end to the other. Next build a ridge about six inches high across the mouth of a U-shaped valley, near the hinge, using a mixture of sand and pebbles. Then fill the upland space to a depth of eight inches with a mixture of four parts of crushed ice (or snow, if it happens to be available outside) to one part of sand. Bury several fist-sized lumps of ice in the sand downgrade from the ridge and let the table stand until the ice melts. The resulting surface will be marked by many features typical of glacial land forms. Several small lakes may form in the 'till plain' above the ridge of sand and pebbles. The ridge, which will have become somewhat eroded, represents a terminal moraine: the rubble deposited at the edge of a glacier. An 'outwash plain' will have formed downgrade from the terminal moraine, marked here and there by random pebbles and perhaps by a stream bed and depressions, known as kettles, that mark points where lumps of ice were buried—all typical remnants of ice erosion that can be observed in the northeastern U.S. as results of the continental glaciation that ended about 10,000 years ago.

"Some features of the crust's vertical excursions, such as the great uplift currently under way in the southwestern U.S., are quite easy to simulate. These uplifts invariably open cracks, or faults. In nature displacement at the interface can amount to as little as a fraction of an inch or to many feet. In the case of the Sierra Nevada a block of granite hundreds of miles long has split from the rest of the crust and has tilted in such a way that successive displacements have

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raised one side of the block thousands of feet and have similarly lowered the other side.

"To investigate faulting of three principal types remove the plastic sheeting from the stream table, place the automobile jack under the larger section and pile the wet sand level with the edges of the table as far as it will extend above and below the hinge. As you jack up the larger section, observe the sand. A crack will appear in the vicinity of the hinge, and as the larger section continues to rise the block of sand in the larger section will slide below that in the smaller section. This is an example of compression faulting. Note the angle of the fault with respect to the horizontal. Without disturbing the position of the table, smooth the sand at the fault and tamp it down lightly. Then reverse the jack and lower the larger section. A tension fault will now appear. Observe that the angle of this fault makes a large angle in relation to that of the compression fault. Jack up the larger section again, make a deep V-shaped trench across the table above the hinge and fill it with dry sand. Reverse the jack and lower the larger section. Two faults will appear, one on each side of the trench. The surface of the dry sand will drop below that of the wet material and form a 'graben,' a flat-bottomed trench with sloping walls. The upper valley of the Rhine River is a typical example, a depressed area some 200 miles long and 20 miles wide between faults bounding the Black Forest on the east and the Vosges Mountains on the west.

"A particularly fascinating series of experiments can be based on the erosive action of water waves on coast lines. Set up the stream table to form a deep basin some three feet square at the outlet end of the smaller section and mold wet sand into a sheer cliff about six inches high. Fill the basin to a depth of some four inches and set up the wave generator to produce waves about two or three inches from crest to crest. After five minutes lower the water to a depth of two inches. Observe the shape of the beach that emerges and particularly how the cliff has been undercut here and there. Such undercutting frequently carves sea caves from the rock, such as the Grotta Azzurra (Blue Grotto) on the island of Capri. Beach formations that stand high above present water levels are common features, such as those surrounding Great Salt Lake in Utah. Wave action is also responsible for such features as the long, thin offshore sand bars that characterize the eastern coast of the U.S. To observe the formation of sand bars, shut off the wave generator and build a smooth bank of sand the width of the tank and extend it into the water about a foot so that the surface of the sand is submerged an inch. Start the wave generator. Wave action will quickly transport sand from the leading edge of the bank to a region

Delta forming on stream table at mouth of river

Point of View...Times 32

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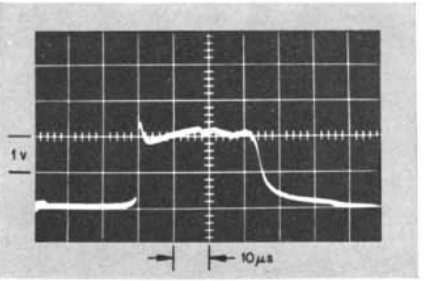
Mature river valley cut in sand of stream table

behind it, where some of it will form a long offshore sand bar. After a few minutes the growing sand bar will begin to interfere with the transport mechanism and the bottom will stabilize as a profile of equilibrium. Thereafter, if the amplitude of the waves does not increase, the sand bar and shallow basin behind it will remain as permanent features.

"Wave transport frequently links a small offshore island to the mainland by a sand bar, known as a tombolo. The transported sand may come from the mainland or from the island, depending on the wave action and the nature of the terrain. To simulate the formation of a tombolo, shape an offshore island on a shallow submerged shelf and generate waves that approach the island obliquely. In time the tombolo will form on the leeward side of the island in line with the advancing wave front. The agency of turbidity currents is responsible for the large-scale transport of submarine sediments. These can be simulated by pouring dilute sirup into the water at the edge of a steeply sloping beach. The currents are easy to follow by eye if a few drops of food coloring are added to the sirup.

"Numerous other experiments have been made. It is possible, for example, to simulate the formation of pillow lava: the irregularly rounded deposit that forms when molten lava flows into a lake or the sea. The glassy exterior of such pillows is caused by the rapid crystallization that occurs when the lava makes contact with the water. Cavities in the pillows are usually rich in minerals that are derived from gaseous elements trapped in pockets of the molten material. Realistic pillows are formed when molten solder is poured down a steep beach of the stream table.

"The apparatus invites much experi-



Super-orbital entry of a space vehicle—one returning to earth from a planet, rather than from an earth-orbiting mission—would result in searing *radiative* heating in addition to the more familiar *convective* type. As a spacecraft nose enters atmosphere, it pushes the thin air aside. A boundary layer is formed next to the skin. Ahead of that is a compressed mass of air; fronting that, a shock wave. The air behind the shock wave becomes incandescent, ionizes, and radiates to the heat shield. Within the boundary layer, friction heats the nose cone by convection.

Lockheed scientists believe that at higher than escape speed a blunt-nosed vehicle may be unable to sustain the radiative heating. Consequently, a return to the previously discarded sharp nose is indicated. Fluid mechanicists are calculating the heat load, determining how rapidly the nose will ablate and how to keep it sharp. Current shock tube tests are providing some clues.

Another research project in Lockheed's Fluid Mechanics Laboratories relates to the flow of buoyant fluids. A typical study program is the determination of how liquid hydrogen, stored in a tank in space, stratifies. This, in turn, determines the level of pressurization required in order to extract all of the fluid. Scientists made a mathematical model of what they think occurs inside the tank. With this as a guide, an actual tank was constructed to obtain measurements and photographs of the flow to verify their theories.

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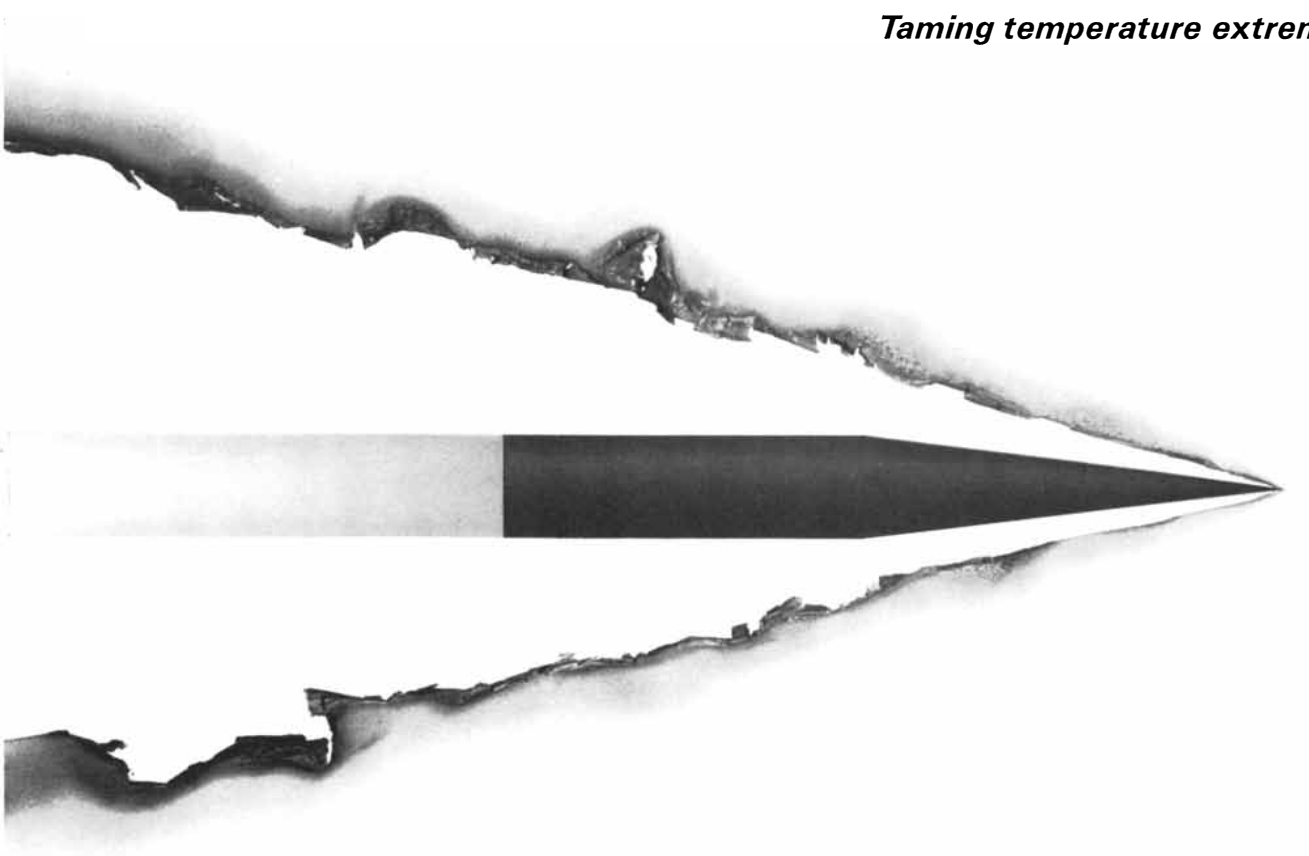
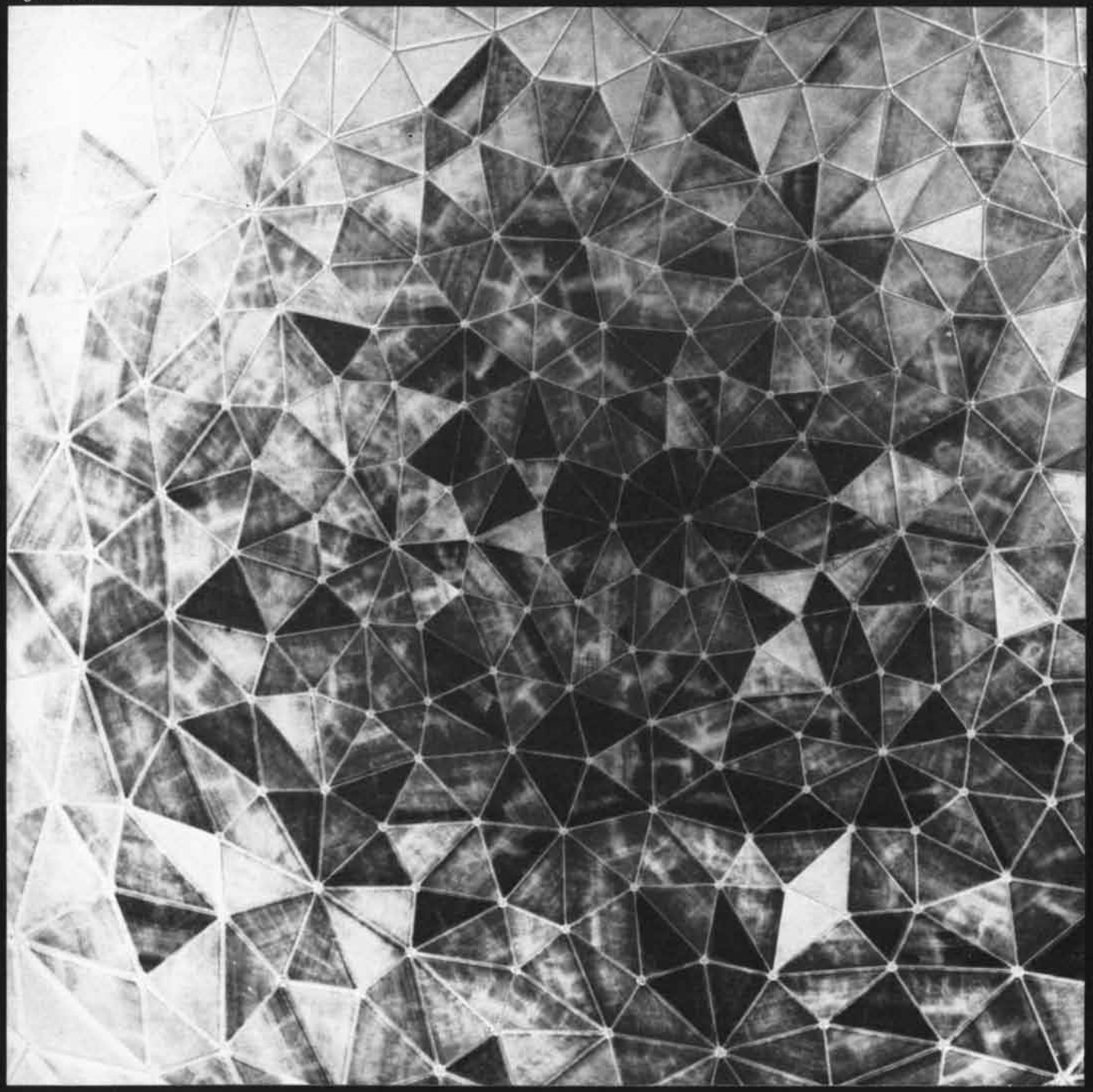


Rigid Radome



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Tombolo between mainland and island, formed by wave action

mental work that remains untried. It should be possible to simulate the flow of glaciers by means of silicone putty or other plastic media, and the features that derive from glacial melting could be developed in greater detail, perhaps by supplementing the melting ice with a water source. Then too, dunes and other effects of wind erosion can be investigated by the experimenter who has access to a source of compressed air. I have reproduced some formations characteristic of arid regions, such as the piles of debris known as talus that accumulate at the bottom of steep cliffs, simply by pushing dry sand over the top of a rise. We are continuing to develop new stream-table demonstrations here at Columbia University that are intended to serve primarily as teaching aids. The apparatus will also be used in a series of research projects."

Talus pile formed by sand falling over cliff

BOOKS

An account of the evolution of our concept of childhood

by Dennis H. Wrong

CENTURIES OF CHILDHOOD: A SOCIAL HISTORY OF FAMILY LIFE, by Philippe Ariès. Alfred A. Knopf, Inc. ($8.50).

The average social scientist is thoroughly ignorant of Western social history. He is likely to know more about the kinship system of the Trobriand Islanders and the sexual mores of the Eskimos than he knows of the attitudes toward children or the kind of school system that existed in western Europe before the 19th century. Philippe Ariès' *Centuries of Childhood,* which intensively explores the last subjects, among others, is bound therefore to come as something of a revelation, casting a new light on the contemporary sociologist's favorite generalizations about recent trends in parent-child relations, the connection between the family and the larger society, and the "socialization" of the young in general.

That marriage and the family are universal institutions and that all societies must make provision for the maintenance and socialization of children (which, indeed, is what primarily accounts for the universality of marriage and the family) are today sociological commonplaces. It is also well known that our contemporary laws governing marriage, divorce and the rights and obligations of parenthood, our kinship nomenclature and the balance we strike between the family group created by marriage and the extended family of affinal relatives ("in-laws") are deeply rooted in the Western past, stemming from Hebrew, Christian and classical influences. Demographic historians have, however, only recently become fully aware of the distinctiveness of the Western family as an enduring "structural type" when contrasted with the joint family systems of the great Asian civilizations. The Western family, they have concluded, stresses to a unique degree the priority of the marriage relation over ties of unilateral descent and thus grants greater economic and residential independence to the married pair and their offspring than is common in the Orient, where the nuclear group is absorbed into a larger household of paternal kin.

The interest of demographic historians has centered on the different effects of the Western and Asian family systems on the level of the birth rate and attitudes toward procreation, a difference that may have considerable bearing on the future of the underdeveloped countries now experiencing a population explosion that began in the West nearly two centuries ago. The Western family type was, of course, firmly established long before Europe's demographic revolution, and it may well have provided a favorable setting for the eventual mass adoption of birth control that has curtailed rapid Western growth in the present century. In fact, the recent work of several demographic and economic historians contains the germs of a "familistic" theory, not only of the Western population transition but also of the genesis of capitalism and the Industrial Revolution themselves, which have so often been treated as independent causes of demographic change.

Ariès is a demographic historian, the author of an important study of French population since the 18th century. It was "the study of modern demographic phenomena," he tells us, that led him to conclude that "the family occupied a tremendous place in our industrial societies and that it had perhaps never before exercised so much influence over the human condition." Such a conclusion flatly contradicts the widely held view that the family has suffered a decline in industrial society, that—in the language of an influential school of family sociologists—it has been "losing its functions" and becoming in consequence a less significant focus of our lives. Accordingly, although Ariès' point of departure was demographic history, he has gone beyond it in an attempt "to look back into our past to find out whether the idea of the family had not been born comparatively recently..." The result is a book that, although of limited interest to the population specialist, is endlessly fascinating to students of the family, of life in the premodern West in general and of the changing sensibilities of Western man as expressed in his manners, morals, art and religion.

The hard facts of demography and the only slightly less firm data on the formal structure of the family are quickly passed over as the author attempts to trace a moral revolution in the evaluation of childhood, the treatment of children and the significance attached to family life. Personal memoirs and correspondence, family portraits, the echoes of the past buried in colloquial speech, the subjects and genres of classical painting, religious and "profane" iconography, manuals of etiquette, the published sermons of moralists, old school registers, official histories of educational institutions—these are his sources, as they must necessarily be those of social historians studying beliefs and customs that were so taken for granted as the backdrop of daily life they left few enduring records of their existence in an age antedating universal literacy, the ubiquity of the printing press and the omnivorous fact-collecting of modern social science.

How did our European cultural and biological ancestors evaluate childhood as a period of life in the 16th, 17th and 18th centuries, the era that is the seedbed of so much of the "modern" and the graveyard of so much of the "medieval"? When did they first begin to see childhood as an irrecoverably previous age, worthy of celebration and fixation in art, requiring enrichment by parental solicitude and protection from too early exposure to the corruptions and workaday cynicism of adult life? Was the late medieval and early modern world addicted to the extreme age-grading we take so much for granted today? ("How old are you?" is usually the first question we put to a child we have just met.) How did the grouping of children into school classes differentiated by both

age level and progressively more "advanced" subjects of study evolve—a feature of modern schooling that has not been questioned even by the most radical educational reformers? Is the notion of the family as the arena of an intense "private life," a fortress protecting the individuality of the person, truly an ancient heritage of Western culture, as is so often assumed by writers bewailing the forces of "mass society" that are today allegedly breaching its walls?

These are the main questions to which Ariès addresses himself. His answers reveal a fundamental change of outlook, a transformation of sensibility, that took place in the period he covers. This change occurred within the structural type of the Western family institution, which remained constant throughout. Ariès' data therefore suggest that crucial historical shifts in feeling and imagination may escape the notice of contemporary sociologists whose "structural bias" disposes them to stress enduring institutional forms subject at most to gradual modifications of type. "Not that the family did not exist as a reality," he observes of the period preceding the changes he has described, "but it did not exist as a concept."

Nor does Ariès find that the demographic changes of the early modern period account for the revolution in sensibility he records; it would be highly plausible to interpret an increased concern with childhood and a new solicitude for children as results of the decline in infant mortality that made it easier for parents to cherish each child as an irreplaceable individual by reducing the risk of early death and the resulting shock of bereavement. But Ariès finds that the new interest in the child preceded by more than a century the medical and public health discoveries that decisively reduced infant mortality. He suggests, in fact, that the causal link may have run in the other direction, with increased concern for children producing a state of mind favorable to all hygienic precautions and to the rapid spread of such particular innovations as smallpox vaccination.

Centuries of Childhood is divided into three sections. The first deals with "the idea of childhood." Evidence ranging from iconography depicting the "ages of life" to the history of games and children's dress is surveyed to show the evolution from the complete lack of attribution of any special character to childhood in medieval society to the intense preoccupation with the physical, moral and—more recently—psychological welfare of children that had developed by the 18th century and still obsesses us today. The second section, occupying roughly half the book, is a history of schooling from the Middle Ages to the end of the *ancien régime,* comprehensively tracing the growth of different types of school and their curriculums, the origins of the school class, the progress of discipline and the development of age-grading in education. The book's final section discusses the family, particularly the "concept of the family." We are shown the metamorphosis of the great, sprawling aristocratic and middle-class households of the late Middle Ages, scarcely distinguishing between members of the family, servants and regular visitors, into the sharply defined unit of the married couple and their children, ensconced in the absolute privacy of their "home," that constitutes the modern family.

Ariès draws his material primarily from French sources, particularly in the section on the school, although he makes a sustained effort to cover developments in England as well. Germany, Switzerland, the Low Countries and Italy are referred to occasionally, usually when the evidence is iconographic. The Latin texts of the Church fathers and the later Renaissance humanists were influential, of course, throughout western Europe, so that much of Ariès' account of early postmedieval society refers to general conditions and needs no specific geographic reference.

Artists in the Middle Ages were not even capable of correctly drawing children. They pictured them as little men, fully equipped with the muscular development and bodily proportions of adults. And children were pictured only in religious art; although adult portraiture was popular, no effort was made to preserve the transitory likeness of the child until funeral effigies of dead children became common in the 16th century. Before this time and for a considerable period afterward in the lower classes and rural areas, the child was regarded at most as a charming little plaything, a domestic pet, and his death was not much more of an occasion for grief and mourning than is that of a pet dog or cat today.

In the Middle Ages children were weaned rather later—at about the age of seven—than is the custom today, but as soon as weaning was completed they were removed from the care of their mothers or nurses and plunged straight into adult life. There were no special games or pastimes considered to be exclusively appropriate for children. Games like blindman's buff or hide-and-seek,

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	S	P	R
S	0	1	-1
P	-1	0	1
R	1	-1	0

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*Williams, J. D., *The Compleat Strategyst*

which later were regarded solely as childish diversions, and which are still part of the strangely traditional and autonomous culture of childhood, were originally played by adults too. Conversely, children of five and six played chess, danced complicated ballet steps and learned to perform on the lute and violin.

No effort was made to conceal the facts of sexuality from small children. Their sex organs were fondled and joked about by adults. The lack of privacy in the medieval household, where any room might serve temporarily as a bedroom and where adults and children commonly shared the same bed, made it difficult for adults to conceal their sexual activities from children; indeed, they had little inclination to do so. Freud's once shocking discovery of infantile and childish curiosity about sex was no more than a rediscovery of what medieval parents and nurses matter-of-factly assumed. In this sense the now vanished Victorian belief in childish innocence did not exist in medieval society, although open references to sexuality before children were permitted because it was thought that children lacked all true sexual motivation before the age of puberty. There was no awareness of the connection between infantile and adult sexuality on which psychoanalysis so strongly insists.

The change from the casual medieval attitude toward childhood to our current tense concern with it passed through several stages. By the 16th century adult expressions of pleasure at the playfulness and prattling of small children, a pleasure that had previously "formed part of the huge domain of unexpressed feelings," amounted virtually to a "cult of the child" in upper-class families. No less a personage than Montaigne protested irritably: "I cannot abide that passion for caressing newborn children, which have neither mental activities nor recognizable bodily shape by which to make themselves lovable, and I have never willingly suffered them to be fed in my presence." Yet, as Ariès points out, Montaigne's very annoyance at the "coddling" of children "was as novel as 'coddling,' and even more foreign . . . to the indifferent attitude of people in the Middle Ages." His wish to segregate children from adults was shared by the 17th-century moralists and pedagogues whose "fondness for childhood and its special nature no longer found expression in amusement and 'coddling' but in psychological interest and moral solicitude."

These moralists and pedagogues—of whom the Jesuits and the Jansenists of Port Royal were the most important in France—eventually won the day. Their victory resulted in the creation of a system of schooling conceived of as being a careful, methodical preparation of the child for adult life. The contrast with the old free mingling of children and adults in the Middle Ages could scarcely have been greater. Moreover, the goals of education were no longer merely intellectual or vocational but included the shaping of the child's moral character as well. Thus the school became a thoroughly authoritarian institution in which a corps of disciplinarian masters ruled over a "proletariat" of powerless children. The old freebootery of student life in the Middle Ages—next to which the much deplored hedonism and irresponsibility of our contemporary adolescent and college-age youth seem tame—became a thing of the past. The shutting off of the child in a separate, hierarchical world outside the family reached its zenith in the boarding schools of the 19th century, of which the great English public schools are the best-known examples. The reaction to this incarceration of the child in educational prisons came at the end of the 19th century, when "the family was substituted for the school as the predominant moral setting."

Most of the developments I have summarized applied to boys alone. Girls remained comparatively undifferentiated from women for a longer time: in dress; in the more tenacious belief that, except for religious instruction, they needed no special education outside the family, which effectively delayed the extension of schooling to girls until the late 18th and early 19th centuries; and in the survival through the 17th century of an exceedingly early age at marriage for females—13- and 14-year-old brides were by no means uncommon.

The interest in childhood, first manifest in the 16th century, was part of a developing interest in the family—that is, the "nuclear family" of parents and children—that originated in the 15th century, coinciding with a decline in the value attached to the hereditary line. The hereditary line had been glorified in medieval society, although it had never been the basis for the household group and so lacked the "functional" economic and child-rearing significance of the Oriental unilineal descent group. The Church disapproved of the emphasis on the "pagan" blood ties of the hereditary line, but it did not assume full control of marriage, transforming it into a sacrament, until the 13th century. And it was not until the 16th century that the

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family became a theme of religious iconography. At the same time, the practice of private family prayers and worship became common, indicating the new value attached to a group that had previously "existed in silence," failing to "awaken feelings strong enough to inspire poet or artist."

But before the family could come to be regarded as the virtual extension of the self that it is today, or even the lair from which one sallied forth to engage the outside world of the Victorian period, more mundane changes in the conditions of life had to take place. The houses of the rich until the end of the 17th century "sheltered, apart from the family proper, a whole population of servants, employees, clerics, clerks, shopkeepers, apprentices and so on." No clear distinctions were made between social, professional and private life, which brought together much the same people in any case. All activities were carried on in the family's living quarters, where the same rooms served successively—and often simultaneously—as salons, offices and bedrooms. It was the social (and often enough sexual) promiscuity of life in the big houses that spurred the clerical pedagogues to their task of building a school system that would effectively remove the child from the family during what were regarded as his formative years. In spite of the earlier development of a new emotional relation between parents and children, it was not until the 18th century that "the family began to hold society at a distance, to push it back beyond a steadily extending zone of private life." The change was reflected in the new structure of the house: the old all-purpose rooms disappeared to be replaced by specialized bedrooms and dining rooms, and the rooms now opened off a central corridor, so that it was no longer necessary to pass through each room in traversing the house. Privacy and domesticity, those two prized and interlinked modern values, were born together.

It is not feasible to summarize all the information assembled by Ariès that challenges the stereotyped view of the past held even by most scholars and social scientists. One major conclusion suggests itself, although my own ignorance may have given me an exaggerated view of its novelty. We are accustomed to regarding the Middle Ages as an "age of faith" and to seeing our subsequent history as a steady movement away from a spiritually unified medieval Christendom toward the pluralistic, secularized, science-centered world of the present. The Renaissance, the Reformation, the

Enlightenment and the Industrial Revolution are seen as successive stages in this movement. But Ariès' data suggest that Christian ideas and sensibility had little vital influence on social relations and daily life until the 16th century. Although the Church was a crucial unifying and centralizing institution in the polycentric world of medieval feudalism, its relation to daily life, to the web of custom, resembled more closely the relation of the Catholic Church today to the syncretic culture of the part-Indian, part-Negro populations of Central America than it resembled the later clerical reshaping of domestic habits achieved by the reformers of the Reformation and the Counter Reformation. Thus our modern sensibility, while it may properly be described as post-Christian, is in no sense postmedieval. In our attitudes toward the family and childhood we stand in vital respects closer to Christian thought and feeling, even in its more moralistic and puritanical forms that we see ourselves as reacting against, than to the gay, casual, frequently coarse outlook of the Middle Ages, which cannot even be characterized as the reverse of "child-centered" since it lacked any distinct conception of childhood.

Social history of the kind Ariès gives us reveals more fully than other kinds of history the value of what is called historical perspective. It does so because in exploring the world of childhood and the family, a world in which we are all intimately involved, it succeeds in communicating more profoundly a sense of the strangeness of time and change in the life of man and society. Our familiarity with the subject is enhanced because it is the life of our own historical ancestors that is described in *Centuries of Childhood*. Echoes of that life persist today in the form of beliefs, archaisms of speech and minor customs, twisted and distorted in the crucible of historical transformation, surviving in "form" but not in "function," as the anthropologist would put it. Yet the very fact that this is so, that we are tied to the men and women of the Middle Ages by a thread of cultural continuity, enables us to experience more deeply what the anthropologist calls "culture shock" in confronting these lives so different from ours and yet marked with faint but decisive traces of similarity. No reading of anthropological materials on the kinship systems and domestic lives of primitive peoples can have such an impact. Nor, with all his opportunities for field observation, is it as easy for the anthropologist to succeed in discovering in his data "the tremor of life that he can feel in his own

existence," to quote Ariès' brilliant summation of the ultimate aim of the social historian.

Short Reviews

NATURE ADRIFT, by James Fraser. Dufour Editions ($8.95). This is a lovely book about the marine plankton. The word "plankton" is a scientific omnibus term directly borrowed from the Greek in 1887 by the German zoologist Victor Hensen; it means that which is passively drifting or wandering. It covers an enormously varied constituency of fishes and other salt-water organisms ranging in size from minute flora a ten-thousandth of an inch in diameter to the largest jellyfishes, such as the big stinger *Cyanea*, which is a yard or so across and has a thick set of tentacles that can extend as far as 30 feet. The term is useful, but it is far from precise in that many of the animals to which it is applied are not really passive drifters. They can swim, although their movements are small compared with those of the water itself, and they can move up and down to a surprising extent. Their general distribution, however, is determined by their environment. It should be pointed out that the term "plankton" includes the "young free-living stages of many animals that are relatively sedentary as adults, such as the mollusks and barnacles, the young stages of bottom-dwelling animals such as crabs and worms, the floating fish eggs and the young fish after they hatch and before their own swimming powers are sufficiently developed for them to choose their own whereabouts." In addition to the plankton, comprising permanent and transient members, there are two other main aquatic communities: the benthos, which live on the bottom, and the nekton, which swim about freely.

After a brief historical sketch and a chapter on methods of separating the tiny and middle-sized organisms from the water—both the simple things any amateur can do and the sophisticated procedures and apparatus of the specialist—Fraser describes in detail many of the fascinating and exotic kinds of plankton. He covers, among other things, the tiny nanoplankton, some of which have flagella that enable them to swim several times their own length in a second; the beautifully sculptured diatoms, abundant since Cretaceous time, that have thick shells of silica and cannot swim and whose skeletons carpet the ocean floor; the phosphorescent dinoflagellates that in vast crowds emit an undefined "cloud of light"; the coc-

colithophores, minute plants that are housed in calcareous plates and require so little light that in clear waters they live most abundantly at a depth of about 1,000 feet.

To the zooplankton belong the protozoa, the sea anemones, the corals and the incredibly shaped jellyfishes. The above-mentioned *Cyanea*, in spite of its stinging tentacles, forms a protective umbrella for schools of small fishes, particularly young whitings and rocklings, which use the umbrella for a sunshade on bright days and appear to be immune to the jellyfish's sting. There are also the worms, the mollusks (including the sea butterfly *Spiratella*, which gives out a sepia-colored stain that darkens the inside of herring that feed on the organism, producing what is known in the trade as "black gut" and impairing their preservability), the comb jellies, the squids and the octopuses; the many hundreds of species of copepods, whose total numbers in the sea reach astronomical figures; the Amphipoda, including the water-jumping species *Themisto*, whose outer surface has the surprising property of being unwettable, so that if any part of it comes above the water the effect of surface tension brings the rest out to float, quite dry; the Thaliacea, a species of which (*Thalia democratica*) lives in aggregates of loosely attached chains.

One learns that around the Faroe Islands the annual production of haddock eggs alone—which on hatching enter a planktonic stage—is about six trillion and that pilchard eggs in the English Channel run yearly to 400 trillion, that an intriguing new hypothesis has been advanced to account for the strange life history of European and American eels; that the fairy shrimp Mysidacea has balancing organs in the inner vanes of its tail, each of which holds a tiny pebble free to move about in a spherical container and let the shrimp know which way up is. Geographical and seasonal distribution of the plankton are discussed, as are the food chain in the sea, the plankton's relation to the fisheries, how different zooplankton move (diurnal migrations of microorganisms in the lagoon at Bikini after the atomic explosion led to the curious effect that the radiation level of the ships lying there, not very great at first, increased steadily each night as the organisms, each carrying a small dose, rose and were eaten by the barnacles attached to the ships' bottoms), plankton as a food for man (a difficult and questionable resource) and as a fertilizer for the sea (that is, the necessity for increasing the growth of

plankton in order to increase the fish population). The book has many fine diagrams and superb photographs, some in color.

ASTRONOMY, by Fred Hoyle. Doubleday & Company, Inc. ($12.95). One has come to expect from Fred Hoyle sound, clear, attractively written popularizations of science. He is a fine astronomer with a comprehensive grasp of related sciences such as physics, and he has an original cast of mind, as exhibited both in his professional and in his literary work. This book is up to his mark. It is a history of man's investigation of the universe from ancient times to the present, with explanations of the major principles and achievements, descriptions of the tools of astronomy, of the work of the Greeks, of such pre-eminent figures as Copernicus, Galileo, Kepler and Newton. Separate chapters are devoted to the theory of gravitation, the post-Newtonian era, the nature of light, the birth of modern astronomy, stars as thermonuclear reactors, the structure of our galaxy and the several contemporary hypotheses about the dynamics and nature of the universe. Characteristic of Hoyle's independence of view is his upgrading of Ptolemy, based on a searching analysis of his procedures, and a somewhat surprising depreciation of Galileo's contribution to theory. Whether or not one agrees with these assessments, one cannot fail to be enlightened by Hoyle's clear and forceful exposition. The book has more than 400 illustrations and diagrams, including a number of color reproductions.

RECENT DEVELOPMENTS IN GENERAL RELATIVITY. A Pergamon Book. The Macmillan Co. ($8). This book, dedicated to Leopold Infeld, a leading student of relativity theory, consists of 40-odd papers dealing with such matters as motion, relativity and cosmology, the quantization of the gravitational field, experimental verifications of general relativity theory, relativity based on chronometry, the analogy between charge and spin in general relativity, interacting gravitational and spinor fields. Many prominent scientists from different parts of the world are contributors. Relativity, it is evident, is as current and lively a subject as ever.

KNOWLEDGE AND WONDER, by Victor F. Weisskopf. Doubleday & Company, Inc. ($4.95). This book is based on a series of lectures that Weisskopf gave at the Buckingham School in Cambridge, Mass., to an audience of young students, faculty and parents; in other words, to people with no special grounding in science. It is a kaleidoscopic view of what man knows today about his world. Chemistry, physics, geology, astronomy and biology (including biochemistry) are all drawn on to compose the picture. The author has done an admirable job in the brief space of little more than 200 pages. He is unfailingly lucid, he unravels the hardest knots quickly and gracefully, his metaphors and analogies give light to the mind. It would be difficult to find a more painless introduction to modern notions of astronomy and cosmology, electricity and magnetism, nuclear physics and quantum theory, the chemical processes of life. Highly recommended.

ATOLL ENVIRONMENT AND ECOLOGY, by Herold J. Wiens. Yale University Press ($15). Based on a great mass of data, some of it old but much of it new, and in part on the author's observations during field trips, this book describes the landscape and the physical and biological complex of the coral atoll in its tropical setting. Main topics include the geography, topography and geology of atolls; weather and climate in the Pacific atoll area; the effect of ocean currents, waves and storms on atolls; the nature and distribution of atoll fauna and flora; human life on atolls. Many diagrams, maps and plates.

THE CRY FOR HELP, edited by Norman L. Farberow and Edwin S. Shneidman. McGraw-Hill Book Co., Inc. ($9.95). A co-operative volume concerned with the phenomenon of suicide. The two main categories cover the community response to the problem and the psychotherapeutic response. A number of essays that set forth the explanations of the suicidal instinct given by leading psychoanalysts make it painfully clear how little theory has added to the understanding of this dark and complex question. An extensive bibliography of some 65 pages covers the writings on suicide from 1897 through 1957.

NAVAHO WITCHCRAFT, by Clyde Kluckhohn. Beacon Press ($4.95). A reprint of the late anthropologist's classic study of the beliefs and practices of Navaho witchcraft, drawing on the fields of psychology, linguistics, cultural history and social psychology. Kluckhohn took the position that the belief in witchcraft and the accompanying practices had both good and bad effects on Navaho society, and he offers much evidence in support of his view. The second part

of the volume consists of his transcription of the witchcraft tales themselves as they were told to him.

THE BIRDS OF THE BRITISH ISLES: VOLUME XI, by David Armitage Bannerman; illustrated by George E. Lodge. Oliver & Boyd Ltd (63 shillings). The 11th volume of this splendid work deals with the pratincoles, stone curlews, bustards, cranes, terns, gulls and kittiwakes. The text is filled with the usual details as to identification, distribution, behavior, breeding habits and the like, and also with little-known facts and descriptive paragraphs gleaned from the literature of an earlier age. This makes for enjoyable reading. The volume is adorned with 32 color plates prepared by the late George E. Lodge.

WRITING, by David Diringer. Frederick A. Praeger, Inc. ($6.95). This 25th volume in the attractive series "Ancient Peoples and Places" presents a readable, fully illustrated survey of the origins and early history of writing: primitive means of communication, scripts of the ancient Near East, Far East and pre-Columbian America, phonetic scripts and diffusion of the alphabet. Diringer, who is lecturer in Semitic Epigraphy at the University of Cambridge, has written widely on the alphabet and related topics. Photographs, line drawings and maps.

AN INTRODUCTION TO LOGIC, by Morris R. Cohen and Ernest Nagel. A Harbinger Book ($1.65). This paperback consists of the first part of Cohen and Nagel's *An Introduction to Logic and Scientific Method,* one of the best known and most highly esteemed of modern texts in the field. It contains all the material on formal logic to be found in the larger work and covers a part of the subject that can be conveniently covered in a one-semester course. The ordinary reader who wishes to acquaint himself with the basic ideas of deductive logic and demonstrative reasoning will, like the student, find no better guide.

A DIARY OF BATTLE: THE PERSONAL JOURNALS OF COLONEL CHARLES S. WAINWRIGHT, 1861–1865, edited by Allan Nevins. Harcourt, Brace & World, Inc. ($8.75). Allan Nevins describes this record as "the most comprehensive and historically useful field diary by a Civil War officer I have seen." Colonel Wainwright of the First Regiment New York Volunteer Light Infantry was with the Army of the Potomac throughout the war from the battles of Antietam, Fredericksburg and Chancellorsville to Gettysburg, Spotsylvania, Petersburg and Appomattox. He presents a detailed day-to-day chronicle that describes ordinary events and the drama of battle, the behavior of plain soldiers and that of the commanding generals, and gives his personal views on the conduct of the war and on the character of the civilian leaders. Wainwright was a gentleman, strong-minded and strong-willed, courageous, well read, somewhat cold and full of condescensions and prejudices. (Of Lincoln, for example, he writes: "I was ashamed to think that such a gawk was President of the United States.") A better field officer could not have been desired. The war was obviously the high point of his life; little is known about what he did before he became an officer or what he did after being mustered out. He died, a bachelor, in Washington at the age of 82. An engrossing and remarkable work, skillfully edited by Nevins, that gives a wonderfully vivid picture of the events of the war.

SURREY, by Ian Nairn and Nikolaus Pevsner ($7.50); NORTH-EAST NORFOLK AND NORWICH, NORTH-WEST AND SOUTH NORFOLK, by Nikolaus Pevsner ($2.95 each). Penguin Books, Inc. These volumes in the series "The Buildings of England" continue Pevsner's remarkable survey, of which some 20 installments have already appeared. They are incomparable guidebooks: well illustrated and filled with historical and architectural information. It should be noted that each of these is also available as a paperback.

THE FRENCH REVOLUTION FROM ITS ORIGINS TO 1793, by Georges Lefebvre. Columbia University Press ($6). The first translation into English of what is widely regarded as the best single treatment of the French Revolution. It was written by the pre-eminent authority on the subject, who died in August, 1959, in his 86th year. It is a tightly packed book, immensely learned, with each of its sentences meant to count. This does not make it easy to read, but it will richly repay careful study. The present volume represents the first half of Lefebvre's history; a translation of the second volume, carrying the account to 1800, is now in preparation. Included is the author's invaluable annotated bibliography of works published in all languages and covering all aspects of the books' contents.

THE AGE OF ELECTRONICS, edited by Carl F. J. Overhage. McGraw-Hill Book Co., Inc. ($7.95). A collection of

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historical essays based on lectures given to mark the 10th anniversary of the founding of the Lincoln Laboratory of the Massachusetts Institute of Technology. Among the topics are the origins of electromagnetic theory (Hendrik B. G. Casimir), communications (Lloyd V. Berkner), radar (Ivan A. Getting), electronic computers (Stanislaw M. Ulam), radio astronomy (Edward G. Bowen), transistors (William Shockley), masers (Charles H. Townes) and satellite relays (John R. Pierce).

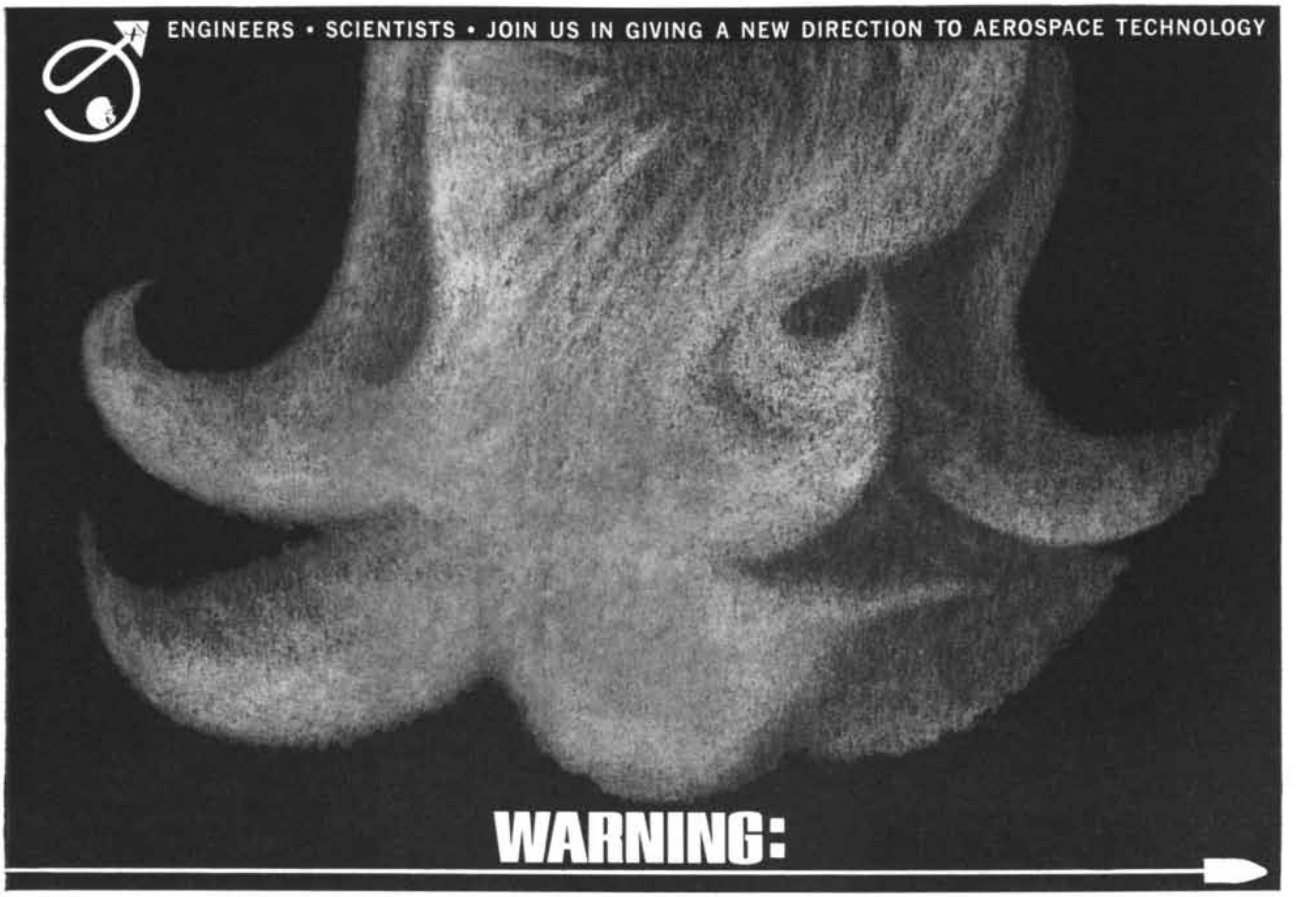
PHYSIQUE SOLAIRE ET GÉOPHYSIQUE, by A. Dauvillier. Masson & Cie. (72 francs). This French monograph by a leading astrophysicist who is professor at the College de France describes the results of his own researches and his observations at the Pic du Midi Observatory, having to do with such topics as the sun's magnetism, the solar "wind," the sun's emission of electrons, relations between solar and terrestrial phenomena. Many diagrams and photographs.

SPACE LOGISTICS ENGINEERING, edited by Kenneth Brown and Lawrence D. Ely. John Wiley & Sons, Inc. ($16.95). This volume in the "University of California Engineering and Physical Sciences Extension Series" discusses the numerous factors affecting space logistics, "with the purpose of enabling the space vehicle designer to consider these factors during the initial design rather than having to incorporate them as an afterthought."

THE NEW SCIENTIST, edited by Paul C. Obler and Herman A. Estrin. Anchor Books ($1.25). A collection of essays on the methods and values of modern science. Among the contributors are Gerald Holton ("Modern Science and the Intellectual Tradition"), Francis Bello ("The Young Scientists"), Anne Roe ("The Psychology of the Scientist"), Bertrand Russell ("The Social Responsibilities of Scientists"), C. P. Snow ("The Moral Un-Neutrality of Science"), J. Bronowski ("The Educated Man in 1984"), George Boas ("The Humanities and the Sciences"), E. A. Burtt ("The Value Presuppositions of Science") and P. W. Bridgman ("Quo Vadis"). A paperback.

Notes

ELSEVIER'S DICTIONARY OF GENERAL PHYSICS IN SIX LANGUAGES, compiled and arranged by W. E. Clason. American Elsevier Publishing Co., Inc. ($22.50). An English, French, Spanish, Italian,



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Dutch and German dictionary arranged on an English alphabetical basis, setting forth the essential terminology of various branches of physics.

THE LOGIC OF CHANCE, by John Venn. Chelsea Publishing Co. ($4.95). A reprint of a 19th-century classic on the foundations of probability.

A SHORT HISTORY OF ASTRONOMY: FROM EARLIEST TIMES THROUGH THE NINETEENTH CENTURY, by Arthur Berry. Dover Publications, Inc. ($2). An unabridged republication, fully illustrated, of a standard work. In special fields and on innumerable specific points historical knowledge has undoubtedly left Berry far behind, but as a general introduction for the nonspecialist and the student this book deservedly retains its popularity.

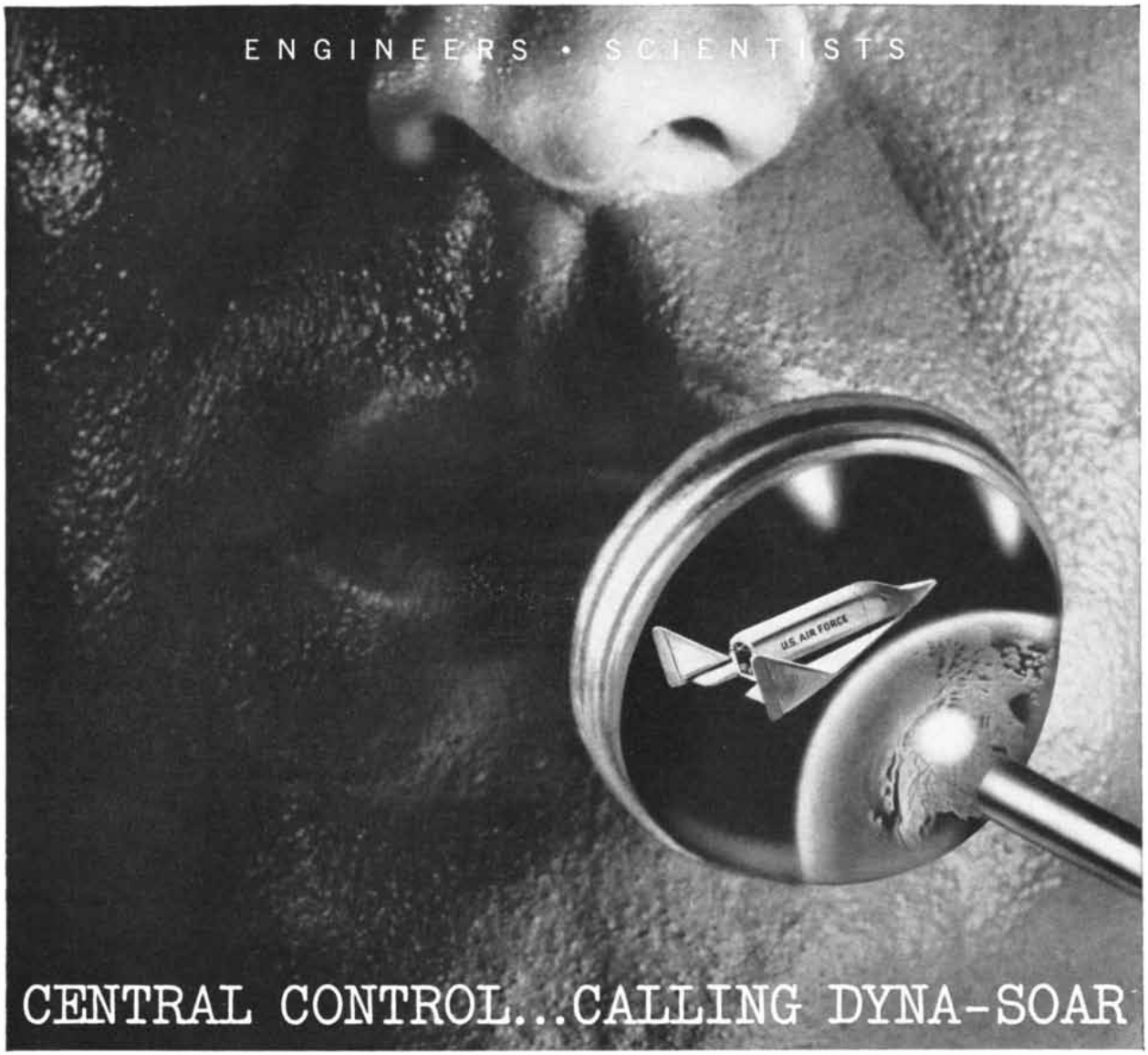
ENERGY FOR MAN, by Hans Thirring. Harper Torchbooks ($1.95). As a popular survey of energy resources from windmills to nuclear power, this masterly book is without peer. A paperback.

PALAEONTOLOGY: INVERTEBRATE, by Henry Woods. Cambridge University Press ($2.50). A paper-backed reprint of the eighth edition of a standard book that deals specifically with the fossils of invertebrates.

FUNDAMENTAL PROBLEMS IN TURBULENCE AND THEIR RELATION TO GEOPHYSICS, edited by François N. Frenkiel. American Geophysical Union ($5). The proceedings of a symposium organized by the International Union of Geodesy and Geophysics and the International Union of Theoretical and Applied Mechanics and held at the University of Aix-Marseilles in 1961. The papers are concerned with atmospheric and oceanic turbulence phenomena.

HISTORICAL ATLAS OF RELIGION IN AMERICA, by Edwin Scott Gaustad. Harper & Row, Publishers ($8.95). A historical survey and statistical compilation covering the growth and trends of religion in America for three centuries. The text (which gives a running account of the development of organized religion) and the many maps and charts (which give names, places and numbers) combine to make a volume of exceptional interest.

PLATO'S THEORY OF KNOWLEDGE, by Norman Gulley. Barnes & Noble, Inc. ($4.50). A systematic account of the development of Plato's theory of knowl-



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THE PSYCHOANALYTIC STUDY OF THE CHILD: VOLUME XVII, edited by Ruth S. Eissler, Anna Freud, Heinz Hartmann and Marianne Kris. International Universities Press ($8.50). The 17th volume of this annual contains articles on psychoanalytic theory, sundry aspects of normal and pathological child development, and clinical studies.

THEORY OF GROUND WATER MOVEMENT, by P. Ya. Polubarinova-Kochina. Princeton University Press ($10). A translation of what is now regarded as a classic Russian monograph dealing with problems of flow in porous media.

INSIDE THE LIVING CELL, by J. A. V. Butler. Science Editions, Inc. ($1.65). A paper-backed edition of a fine popular account of present concepts of the living cell by a British physical chemist.

MATHEMATICAL METHODS IN SMALL GROUP PROCESSES, edited by Joan Criswell, Herbert Solomon and Patrick Suppes. Stanford University Press ($9.75). Twenty-two papers presented at a 1961 symposium held at Stanford University that display some of the mathematical methods applied to problems of interpersonal behavior in small groups.

THE REFORMATION OF THE 16TH CENTURY, by the Reverend Charles Beard. Ann Arbor Paperbacks ($2.95). An inexpensive reissue of a noted study by an English divine (1827–1888) that considers the Reformation in its relation to modern thought and knowledge and discusses its role in shaping the critical and scientific spirit of today.

ŒUVRES DE P. L. TCHEBYCHEF, edited by A. Markoff and N. Sonin. Chelsea Publishing Company ($27.50). A two-volume reprint of the French edition of the collected papers of Pafnouty Lvovitch Tchebychef, an eminent mathematician of the 19th century, known for his researches in number theory, analysis, algebra and other branches of mathematics.

CLASSICS IN LOGIC, edited by Dagobert D. Runes. Philosophical Library, Inc. ($10). An 800-page anthology of readings in epistemology, theories of knowledge and dialectics. This is an ill-considered hodgepodge of a book made up of snippets, fragments and many an exerpt from forgotten writings that deserve to be forgotten.

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A DEMONSTRATION OF INSIGHT: THE HORSE-AND-RIDER PUZZLE. Martin Scheerer, Kurt Goldstein and Edwin

WORLD'S NEWEST JET. Boeing 727, America's first short-range jetliner, is shown taking off on early test flight. Powered by three rear-mounted turbofan engines, the 727 can operate from 5000-foot runways. It will bring jet-travel advantages to hundreds of smaller cities. The 727 can carry 70 to 114 passengers at speeds up to 600 mph. Now undergoing one of the most intensive test programs in airliner history, the 727 enters service early next year. These airlines have ordered 131 Boeing 727s: American, Ansett-ANA, Eastern, Lufthansa, Trans-Australia, TWA, and United.

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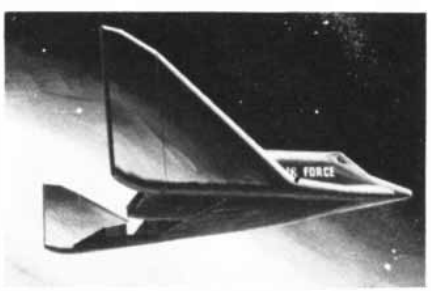
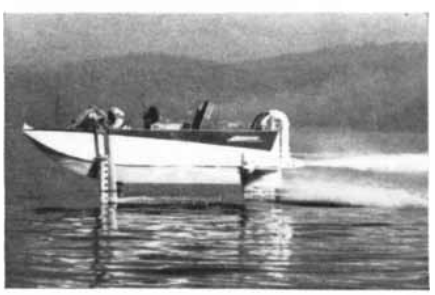


X-20 DYNA-SOAR, the U. S. Air Force's space glider, shown in drawing above, will rocket into earth orbit atop booster. Pilot will be able to fly X-20 back through atmosphere for landing at field of his choice. Boeing is X-20 system contractor.

SATURN V in drawing, right, will be world's largest rocket, some 350 feet high. Boeing holds NASA contract to develop, build and test the S-1C first-stage booster, which will develop thrust equal to about 160,000,000 horse power.



PUMP JET is experimental boat built by Boeing to test submerged foil systems and water-jet propulsion. Pump, driven by Boeing turbine, exhausts 30-foot stream of water developing 2,000 pounds of thrust, and speeds to 45 knots.

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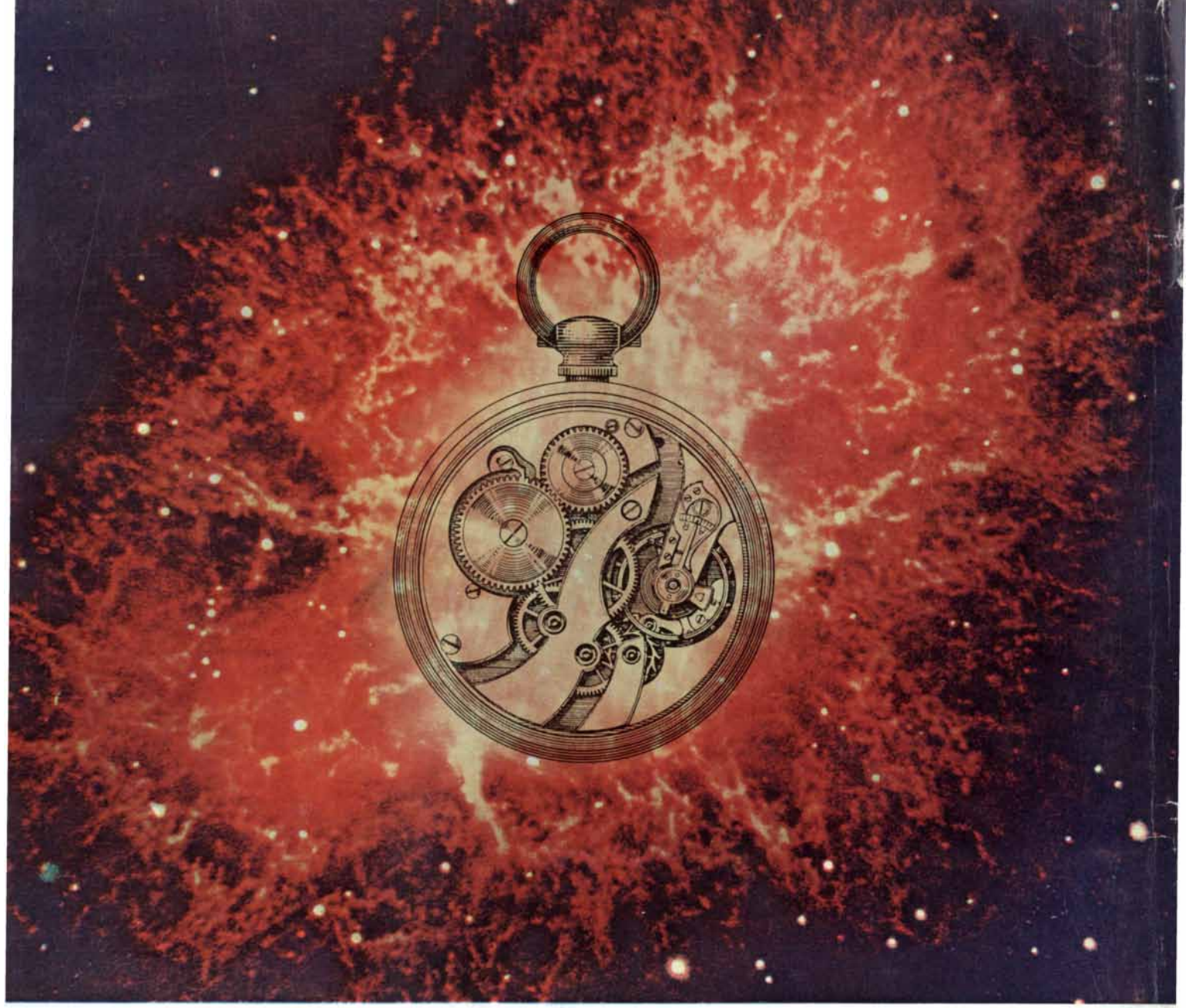

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