SCIENTIFIC AMERICAN

ANCIENT GREEK COMPUTER

FIFTY CENTS

June 1959

PIRATES! in the sea of corn

ANY BUCCANEER who ever sailed under the Jolly Roger would be happy with a tiny cut of the plunder *corn borers* take from cornfields every year. But now, with Shell Chemical's insecticide *endrin,* the sailing is rough for insect freebooters.

Corn borers burrow into cornstalks, eating them hollow while hidden from view and protected from attack. Stalks sag and bend, ears are small and poorly formed because nourishment is cut off.

Now endrin kills hungry corn borers *before* they have a chance to do their disappearing act. The result: cornstalks perk up their ears . . . farmers build up their profits.

The development of more powerful insecticides to fight caterpillars like corn borer, sugar cane borer and armyworm is still another way Shell Chemical helps guard an abundant land.

SHELL

Shell Chemical Corporation

Chemical Partner of Industry and Agriculture

NEW YORK

Established 1845 **SCIENTIFIC AMERICAN** June, 1959 Volume 200 Number 6

ARTICLES

DEPARTMENTS

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THE COVER

The photograph on the cover shows a fragment of an ancient mechanism that has recently been identified as a device for calculating, among other astronomical phenomena, the motions of the stars and planets (*see page 60*). Dated from the first century B. C., the mechanism was discovered in 1901 by sponge divers exploring a shipwreck close to the small Greek island of Antikythera.

THE ILLUSTRATIONS

Cover photograph
by Derek J. de Solla Price

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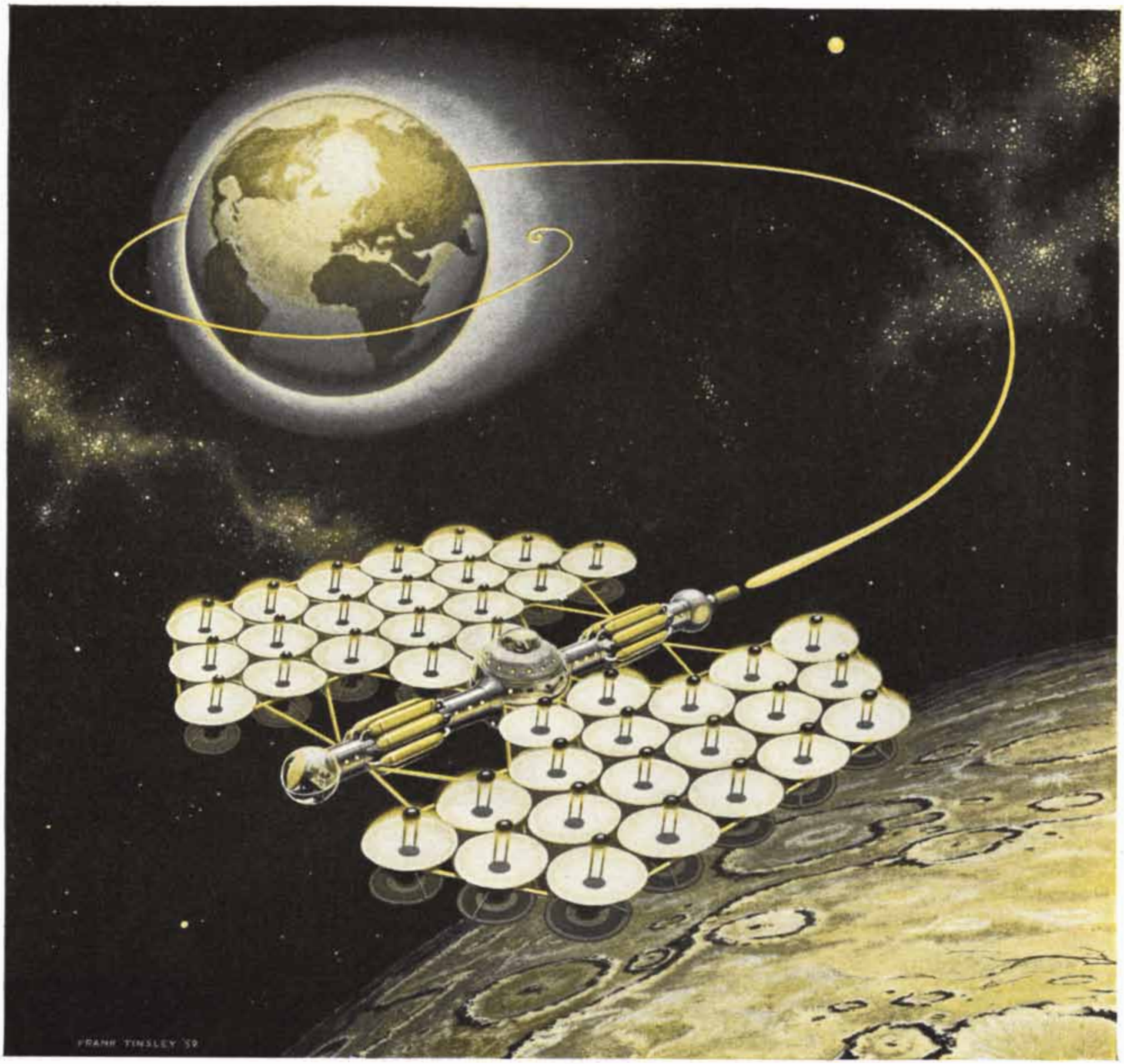
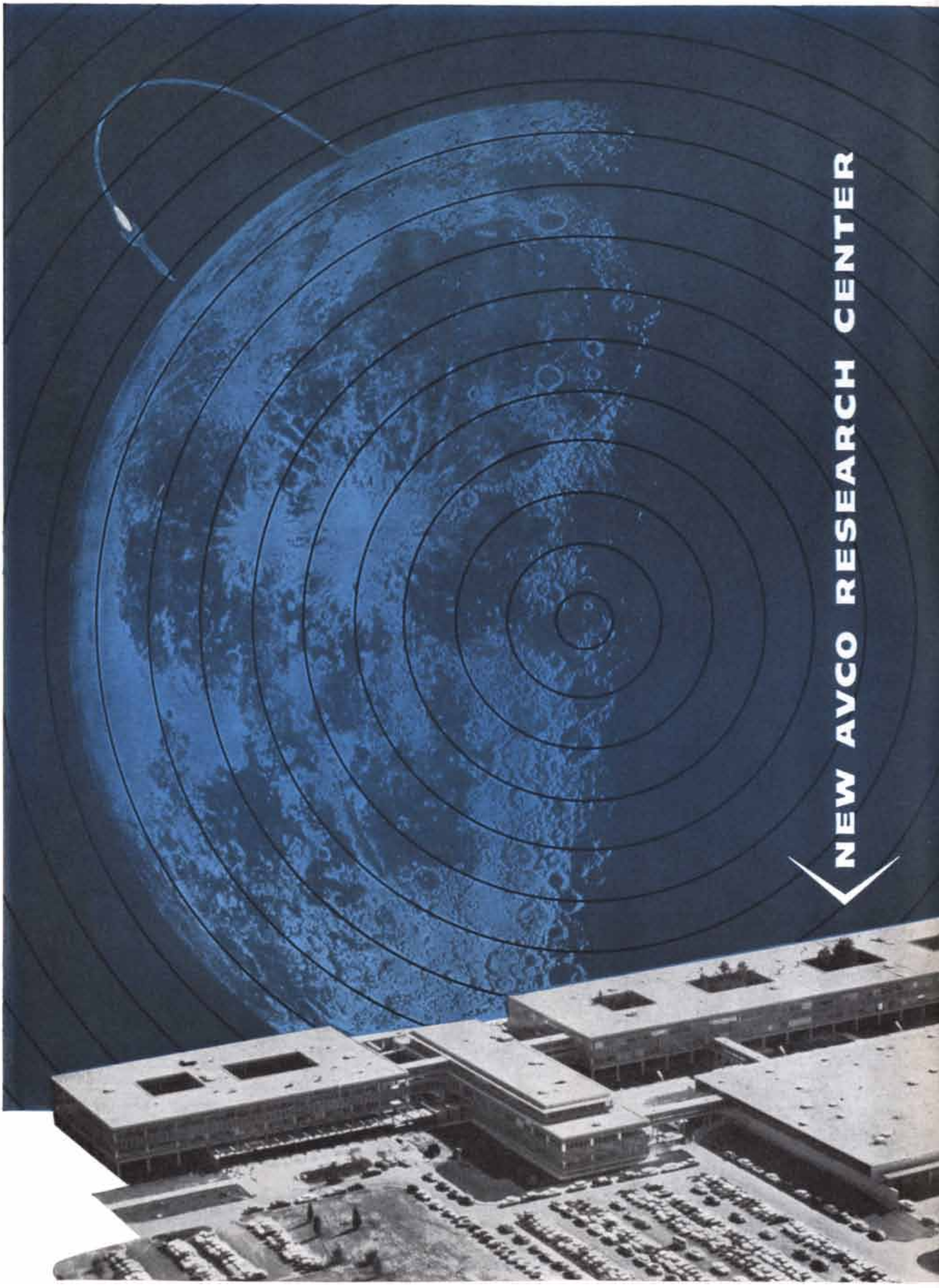

FRANK TINSLEY '59


NEW AVCO RESEARCH CENTER

Space age research gets a new headquarters

One of the largest and best-equipped research facilities in the nation is the new 16-million-dollar Avco Research Center at Wilmington, Massachusetts. Here, research and development in space age technology is already being conducted in areas ranging from missile re-entry to satellite design. From work such as this—and equally important work at the nearby Avco Research Laboratory—will come further contributions to national security and the conquest of space!

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Approximate Chemical Analysis of Asbestos

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MgO	40-42	Al_2O_3	Tr-3
H_2O	12-15	CaO	0-.3
FeO	Tr-6		

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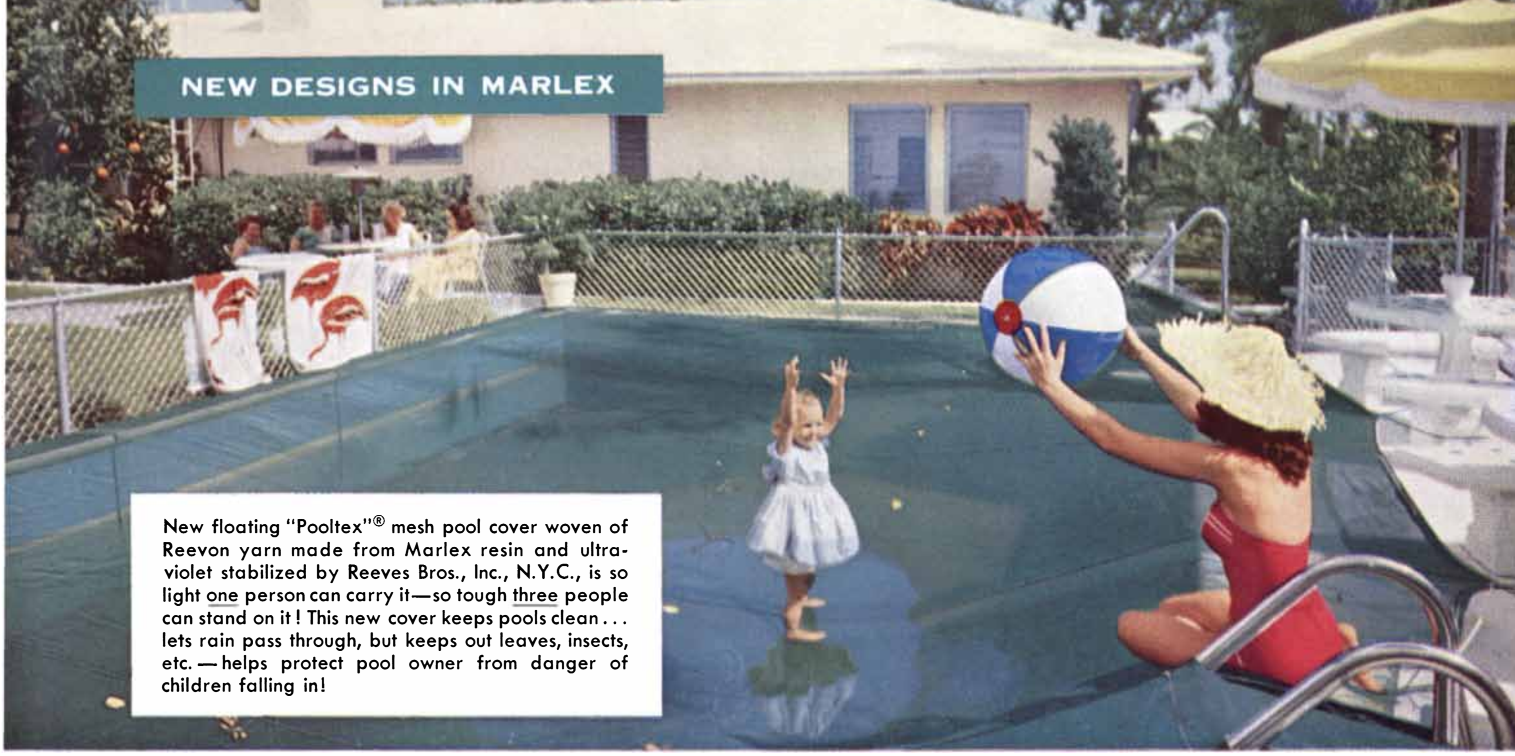

New floating "Pooltex"® mesh pool cover woven of Reevon yarn made from Marlex resin and ultra-violet stabilized by Reeves Bros., Inc., N.Y.C., is so light one person can carry it—so tough three people can stand on it! This new cover keeps pools clean . . . lets rain pass through, but keeps out leaves, insects, etc.—helps protect pool owner from danger of children falling in!

Get in the swim—with water sports products made of MARLEX*. . . the tough, rot-proof, floating plastic!

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*MARLEX is a trademark for Phillips family of olefin polymers.

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Fishing tackle boxes injection-molded from MARLEX by Plano Molding Co., Plano, Ill., are lightweight, rugged and corrosion-proof. These unbreakable tackle boxes will not crack or dent, and are completely weather-proof. Their attractive finish is durable and scratch-resistant.

Many leading manufacturers offer rope made of MARLEX to the marine market for ski tow ropes, hawsers, shrouds, life lines, heaving lines and general usage. Unbreakable, unsinkable rot-proof handles for ski tow ropes are molded from MARLEX by Lock-Hauer Co., Portland, Ore.

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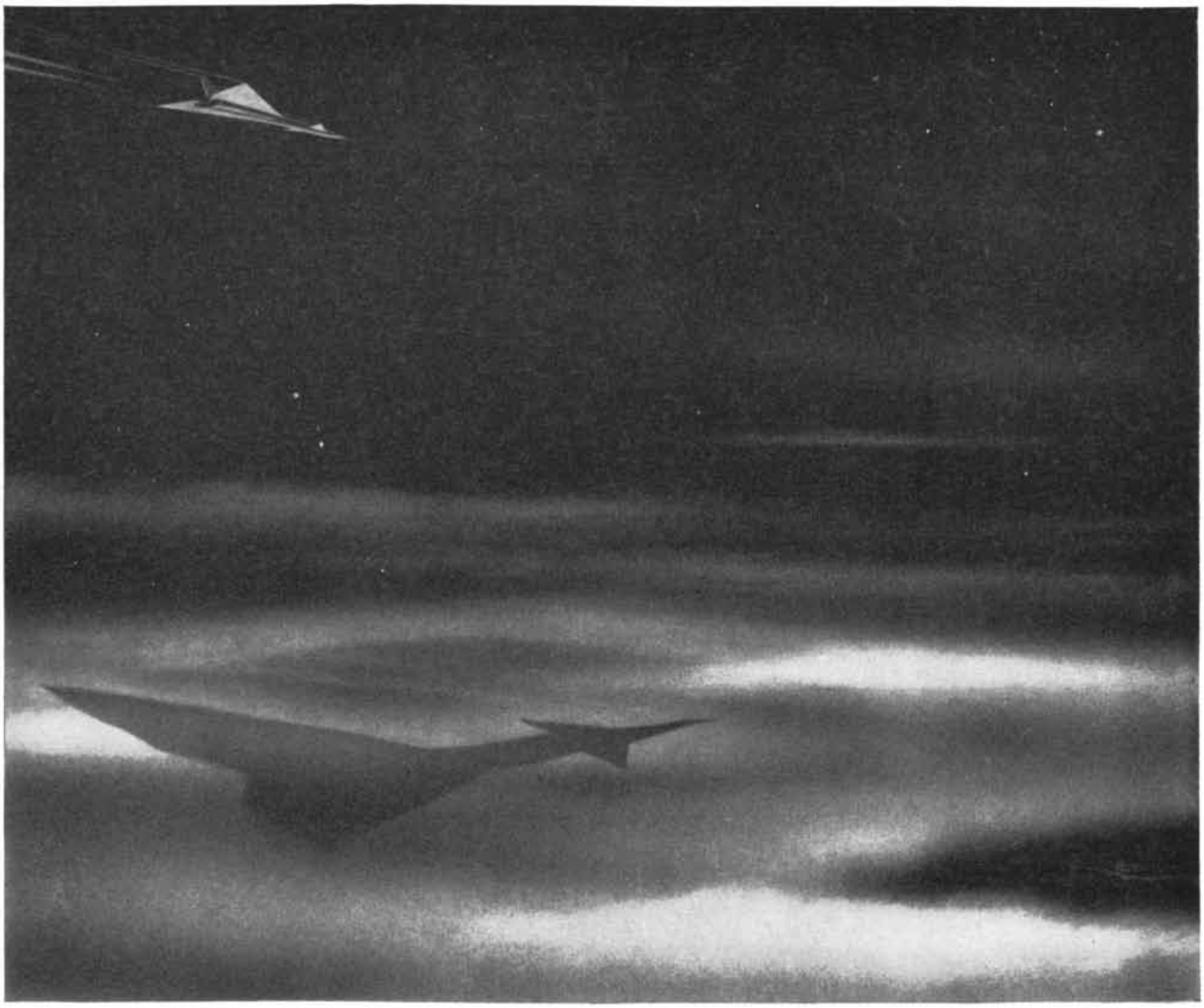

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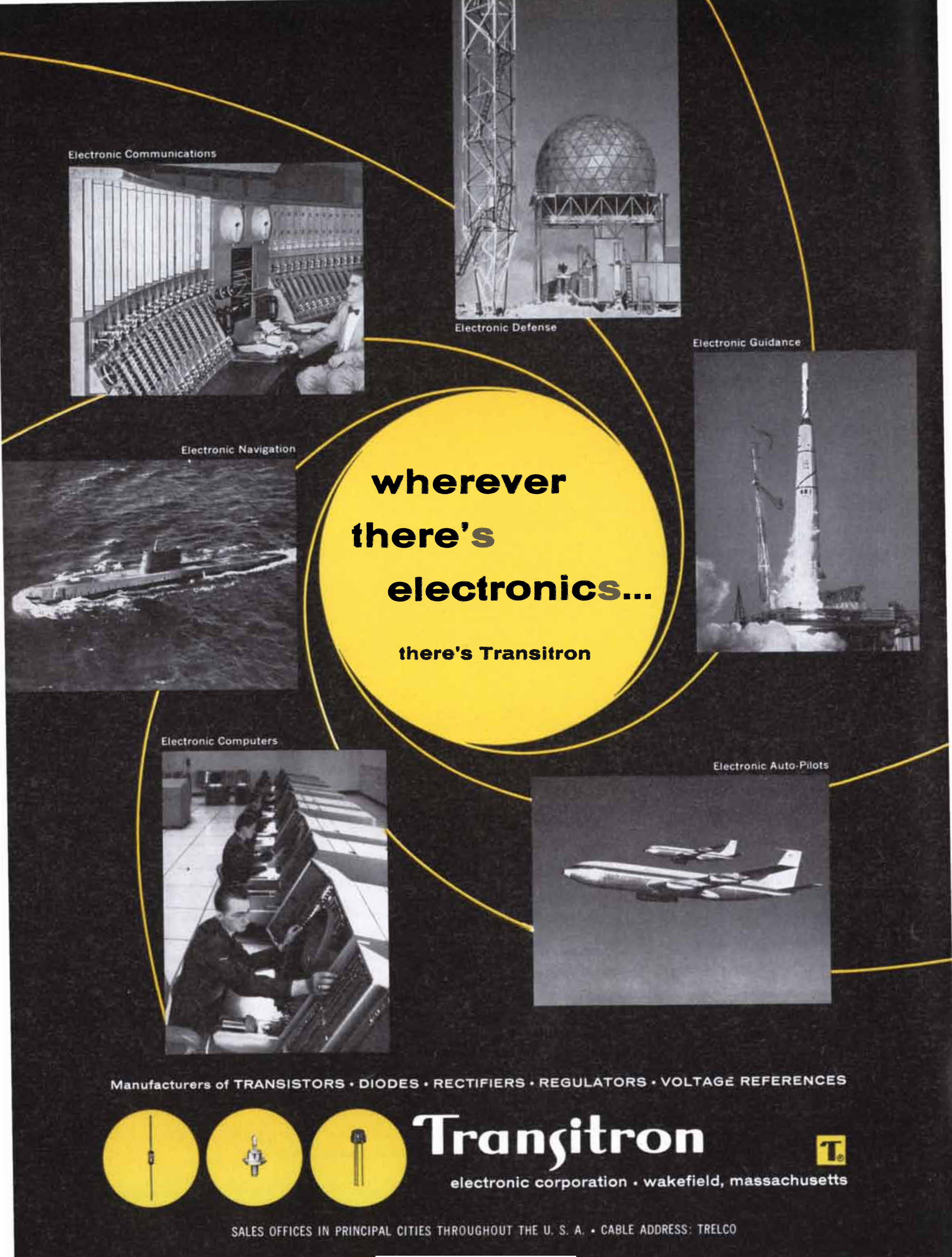
Expansion of our operations has created openings for additional senior engineers. Write to L. C. Wolfe, Chief Engineer.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HAWTHORNE, CALIFORNIA
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LETTERS

Sirs:

In a letter in your April issue Mr. Merril Eisenbud, Manager of the New York Operations Office of the United States Atomic Energy Commission, New York, criticizes the review by James R. Newman of my book *No More War!*

It is my opinion that Mr. Eisenbud's criticism is unjustified and seriously misleading.

Mr. Eisenbud says "James R. Newman reviewed Linus Pauling's book *No More War!* in your February issue and referred to a statement which I am said to have made. Mr. Newman writes: 'Merril Eisenbud, an Atomic Energy Commission official, wrote an article in 1955 which stated that "the total fallout to date from all tests would have to be multiplied by a million to produce visible, deleterious effects except in areas close to the explosion itself." ' . . . Newman's information, which comes in part from Professor Pauling's monograph, is incorrect. This statement did not come from an article I wrote. . . . I have admired Mr. Newman's writing for many years. . . . However, when even as reliable a writer as Mr. Newman will take confused fourth-hand information, and further confuse it in creating a fifth-hand version, one begins to wonder when to trust the 'facts' he reads."

The quoted statement attributed to Mr. Eisenbud appeared in an article in

Scientific American, June, 1959; Vol. 200, No. 6. Published monthly by Scientific American, Inc., 415 Madison Avenue, New York 17, N. Y.; Gerard Piel, president; Dennis Flanagan, vice president; Donald H. Miller, Jr., vice president and treasurer.

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AT RAYTHEON

Scientific imagination focuses on SONICS

Sound waves generated by electro- and hydro-acoustic transducers are used in a wide variety of applications. Flow metering, medical therapy and diagnosis, and degreasing of small parts are a few. Covering about 25 octaves, the sonic spectrum ranges from audible to ultrasonic frequencies as high as 10^9 cycles.

Raytheon scientists have made noteworthy contributions to transducer technology and acoustic propagation techniques. Examples: the development of the first low-cost depth sounder, the practical application of ultrasonics in machining refractory materials, and the use of electromechanical filters for spectrum analysis. Currently, Raytheon is producing for the Navy the AN/BQQ-1 sonar—the most comprehensive underwater sound system yet devised for detecting, tracking and attacking enemy submarines.

Among the distinguished scientists at Raytheon who are expanding basic knowledge of sonics is Dr. Theodor F. Hueter of the Government Equipment Division's Sonar Department.

RAYTHEON COMPANY, Waltham, Mass. RAYTHEON *Excellence in Electronics* the *New York Sunday News* of March 20, 1955. It is reproduced on page 1,279 of *The Nature of Radioactive Fallout and Its Effects on Man*, the report of hearings before the Special Subcommittee on Radiation of the Joint Congressional Committee on Atomic Energy.

Mr. Eisenbud's letter to you suggests strongly that the quotation attributed to him was not made by him. But he does not deny that he made the statement. In his testimony before the Special Congressional Subcommittee (page 1,274) Senator Anderson had said to him: "Mr. Eisenbud, this statement was made on 20 March 1955. I understand you do not question the accuracy of the quotation." Eisenbud replied "I do not question the accuracy of the quotation nor will I certify it."

On February 24, 1959, I wrote to Mr. Eisenbud, pointing out that in his testimony he had not questioned the accuracy of the quotation. In my letter I stated that "I note that you do not question the accuracy of the statement attributed to you by the writer of the article in the *Sunday News* either in your letters to *Scientific American* or to me or in your testimony before the Special Subcommittee on Radiation." I have received no answer, and I conclude that there is no reason to doubt that the statement is properly attributed to Mr. Eisenbud.

In view of these facts, I believe that Mr. Eisenbud's letter to you is seriously misleading.

LINUS PAULING

Gates and Crellin Laboratories
California Institute of Technology
Pasadena, California

Sirs:

Perhaps it should be stated even more definitely than Robert A. Hall did in his excellent and thought-provoking piece ["Pidgin Languages"; SCIENTIFIC AMERICAN, February] that pidginization and creolizing are not the result of the impact of well-developed languages of the Western world on underdeveloped idioms of more primitive cultures but rather the normal way languages split up and develop daughter languages. The fact that no such thing has happened in Europe for hundreds of years should not blind us to the fact that our own mother tongues are nothing but the result of creolization at an earlier stage. As a romancist, Dr. Hall will undoubtedly agree that French, Italian, Spanish, Portuguese, Catalan, Provençal, Romansch and Rumanian are, in their origin, noth-

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THE priceless ingredient of civilization...its most valuable "raw material"...is the life of the human being. Second only to the safety of the individual is the preservation and protection of those things which contribute to his life...food, places to live and work, and ways of getting there.

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Infrared systems represent a field in which Servo Corporation enjoys technological leadership based on many years' experience. Out of its Infrared Research Laboratories came the SERVOSAFE® Hot Box Detective*, a device supplied by the Railroad Products Division and now in use on 17 leading U. S. railroads.

The SERVOSAFE system spots overheated journal boxes—"hot boxes" which can lead to derailments and loss of time, goods, lives. It automatically examines each and every journal box as a train passes. When a hot box is detected, a stop signal is tripped, the tower operator is alerted, and a graph points out *which* journal box on *which* side of *which* truck on *which* car is dangerously overheated.

All this happens in seconds. By the time the train rolls to a halt, the one dangerous journal box out of harmless hundreds is located immediately; and the danger is corrected. The train then proceeds in safety.

The value of such split-second detection can be added in terms of the number of cars which need *not* be sidetracked for costly repairs—or the tons of perishable goods which need *not* perish—or the consignments which need *not* be delayed.

The value may also be measured in terms of *people*...of ourselves, our wives, and our children.

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Air safety depends on knowledge of weather conditions. The SERVOFLIGHT Radio Theodolite tracks weather balloons for this purpose, passing on information about temperature, humidity, pressure, wind directions, and speeds.

And so it goes with other divisions and products...infrared systems for industry to provide safe control of industrial processes...and, of course, military systems which guard against surprise enemy attack. Thus, in every respect, Servo Corporation products serve safety through science.

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ing but different forms of creolized Latin. It can also be stated that medieval English was, at different periods, first creolized Old Norse and then creolized Norman French. . . .

GUNNAR LEISTIKOW

New York, N. Y.

Sirs:

It is tempting to think that the Romance languages may be of creolized origin. However, we must distinguish two main types of linguistic change: (1) the "normal" kind, slow and gradual, extending over centuries and millennia; and (2) the sudden, drastic reduction and brusque, extensive re-structuring involved in the formation of a pidgin. The historical evidence shows clearly that the differentiation of the Romance languages and of the other group mentioned by Mr. Leistikow was of the first, not the second, kind. Furthermore, there is no evidence that there was ever a time when the ancestral forms of these languages were never spoken by anyone as his or her native language, as would be required by the other part of our definition of a pidgin.

ROBERT A. HALL, JR.

Cornell University
Ithaca, N. Y.

Sirs:

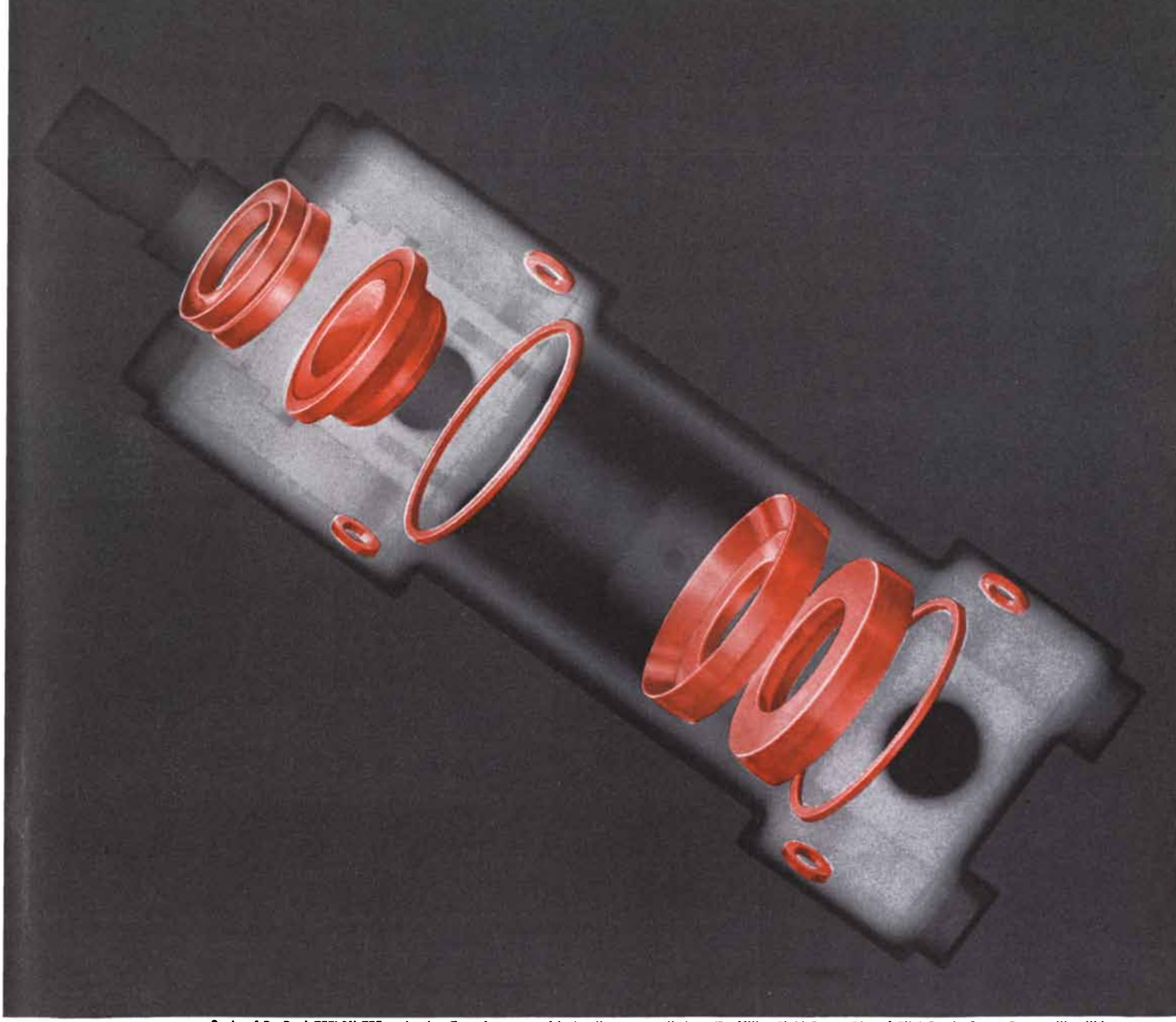
"Reactor Fuel Elements" by James F. Schumar [SCIENTIFIC AMERICAN, February] is not only a clear and interesting article, but it is a sturdy blow in the long battle for good grammar and diction. Only once does he use the bastard word "cladding" and then in quotes to show its questionable nature.

Use of "clad" as a root verb with all normal verbal inflections is gaining ground, largely because engineering ears used to "metal-clad" don't accept the other tenses, "clothe" and "clothing," in association with metal.

The English language is rich with bastard forms already. Not legitimacy, but usefulness, should be the criterion for accepting new words. Mr. Schumar's prose clearly demonstrates that the language doesn't need these illogical and ear-grating forms.

VAN V. TRUMBULL

General Electric Company
Schenectady, N. Y.



Seals of Du Pont TEFLON TFE resins boost performance of hydraulic power cylinder. (By Miller Fluid Power Div. of Flick-Reedy Corp., Bensenville, Ill.)

THE INSIDE STORY: Seals that help put the muscle in machines

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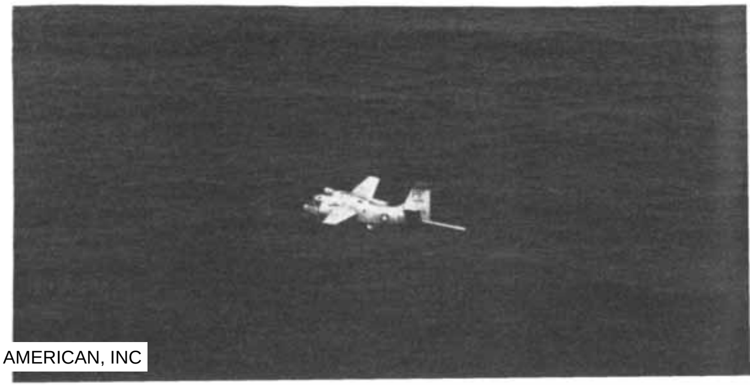
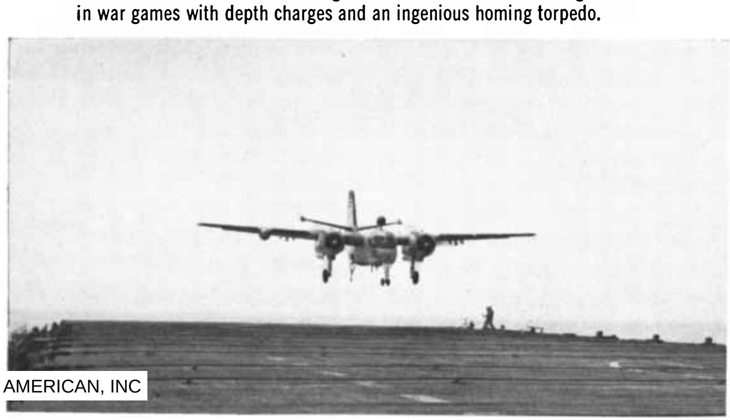
Here are Grumman S2F Trackers on board aircraft carrier, mainstay of United States Navy HUK Group on Anti-Submarine Warfare maneuvers.

S2F starts search with electronic gear that can detect snorkel, periscope, or sub radar, even the submerged sub's disturbance of the earth's magnetic field.



Personnel of Combat Intelligence Center are receiving S2F Tracker report of contact and the dropping of detection devices to pinpoint submarine.

Grumman S2F Tracker is returning to aircraft carrier after "sinking" submarine in war games with depth charges and an ingenious homing torpedo.



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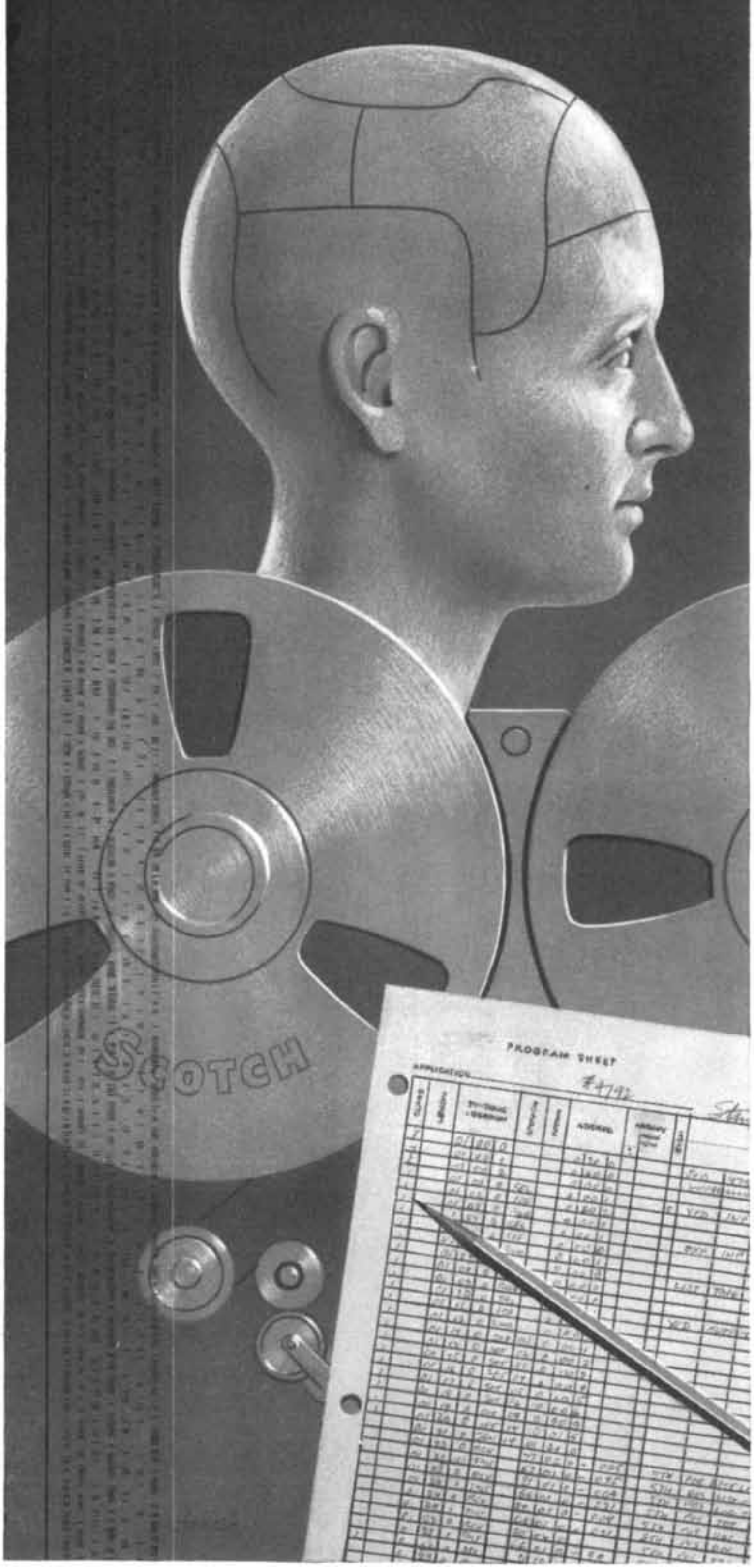
FOR INSTRUMENTATION USE



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. . . WHERE RESEARCH IS THE KEY TO TOMORROW

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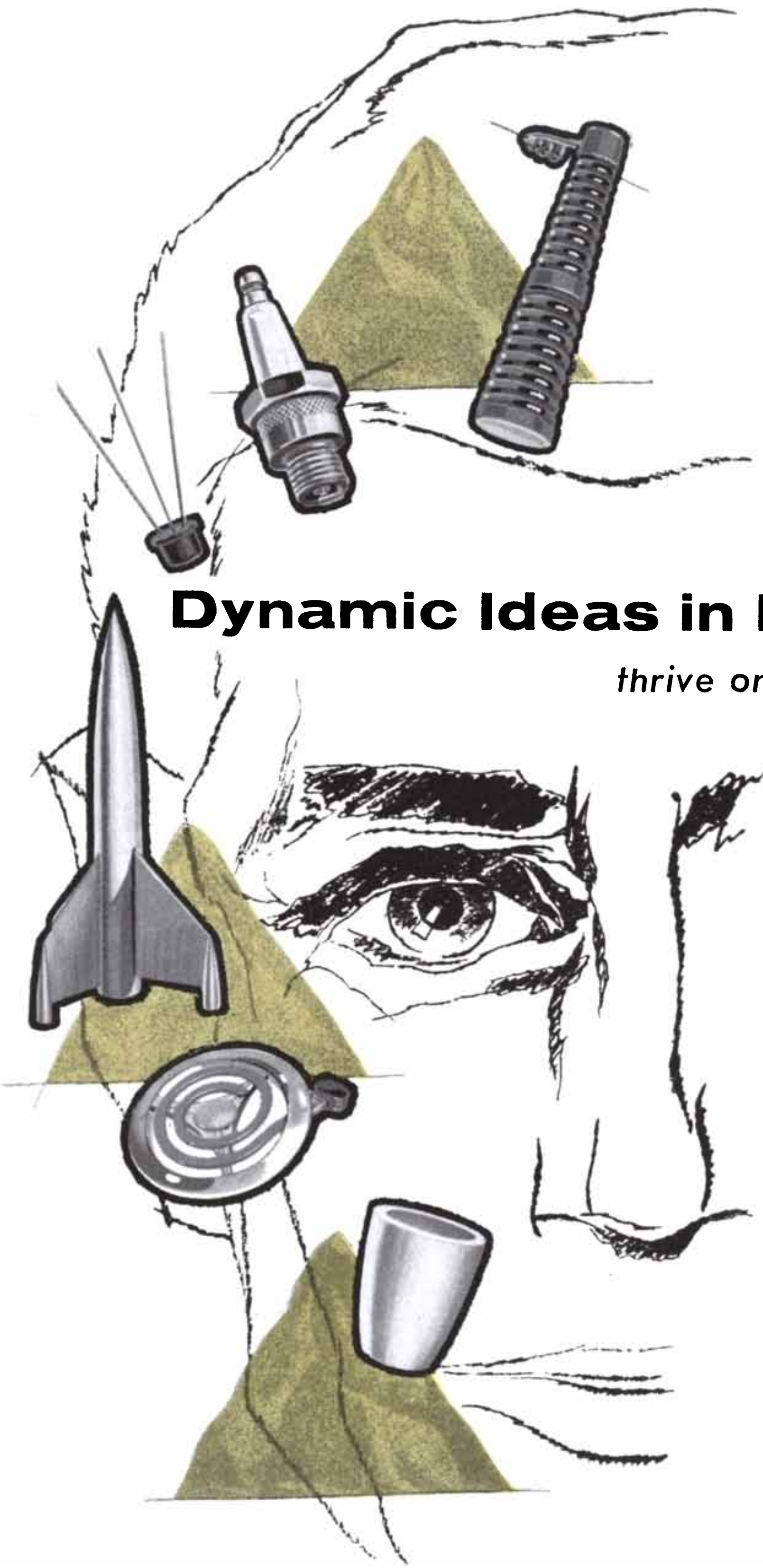

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50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

JUNE, 1909: "The *Zeppelin II*, the large dirigible balloon built by Count Ferdinand von Zeppelin, left its floating shed on Lake Constance late on Saturday night, May 29th, with the supposed object of sailing to Berlin. At Bitterfeld, 465 miles from its starting point, the Count decided to return, as he had lost some gas. At Goppingen a descent was made to replenish the supply of fuel. The motors had already stopped, and the airship was nearing the ground in an open field, when a gust of wind carried it against a tree with considerable force. The prow of the balloon was crushed in. Later dispatches report great skill, promptitude and spirit on the part of Count Zeppelin in making repairs, congratulatory telegrams from the German Emperor and—six weeks required to restore the balloon. It is a very great feat so to construct an immense gas bag so as to navigate it continuously for 36 hours, traversing 850 miles. Yet if such damage can be caused by a puff of wind the moment the controlling motors are stopped, we maintain that nothing lighter than air is going to give us the ultimate solution of the problem of mechanical flight, any more than we are limited to materials lighter than water for the navigation of the sea."

"The Council of the Röntgen Society has decided that the gamma-ray ionization from one milligram of pure radium shall be regarded as a standard, and called a unit of radioactivity. Three substandards of radium bromide are to be prepared, and comparison will be made in the specimen of the purest radium bromide at the Victoria University in Manchester."

"Mr. Marconi denies the statement which has recently been made that wireless telegraph waves are injurious to operators, and that they produce various diseases such as conjunctivitis and corneal ulcers. To use his own words: 'During the 12 years or so of our operations we have had to deal with no single case

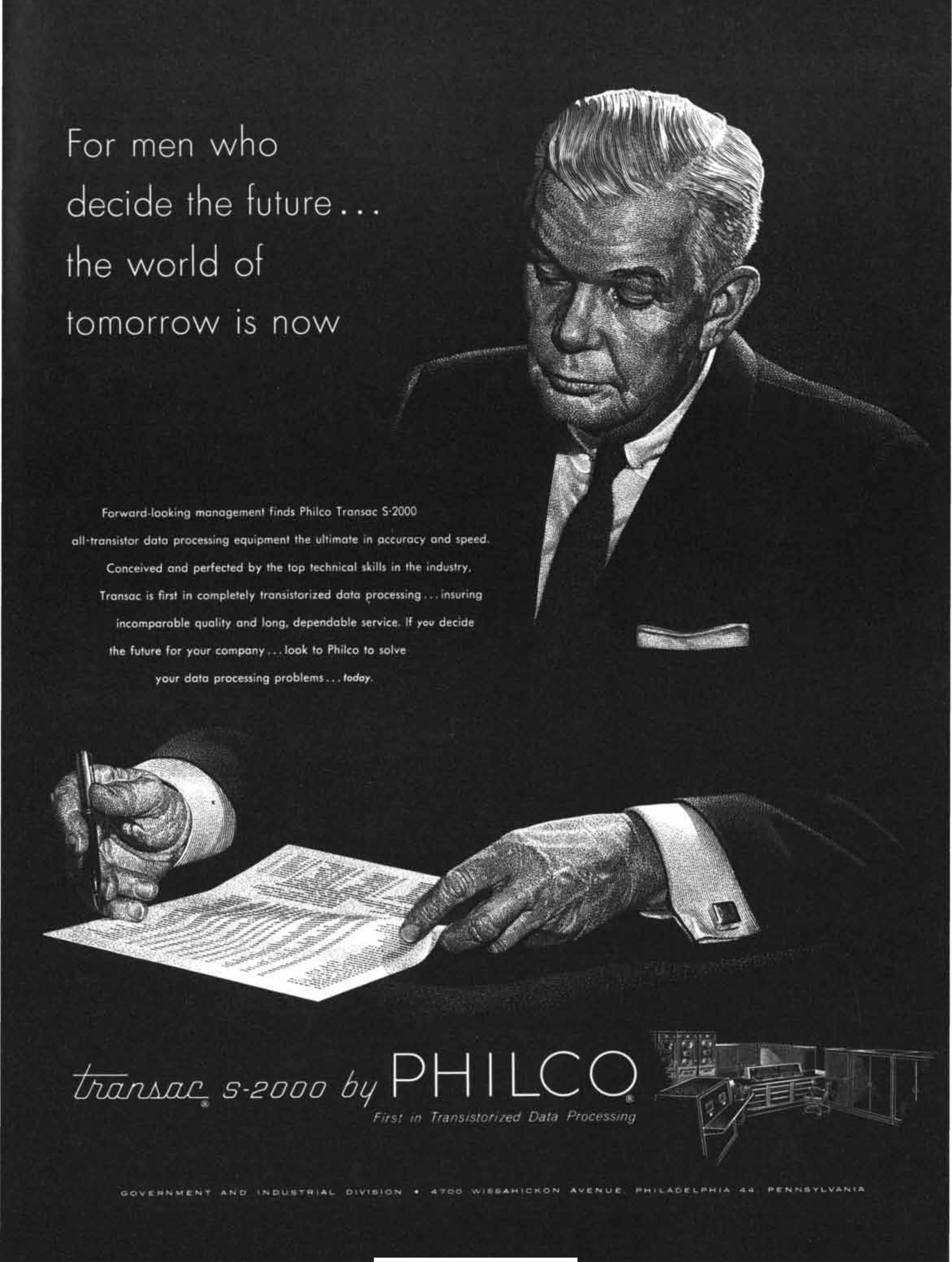
of compensation for any injury of this origin.' "

"Wilbur and Orville Wright are extremely careful in making their experiments, and both have a great amount of patience. They always delve to the bottom of any problem they have to solve. As their only sister, Miss Katherine, so aptly puts it: 'To hear them argue around and knock the bottom out of each other's ideas till, at the end of three hours, you find Orv where Wil started off and Wil where Orv began, is just the killingest thing imaginable, and makes them both burst out laughing—but it saves them no end of useless experiment.' "

"When the great Cunard turbine boats *Lusitania* and *Mauretania* made their appearance, it was predicted that they would never be surpassed in size or speed. In speed they probably never will be surpassed, but in size they are destined to be greatly surpassed by the *Olympic*, which is now under construction at Belfast for the White Star Company. These truly enormous vessels (the sister ship will be named *Titanic*) will be 890 feet in length, 92 feet in beam and 64 feet in molded depth."

"Prince Henry, brother of the German Emperor, is the inventor of an automatic window washer. It is intended for the purpose of wiping off moisture from the glass wind-break of an automobile, so that the rider's vision may be clear at all times."

JUNE, 1859: "Alexander von Humboldt, the great philosopher, traveler and author, expired on June 6 in Berlin, Prussia, at the advanced age of 91 years. Von Humboldt received a high education in the University of Göttingen. His fame as a mineralogist was early established, and at 23 years of age he was appointed to the important government post of Superintendent of Mines in Franconia. He visited the New World under the patronage of the Spanish Government, and in 1799 commenced to explore the great valley of the Orinoco. During the five years he was a traveler in our hemisphere, he visited the sources of the Amazon, climbed the snow-capped peaks of the Andes, and under a burning sun traversed vast plains, pesti-



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lential swamps, and barren deserts where the foot of white man had never trod before. His published accounts of these travels attracted the attention of the whole civilized world. They were printed in 17 large volumes, richly illustrated with figures of the subjects described. They embraced geography, zoology, botany, mineralogy, the natural history of animals, astronomy, geology, climatology, in short, every branch of science. So varied and profound were his attainments that it was at once felt that he stood out in bold relief as the most accomplished traveler that ever lived. For the past 50 years he has been the Nestor of science, and has gone down to the grave bearing the esteem of all men, and 'laden with wealth and honors nobly won.'"

"SCIENTIFIC AMERICAN is no new enterprise. Its character and influence have been acknowledged and felt for nearly 14 years past. It is the only journal of its kind in the U. S. which has met with success; since its commencement no less than 15 similar journals have been started, and have expired after a brief and unhealthy career. The publishers of SCIENTIFIC AMERICAN respectfully announce to their readers and the public generally, that, on the first day of July *next* (1859), their journal will be enlarged and otherwise greatly improved. Instead of eight pages in each number as now, there will be *sixteen*."

"There are now six lines of street railroads in New York City, which, taken all together are about 45 miles in length. They are great corporations in every sense of the term, for they carried during the past year no less than 27,057,000 passengers, and earned $1,352,000. These roads employ about 2,000 horses and mules to draw the cars."

"The inventor of friction matches was John Walker, a chemist of Stockton, England, who died on May 5 at the advanced age of 79 years. He made the discovery nearly half a century ago while experimenting with various chemical substances, and for a number of years he realized a handsome income from the sale of matches at the price of about 36 cents a box."

"Ozone, according to Professor Faraday in a late lecture, is oxygen gas under electrical excitement. It can be formed by passing the electric spark directly through the gas or by making the electric current pass over the exterior of a tube containing oxygen."

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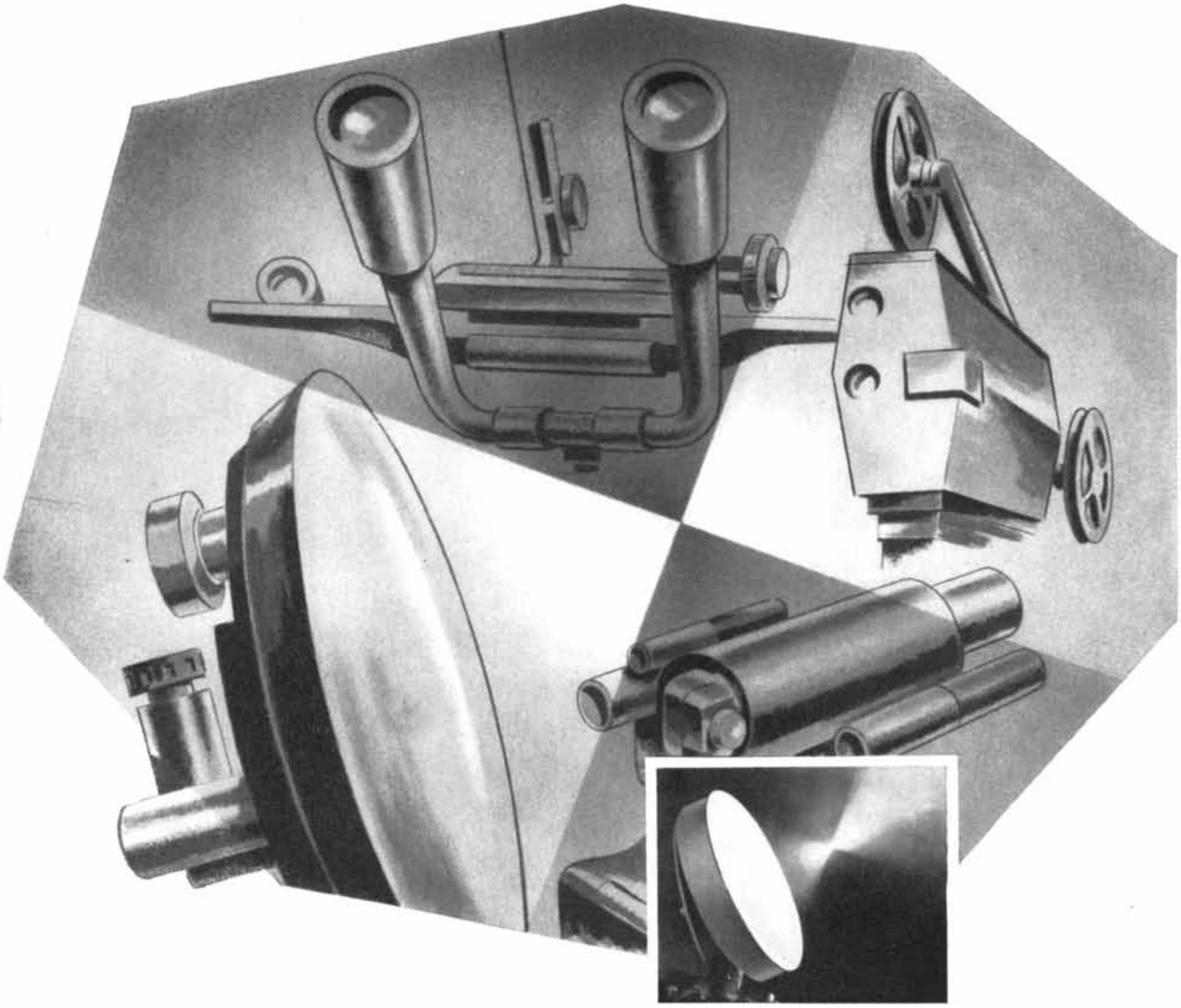

Unbreakable Repli-Kote Mirrors out-perform glass, slash costs

These new lightweight, low distortion Repli-Kote Mirrors of cast epoxy resin offer design engineers optical reflectors with a matchless combination of properties, impossible with glass. A single master mirror is all that's necessary for mass producing precision Repli-Kote Mirrors—at significant cost savings.

Optical Precision — 6″—5¼″ Focal Length Repli-Kote paraboloid mirrors have been produced in quantity with an accuracy permitting 90% of incident collimated light to be concentrated within a disc of 0.1 mm diameter. Higher rate of thermal diffusion through epoxy also lowers distortion caused by temperature transients.

Permanent Reflective Surface — High vacuum applied, silicon monoxide protected aluminum reflective surface is *permanently* bonded to epoxy backing, will resist flaking or peeling for extended periods.

High Mechanical and Thermal Shock Resistance — Repli-Kote Mirrors have withstood impacts *as severe as 22,000 g*, undergone rapid temperature cycling from −55°C to +125°C with no measurable physical change.

Light Weight—Repli-Kote Mirrors cast of epoxy are much lighter than glass. Suitable fillers can be added if desirable.

Any Shape—Paraboloids, hyperboloids, ellipsoids and more complex aspheric surfaces not previously reproducible in glass by mass production methods can now be quickly fabricated.

Ease of Mounting—Fixtures, threaded inserts, electrical components can be molded directly into the mirror backing, opening an almost limitless field of design possibilities. Repli-Kote Mirrors are also easily machined.

If you are working on tracking and guidance systems—or any system employing reflective optics—durable, lightweight, precision Repli-Kote Mirrors offer you greater design and production freedom. Let us help you make the most of Repli-Kote Mirrors in building a better product at lower cost.

Address Inquiries *to Repli-Kote, Singer-Bridgeport, 915 Pembroke Street, Bridgeport 8, Conn.*

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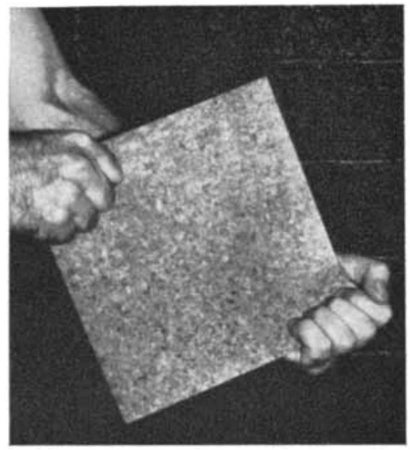
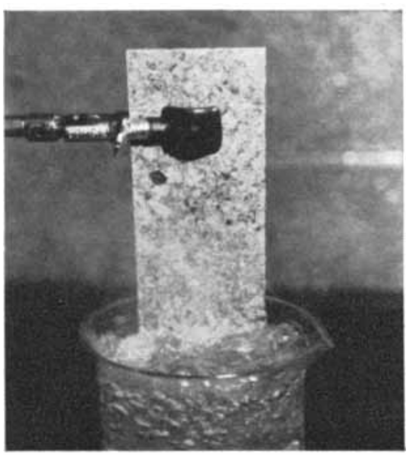
Look what happens when you add a pinch of permanence

1. WANT DURABILITY IN YOUR PRODUCT? Who doesn't! Here's how one manufacturer gets it. Floors take a beating—but *this* floor can stand the gaff for years. It's cork tile by Kentile, Inc. The permanence is *built in* with phenolic resins by Durez.



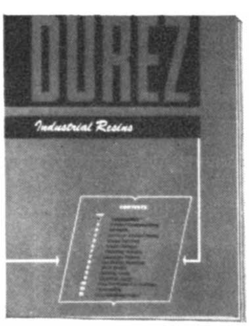
2. CORK GRANULES are locked together to stay. You can bond many materials this way—with Durez resins that soften under heat, then set hard.



3. NOT EVEN BOILING WATER can weaken the good, strong bond Durez resins provide. These resins resist heat, moisture, abrasion—for keeps.

4. WHERE can you use them? Here are examples. Rubber, paper, sand, asbestos, ground wood—Durez resins bond them all into strong, useful products.

5. IT DOESN'T TAKE MUCH. Often, one part in ten gives you the properties you want. And phenolic is one of the cheapest bonding agents you can buy!



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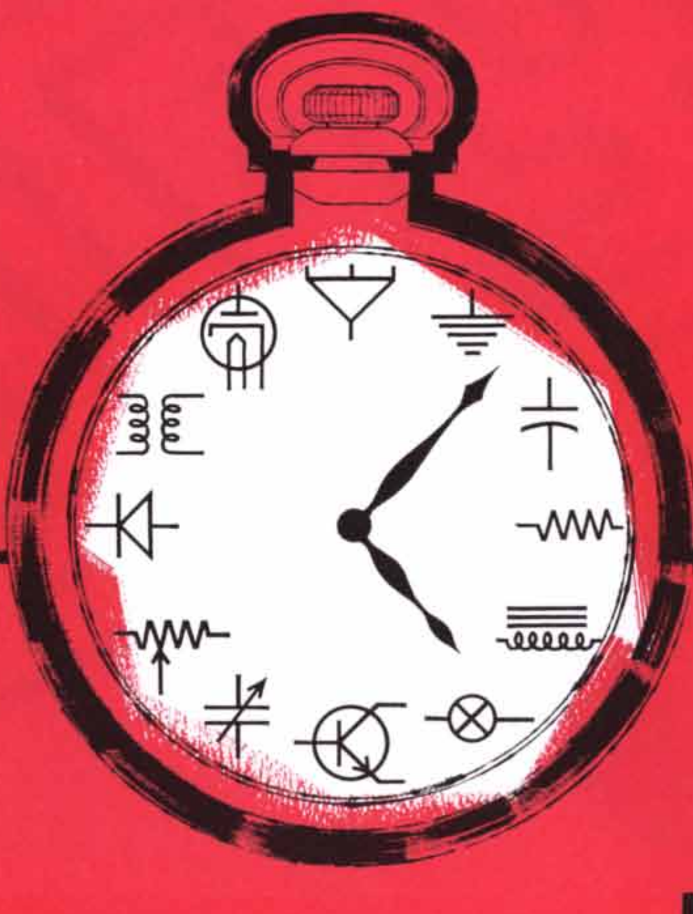

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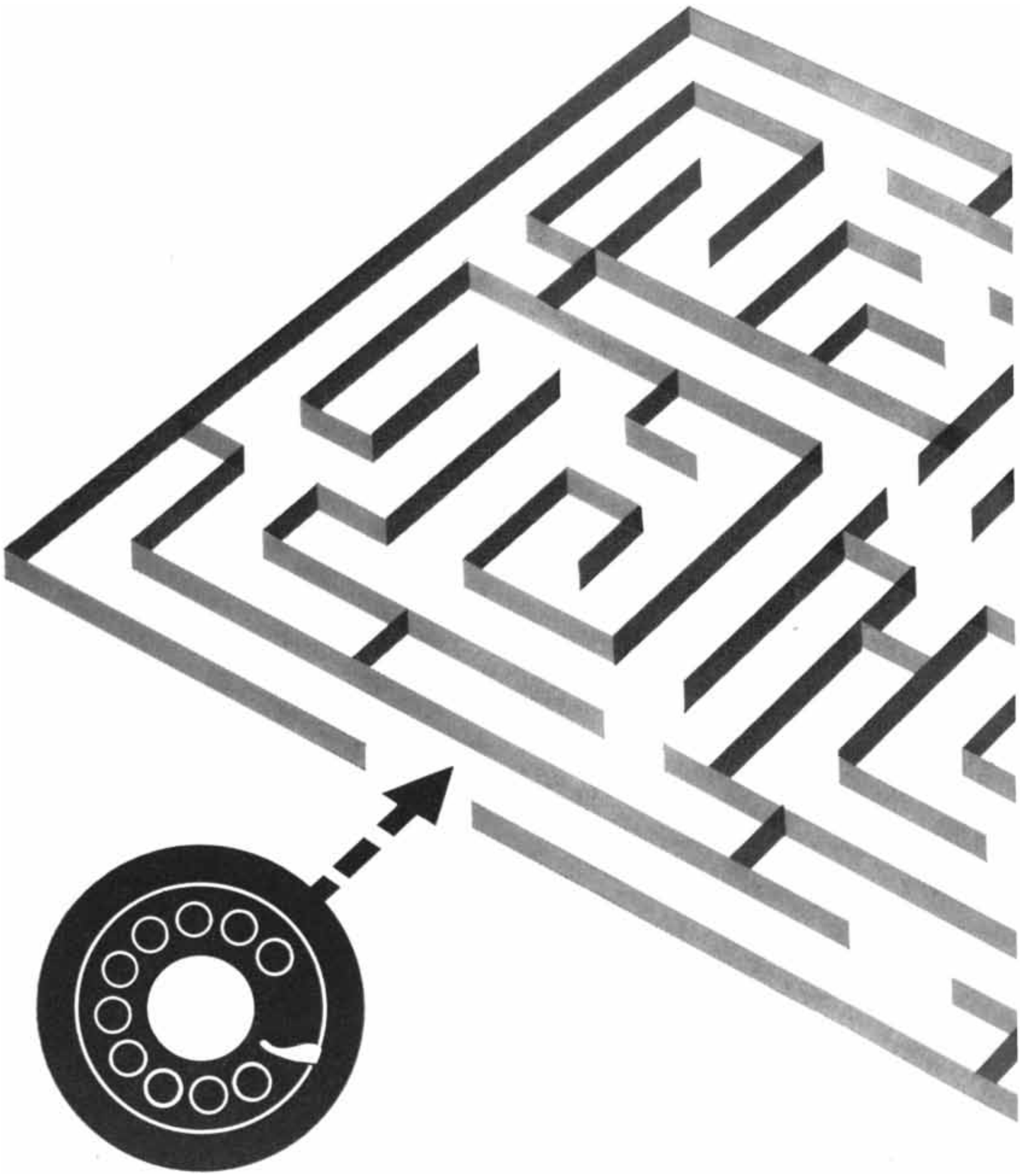
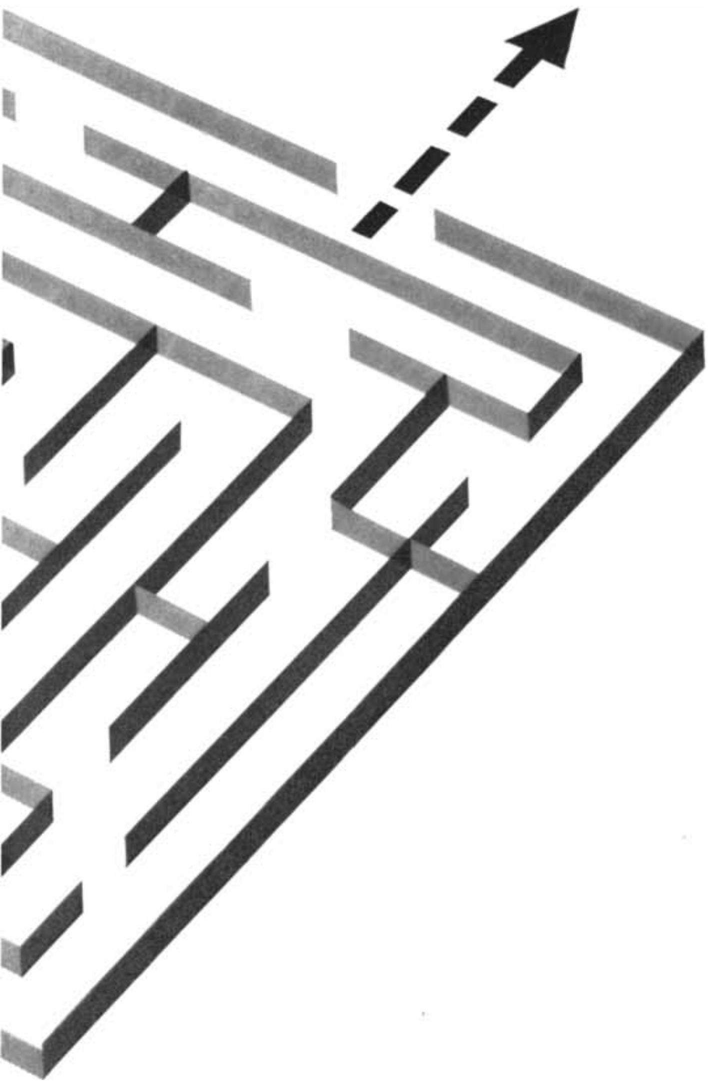
Automation cut its teeth on the

...how ITT's early work in telephony advanced



telephone

the art of automation



The dial telephone exchange was one of the first examples! Today, automatic switching and new electronic techniques for automation are altering the operations of virtually every business and industry.

It was natural that ITT System companies, pioneers in the first, should be leaders in the second.

Customers have ranged from mail-order houses, railroads, libraries and oil companies to the air forces of several NATO governments.

There have been dramatic results.

One example is the automatic check-processing system developed by ITT System companies for one of the nation's largest banks. It codes, sorts and verifies checks. It performs all normal bookkeeping and accounting operations for demand deposits.

Another is the automation system for a large steel mill which records the program of requirements for every job, then feeds back information to production control centers as each phase is completed.

Still another: the first automatic U. S. post office, now under construction in Providence, Rhode Island.

Hundreds of others could be cited. Each required a complete understanding of automation from the design of a simple switch to the functioning of a fully-integrated electronic complex.

The ITT System has many specialists in this field. Among them: Intelex Systems Incorporated in retained-document automation; Kellogg Switchboard and Supply Company in automatic switching; Airmatic Systems Corporation in automatic-switch pneumatic tube and document-conveyor systems; ITT Federal Division in automatic test equipment, both military and industrial. ITT's European subsidiaries add to this experience.

To learn more about ITT's abilities in the area of automation, write for further information.

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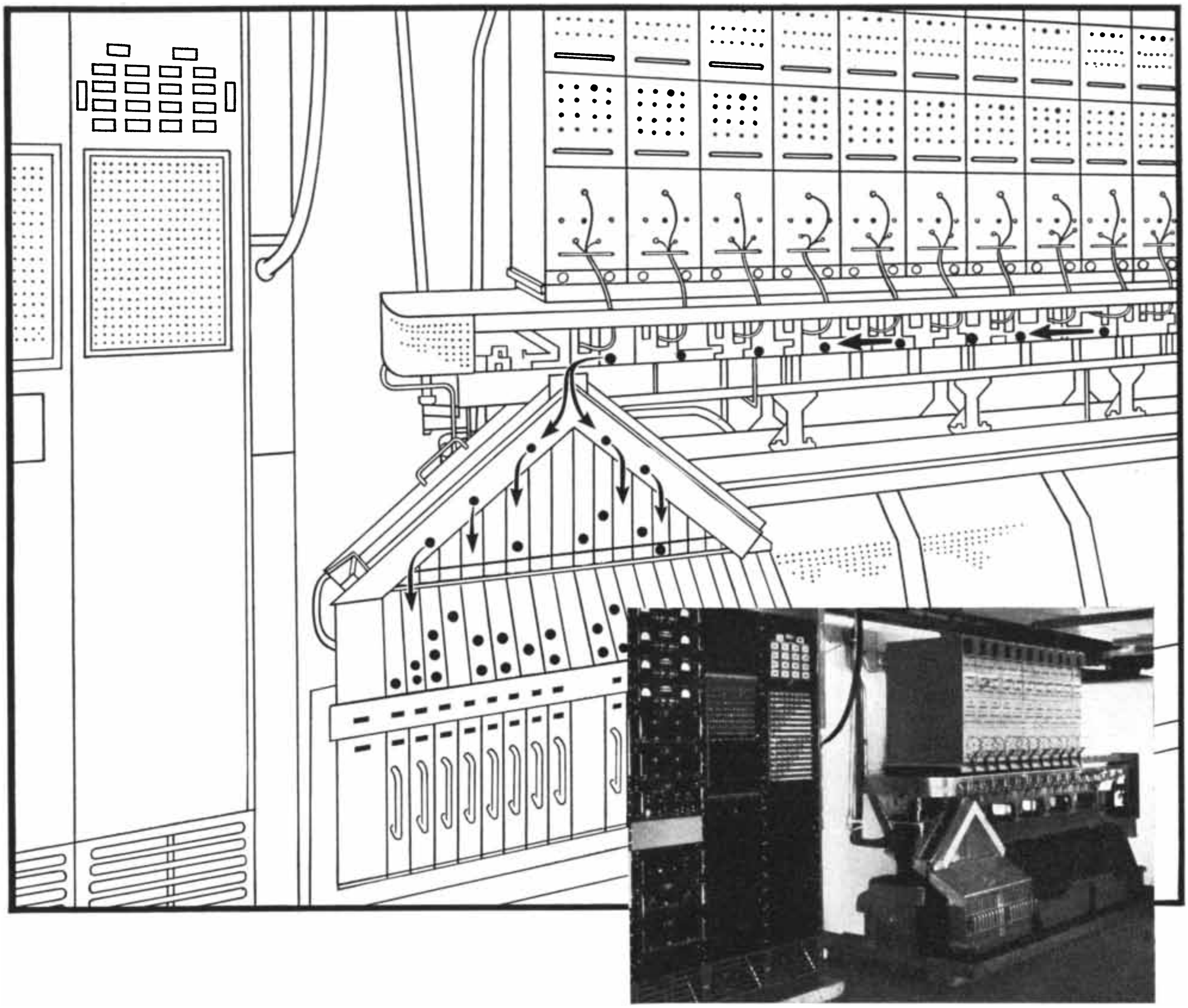
THE AUTHORS

HERBERT FRIEDMAN ("Rocket Astronomy") is superintendent of the Atmosphere and Astrophysics Division of the Naval Research Laboratory. He graduated from Brooklyn College and in 1940 received a doctoral degree in physics from Johns Hopkins University. After a year as a physics instructor at Johns Hopkins he joined the Naval Research Laboratory, where he became head of the Electron Optics Branch. For the past 10 years he has been engaged in research by means of rockets. At present his primary concern is the instrumentation of earth satellites.

DEREK J. DE SOLLA PRICE ("An Ancient Greek Computer") is a fellow of the Institute for Advanced Study in Princeton, N. J., where he studies ancient astronomy and the history of scientific instruments. He acquired an interest in the latter subject while working as laboratory assistant in a British technical college. Price is a Londoner by birth and a graduate of the University of London, from which he received a Ph.D. degree for his World War II research in experimental physics. "After holding a Commonwealth Fund Fellowship in mathematical physics at Princeton University and a lectureship in mathematics at the University of Malaya in Singapore I returned to England in 1950," he says. "Out of chagrin at not being able to cover all parts of physics and mathematics at the research front, I contrived to deal with 'science in the large' in the humanistic tradition, and proceeded to a second Ph.D. (from the University of Cambridge) in the history of science." For his second doctoral dissertation Price edited a medieval English text on astronomy. This work drew considerable attention because of two claims made by Price: that the work was by Geoffrey Chaucer and that it was the only extant manuscript in Chaucer's own handwriting. Price returned to the U. S. two years ago to help plan the Smithsonian Institution's new National Museum of History and Technology.

HARRY F. HARLOW ("Love in Infant Monkeys") is George Cary Comstock Professor of Psychology and head of the Primate Laboratory at the University of Wisconsin. He received his A.B. from Stanford University in 1927 and his Ph.D. from the same institution in 1930, the year in which he joined the

TECHNOLOGICAL LEADERSHIP IN SEMICONDUCTORS



How DATAC rates semiconductors

Now in operation at Sylvania's Semiconductor Division is DATAC, Digital Automatic Tester and Classifier. Designed and developed by engineers of the Division, it automatically subjects semiconductors to 16 separate tests and classifies them into as many as 256 different categories at a speed of 1500 per hour. DATAC rates each semiconductor on each test. It compares the final test results with predetermined standards and then places each unit in its proper category. Replaceable plug-in test modules enable Sylvania's DATAC to test for an almost infinite variety of electrical and mechanical characteristics and parameters.

For the circuit designer . . . DATAC means new uniformity and higher quality in semiconductors. It eliminates damage due to excessive handling and reduces human error to a minimum, assuring duplicate performance from unit to unit. Continuous operation has proved test accuracy within a tight 0.5 percent limit for all parameters. The end result is a new standard of excellence in semiconductor devices.

At Sylvania, technological achievements like DATAC are in progress every day. Always, the objective is to produce the best possible semiconductor at the lowest possible cost.

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Wisconsin faculty. Harlow is currently president of the American Psychological Association.

ANTHONY H. ROSE ("Beer") is a lecturer in microbiology at Heriot-Watt College in Edinburgh, Scotland. He studied industrial fermentation at the University of Birmingham, from which he graduated in 1950. In 1954 he acquired a Birmingham Ph.D. in applied biochemistry and, in addition, one of the first King George VI Fellowships of the English-Speaking Union, which brought him to the Institute of Microbiology at Rutgers University. Later he was drafted into the Royal Air Force as an education officer and held a fellowship in fermentation in the National Research Council of Canada.

LIONEL S. PENROSE ("Self-Reproducing Machines") is Galton Professor of Eugenics at University College London. He pursued his undergraduate studies at St. John's College in the University of Cambridge, then studied medicine at St. Thomas's Hospital in London. In 1928 he became a member of the Royal College of Surgeons and a licentiate of the Royal College of Physicians (the licensing bodies for physicians for England and for London, respectively). Two years later he obtained at Cambridge the degree of M.D. (in British practice an advanced research degree). During the 1930s Penrose was research medical officer of the Royal Eastern Counties' Institution of Colchester. From 1939 to 1945 he directed psychiatric research for the Canadian province of Ontario.

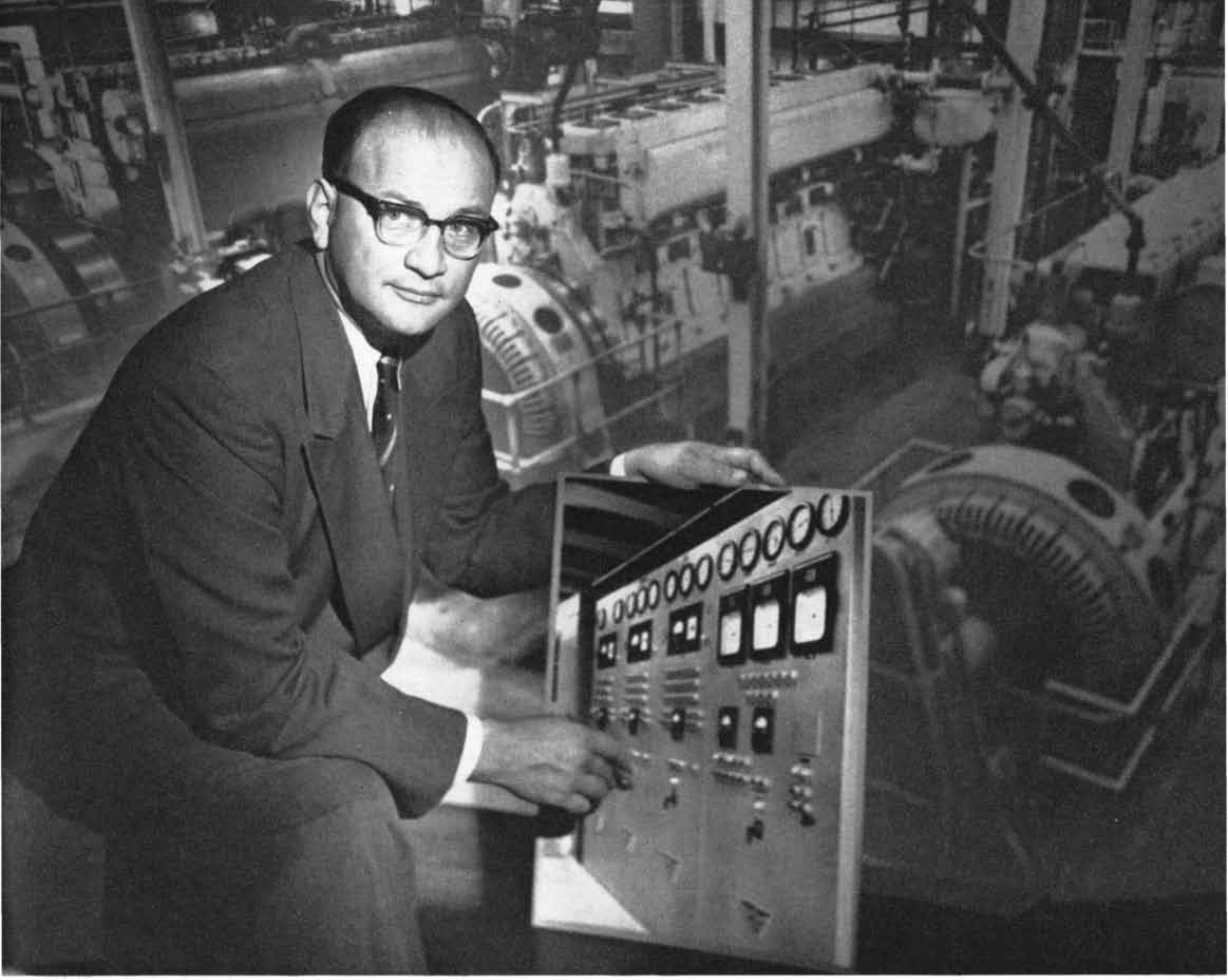
ARTHUR UHLIR, JR. ("Junction-Diode Amplifiers") is director of semiconductor research and development at Microwave Associates, Inc. He studied chemical engineering at the Illinois Institute of Technology, where he was class valedictorian at his graduation in 1945. For several years he was an engineer in the employ of the Armour Research Foundation working on fluid mechanics and thermodynamics. He then studied physics at the University of Chicago under an Atomic Energy Commission predoctoral fellowship, acquiring his Ph.D. in 1952.

G. P. WELLS ("Worm Autobiographies") is professor of zoology at University College London. He is the elder son of H. G. Wells (G. P., H. G. and Sir Julian Huxley were the three co-authors of a well-known popular work on biology: *The Science of Life*). Wells gradu-

ated from the University of Cambridge, then spent a year at Harvard University and another year at the Marine Biological Laboratory in Plymouth, England, before his appointment as a lecturer at University College London in 1931.

MEYER FORTES ("Primitive Kinship") is currently in residence at the Center for Advanced Study in the Behavioral Sciences in Palo Alto, Calif. He is on leave of absence from the University of Cambridge, where he is William Wyse Professor of Social Anthropology and a fellow of King's College. Fortes received his undergraduate training at the University of Capetown in his native South Africa, where, he says, "It was almost inevitable that I should become concerned with the race question." As a student of race psychology at the London School of Economics and University College London, he attempted for three years to design a nonverbal cross-cultural intelligence test. The techniques he worked out have since been developed into the widely used Progressive Matrices Test. Fortes, however, ceased to believe in the possibility of a truly culture-free assessment of intelligence. As a sideline he had worked in a London child-guidance clinic, and he observes: "I could not help discovering that economic and other social disabilities produced some kinds of personality disability and some degree of intellectual retardation." To sharpen his understanding of these social factors, Fortes abandoned laboratory psychology for a year's study of juvenile delinquency in London's East End. At the same time he came under the influence of two psychoanalytically oriented anthropologists: C. G. Seligman and Bronislaw Malinowski. For 18 months he studied anthropology at the University of London under Seligman and Malinowski. Then he went to the Gold Coast (now Ghana), where for most of four years he lived with the Tallensi tribe, studying their patterns of family life. In 1939 he was appointed lecturer at the University of Oxford, where he studied family and kinship with the leading authority on these subjects, A. R. Radcliffe-Brown. Later, while on wartime service in the Gold Coast, Fortes studied an important matrilineal tribe, the Ashanti.

I. BERNARD COHEN, who reviews Arthur Koestler's *The Sleepwalkers* in this issue, is associate professor of the history of science and of general education at Harvard University. He has contributed a number of articles to this magazine.



Frank L. Friedli, *Manager En-Tronics Sales, The Cooper-Bessemer Corporation, reports on...*

How automation pays off at Nantucket

Nantucket Gas and Electric Company had a costly power plant problem caused by Nantucket's population variation from a normal 3500 to a summertime 15,000. Now, everything is under control with a *fully automatic* Cooper-Bessemer En-Tronics system.

Peak load on this resort island requires three Cooper-Bessemer engines driving generators totaling 2950 kw capacity. The background photo shows this installation.

The En-Tronics control system, shown in the other photo, makes possible unattended operation. It starts engines, puts them on the line when the load builds up, takes them off when not needed, maintains correct frequency at all times, and increases plant efficiency over manual control. It also improves plant reliability, sensing irregularities and taking corrective action quickly.

Mr. C. G. Snow, Vice President of the Nantucket utility says, "It is expected that cost of the En-Tronics installation will be paid off rapidly from savings."

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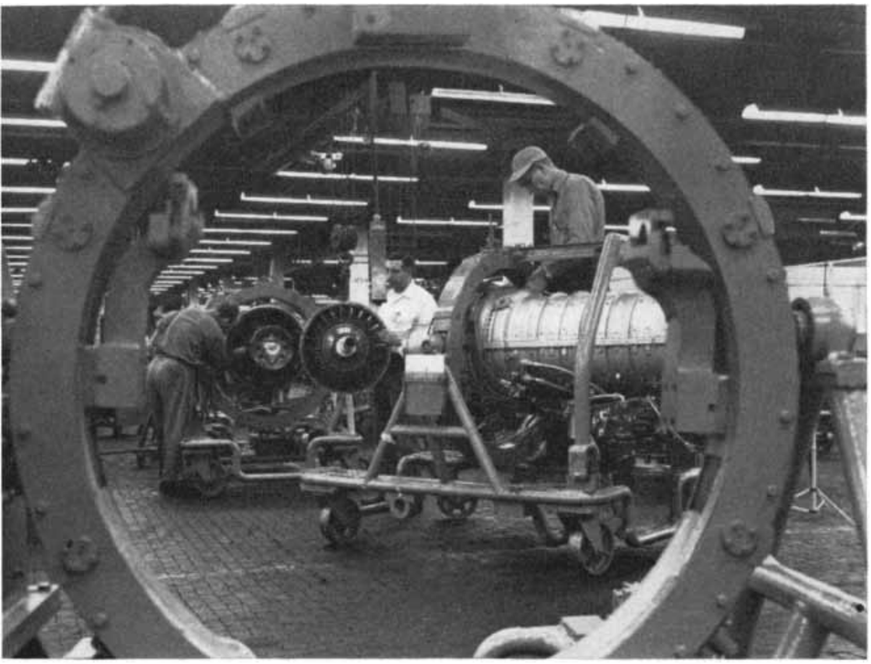
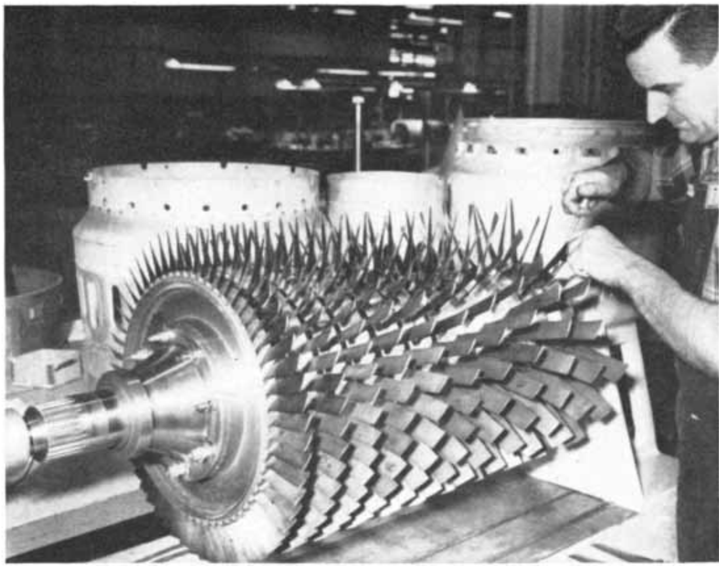
Why Westinghouse designs advanced propulsion systems more rapidly, meets all requirements on time



PRODUCTION POTENTIAL. The Aviation Gas Turbine Division at Kansas City has built more than 6,000 engines and associated spare parts. Engineering and Production experience with conventional gas turbine propulsion systems continues to be characterized by high-quality, on-schedule performance.

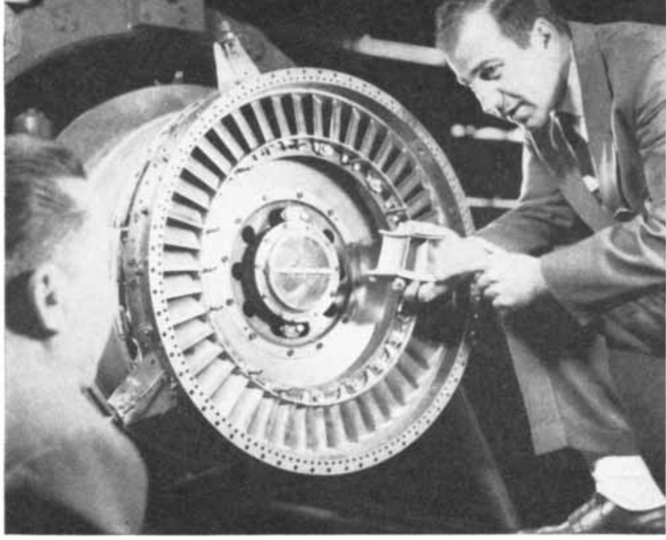
AUTOMATIC PRODUCTION TESTING, developed by Westinghouse, improves and speeds final pre-shipment testing. Test cell controls put engine through required tests automatically and record test results on the form prescribed for the engine log book.

FLIGHT TEST OPERATIONS. Following thorough component testing under simulated operating conditions in the Low and High Power Laboratories, Westinghouse engineers at the AGT Division's Flight Test Center at NAS Olathe, Kansas, test all propulsion systems under actual flight conditions.

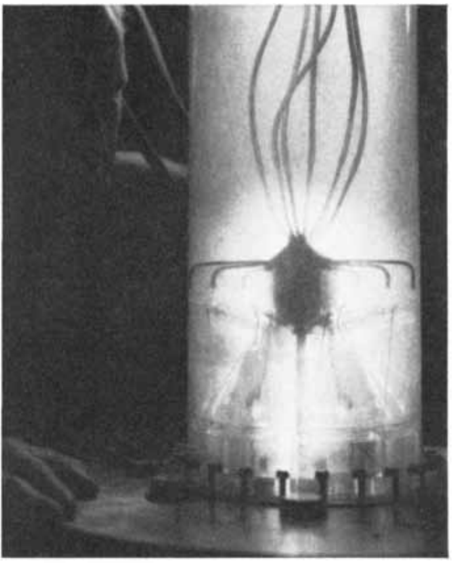


EXPERIMENTAL DEPARTMENT. This specialized factory-within-a-factory converts ideas into working prototypes. Independent engineering, tool design, progress and material control, permit self-sufficiency. Above, blades of a test cell bound compressor rotor are checked for proper balance.

ROLLS-ROYCE INFORMATION INTERCHANGE. A Rolls-Royce representative, resident at the AGT Division, here discusses new design concept with Westinghouse technical management. The Rolls-Royce-Westinghouse ten-year agreement permits faster jet engine design and production cycles.

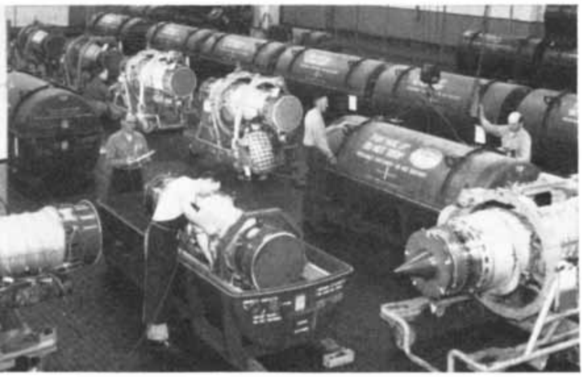


AIR-COOLED TURBINE NOZZLES permit more efficient operations at higher temperatures. Design permits air to enter through wide slots on one side, pass through interior, and leave through smaller slots along blade's trailing edge. This cools the vane and lets turbine operate at higher temperatures.



NEW FUEL INJECTOR DESIGN—fashioned from inexpensive plastic—is tested with colored water and air bubble mixture in this flow analogy test rig to predetermine its performance characteristics. Test minimizes time-consuming and costly testing previously required with expensive handmade metal prototypes.

VIBRATION AND STRESS ANALYSIS data are obtained in hours instead of days with this special Westinghouse-developed Strain Gage Analyzer. From signals recorded on 14 channel magnetic tape, the analyzer plots multiple continuous curves visualizing vibration frequency and strain at varying engine speeds.



LINE-FLOW PRODUCTION. The 85-acre Kansas City plant of AGT is well adapted to line-flow production techniques. This system permits smoother and more efficient engine production . . . a characteristic of quality performance.

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The low specific heat of Tenite Butyrate makes it an ideal material for sheet thermoforming. With Butyrate there is no need for special preheating oven equipment. Vacuum, air pressure, and mechanical methods are used with inexpensive molds on fast-cycle machines. Available in special weather-resistant formulations and popular sign colors, sheet of Butyrate can also be decorated with lacquers before or after forming.

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When your product needs call for a material that has superior impact and weather resistance, yet is light in weight, lustrous, easy and economical to form or fabricate —consider Tenite Butyrate. For additional information concerning its physical properties and uses, write to EASTMAN CHEMICAL PRODUCTS, INC., subsidiary of Eastman Kodak Company, KINGSPORT, TENNESSEE.

TENITE
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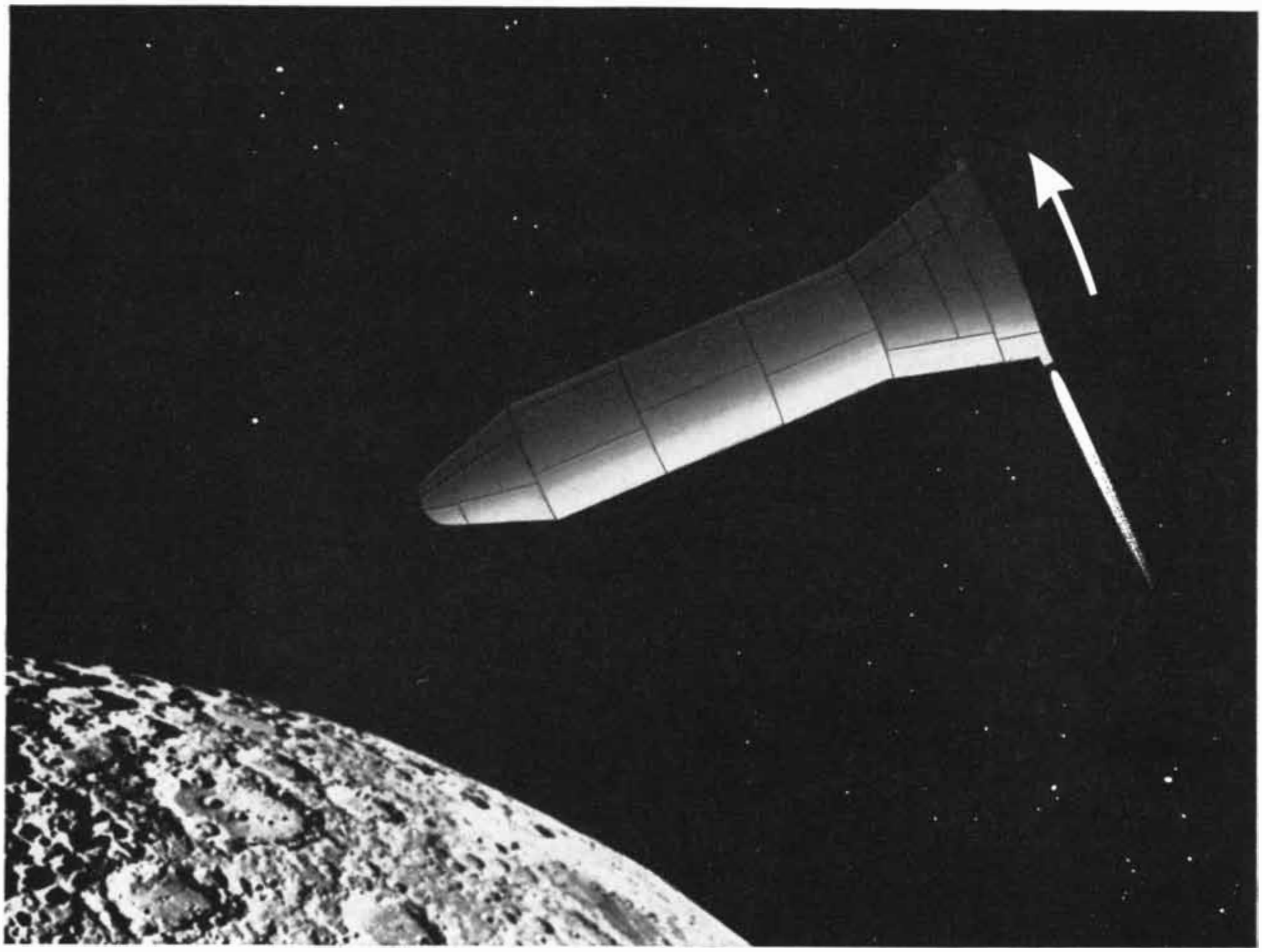
EDCO Tel-A-Flasher signs consist of individual letter panels which can be rotated within their frames to any desired angle. Panels are 15"-diameter or 20"-diameter discs of Tenite Butyrate plastic with raised letters (11" or 15" respectively) vacuum formed into their surface. Manufactured and marketed by Electrical Development Company, 719 E. Madison, P. O. Box 3472, Phoenix, Arizona. Butyrate sheet extruded by Jet Specialties Co., Inc., Los Angeles 63, California.



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Rocket Astronomy

Rockets which briefly soar above the greater part of the earth's atmosphere, where short wavelengths such as the ultraviolet are filtered out, have gathered new information about the universe

by Herbert Friedman

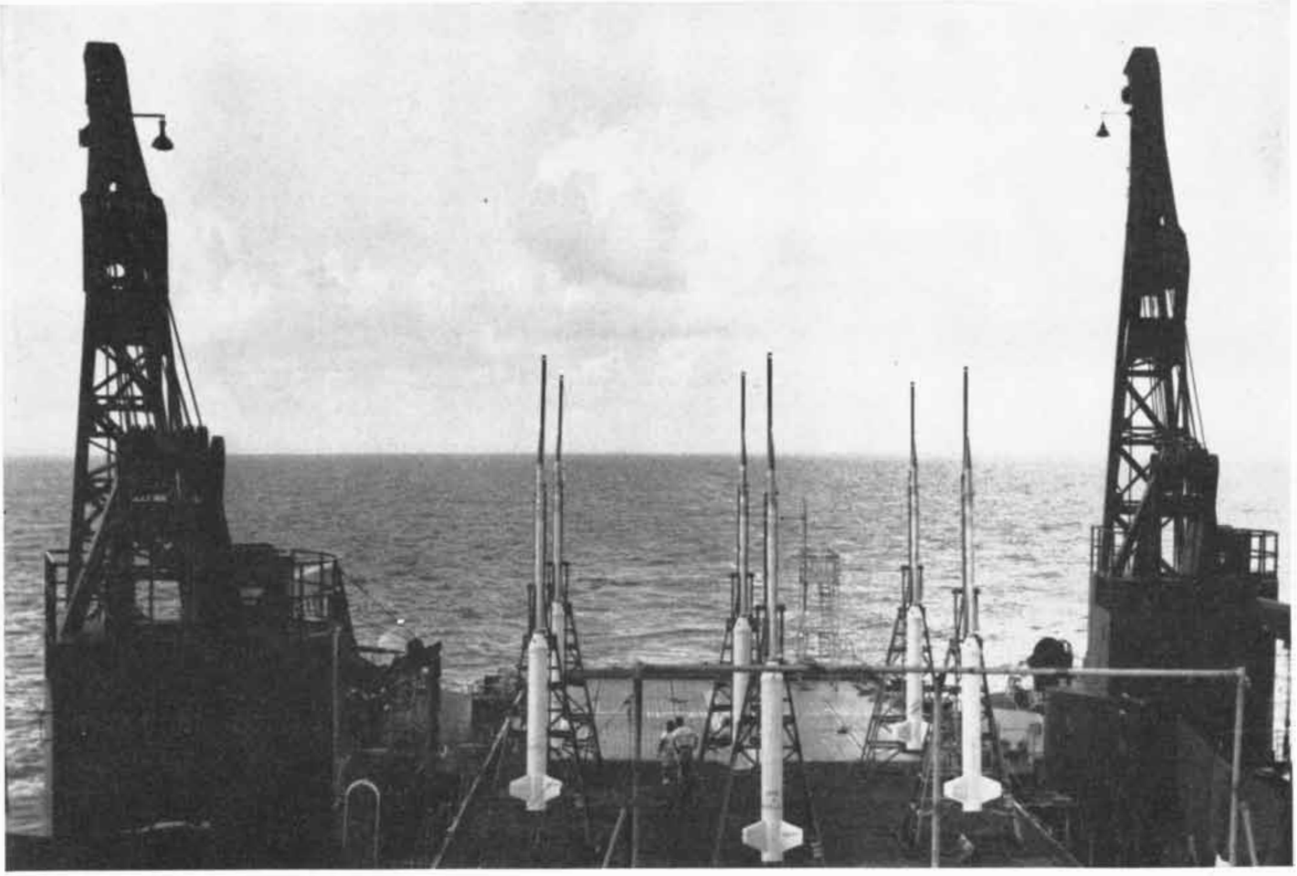
We perceive only a few octaves of the radiance of the cosmos when we look out through the sky. The sun and the other stars, the great clouds of interstellar dust and gas and the moon and the planets together flood the universe with radiant energy on all wavelengths of the electromagnetic spectrum, from the shortest gamma rays out to the longest radio waves. On earth, however, all we can see is the radiation admitted through two "windows" in our atmosphere: one open to visible light; the other, to the band of radio waves from one centimeter out to 40 meters. The atmosphere absorbs or reflects back into space all other wavelengths. No radiation of wavelength shorter than 2,850 angstrom units reaches the ground; the harsh ultraviolet rays, X-rays and gamma rays are absorbed by interaction with the atoms and atomic particles in the thin upper reaches of the atmosphere, at 16 miles and above. Life could of course not exist without this shelter; if such energetic radiations could penetrate the atmosphere, they would prevent the formation of the large molecules of living matter. But these same radiations bear so much information about the processes of the universe that astronomers have dreamed of the day when they could set up their instruments in outer space.

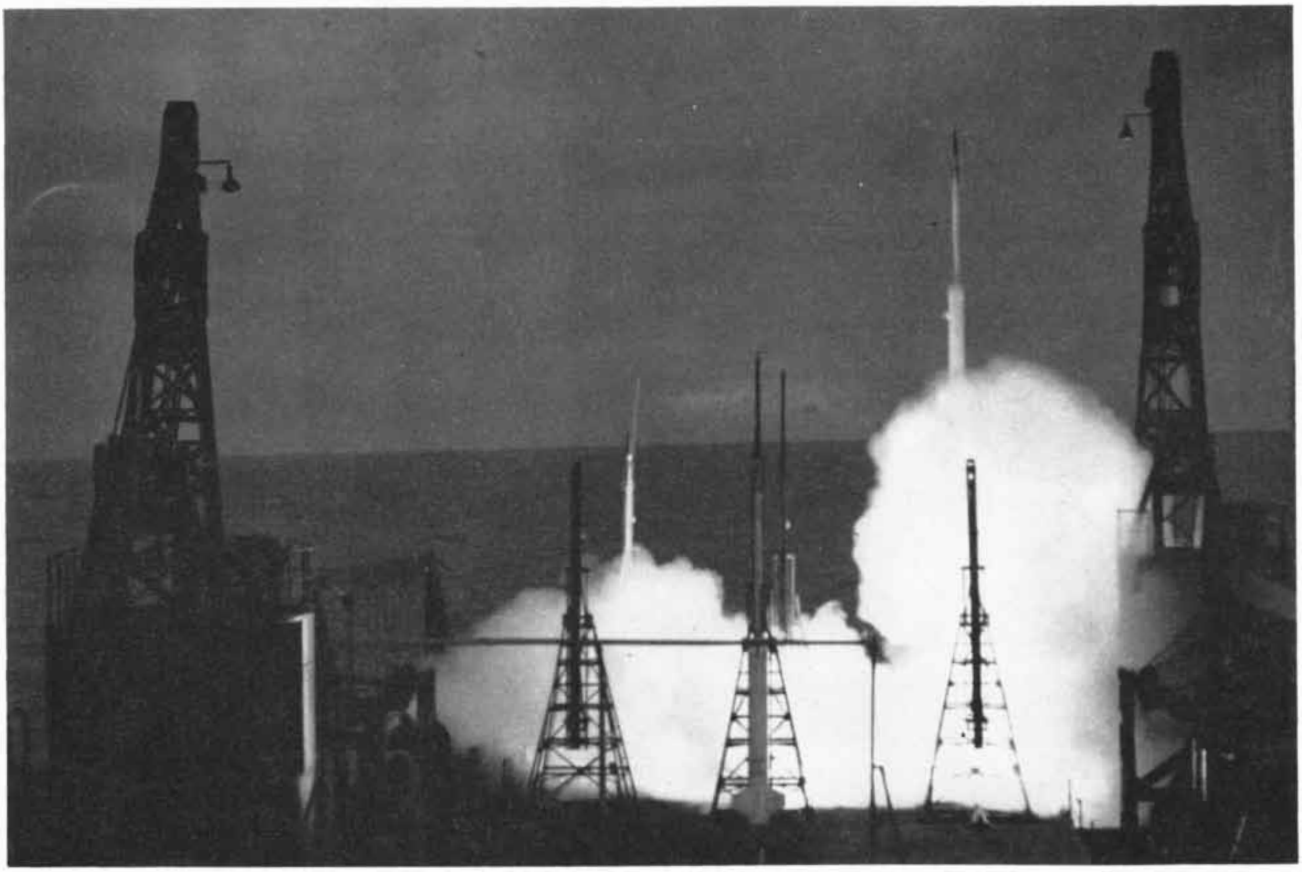
That day is now at hand. During the past 10 years rockets have been giving us our first glimpses of how the universe looks at wavelengths shorter than those of visible light. The glimpses last only two to five minutes, as the rocket coasts around the top of its trajectory, and rockets provide highly unstable platforms for our instruments. But we have made some unexpected discoveries and have beheld some marvelous sights. The dominant color of the nearby universe appears to be a far ultraviolet, at the wavelength of 1,216.7 angstroms, almost two octaves higher in frequency than the violet edge of the visible spectrum. The sun shines more brightly at this so-called Lyman-alpha line than at any other; if our eyes could perceive the Lyman-alpha radiation in the night sky, its diffuse glow would overwhelm the other radiations of the stars. Elsewhere in the universe vast clouds of dust and gas shine so brightly with ultraviolet light that they hide the hot stars that generate this energy in their interiors. Since the sun is the nearest star, we have the most to report about it. We have now explored the major features of the solar spectrum down to one-angstrom X-rays, and we have deepened our understanding of how the sun interacts with the earth's atmosphere. The abundant yield of these first ventures into space makes it plain that a major fraction of all future astronomical investigation will be carried on from stations above the atmosphere.

The rocket astronomer relies on the same two instruments—the telescope and the spectroscope—that are employed by his earth-bound colleagues. But a rocket is mostly fuel and engine and allows little space and weight for the observatory payload. A small solid-propellant system such as the Nike-Asp can carry about two cubic feet of instruments weighing about 50 pounds to an altitude of 150 miles; the larger Aerobee-Hi rocket accommodates about 10 cubic feet and 200 pounds of payload on a trip to the same altitude. The firing of a larger liquid-fueled rocket involves lengthy preflight preparations, and firing time is frequently dictated by considerations other than the best moment for the experiment. But even though the solid-propellant rocket offers greater freedom of operation, its explosive start may subject its instrumentation to the shock of transient accelerations amounting to several hundred times that of gravity.

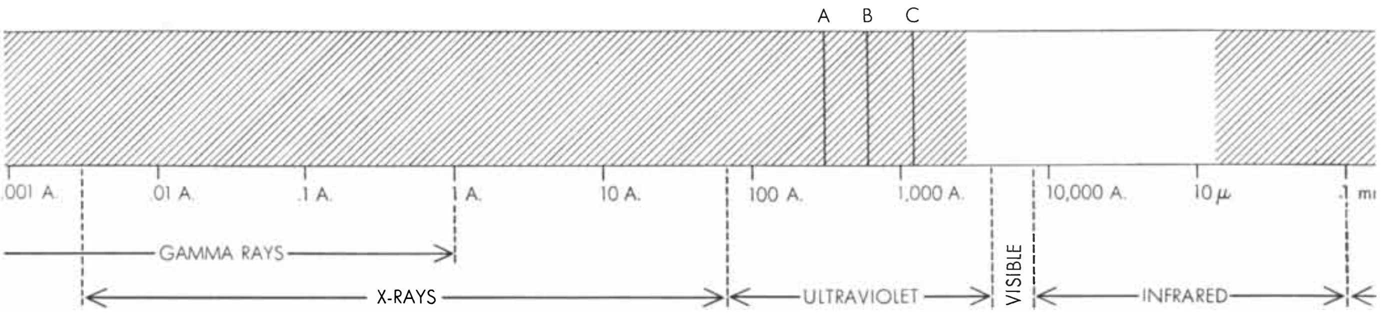
The instruments must be designed to function with the vehicle in erratic motion. It has been the practice to stabilize the rockets in flight merely by causing them to spin, like a rifle bullet, on their long axes; the rocket may nonetheless wobble about its spin axis, enter a flat spin or tumble. When the sun is to be observed, such behavior reduces the available exposure time to a small percentage of total flight time; this can be offset to a certain degree by the use of sun-following devices and biaxial pointing-controls.

The recovery of exposed film introduces the final set of design problems. The film-holder must be strong enough





SIX ROCKETS WERE FIRED from the *U.S.S. Point Defiance* to make observations of the sun's radiation during the Pacific eclipse of October 12, 1958. At top the rockets are ready for firing. At bottom the fourth rocket is fired in the darkness of the eclipse.



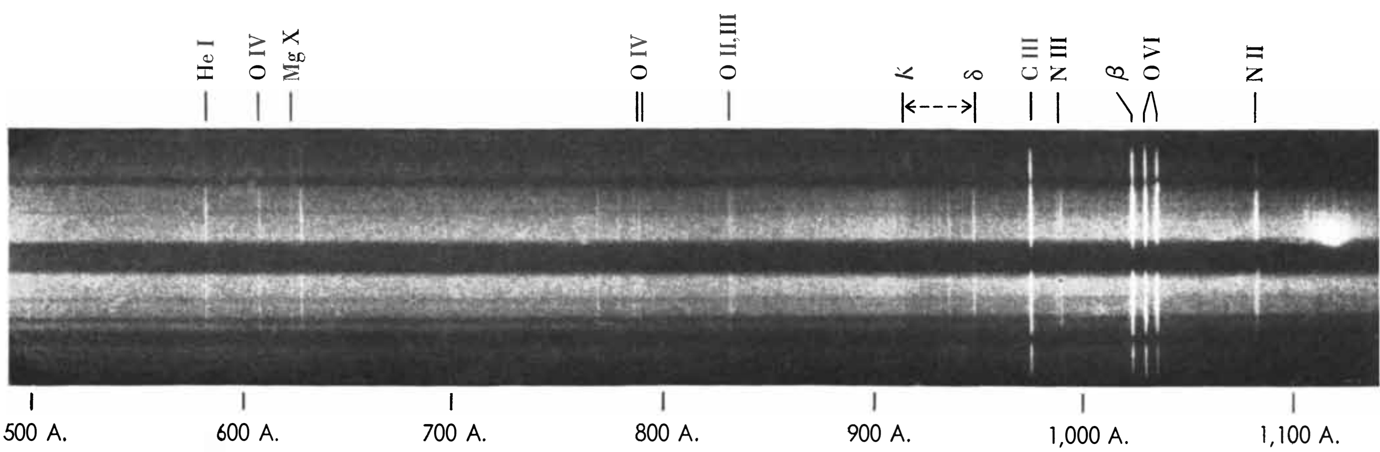
"WINDOWS" in the earth's atmosphere which admit electromagnetic radiation are indicated by the unhatched areas in this chart of the electromagnetic spectrum. The shorter wavelengths are measured in angstrom units (A.) or microns (μ). To the left of the win-

to withstand the impact of coming to earth; if it is to be recovered at sea, it must float. In the latter case a radio transmitter must be included to broadcast its position. Telemetering the measurements while the rocket is aloft eliminates some of these problems but introduces limitations of its own. Whether the precious instrumentation succeeds or fails in its mission, it is almost invariably destroyed upon falling to earth.

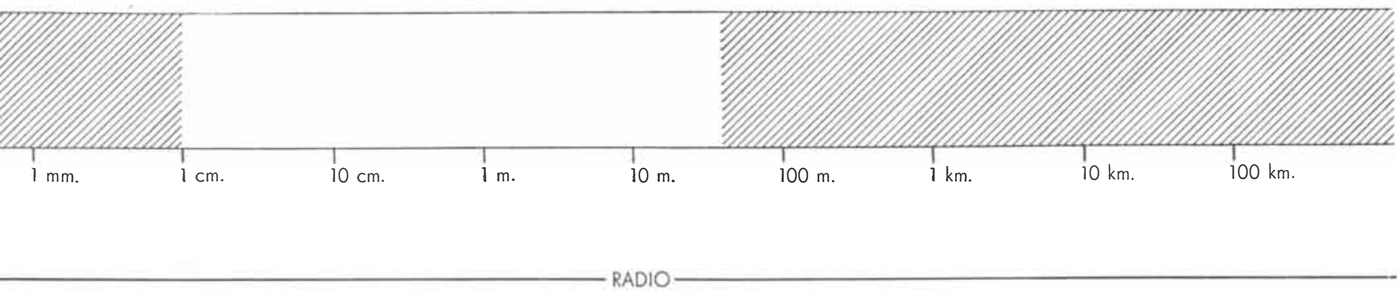
The sun was the first object to be studied by rocket astronomy. The initial objective was to get pictures of the solar spectrum in the ultraviolet, where spectral emission and absorption lines hold clues to so many aspects of the sun's constitution and behavior. But early efforts to obtain spectrograms of this biggest and brightest of all targets met with so many misfortunes that the spectrograph was supplemented by simple photon-counters and ion chambers tuned to narrow bands of wavelengths. For example, a chamber filled with nitric-oxide gas (which is ionized by wavelengths below 1,350 angstroms) and with a window of lithium fluoride (which is transparent to wavelengths above 1,060 angstroms) gives us a detector that responds only to wavelengths from 1,060 to 1,350 angstroms. This band of course includes the Lyman-alpha line at 1,216.7 angstroms. More recently Richard Tousey and his associates at the Naval Research Laboratory have secured spectrograms of high resolution down to 584 angstroms, using a spectrograph with a concave diffraction grating. Improvements in coatings that reflect ultraviolet radiation will soon make it possible to record the Lyman-alpha region with fine resolution in hundredths of a second.

From the spectrograms and photon-counter readings made to date we have been able to plot an approximate map of the solar spectrum over the entire short-wavelength region. The sun's visible spectrum (from 4,000 to 7,000 angstroms) tells us that the photosphere (the surface of the sun as seen in white light) has a temperature of 6,000 degrees Kelvin (degrees centigrade above absolute zero). In this region of the spectrum thousands of dark absorption lines indicate the presence of cooler gases, with temperatures as low as 4,000 degrees K., in the upper layers of the photosphere. The first rocket spectrograms reaching to 2,000 angstroms in the ultraviolet indicated a brightness and apparent temperature of 5,000 degrees, and measurements with photon counters out to 1,200 angstroms extended this trend of decreasing brightness down to 4,000 degrees. Apparently the decrease in solar emission in this spectral region is due to the crowding together of the absorption lines of the cooler gases in the upper photosphere. Spectrograms of higher resolution will reveal the abundance of the many rare constituents of the solar atmosphere (*e.g.*, the halogens, arsenic, selenium, tellurium and radon) which give rise to these lines. At 2,100 angstroms the absorption lines are so crowded that they become almost continuous; they finally disappear at about 1,700 angstroms.

Below 1,600 angstroms the rocket spectrograms begin to provide information about the sun's chromosphere. This transition region, about 10,000 miles deep, between the comparatively cool photosphere and the million-degree solar corona is visible during eclipses as a thin red ring. It derives its red color from the hydrogen-alpha emission line



ULTRAVIOLET SPECTRUM of the sun was made on March 13 from a Naval Research Laboratory Aerobee rocket which rose to a height of 123 miles. The spectrum shows about 100 ultraviolet emission lines: 60 more than had been observed previously. Of the lines labeled here, the brightest is the Lyman-alpha line of hydrogen (α). The additional Greek letters indicate other lines of



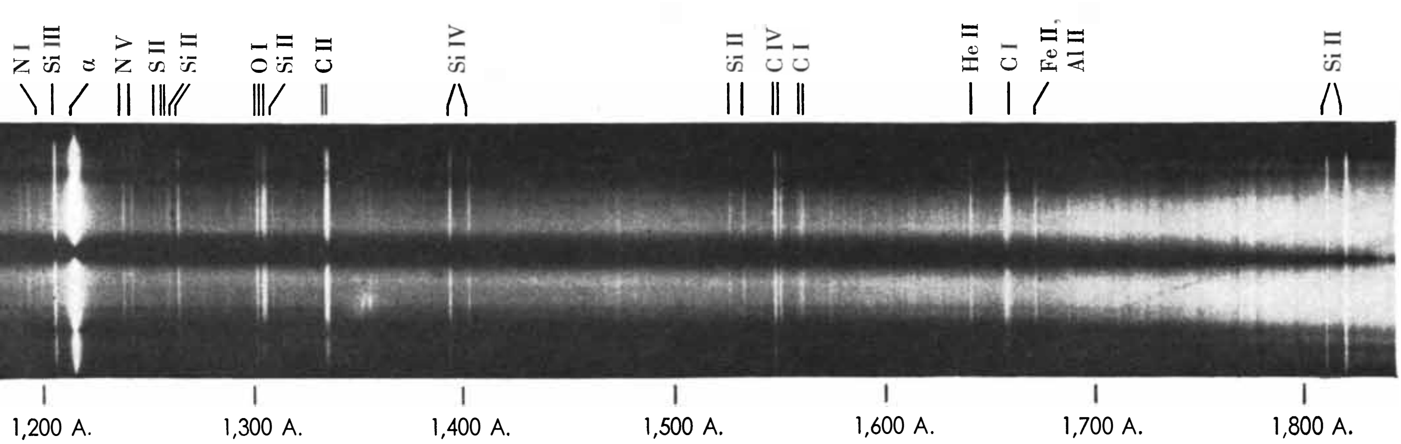
dow at left are three important spectral lines to which the atmosphere is opaque: the 304-angstrom line emitted by singly ionized helium (A), the 584-angstrom line emitted by un-ionized helium (B) and Lyman-alpha line emitted by un-ionized hydrogen (C).

at 6,563 angstroms in the visible spectrum. In the ultraviolet region the chromosphere radiates strong emission lines, many of them associated with highly ionized atoms of oxygen, nitrogen, carbon, silicon and helium.

The chromosphere is also the source of the sun's powerful Lyman-alpha radiation at 1,216.7 angstroms. This is the primary resonance wavelength of hydrogen; it is associated with the jumping of the atom's single electron between its first and second energy levels or shells, a photon being absorbed when the electron jumps to the second shell and emitted when it falls back to the first shell. Since hydrogen is by all odds the most abundant constituent of the sun and of the universe as a whole, it is no surprise that Lyman-alpha radiation is so prominent in the solar spectrum and in the universe.

From the solar X-ray spectrum (below 100 angstroms) we have gained new insight into the nature of the corona and its interaction with the earth's atmosphere. The hot, tenuous gas of the corona, reaching millions of miles out into space, is visible only during solar eclipses; it is so thin that faint stars can be seen through it, and comets traverse it without detectable drag. Since rocket investigations of the X-ray spectrum have so far been conducted only with narrow-band photodetectors, the distribution of energy in this region is not yet fully plotted. The peak of emission at about 60 angstroms, observed when the sun is quiet, indicates that the corona has a steady temperature of 500,000 degrees. When the sun is disturbed by the passage of sunspots and other manifestations visible in the photosphere, it is believed that the corona develops local condensations in which temperatures rise to millions of degrees [see "Hot Spots in the Atmosphere of the Sun," by Harold Zirin; SCIENTIFIC AMERICAN, August, 1958]. Although rocket measurements are still scanty, they support this belief; they show X-ray emission in the extremely short wavelengths of five or six angstroms, which indicate extremely high temperatures and are well correlated with other symptoms of solar disturbance.

Before the advent of rocket astronomy our understanding of solar ultraviolet and X-ray emission was predicated upon the indirect evidence of the behavior of the ionized layers of the earth's upper atmosphere. The daily cycle of growth and decay in the density of electrons at altitudes between 50 and 200 miles is a plain indication of the ionizing action of these high-energy radiations. Now, with the direct records of the sun's emission in this region of the spectrum, we have acquired a clearer understanding of what goes on in our ionosphere. We can see that the Lyman-alpha radiation induces the formation of the lowest, or "D," region of the ionosphere (45 to 55 miles) by ionizing nitric oxide, even though this compound is present only in a concentration of one part per million. The "E" region (60 to 80 miles) can be attributed principally to X-rays from the quiet corona, which ionize any of the atmospheric gases. It has been known that the electron density of the E region varies in perfect harmony with sunspot number; now rocket observations reveal a similar correlation with solar X-ray emission. When the sun is active, the increased intensity of X-rays arriving in the E region increases the over-all electron density, and the output of harder and more penetrating X-rays in the five- to 20-angstrom band spreads the E re-



hydrogen. The other symbols denote lines emitted by the variously ionized atoms of helium (He), oxygen (O), magnesium (Mg), carbon (C), nitrogen (N), silicon (Si), sulfur (S), iron (Fe) and aluminum (Al). The Roman numerals refer to the number of electrons removed from the atom. The experiment was designed by J. D. Purcell, D. M. Packer, W. D. Hunter and Richard Tousey.

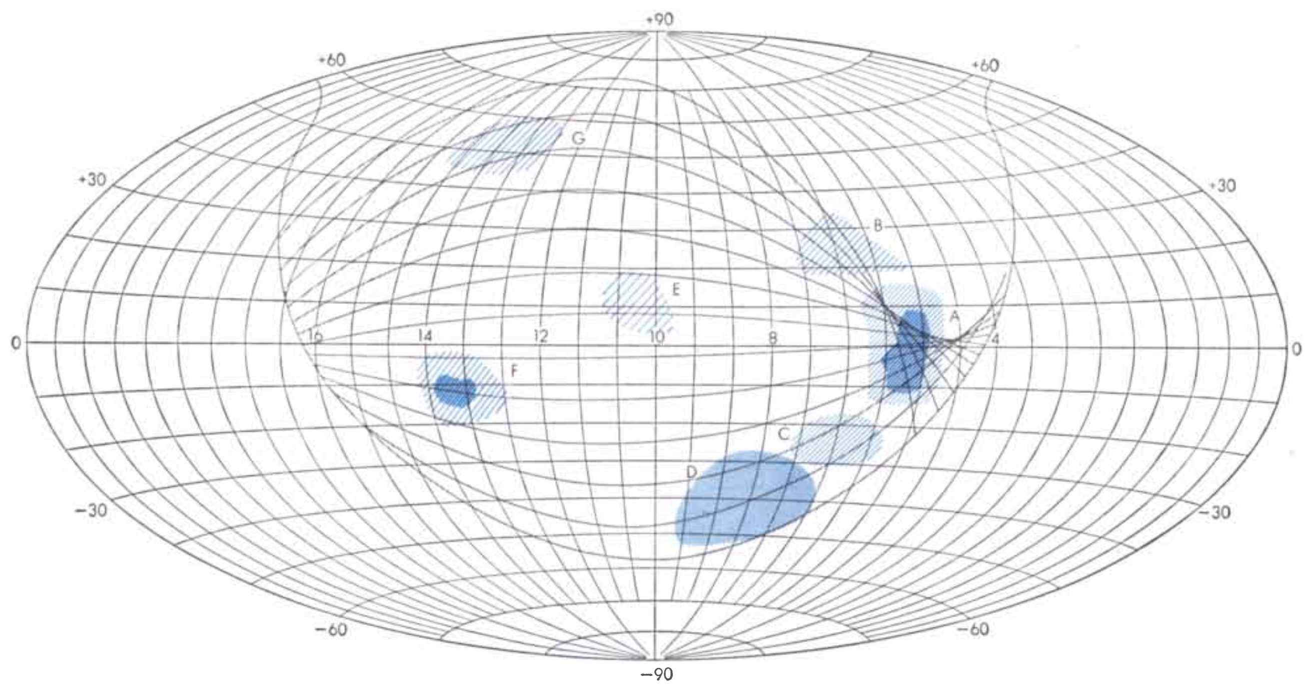
gion to lower altitudes. In the top, or "F," layer of the ionosphere, most of the ionization is apparently caused by the far-ultraviolet emission of the principal resonance line of singly ionized helium, at 304 angstroms.

The most impressive disturbances of the ionosphere, associated in human affairs with the blackout of radio communications, have been found to coincide with the most spectacular event observed on the face of the sun: the solar flare. A flare begins as a local brightening in the vicinity of a sunspot group, visible in the red hydrogen-alpha line. In a few minutes it may flash to 10 times the brightness of the surrounding photosphere and spread over hundreds of millions of square miles. Almost simultaneously a burst of ionizing radiation announces the event in the terrestrial atmosphere by a sudden short-wave radio fade-out. This effect was traced some time ago to increased ionization in the D region. A principal objective of rocket astronomy during the sunspot maximum of the International Geophysical Year was to get a direct measurement of the ionizing radiation which causes these effects in association with solar flares.

It is no easy matter, however, to fire a rocket during a solar flare. Even in a sunspot maximum there may be only one interesting flare in each 50-hour period. To catch such a transitory event requires push-button rocketry. In 1956 the trap was set by launching a "rockoon"—a small solid-propellant rocket hoisted through the lower atmosphere by a balloon—from the deck of a ship in the Pacific Ocean early in the morning on each of 10 days. The ship would track the balloon, floating aloft at 80,000 feet, waiting to fire the rocket upon receipt of word that a flare had been detected. In 10 tries only one small flare was caught. But the record of the X-ray signals telemetered from the ionosphere clearly revealed a major enhancement and hardening of the X-ray spectrum. In August, 1957, a Naval Research Laboratory station on tiny San Nicolas Island 70 miles off the coast of California succeeded in firing a number of two-stage solid-propellant rockets within minutes after the appearance of solar flares. These soundings detected X-rays with wavelengths as short as one or two angstroms in the output of large flares. Such hard X-rays imply temperatures as high as 10 million degrees in the corona above the visible flare.

As these observations suggest, the sun is an intricate engine with many local events and variations to be observed in the structure of its atmosphere. Until quite recently, however, solar physicists had been concerned primarily with the sun's average characteristics, treating the photosphere, chromosphere and corona as if they were a series of homogeneous concentric spheres. Then an accumulating mass of observations showed that all three regions are intimately associated in a dynamic complex of processes involving sunspots and their magnetic fields, bright local patches called plages, jets of hot gas called spicules and major eruptions in the form of prominences and flares. Rocket astronomers accordingly are now challenged to detect localized sources of ionizing radiation on the sun and to correlate these with the events observed in the visible spectrum.

The ultraviolet image of the sun has already been photographed with high fidelity by a rocket camera designed by Tousey and his colleagues at the Naval Research Laboratory. This camera employs two concave diffraction-gratings to produce a pure monochromatic image of the sun in the Lyman-alpha line, with sufficient brightness to resolve detail down to 20 seconds of arc in an exposure of two hundredths of a second. The picture made with it clearly shows that Lyman-alpha emission is enhanced in areas of bright hydrogen and calcium plages [*see illustrations on pages 58 and 59*]. Still another camera may make it



SKY MAP at the ultraviolet wavelength of 1,300 angstroms is based on another Aerobee flight. The numbers around the edge of the map denote declination (corresponding to geographic latitude) in degrees; the numbers across the middle, right ascension (corresponding to longitude) in hours. The lines superimposed on these coordinates show where the rocket's photon counter scanned the sky as the rocket spun on its axis. The colored areas, which strongly emit ultraviolet radiation, are in Orion (A), Taurus (B), Canis Major (C), Puppis and Vela (D), Leo (E), Virgo (F) and Ursa Major (G). The area in Virgo is centered on the star Spica.

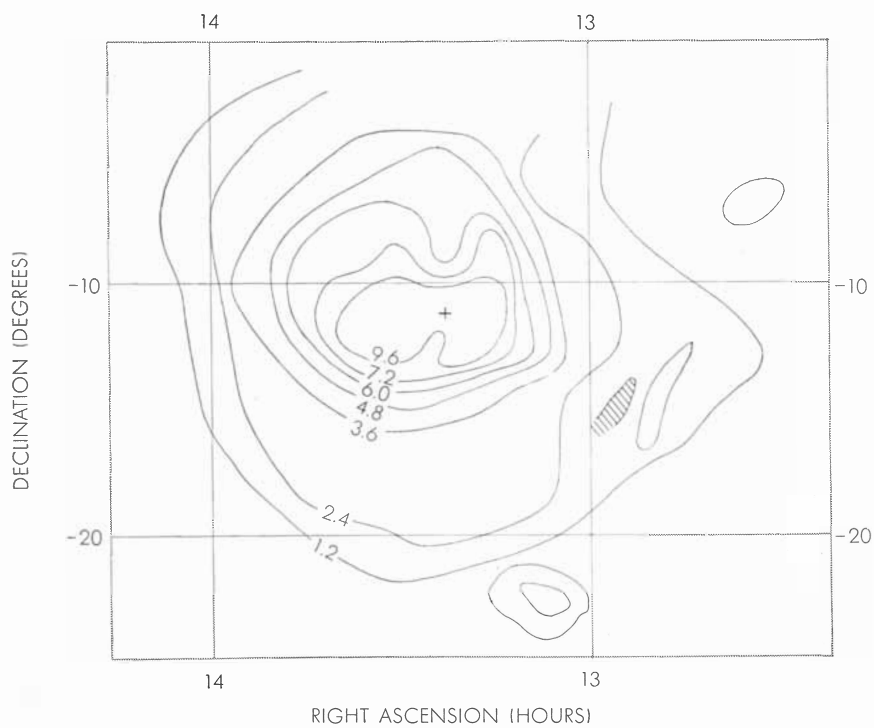
possible to secure a telemetered television-style picture of the sun. This system employs a mirror with a photodetector mounted at its focus; by wobbling the mirror the photodetector can be made to scan the image of the sun and report its readings to the ground.

To record the X-ray image of the sun presents greater technical difficulties. Last fall, however, the Naval Research Laboratory seized an opportunity presented by nature to secure a picture of the X-ray sun. The occasion was the South Pacific eclipse of October 12, observed by rockets fired from the deck of the *U.S.S. Point Defiance*. As the moon crossed the face of the sun, six rockets were launched in sequence to take turns measuring the X-ray and ultraviolet emission coming from the uneclipsed portions of the solar disk [*see illustrations on page 53*]. From the still incompletely analyzed data, it appears that at totality the ultraviolet emission dropped to a low level, while the X-ray flux remained at an appreciable fraction of the intensity of the uneclipsed sun. The X-ray picture of the sun reconstructed from these measurements resembles a doughnut: dark in the center, bright near the rim and somewhat larger than the visible disk.

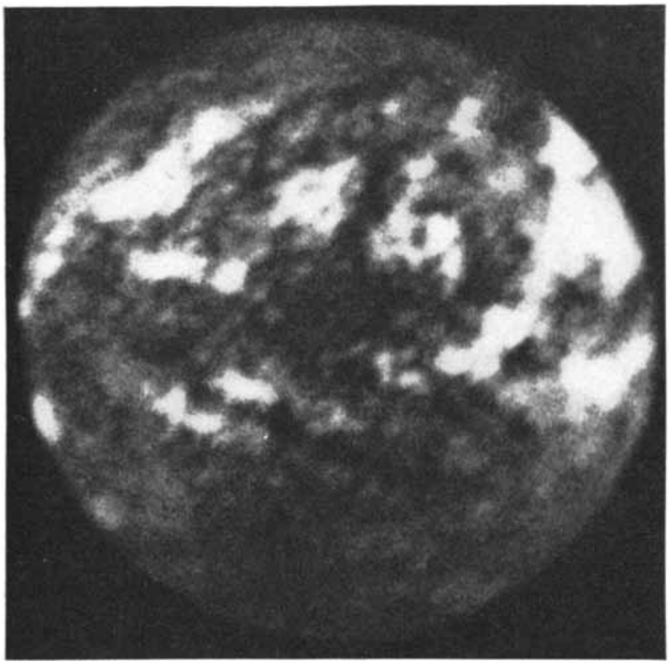
Emboldened by the progress of solar rocket-astronomy, our group at the Naval Research Laboratory set out in 1956 to investigate the ultraviolet and X-ray emissions of other stars. But the light from all the other stars combined adds up to only one billionth the light from the sun. To compound the difficulty, we could not expect to get more than the briefest glance at any piece of sky from our tumbling, spinning observatories. Talbot A. Chubb, Edward T. Byram and J. E. Kupperian, Jr., therefore fitted our first night rocket with the most sensitive photodetectors they could construct—instruments responsive to one out of 10 quanta of far-ultraviolet radiation. As the rocket cleared the top of the lower atmosphere the detectors were choked with an overwhelming flux of radiation. We had not been prepared to discover that the entire sky glows so brightly in the Lyman-alpha line. Counters operating on slightly longer wavelengths in the band from 1,230 to 1,350 angstroms, however, produced the first records of starlight in the far ultraviolet.

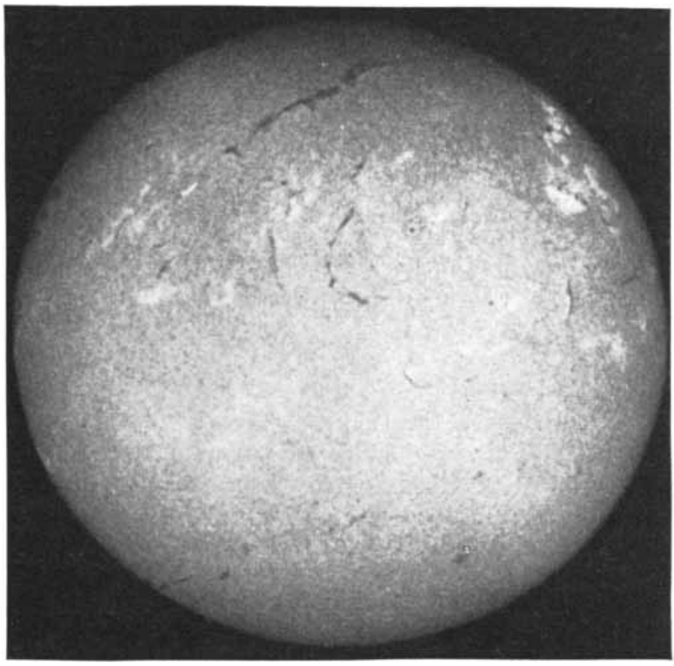
In our next flight, early in 1957, we determined to secure records of individual ultraviolet stars. In order to restrict the angle of vision of our counters we equipped them with collimators made of bundles of short lengths of hypodermic

ULTRAVIOLET AREA IN ORION is plotted in greater detail. The coordinates correspond to those in the map on the opposite page. The dots represent bright stars. The numbers on the contours refer to units of .0001 erg per square centimeter per second at 1,300 angstroms.



ULTRAVIOLET AREA AROUND SPICA is plotted in the same manner. The position of Spica itself, the ultraviolet radiation of which is drowned out, is indicated by the small cross.





ULTRAVIOLET PHOTOGRAPH of the sun at left was made during the Aerobee flight of March 13. The three photographs to the right were made at the same time from the ground. The photograph at left was made by Lyman-alpha radiation. The second

needles; the field of view through these tubes was about three degrees wide, roughly what you see when you look through a bundle of drinking straws. Clusters of four of these counters, tuned to the 1,230- to 1,350-angstrom band, were arranged around the rocket cylinder 120 degrees apart, and the counters in each cluster were pointed to sweep out a fan 30 degrees wide. When the rocket was flown, this arrangement of instruments, combined with the complex motion of the rocket, successfully scanned a major portion of the celestial hemisphere. To locate the sources of emission picked up by the counters the rocket carried a magnetometer and airglow detectors that continuously recorded the orientation of the rocket with respect to the earth's magnetic field and the airglow horizon. These records, plus visible-light signals from the brightest stars, made it possible to achieve an accuracy of about one degree in transposing the signal records to a map [*see illustration on page 56*].

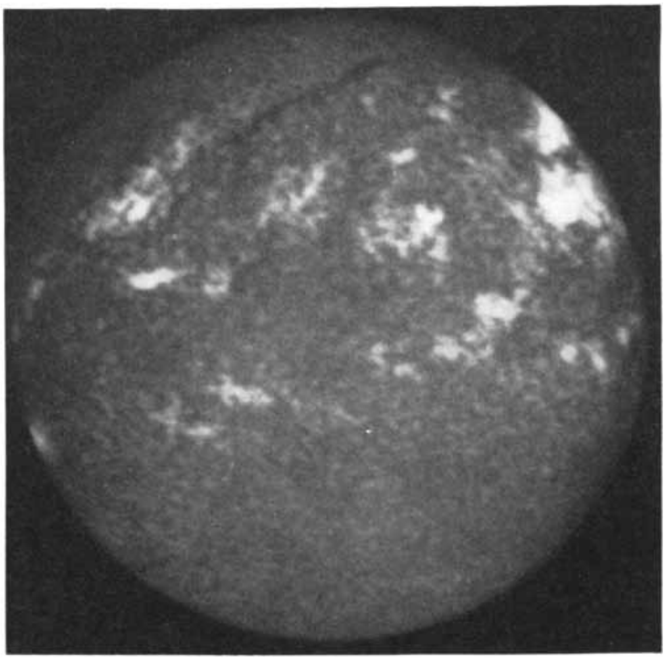
As the map shows, we did not succeed in registering the discrete images of ultraviolet stars. Our survey yielded instead a completely unexpected and still unexplained discovery. Where we had hoped to find bright ultraviolet stars in the locations of extremely hot stars (identified by their visible-light images), the map shows extended regions of extreme ultraviolet brightness. The brightest of these regions, in Orion, coincides with the familiar visible nebulosity surrounding the hot stars in that constellation. Even though the density of the particles in these clouds is about a ten millionth that of a good laboratory vacuum, the total volume of the clouds, 20 to 25 light years in diameter, is so great that they can be seen by the naked eye. It is therefore not surprising to find that the same region glows brightly in ultraviolet radiation. What is surprising is that this nebulosity glows as brightly in the ultraviolet as it does in the visible spectrum, covers an even larger region of sky and overwhelms the ultraviolet images of the individual stars. No known mechanism can explain this emission.

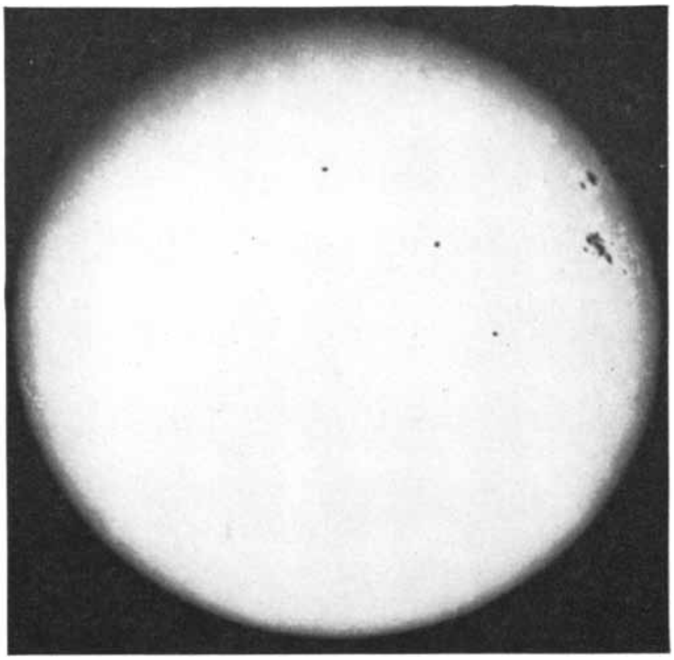
Even more puzzling is the ultraviolet nebulosity surrounding the star Spica. Analysis of the visible spectrum of this star had indicated that its temperature was 28,000 degrees. According to theory, such a hot star should ionize hydrogen in surrounding space out to a distance of 40 light-years, and this region should glow in the visible spectrum. But no visible nebulosity can be seen around Spica. In the ultraviolet spectrum, however, our records show that the star generates a nebulosity that extends over the vast space of 400 square degrees and has a surface brightness comparable to that of the nebulosity in Orion. In the midst of this bright cloud Spica itself remains hidden. But if we accept the temperature of 28,000 degrees, it should stand out 30 times brighter than its nebulosity.

Before we can begin to understand the full significance of these observations we must secure readings in other regions of the spectrum and at much finer resolution. Fortunately the ultraviolet nebulosities are so bright that we may confidently expect to resolve them in photographic spectrograms and thus secure finer detail than can be achieved by photodetectors.

Meanwhile the extended Lyman-alpha glow, which apparently obliterates all objects radiating in its wavelength outside our solar system, presents another riddle for further investigation. A phenomenon of interplanetary space, it appears to be solar Lyman-alpha emission that is reflected and diffused by resonance from atoms of neutral hydrogen. In brightness it exceeds the combined intensity of all visible starlight. This of itself may give us a new measure of the density of matter in interplanetary space. Calculation from the observed flux shows that there must be a few tenths of a neutral hydrogen atom per cubic centimeter and, since the interplanetary gases are 99 per cent ionized, about 100 times as many protons and electrons.

We must be cautious, however, in generalizing to interplanetary space from observations made in the vicinity of the earth. It may be that these gases





photograph was made at the Naval Research Laboratory by the red hydrogen-alpha spectral line; the third photograph, at the McMath-Hulbert Observatory by the "K" line of calcium. The fourth photograph was made at the U. S. Naval Observatory by white light.

constitute an even more local phenomenon, a kind of corona traveling with the earth. The noted geophysicist Sydney Chapman has postulated that the terrestrial hydrogen atmosphere reaches 50 to 100 earth radii into space before it merges with the extended corona of the sun. Our rocket probes have so far operated well inside these dimensions. If the hydrogen that produces this diffuse glow is indeed restricted to the earth-moon system, it should be possible to map its distribution by measuring the variation in brightness with detectors carried aboard a moon-bound rocket.

High-resolution analysis of the glow may also help to settle the question. The bright line of radiation that traverses a cold neutral gas will show a dark absorption line at its center. If the Lyman-alpha glow in the night sky has its origin in interplanetary gases and is filtered by extended terrestrial hydrogen before it reaches our instruments, it should show such a line when it is observed in a direction away from the sun. Alternatively, if the glow is observed in the direction of the earth's motion on its orbit, the Doppler shift introduced by the velocity of the earth should be sufficient to displace the bright line of the glow away from the absorption line of terrestrial hydrogen.

Though the Lyman-alpha glow constitutes an interesting feature of interplanetary space, it extends into that region the barrier astronomy seeks to escape by carrying its instruments outside the earth's atmosphere. The glow has so far prevented us from observing stars and interstellar hydrogen-clouds at this important wavelength. It may be possible to see through the glare if we can replace our hypodermic-needle collimators with mirror telescopes; sharper angular resolution should improve the intensity of star signals with respect to the background. As the field of view is narrowed, however, it will be necessary to develop better pointing controls. Another approach is suggested by the fact that the lines of emitted radiation tend to be broad, whereas resonantly scattered radiation is highly monochromatic. An instrument tuned to wavelengths just half an angstrom unit off center should be able to "see around" the night sky-glow and get a clear view of the broader Lyman-alpha emission line from hot stars. Such tuning should also make it possible to pick up the line from other sources displaced by the Doppler effect due to the earth's motion.

A pessimistic note has recently been sounded by Lawrence A. Aller of the University of Michigan, to the effect that interstellar hydrogen may absorb almost all of the Lyman-alpha and shorter-wavelength radiation from even the nearest stars. The density of neutral hydrogen in the plane of the galaxy may be such that only X-rays can penetrate to the earth from the galactic center. Perhaps the most immediate task of rocket astronomy is to map the sky for holes or regions of relative transparency.

Rocket astronomy has not yet undertaken the observation of celestial objects in the X-ray spectrum. Such cosmic-ray sources as the Crab Nebula, however, have high priority in experiments now being designed and instrumented. At the other end of the spectrum rocket astronomers will have a special interest in the information that may be carried by infrared radiation. On these wavelengths we may be able to look inside the dense clouds of dust and gas in which, it is thought, stars are still being formed. Outside the filter of the earth's atmosphere it will also be possible to extend the range of radio astronomy 100-fold beyond the window through which terrestrial radio observatories now look at the universe. Studies of long-wave outbursts from the sun and Jupiter also have high priority.

In the not-too-distant future rocket astronomy will doubtless give way to satellite astronomy. Satellites of more than 1,000 pounds payload are already being designed in the U. S. They will provide stable platforms from which telescopes may be pointed to track stars, planets and nebulae, and to monitor events such as flares on the surface of the sun. Eventually, when it is possible to man these satellites, we may observe even the faintest stars. The first discoveries of rocket astronomy guarantee that the effort will be worthwhile.

An Ancient Greek Computer

In 1901 divers working off the isle of Antikythera found the remains of a clocklike mechanism 2,000 years old. The mechanism now appears to have been a device for calculating the motions of stars and planets

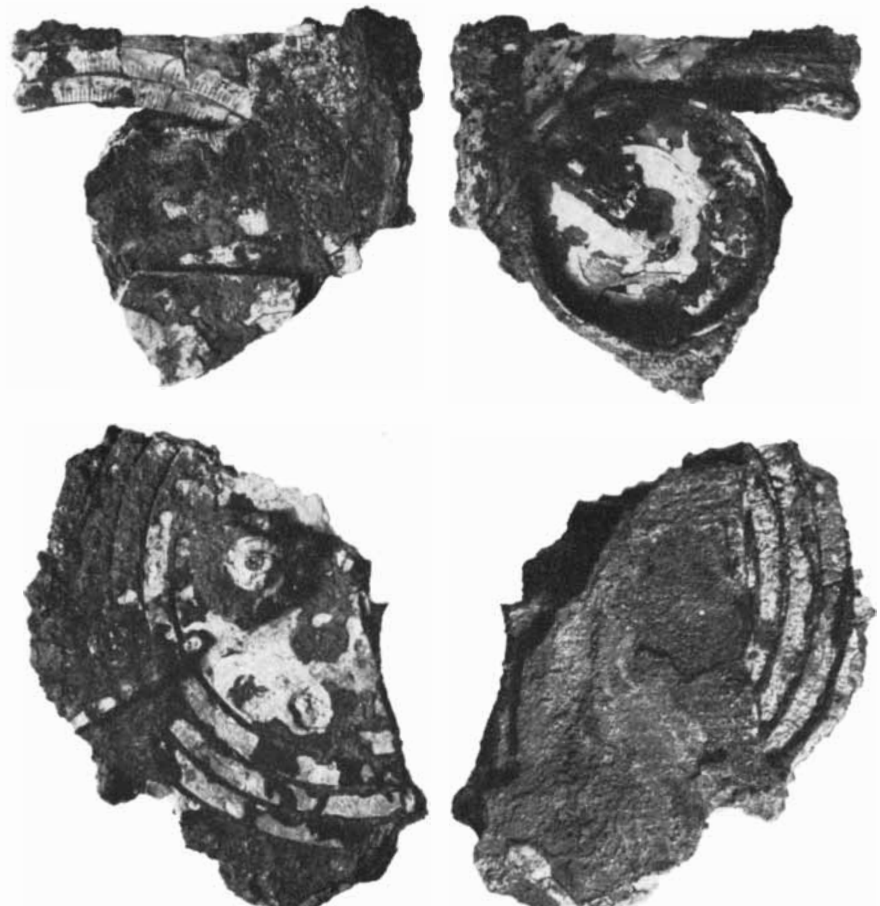
by Derek J. de Solla Price

Among the treasures of the Greek National Archaeological Museum in Athens are the remains of the most complex scientific object that has been preserved from antiquity. Corroded and crumbling from 2,000 years under the sea, its dials, gear wheels and inscribed plates present the historian with a tantalizing problem. Because of them we may have to revise many of our estimates of Greek science. By studying them we may find vital clues to the true origins of that high scientific technology which hitherto has seemed peculiar to our modern civilization, setting it apart from all cultures of the past.

From the evidence of the fragments one can get a good idea of the appearance of the original object [*see illustration on page 62*]. Consisting of a box with dials on the outside and a very complex assembly of gear wheels mounted within, it must have resembled a well-made 18th-century clock. Doors hinged to the box served to protect the dials, and on all available surfaces of box, doors and dials there were long Greek inscriptions describing the operation and construction of the instrument. At least 20 gear wheels of the mechanism have been preserved, including a very sophisticated assembly of gears that were mounted eccentrically on a turntable and probably functioned as a sort of epicyclic or differential gear-system.

Nothing like this instrument is preserved elsewhere. Nothing comparable to it is known from any ancient scientific text or literary allusion. On the contrary, from all that we know of science and technology in the Hellenistic Age we should have felt that such a device could not exist. Some historians have suggested that the Greeks were not interested in experiment because of a contempt—perhaps induced by the existence of the institution of slavery—for manual labor. On the other hand it has long been recognized that in abstract mathematics and in mathematical astronomy they were no beginners but rather "fellows of another college" who reached great heights of sophistication. Many of the Greek scientific devices known to us from written descriptions show much mathematical ingenuity, but in all cases the purely mechanical part of the design seems relatively crude. Gearing was clearly known to the Greeks, but it was used only in relatively simple applications. They employed pairs of gears to change angular speed or mechanical advantage, or to apply power through a right angle, as in the water-driven mill.

Even the most complex mechanical devices described by the ancient writers



THREE PRINCIPAL FRAGMENTS of the Antikythera mechanism are shown from both sides. One pair of views is at top on the left-hand page; the second pair, at bottom on the

Hero of Alexandria and Vitruvius contained only simple gearing. For example, the taximeter used by the Greeks to measure the distance traveled by the wheels of a carriage employed only pairs of gears (or gears and worms) to achieve the necessary ratio of movement. It could be argued that if the Greeks knew the principle of gearing, they should have had no difficulty in constructing mechanisms as complex as epicyclic gears. We now know from the fragments in the National Museum that the Greeks did make such mechanisms, but the knowledge is so unexpected that some scholars at first thought that the fragments must belong to some more modern device.

Can we in fact be sure that the device is ancient? If we can, what was its purpose? What can it tell us of the ancient world and of the evolution of modern science?

To authenticate the dating of the fragments we must tell the story of their discovery, which involves the first (though inadvertent) adventure in underwater archaeology. Just before Easter in 1900 a party of Dodecanese sponge-divers were driven by storm to anchor near the tiny southern Greek island of Antikythera (the accent is on the "kyth," pronounced to rhyme with pith). There, at a depth of some 200 feet, they found the wreck of an ancient ship. With the help of Greek archaeologists the wreck was explored; several fine bronze and marble statues and other objects were recovered. The finds created great excitement, but the difficulties of diving without heavy equipment were immense, and in September, 1901, the "dig" was abandoned. Eight months later Valerios Staïs, an archaeologist at the National Museum, was examining some calcified lumps of corroded bronze that had been set aside as possible pieces of broken statuary. Suddenly he recognized among them the fragments of a mechanism.

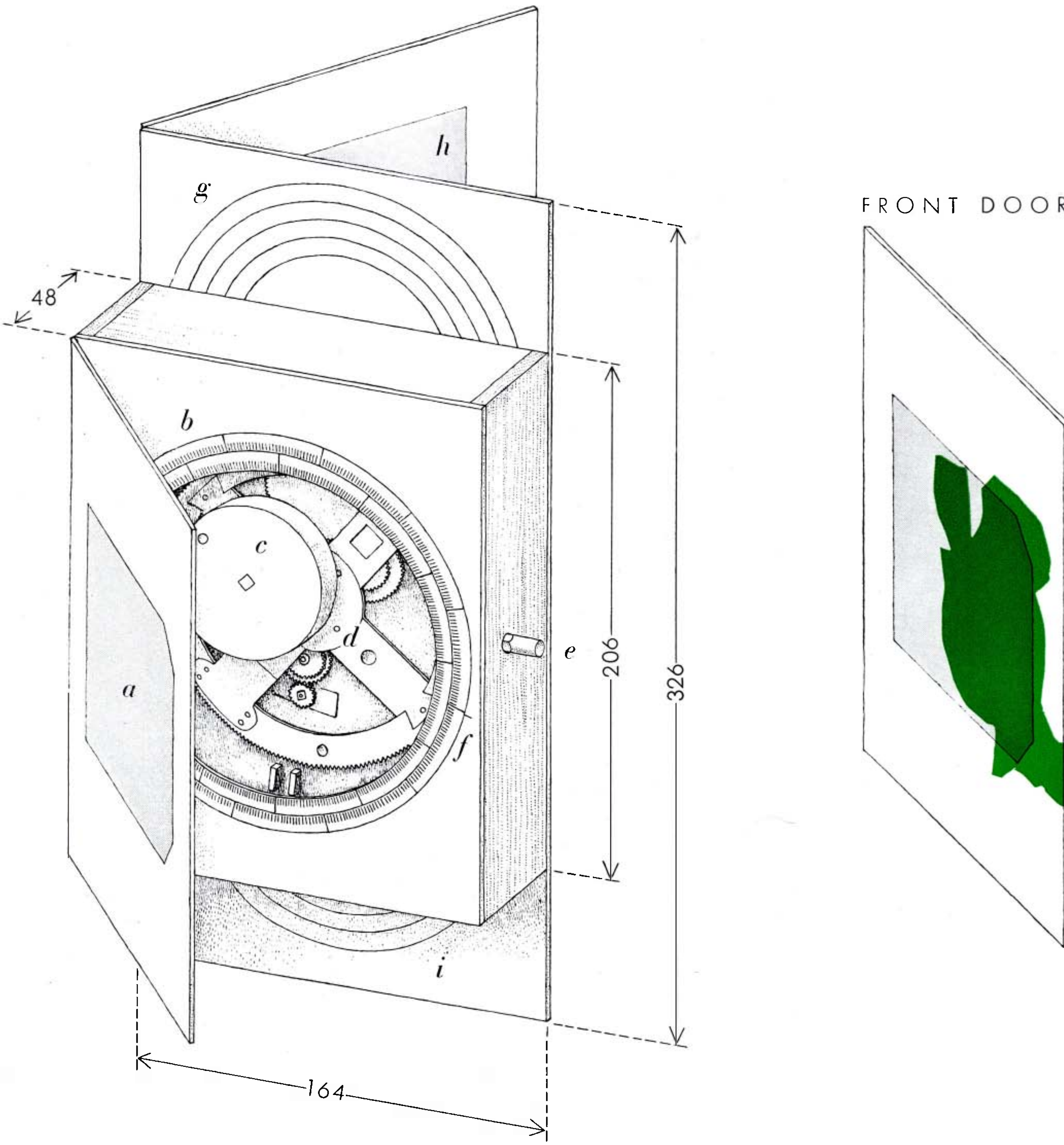
It is now accepted that the wreck occurred during the first century B.C. Gladys Weinberg of Athens has been kind enough to report to me the results of several recent archaeological examinations of the amphorae, pottery and minor objects from the ship. It appears from her report that one might reasonably date the wreck more closely as 65 B.C. ± 15 years. Furthermore, since the identifiable objects come from Rhodes and Cos, it seems that the ship may have been voyaging from these islands to Rome, perhaps without calling at the Greek mainland.

The fragment that first caught the eye of Staïs was one of the corroded, inscribed plates that is an integral part of the Antikythera mechanism, as the device later came to be called. Staïs saw immediately that the inscription was ancient. In the opinion of the epigrapher Benjamin Dean Meritt, the forms of the letters are those of the first century B.C.; they could hardly be older than 100 B.C. nor younger than the time of Christ. The dating is supported by the content of the inscriptions. The words used and their astronomical sense are all of this period. For example, the most extensive and complete piece of inscription is part of a parapegma (astronomical calendar) similar to that written by one Geminos, who is thought to have lived in Rhodes about 77 B.C. We may thus be reasonably sure that the mechanism did not find its way into the wreck at some later

left-hand page; the third pair, on the right-hand page. How the fragments were used to reconstruct the appearance of the original mechanism is shown on the next two pages. The fragments are presently located in the Greek National Archaeological Museum in Athens.

period. Furthermore, it cannot have been very old when it was taken aboard the ship as booty or merchandise.

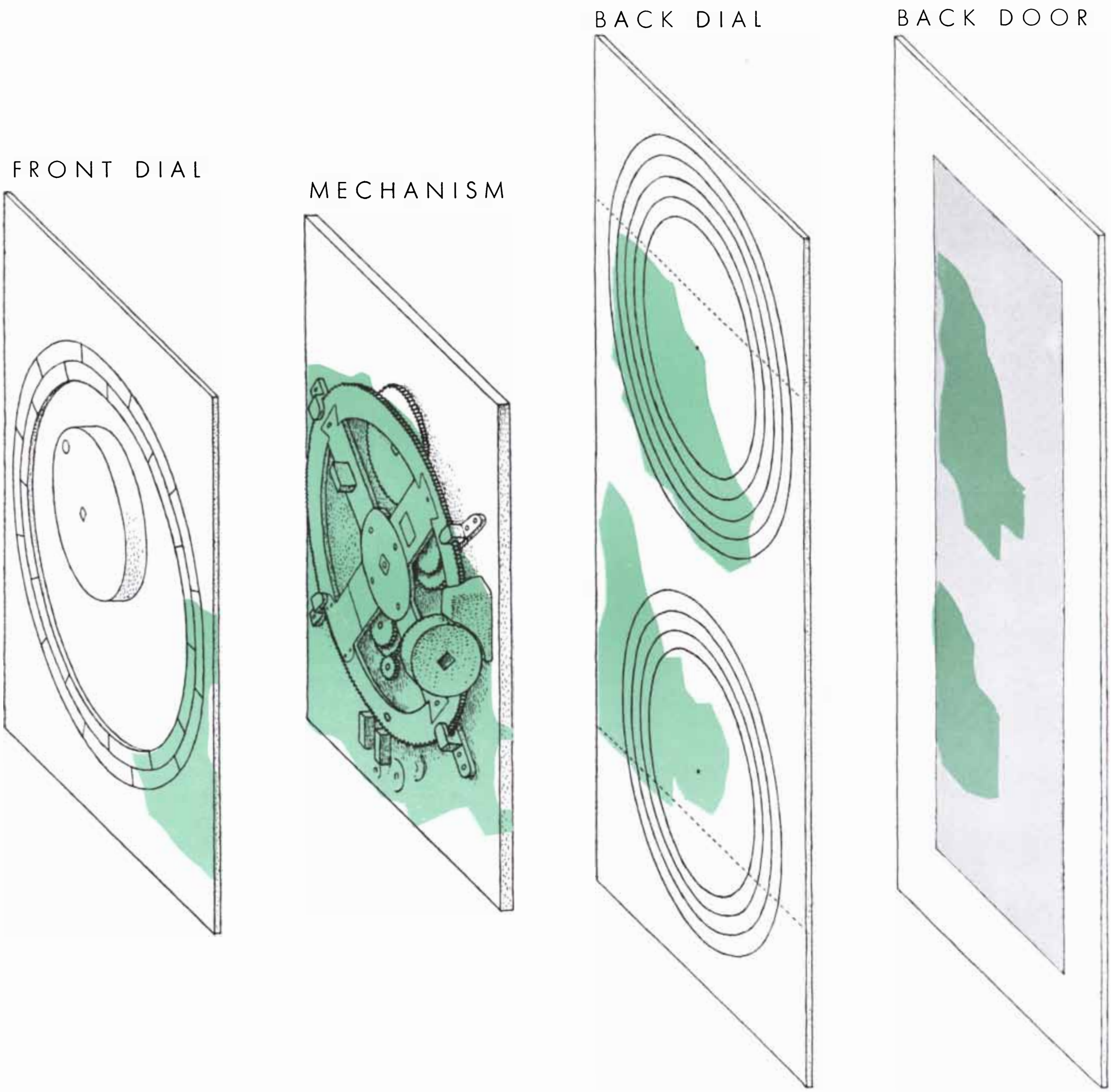
As soon as the fragments had been discovered they were examined by every available archaeologist; so began the long and difficult process of identifying the mechanism and determining its function. Some things were clear from the beginning. The unique importance of the object was obvious, and the gearing was impressively complex. From the inscriptions and the dials the mechanism was correctly identified as an astronomical device. The first conjecture was that it was some kind of navigating instrument—perhaps an astrolabe (a sort of circular star-finder map also used for simple observations). Some thought that it might be a small planetarium of the kind that Archimedes is said to have made. Unfortunately the fragments were covered by a thick curtain of calcified material and corrosion products, and these concealed so much detail that no one could be sure of his conjectures or reconstructions. There was nothing to do but wait for the slow and delicate work of the Museum technicians in cleaning away this curtain. Meantime, as the



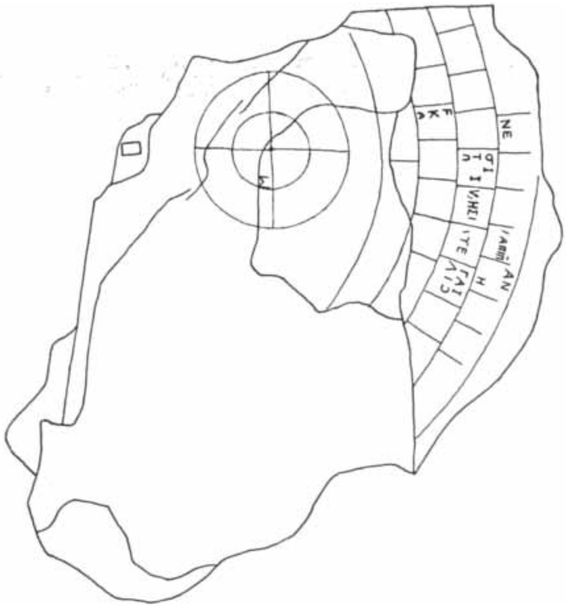
MECHANISM IS PARTLY RECONSTRUCTED at left. Exploded diagram at right shows how the fragments (*color*) are related to the plates of the mechanism. Some fragments include parts of more than one plate. The labeled parts in the reconstruction are: front-work proceeded, several scholars published accounts of all that was visible, and through their labors a general picture of the mechanism began to emerge.

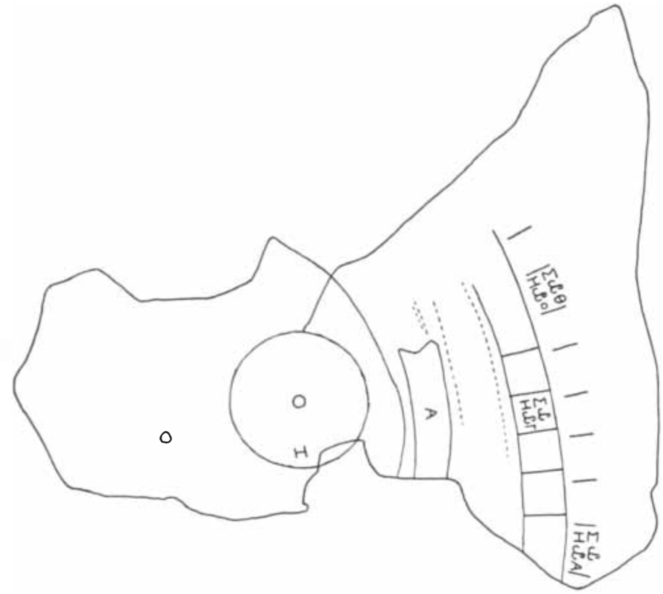
On the basis of new photographs made for me by the Museum in 1955 I realized that the work of cleaning had reached a point where it might at last be possible to take the work of identification to a new level. Last summer, with the assistance of a grant from the American Philosophical Society, I was able to visit Athens and make a minute examination of the fragments. By good fortune George Stamires, a Greek epigrapher, was there at the same time; he was able to give me invaluable help by deciphering and transcribing much more of the inscriptions than had been read before.

We are now in the position of being able to "join" the fragments and to see how they fitted together in the original machine and when they were brought up from the sea [*see illustrations on these two pages*]. The success of this work has been most significant, for previously it had been supposed that the various dials and plates had been badly squashed to-



door inscription (*a*), front dial (*b*), eccentric drum (*c*), front of mechanism (*d*), input shaft (*e*), fiducial mark (*f*), four slip rings of upper back dial (*g*), back-door inscription (*h*), three slip rings of lower back dial (*i*). The dimensions are given in millimeters.





SEGMENTS OF THREE DIALS of the mechanism are visible in the fragments. At left is a simplified drawing of one fragment showing a segment of the upper back dial. At upper right in this drawing may be seen the four slip rings of the dial; within the rings is a small subsidiary dial. Second from left is a segment of the lower back dial. At right in this drawing is a fixed scale; within it

gether and distorted. It now appears that most of the pieces are very nearly in their original places, and that we have a much larger fraction of the complete device than had been thought. This work also provides a clue to the puzzle of why the fragments lay unrecognized until Staïs saw them. When they were found, the fragments were probably held together in their original positions by the remains of the wooden frame of the case. In the Museum the waterlogged wood dried and shriveled. The fragments then fell apart, revealing the interior of the mechanism, with its gears and inscribed plates.

As a result of the new examinations we shall in due course be able to publish a technical account of the fragments and of the construction of the instrument. In the meantime we can tentatively summarize some of these results and show how they help to answer the question: What is it?

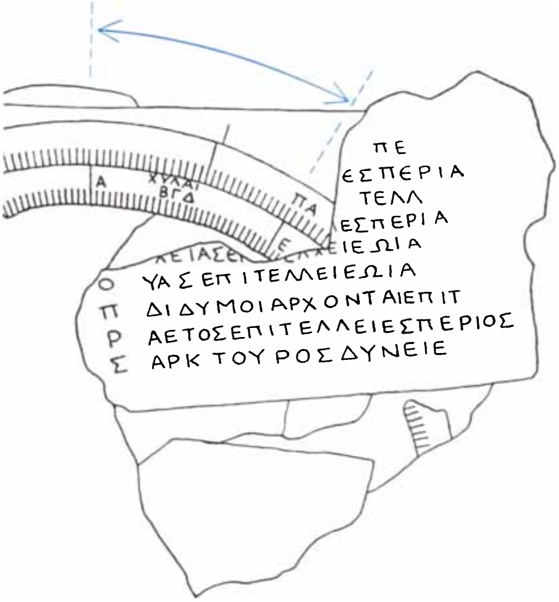
There are four ways of getting at the answer. First, if we knew the details of the mechanism, we should know what it did. Second, if we could read the dials, we could tell what they showed. Third, if we could understand the inscriptions, they might tell us about the mechanism. Fourth, if we knew of any similar mechanism, analogies might be helpful. All these approaches must be used, for none of them is complete.

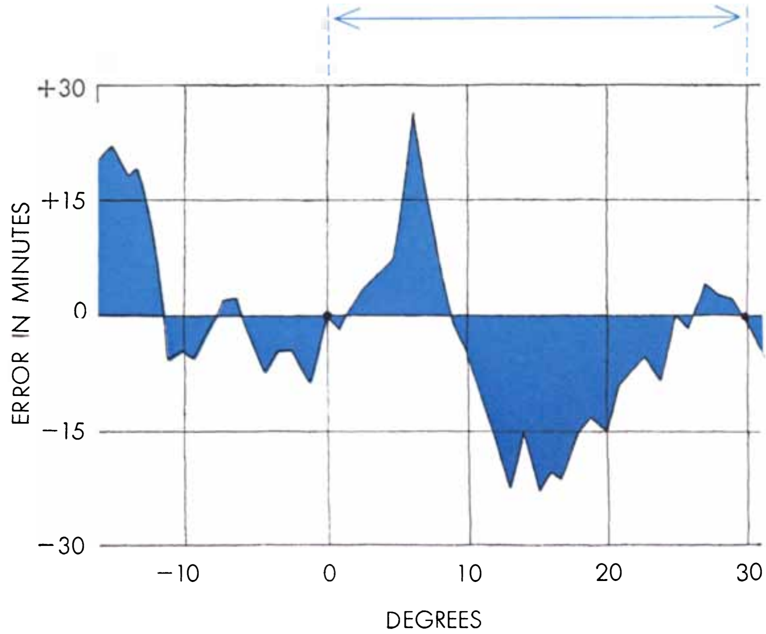
The geared wheels within the mechanism were mounted on a bronze plate [*third from right on preceding page*]. On one side of the plate we can trace all the gear wheels of the assembly and can determine, at least approximately, how many teeth each had and how they meshed together. On the other side we can do nearly as well, but we still lack vital links that would provide a complete picture of the gearing. The general pattern of the mechanism is nonetheless quite clear. An input was provided by an axle that came through the side of the casing and turned a crown-gear wheel. This moved a big, four-spoked driving-wheel that was connected with two trains of gears that respectively led up and down the plate and were connected by axles to gears on the other side of the plate. On that side the gear trains continued, leading through an epicyclic turntable and coming eventually to a set of shafts that turned the dial pointers. When the input axle was turned, the pointers all moved at various speeds around their dials.

Certain structural features of the mechanism deserve special attention. All the metal parts of the machine seem to have been cut from a single sheet of low-tin bronze about two millimeters thick; no parts were cast or made of another metal. There are indications that the maker may have used a sheet made much earlier—uniform metal plate of good quality was probably rare and expensive. All the gear wheels have been made with teeth of just the same angle (60 degrees) and size, so that any wheel could mesh with any other. There are signs that the machine was repaired at least twice; a spoke of the driving wheel has been mended, and a broken tooth in a small wheel has been replaced. This indicates that the machine actually worked.

The casing was provided with three dials, one at the front and two at the back. The fragments of all of them are still covered with pieces of the doors of the casing and with other debris. Very little can be read on the dials, but there is hope that they can be cleaned sufficiently to provide information that might be decisive. The front dial is just clean enough to say exactly what it did. It has two scales, one of which is fixed and displays the names of the signs of the zodiac; the other is on a movable slip ring and shows the months of the year. Both scales are carefully marked off in degrees. The front dial fitted exactly over the main driving-wheel, which seems to have turned the pointer by means of an eccentric drum-assembly. Clearly this dial showed the annual motion of the sun in the zodiac. By means of key letters inscribed on the zodiac scale, corresponding to other letters on the parapegma calendar plate, it also showed the main risings and settings of bright stars and constellations throughout the year.

The back dials are more complex and less legible. The lower one had three slip rings; the upper, four. Each had a little subsidiary dial resembling the "seconds" dial of a watch. Each of the large dials is inscribed with lines about every six degrees, and between the lines there are letters and numbers. On the





were three slip rings and within them a subsidiary dial. Third from left is a segment of the front dial. The upper scale in this drawing pertains to the months; the lower scale, to the zodiac. The inscribed area is a parapegma plate. The graph at far right shows the errors (in minutes of arc) of the graduations in the zodiac scale. The arrow above the scale is related to the arrow above the chart.

lower dial the letters and numbers seem to record "moon, so many hours; sun, so many hours"; we therefore suggest that this scale indicates the main lunar phenomena of phases and times of rising and setting. On the upper dial the inscriptions are much more crowded and might well present information on the risings and settings, stations and retrogradations of the planets known to the Greeks (Mercury, Venus, Mars, Jupiter and Saturn).

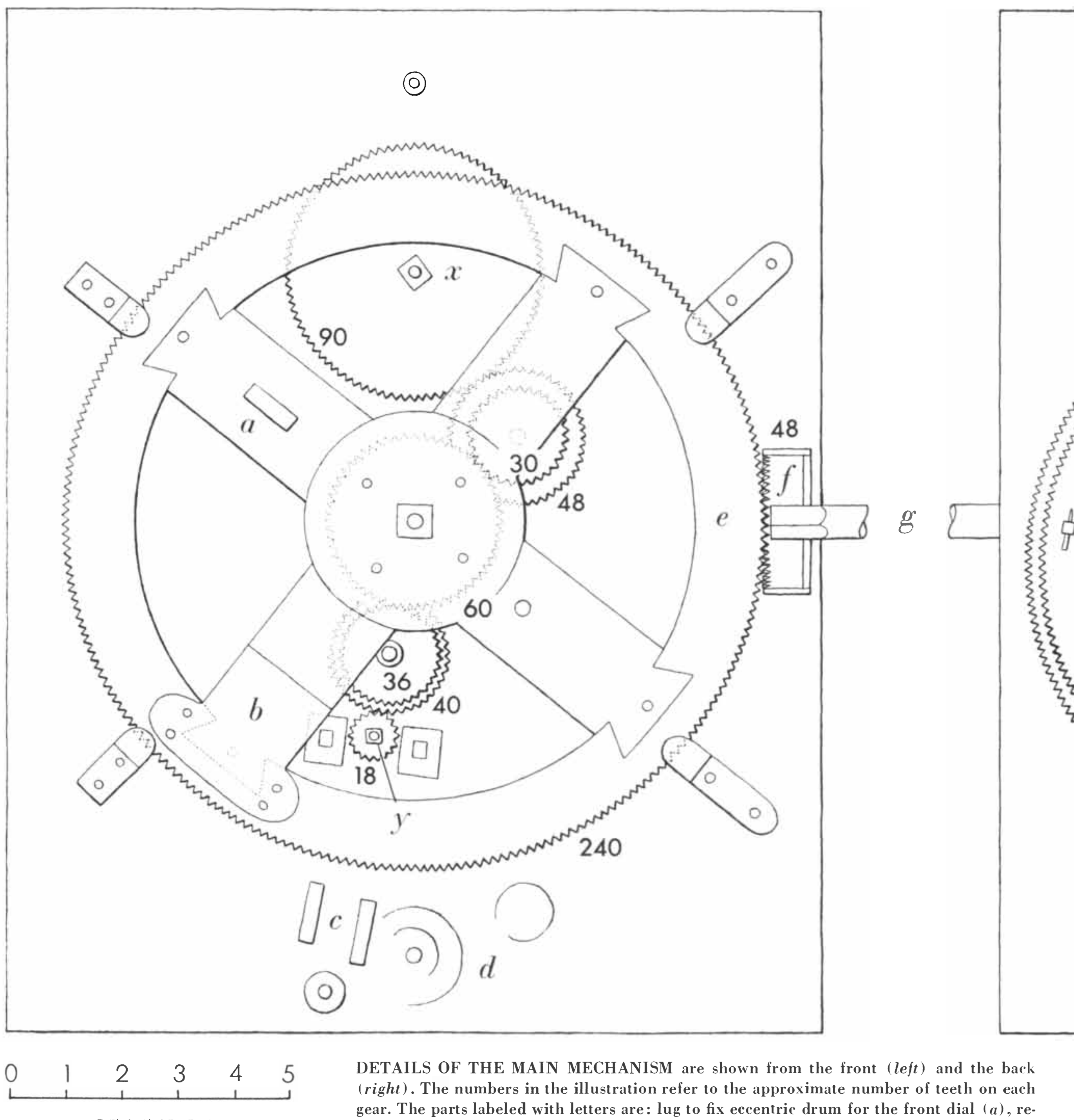
Some of the technical details of the dials are especially interesting. The front dial provides the only known extensive specimen from antiquity of a scientifically graduated instrument. When we measure the accuracy of the graduations under the microscope, we find that their average error over the visible 45 degrees is about a quarter of a degree. The way in which the error varies suggests that the arc was first geometrically divided and then subdivided by eye only. Even more important, this dial may give a means of dating the instrument astronomically. The slip ring is necessary because the old Egyptian calendar, having no leap years, fell into error by 1/4 day every year; the month scale thus had to be adjusted by this amount. As they are preserved the two scales of the dial are out of phase by 13½ degrees. Standard tables show that this amount could only occur in the year 80 B.C. and (because we do not know the month) at all years just 120 years (*i.e.*, 30 days divided by 1/4 day per year) before or after that date. Alternative dates are archaeologically unlikely: 200 B.C. is too early; 40 A.D. is too late. Hence, if the slip ring has not moved from its last position, it was set in 80 B.C. Furthermore, if we are right in supposing that a fiducial mark near the month scale was put there originally to provide a means of setting that scale in case of accidental movement, we can tell more. This mark is exactly 1/2 degree away from the present position of the scale, and this implies that the mark was made two years before the setting. Thus, although the evidence is by no means conclusive, we are led to suggest that the instrument was made about 82 B.C., used for two years (just long enough for the repairs to have been needed) and then taken onto the ship within the next 30 years.

The fragments show that the original instrument carried at least four large areas of inscription: outside the front door, inside the back door, on the plate between the two back dials and on the parapegma plates near the front dial. As I have noted, there are also inscriptions around all the dials, and furthermore each part and hole would seem to have had identifying letters so that the pieces could be put together in the correct order and position. The main inscriptions are in a sorry state and only short snatches of them can be read. To provide an idea of their condition it need only be said that in some cases a plate has completely disappeared, leaving behind an impression of its letters, standing up in a mirror image, in relief on the soft corrosion products on the plate below. It is remarkable that such inscriptions can be read at all.

But even from the evidence of a few complete words one can get an idea of the subject matter. The sun is mentioned several times, and the planet Venus once; terms are used that refer to the stations and retrogradations of planets; the ecliptic is named. Pointers, apparently those of the dials, are mentioned. A line of one inscription significantly records "76 years, 19 years." This refers to the well-known Calippic cycle of 76 years, which is four times the Metonic cycle of 19 years, or 235 synodic (lunar) months. The next line includes the number "223," which refers to the eclipse cycle of 223 lunar months.

Putting together the information gathered so far, it seems reasonable to suppose that the whole purpose of the Antikythera device was to mechanize just this sort of cyclical relation, which was a strong feature of ancient astronomy. Using the cycles that have been mentioned, one could easily design gearing that would operate from one dial having a wheel that revolved annually, and turn by this gearing a series of other wheels which would move pointers indicating the sidereal, synodic and draconitic months. Similar cycles were known for the planetary phenomena; in fact, this type of arithmetical theory is the central theme of Seleucid Babylonian astronomy, which was transmitted to the Hellenistic world in the last few centuries B.C. Such arithmetical schemes are quite distinct from the geometrical theory of circles and epicycles in astronomy, which seems to have been essentially Greek. The two types of theory were unified and brought to their peak in the second century A.D. by Claudius Ptolemy, whose labors marked the triumph of the new mathematical attitude toward geometrical models that still characterizes physics today.

The Antikythera mechanism must therefore be an arithmetical counterpart of the much more familiar geometrical models of the solar system which were known to Plato and Archimedes and evolved into the orrery and the planetarium. The mechanism is like a great astronomical clock without an escapement, or like a modern analogue computer which uses mechanical parts to save tedious calculation. It is a pity that we have no way of knowing whether the device was turned automatically or by hand. It might have been held in the hand and turned by a wheel at the side so that it would operate as a computer, possibly for astrological use. I feel it is more likely that it was permanently mounted, perhaps set in a statue, and displayed as an exhibition piece. In that case it might well have been turned by the power from a water clock or some other device. Perhaps it is just such a wondrous device that was mounted inside the famous Tower of Winds in Athens. It is certainly very similar to the

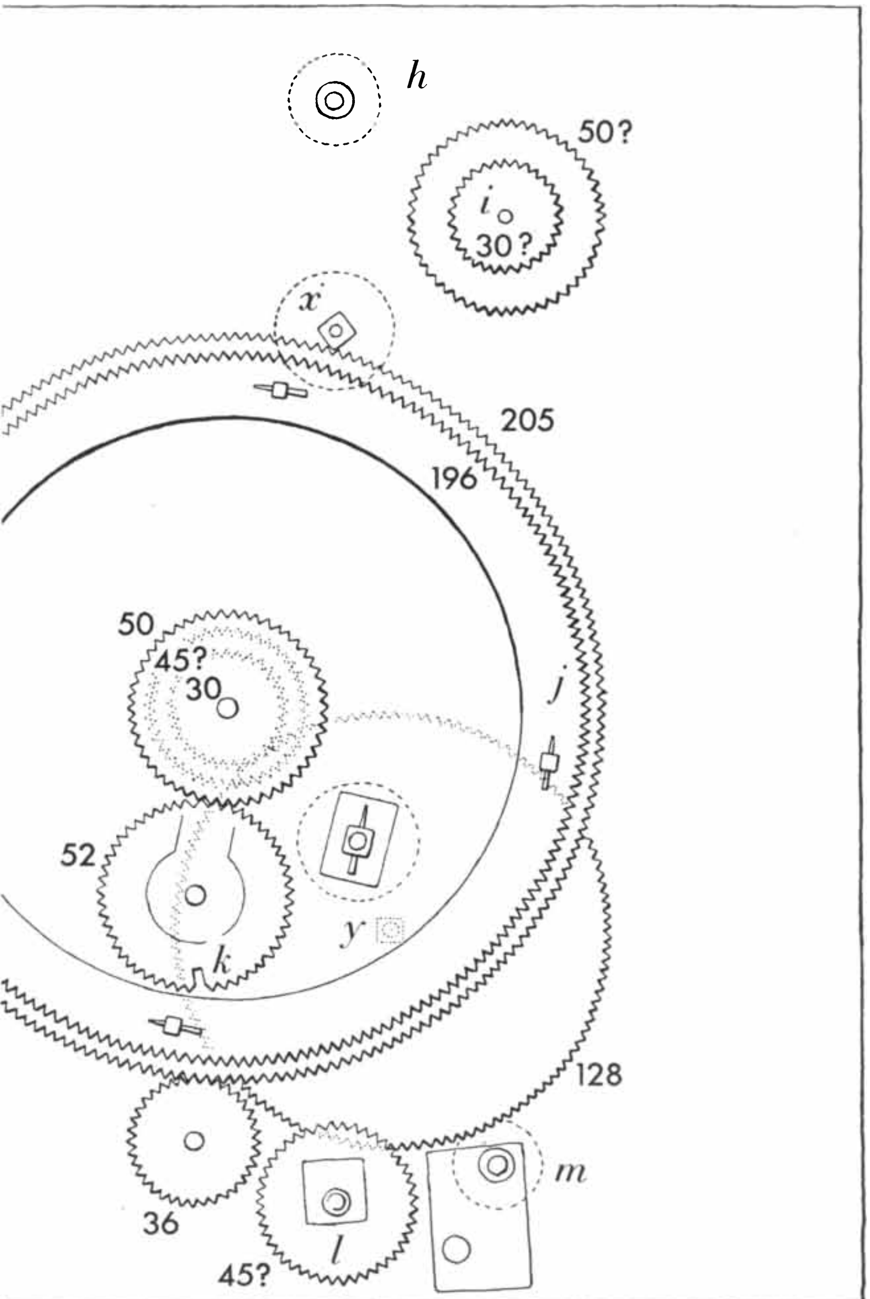


DETAILS OF THE MAIN MECHANISM are shown from the front (*left*) and the back (*right*). The numbers in the illustration refer to the approximate number of teeth on each gear. The parts labeled with letters are: lug to fix eccentric drum for the front dial (*a*), repair to spoke (*b*), guide channel for spring to hold gear of 18 teeth (*c*), rivets for great astronomical cathedral clocks that were built all over Europe during the Renaissance.

It is to the prehistory of the mechanical clock that we must look for important analogies to the Antikythera mechanism and for an assessment of its significance. Unlike other mechanical devices, the clock did not evolve from the simple to the complex. The oldest clocks of which we are well informed were the most complicated. All the evidence points to the fact that the clock started as an astronomical showpiece that happened also to indicate the time. Gradually the timekeeping functions became more important and the device that showed the marvelous clockwork of the heavens became subsidiary. Behind the astronomical clocks of the 14th century there stretches an unbroken sequence of mechanical models of astronomical theory. At the head of this sequence is the Antikythera mechanism. Following it are instruments and clocklike computers known from Islam, from China and India and from the European Middle Ages. The importance of this line is very great, because it was the tradition of clockmaking that preserved most of man's skill in scientific fine mechanics. During the Renaissance the scientific instrument-makers evolved from the clockmakers. Thus the Antikythera mechanism is, in a way, the venerable progenitor of all our present plethora of scientific hardware.

A significant passage in this story has to do with the astronomical computers of Islam. Preserved complete at the Museum of History of Science at Oxford is a 13th-century Islamic geared calendar-computer that has various periods built into it, so that it shows on dials the various cycles of the sun and moon. This design can be traced back, with slightly different periods but a similar arrangement of gears, to a manuscript written by the astronomer al-Biruni about 1000 A.D. Such instruments are much simpler than the Antikythera mechanism, but they show so many points of agreement in technical detail that it seems clear they come from a common tradition. The same 60-degree gear teeth are used; wheels are mounted on square-shanked axles; the geometrical layout of the gear assembly appears comparable. It was just at this time that Islam was drawing on Greek knowledge and rediscovering ancient Greek texts. It seems likely that the Antikythera tradition was part of a large corpus of knowledge that has since been lost to us but was known to the Arabs. It was developed and transmitted by them to medieval Europe, where it became the foundation for the whole range of subsequent invention in the field of clockwork.

On the one hand the Islamic devices knit the whole story together, and demonstrate that it is through ancestry and not mere coincidence that the Antikythera mechanism resembles a modern clock. On the other hand they show that the Antikythera mechanism was no flash in the pan but was a part of an important current in Hellenistic civilization. History has contrived to keep that current dark to us, and only the accidental underwater preservation of fragments that would otherwise have crumbled to dust has now brought it to light. It is a bit frightening to know that just before the fall of their great civilization the ancient Greeks had come so close to our age, not only in their thought, but also in their scientific technology.



the axles and support blocks at the back (*d*), main driving wheel (*e*), crown wheel (*f*), input axle (*g*), shaft of the upper-dial main pointer (*h*), shaft of the upper-dial subsidiary pointer (*i*), epicyclic turntable (*j*), repair to tooth (*k*), shaft of the lower-dial main pointer (*l*), shaft of the lower-dial subsidiary pointer (*m*), axles through the plate (*x* and *y*).

Love in Infant Monkeys

Affection in infants was long thought to be generated by the satisfactions of feeding. Studies of young rhesus monkeys now indicate that love derives mainly from close bodily contact

by Harry F. Harlow

The first love of the human infant is for his mother. The tender intimacy of this attachment is such that it is sometimes regarded as a sacred or mystical force, an instinct incapable of analysis. No doubt such compunctions, along with the obvious obstacles in the way of objective study, have hampered experimental observation of the bonds between child and mother.

Though the data are thin, the theoretical literature on the subject is rich. Psychologists, sociologists and anthropologists commonly hold that the infant's love is learned through the association of the mother's face, body and other physical characteristics with the alleviation of internal biological tensions, particularly hunger and thirst. Traditional psychoanalysts have tended to emphasize the role of attaining and sucking at the breast as the basis for affectional development. Recently a number of child psychiatrists have questioned such simple explanations. Some argue that affectionate handling in the act of nursing is a variable of importance, whereas a few workers suggest that the composite activities of nursing, contact, clinging and even seeing and hearing work together to elicit the infant's love for his mother.

Now it is difficult, if not impossible, to use human infants as subjects for the studies necessary to break through the present speculative impasse. At birth the infant is so immature that he has little or no control over any motor system other than that involved in sucking. Furthermore, his physical maturation is so slow that by the time he can achieve precise, coordinated, measurable responses of his head, hands, feet and body, the nature and sequence of development have been hopelessly confounded and obscured. Clearly research into the infant-mother relationship has need of a more suitable laboratory animal. We believe we have found it in the infant monkey. For the past several years our group at the Primate Laboratory of the University of Wisconsin has been employing baby rhesus monkeys in a study that we believe has begun to yield significant insights into the origin of the infant's love for his mother.

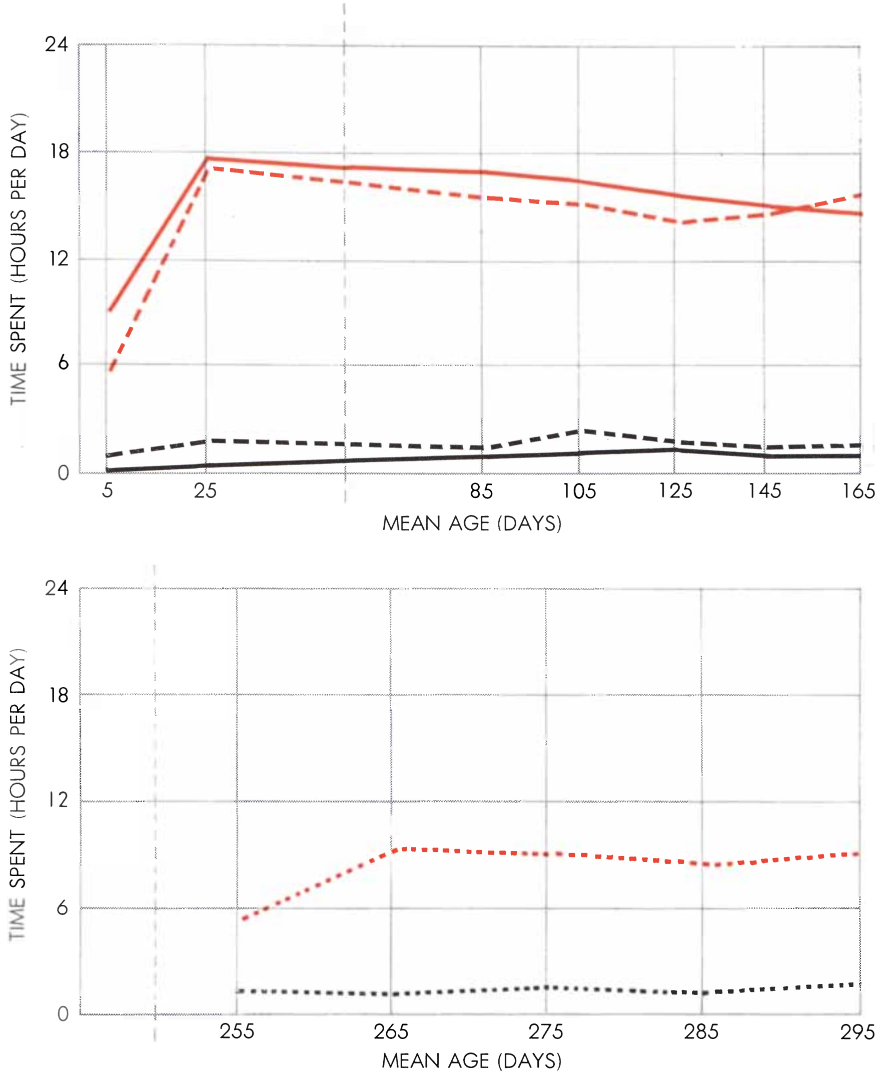
Baby monkeys are far better coordinated at birth than human infants. Their responses can be observed and evaluated with confidence at an age of 10 days or even earlier. Though they mature much more rapidly than their human contemporaries, infants of both species follow much the same general pattern of development.

Our interest in infant-monkey love grew out of a research program that involved the separation of monkeys from their mothers a few hours after birth. Employing techniques developed by Gertrude van Wagenen of Yale University, we had been rearing infant monkeys on the bottle with a mortality far less than that among monkeys nursed by their mothers. We were particularly careful to provide the infant monkeys with a folded gauze diaper on the floor of their cages, in accord with Dr. van Wagenen's observation that they would tend to maintain intimate contact with such soft, pliant surfaces, especially during nursing. We were impressed by the deep personal attachments that the monkeys formed for these diaper pads, and by the distress that they exhibited when the pads were briefly removed once a day for purposes of sanitation. The behavior of the infant monkeys was reminiscent of the human infant's attachment to its blankets, pillows, rag dolls or cuddly teddy bears.

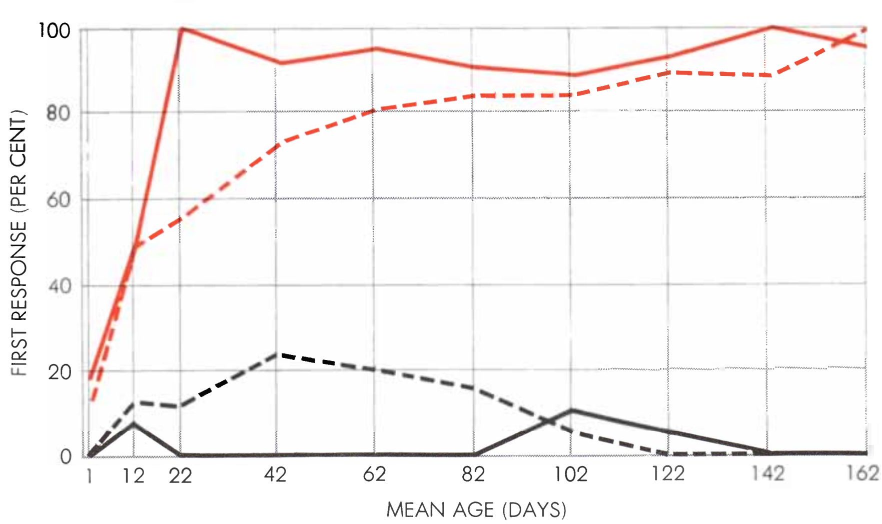
These observations suggested the series of experiments in which we have sought to compare the importance of nursing and all associated activities with that of simple bodily contact in engendering the infant monkey's attachment to its mother. For this purpose we contrived two surrogate mother monkeys. One is a bare welded-wire cylindrical form surmounted by a wooden head with a crude face. In the other the welded wire is cushioned by a sheathing of terry cloth. We placed eight newborn monkeys in individual cages, each with equal access to a cloth and a wire mother [*see illustration on opposite page*]. Four of the infants received their milk from one mother and four from the other, the milk being furnished in each case by a nursing bottle, with its nipple protruding from the mother's "breast."

The two mothers quickly proved to be physiologically equivalent. The monkeys in the two groups drank the same amount of milk and gained weight at the same rate. But the two mothers proved to be by no means psychologically equivalent. Records made automatically showed that both groups of infants spent far more time climbing and clinging on their cloth-covered mothers than they did on their wire mothers. During the infants' first 14 days of life the floors of the cages were warmed by an electric heating pad, but most of the infants left the pad as soon as they could climb on the unheated cloth mother. Moreover, as the monkeys grew older, they tended to spend an increasing amount of time clinging and cuddling on her pliant terry-cloth surface. Those that secured their nourishment from the wire mother showed no tendency to spend more time on her than feeding required, contradicting the idea that affection is a response that is learned or derived in asso-

CLOTH AND WIRE MOTHER-SURROGATES were used to test the preferences of infant monkeys. The infants spent most of their time clinging to the soft cloth "mother," (*foreground*) even when nursing bottles were attached to the wire mother (*background*).



STRONG PREFERENCE FOR CLOTH MOTHER was shown by all infant monkeys. Infants reared with access to both mothers from birth (*top chart*) spent far more time on the cloth mother (*colored curves*) than on the wire mother (*black curves*). This was true regardless of whether they had been fed on the cloth (*solid lines*) or on the wire mother (*broken lines*). Infants that had known no mother during their first eight months (*bottom chart*) soon came to prefer cloth mother, but spent less time on her than the other infants.



RESULTS OF "FEAR TEST" (*see photographs on opposite page*) showed that infants confronted by a strange object quickly learned to seek reassurance from the cloth mother (*colored curves*) rather than from the wire mother (*black curves*). Again infants fed on the wire mother (*broken lines*) behaved much like those fed on cloth mother (*solid lines*).

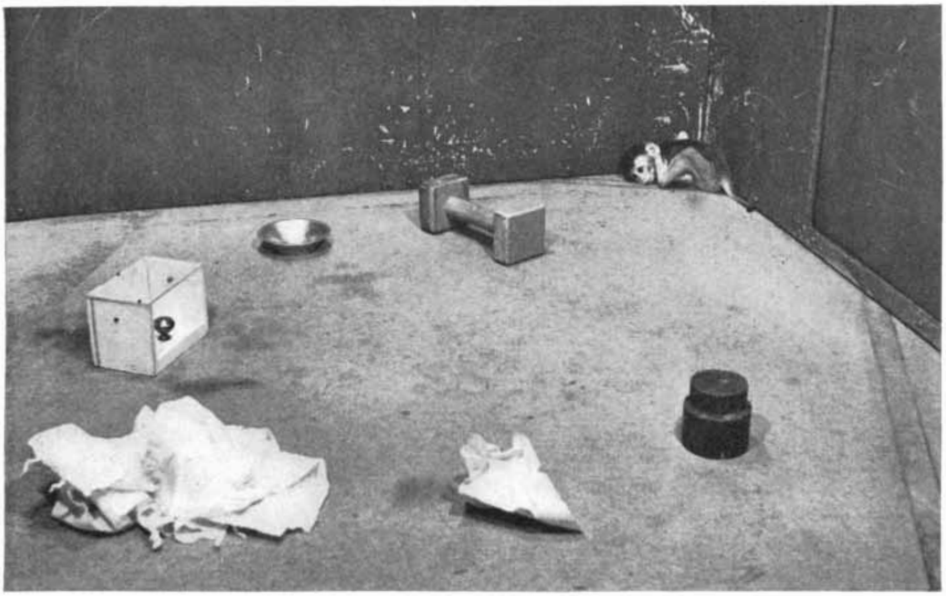
ciation with the reduction of hunger or thirst.

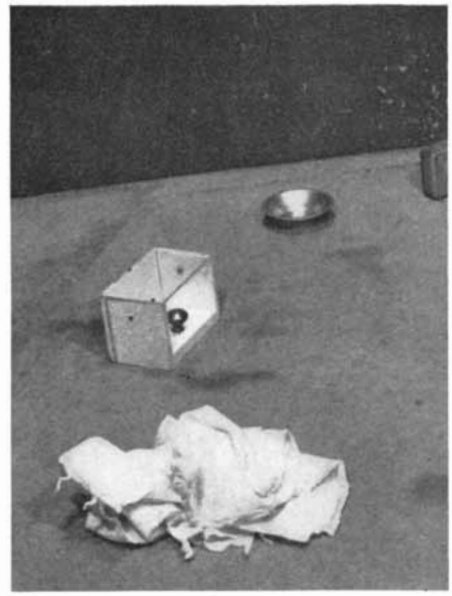
These results attest the importance—possibly the overwhelming importance—of bodily contact and the immediate comfort it supplies in forming the infant's attachment for its mother. All our experience, in fact, indicates that our cloth-covered mother surrogate is an eminently satisfactory mother. She is available 24 hours a day to satisfy her infant's overwhelming compulsion to seek bodily contact; she possesses infinite patience, never scolding her baby or biting it in anger. In these respects we regard her as superior to a living monkey mother, though monkey fathers would probably not endorse this opinion.

Of course this does not mean that nursing has no psychological importance. No act so effectively guarantees intimate bodily contact between mother and child. Furthermore, the mother who finds nursing a pleasant experience will probably be temperamentally inclined to give her infant plenty of handling and fondling. The real-life attachment of the infant to its mother is doubtless influenced by subtle multiple variables, contributed in part by the mother and in part by the child. We make no claim to having unraveled these in only two years of investigation. But no matter what evidence the future may disclose, our first experiments have shown that contact comfort is a decisive variable in this relationship.

Such generalization is powerfully supported by the results of the next phase of our investigation. The time that the infant monkeys spent cuddling on their surrogate mothers was a strong but perhaps not conclusive index of emotional attachment. Would they also seek the inanimate mother for comfort and security when they were subjected to emotional stress? With this question in mind we exposed our monkey infants to the stress of fear by presenting them with strange objects, for example a mechanical teddy bear which moved forward, beating a drum. Whether the infants had nursed from the wire or the cloth mother, they overwhelmingly sought succor from the cloth one; this differential in behavior was enhanced with the passage of time and the accrual of experience. Early in this series of experiments the terrified infant might rush blindly to the wire mother, but even if it did so it would soon abandon her for the cloth mother. The infant would cling to its cloth mother, rubbing its body against hers. Then, with its fears assuaged through intimate contact with the moth-

FRIGHTENING OBJECTS such as a mechanical teddy bear caused almost all infant monkeys to flee blindly to the cloth mother, as in the top photograph. Once reassured by pressing and rubbing against her, they would then look at the strange object (*bottom*).





"OPEN FIELD TEST" involved placing a monkey in a room far larger than its accustomed cage; unfamiliar objects added an additional disturbing element. If no mother was present, the infant would typically huddle in a corner (*left*). The wire mother did

er, it would turn to look at the previously terrifying bear without the slightest sign of alarm. Indeed, the infant would sometimes even leave the protection of the mother and approach the object that a few minutes before had reduced it to abject terror.

The analogy with the behavior of human infants requires no elaboration. We found that the analogy extends even to less obviously stressful situations. When a child is taken to a strange place, he usually remains composed and happy so long as his mother is nearby. If the mother gets out of sight, however, the child is often seized with fear and distress. We developed the same response in our infant monkeys when we exposed them to a room that was far larger than the cages to which they were accustomed. In the room we had placed a number of unfamiliar objects such as a small artificial tree, a crumpled piece of paper, a folded gauze diaper, a wooden block and a doorknob [*a similar experiment is depicted in the illustrations on these two pages*]. If the cloth mother was in the room, the infant would rush wildly to her, climb upon her, rub against her and cling to her tightly. As in the previous experiment, its fear then sharply diminished or vanished. The infant would begin to climb over the mother's body and to explore and manipulate her face. Soon it would leave the mother to investigate the new world, and the unfamiliar objects would become playthings. In a typical behavior sequence, the infant might manipulate the tree, return to the mother, crumple the wad of paper, bring it to the mother, explore the block, explore the doorknob, play with the paper and return to the mother. So long as the mother provided a psychological "base of operations" the infants were unafraid and their behavior remained positive, exploratory and playful.

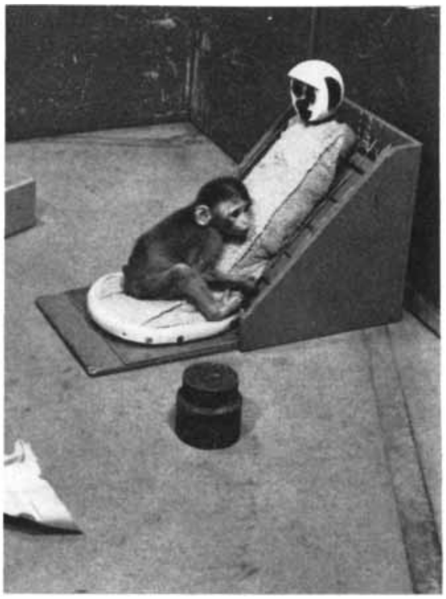
If the cloth mother was absent, however, the infants would rush across the test room and throw themselves facedown on the floor, clutching their heads and bodies and screaming their distress. Records kept by two independent observers—scoring for such "fear indices" as crying, crouching, rocking and thumb- and toe-sucking—showed that the emotionality scores of the infants nearly tripled. But no quantitative measurement can convey the contrast between the positive, outgoing activities in the presence of the cloth mother and the stereotyped withdrawn and disturbed behavior in the motherless situation.

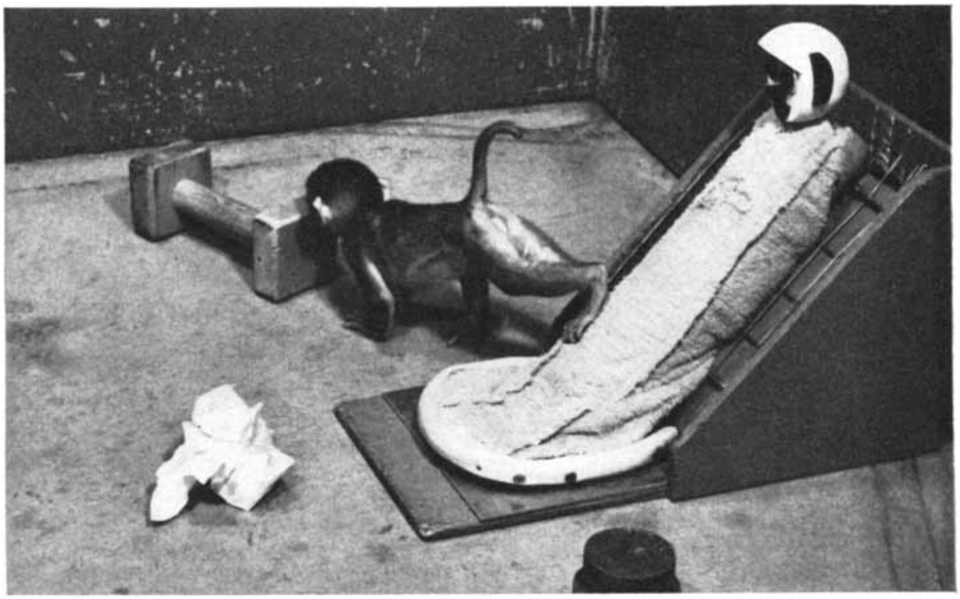
The bare wire mother provided no more reassurance in this "open field" test than no mother at all. Control tests on monkeys that from birth had known only the wire mother revealed that even these infants showed no affection for her and obtained no comfort from her presence. Indeed, this group of animals exhibited the highest emotionality scores of all. Typically they would run to some wall or corner of the room, clasp their heads and bodies and rock convulsively back and forth. Such activities closely resemble the autistic behavior seen frequently among neglected children in and out of institutions.

In a final comparison of the cloth and wire mothers, we adapted an experiment originally devised by Robert A. Butler at the Primate Laboratory. Butler had found that monkeys enclosed in a dimly lighted box would press a lever to open and reopen a window for hours on end for no reward other than the chance to look out. The rate of lever-pressing depended on what the monkeys saw through the opened window; the sight of another monkey elicited far more activity than that of a bowl of fruit or an empty room [see "Curiosity in Monkeys," by Robert A. Butler; Scientific American, February, 1954]. We now know that this "curiosity response" is innate. Three-day-old monkeys, barely able to walk, will crawl across the floor of the box to reach a lever which briefly opens the window; some press the lever hundreds of times within a few hours.

When we tested our monkey infants in the "Butler box," we found that those reared with both cloth and wire mothers showed as high a response to the cloth mother as to another monkey, but displayed no more interest in the wire mother than in an empty room. In this test, as in all the others, the monkeys fed on the wire mother behaved the same as those fed on the cloth mother. A control group raised with no mothers at all found the cloth mother no more interesting than the wire mother and neither as interesting as another monkey.

Thus all the objective tests we have been able to devise agree in showing that the infant monkey's relationship to its surrogate mother is a full one. Comparison with the behavior of infant monkeys raised by their real mothers confirms this view. Like our experimental monkeys, these infants spend many





not alter this pattern of fearful behavior, but the cloth mother provided quick reassurance. The infant would first cling to her (*center*) and then set out to explore the room and play with the objects (*right*), returning from time to time for more reassurance.

hours a day clinging to their mothers, and run to them for comfort or reassurance when they are frightened. The deep and abiding bond between mother and child appears to be essentially the same, whether the mother is real or a cloth surrogate.

While bodily contact clearly plays the prime role in developing infantile affection, other types of stimulation presumably supplement its effects. We have therefore embarked on a search for these other factors. The activity of a live monkey mother, for example, provides her infant with frequent motion stimulation. In many human cultures mothers bind their babies to them when they go about their daily chores; in our own culture parents know very well that rocking a baby or walking with him somehow promotes his psychological and physiological well-being. Accordingly we compared the responsiveness of infant monkeys to two cloth mothers, one stationary and one rocking. All of them preferred the rocking mother, though the degree of preference varied considerably from day to day and from monkey to monkey. An experiment with a rocking crib and a stationary one gave similar results. Motion does appear to enhance affection, albeit far less significantly than simple contact.

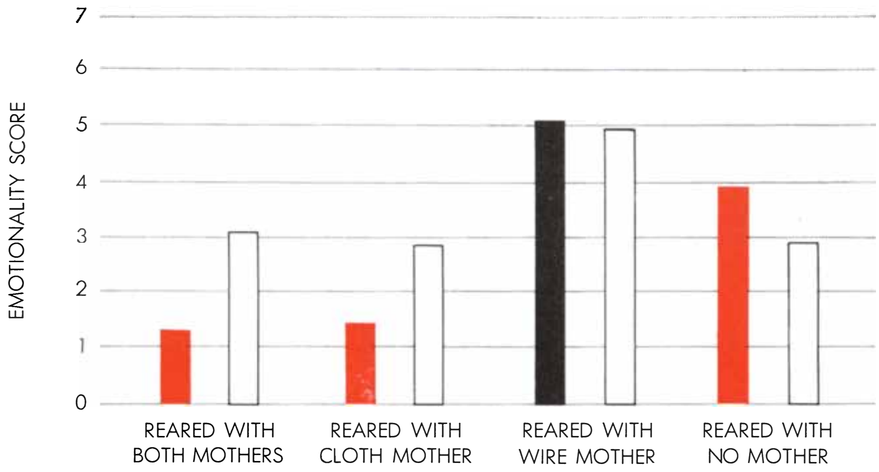
The act of clinging, in itself, also seems to have a role in promoting psychological and physiological well-being. Even before we began our studies of affection, we noticed that a newborn monkey raised in a bare wire cage survived with difficulty unless we provided it with a cone to which it could cling. Recently we have raised two groups of monkeys, one with a padded crib instead of a mother and the other with a cloth mother as well as a crib. Infants in the latter group actually spend more time on the crib than on the mother, probably because the steep incline of the mother's cloth surface makes her a less satisfactory sleeping platform. In the open-field test, the infants raised with a crib but no mother clearly derived some emotional support from the presence of the crib. But those raised with both showed an unequivocal preference for the mother they could cling to, and they evidenced the benefit of the superior emotional succor they gained from her.

Still other elements in the relationship remain to be investigated systematically. Common sense would suggest that the warmth of the mother's body plays its part in strengthening the infant's ties to her. Our own observations have not yet confirmed this hypothesis. Heating a cloth mother does not seem to increase her attractiveness to the infant monkey, and infants readily abandon a heating pad for an unheated mother surrogate. However, our laboratory is kept comfortably warm at all times; experiments in a chilly environment might well yield quite different results.

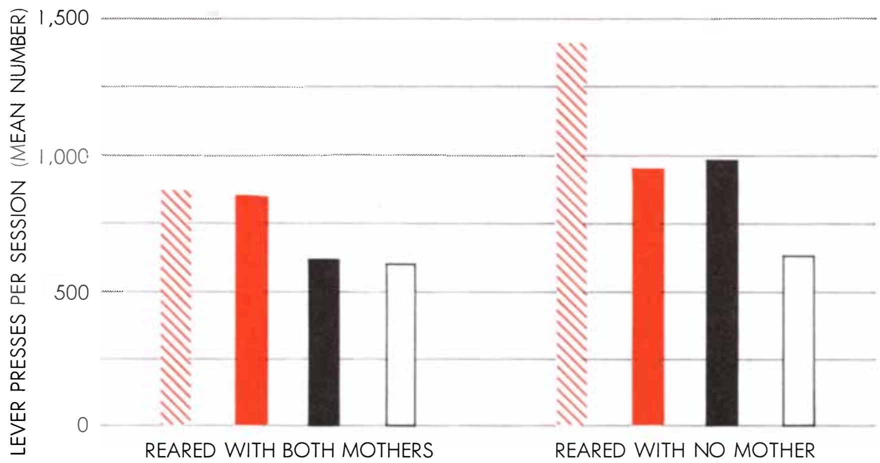
Visual stimulation may forge an additional link. When they are about three months old, the monkeys begin to observe and manipulate the head, face and eyes of their mother surrogates; human infants show the same sort of delayed responsiveness to visual stimuli. Such stimuli are known to have marked effects on the behavior of many young animals. The Austrian zoologist Konrad Lorenz has demonstrated a process called "imprinting"; he has shown that the young of some species of birds become attached to the first moving object they perceive, normally their mothers [see " 'Imprinting' in Animals," by Eckhard H. Hess; SCIENTIFIC AMERICAN, March, 1958]. It is also possible that particular sounds and even odors may play some role in the normal development of responses or attention.

The depth and persistence of attachment to the mother depend not only on the kind of stimuli that the young animal receives but also on when it receives them. Experiments with ducks show that imprinting is most effective during a critical period soon after hatching; beyond a certain age it cannot take place at all. Clinical experience with human beings indicates that people who have been deprived of affection in infancy may have difficulty forming affectional ties in later life. From preliminary experiments with our monkeys we have found that their affectional responses develop, or fail to develop, according to a similar pattern.

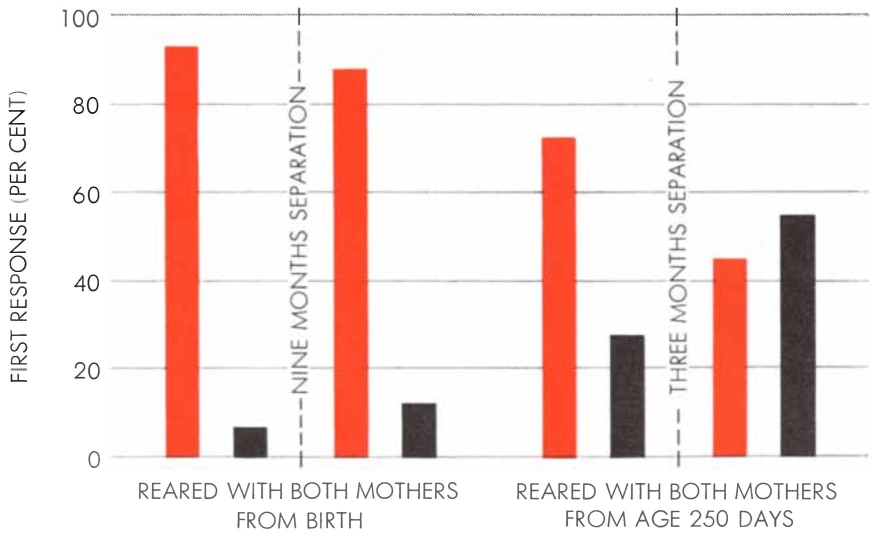
Early in our investigation we had segregated four infant monkeys as a general control group, denying them physical contact either with a mother surrogate or with other monkeys. After about eight months we placed them in cages with access to both cloth and wire mothers. At first they were afraid of both surrogates, but within a few days they began to respond in much the same way as the other infants. Soon they were



SCORES IN OPEN FIELD TEST show that all infant monkeys familiar with the cloth mother were much less disturbed when she was present (*color*) than when no mother was present (*white*); scores under 2 indicate unfrightened behavior. Infants that had known only the wire mother were greatly disturbed whether she was present (*black*) or not (*white*).



"CURIOSITY TEST" SHOWED THAT monkeys reared with both mothers displayed as much interest in the cloth mother (*solid color*) as in another monkey (*hatched color*); the wire mother (*black*) was no more interesting than an empty chamber (*white*). Monkeys reared with no mother found cloth and wire mother less interesting than another monkey.



EARLY "MOTHERING" produced a strong and unchanging preference for the cloth mother (*color*) over the wire mother (*black*). Monkeys deprived of early mothering showed less marked preferences before separation and no significant preference subsequently.

spending less than an hour a day with the wire mother and eight to 10 hours with the cloth mother. Significantly, however, they spent little more than half as much time with the cloth mother as did infants raised with her from birth.

In the open-field test these "orphan" monkeys derived far less reassurance from the cloth mothers than did the other infants. The deprivation of physical contact during their first eight months had plainly affected the capacity of these infants to develop the full and normal pattern of affection. We found a further indication of the psychological damage wrought by early lack of mothering when we tested the degree to which infant monkeys retained their attachments to their mothers. Infants raised with a cloth mother from birth and separated from her at about five and a half months showed little or no loss of responsiveness even after 18 months of separation. In some cases it seemed that absence had made the heart grow fonder. The monkeys that had known a mother surrogate only after the age of eight months, however, rapidly lost whatever responsiveness they had acquired. The long period of maternal deprivation had evidently left them incapable of forming a lasting affectional tie.

The effects of maternal separation and deprivation in the human infant have scarcely been investigated, in spite of their implications concerning child-rearing practices. The long period of infant-maternal dependency in the monkey provides a real opportunity for investigating persisting disturbances produced by inconsistent or punishing mother surrogates.

Above and beyond demonstration of the surprising importance of contact comfort as a prime requisite in the formation of an infant's love for its mother—and the discovery of the unimportant or nonexistent role of the breast and act of nursing—our investigations have established a secure experimental approach to this realm of dramatic and subtle emotional relationships. The further exploitation of the broad field of research that now opens up depends merely upon the availability of infant monkeys. We expect to extend our researches by undertaking the study of the mother's (and even the father's!) love for the infant, using real monkey infants or infant surrogates. Finally, with such techniques established, there appears to be no reason why we cannot at some future time investigate the fundamental neurophysiological and biochemical variables underlying affection and love.

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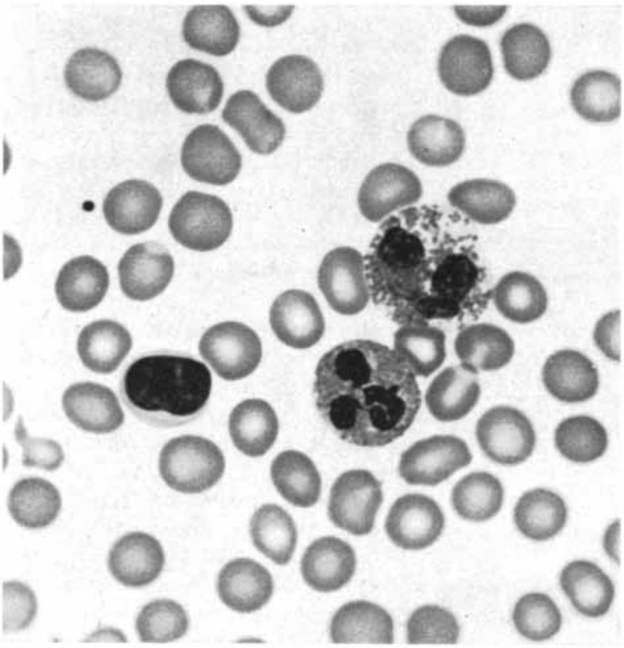
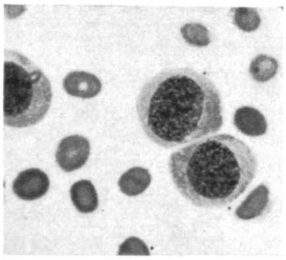
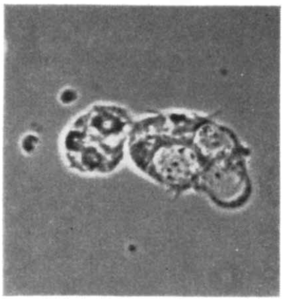


Among the red cells, three of the principal types of white cells, left to right: a lymphocyte, representing about 30% of the white cells; a neutrophil, representing 60%; an eosinophil, representing about 2%.



Megaloblastic cells, characteristic of the pattern of red cell maturation in pernicious anemia.



Erythrophagocyte, seen in an uncommon blood condition, where white cells swallow red cells. Here is one that has eaten three.

The objective documentation of hematological observations through properly controlled photomicrography is treated with some depth in the current issue of our periodical *Medical Radiography and Photography*. It contains some excellent color photomicrographs, including a series which depicts the maturation of human blood cells. However, if we were to go to the expense of reproducing the color on this page, it would use up money better spent in face-to-face instruction in hematological photomicrography for those who need it. You can look at the color all you want to by requesting a copy of the blood issue of *M. R. & P.* from Eastman Kodak Company, Medical Sales Division, Rochester 4, N. Y.

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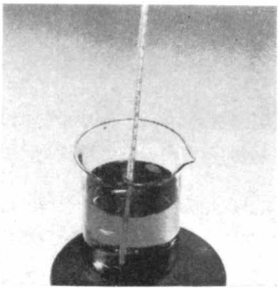
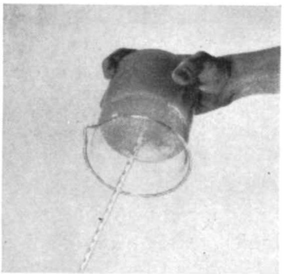


2. Heat to about 75°C and cool.



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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

Kodak
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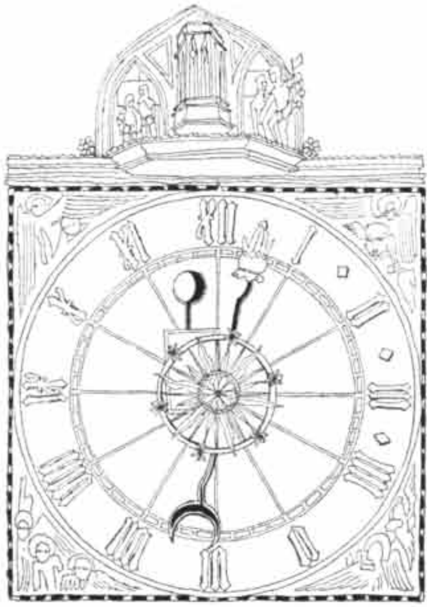


SCIENCE AND

Strontium in the Skeleton

A week of hearings before a subcommittee of the Joint Congressional Committee on Atomic Energy produced testimony that the fallout of fission products already injected into the upper atmosphere will ultimately double the population's exposure to radiation from this source. Witnesses agreed that resumption of tests at the rate prevailing during the past five years would ultimately constitute a world-wide threat to public health. But there was dispute as to the standards of permissible exposure to fission products (especially strontium 90), and so no agreement as to the hazard created by atomic-weapons tests.

According to the General Advisory Committee of the Atomic Energy Commission, nuclear explosions totaling 65 megatons of fission energy have burdened the atmosphere with fission products equivalent to 100 pounds of strontium 90. About 50 pounds have already fallen out, and most of the balance will come down over the next few years. Nearly three quarters of the fallout, the A.E.C. reported in a separate statement, is of Western, primarily U. S., origin. The General Advisory Committee noted, however, that the average lifetime exposure to external radiation from fallout would come to "less than 5 per cent as much as the average exposure to . . . background radiation." (The equivalent A.E.C. estimate in 1956 was 2.3 per cent.) It described internal radiation from strontium 90 in food and water as being "less of a hazard than the amount of radium normally present in public drinking water supplies in certain places in the United States."

Before the hearings began the National Committee on Radiation Protection and Measurements had issued a report downgrading the strontium-90 hazard. The Committee recommended that the permissible concentration of strontium 90 in the human skeleton might safely be doubled. At the same time the principal assumption underlying prevailing standards of permissible exposure was sharply questioned by W. O. Caster, a physiological chemist of the University of Minnesota. Writing in the *Minnesota Chemist*, he pointed out that these standards invariably assume uniform distribution of strontium in the human skeleton. Swedish investigators have shown, however, that local "hot spots" in the skeleton may contain up to 60 times the average concentration. Current standards of permissible concentration, Caster concludes, may be 60 times too high for safety. Thus an average concentration of 180 strontium units, which the A.E.C. now regards as "safe," would "double and perhaps triple a person's chances of having leukemia and place him just above the threshold for bone damage." Caster believes that the standard might well be set as low as three strontium units.

In the Joint Committee hearings Wright Langham of the Los Alamos Scientific Laboratory presented estimates showing that the average world level of strontium in human skeletons will rise to a maximum of seven strontium units in the mid-1960's. The level will be higher in the countries of the Far East because of differences in diet.

Another witness, Charles L. Dunham, director of the A.E.C. Division of Biology and Medicine, testified that strontium in the bones of young children in this country might reach an average of 10 units. Over the next 70 years, he said, this dosage could produce 3,500 to 7,000 cases of bone cancer, and perhaps twice as many cases of leukemia. He later indicated that these estimates assume uniform distribution of strontium in the skeleton.

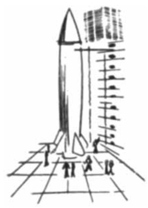
Over-all Structure of a Protein

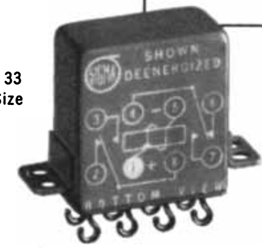
The tertiary structure of a protein—the three-dimensional arrangement of the chains of amino acid units in the protein molecule—has been worked out for the first time. Surprisingly the molecule is almost totally lacking in symmetry, and it is far more complex than could have been predicted by any existing theory of protein structure. This was stated by J. C. Kendrew of the Cavendish Laboratory at the University of Cambridge, who described his work on the protein myoglobin at the recent Atlantic City, N. J., meeting of the Federation of American Societies for Experimental Biology.

Kendrew explained that proteins have three levels of structure: the sequence of their amino acid units (primary structure); the way in which the amino acid units are coiled or folded in a long polypeptide chain (secondary structure); and finally the way in which the polypeptide chain is arranged in molecules of various over-all forms (tertiary structure).

Kendrew has constructed a solid model of the myoglobin molecule which has the polypeptide chains arranged like a ball of thick spaghetti; a heme group (which performs the oxygen-binding function of the molecule) sticks out on one side. The main body of the molecule, which facilitates the chemical action of the heme group in some still-unknown manner, appears to be a single convoluted polypeptide chain some 300 angstrom units long. Apparently the helical secondary structure of the main chain is not uniform throughout, because the molecule's 152 amino acid units would form a chain only 228 angstroms long if they were coiled in the tight "alpha-helix" predicted by theory. The 300-angstrom length suggests that the chain is pulled out in some regions.

Kendrew determined the protein's structure by using an X-ray-diffraction method of Max F. Perutz, a colleague who has been working to determine the tertiary structure of the complex molecule of hemoglobin. Perutz's difficulties led Kendrew to focus on the simpler and much smaller molecule of myoglobin: an oxygen-binding protein found mainly in the muscles of birds or of whales. Kendrew attached atoms of metals with high electron-density (such as mercury, silver and gold) on the polypeptide chain and then bounced X-rays from them to make electron-density maps of the molecule. The maps





were combined mathematically in a digital computer to yield the geometry of the final model.

A Lively Moon?

The moon, long pictured as a cold, dead companion of the earth, may in reality have a hot interior and a shifting surface which periodically discharges gases.

At the annual meeting of the National Academy of Sciences in Washington, Dinsmore Alter, director emeritus of the Griffith Observatory in Los Angeles, reported that photographs of the moon made on October 26, 1956, with the 60-inch reflecting telescope on Mount Wilson revealed an "obscuration" over part of the crater Alphonsus. The Mount Wilson plates led a Soviet astronomer, Nikolai A. Kozyrev, to train the 50-inch Crimea Observatory reflector and a prism spectrograph on Alphonsus, and on November 3, 1958, Kozyrev obtained spectrograms confirming a discharge of gas from the crater. On the night of November 18-19, a cloud was seen over Alphonsus by astronomers and amateur observers in England, California and New Jersey.

The Alphonsus observations recall numerous reports by amateur astronomers during the past two centuries of changes in the lunar surface. Professionals have ignored all such claims since 1902, when Simon Newcomb described the moon with finality as "a world . . . on which nothing ever happens." A new theory, also presented at the National Academy meeting, not only suggests an explanation of the Alphonsus observations but also presents a new and radically different picture of the moon.

The theory was advanced by Harold C. Urey, Walter M. Elsasser and M. G. Rochester of the University of California. Its central feature is its rejection of the concept of a homogeneous moon with uniform internal density. Instead, Urey and his colleagues assert, the moon was formed from some tens or hundreds of thousands of accumulating masses of varying density. Since no melting occurred, heavier masses are distributed irregularly through the moon rather than concentrated at the center; and there are irregular variations in the moon's internal density.

The theory was developed in order to account for a troublesome irregularity in the shape of the moon, a projection of about a mile in the directions toward and away from the earth. Classical theory portrays the irregularity as a frozen tidal wave, an explanation requiring, according to Urey and his colleagues, a moon with great internal rigidity and improbably low internal temperature.

The irregularity is easily accounted for by the new theory. Moreover, the new hypothesis allows for "considerable" movement of the lunar surface and the escape of gas as a result of heating of the moon's interior.

Toward the Mohole

Late in May a flotilla of research vessels gathered in the Atlantic 200 miles north of Puerto Rico to carry out the first step toward transforming the Mohole [see "The Mohole," by Willard Bascom; SCIENTIFIC AMERICAN, April] from idea to reality. The flotilla met to examine a 200-by-150-mile rectangle of the ocean bottom as a possible site for the hole through the earth's crust to the mantle below.

Sponsors of the Mohole propose to drill in the open sea because the earth's crust is thinner beneath the sea than beneath the continents. The area now being surveyed is known as the Outer Ridge; it is a slight rise in the ocean floor from the abyssal plain east of the Bahamas. In the region of the Outer Ridge, which lies some 14,000 feet below the surface of the sea, the earth's crust is only three and a half miles thick. By contrast, in continental areas the Mohorovicic discontinuity—the boundary between the crust and the mantle—is 15 to 20 miles down.

Four ships are conducting the survey under the sponsorship of the AMSOC-Mohole Committee of the National Academy of Sciences. They are the *Vema,* from the Lamont Geological Observatory of Columbia University; the *Gibbs,* operated by Columbia's Hudson Laboratories for the Navy; the *Bear,* from the Woods Hole Oceanographic Institution; and the *Hidalgo* of the Texas Agricultural and Mechanical College. Coordinator of the survey is John E. Nafe of the Lamont Observatory, chief scientist aboard the *Vema.*

The four vessels are carrying out a variety of studies to determine whether the strata below the Outer Ridge are suitable for drilling. The program includes measurements of seismic refraction, gravity and ocean-floor heat-flow. In addition, cores will be taken from the bottom to determine whether fossil-bearing sediments are present. One of the chief objectives of the Mohole project is to find deep sedimentary layers with fossils from the first billion years of

DYNA-SOAR

Dyna-Soar (for dynamic soaring) is a joint project between the Air Force and the NASA, and is an attempt to solve the technical problems of manned flight in the sub-orbital regions. Advance knowledge on the project indicates how a boost-glide vehicle can operate from the outer fringes of the atmosphere where it can maneuver and be recovered undamaged. Studies show that by varying the original rocket boost, and thus the velocity, and with the control available to the pilot, the Dyna-Soar aircraft can circumnavigate the earth, followed by a normal and controlled landing. Boeing Airplane Company, one of the competing companies for the development contract for the complete boost-glide system, has delegated to RCA the responsibility for the development of important electronic components of Dyna-Soar.

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life, a period in evolutionary history that is now nearly a complete blank.

The survey will be completed by mid-June, but the results will not be known for several months. Drilling sites in the Pacific are also under consideration.

Porpoise Hydrodynamics

A secret well kept among porpoises is the way they manage to slide through the water at eight or 10 knots while hanging motionless in the bow wave of a ship. Certainly there is method in their motion, but what is the method? Writing in *Science*, P. F. Scholander of the Scripps Institution of Oceanography rejects one contemporary theory that explains the porpoise's movements in terms of gravity: When the porpoise exhales, the theory goes, it is heavier than water and can thus use its weight to slide down the slope of the wave. Scholander notes that, in a wave with a slope of 15 degrees, the forward component of the weight of a completely deflated porpoise would be only about one kilogram—barely enough to push the breathless animal along in smooth laminar flow, and not nearly enough to propel it through turbulently flowing water.

The porpoise's secret, says Scholander, lies in the tilt of its tail: It gets a forward push by leaning its tail fluke against the uprushing water of the wave. To measure this push quantitatively Scholander suspended a streamlined vane roughly the area of a porpoise's tail in the bow wave of a ship. A string made it possible to tilt the vane at various angles to the water rushing past it, and a lever attached to the vane indicated its drag in various positions. These measurements showed that the shear force of the bow wave at eight knots could impart a forward force of 18 or 20 kilograms to a porpoise that kept its tail properly down. Moreover, because the water rushes both upward and outward, the playful porpoise may roll over on its side—which many rail-hangers have seen them do—and still enjoy the effortless fluid drive. Scholander summarizes the significance of his hydrodynamic experiments by stating: "This, I believe, is the way dolphins [porpoises] ride the bow wave, and if it is not, they should try."

Colicine K

More than 30 years ago investigators in Europe turned up the fact that some strains of the ubiquitous colon bacillus (*Escherichia coli*) generate agents specifically and selectively toxic to other strains of the bacillus. Investigation over the years has yielded a total of 17 distinct colicines (as these agents are called), and has opened an intriguing area of research.

Colicines are elaborated by 20 to 25 per cent of the nearly 200 strains of *E. coli* that can be distinguished by antigen-antibody testing procedures. While mainly active against strains of *E. coli,* some colicines show activity against certain strains of Salmonella and other enteric bacteria. A puzzling relationship exists between the ability to generate colicines and resistance to bacteriophages, the viruses which infect bacteria. For example, *E. coli* mutants resistant to the phage T6 are frequently resistant to colicine K. No chemical relationship seems to exist, however, between colicine K and phage T6.

A clue to the nature of the mysterious colicines was reported to the meeting of the National Academy of Sciences. Colicine K is a part of the so-called O antigen, a complex, variable antigen found in *E. coli* and several other species of bacteria.

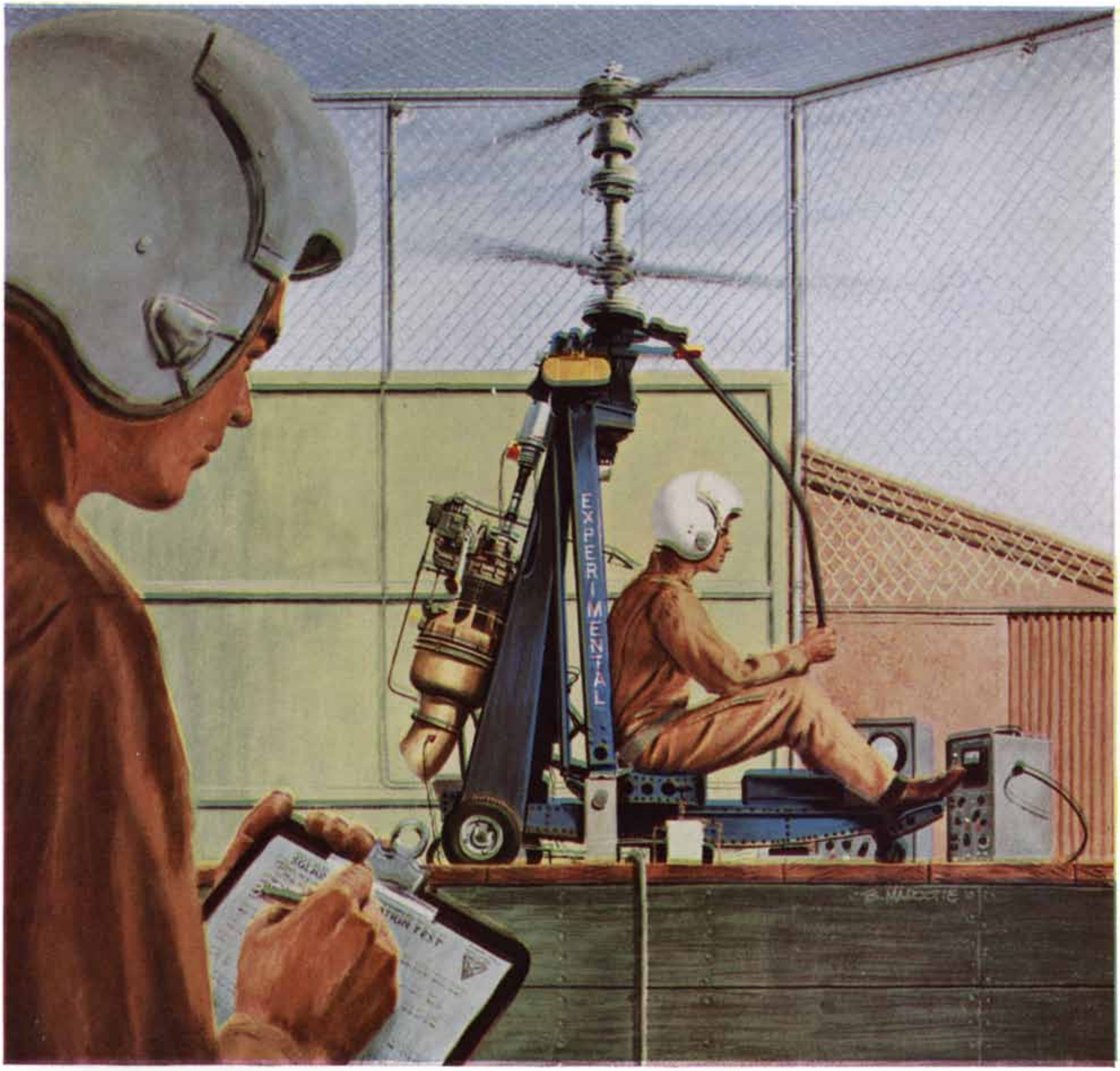
Walter F. Goebel of the Rockefeller Institute and Tsunehisa Amano of Osaka University obtained purified O antigen from a colicinogenic *E. coli* strain, K235, and also from a non-colicinogenic mutant of K235. Immunological tests showed the two O antigens to be identical in all respects save one. O antigen from the colicinogenic strain was highly toxic to certain *E. coli* strains that do not generate colicine K, whereas O antigen from the non-colicinogenic mutant was not. According to Goebel, the colicine-K property probably resides in the protein portion of the bactericidal O antigen.

For the present, research on colicines is of purely theoretical interest. Attempts to utilize O antigens during World War II for immunization against bacillary dysentery revealed that these antigens, when administered by injection, are highly toxic to many species, including man.

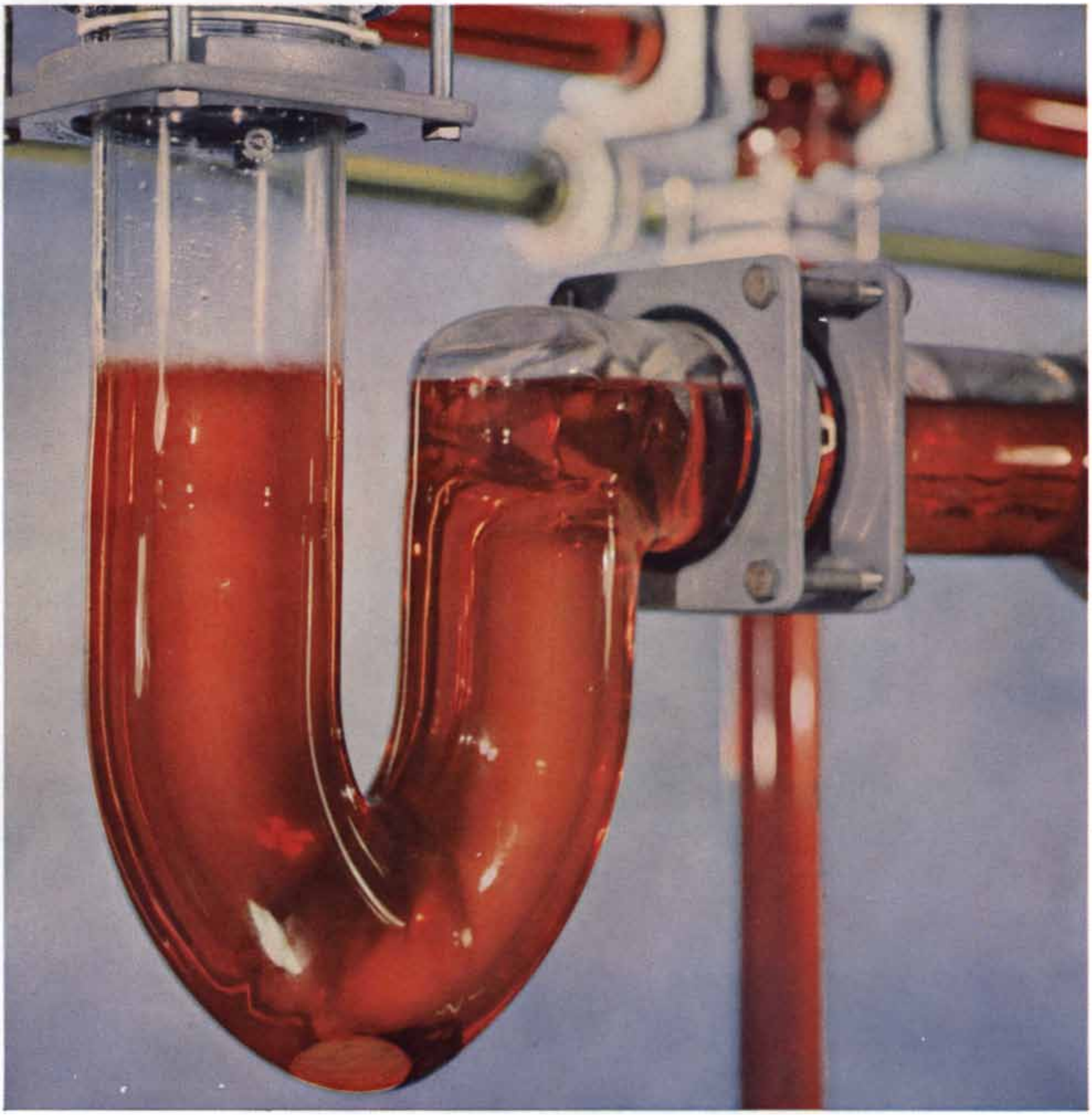
Space Menus

The problems of eating and drinking under weightless conditions in space, long a topic of speculation among science-fiction writers, are now under investigation in a flying laboratory. Preliminary results indicate that space travelers will drink from plastic squeeze bottles and that space cooks will specialize in semiliquid preparations resembling baby food.

Julian E. Ward, Willard R. Hawkins and Herbert Stallings of the U. S.



Test of Solar Titan *gas turbine engine in one-man helicopter.*



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CORNING GLASS WORKS
CORNING MEANS RESEARCH IN GLASS

CORNING CAN DO ALMOST ANYTHING WITH GLASS

Air Force School of Aviation Medicine have studied the experiences of 25 volunteers who attempted to eat and drink during "parabolic flights" in a jet fighter. (Parabolic flight temporarily balances centrifugal force against gravity to produce brief periods of weightlessness.)

According to a report in *The Journal of Aviation Medicine*, almost all the volunteers found that drinking from an open container was a frustrating and exceedingly messy process. Under weightless conditions even a slowly lifted glass of water was apt to project an amoeba-like mass of fluid onto the face. Drinking from a straw was hardly more satisfactory. Bubbles of air remained suspended in the weightless water, and the subjects ingested more air than water. Only the squeeze bottle provided a satisfactory means of conveying water to the mouth; sucking the water or squirting it as from a wine skin were equally effective.

The volunteers had no difficulty in swallowing water or semiliquid foods. Solid or semisolid foodstuffs, however, often tended to float upward into the nasal passages instead of downward into the stomach. Even liquids sometimes failed to stay down after being swallowed, especially following light pressure on the abdomen.

Heart-Lung Machines and Cancer

Heart-lung machines, originally developed to provide oxygenated blood for patients during heart surgery, have begun to find other applications. One of the most striking was reported at a recent American Cancer Society seminar. It is the use of the heart-lung apparatus to perfuse malignant tumors with blood "spiked" with doses of cancer-suppressing chemicals far more concentrated than could be administered to the patient as a whole.

The procedure was devised by Oscar Creech, Jr., of the Tulane University Medical School, but is also under investigation in other medical centers. Creech himself has employed it in 110 patients so far.

The technique is applicable only to cancers confined to one region of the body. Skillful surgery is required to single out and connect to the heart-lung machine blood vessels draining the cancer area, and to isolate the rest of the patient's circulation from the "spiked" blood. But it has proved possible to perfuse a surprisingly long list of organs. Perfusions of the leg, lung, breast, liver, colon, pelvis and brain have been carried out by Creech and other surgeons without dangerous leakage of anti-cancer chemicals to other parts of the patient's body. Patients have been perfused for up to an hour, and some of them have been perfused repeatedly without harm.

As yet, knowledge of the most effective drugs and dosages is limited. Nevertheless, perfusion has halted the progress of the disease for periods of up to two years in 32 of Creech's patients, all with advanced forms of cancer unmanageable by other means. Among the patients whose disease has been arrested are 19 with melanoma (of 31 melanoma patients treated altogether), ordinarily one of the most rapidly fatal types of cancer.

Atomic-Age Accident

It was a miniature nuclear explosion and one man died from it—that much was clear at the time. But exactly what caused the radiation burst at the Los Alamos Scientific Laboratory on December 30 was not clear until the inquiry report was published. In *Nucleonics* the investigating committee (headed by Hugh C. Paxton of Los Alamos) reconstructed the steps that led to the explosion.

At about 4:30 in the afternoon a technician peered through a viewing port at the plutonium solutions in a mixing vessel not much larger than a household hot-water tank. This tankful was a little different from the 75 other batches he had processed, because he had decided to handle two batches simultaneously, apparently to save time. The plutonium in the tank totaled 3.37 kilograms. He pressed the agitator switch and the solutions swirled together; there was a muffled roar and a blue flash—the telltale Cerenkov radiation from fissioning nuclei. Forty feet away another technician heard the explosion and saw its light reflected "like a photoflash" from the walls. He and another worker rushed to help the injured man, who ran from the tank shouting that he was "burning up," mistakenly believing that he had been burned by acid. Not realizing what had happened, his fellow-workers hurried him back past the radioactive tank to get him to a shower. Their efforts were worse than useless: the injured man was already past help, and in passing the tank his rescuers picked up significant radiation doses themselves.

Although the mild explosion did not rupture the tank and no solutions escaped, the burst's 10^{17} fissions raked the victim with radiation equivalent to 12,000 roentgens, 20 times the dose considered lethal to man. Within 15 minutes he had lapsed into deep shock; 36 hours later he died. The other two workers apparently suffered no serious ill-effects from the much smaller doses they had received.

It was the U. S. atomic-energy program's third fatal radiation accident. The previous fatalities, one in 1945 and one in 1946, also occurred at Los Alamos.

The Fainting Trumpeter

Professional trumpet players know that when they hold a loud high note for several bars they may grow dizzy or black out. The dizziness is caused by high air pressure within the chest which lowers the supply of blood to the brain. Small boys achieve the same effect by holding their breath while a friend squeezes them around the chest.

M. Faulkner, of the University of California at Santa Barbara, and E. P. Sharpey-Schafer, of St. Thomas's Hospital in London, recently set out to measure the pressures produced by blowing the trumpet and other wind instruments. Their subjects, as described in the *British Medical Journal,* were a surgeon once associated with a University of Cambridge dance band, "a novice . . . who purports to be learning the oboe," and Faulkner himself, who plays and teaches the trumpet professionally.

The two investigators report that a professional trumpet player hitting high D reaches a mouth pressure of 160 millimeters of mercury (a little more than three pounds per square inch). Neither of the two nonprofessionals could reach either high D or 160 millimeters. The oboist achieved only 60 millimeters during loud, high notes on his own instrument; comparable notes on the French horn required even lower pressures.

Faulkner and Sharpey-Schafer note that many leading orchestras ease the strain on the first trumpeter by employing an assistant or "mate" who can take over during long, difficult passages such as are frequent in the music of Richard Wagner. In theory, orchestras desiring to economize could dispense with the mate by having the trumpeter lie supine on the floor, thereby increasing the blood supply to his brain. It would be equally effective, the two investigators state, to dress the trumpeter in a high-altitude pilot's pressure suit "which could be surreptitiously inflated by a switch on the conductor's desk" at appropriate points in the score.

A scientific computer makes economic news!

Honeywell 800 costs thousands less than any other high-speed computer

New, all-transistorized Honeywell 800 matches the practical speed and performance of its fastest competition in the scientific field—yet costs at least one third less. Medium-scale in size (and price), Honeywell 800 can tackle and solve with ease scientific problems that would stretch the capabilities of some of the most expensive computers now on the market. New, exclusive features of design and logic equip Honeywell 800 to handle scientific computation with unparalleled economy—a vital consideration as research directors everywhere count engineering costs more closely.

High Internal Operating Speeds

Honeywell 800 gives you an internal operating speed of 30,000 three-address operations per second, the equivalent of 70,000 single-address operations as performed by conventional computers. Honeywell 800 can invert an 80 by 80 symmetric matrix in 75 seconds — or fit 100 points with a 10th degree polynomial curve in *one* second. The trajectory of an artillery shell can be determined in 1/30th the time it takes the shell to describe it.

Expandable Memory

The high-speed magnetic core memory of Honeywell 800 is available in modules of 4,096 words, up to a practical maximum of 4 modules (16,384). Of course, if your scientific problems demand an even greater capacity, upward adjustments can be made. And remember — the memory capacity of Honeywell 800 is expressed in 48-bit words, which are half again as long as those of most other systems.

Also available are magnetic tape units capable of operating at a peak rate equivalent to 112,000 decimal digits per second. With such high speed you can now invert large matrices or solve large linear programming problems — fast and efficiently — without the expense of a huge memory.

Both Decimal and Binary Floating Point

Honeywell 800's exclusive ability to work in either decimal or binary, fixed or floating point arithmetic enables you to choose the form most convenient to your purposes.

Longer Words Speed Problem Solutions

The greater length of the Honeywell 800 word permits the System to utilize single-precision arithmetic when other computers would be forced to slow down for double precision.

The floating decimal word in Honeywell 800 has a range of 63 digits before the decimal point to 64 zeroes plus 10 digits after it. This sharply reduces the overflow or underflow which complicates programming on other computers. Also, the mantissa (base number) has 10 digits, minimizing the need for drawn-out, multiple-precision computation.

The floating binary word provides even greater range and precision. Numbers may range from the equivalent of 75 decimal places before the decimal point to 76 zeroes and 12 decimal digits after it. The mantissa has 40 binary places, the equivalent of 12 decimal digits.

Maximum Flexibility in Programming Structure

As you would expect from the company "First in Control," Honeywell engineers and scientists have designed Honeywell 800 to give the programmer much greater control, freedom and flexibility in handling scientific computations. Besides three-address instructions, greater word length and the option to work in binary or decimal, floating or fixed-point arithmetic, Honeywell 800 offers the programmer several other major advantages in flexibility.

Indexing (64 index registers) reduces the number of orders required in inductive programming, hence steps up computing speed and conserves memory space. *Word Masking* adds the flexibility of variable-length words to the speed and efficiency of fixed-length words. *Indirect Addressing* enables you to perform such functions as a table look-up or an interchange of rows and columns of a matrix with a single instruction. Honeywell 800's exclusive *Bi-Sequence Operation Mode* gives you the flexibility to depart from the basic program sequence and return to the proper point — without writing special instructions.

Full Complement of Input-Output Devices

In addition to magnetic tape, Honeywell 800 features a full range of standard and high-speed input-output devices in both on-line and off-line models. These include keyboard, paper-tape, punched card and printing devices. Buffering, input-output trunks and internal control have also been designed to simplify the addition of special purpose equipment.

No other system can be adapted so closely to your immediate and specific requirements, or be expanded so easily and economically as those requirements grow.

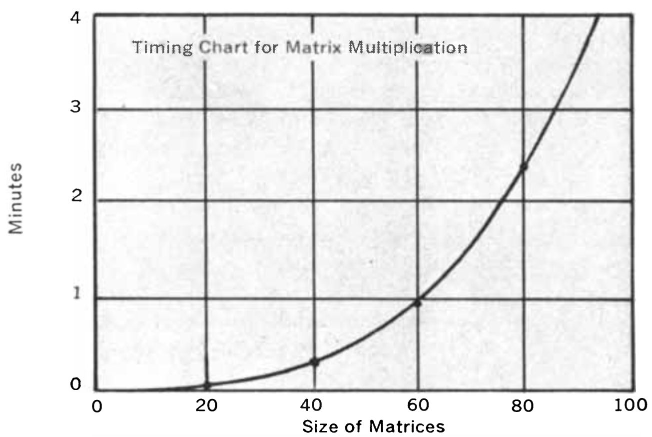
Automatic Error Correction

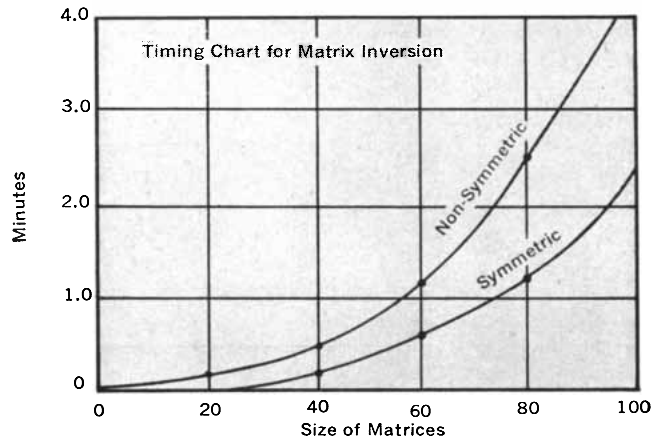
Completely self-checked internally and externally, Honeywell 800 offers you still more: *Orthotronic Control.* This exclusive means of tape error correction has economically raised the reliability level of Honeywell 800 far beyond the reach of any other computer.

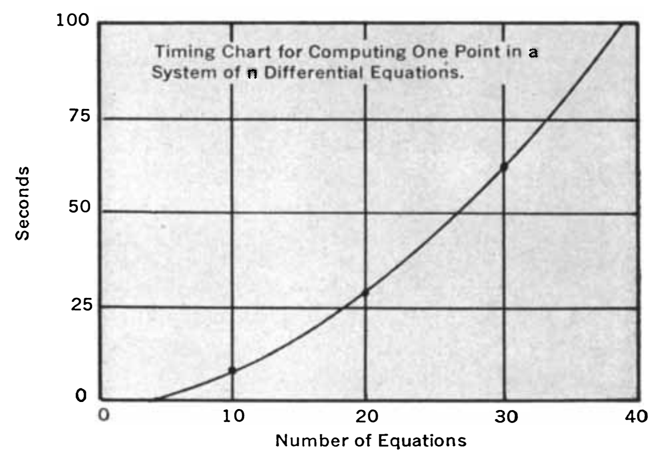
With Honeywell 800 you could easily expect to perform — without interruption — a matrix inversion requiring 1½ days of computer operation. Orthotronic Control is another reason why Honeywell 800 can introduce new economy to scientific computation.

Data Processing Goes On Simultaneously

Honeywell 800's much-heralded principle of Automatically Controlled Parallel Processing enables this System to process business data *at the same time* scientific problems are being solved. Several different and independently programmed jobs can be processed simultaneously —business, scientific or both. Even a minimum use of parallel processing insures your company of operating efficiency and economy that no other system can approach.







AUTOMATIC PROGRAMMING AND LIBRARY ROUTINES CUT COSTS OF PROBLEM PREPARATION

Automatic programming aids and library routines currently in preparation include the following:

Algebraic Compiler

The Honeywell 800 Algebraic Compiler utilizes the same scientific language used on several other popular computers. The subroutine library consists of routines commonly used in solving scientific problems. Thus, existing programs written in this language can be run on Honeywell 800. Because of the speed and efficiency of Honeywell 800, some of these programs will be processed faster than on the system for which they were written.

Assembly Program

The Honeywell 800 Assembly Program assists the programmer by providing automatic translation from simple pseudo codes to machine language, assigning memory addresses to symbolic tags — assembling various routines comprising the program, and various housekeeping functions associated with program preparation. The job of writing programs is greatly simplified, costs are reduced and accuracy in program preparation is increased.

Automatic Problem Checkout

The Honeywell 800 Automatic Problem Checkout is a set of routines designed to provide the programmer with a complete evaluation of his program under operating conditions. Errors are located more quickly, changes made more easily, machine time for checking purposes is minimized and program management is made more workable and predictable.

Scientific Routines

An expandable library of Honeywell 800 scientific routines is being made available for computations involving trigonometric functions, matrix multiplication, matrix inversion, interpolation, curve fitting, ordinary differential equations, and linear programming.

Data Processing Compiler

The Honeywell 800 Data Processing Compiler simplifies problem preparation and coding and provides for convenient utilization of pre-tested library routines. The programmer prepares his problem in easily-learned business-language codes, which are then automatically translated into machine language by the translator. Individual routines, whether prepared or extracted from the library, are compiled into a complete program at machine speeds. Provision for expanding, modifying and maintaining the subroutine library are included in the Honeywell 800 Data Processing Compiler.

In addition, generator routines for input and output editing and sorting further reduce programming costs.

"*Honeywell 800, a Superior Scientific Computer*" is a booklet containing full details and specifications of this new and exciting *economic* approach to complex scientific computation. To get your copy, just write Minneapolis-Honeywell, DATAmatic Division, Dept. S1, Newton Highlands 61, Massachusetts.

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ELECTRONIC DATA PROCESSING

BEER

Man has made this exquisite beverage for 6,000 years, but it is only in the past century that he has begun to understand the subtle enzyme chemistry and microbiology of the process

by Anthony H. Rose

Any solution of the sugary substances of grains, if permitted to stand, will soon become infected by microorganisms. With a little care, the fermentation process that follows can be made to yield a potable, mildly alcoholic beverage. Men have made this discovery wherever they have cultivated grains. Archaeological evidence shows that brewing had developed into a serious art as long as 6,000 years ago in the valley of the Nile. The peoples of the Orient long ago learned to brew sake and related beverages from rice. In the New World, in 1502, Columbus was presented with "a sort of wine made from maize, resembling English beer."

What we call beer—the brew of barley malt flavored with the bitter essences of the hop flower—has been the folk beverage of northern Europe from earliest times. In the monasteries of medieval Europe brewing was as widely practiced as baking. The monastic imprint is seen today in the symbols of quality XX and XXX; in Bavaria one nunnery still has a sister brewmistress! But beer was also one of the first commodities to be industrialized. By the middle of the 17th century such great brewing centers as Oxford, Burton-on-Trent and Munich were already establishing their reputations. It fell to Charles I of England to recognize beer as a source of tax revenue; he imposed the first beer duty in 1643. Brewed and consumed in increasing quantity throughout the 18th and 19th centuries, beer became a major source of nourishment, refreshment and solace to the peoples of Western civilization. In the words of A. E. Housman, "Malt does more than Milton can,/To justify God's ways to man." Today the Belgians, consuming 31 gallons per capita per year, lead the beer drinkers of the world; the U. S. ranks about sixth.

While brewing has not lacked for esthetic appreciation throughout its long history, it is only recently that we have begun to understand what a remarkable art it really is. Now that we know a little microbiology and biochemistry we can see that the brewmaster, by trial and error, has been manipulating some of the subtlest processes of life. To scientific studies we owe many improvements in brewing technology, especially under the heading of quality control. But in some ways the debt runs more heavily the other way. A study of the diseases of beer led Louis Pasteur to discover that yeasts bring about the desired fermentation to alcohol, and that "sickness" in beer is caused by bacteria that yield lactic acid, acetic acid or other unwanted end-products. This discovery not only laid the foundations of the scientific approach to brewing but also helped to open up the whole field of microbiology. The problems of brewing technology played a similar role in the birth of biochemistry. When the German brothers Eduard and Hans Buchner showed in 1897 that cell-free extracts of yeast could cause fermentation of sugar, they exploded once and for all the cherished notions of "vitalism." Their discovery opened the way for all subsequent work on the chemistry of life. As a result of two generations of scientific investigation, the ancient lore of brewing is now enriched by knowledge that has relevance to the enjoyment as well as to the brewing of beer.

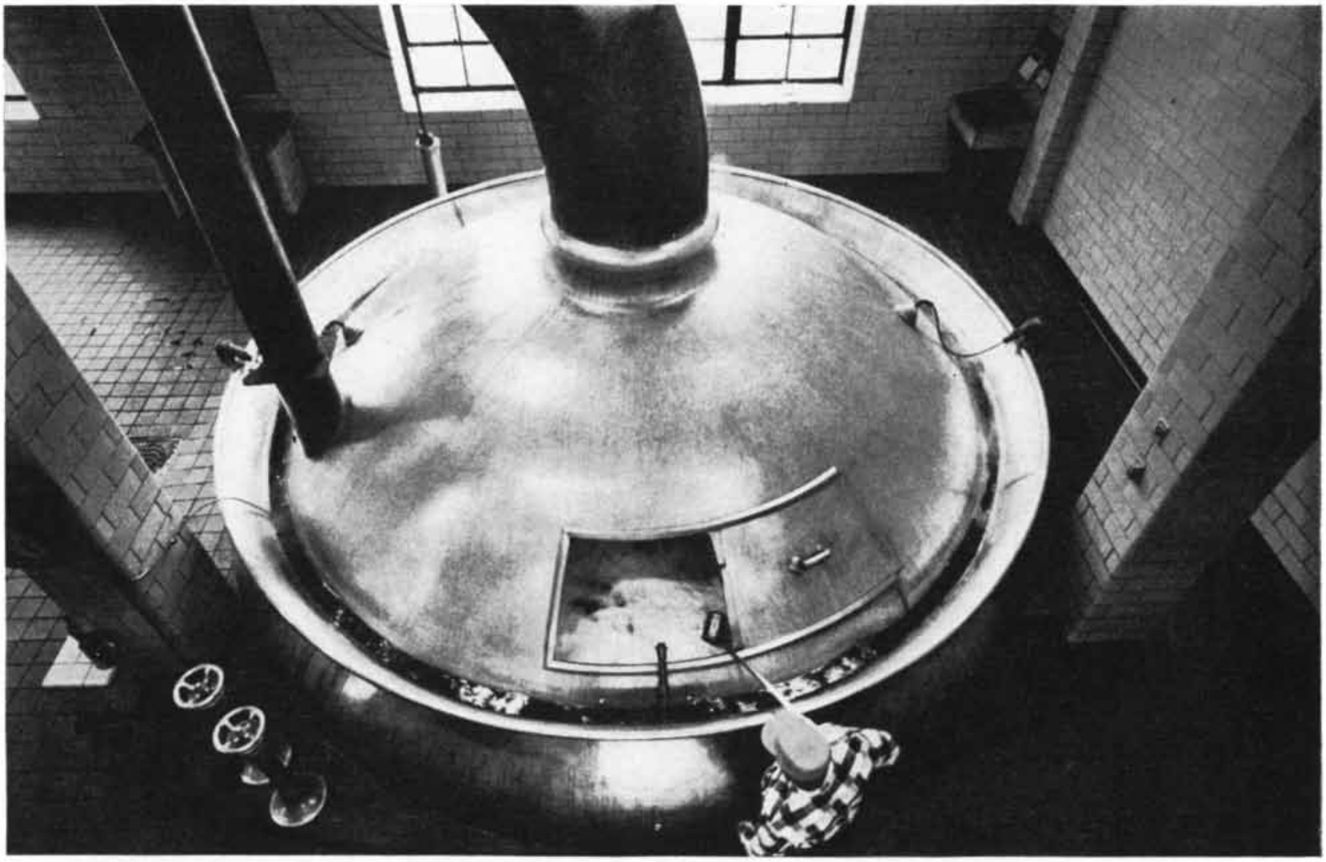
The Barley Corn

The key step in the brewing process is of course the addition of yeast to the brew; the yeast ferments or breaks down certain of the grain sugars to alcohol and carbon dioxide, producing "young" or "green" beer. This step, however, comes only as the climax to a whole series of operations that play a decisive part in determining the ultimate taste, aroma and appearance of beer. Of the first importance is the character of the grain from which beer is made. The word "beer" comes from the Saxon word for barley: *baere*. Barley was one of the most important cereals in the early civilizations. Even when barley was displaced by wheat as a raw material for baking, it retained its pre-eminence in brewing.

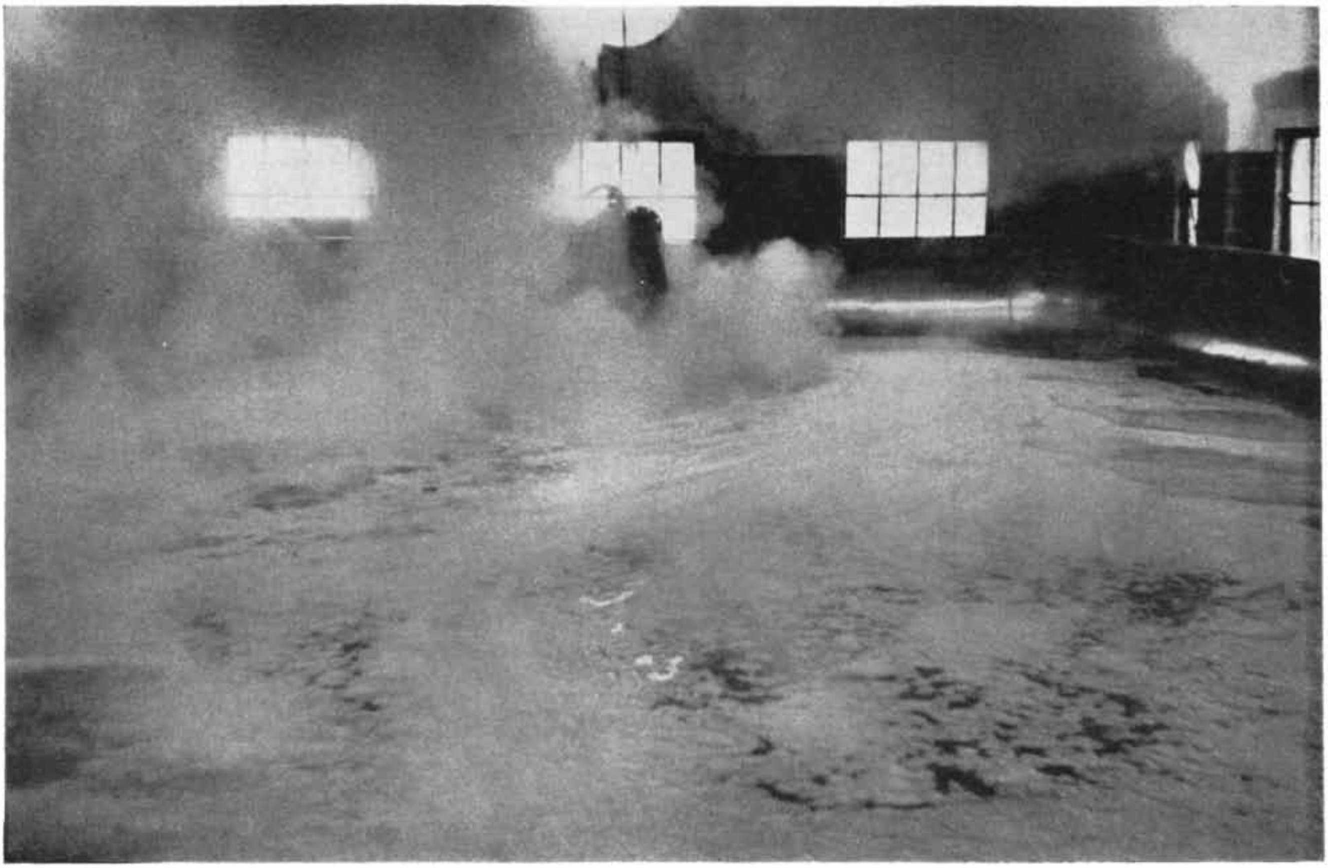
The barley corn or seed is a spindle-shaped structure. If we remove the protective husk of the corn, we see the tiny embryo of the plant and the relatively large mass of endosperm tissue, which consists mainly of food reserves that support the germination of the embryo. It is the food reserves, in particular the polysaccharide constituents, that are important to the brewer. These polysaccharides are large molecules made up of smaller sugar units such as glucose and maltose.

Now if brewer's yeast is merely added to a suspension of ground raw barley corns in water, no fermentation occurs. The yeast cannot convert the barley polysaccharides directly into alcohol and carbon dioxide; it can only act upon the simple sugars from which the polysaccharides are formed. The polysaccharides must therefore be hydrolyzed (broken down with the addition of water) to their component sugars. This could be accomplished quite simply by cooking the grain with a dilute mineral acid, but since the object is to produce a palatable beverage, such a procedure is far too drastic. The brewer employs a much gentler process.

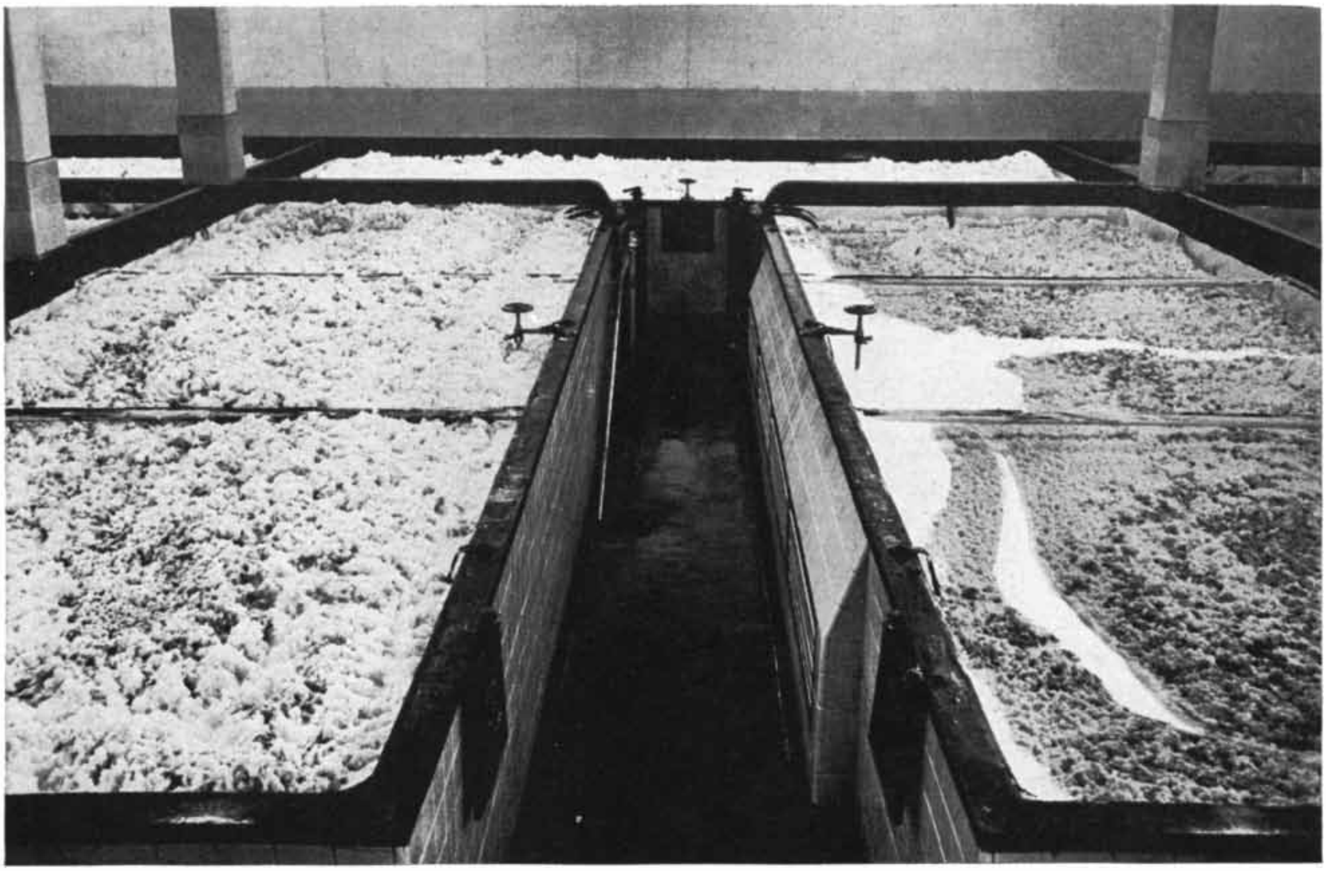
It happens that the polysaccharides must be broken down in the process of



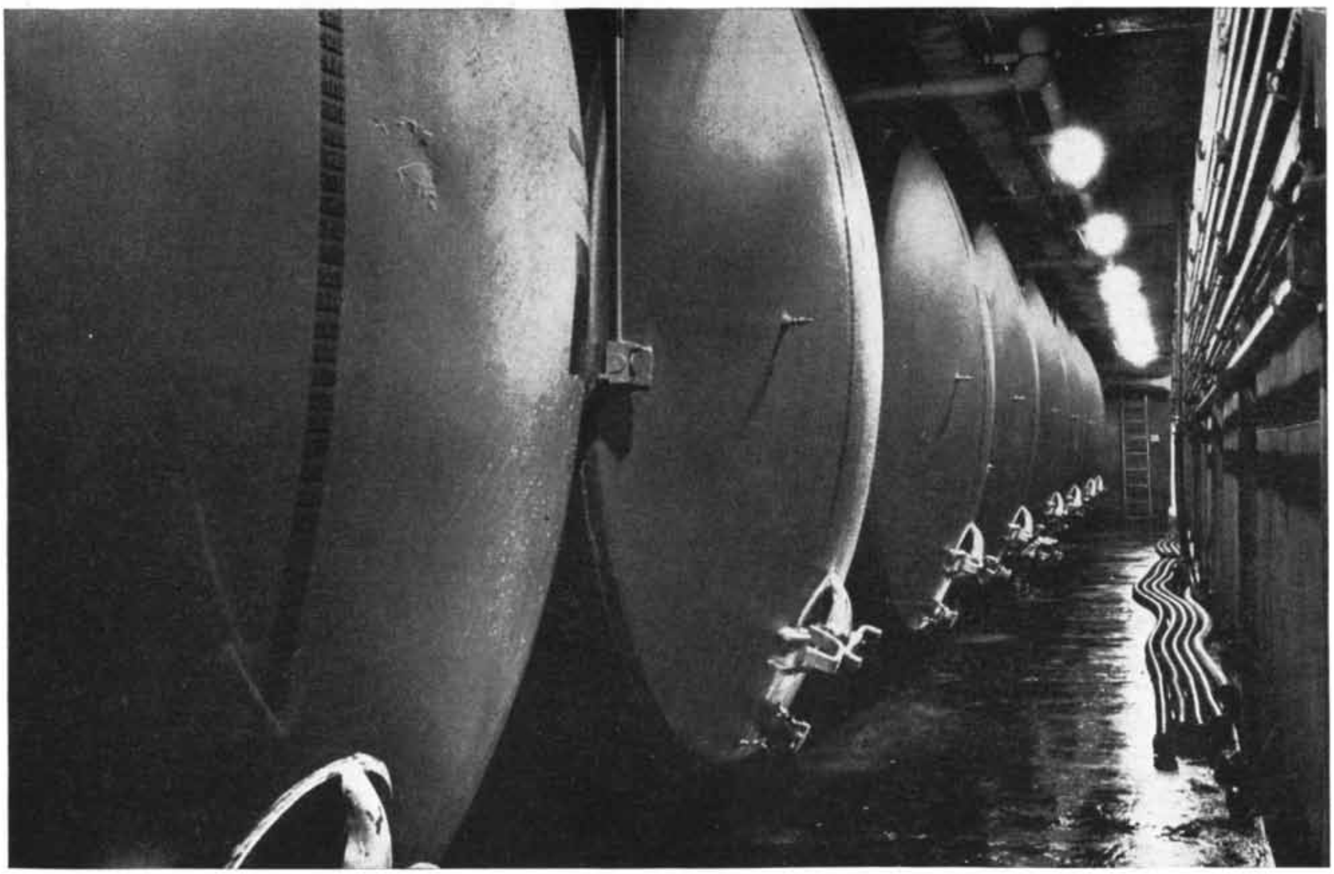
BREW KETTLE in a New York brewery is filled with malt wort produced by allowing the enzymes of barley corns to digest the protein and starch of the barley and of "adjuncts." Here the wort is boiled to destroy the enzymes. Hops are added by the man at bottom.



SETTLING TANK is where the wort cools and solids settle out of it after it has left the brew kettle. The wort is now further cooled and sent to the fermenting tanks (*see illustration at top of next page*). The entire process is outlined on pages 94 and 95.



OPEN FERMENTING TANK is where yeast is added to the wort, which has been filtered of its hops and cooled. The yeast enzymes now ferment the wort sugars to alcohol. Here the yeast sinks to the bottom of the tank; on the top is a foam caused by fermentation.



LAGER TANKS are where the "green" beer is aged for several weeks at 32 degrees F. The beer is then filtered to remove traces of yeast and a suspension of protein that is precipitated by chilling. Finally the beer is carbonated and bottled, canned or barreled.

germination in order to supply the sprouting embryo with the simpler sugar units it requires for growth. This breakdown is brought about by the action of certain enzymes that are manufactured inside the grain, several different enzyme systems taking part in the breakdown of various endosperm constituents. The most important of these are the amylases, which hydrolyze the polysaccharides. But barley also contains proteins, and these large molecules are also broken down into their component peptides and amino acids. The brewers of old learned to prepare the grain for fermentation by utilizing this elegant built-in enzymic apparatus, even though they could hardly have suspected how it works.

The first step in brewing, then, is to germinate the barley. In this "malting" process the grain is steeped in water and then transferred to aerated chambers or slowly revolving drums in which careful control of temperature, moisture and oxygen promotes uniform germination. When the desired stage of growth has been reached, gentle heating brings germination to a halt, with temperature again carefully controlled to minimize the damage to heat-sensitive enzymes Prolonged heating produces a darker grain, sometimes employed in the brewing of darker beers. At this point, however, only a small proportion of the endosperm polysaccharides has been broken down. The object in malting is not to get the hydrolysis well under way, but simply to allow the grain to manufacture all of the necessary enzymes. Malting is predominantly a mobilizing or "tooling-up" process. Nowadays, in fact, malting is not strictly a part of the brewer's operations; it is carried out by maltsters, who then deliver prepared malt to the brewery.

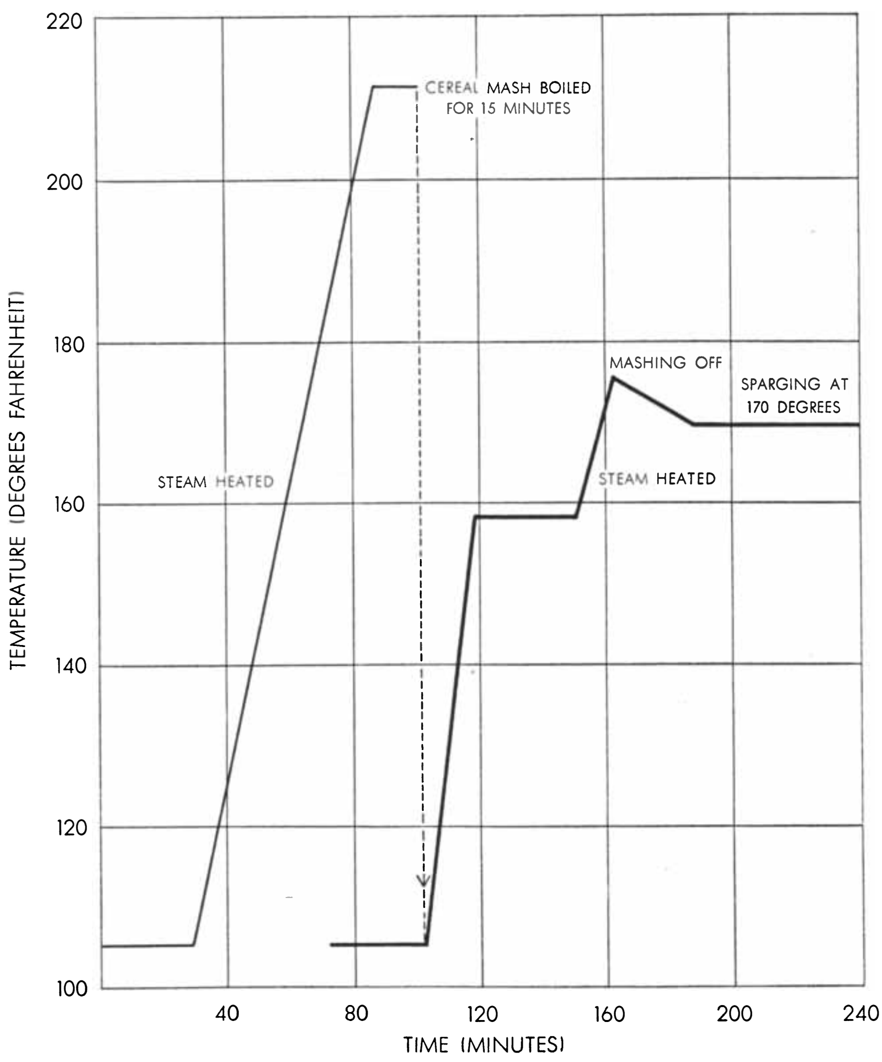
The Mashing Process

The brewing process proper begins with "mashing": Ground malt is mixed with hot water, and permitted to stand for a short time. Now the malt enzymes go to work, and the breakdown of the polysaccharides begins. Since the enzymic capacity of the malt far exceeds that required to break down all of the endosperm starch, other starchy materials are added to the mash. These "adjuncts" increase the volume of fermentable sugars but contribute little if anything to the taste and aroma of the beer. As the enzymes digest the starch and proteins of the malt, the breakdown products—sugars, peptides and amino acids—dissolve and diffuse into the water to make sweet malt "wort," the liquor that the yeast is later to ferment.

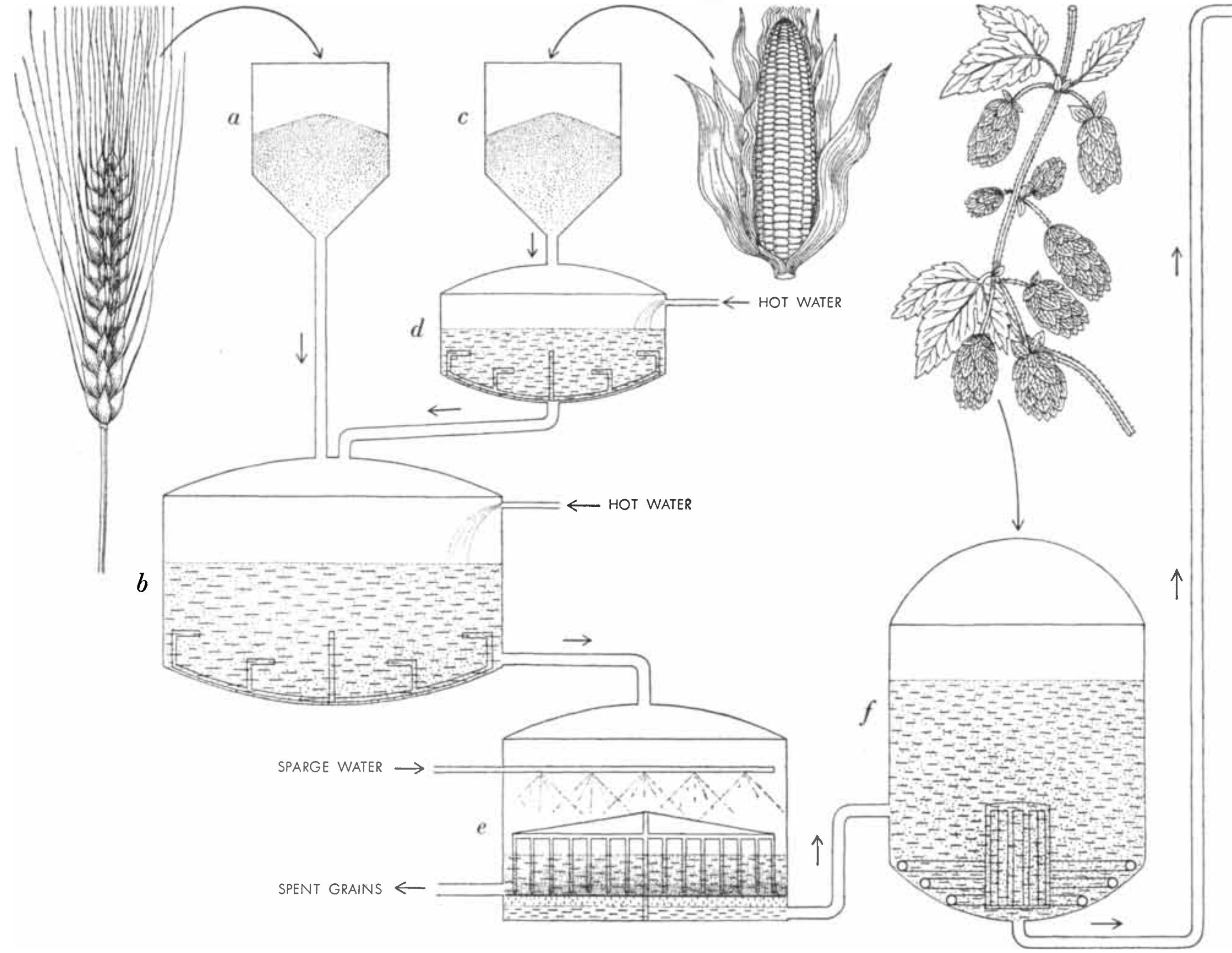
Generations of brewmasters learned empirically to subject the mashing process to precise control by the regulation of temperature, the temperature cycle being designed in each case to yield the sugar content and other qualities in the wort called for by the type of beer being brewed. Usually the malt is first mixed with water at a temperature of 105 degrees Fahrenheit, and is kept at this temperature for an initial "resting" period of 30 minutes. Meanwhile, in a separate mash tub, the cereal adjuncts are infused with water at the same temperature and brought gradually to a boil. When the contents of this tub have been cooked to a gelatinous texture, they are added to the malt mash, resulting in a final mixing temperature of some 157 degrees F. After being maintained at about this temperature for another half hour, the mixture is "mashed off" or stabilized by heating it up to 175 degrees, a temperature that destroys most of the enzymes.

Today we can explain the importance of temperature control during mashing because we have made the acquaintance of the principal enzymic actors in the process. Each of these enzymes functions best in a characteristic range of temperature. During the resting period, when the temperature is held at 105 degrees, the protein-decomposing enzymes find the environment most congenial. The peptides and amino acids produced by the breakdown of proteins do not contribute directly to the production of alcohol; however, they provide essential food substances for the yeast and give the beer body as well as head-retaining properties. Thus it is important that just the right amount of protein should be broken down in the mashing process.

As the mash is heated up by the addi-



TEMPERATURE of cereal-mash adjuncts (*curve at left*) and malt (*curve at right*) is plotted against time. The malt is heated largely by the addition (*broken line*) of the adjuncts.



ENTIRE BREWING PROCESS is outlined in this flow chart. The barley corns are ground and placed in the malt hopper (*a*); from thence they go to the mash tub (*b*). Corn (or other adjuncts) is placed in the adjunct hopper (*c*), boiled in the adjunct cooker (*d*) and added to the mash. The malt wort is then filtered in the lauter tub (*e*). The clear wort goes to the brew kettle (*f*), where hops

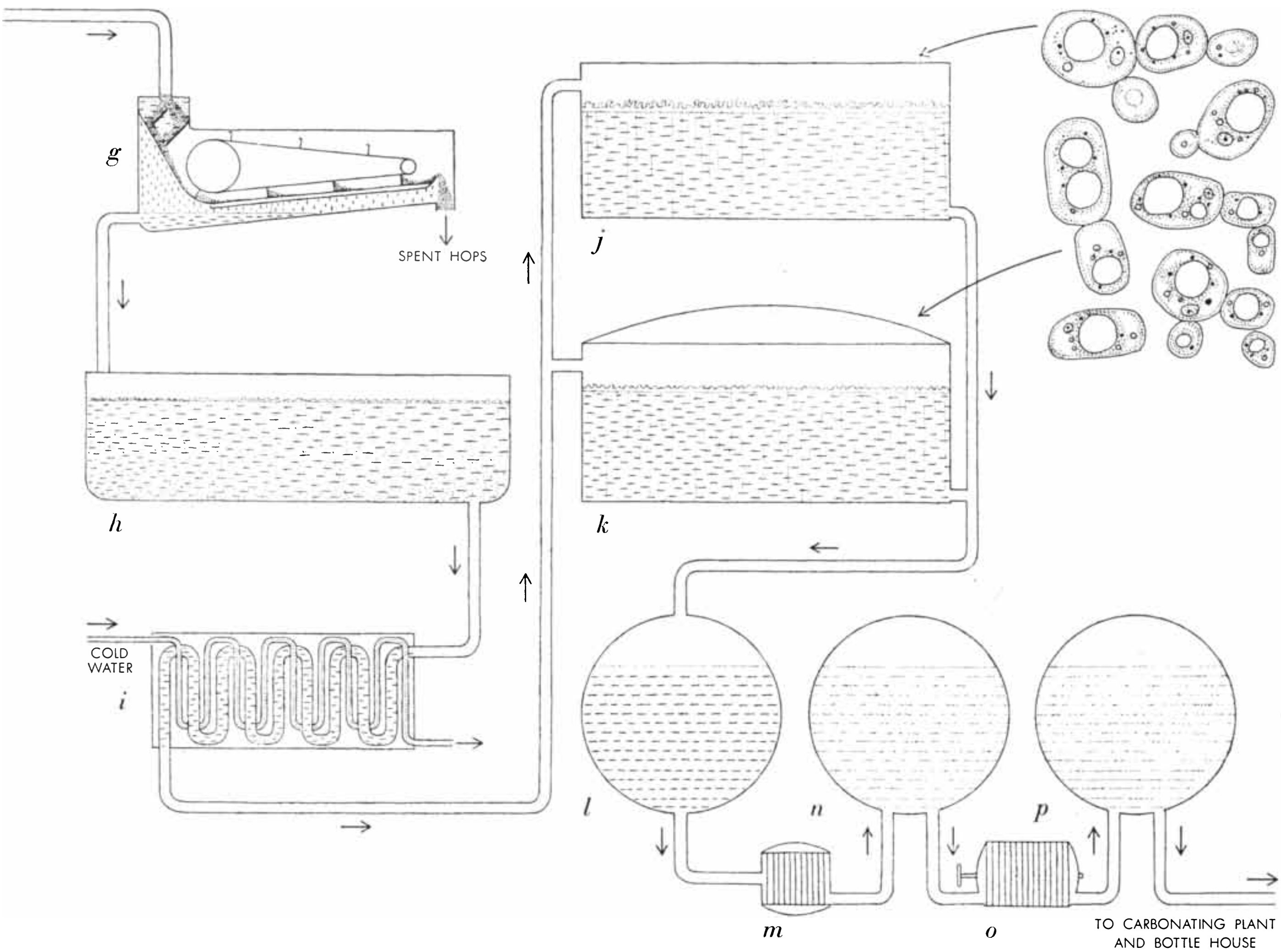
tion of the adjunct mixture, the starch-digesting enzymes—the amylases—come into play. Starch is not a simple polysaccharide, but consists of a mixture of two glucose polymers: amylose, made up of straight chains of glucose units, and amylopectin, made up of branched chains. Moreover, there are at least two distinct starch-hydrolyzing enzymes in malt: alpha- and beta-amylase. The unbranched amylose chains are broken down by beta-amylase, which chops off the glucose units two at a time to give the disaccharide maltose. Theoretically beta-amylase can break down the amylose completely; in practice the reaction is inhibited by the accumulation of breakdown products. But beta-amylase cannot completely break down the amylopectin molecule, because its action is halted at points where the chain branches. The other enzyme, alpha-amylase, makes up for this deficiency; it is able to split the branched chains into smaller fragments and thus provide additional straight chains that can be nibbled away by the beta-amylase. The beta enzyme prefers temperatures in the region of 140 degrees F., while the alpha enzyme acts most efficiently at the slightly higher temperature of 150 to 170 degrees. Thus the relative proportions of alpha- and beta-amylase activity can be controlled by the temperature of the mash and by the profile of the curve on which the temperature is shifted.

Higher temperatures will tend to promote alpha action and discourage beta, and will thus result in a smaller proportion of fermentable sugars. Worts of this type have a correspondingly higher proportion of dextrins (short units, both branched and unbranched), which cannot be fermented by brewer's yeast but which contribute to the character and body of the beer and help to maintain a stable foam. Brewers use worts of this type to brew beers with a low content of alcohol. Thus careful control of temperature during mashing has always given the brewmaster an opportunity to exercise his skill. Only recently have we come to realize that he is in fact the choreographer of an enzymic ballet.

After mashing off, the contents of the tub are transferred to the "lauter" tub (*lauter* in German means "clear"). This is a cylindrical tank having a false bottom of slotted plates, through which the clear malt wort is run off, the cereal husks forming an ideal filter bed. The husks are further "sparged," or leached with hot water to augment the volume of wort extracted. At this point the brewing process yields a valuable by-product in the form of the spent grains, which make excellent cattle feed.

The Addition of Hops

The clear malt wort is now run into a steam-heated copper or stainless-steel brew kettle, in which it is boiled for 30 to 60 minutes. In the process any remaining enzymes are destroyed, and the



are added. The hops are removed by the hop strainer (g); other substances, by a settling tank (h). The wort is now cooled (i) and sent to open (j) and closed (k) fermenting tanks. In the closed tank carbon dioxide is collected and later used to carbonate the beer. After fermentation the green beer goes to lagering tanks (l, n and p). As it passes from one tank to next it is filtered (m and o).

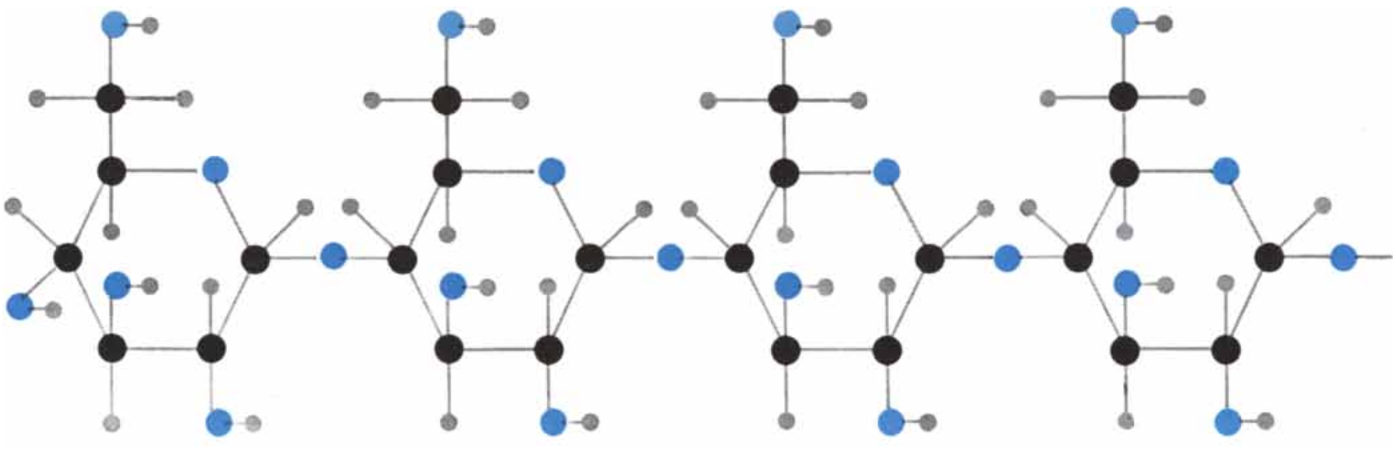
wort is sterilized and somewhat concentrated. More important, dried hops are added to the boiling wort in amounts and at intervals that vary with the type of beer. German beers and the U. S. beers that are modeled on them are usually hopped at the rate of about half a pound for each barrel, but for the English ales the rate is much higher, in some cases as high as a pound and a half per barrel. Hops are added primarily to impart the characteristic aroma and pleasant bitterness of beer. Although hops are now universally used for this purpose, it is interesting to note that prior to the 17th century mixtures of various herbs were commonly employed to flavor beer. Thus in Thomas Tryon's *A New Art of Brewing Beer, Ale and Other Sorts of Liquors*, published in 1691, we read: "Here give me leave to tell you that there are a great number of brave Herbs and Vegitations that will do the business in brewing as well as Hops. . . . Penny Royal and Balsam . . . are of excellent use in Beer and Ale: the like is to be understood of Mint, Tansie, Wormwood, Betony . . . and good Hay." The hops of brewing are the cone-shaped flowers of the female hop plant, each cone consisting of a spindle with between 50 and 100 petals. The hop flowers are picked when ripe, and are dried and pressed before being shipped to the brewery. A century ago most of the hops in the U. S. came from New York and Vermont; the principal hop-producing areas are now along the Pacific coast and in Idaho.

Boiling in the brew kettle extracts from the hops a variety of substances. These include oils and complex bittering substances such as humulone, cohumulone and adhumulone, all of which contribute to the flavor and aroma of beer. Antiseptic substances are also extracted; these help to prevent microbial spoilage in the finished beer. In addition, the hops contribute tannins. These are of special importance in the brewing process, for they combine with the protein in wort to form an insoluble sludge that settles to the bottom of the brew kettle. If the protein is allowed to remain in the wort, it tends to precipitate later as a haze in the beer, a considerable hazard to consumer acceptance.

After boiling, the hops are strained off and the wort is cooled to 45 or 50 degrees F. Cooling throws down a further deposit of protein-tannin sludge, which is filtered off. Just before the cool wort is transferred to the fermentation tank, it is aerated with sterile air to make it more hospitable to the yeast that is to be planted in it.

Top- and Bottom-Fermentation

Here we come to one of the major differences between British and Continental practice. It is this difference that occasions so much confusion among U. S. consumers, who enjoy the privilege of choice between the products of both types of brewing. The distinction arises



STARCH of malt is a polymer of glucose, that is, a repeating chain of glucose units. A single glucose unit is shown to the right of the broken line, which indicates that the chain is repeated. The black balls represent carbon atoms; the gray balls, hydrogen atoms; the colored balls, oxygen atoms. Starch is actually a mixture of two glucose polymers: amylose, consisting of a straight chain of

from the behavior of the yeast during fermentation. In Britain brewers still employ types of yeast that rise to the surface during fermentation. The "top-fermentation" beers come in many varieties, from relatively pale ales to porter (a dark, heavy ale popular in Ireland) and stout (also dark and heavy, but with a higher alcoholic content). In the U. S. top-fermentation and a taste for ales arrived on the *Mayflower*. The Pilgrims recorded that they landed at Plymouth with misgivings and were forced to settle on that forbidding shore because they had drunk all their beer. But they had brought their yeast balm, and ales are still preferred in New England.

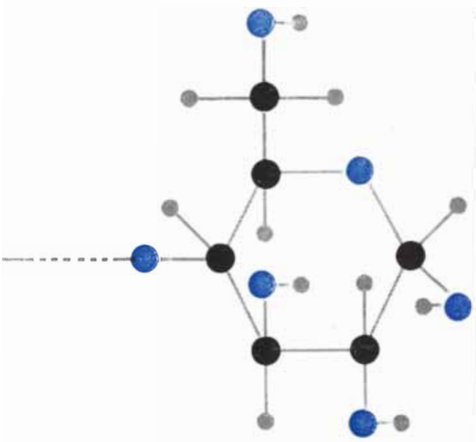
Elsewhere in the U. S. the brewing industry derives its traditions from the brewmasters who came from Germany in the 19th century to set up large commercial breweries. The Germans brought the new technique of "bottom-fermentation," which, as the term indicates, employs a yeast that settles to the bottom during fermentation. The German "lager" beers are usually paler than ales, and are rather more mellow in flavor. There are three main types: Münchner, Dortmunder and Pilsener, named after the towns in which they were first brewed and here listed in order of their color from dark to pale. Under the pressures of standardization arising from mass distribution U. S. beers have tended to become increasingly pale and thus to resemble the Pilsener beer; they have less hop flavor, however, and are much more highly carbonated. A seasonal exception to this trend is bock beer, the dark, full-flavored beer that certain U. S. brewers still put on the market in the spring. Originally brewed in Bavaria during the Easter celebrations, bock beer gets its name from the German word for goat, which animal is the zodiacal sign for the month of March.

Whether top- or bottom-fermentation is used, about one pound of yeast slurry is "pitched" into the tank for each barrel of beer. Malt wort furnishes an ideal diet for yeast; during the fermentation period of six to nine days the organisms not only multiply about threefold but also break down a large proportion of the sugars in the wort to alcohol and carbon dioxide. The concentration of alcohol at the end of the process is about 4 per cent in lager beers and somewhat higher in ales. Thanks to investigations founded by the Buchner brothers, we now know of the dozen or so enzyme reactions involved in the fermentation of sugar to alcohol. Some of the energy that is produced is utilized for growth, but by far the greater part of it escapes as heat. To keep the fermenting brew at the optimum temperature (55 degrees F. for lager beers and 60 to 65 degrees for British ales) the fermentation tank must be refrigerated. Before the advent of mechanical refrigeration, beer was commonly fermented in caves or underground cellars; the fermentation section of a brewery is still quite often referred to as the "cellar." In addition to fermenting the sugar, yeast also brings about a host of other changes in the chemical composition of the wort; very little is known, however, of the nature of many of these changes.

The Yeast Organism

Most of the bottom-fermentation yeasts used in the U. S. and in Europe today are strains of *Saccharomyces carlsbergensis*, which takes its name from the great Carlsberg brewery in Copenhagen, or of *Saccharomyces cerevisiae*. Top-fermentation yeasts are all strains of *Saccharomyces cerevisiae*. Our familiarity with these microorganisms goes back only to Pasteur. But even before the mid-19th century brewing yeasts were selected by spontaneous fermentation and by long-continued and repeated transfers from one brew to another. At least one archaeologist has claimed that traces of yeast found in urns dating back to 1440 B.C. were decidedly superior to those in vessels of 3400 B.C. The Danish botanist Emil Christian Hansen was one of the first to develop techniques for isolating yeasts in pure culture, and he introduced these yeasts into breweries. Today many brewers employ pure strains of yeast that are especially suited to brewing. The cultures are renewed at intervals varying from a few months to several years; by careful control the yeast may be kept reasonably free from contaminating microorganisms.

At the end of fermentation the yeast has settled to the bottom of the vessel. The green beer is now pumped into large lager tanks, where it is kept at about 32 degrees F. for several weeks. The yeast, separated from the beer, can be used again. Lagering permits the beer to mature, with the result that both taste and aroma become decidedly mellower. We are, however, almost completely ignorant of the nature of these maturation changes. In all probability they are largely attributable to the production of minute amounts of unidentified alcohols and esters by the traces of yeast that remain in the beer. After lagering, further filtration through diatomaceous earth removes these traces of yeast and also a fine suspension of protein that is precipitated by chilling. The beer is then carbonated, usually by the injection of carbon dioxide but occasionally by a secondary fermentation under pressure, known as "krausening." When the product is bottled or canned, it must be pas-



glucose units, and amylopectin, consisting of branched chains. The straight chain of amylose may consist of as many as 300 units.

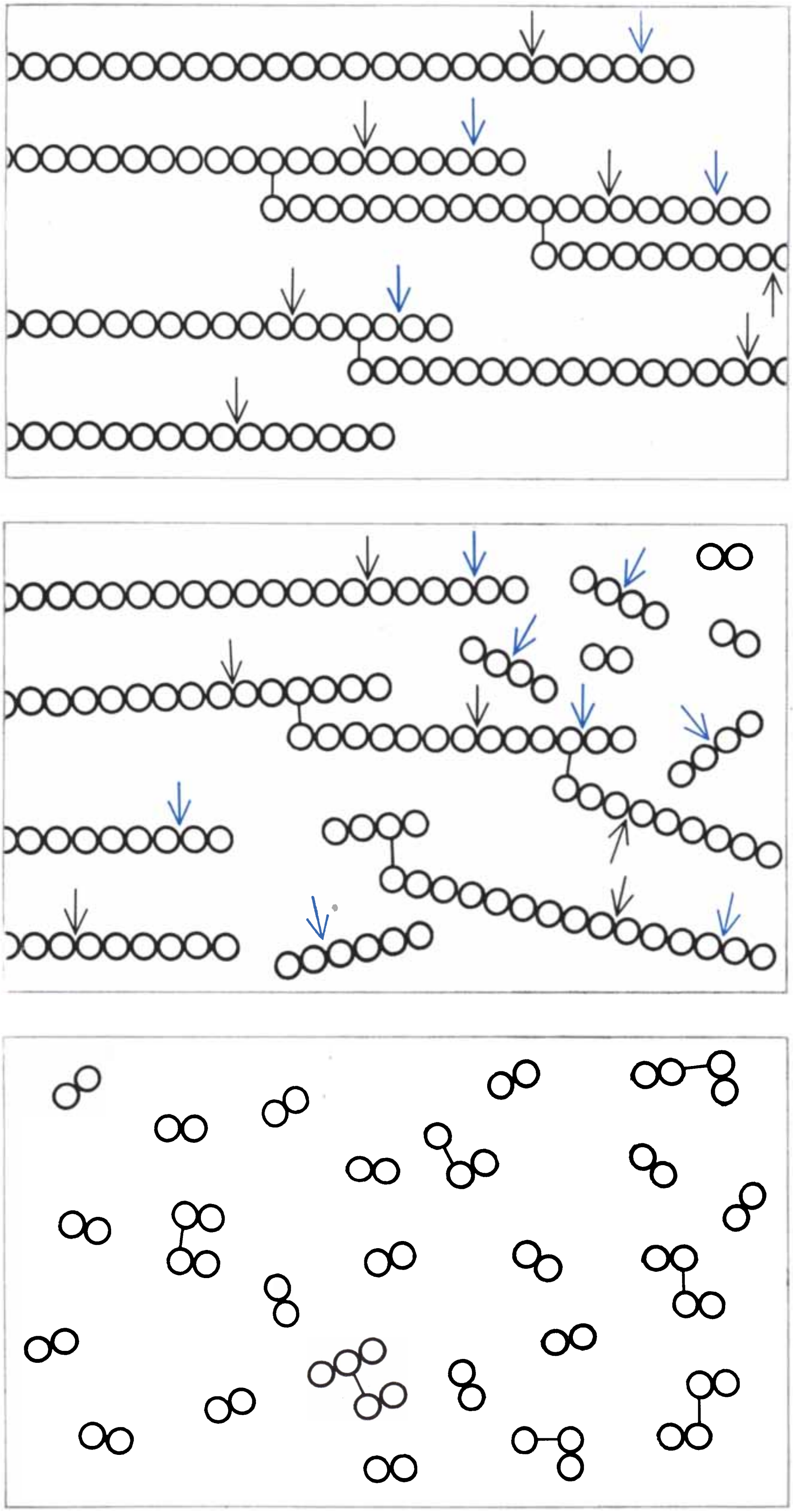
teurized by heating it to a temperature of about 140 degrees F. for 15 to 20 minutes, a treatment that is sufficient to kill most of the microorganisms capable of growing in beer. The beer marketed in aluminum or stainless-steel kegs to the restaurant and bar trades is not pasteurized, and so is kept under refrigeration until it is consumed.

The sequence of operations for converting barley and hops into beer that we have reviewed here is the result of centuries of empirical development. Though the knowledge gained in the past 50 years has disclosed the solid scientific foundations upon which the art has rested, it has so far improved upon it only in detail. However, with the deeper understanding provided by the biochemist, the brewmaster is better equipped to deal with problems that continue to arise even after 6,000 years.

The Problem of Haze

Probably the most pressing brewing research problem arises from the new habit of drinking beer from cans and bottles that have been kept in storage and are then decanted into clear glasses. For centuries beer was dispensed from kegs and drunk out of mugs and tankards; it was then judged solely by taste and smell. But in the recent past the locus of beer drinking has shifted to the home. It has now become necessary to produce beers that can be shipped long distances and kept on the shelf for unpredictable periods of time in a variety of temperatures, and will still be crystal-clear when they are poured into a glass. Unfortunately beers that have been so treated often tend to develop a haze, and consumer demand requires that this be eliminated.

One type of haze is caused by infec-



STARCH IS BROKEN DOWN by the enzymes alpha-amylase (*black arrows*) and beta-amylase (*colored arrows*). In the top drawing each glucose unit is represented by a small circle. At the top and bottom of this drawing are straight chains; in the middle are branched chains. In the middle drawing the beta-amylase splits off two glucoses at a time; the alpha-amylase splits off a larger number of glucoses, which are in turn broken down by beta-amylase. In the bottom drawing is the mixture of maltose (a two-glucose sugar) and dextrins (short, branched chains of glucose) that ultimately results from the process.

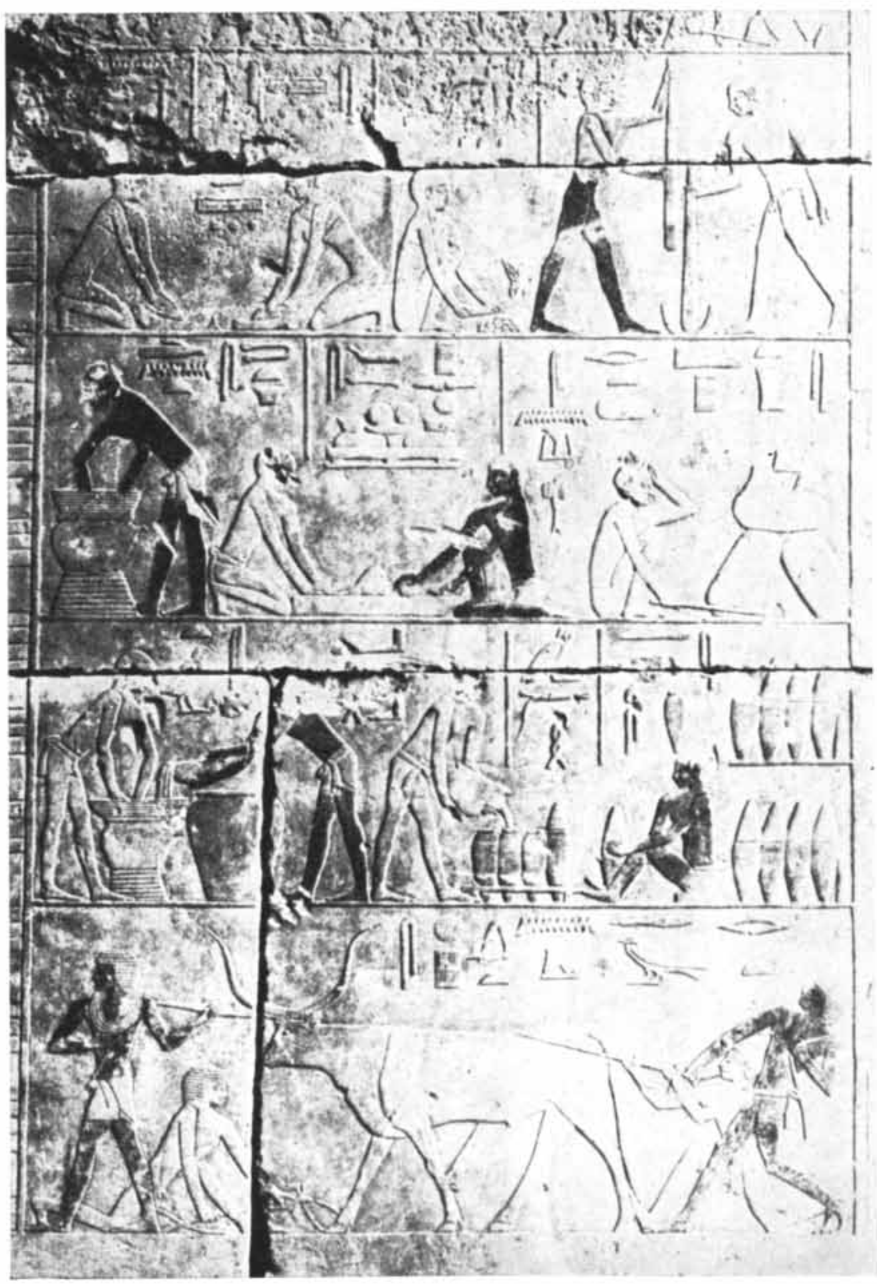
tion. Even after fermentation the finished beer contains sufficient food substances to support growth of a large number of microorganisms. Infection can occur in spite of pasteurization and the additional protection afforded by hop antiseptics in the beer. Fortunately the acidity of beer precludes the possibility of infection by microorganisms that cause disease in humans. The offending microorganisms are either bacteria (*e.g.*, species of *Pediococcus*, *Lactobacillus* and *Acetobacter*) or so-called wild yeasts, microorganisms closely related to the yeast used in fermentation. Beers infected by these microorganisms become hazy, and develop undesirable flavors. Although such spoilage can be troublesome, it can usually be prevented by strict attention to cleanliness in the brewhouse.

Far more serious are the nonbiological hazes. Here the turbidity is the result of the precipitation of fine particles of organic matter, predominantly protein. As we have seen, most of the protein is removed from wort when it is boiled and infused with hops, the tannins in the hops (and some from the malt husk) combining with the proteins to form an insoluble sludge. However, this protein-tannin complex continues to precipitate slowly from the beer even after packaging, so that after a period of storage the beer may well develop a pronounced haze. One cure for the condition is to add protein-digesting enzymes to the finished beer. This "chill-proofing" is not entirely satisfactory because too much enzyme may break down those peptides that give the beer its head-retaining properties. Another approach is based upon the fact that oxygen is conducive to haze formation. Thus various antioxidants, including ascorbic acid (vitamin C), have been added to beer to improve its stability. In recent years, however, a more fundamental attack on the problem has been launched; this work aims at identifying the haze components, tracking down their origin and then removing them from the scene of action. Unfortunately the chemistry of the proteins and tannins that make up hazes is extremely complex. Recent work at the Brewing Industry Research Foundation in England suggests, however, that we may be on the right track. Chemical analysis has shown that the trouble is often caused by one particular group of tannin substances known as anthocyanogens; they are commonly found in association with the proteins in hazes. It happens that these anthocyanogens can be removed from beers by adsorption on a polyamide resin such as

nylon. Experimental brews treated in this way have shown a considerably extended shelf-life.

The Intrusion of Science

Since he deals in such evanescent commodities as taste and aroma, the brewer is understandably cautious in his approach to innovation in the brewing process. He has nonetheless been encouraged by the success of the scientific techniques so far employed and has begun to take a more critical view of the time-honored methods of his craft. The biochemist and microbiologist are now well established in brewing research laboratories; soon they will be joined by representatives of other disciplines. Brewers are looking to geneticists, for example, to improve the strains of yeast. Perhaps chemical engineers will bring about the most revolutionary changes in brewing during the next decade or so. For example, techniques for replacing the traditional batch-method of brewing by a continuous process are already in the pilot-plant stage. Clearly the intrusion of science into the art of brewing promises to bring great changes in the procedures that have served so well for six millennia.



BREWING IN ANCIENT EGYPT is depicted by this relief in the Rijksmuseum of Leiden. At left in the third row a brewer pours water into a vat; at right the beer is poured into jars.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announces
Delrin®
ACETAL RESIN
. . . a completely new engineering material offering
a combination of properties unmatched by any other thermoplastic

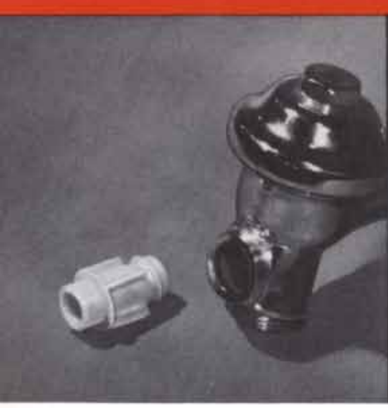
This is Du Pont Delrin:®

"Delrin" acetal resin is a highly crystalline, stable form of polymerized formaldehyde. This completely new material offers you metal-like mechanical properties, such as a high degree of strength and rigidity, plus other properties that metals do not possess.

The combination of properties offered by "Delrin" is unequaled by any other thermoplastic. For example, "Delrin" has high dimensional stability, tensile and flexural strength, resilience and toughness. Most importantly, "Delrin" retains these desirable properties under a wide range of service conditions—temperature, humidity, solvents and stress.

Over the past three years, "Delrin" has been

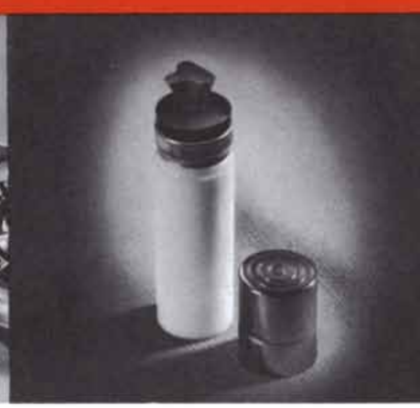
Typical performance and production advantages of "Delrin"



A brass part in a commercial flush valve was duplicated in "Delrin". This part operated perfectly for 18 months—the period of test—although it was completely and continuously immersed in water. The outstanding dimensional stability of "Delrin" under a wide variety of service conditions has also been proved, for example, in showerheads (continuously running water at 150°F.), and movie projector gears (run over 2,000 hours at ambient humidity).

This textile solution pan is ordinarily made of stainless steel. It must have resistance to oils and organic solvents, a clean, smooth surface; it also requires several threaded inserts plus other details. In normal quantities, stainless steel pans cost approximately $25 each. Injection molded in "Delrin", the cost was quoted at about $3 each. Testing showed that "Delrin" provided the required finish without machining, the needed solvent resistance, plus a weight saving of 75%.

A zinc die-casting mold was used to make this instrument cluster of "Delrin". Weight was reduced over the zinc component by almost 80%. In addition to manufacturing economies, further savings in assembly are indicated: self-tapping screws can be used, since the creep resistance of "Delrin" prevents loosening or stripping. These clusters can be molded in integral color or painted, and with a conventional mold would require little, if any, mechanical finishing.



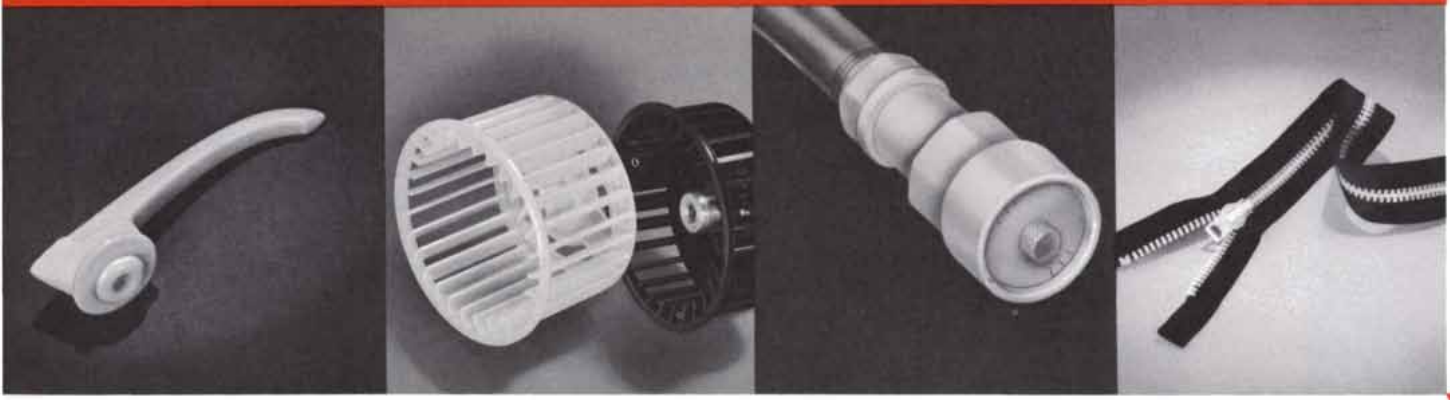
Aerosol containers made of "Delrin" were shelf-stored for over a year; others stored for 3 months at 130°F. In both cases, the contents were still completely dischargeable. "Delrin" retains its strength and toughness for long periods, even when exposed to elevated temperatures and organic solvents. Equally important are the new opportunities for high styling opened by "Delrin"—the freedom to design in new shapes and integral colors to suit purchasing trends.

tested in hundreds of end-use applications by a host of industrial concerns. These tests have confirmed that parts made of "Delrin" can compete *on a performance and cost basis* with parts made of many metals, rubber, glass or wood. Of the various end-uses tested, 75% would normally be made of metal and another 10% of rubber, glass or wood. These tests have resulted in many applications of "Delrin" now being readied for commercial production—including gears, bearings, housings, containers, plumbing and hardware parts, pump impellers, "squirrel-cage" blowers, door handles, clothing fitments and many others.

In addition to metal-like performance, "Delrin" offers you the manufacturing economies inherent in the production methods of the plastics industry. "Delrin" is easily injection molded, extruded, blow-molded or fabricated with conventional machine tools.

Illustrated below are a few of the applications of "Delrin" which have undergone extensive field service tests. The performance and economies listed were indicated during comparative evaluations made with materials in use at the time of the tests. These applications, together with additional data on the following page, may well suggest ways in which this versatile new engineering material can help *you* improve a product, lower its cost or develop new designs for your profit. Your inquiry is invited (see coupon on next page).

evaluated during three years of field tests . . .



Accessories usually made of metal, such as automotive window cranks and refrigerator door handles, can be economically mass-produced in "Delrin" by injection molding. "Delrin" provides required strength and rigidity. Integral colors, a variety of surface effects and functional details can be produced in one operation. Less weight, improved styling, dependable performance and potential cost savings are made possible by "Delrin".

Industrial components such as this "squirrel-cage" blower—as well as a variety of gears, bearings and other mechanical parts—have demonstrated the ability of "Delrin" to compete with various metals on a performance and cost basis. "Delrin" offers excellent fatigue life even when immersed in oil or water. Rapid production of lightweight, intricate components by the injection molding process can lead to substantial manufacturing economies with "Delrin".

Plumbing fixtures made of "Delrin", such as this showerhead, offer the manufacturer new styling and design advantages . . . and the home owner new latitudes in bathroom décor. Injection molded in integral color, fixtures made of "Delrin" assure builders and home owners of long-term dimensional stability, freedom from rust and mineral build-up. Modern in design, they are durable and dependable in service, and provide opportunities for potential cost savings.

Clothing fitments, such as zippers, clasps and snaps, are also readily and economically molded in "Delrin". Stiffness, toughness and resistance to heat, body oils and perspiration make "Delrin" a logical choice for such uses. Your customers would welcome the light weight, colorability and warm-to-the-touch benefits "Delrin" offers. Extensive field tests have demonstrated that "Delrin" is one of the most promising new materials available to the fitments industry.

TYPICAL PROPERTIES OF "DELRIN" ACETAL RESIN

PROPERTY		ASTM NO.	AVERAGE VALUES FOR "DELRIN"* 500X	AVERAGE VALUES FOR "DELRIN"* 150X
Elongation	—68°F.	D638	13%	38%
	73°F.	D638	15%	75%
	158°F.	D638	330%	460%
Impact strength, Izod	—40°F.	D256	1.2 ft.lb./in.	1.8 ft.lb./in.
	73°F.	D256	1.4 ft.lb./in.	2.3 ft.lb./in.
Tensile strength and yield point,	—68°F.	D638	14,700 psi	
	73°F.	D638	10,000 psi	
	158°F.	D638	7,500 psi	
Compressive stress at 1% deformation		D695	5,200 psi	
at 10% deformation			18,000 psi	
Flexural modulus,	73°F.	D790	410,000 psi	
	170°F.	D790	190,000 psi	
	250°F.	D790	90,000 psi	
	100% RH 73°F.	D790	360,000 psi	
Flexural strength		D790	14,100 psi	
Sheer strength		D732	9,510 psi	
Heat distortion temperature,	264 psi	D648	212°F.	
	66 psi	D648	338°F.	
Fatigue endurance limit, 50 to 100% RH 70°F.			5,000 psi	
	100% RH 150°F.		3,000 psi	
Water absorption, 24 hours immersion		D570	0.12%	
equilibrium, 50% RH		D570	0.2%	
equilibrium, immersion, 77°F.			0.9%	
Specific gravity		D792	1.425	
Rockwell hardness		D785	M94, R120	
Flammability		D635	1.1 in./min.	
Melting point (crystalline)			347°F.	
Flow temperature		D569	363°F.	

PROPERTY	ASTM NO.	AVERAGE VALUES FOR "DELRIN"*
Deformation under load (2,000 psi at 122°F.)	D621	0.5%
Coefficient of linear thermal expansion	D696	4.5×10^{-5} per °F.
Taber abrasion (1000 gm. load, CS-17 wheel)	D1044	20 mg/1000 cycles
Thermal conductivity		1.6 BTU/hr./sq. ft./°F./in.
Specific heat		0.35 BTU/lb./°F.
Modulus of rigidity		178,000 psi
Poisson's ratio		0.35
Dielectric constant, 73°F., 10^2-10^5 cps	D150	3.7
Dissipation factor, 73°F., 10^2-10^5 cps	D150	.004
Dielectric strength, short time	D149	500 V/mil
Volume resistivity	D257	6×10^{14} ohm/cm
Resistivity	D257	2×10^{13} ohm
Arc resistance	D495	129 seconds (burns)

Permeability: (gms loss/24 hrs/100 in² area/mil thickness. Determined on bottles with 35-50 mil wall thickness.)

	P Factor at 73° F.:
Water	1.9
Ethanol	0.2
Freon® 12-114 (20/80)	< 0.2
Methyl Salicylate	0.3

Resistance to Organics: (% wgt. gain—12 mo. total immersion Vol. change proportional to wgt. change.)

	Room Temp.	122° F.
CCl_4	1.2	5.7
Toluene	2.6	2.8
Acetone	4.9	2.6
Alcohol	2.2	1.9
Ethyl Acetate	2.7	2.9

*These values are representative of those obtained under standard ASTM conditions and should not be used to design parts which function under different conditions. Since they are average values, they should not be used as minimums for material specifications.

DELRIN® ACETAL RESIN *offers design engineers a new combination of properties*

"Delrin" acetal resin offers you a combination of properties and potential cost advantages never before offered by any single material. Specific values of typical properties of "Delrin" are listed in the table above . . . and the advantages implicit in these figures have been thoroughly tested in a wide variety of end-uses.

Today is your best opportunity to consider how Du Pont "Delrin" can help you improve the design of a product or develop your designs on new products. Within the next few weeks a new plant to manufacture "Delrin" in commercial quantities will come on stream at Parkersburg, W. Va. This plant is your assurance that your design improvements can fast become practical realities. Commercial molders, already familiar with "Delrin", can provide you with valuable assistance in your problem.

A specialized group of Du Pont engineers, as well, can help you with their experience and knowledge gained during years of market development work with "Delrin". They may well have tested the very product or component you are considering.

FOR MORE SPECIFIC INFORMATION MAIL THIS COUPON

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BETTER THINGS FOR BETTER LIVING
. . . *THROUGH CHEMISTRY*

SELF-REPRODUCING MACHINES

In which simple units are built which assemble themselves into larger units, which in turn make copies of themselves from other simple units. The process sheds light on the self-reproduction of biological molecules

by L. S. Penrose

The mass production of multiple copies of the same object by printing or by assembly of prefabricated parts is an event so commonplace that examples can immediately be called to mind. The reader has one at hand in the copy of SCIENTIFIC AMERICAN in which he reads these words. The idea of an object reproducing itself, however, is so closely associated with the fundamental processes of biology that it carries with it a suggestion of magic. Indeed, the construction of a machine capable of building itself might be judged to be impossible and to belong to the category of perpetual-motion engines. At the present time, however, advances in genetics are rapidly leading biologists to focus their attention upon the structure and function of self-reproducing molecular chains which, in the nuclei of living cells, preside over all their functional activities. The structure of these chains of nucleic acid is already quite well understood. But the general theory of self-reproduction, in which the replication of nucleic acid would represent a special case, has not been much investigated.

The theory has two aspects, which can be called the logical and the mechanical. The logical part was first investigated by the late John von Neumann of the Institute for Advanced Study in Princeton, N. J. He decided in 1951 that it must be possible to build an engine that would have the property of self-reproduction. The method would be to construct a machine that is capable of building any describable machine. It would follow logically that such a machine would be able to build another machine just like itself. Each machine would carry a sort of tail bearing a code describing how to make the body of the machine and also how to reprint the code. According to von Neumann's associate John G. Kemeny, the body of the machine would be a box containing a minimum of 32,000 constituent parts and the "tail" would comprise 150,000 units of information. On the mechanical side the elementary parts, out of which this object was to be built, were considered to be likely to include rolls of tape, pencils, erasers, vacuum tubes, dials, photoelectric cells, motors, batteries and other devices. The machine would assemble these parts from raw material in its environment, organize them and transform them into a new replica of itself [see "Man Viewed as a Machine," by John G. Kemeny; SCIENTIFIC AMERICAN, April, 1955]. Since the aim of von Neumann's reflections was to resolve the logical conditions of the problem, the stupendous mechanical complexity of the machine was of no consequence.

The mechanical problems involved in constructing such a machine have been investigated by Homer Jacobson of Brooklyn College in New York. In one experiment he built an electrically powered railroad track around which two kinds of trucks, respectively called "head" and "tail," could circulate. Initially these trucks were arranged in a random order. If a head and a tail were first assembled upon a siding, however, they would signal to another head and another tail to connect up on an adjacent siding. So long as there were trucks and sidings available this process could continue, and the head-tail machines would be assembled automatically. The design of the trucks and of the railroad itself involved considerable complexity and a great many different elements such as wires, tubes, batteries, switches, wheels, photoelectric cells and resistances. This intricate apparatus generated only one kind of building operation, but the operation was indeed a kind of self-replication.

SELF-REPRODUCING DESIGN is identical with its own photographic negative, except for checkerboard border surrounding it.

Together with Roger Penrose I have approached the problem in a more radical manner, without the encumbrance of prefabricated units such as wheels and photoelectric cells. Our idea was to design and, if possible, to construct simple units or bricks with such properties that a self-reproducing machine could be built out of them. One everyday example of mechanical self-replication involving simple units is the "zipper" fastener. Here the self-replicating unit is the pair of interlocked hooks; the zipper-slide provides the energy to push each pair of hooks together. As soon as one pair is connected, a whole chain made up of similarly connected pairs can be formed. The example is defective in that only one type of connection is formed in the zipper, and the units are not completely separate before the action takes place. Another simple instance of self-replication is offered by a suitably designed mold, template or photograph. Ordinarily such replication calls first for a negative from which a positive like the original can be recovered. A negative can, however, be combined with the positive in such a way that, by replicating both at the same time, the two steps are reduced to one. Thus in the illustration on the preceding page we have a design whose negative will be identical with the original because of its peculiar symmetry. This suggests that it is convenient, and perhaps necessary, for a self-replicating object to carry its own template or negative.

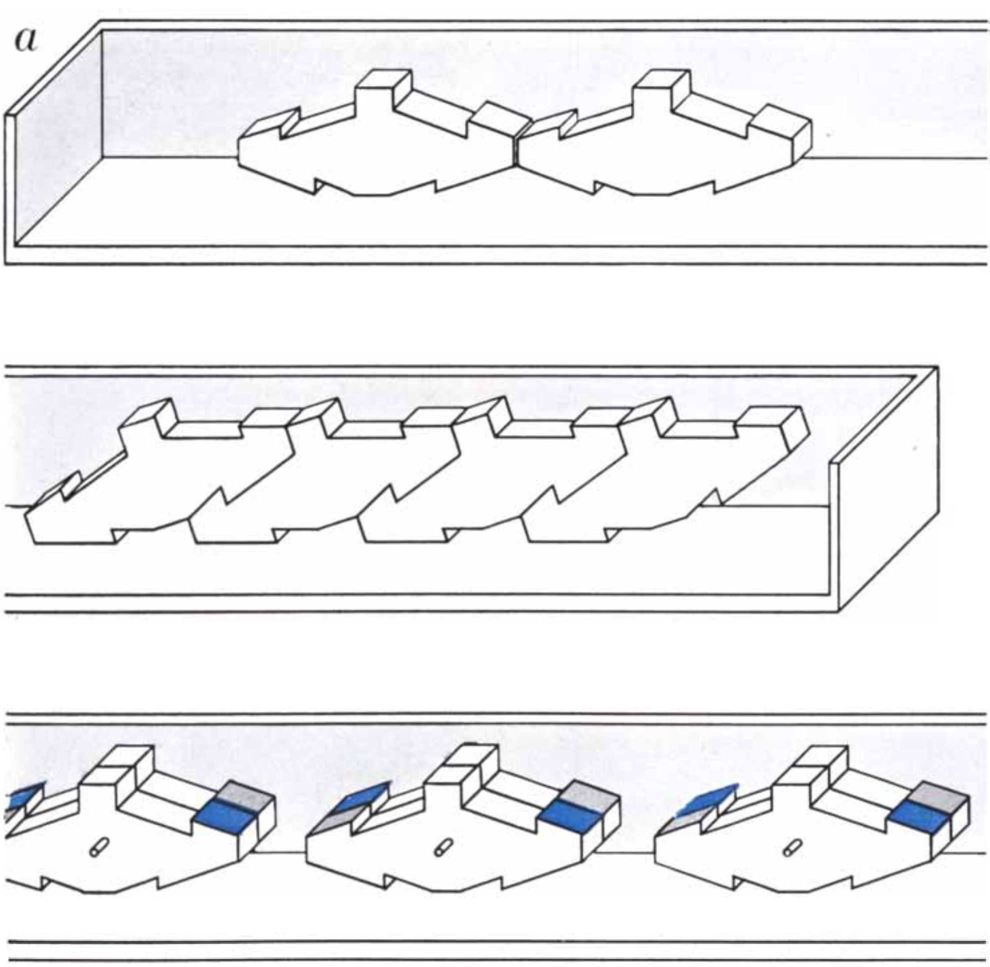
In the design of the units or bricks for our self-replicating machine we laid down certain arbitrary standards. The units, we decided, must be as simple as possible. They must be of as few different kinds as possible. And they must be capable of forming at least two (preferably an unlimited number) of distinct self-reproducing structures. Finally we decided that the energy necessary to engage these units in the process of self-replication should be supplied in the simplest manner, by merely shaking the units in a confined space but otherwise allowing them as much freedom of movement as possible.

One essential condition was to be that the units would not form self-reproducing machines just because they were moved about. They were to reproduce themselves only when the object to be replicated was introduced as a pattern for copying. The logic of this condition is to be found in William Harvey's maxim: *Omne vivum ex ovo* (in modern form: No life except from life). By definition, self-reproduction requires a "self" to be reproduced.

In fanciful terms, we visualized the process of mechanical self-replication proceeding somewhat as follows: Suppose we have a sack or some other container full of units jostling one another as the sack is shaken and distorted in all manner of ways. In spite of this, the units remain detached from one another. Then we put into the sack a prearranged connected structure made from units exactly similar to those already within the sack. Such a structure might arise, of course, by chance in response to random shaking, but this would be very unlikely indeed, as is the case with the analogous process of mutation in genetics. Now we agitate the sack again in the same random and vigorous manner, with the seed structure jostling about among the neutral units. This time we find that replicas of the seed structure have been assembled from the formerly neutral or "lifeless" material. It follows that each replica is capable of self-reproduction like the original seed, and that reproduction will continue until all the "food" is used up.

The building of actual models in our investigation began with a much simpler experiment in mind. In the inorganic world the most obvious analogy to self-reproduction in living matter is the growth of a crystal. The construction of an artificial crystal that would repeat some prearranged pattern indefinitely seemed to offer a useful starting point. The first machine built on these lines proved most illuminating. It consisted of two pieces of plywood cut to a special shape, each about four inches long and a quarter-inch thick, standing end to end on the inner surface of the long side of a shallow rectangular box resting on its side [*see illustration labeled "a" on these two pages*]. The box can be subjected to side-to-side agitation of a vigorous and irregular character, causing the pieces of plywood to move in one dimension from side to side, each colliding with its nearest neighbors. In the "neutral" position in which the pieces of plywood appear, however, they do not link under the influence of shaking alone. But if a "seed" consisting of two linked pieces is added, this seed will link up with adjacent pieces standing on either side of it on the track. Eventually all the available neutral pieces will become attached to the "crystal." If the seed is inclined in the opposite direction, a complementary aggregate is built.

Certain principles become evident from the study of this machine. Here copying consists in imparting the same tilt to each unit. The seed carries, as it were, a positive pattern at one end and a complementary negative pattern at the other. These patterns influence the neutral units as they come into close contact with the seed, causing them to tilt in the positive or negative manner. Once tilted or "activated," the units are caught and locked to the growing crystal by the complementary notches cut into the profiles of the plywood pieces. These notches enable energy to be trapped and thus convert the energy of motion conveyed by agitation into the potential energy



MECHANICAL "CRYSTAL" demonstrates some of the underlying principles of self-reproducing machines. At upper left in *a* appear two identical units at the "neutral" position in which they are unable to link up with one another. Introduction of two linked units

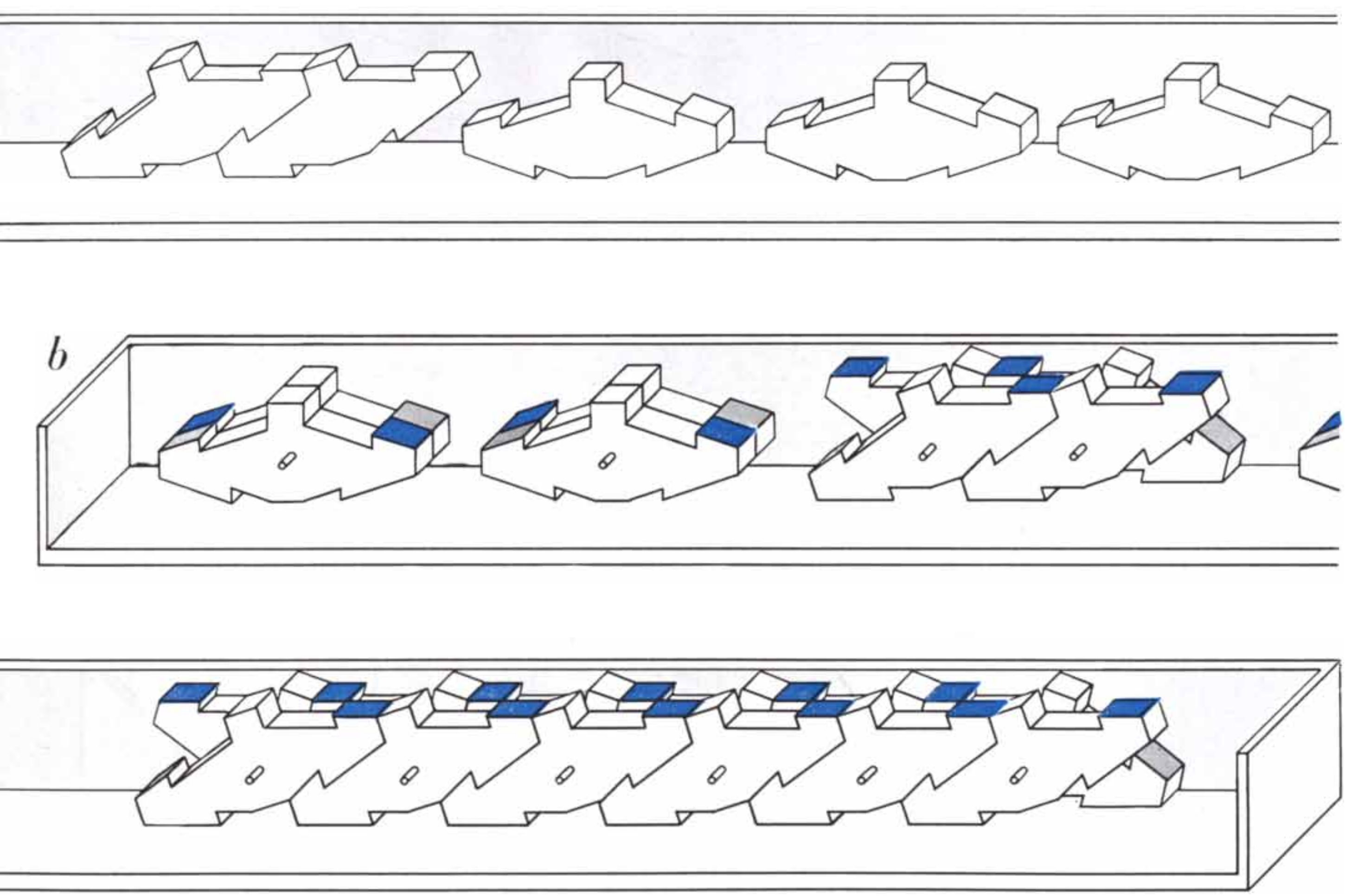
that binds the structure. Energy traps are characteristic of living matter, although they occur also in artificial and natural structures. A pool that retains water after a tide has receded is typical. In chemistry the bonding of an endothermic compound is analogous to a latch. Unless our synthetic structures contained more potential energy than their constituent units separately, it would be difficult to prevent spontaneous aggregation.

The crystallizing or, we might say, the polymerizing machine can be greatly improved by making units out of two plywood elements tied together by an axle so that they can pivot in opposite directions [*see illustration labeled "b" on these two pages*]. As can be seen, there are four ways of arranging the seed, of which two are essentially the same and the other two are mirror images. Besides giving rise to more types of seed in the case where the two parts of each unit are tilted in opposite senses, the double units form much stronger structures than single units.

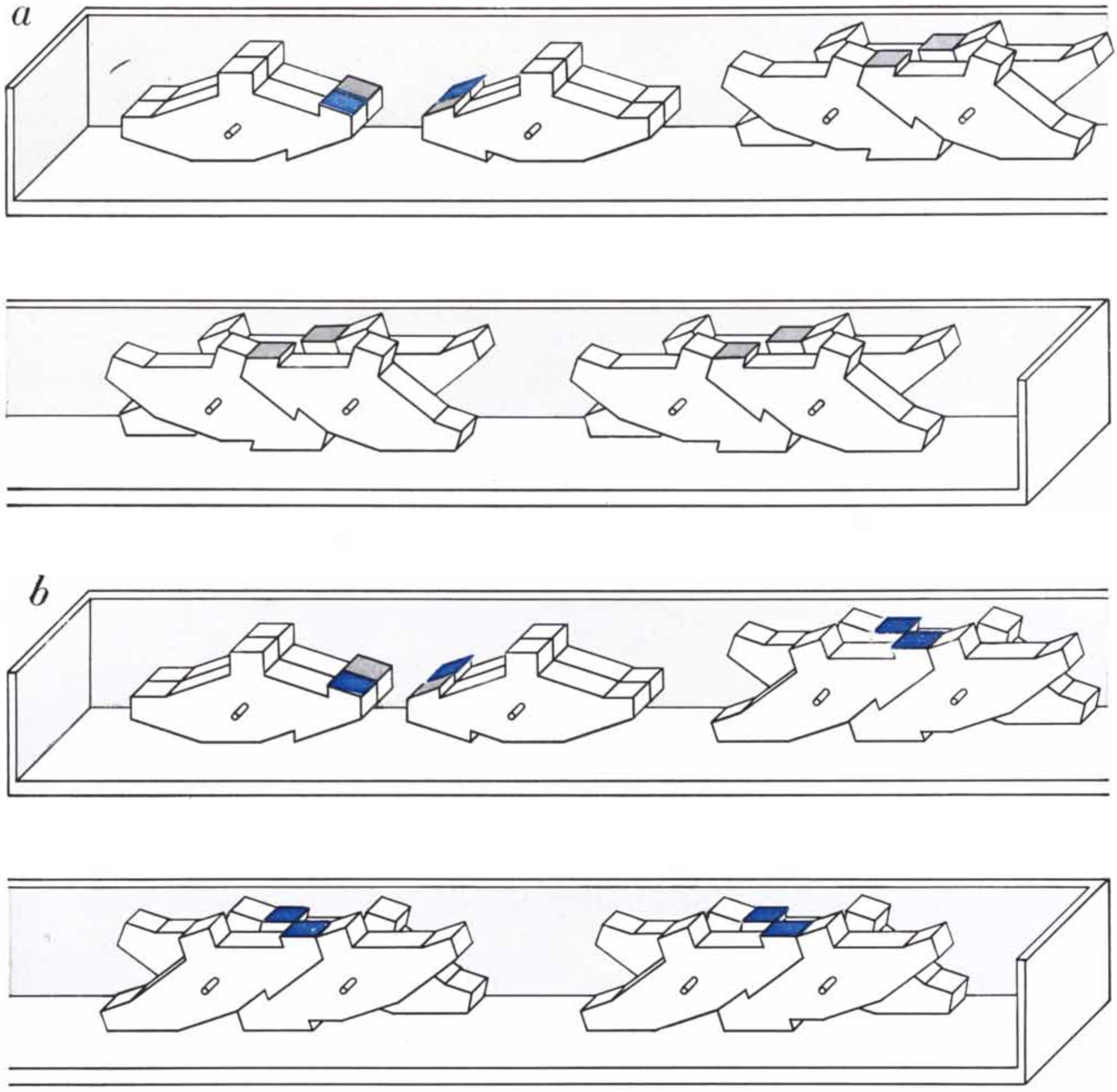
The problem of reproducing an object the same size as the seed has now to be solved. This is done with surprising facility. It is only necessary to alter the basic units by removing one pair of notches from each of them. In effect the crystal is broken up into discrete bodies, each made of two units [*see top illustration on next page*]. Two stable mirror-image seeds can be constructed, and either may be used as a starter. In a long box or track, populated with neutral units randomly arranged, the presence of a seed causes other structures of its own kind to be built wherever two neutral units are in the appropriate relative positions.

This design provides a simple and convincing demonstration of artificial self-reproduction. Either type of seed may be introduced into the track; since they and their offspring are easily distinguished, it can be seen that each breeds true to type.

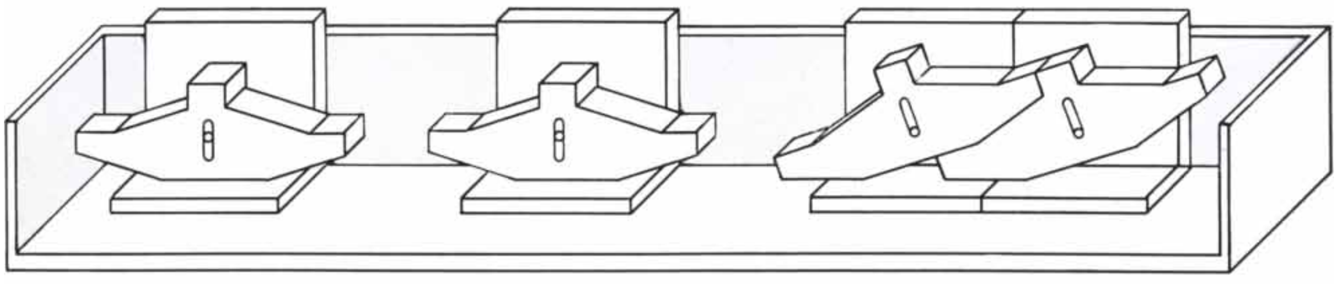
A point that emerges here, when the process is critically examined, is that during agitation some units transmit the tilted pattern of the seed although they do not find a partner to link with. These temporarily activated units tend to slide away from one another and from the completed structures, thereby tending to push some of the completed structures apart when agitation has subsided. It is convenient in self-reproduction to arrange that the fresh complexes should repel one another once they have been formed. If they separate widely, they can pick up "food" from different places and they do not interfere with one another's subsequent reproduction. In a restricted one-dimensional track this point is irrelevant. But it becomes significant in the next phase of the discussion, when we consider how we might lift the one-dimensional restriction of the track and make it possible for our self-replicating



as a "seed" in panel at upper right imparts tilt and makes it possible for entire group of units to link up and form a single structure when subjected to agitation in the horizontal plane. In *b* two doubled units are shown, first in neutral position and then linked up to form a seed. When this seed is agitated with neutral units at lower left, all join to form the crystal structure at lower right.



SELF-REPRODUCTION is here demonstrated by units of a simple kind, identical with those that form the "crystal" on the preceding two pages except that the units each lack hooks at one end. In *a* the seed is formed with the gray telltale mark showing at the linkage; in *b* the seed unit is formed with the colored telltale mark showing. When the seed of each kind is agitated in the horizontal plane with neutral units, the appropriate tilt is imparted to the neutral units and they link up to reproduce the structure of their seed.



ACTIVATING CAM-LEVER incorporates the simple tilting principle of the self-reproducing machines shown above for use with more complex structures shown on page 111. These cams, held in tilted position by dowel in slot, transmit activation but do not link.

structures to move about freely in two dimensions.

In order to fit the units for self-reproduction into the larger world of two dimensions, it is necessary to complicate their design beyond the rudimentary shapes that have worked thus far. With units moving over a plane surface, without the support of the back wall of the one-dimensional track, a firm base for each must be provided. A simple solution is to mount the plywood element on a horizontal pivot fixed to an upright, which is in turn attached to the base of the unit. The element capable of tilting and transmitting its tilt then becomes a sliding cam-lever. To allow greater variety of interaction between units, the hooking mechanism can now be separated and made independent of the tilting process by transferring it to a different part of the unit [*see bottom illustration on opposite page*].

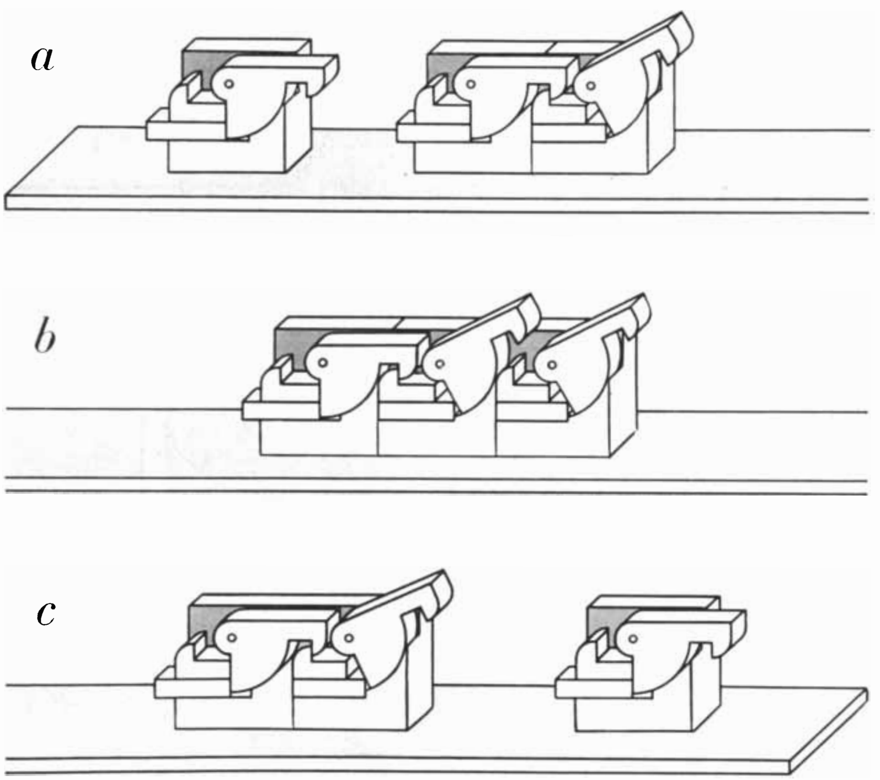
In the two-dimensional situation the simpler design permitted an activated unit to slide away and lose contact with a "live" group after it had gone part of the way toward building a new replica. This is quite uneconomical from the energy standpoint. We must therefore arrange matters so that a unit may hook on to a two-unit live group temporarily and be released when a fourth unit becomes attached to the group. We are thus led to consider mechanisms for making and releasing links in special circumstances. One such latch depends for its release upon the presence of another unit in close contact. The effect of this, as shown in the illustration at right, is to maintain combinations already built out of new pieces. But this arrangement produces no fresh structures. It would give us a sort of steady state. In order to make a reproducing complex with this device, the system of linkage and release must be doubled as shown in the illustration on the next page. Here each unit contains two releasable hooks facing in opposite directions. Though they are shown one above the other, they would in practice be mounted side by side on the same axle. With such an arrangement of latches the addition of a third unit to a linked pair creates a triple complex that does not separate until a fourth unit is added. When this has taken place, the two similar pairs of units disengage and gently repel each other as their hooks settle down to their lowest possible states of energy.

It must be noted that this system of reproduction is incomplete because two pieces can link without any previous activation, that is, tilting caused by contact with a special seed. An activating element of some kind must be supplied so that neutral units cannot form links except in the presence of a live group that carries the activating principle. For this purpose the sliding cam-lever can be used to preserve a tilt and transmit it to neutral units; only those units that have been thus activated can approach each other close enough to link.

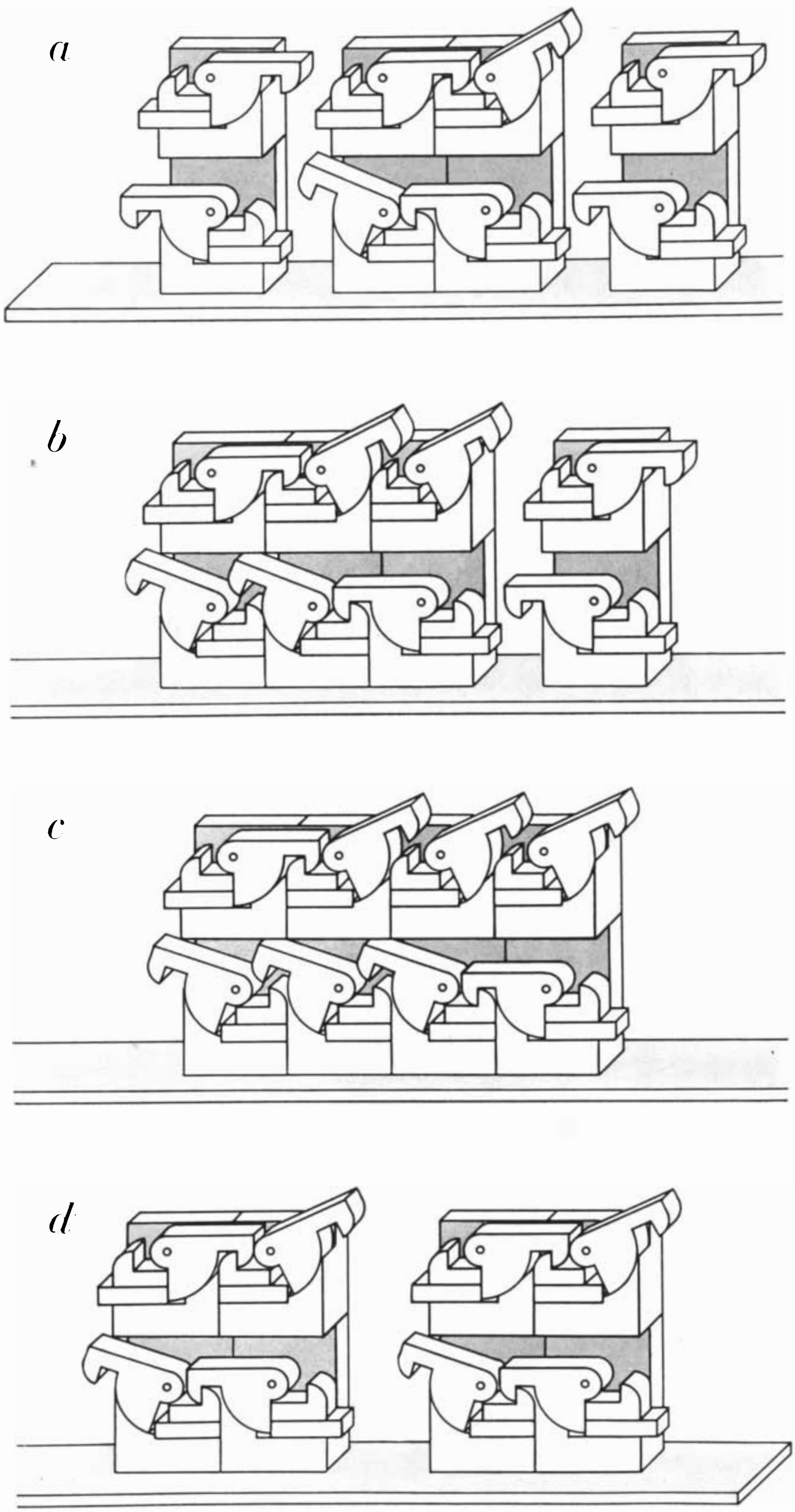
An interesting feature of this system is that it can replicate in two ways. If a live structure made of two units receives two neutral food units, both of them from either its left or right side, it will link them to itself and then release them linked to each other. On the other hand, if the original structure receives two food units, one on either side, it will link them to itself and then come apart in the middle [*see bottom illustration on page 111*]. As in the case of a single-celled organism, the original unit is destroyed in the process of replication. By the addition of special devices to the units it is possible to distinguish between these two kinds of replication; that is, one device will ensure that two units of food will always be taken in on one side, and another device will ensure that the two neutral units are added one on each side. If there is no scarcity of food, it is likely that neutral units will be simultaneously available on both sides. For efficient reproduction, therefore, the second type of replication, that is, addition on either side and division of the seed, should be adopted as the standard.

Another useful adjunct is a counting device. This can take the form shown in the top illustration on page 111. Such an element, which prevents more than four units from coming into close contact with one another, can be attached to each unit. The counter exerts its effect in that phase of reproduction, just before division, when the complex must cease accepting food. Before reproduction can be resumed the accretion of neutral units must stop long enough to enable the enlarged complex to come apart. The self-reproducing machine may also be equipped to make a kind of protective covering for itself out of "skin" units available in the environment. The skin would have to be thrown off in order to repeat self-replication.

The self-reproducing machine now requires one more adjunct to fit it for activity in two-dimensional space. To bring units into proper alignment for interlocking when random motion causes them to collide, their bases must be pro-



STEADY-STATE SYSTEM of hook and release is demonstrated here. When two units abut one another (*a*), one hooks onto the other, but the one that is hooked is itself set in release position. The addition from the left of a third unit (*b*) causes the first two to unhook (*c*).



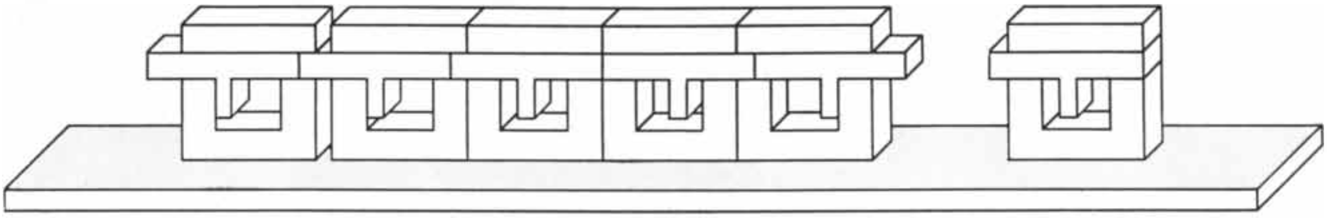
DOUBLE-HOOK UNITS, in contrast to steady-state system, possess capacity for self-reproduction. Cycle begins with linked group and two neutral units (*a*). Addition of neutral unit at left (*b*) causes one of two hooks in linked group to release. Addition of fourth unit (*c*) causes second hook in linked group to release. Linked group parts (*d*) in two replicas.

vided with interdigitating guides. The guides can also serve passively as hooks [*see top illustration on page 112*]. Some of the guides ensure correct apposition of hooks or activating levers and others cause the firm attachment of rows of pieces. With this additional device our units are endowed with a sufficient number of mechanical principles to enable self-reproducing machines of any desired degree of complexity to be built from them. Yet the units are of fairly simple construction and are either all of one kind or of a few different kinds.

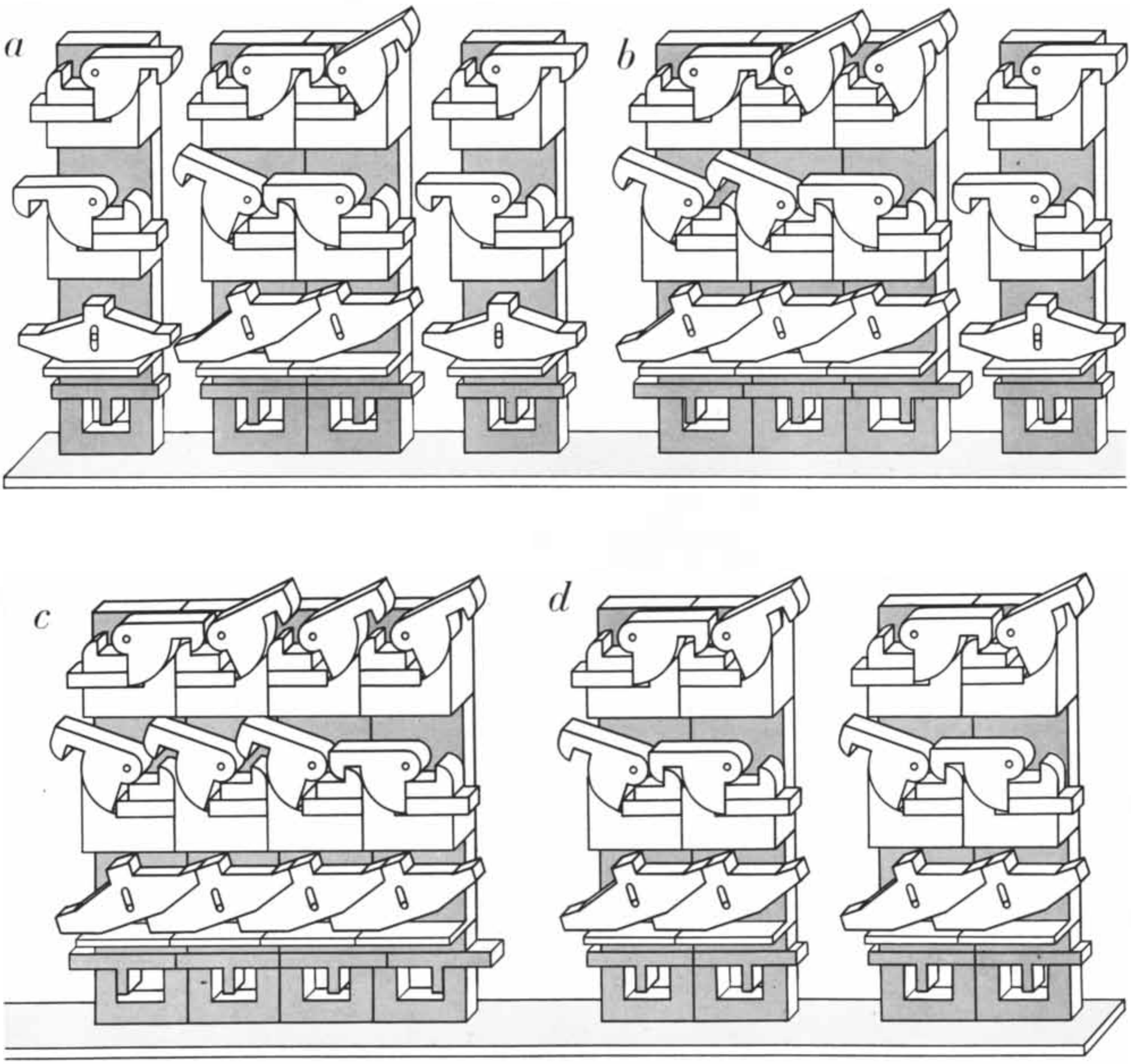
The replication scheme of one such machine, made out of a set of units of two kinds, is shown in the bottom illustration on page 112. To ensure that replication proceeds regularly and that attempts at interconnection do not end in a tangle of hooks and guides, an ordering mechanism is included; an asterisk in the diagram indicates positions where the ordering mechanism permits new units to be added. The units each have two levers of the kind which can be activated positively or negatively, that is, tilted up or down; thus four types of activated units or rows of units are possible. The chain of units acting as a seed may be built in any predetermined number of rows and each row can be set with any one of four types of activation. When a fresh unit is added on either side of the double chain, no additional units of the same kind can attach themselves in that row. A different type of unit now forms a nonreplicating protective "skin" chain in response to the activating pattern of the complex. When all the open positions are filled with appropriate units, the self-replicating machine splits in two, sheds its skin, and the process may begin again.

The design of units suitable for forming the protective chains presented peculiar difficulties; in overcoming these I came upon a new method of controlling and sequencing the latching and unlatching which provides an elegant solution of the von Neumann problem. A single string of determinate length, made up of units of a slightly different design, can replicate itself in the manner shown in the illustration on page 114. The addition of each new unit to the daughter chain has the effect of releasing the one behind it from the original chain. The final unit to join the new chain does not attach itself to the old chain at all, although it releases the new one from the old.

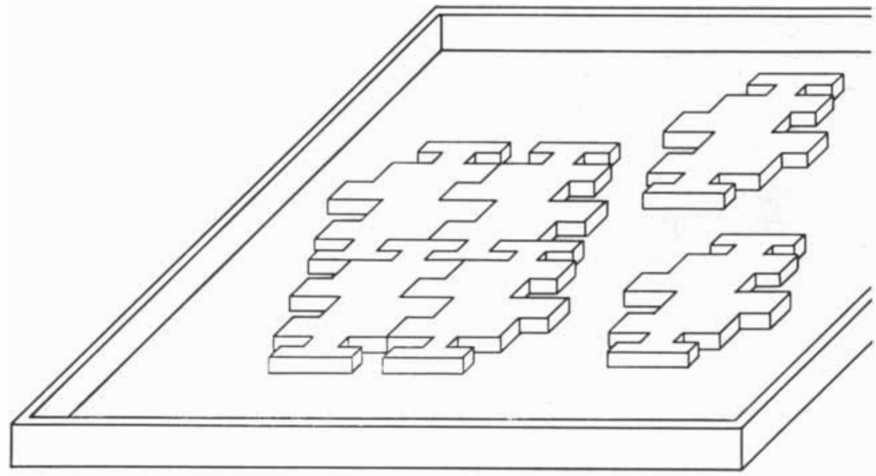
Here it should be emphasized that



BLOCKING DEVICE prevents more than four units from coming close together. When four units are in close contact, the sliding bar protrudes at either end of the group, keeping other units away. Device keeps groups from growing too large before they divide.



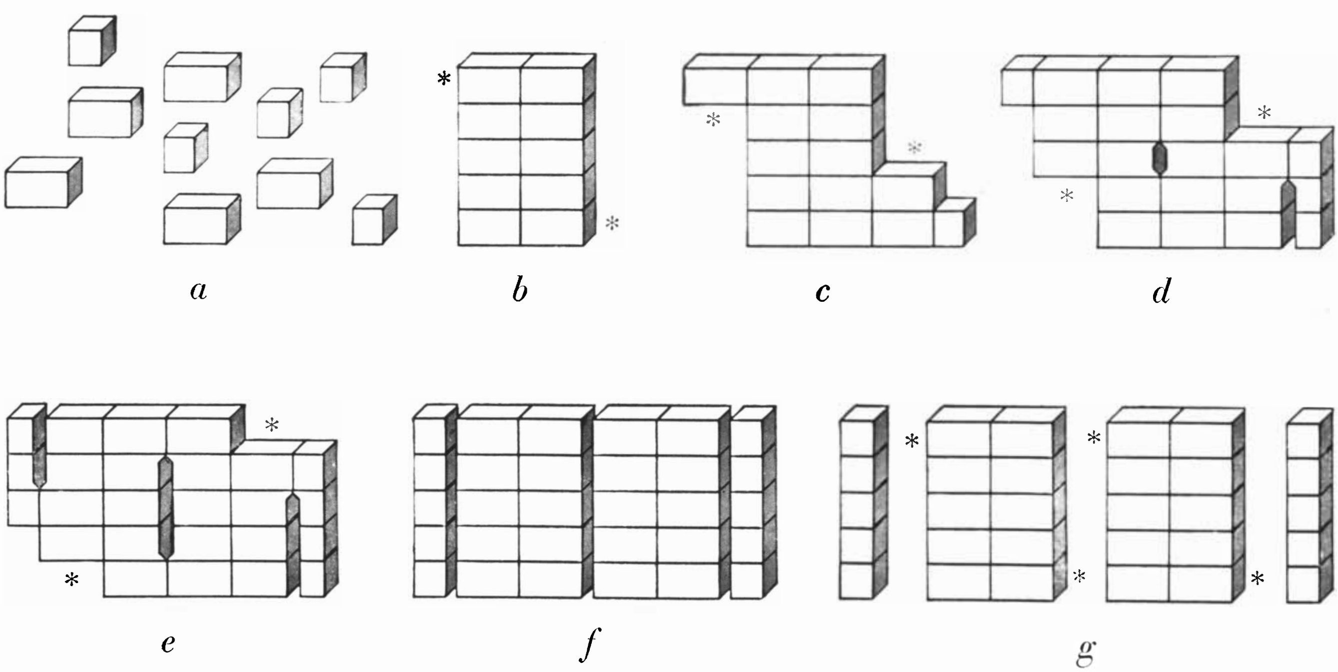
COMPLETE SELF-REPRODUCING MACHINE incorporates the basic elements and principles depicted in the preceding illustrations. The seed (at center in *a*) is linked by double hooks, incorporates the tilted cam-lever activating principle and is protected by the blocking device in its base. When the neutral unit at left joins the seed (*b*), it disengages one of the hooks holding the seed together and sets the blocking mechanism so that only one more neutral unit can be added. When the fourth unit joins the triple group (*c*), it disengages the second hook in the original seed, causing it to come apart in the middle and form two replicas of itself (*d*).



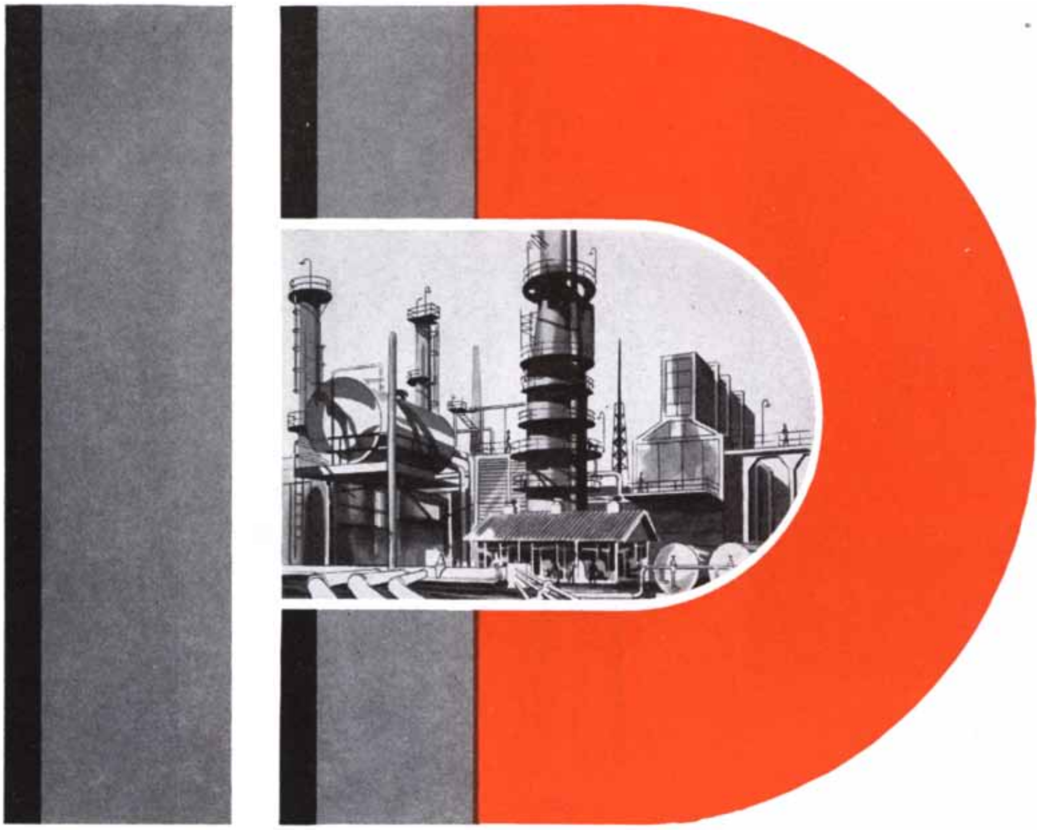
INTERDIGITATING BASES, on which superstructures capable of activation, hooking and release can be mounted, are designed to permit self-reproducing machines to operate in two dimensions and to orient themselves to one another for the purposes of self-reproduction.

each activated unit contains a message, that is, information that it transmits to neutral units. The total quantity of information depends upon the number of tilted levers and sometimes upon other features. The nucleus of a living cell also contains information that enables it to collect and build the substances necessary for its own replication. Natural selection encourages the reproduction of nuclei that have the most efficient information for dealing with their surroundings. In artificial self-reproduction, equivalent programs of information would equip the machine not only to assemble themselves, but to build up their own structures out of their environment, to release energy sources and, in a sense, to provide their own track or table to guide interactions. Such an elaborate scheme is so far unattainable in practice. We have to be content with making a very parasitic organism. It is not, however, much more helpless than a virus. With such an object we can even provide a mechanical demonstration of the role of information in natural selection. To two machines, distinguished by key arrangements of their tilting cam-levers, we present neutral units locked up in a kind of matrix. These food units can be unlocked and brought into circulation by certain arrangements of tilting and not by others. Thus one mechanical creature will be able to unlock a plentiful supply of food while the other will starve and be shown to be relatively unfit in the struggle for self-replication.

Another feature of living things can be incorporated in the self-replicating machine. This is the capacity to change the program of information it transmits to its daughters. Of course change might be introduced by mistakes in reproduction even with well-constructed machines, but this, like genetic mutation in living things, is likely to be unfavorable and must be avoided by an efficient designer. Living organisms, however, exchange parts of their programs in a process known as recombination. In a very elementary form, something like this can be imitated mechanically. Now



GENERALIZED SYSTEM of self-reproduction is based on units of two kinds (*a*). The larger "body" units (*b*) form a live group; the asterisks indicate activated points at which units of the same kind can be added. The group begins to grow (*c*), with a smaller "skin" unit attaching itself at lower right. When units are attached at corresponding points on both sides (*d*), the body units come apart and the skin units also begin to peel off (*e*). With growth completed, the original group splits, yielding two replicas of itself (*f*). As the skin units come loose (*g*) the two daughter groups become activated and are ready to begin the reproduction cycle again.



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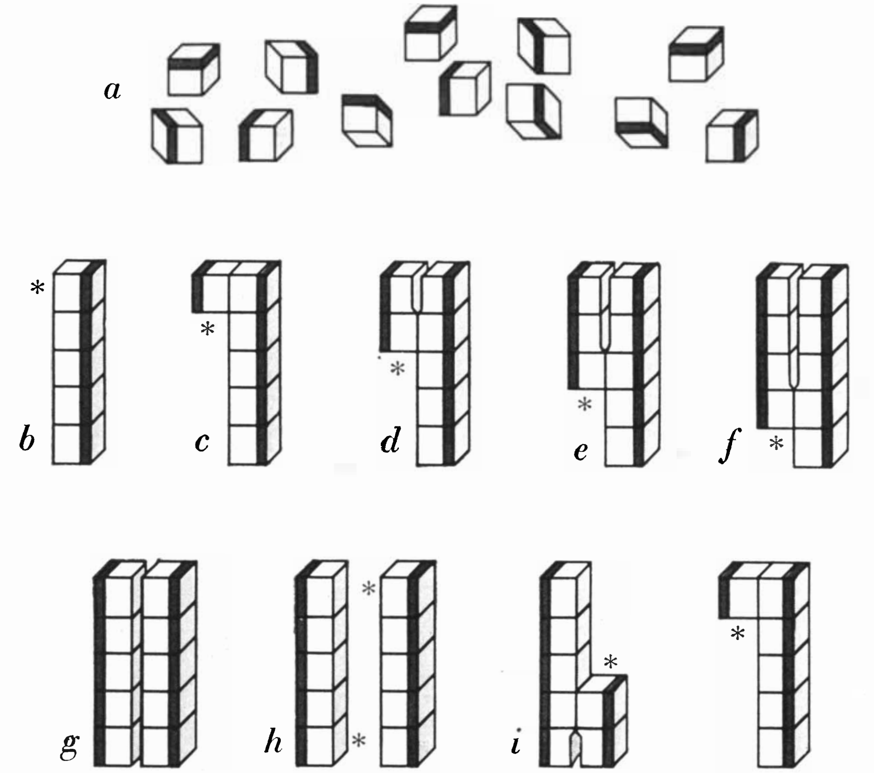
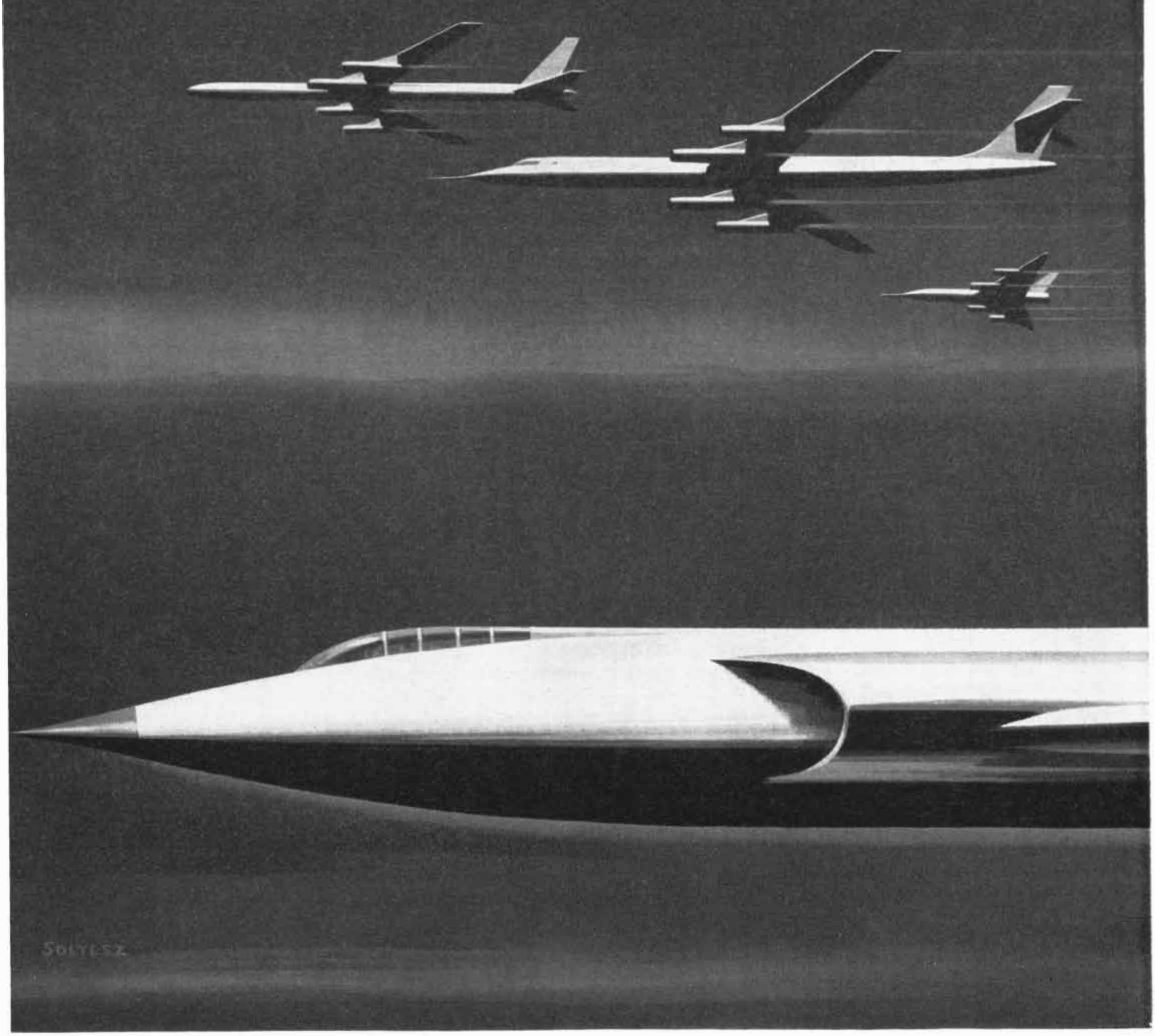


MORE ELEGANT DESIGN for a self-reproducing system is depicted. Identical units (*a*) form a live five-unit group (*b*), activated for growth at the point indicated by asterisk. As growth proceeds (*c*, *d* and *e*) each new unit causes the preceding unit in the new column to become detached from the old. Addition of the last unit (*f*) causes the two groups to come apart (*g*). The activated daughter groups (*h*) now reproduce from neutral units (*i*).

if two machines carrying different programs should stand for a moment side by side, new units, approaching in one particular direction, might pick up their program half from one and half from the other. Thus if the program of one parental complex is described as AA and the other as BB, the new complex generated in these circumstances would have the program AB. This is easy to accomplish with a machine consisting of a single pair of units, but for a chain it presents many mechanical difficulties. These complexes would, in the ordinary way, breed true; only on rare occasions would the pieces come into apposition in the manner that is necessary to produce recombination.

It has been said that the fundamental mechanisms of the biological machine may perhaps be elucidated with the aid of theoretical models. The machines discussed here, however, are not models in this sense. They are machines in their own right, conceived for the specific purpose of self-reproduction. In some ways they may resemble living organisms and, insofar as this is so, they may help to explain how some primitive forms of life originated, maintained themselves and eventually developed into more complex and more stable structures.

Self-reproductive chains of mechanical units may help to explain the way in which nucleic acids in living cells actually replicate. But they are more likely to assist in the understanding of systems of simpler character, like those that must have preceded the nucleic acids in the evolution of life. These structures may have occurred in molecules composed of polysaccharides, amino acids or phosphates. At least we need not suppose that they were anything like as complex as the nucleic acids. Such organic counterparts of the self-replicating machine are not, perhaps, accessible to our observation today in nature. Charles Darwin suggested in 1871 that the spontaneous appearance of very elementary forms of life might still be occurring. But he also pointed out that if a protein compound ready to undergo complex changes were spontaneously produced in the present day, it "would be instantly devoured or absorbed, which would not have been the case before living creatures were formed."



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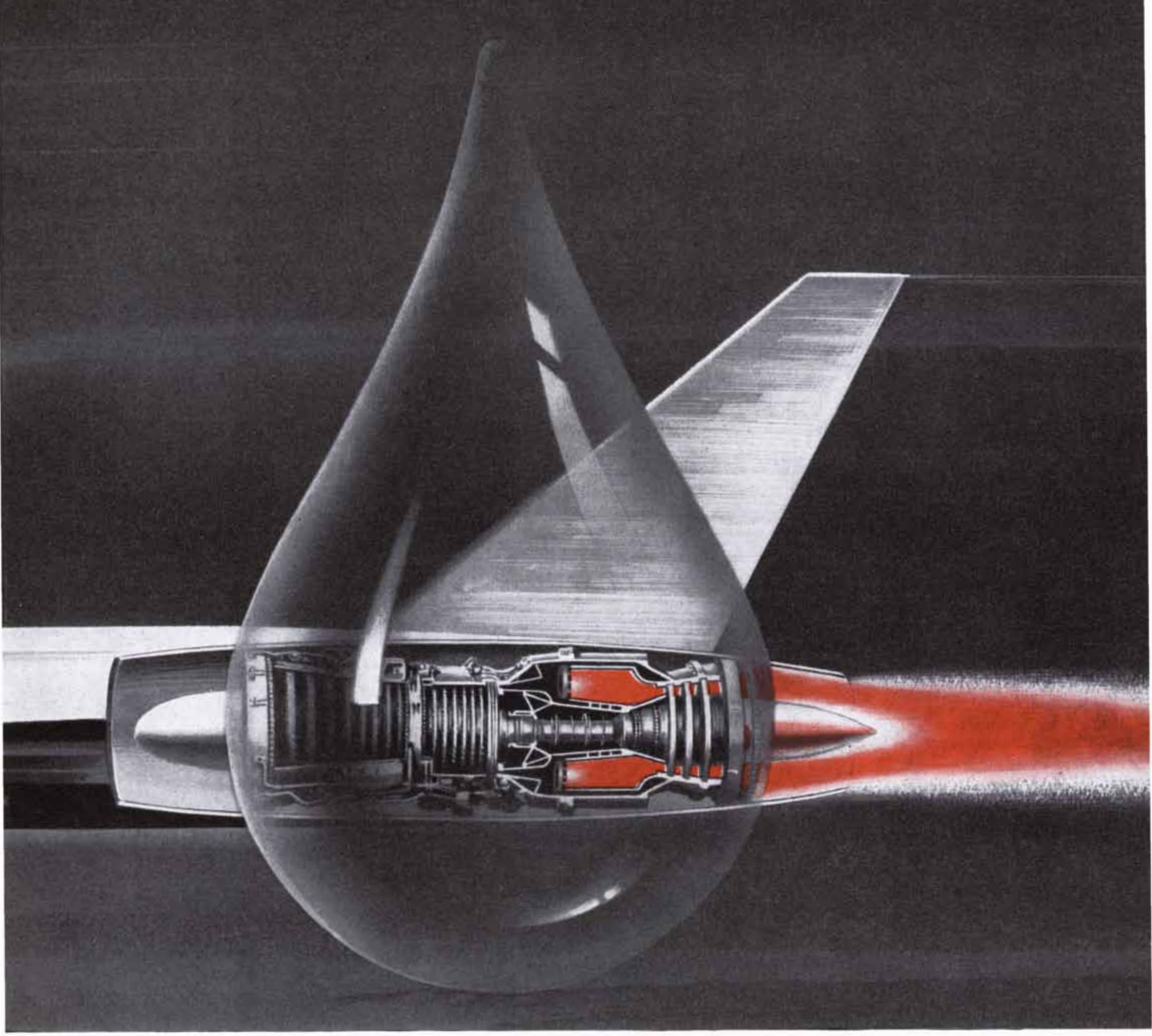


opens the way for new superspeed jets

Junction-Diode Amplifiers

They are simpler than the maser, quieter than the vacuum tube. Their low internal noise permits them to amplify radio signals much too faint for conventional receivers

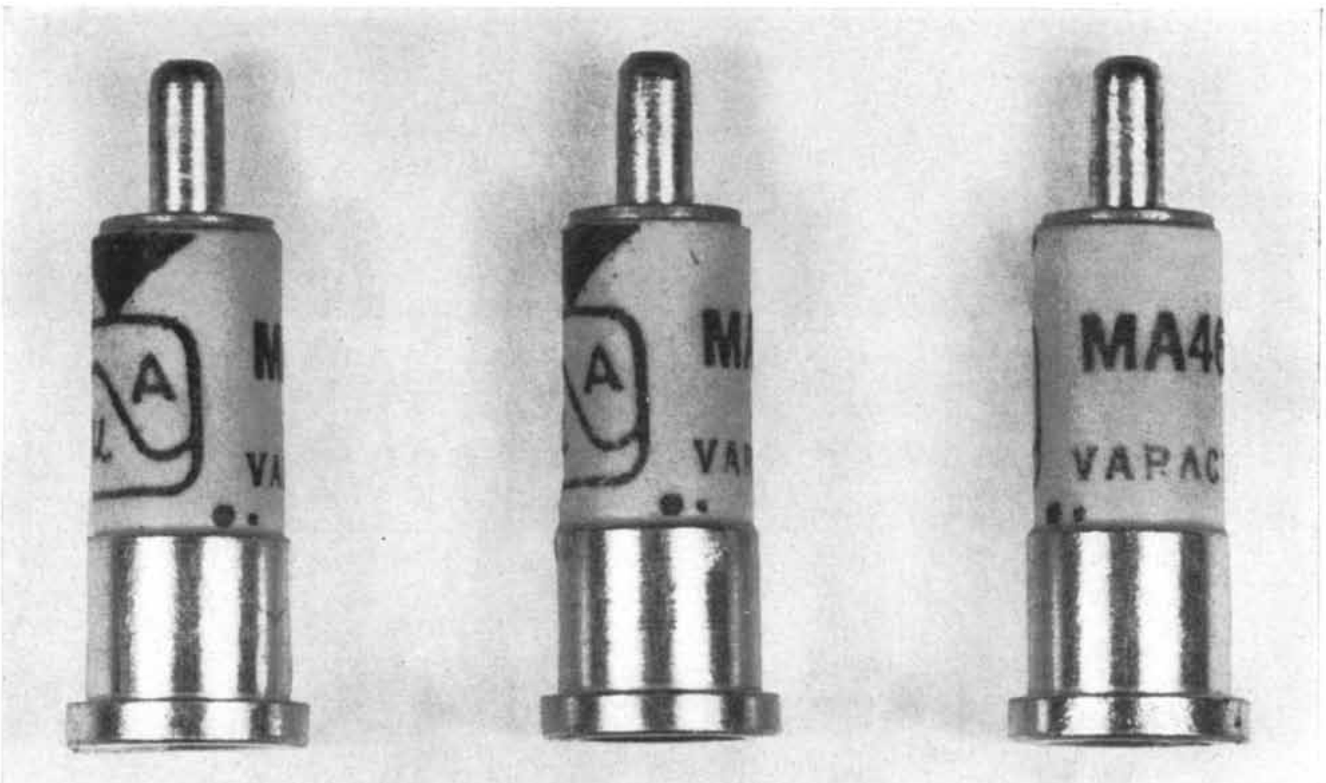
by Arthur Uhlir, Jr.

The faint radio signals of celestial objects, artificial satellites and long-range radar often reach us as no more than whispers from a noisy sky. Once captured by an antenna, these signals must be sharply amplified in a radio receiver. But conventional receivers have an unhappy tendency to generate more radio noise than the sky itself. In such receivers weak signals are often so scrambled with noise that they emerge with their messages distorted or completely drowned out. It is not enough for a receiver amplifier to boost signal strength; it must do its job quietly, without submerging the signal in noise.

A familiar example of radio noise is the "snow" that appears on television screens. Usually noise originates in the three-element vacuum tubes (triodes) employed in the receiver circuit. In vacuum-tube development great pains have been taken to fashion microscopic tube-elements to reduce high-frequency noise. Progress has been good, but the conquest of noise has not yet been granted to the vacuum-tube art.

Recognizing the need for still less noise, researchers have tried radically new approaches. Elaborate solid-state devices known as masers [see "The Maser," by James P. Gordon; Scientific American, December, 1958] have been operated with considerable success. Within the past year the junction diode—a two-element solid-state device—has come into its own as one of the best all-around amplifying devices.

Junction-diode amplifiers are much smaller and less complex than masers, yet they are practical rivals of masers as low-noise amplifiers over a wide



MOUNTED DIODES (*shown greatly magnified*) are roughly the size of a .22-caliber cartridge: about 7/8 inch long and 1/4 inch in diameter. A metal anode-contact extends from the top of the casing; the metal bottom of the casing is the cathode contact.

range of the radio-frequency spectrum. They also have many of the virtues of the well-known transistor: they are cheap, reliable and rugged, and they require very little power. But properly designed junction diodes amplify quietly at much higher frequencies than transistors, which permits their use in long-range radar and in radio telescopes. Junction-diode amplifiers have been used to track a rocket 400,000 miles into space; they have picked up ultrahigh-frequency (UHF) television signals at a distance of 100 miles; and they have now been installed in the giant Jodrell Bank radio telescope in England.

Maser and junction-diode amplifiers share one great advantage in weak-signal reception: they both add very little operating noise to the signals they amplify. Noise is basically caused by the disorganized motion of atoms or electrons. The "sensible" temperature of a device—that is, whether it feels hot or cold to the touch—is a measure of this disordered motion at the microscopic level. Thus the vacuum tube, which has a hot cathode that continuously boils off electrons, starts at a noise disadvantage with respect to junction diodes and transistors, which usually operate at room temperature. These devices are in turn at a noise disadvantage with respect to the maser, which is refrigerated with liquid helium at –268 degrees centigrade.

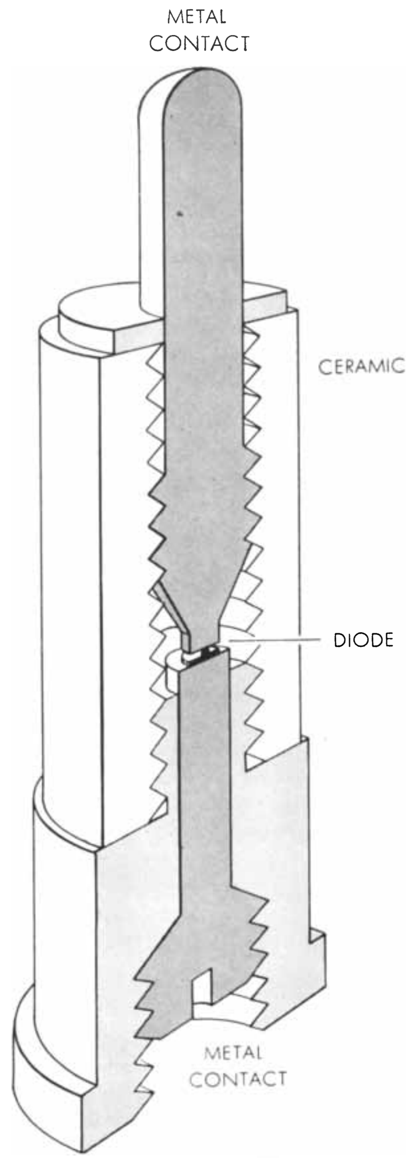
For any device to work as an amplifier, organized motion must be imposed on the basic disorder caused by the thermal motion of its electrons and atoms. The effectiveness of any organizing force depends on the speed of the electrons involved. In a vacuum electrons can move at very high speed, and this speed, in a painstakingly constructed vacuum tube with a very small spacing between cathode and anode, partially compensates for their high temperature. In the semiconductor materials of which most solid-state devices are made, electrons move hundreds of times more slowly than they do in a vacuum. But semiconductor devices can be made much smaller than even the smallest vacuum-tube electrodes, although as yet they cannot be made small enough to compensate for their slower-moving electrons. Thus in spite of their lower operating temperature transistors still generate more noise than vacuum tubes in amplifying high-frequency electrical signals.

How can the junction diodes have such low noise when they are made of the very same semiconducting materials as transistors? Basically it is a matter of size. The distance that electrons travel in transistors must be reduced by cunning techniques to obtain low-noise performance; junction diodes, on the other hand, are inherently free of this limitation because their operation depends on charges moving back and forth in a very narrow area.

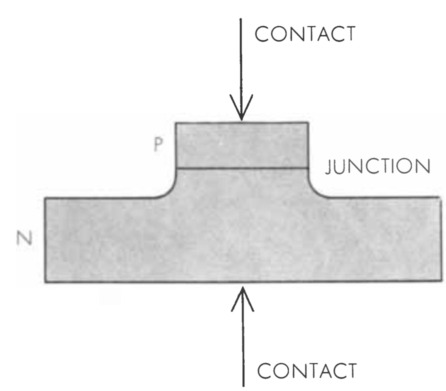
Only in the maser, then, is low noise directly due to low temperature. Present maser materials must be refrigerated to very low temperature to obtain atomic action organized enough for any amplification at all. But at low temperatures the maser is the quietest amplifier ever developed.

In explaining the action of semiconductor and vacuum-tube devices, one can exaggerate the differences between them. Actually, interesting electronic devices can be made from semiconductors because a semiconductor is a solid-state approximation of a vacuum. A perfect vacuum contains no charged particles; neither does a pure semiconductor, in which almost all of the electrons are firmly bound in a crystal lattice. Thermal agitation of the semiconductor lattice will occasionally shake an electron loose and send it bumping through the crystal as a wandering negative charge. The "hole" vacated by the electron will then be positive; it may be filled by another electron, leaving another hole. Thus holes, too, appear to drift through the lattice, as roving positive charges. Thus fundamentally both the vacuum and the semiconductor lattice serve as a medium in which charges can move. In a semiconductor they move more slowly and meet more resistance.

Almost all useful semiconductor devices are made by adding impurities to the crystal which increase the number of mobile charges wandering through it. The number of valence electrons in the added impurity determines whether it will produce a hole or a free electron in the crystal. A "donor" impurity such as phosphorus, which has five valence electrons, will form only four bonds with the four valence electrons of a semiconductor such as silicon, leaving one unbonded electron free to carry current. The phosphorus-doped region will thus have negative (N-type) conductivity. Conversely, an "acceptor" impurity like aluminum has only enough valence electrons to form three bonds, which leaves a hole in the lattice where the fourth bond should be. Another electron can easily fill this hole, bonding the aluminum ion into the lattice and moving the hole. The wandering hole gives the



CUTAWAY VIEW shows how diode and its contacts are arranged inside casing. Diode is only 4/100 inch in diameter.



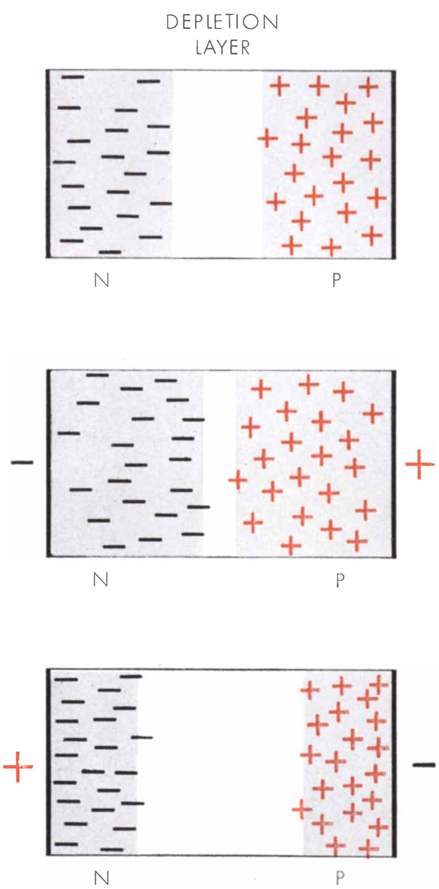
DIODE ITSELF is a silicon crystal divided into positive (P-type) and negative (N-type) areas which contain mobile charges; the junction layer contains no mobile charges.

aluminum-doped region positive (P-type) conductivity.

There are a number of ways to add donor and acceptor impurities to semiconductors. One of the simplest and most satisfactory is solid-state diffusion, in which impurity atoms are applied to the surface of a heated crystal. The heat is not sufficient to melt the crystal, but only to increase the thermal motion of the lattice atoms, permitting the impurity atoms to diffuse through it.

If a donor impurity is diffused into one side of a crystal and an acceptor impurity is diffused into the other, one region of the crystal will have an excess of free electrons and exhibit N-type conduction; the other region will have an excess of holes and exhibit P-type conduction. The boundary between these regions is called a P-N junction.

A transistor is made by adding impurities to form three conducting regions (in either a P-N-P or an N-P-N arrangement) and two P-N junctions. The spacing between them is critical; if the space is wide, the transistor will be noisy. Transistors are triodes whose electrons conduct current by moving through a crystal lattice instead of through a vacuum [see "The Junction Transistor," by Morgan Sparks; SCIENTIFIC AMERICAN, July, 1952].



VOLTAGE APPLIED TO THE DIODE changes width of "depletion layer" at the junction. With no voltage across the diode (*top*), width of depletion layer is constant. A forward voltage (*center*) narrows it; a reverse voltage (*bottom*) makes it wider.

To make a junction diode, only two oppositely charged conducting regions, with a single P-N junction between them, are required [*see illustration at bottom of preceding page*]. A very thin region (typically two millionths of an inch thick in diodes designed for high-frequency amplification) at the junction is free of mobile charges and is called the "depletion layer." The exceedingly small thickness of the depletion layer is one of the features that make junction diodes fast and quiet amplifying devices.

Although the junction diode is made in the same way and from the same materials as a transistor, it has a distinctly different principle of operation. Unlike the transistor, the diode does not falter at the ultrahigh frequencies used in space communication. Like masers, junction diodes must have an external high-frequency power supply, but the diodes do not require refrigeration.

Because junction diodes obtain their power from a high-frequency "pump" oscillator, their circuits differ considerably from the triode circuits used in conventional amplifiers. Of course all amplifiers require a power supply, since they deliver an output signal of greater power than the input. But triodes, either transistors or vacuum tubes, use a direct-current power supply to generate their own high-frequency power. Triodes do this so well, in fact, that they are often used to pump high-frequency energy into diodes. Still, the triodes used in these pump circuits could not by themselves begin to approach the noise performance of the junction diodes as high-frequency amplifiers.

In diode-amplifier circuits, the diode merely controls the pump power in response to a weak incoming signal. The main difference, then, between diode and triode amplifier circuits is that diode circuits have two separate parts: a pump (a high-frequency oscillator) and a control element (the diode itself). Triode amplifiers have only one circuit which must both generate and control high-frequency power. It is not surprising that triodes cannot perform both of these functions as noiselessly as diodes can perform one.

When a high-frequency pump voltage is applied to the terminals of the diode, the thickness of its depletion layer varies [*see illustration on this page*]. As the pump puts a positive potential across the P-type region and a negative potential across the N-type region, the holes and electrons in the diode move toward the junction, narrowing the depletion layer; as the voltage reverses, the charges move toward the ends of the crystal, widening the depletion layer. Because the charges move extremely fast and have less than a millionth of an inch to travel, the time required for the depletion layer to widen or narrow is almost immeasurably small; probably less than 10^{-11} second. This means that the depletion layer can expand and contract millions of times in the time it takes a rifle bullet to travel an inch.

The depletion layer may be compared to the space between the two charged plates of a parallel-plate condenser. If the condenser plates in a simple condenser circuit are rapidly pulled apart and pushed together, current will flow back and forth in the circuit. The energy expended to pull the charged plates apart is put into the circuit, where it is in turn available to do work. If a weak input-signal is fed into the circuit properly, the circuit will amplify the signal by doing work on it. This is approximately what happens in a junction-diode amplifier. The work necessary to widen the depletion layer—analogous to the work required to separate the condenser plates—is done by the powerful high-frequency oscillations of the pump signal. Some of the pump's energy is transferred to a weak input-signal by the diode junction; the resulting output is an amplified signal with the same frequency as that of the input signal. (It is also easy to arrange for the output to have a different frequency.)

To draw another analogy, we may think of the advancing and receding charges in the diode as a ping-pong paddle swinging back and forth very rapidly. The weak input-signal may be compared to a slow-moving ping-pong ball floating toward the paddle. If the ball strikes the paddle at the right instant during its swing, the paddle will whack the ball back in the direction whence it came, but at a much greater speed. In doing this the paddle will transfer some of its energy to the ball in much the same way that the oscillating charges at the junction of the diode transfer some of their energy to a weak microwave-signal. As electrons and holes move back and forth, current flows in the diode circuit. A semiconductor presents a certain amount of resistance to the flow of current. Holes on

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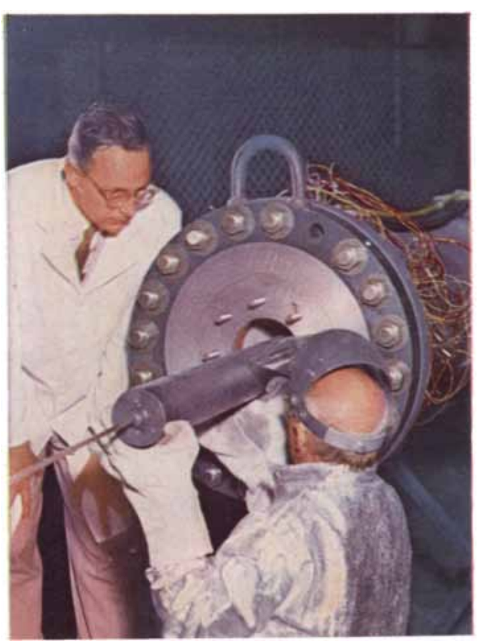

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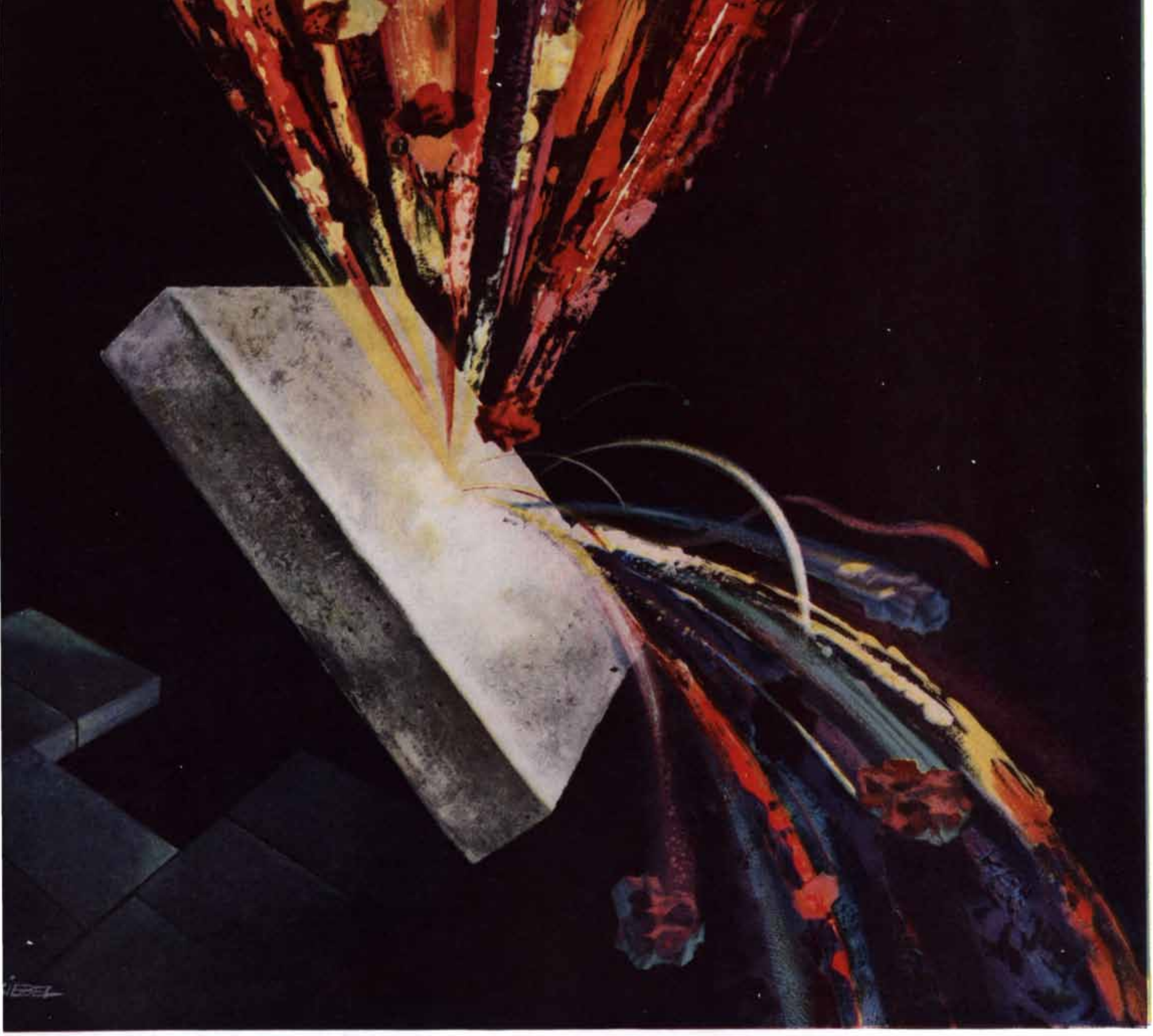

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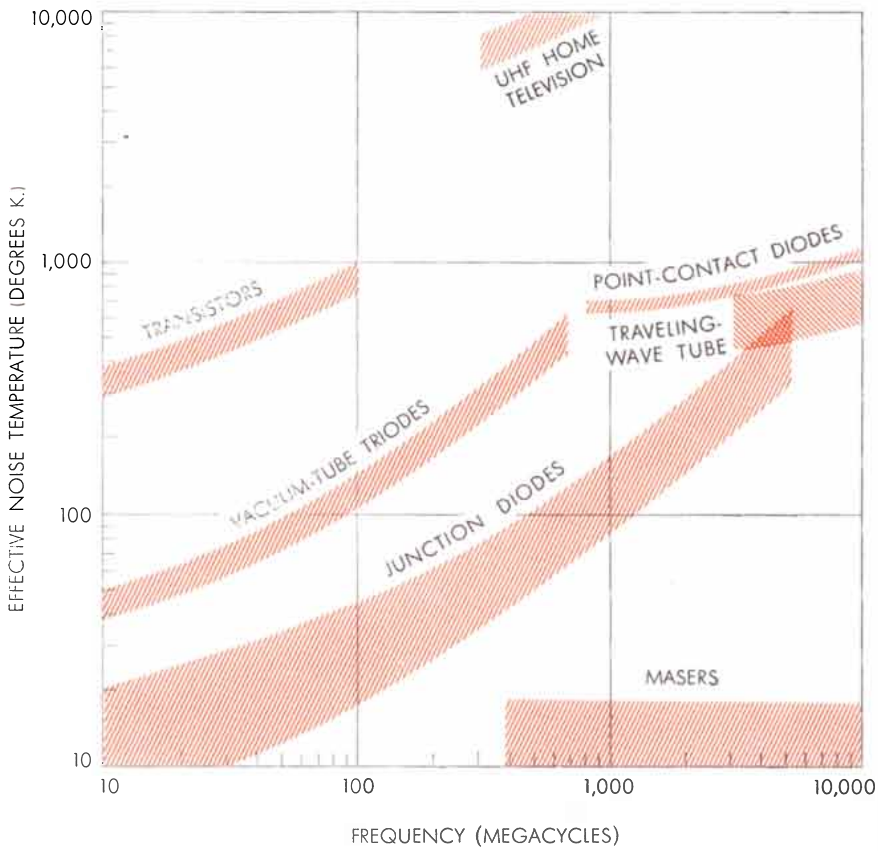


RELATIVE NOISINESS of several different types of amplifiers can be determined by comparing their effective noise temperatures. The only amplifier quieter than junction-diode types at the high frequencies shown above is the maser, which requires refrigeration.

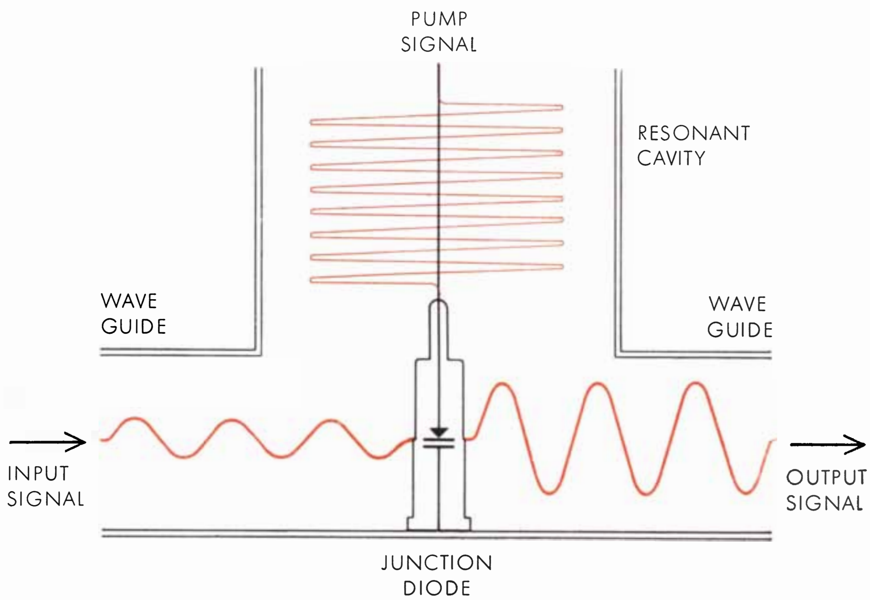
one side of the diode and electrons on the other collide with impurities and with irregularities caused by thermal agitation in the crystal lattice. Charges detouring around these defects in the crystal generate resistive noise, and the resistance dissipates the energy of the signal. Resistance in the diode crystal thus limits the frequency at which diodes can amplify; in present diodes this limit is about 10 kilomegacycles (10^{10} cycles per second).

If the junction diode is to be used at high frequencies, its junction area must be kept quite small; the area of the P-N junction in most of the diodes now in operation is less than the cross section of a human hair. These tiny junctions are more rugged than one might think; they can pass electrical currents of one ampere without damage.

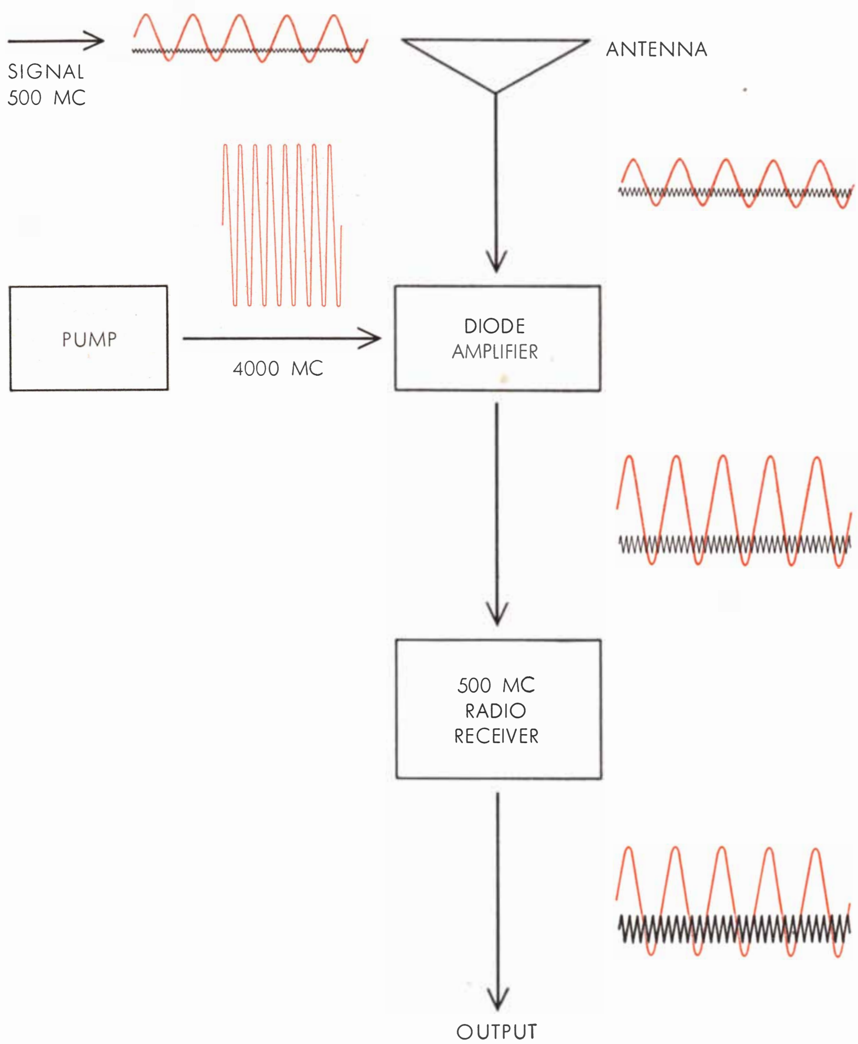
Word-coiners have had a field day with junction-diode amplifiers. Some have called them "reactance amplifiers" or "variable-reactance amplifiers" because circuit elements that store energy are said to have "reactance," in the terminology of the electrical engineer. Junction-diode amplifiers have also been called "parametric amplifiers" and "mavars" ("Modulation Amplification through Variable Reactance"); both of these terms are generally regarded as synonyms for "reactance amplifier." In electronics junction diodes for high-frequency amplification are widely known as "varactors," a name suggested by Marion E. Hines of Bell Telephone Laboratories as a contraction of "variable reactors."

The use of variable reactance for amplification has a long history in the form of magnetic amplifiers for amplifying low-frequency signals. These devices are physically similar to ordinary transformers having one or more coils of wire wound around an iron core. Such magnetic amplifiers may antedate even the vacuum tube, and still have many present-day applications.

The first amplifiers that employed semiconductor diodes were built with germanium diodes made by Harper Q. North of the General Electric Company in connection with World War II radar work. The physical mechanism involved was correctly interpreted, and duly reported as an interesting and promising phenomenon. No appreciable use was



SIMPLE DIODE-AMPLIFIER consists of diode (*shown schematically*) mounted in a tuned resonant cavity. The rapidly changing pump voltage forces the electrons and holes in the diode to vibrate back and forth, which permits the diode to store energy like a movable-plate condenser. The diode uses this stored energy to amplify a weak incoming signal.



SOURCES OF INTERNAL NOISE in radio receivers tend to drown out weak input-signals. Each component adds its operating noise (*black wave*) to the signal (*colored wave*) passing through it. This noise is cumulative; once added, signal and noise are amplified together.

made of the discovery, however, until Bell Laboratories installed germanium-diode amplifiers in a transmitting modulator of a microwave-relay system in 1956. Then a Bell Laboratories group under Robert M. Ryder (of which I was a member) began the development of the diffused-silicon diode as a low-noise amplifying device under a U. S. Army Signal Corps contract for improving the noise performance of radar receivers. The fabrication and evaluation of the first such unit was done by A. E. Bakanowski. The early results were described in the summer of 1957 to a conference of semiconductor-device engineers, who regarded the proposal with interest but were skeptical about its low-noise properties. In the months that followed, experiments at Bell Laboratories, at Stanford University, and at Airborne Instruments Laboratory confirmed that the noise level was indeed low.

The measurement of noise in experimental amplifiers can be very tricky, however, so it was important to see how these amplifiers worked as radio receivers, if indeed they worked at all. So far as is known, the first person to put a junction-diode amplifier to practical use was F. S. Harris, a radio amateur on the staff of Microwave Associates, Inc. He built his own amplifier and tried it out in receiving ordinary radio signals. He found that it worked very well indeed. Then he aimed his amateur antenna at an ultrahigh-frequency (UHF) television transmitter 100 miles away. An ordinary UHF television set connected to this antenna would barely produce an image. With superb close-spaced vacuum-tube triodes a faint picture could be brought in. But with the diode amplifier the picture was still better—as good as one ordinarily receives with a local UHF television station. Thus low noise was proved in the actual reception of information. Furthermore, it was shown that this very different type of amplifier did not mangle the signal in some peculiarly unpredicted fashion, as might well have been the case had the theory and the laboratory experiments overlooked some small but fatal point.

Among the laboratory experimenters M. Uenohara and G. F. Herrmann of Bell Telephone Laboratories deserve special mention. They made a diode amplifier for a wavelength of five centimeters (6,000 megacycles). Theoretical calculations suggest that they obtained very nearly the ultimate performance that the present diodes can yield and that extensions to appreciably shorter wavelengths will require improved diodes. At longer

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Suspension wire is made from gold, platinum, or silver alloy ribbon.

POLE PIECES

Pole pieces are mounted in case adjacent to the coil. Permits rotation.

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Aging process minimizes mechanical defects, such as, permanent zero shift and balance defects, which otherwise might occur after the galvanometer has been in use.

DAMPING

Model 210 galvanometers are normally damped to 64% of critical.

MAGNETIC ASSEMBLY

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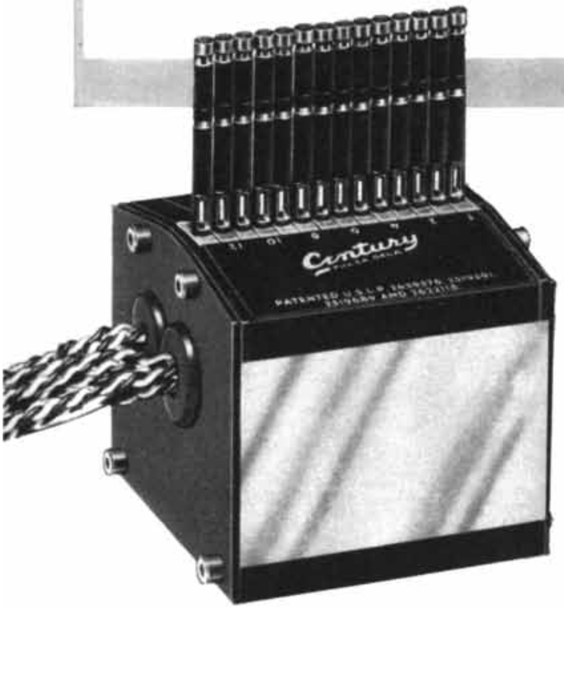
PHYSICAL CHARACTERISTICS

Mirror: Cylindrical, focal lengths 5.88″ or 3.1″
Size: 2.5″ length; .125″ diameter.
Weight: 0.11 oz.
Mounting: Plug in—no external wire connection.
Pole Pieces: Integral with tubular case, except in fluid damped units.
Terminals: Within magnetic assembly. All elements are electrically isolated.
Balance Factor: 0.008 inch per g at 12 inches.



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Electrical connection to the moving coil is made through the tip and a lower portion of the galvanometer case. These surfaces mate automatically with positive leaf spring contacts in the magnetic assembly as the galvanometer is being installed. Twisted pairs of lead wires extend from the leaf spring contacts through one end of the magnetic assembly to the source of excitation. All contact surfaces are gold over silver plate to assure minimum contact resistance.

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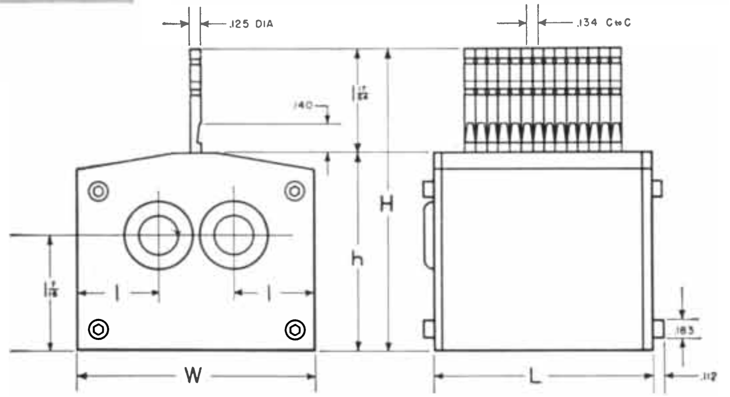
110C102-1	18	2 3/4	3 11/16	2 27/64	2 29/32	18″
110C103-1	24	3 35/64	3 11/16	2 27/64	2 29/32	18″
110C104-1	30	2 23/64	3 11/16	2 27/64	2 29/32	18″
110C200	2	1 9/64	3 11/16	2 27/64	2 29/32	24″
109C100	14	2 9/64	3 15/64	1 31/32	2 1/4	5″



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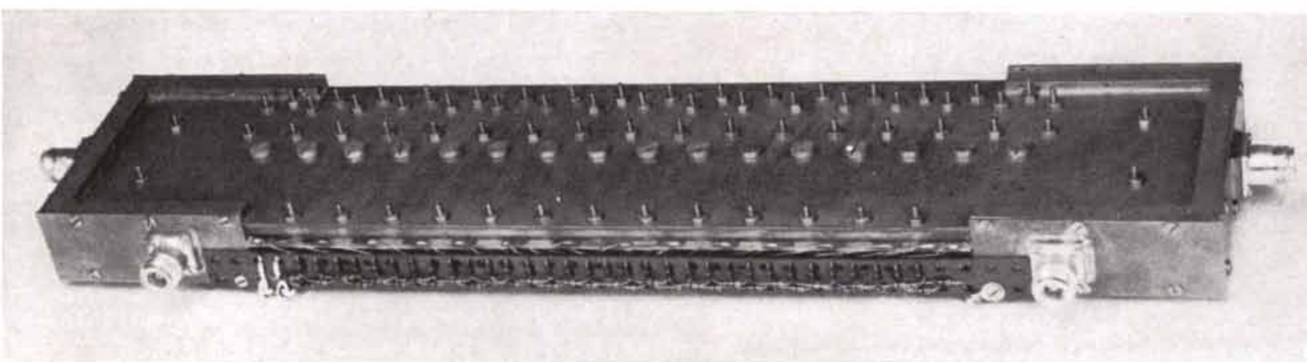
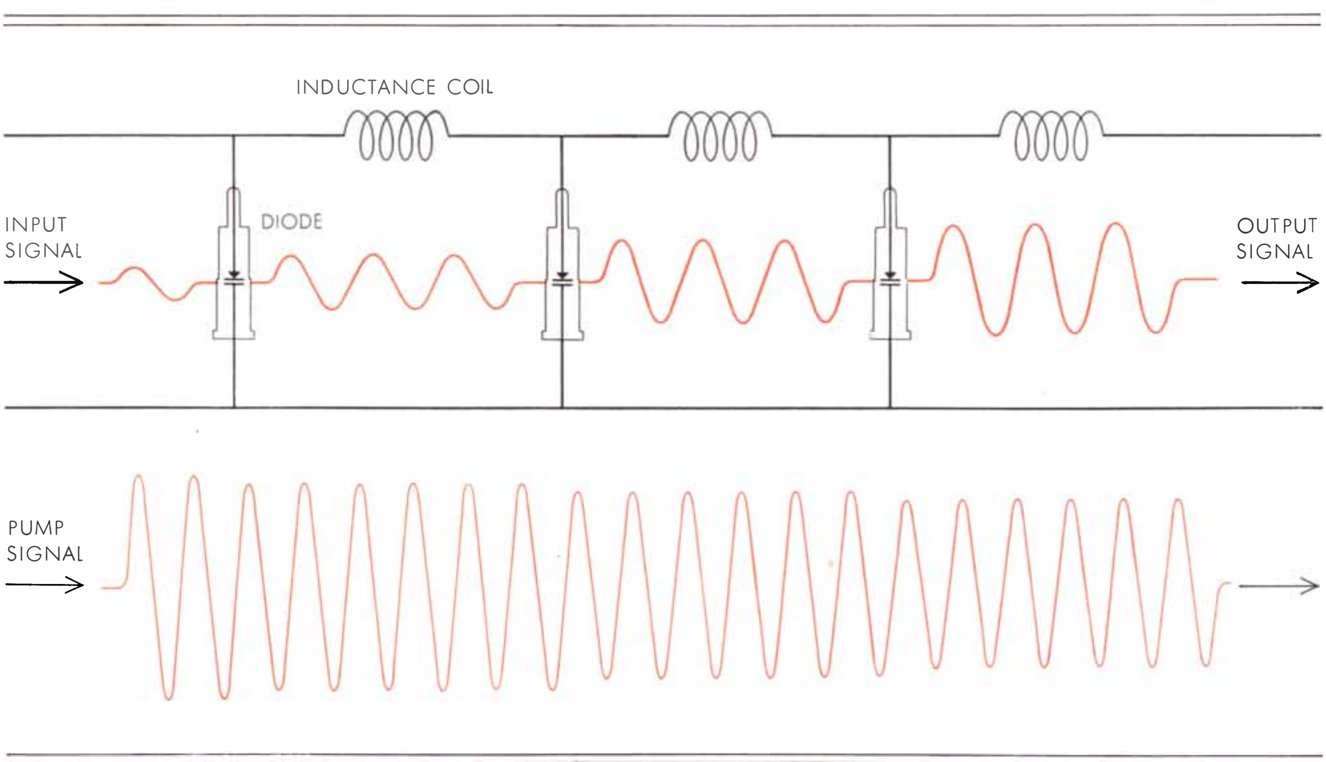
wavelengths (lower frequencies) the diode amplifier becomes increasingly easy to use, and thus it covers a wide range of the radio spectrum. For wavelengths longer than about 10 meters, diodes, transistors and vacuum tubes all operate quietly enough for most radio reception purposes, and the choice of device depends on other properties.

Most radio signals reach the amplifier mixed with sky noise which originates in such radio disturbances as lightning, the aurora, solar storms and the many celestial radio emitters within and without our galaxy. There are a few things that can be done to avoid some of this noise. For example, we can transmit our man-made signals on frequencies where natural noise is lowest. This is one consideration in the choice of a radar frequency—a relatively important consideration now that receiver noise can be reduced by junction-diode amplifiers. The sky is also quieter in some directions than in others; although we do not always have a choice we would prefer to aim our antennas toward the galactic pole, where there are fewer stars or interstellar gas-clouds to set up a radio din. In the past receivers have generally been noisier than the sky. When a faint input-signal nearly saturated with sky noise is picked up by an antenna, the antenna and its lead-in lines add their noise to it and forward the signal to the amplifier [*see illustration at bottom of page 124*]. The amplifier multiplies both the signal and noise strength, and adds its noise to the signal before feeding it to the rest of the receiver.

If the original input-signal stands out strongly against its radio background—in other words, if the input signal-to-





DIODE TRAVELING-WAVE AMPLIFIER consists of a series of junction diodes mounted in the path of the signal, so that input signal and the much-stronger pump signal traverse the circuit together; at each successive diode the weak signal is amplified, becoming progressively stronger as the pump signal becomes weaker. Traveling-wave amplifiers can handle a much wider range of frequencies than simpler types containing only one or two diodes, and thus they have a much greater information-handling capacity.

noise ratio is high—chances are that the output signal, even with the burden of noise added at the receiver, will still be intelligible. On the other hand, very faint signals—radar echoes from Venus, say—can tolerate almost no additional noise burden. Thus low noise in a receiving amplifier becomes more important than high gain (amplifying power).

It is possible to measure amplifier noise quantitatively. An index of noisiness is "effective temperature," which is given in degrees Kelvin (degrees centigrade above absolute zero), with zero degrees equivalent to no noise at all. Junction diodes at room temperature (about 300 degrees Kelvin), can amplify with effective temperatures of 50 to 100 degrees at most frequencies used in long-range radar-tracking, satellite transmission and television.

In long-range radar-tracking the substitution of a 75 degree-K. junction-diode amplifier for a 500 degree-K. vacuum-tube amplifier will increase the range by 30 per cent if the combined sky noise and antenna losses have a typical noise temperature of 150 degrees K. When the object being tracked has its own radio transmitter, the relative improvement is greater; in this case, the range would be increased 70 per cent. Junction diodes developed by our group at Microwave Associates, Inc., were used by the General Electric Company tracking station at Schenectady to receive signals from the Pioneer IV satellite at a distance of 410,000 miles.

For reasons of cost, commercial UHF television receivers do not contain the expensive vacuum tubes necessary for 500-degree noise temperatures; generally their noise temperatures range from 10,000 to 20,000 degrees. Noise reductions of 100-fold are therefore predictable for these receivers, since diode amplifiers can be made economically that will have far lower noise than vacuum tubes.

While most of the early experimenters used just one diode in an amplifier, R. S. Engelbrecht of Bell Telephone Laboratories built a multiple-diode amplifier using the traveling-wave principle. The bottom illustration on page 126 shows how input microwaves travel beside pump microwaves, and how the input is amplified stepwise by each successive diode. The advantage of this type of amplifier is that it can respond to a wide range of signal frequencies, thus giving it great information-handling capacity.

In speculating about the future applications of junction diodes, we should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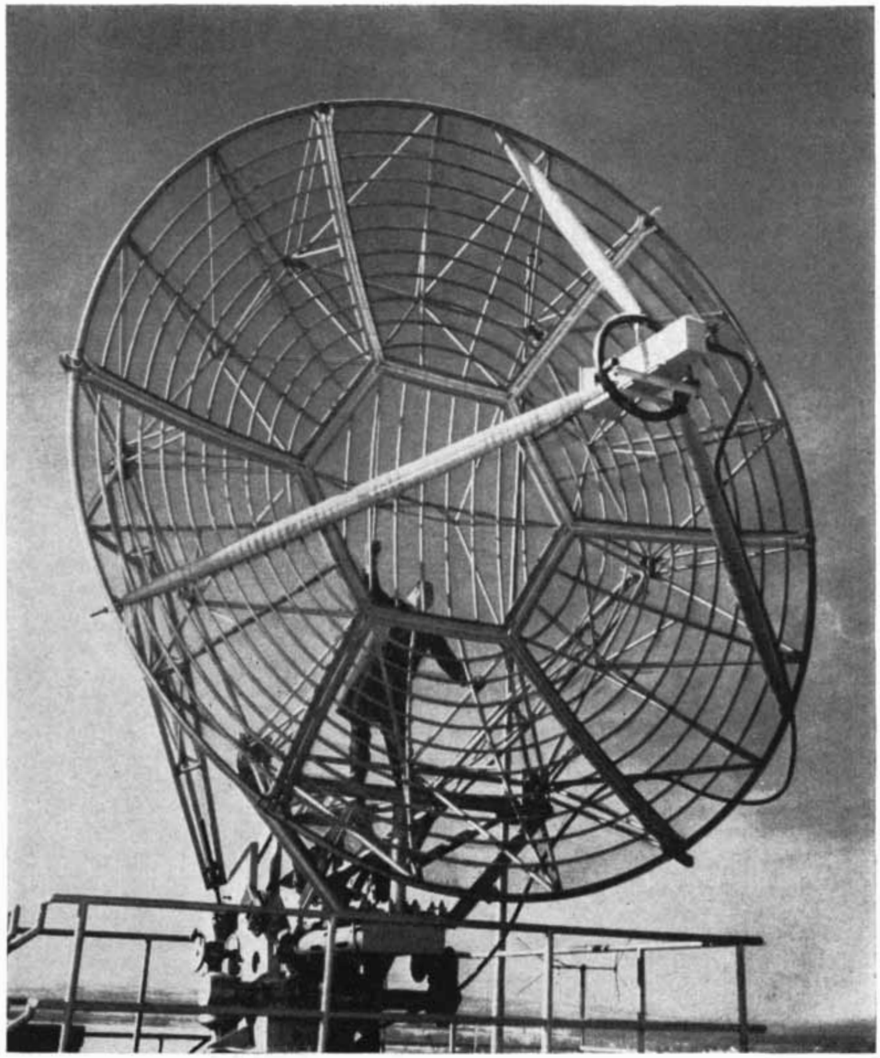
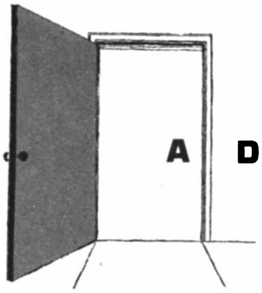


EIGHTEEN-FOOT PARABOLIC ANTENNA coupled with a junction-diode amplifier picked up the radio signals transmitted by the Pioneer IV lunar probe more than 400,000 miles away. The antenna is located at the General Electric Company in Schenectady, N. Y.

mention the proposal of the late John von Neumann for digital computers that could operate 1,000 times faster than present computers. In them we would use diode amplifiers as oscillators. It is well known that oscillators can be made from amplifiers by feeding their output signal back into the input.

Because of their excellent high-frequency response, the diodes in our computer could be pumped with signals far higher in frequency than those presently used in digital computers. In a tuned circuit with a resonant frequency exactly half the pump frequency, the diodes would oscillate at a frequency just one half that of the pump. Such oscillations can take place in two equivalent but distinguishable ways, 180 degrees out of phase. The two states of oscillation could be used to denote the binary digits 0 and 1. Von Neumann has shown that such oscillators could be interconnected to construct a complete logical machine.

Junction-diode amplifiers will also have many applications in the bowels of electronic apparatus in ways that will not affect external performance, but will rather achieve great simplification, improved reliability and reduced power consumption. There are many uses for junction diodes in high-frequency circuits that can be worked out on paper from the supposedly known properties of the diodes. In cases where laboratory work has carefully followed the calculated prescription, the circuit performance has been in remarkable accord with prediction. But laboratory experiments that range off the beaten path are already turning up effects that are difficult to explain theoretically. Some of the new phenomena, when understood, will probably extend the command of high-frequency radio that is offered by the junction diode.



A DOOR IS OPENED... TO NEW ADVANCES IN MISSILE PROPELLANTS

". . . a high throughput, lightweight flying chemical process plant in which quantities up to the order of a ton per second of liquid (or solid) reactants are converted to hot gaseous products at a precise, automatically controlled rate."

BY NOW YOU'VE PROBABLY GUESSED that the first paragraph is a description of a rocket engine from the chemist's point of view.* Of course, there are other viewpoints, such as those of the electronics expert, or the airframe specialist. Chemicals, however, are a specialty with us, and we would like to stick to that side of the subject and cover a few of the more interesting developments in propellants for the "flying chemical process plant."

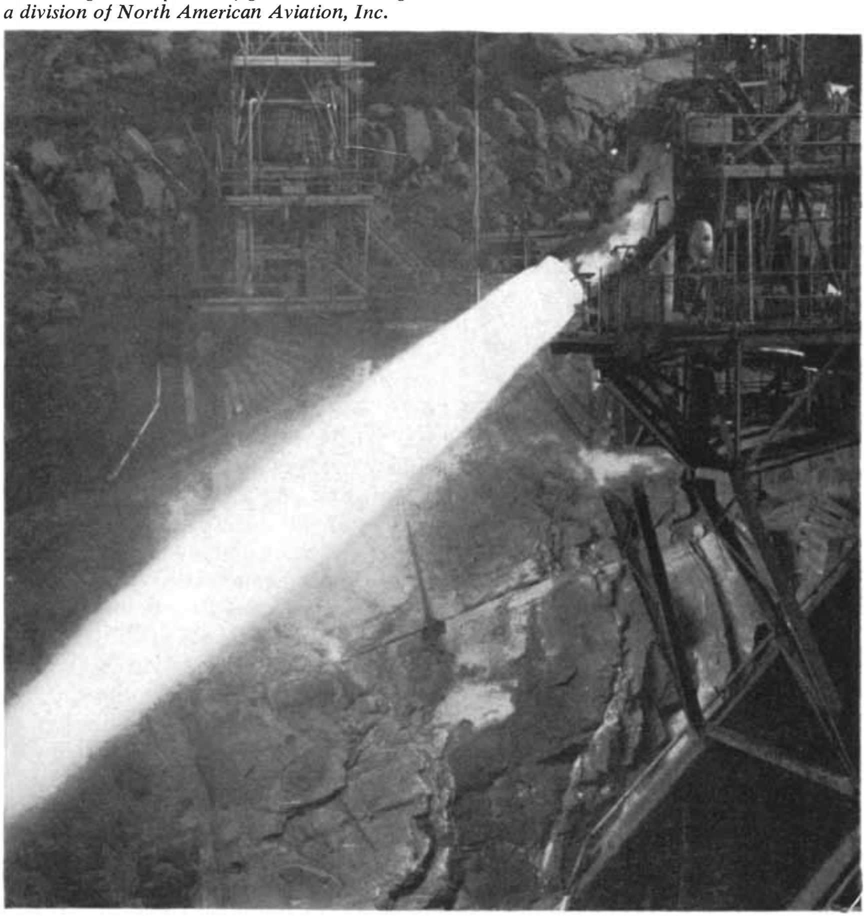
A good starting point is the question of solid and liquid fuels. Generally speaking, most solid fuels have good storability. However, we're glad to say that you can also get excellent storability with some liquids. Chlorine trifluoride and nitrogen tetroxide, for example, require no refrigeration and have been stored without difficulties for a period of over ten years. They can be shipped easily in ordinary steel containers. Both of these liquids are excellent storable oxidizers, each having certain advantages for specific missions. Let's look at some of the more important characteristics of N_2O_4. It is an effective oxidizer which can be used with most fuels, including those containing carbon. And it's effective because of high combustion efficiency. This is especially important. Generally, we feel lucky if most oxidizers reach within 90% of theoretical Isp during combustion. N_2O_4 hits well over 95% efficiency during actual combustion. In addition, count-down can be reduced to seconds with nitrogen tetroxide as an oxidizer. Since it is hypergolic with amine-type fuels, ignition is simple and reliable. Ignition delay is so brief you eliminate rough starts due to accumulation of unreacted propellants in the thrust chamber. Moreover, motors burning such propellants are throttleable.

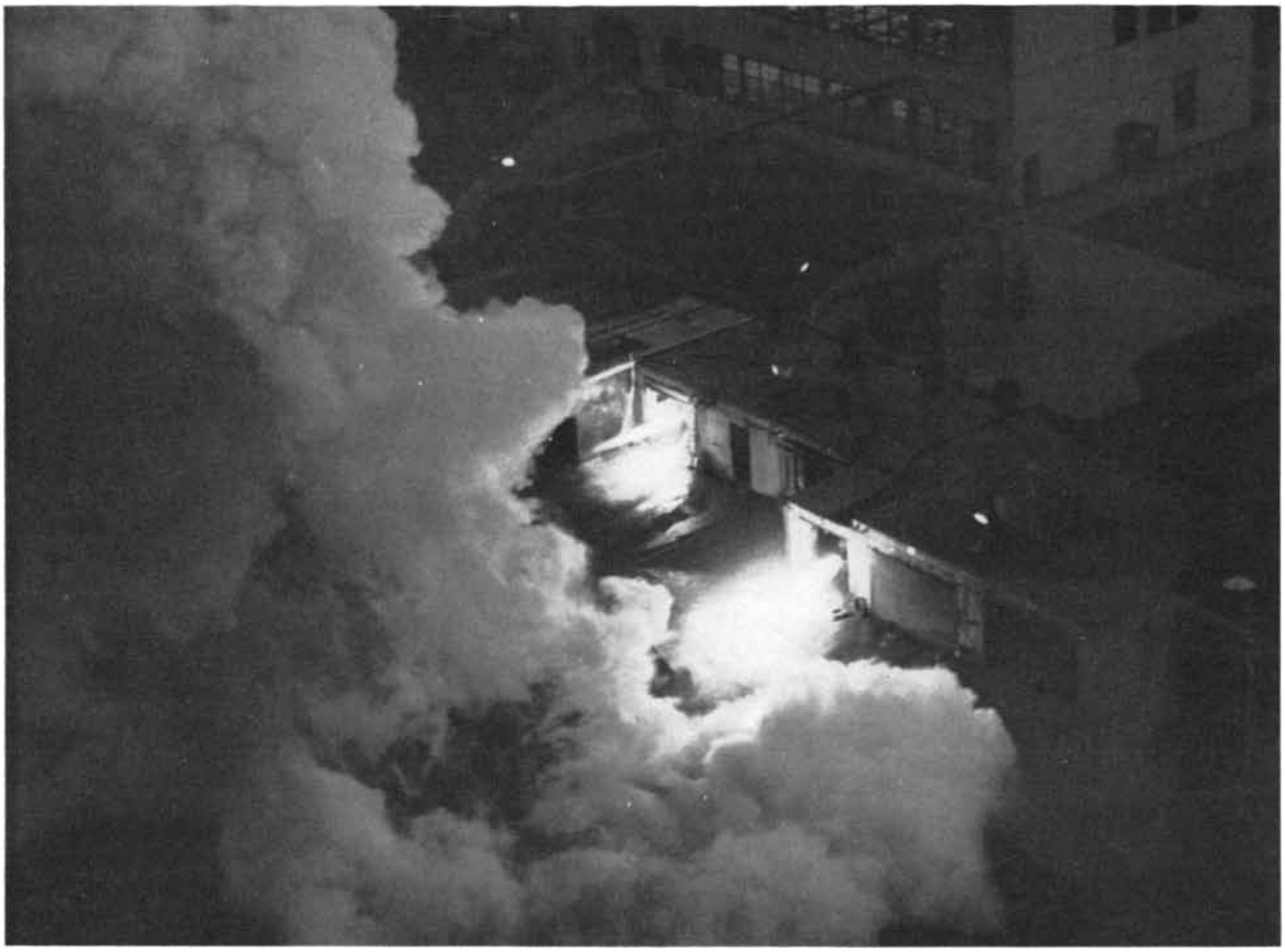
All of this makes our chemists pleased with the product—a chemical which they really know and understand because we have produced it *commercially* (we deliberately italicized) for more than 10 years at our Nitrogen Division. If you are in the missile business and looking for a storable oxidizer, why not check with us? We have special 125-lb. and 2,000-lb. cylinders available for experimental purposes. And if you feel that's rushing it, we also have plenty of literature, including a 59-page Product Bulletin that covers everything from applications and physical properties to specifications and a bibliography.

THE BATTLE FOR THRUST OR Isp. In addition to nitrogen tetroxide and chlorine fluoride, another entry creating more and more interest in the propellant field is fluorine. Our chemists point out that fluorine is not suited for *all* missiles. But for any space projects or other special missions where ultrahigh performance is needed, they feel fluorine is worth investigating. There have been published reports, for example, that booster rocket systems for a manned satellite laboratory would consist of a 321,000-lb. thrust engine burning a hydrogen-fluorine combination for 200 seconds. This is only one of several possible applications. Naturally, the question of handling arises. Here's an area where experience counts—and that's where our General Chemical Division enters the picture.

Fluorine, as you know, once presented seemingly insurmountable problems in handling and transportation. Our research people of the General Chemical Division,

Measuring rocket power of guided missile engine in static test stand at Rocketdyne, a division of North American Aviation, Inc.



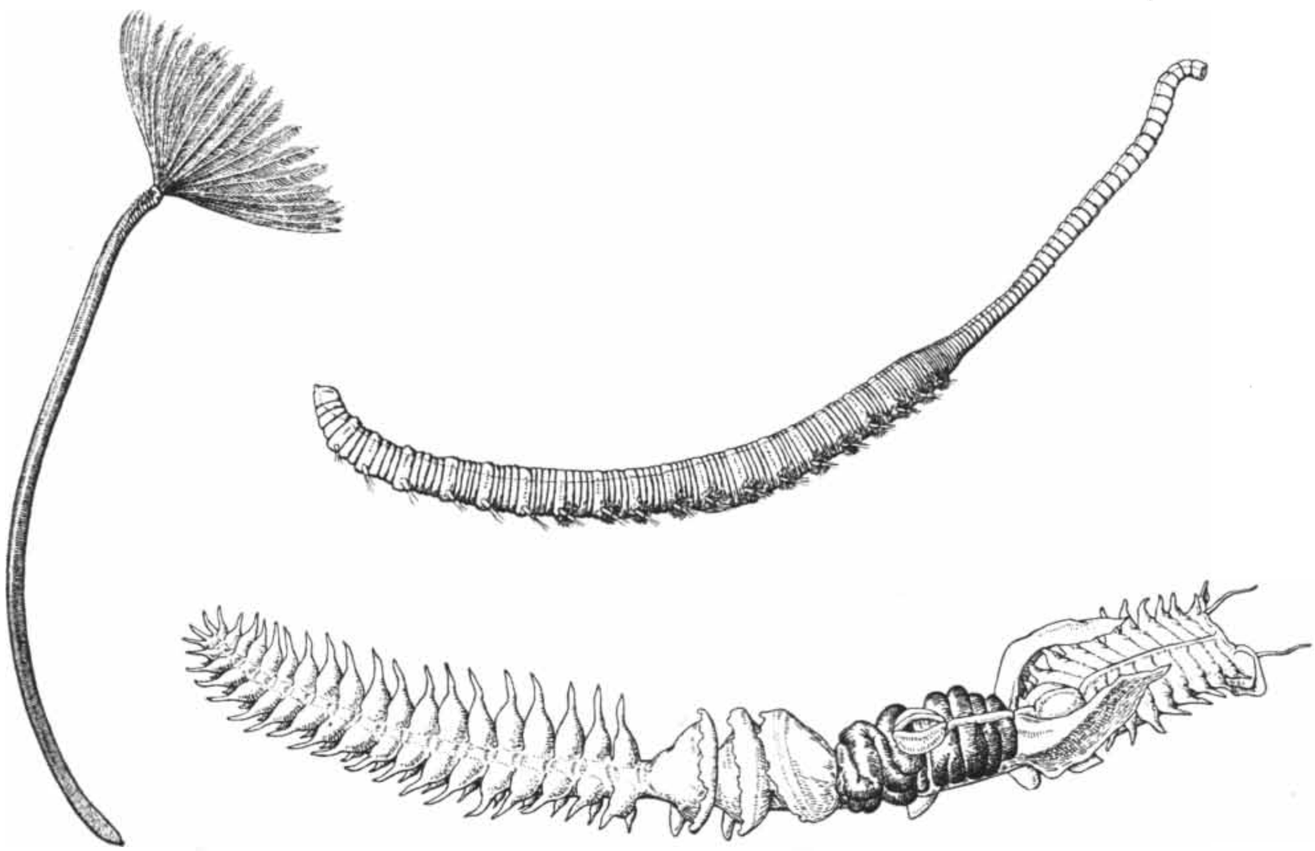


Worm Autobiographies

In which certain marine worms record their own activities on a revolving drum. Because these activities are relatively simple, they provide a convenient means of studying biological rhythms

by G. P. Wells

To study how a worm spends its time may seem a waste of one's own. But if the object is to observe the undisturbed behavior of an animal in something like its natural habitat, and to keep it under continuous observation for long periods, we can hardly find a more convenient subject. The great merit of the worm is that it does so little and does it slowly. A higher animal, like a bird, does so much so fast that anything approaching a complete record of its behavior is well-nigh unobtainable. As a matter of fact, it is nearly always easier to stimulate an animal and watch its reaction in some experiment contrived in the laboratory than to discover how it spends its time when left in peace. Even in the field the almost unavoidable interaction of the observer and the observed may be such that the behavior ceases to be natural. But worms are remarkably indifferent; their simple sense organs make it easy for the observer to remain unobserved. Above all, certain marine worms can be persuaded to write on paper a continuous record of what they are doing and to write it for days and weeks on end, while living their normal lives. To see how their lives are organized and to comprehend the springs of their behavior, we have only to learn to read their writing.



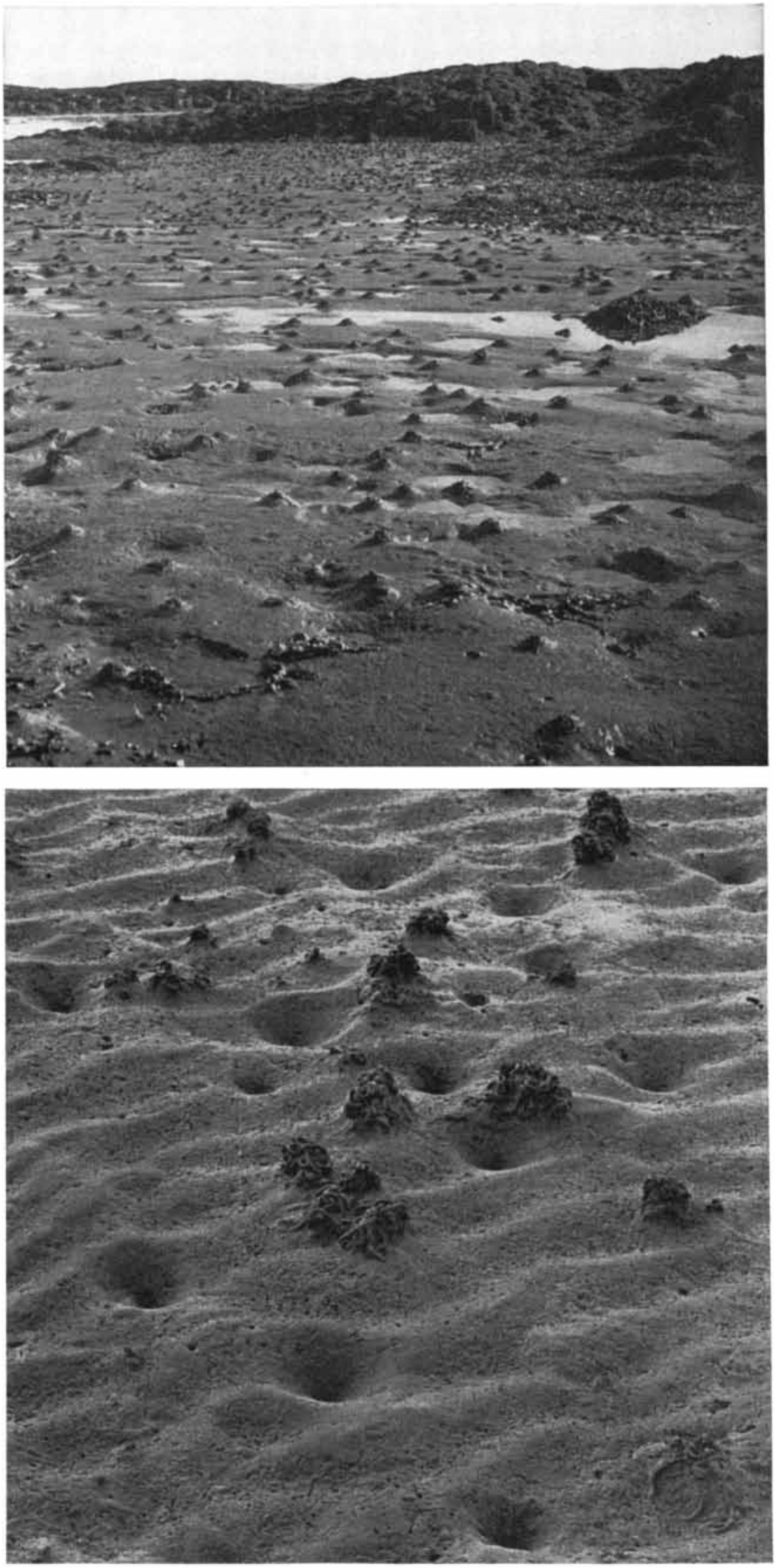
MARINE WORMS used in the author's experiments are the lugworm *Arenicola marina* (*center*), *Chaetopterus* (*bottom*), and the feather-duster worm *Sabella pavonina* (*left*). The bodies of *Sabella* and *Chaetopterus* are usually hidden in tubes of their own making.

Observations in the laboratory have led many writers to describe animal behavior as if it were a series of mere reflex responses, either to stimuli from without or to such inner urgencies as an empty stomach or a full rectum. A well-known college text refers to "that series of responses which constitutes an animal's behavior." Our knowledge of the organism's own contribution to the patterning of its life is comparatively backward, but in the accounts that worms are now able to give us of their lives we can clearly see that the organism is not so abject a slave of its environment as has been supposed.

In Britain, wherever flat beaches of muddy sand are exposed at low tide, one may see thousands of little coiled ropes of sand, up to 30 or 40 per square yard over vast stretches of beach. Each of these coils consists of sand that has been swallowed by a lugworm (*Arenicola marina*), robbed of its nutritious ingredients by the worm's digestive juices, then shot out on the surface of the beach, much as toothpaste may be squirted from a tube. One can find similar castings, and closely related worms, on suitable beaches all around the world. The lugworm is commonly about the size of a fountain pen, and its color may be anything from pink through greenish brown to nearly black. It has a thin tail, used in ejecting the sand-coil onto the surface, and 13 pairs of tufted gills, crimson because the blood contains a hemoglobin rather like our own. The worm leads a sheltered life in a U-shaped burrow underground, staying there for weeks or even months if conditions are favorable. It feeds at the lower end of one arm of the "U," the so-called head shaft, ingesting a column of sand that slides downward as fast as it is consumed, supplying the worm with food in the form of microorganisms and organic matter left by each receding tide.

The lugworm spawns for the first time at two years of age and normally lives to spawn a second time a year later. Then, in most cases at least, it dies. But in this article we are not so much concerned with the crises and climaxes of its life as with its ordinary day-to-day activities.

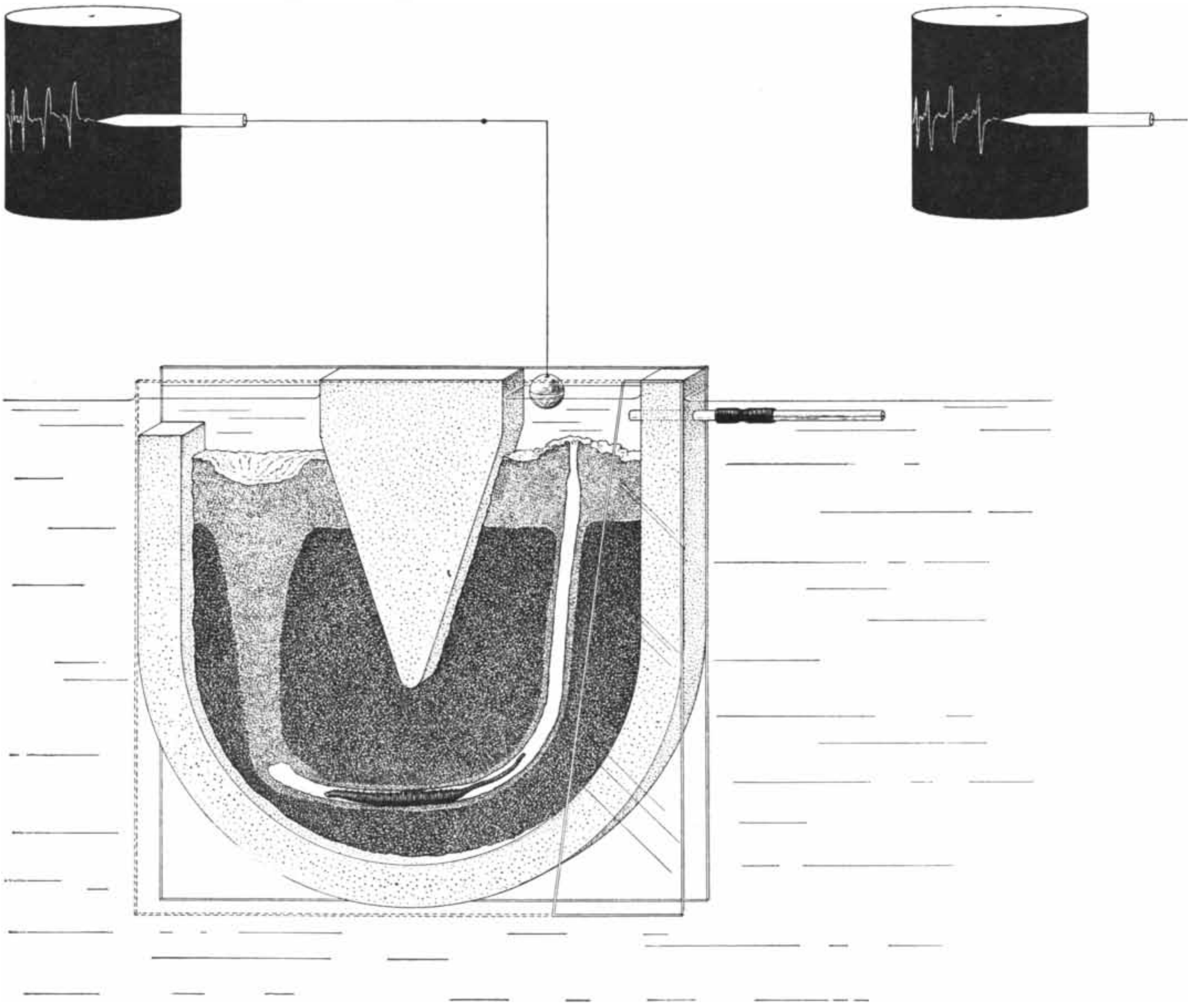
To make the worm record its activities in the laboratory we use the apparatus depicted at left on the next two pages. This consists of two glass plates, each 15 inches square, held about a half-inch apart by pieces of modeling clay, one forming a lopsided U, the other providing a semipartition inside the U.



BEACH OF MUDDY SAND, photographed in Britain by D. P. Wilson, is covered with the mounds and depressions marking the burrows of lugworms. Sand falls into the head end of a burrow, is swallowed by the worm and is ejected in toothpaste-like coils at tail end.

The space between the plates is nearly filled with sand, and the resulting vivarium is immersed in a tank of sea water. A worm placed on the sand digs itself in and presently sets up a burrow which, if the dimensions of the worm and apparatus are properly matched, reaches its two arms up on either side of the partition. Soon castings begin to appear on one side and the sand surface subsides on the other. On the head-shaft side of the partition, water flows freely into the vivarium from the outer tank. On the tail-shaft side, however, the exchange of water with the outer tank is through a glass capillary; the water level on this side thus rises or falls very slightly in response to the worm's activities in its burrow. A float communicates the fluctuation of water level via a lever to a stylus that scratches a continuous record on a drum of smoked paper. The drum turns very slowly: about one revolution per day, or even per week. In this setup the animal is free to do what it likes in tolerably congenial surroundings; almost anything it does will cause a displacement of water and so leave its mark on the tracing. The only experimental interference (apart from the probably unimportant constraint caused by the narrowness of the vivarium) is the imperceptibly small resistance placed on the worm's water currents.

The lugworm, even in its natural habitat, has few activities to occupy it. After feeding for a time it creeps backward up the tail shaft to eject its casting. Occasionally, but only at long intervals, it moves forward up the head shaft, reshaping the column, working up its texture, and perhaps dragging some particularly attractive object, such as a fragment of seaweed, from the sand surface into the shaft. At high tide the worm pumps water through its burrow, mainly to get a supply of oxygen. The stream is driven by swellings that move along the worm's body, closing the burrow and conveying the water by a kind of external peristalsis. At low tide, when the water table falls below the sand surface, the worm must creep backward until it has exposed most of its gills to the moist

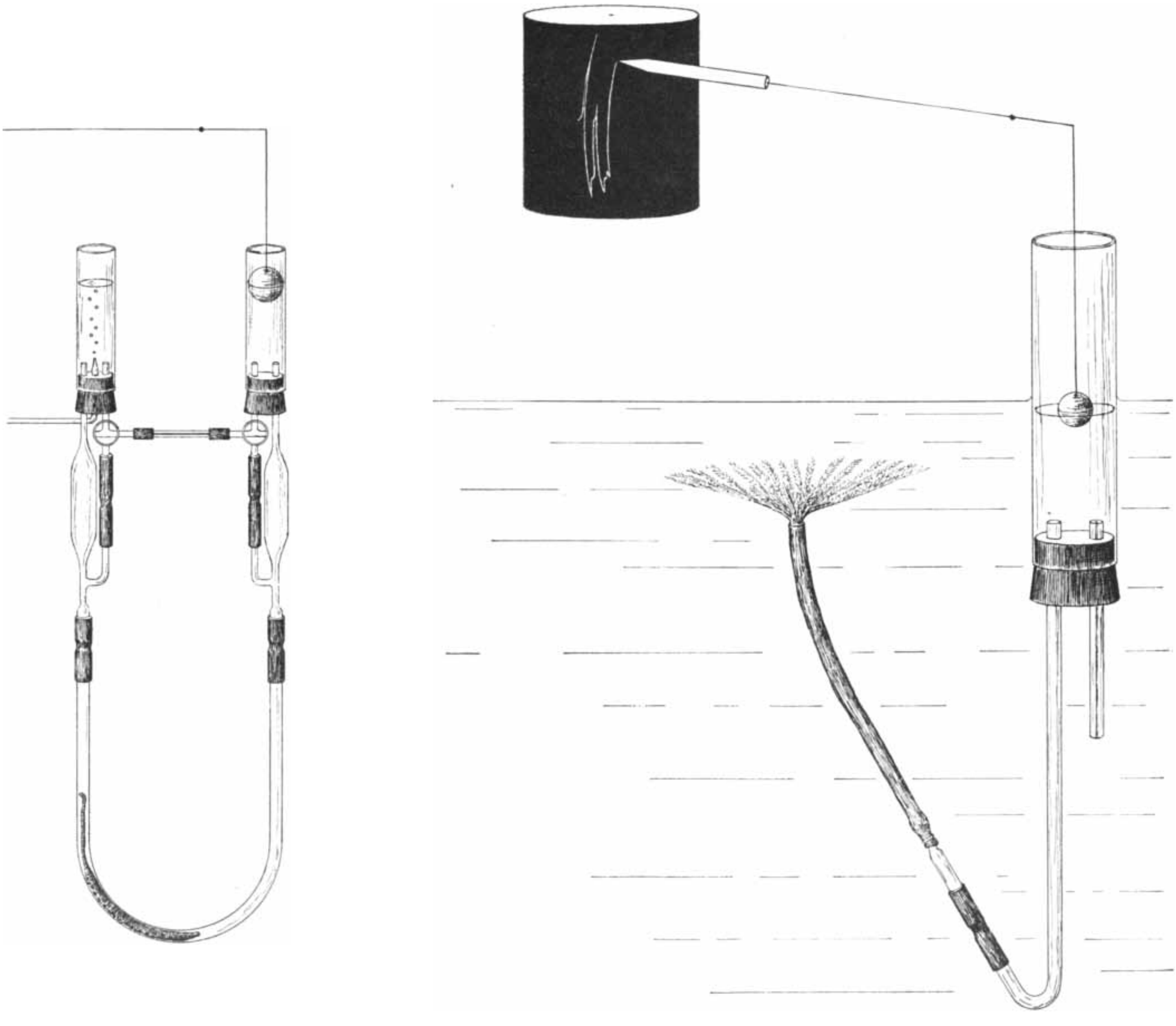


WORMS "WRITE" by means of a stylus pivoting up and down as an attached float rises and falls with their pumping. With the lugworm the author uses a vessel (*left*) made of pieces of modeling clay (*light stippling*) between two sheets of glass. The sand inside

air in the upper part of the tail shaft. When the blood hemoglobin is oxygenated, the worm may return to the stagnant oxygen-deficient water in the bottom of the burrow. If worst comes to worst, a lugworm can live without any oxygen supply at all for several hours.

Now the worm's normal situation deep in the sand is comparatively secure, but its regular backward trips to the surface are perilous. At high tide these trips expose it to predatory crabs or fishes; at low tide, to sea birds and the dangers, very real to a marine invertebrate, of hot sunshine, hard frost or salt-free rain. However, the worm is well adapted anatomically to its mode of life. Its vital organs—heart, kidneys, stomach, and testes or ovaries—are placed in the forward part of its body, which usually remains below. The exposed tail is little more than a muscular tube enclosing a sand-filled rectum. The tail is highly sensitive, however, and shrinks rapidly away from a hurtful stimulus, even throwing off its own extremity if the stimulus is violent enough. When matters have come to such a pass, nothing is lost, for the tail is continuously renewed by growth from its base. The tail is the lugworm's protection and its sacrifice to the terrible gods of the World above the Sand.

As we shall now see, the lugworm's behavior, no less than its anatomy, is well adapted to its way of life. At top left on the next two pages is an extract, about five hours in length, from a lugworm autobiography. Against a fluctuating background, due to variation in the speed of the respiratory stream, is a repeated pattern, occurring regularly at intervals just under 40 minutes. The pattern begins with a downward movement of the curve as the worm creeps backward to the sand surface and the rising water level depresses the writing lever. This is followed by a downward "needle" as the animal shoots out a casting. Then the curve swings upward to a peak as the worm creeps to the bottom of its burrow again and for a while pumps water in a headward direction with exceptional vigor, lowering the water level above the

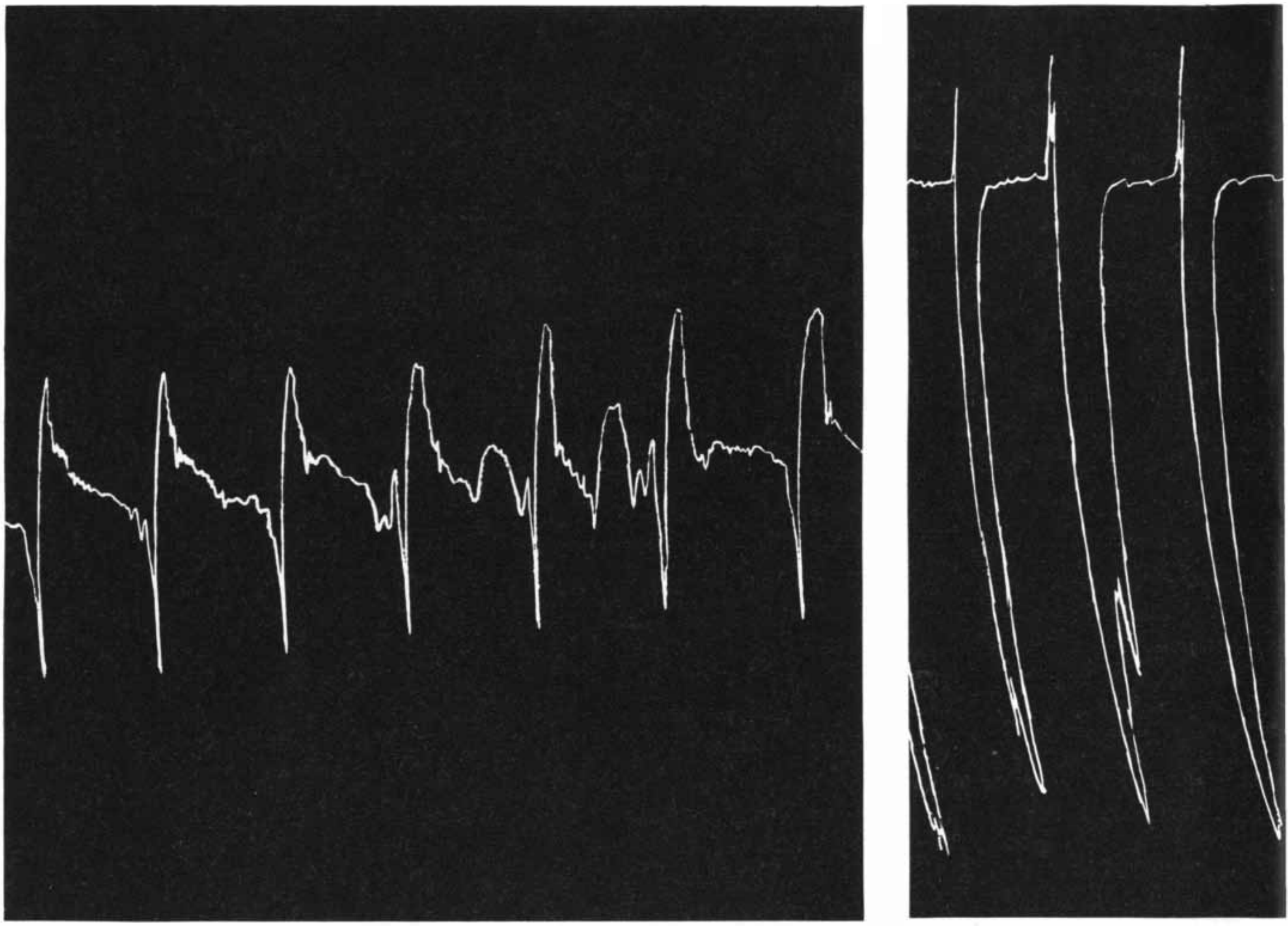


the vessel has been cut away to show the burrow. With *Sabella* and *Chaetopterus*, the natural tube is attached to a glass tube (*shown at right for* Sabella). In the middle illustration is a glass U-tube used to investigate the effects of lack of food or of oxygen.

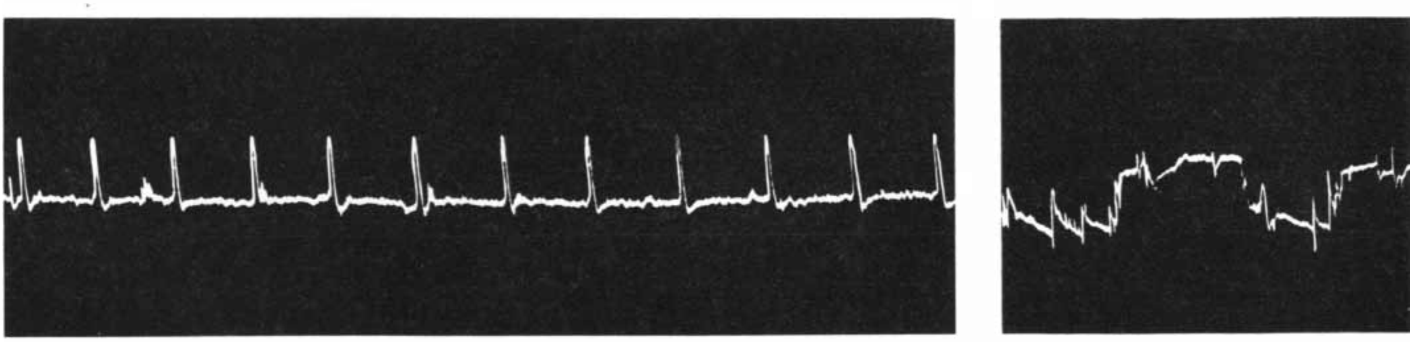
tail shaft. And so the cycle repeats hour after hour.

Whenever a worm is actively feeding and casting, it writes this characteristic pattern. But the creature may also lie still and do nothing, the lever tracing a plain horizontal line; or it may write violent, chaotic wiggles that have still to be interpreted; or it may trace other rhythmic patterns that there is no space here to describe. A long-term record of its behavior always shows these "moods," each of them generally persisting for several hours and then passing suddenly into another. If we observe worms other than *Arenicola marina* in our experimental setup, we see that each species shows different time patterns. A worm can be recognized by its writing on the smoked paper, just as a bird can be recognized by its song.

Chaetopterus variopedatus, a relative of the lugworm in spite of its very unworm-like appearance, ordinarily lives in a parchment-like tube attached to rocks or stones on the sea bottom. It can be made to write by connecting one end of its natural tube to a reservoir with a capillary leak. Like the lugworm, *Chaetopterus* is a creature of moods and may write one of several patterns. The pattern at bottom left on these two pages is that of a feeding worm.

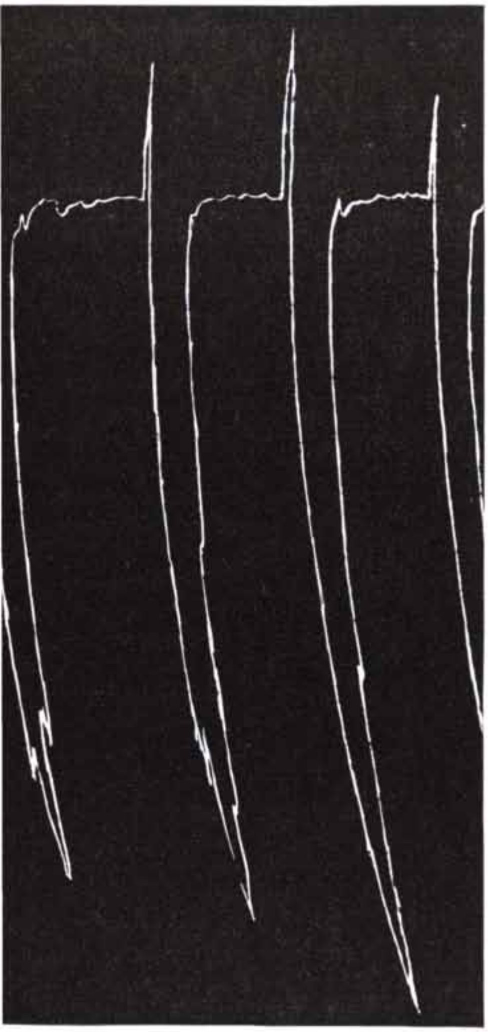


FEEDING LUGWORM made the record at left. At intervals of about 40 minutes it moved backward to the sand surface and shot out a casting, causing the sharp downward "needles." Fasting worm in U-tube made similar excursions although it had nothing to eat or

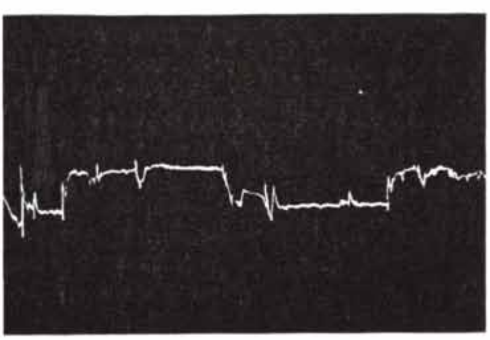


CHAETOPTERUS wrote the record at left while feeding. Its steady tailward pumping was interrupted at regular intervals of about 18 minutes (*upward needles*). Animal making the record at right was mildly irritated. It fanned irregularly and reversed its position

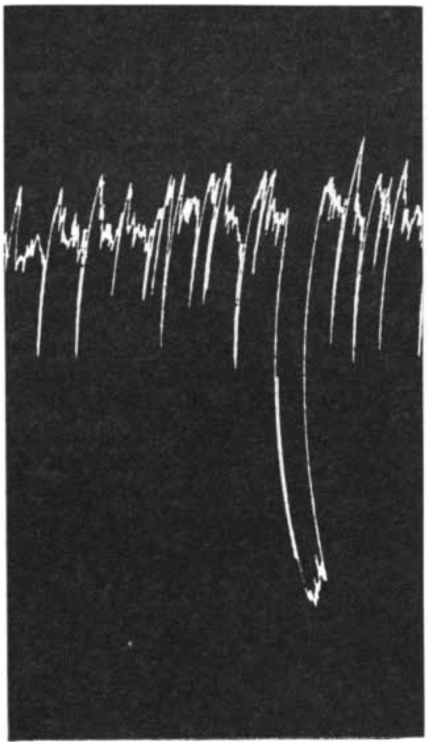
The tracing shows a water stream, driven steadily toward the worm's tail by the three fans in the middle of its body, with brief interruptions (seen as upward needles on the graph) at intervals of about 18 minutes. During each fanning period the animal exudes a net of mucus across the inside of the tube to trap small particles in the sea water. At the next interruption it rolls the net into a ball and swallows it. The graph shows



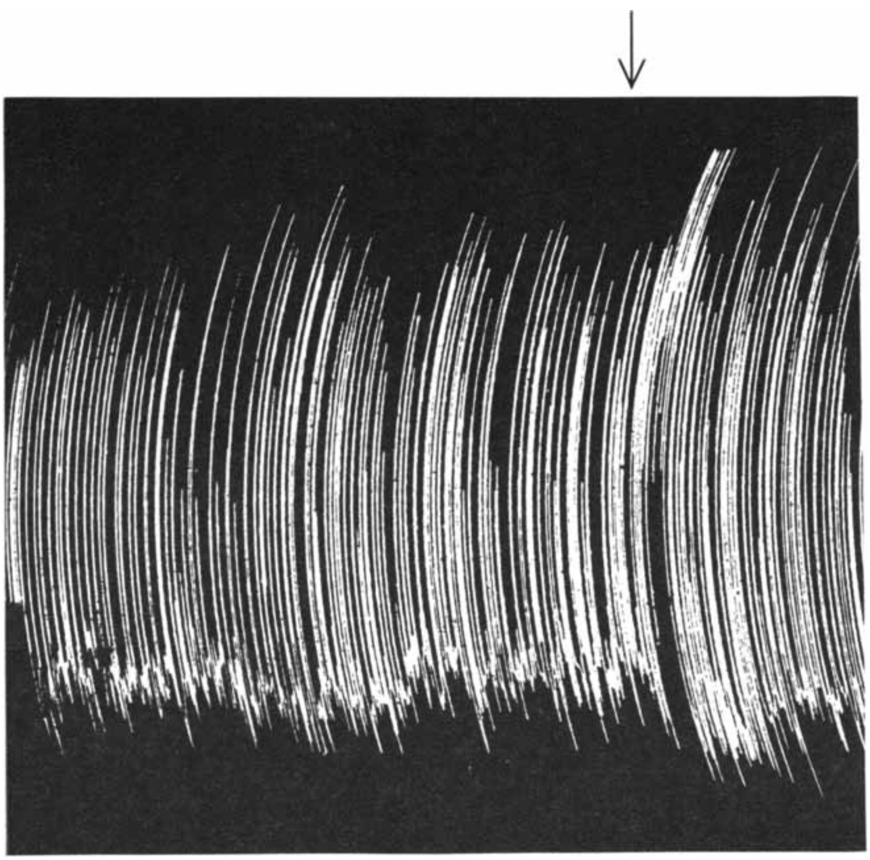
cast. Its writing (*right*) is upside down because its head faced the recording float.



in the tube at half-hour intervals, producing the general wave pattern of the tracing.



RECORDS OF SABELLA SPALLANZANII, each five hours long, show two typical moods. During most of the left-hand extract the worm's crown of tentacles was spread out, and it drove water through the tube toward its head. For half an hour near the end of the record it pumped water tailward (*drop in tracing*). The worm making the record at right had withdrawn into its tube and pumped water in a tailward direction most of the time. About every half hour its tentacles peeped out, and it gave a burst of headward pumping (*peaks*).



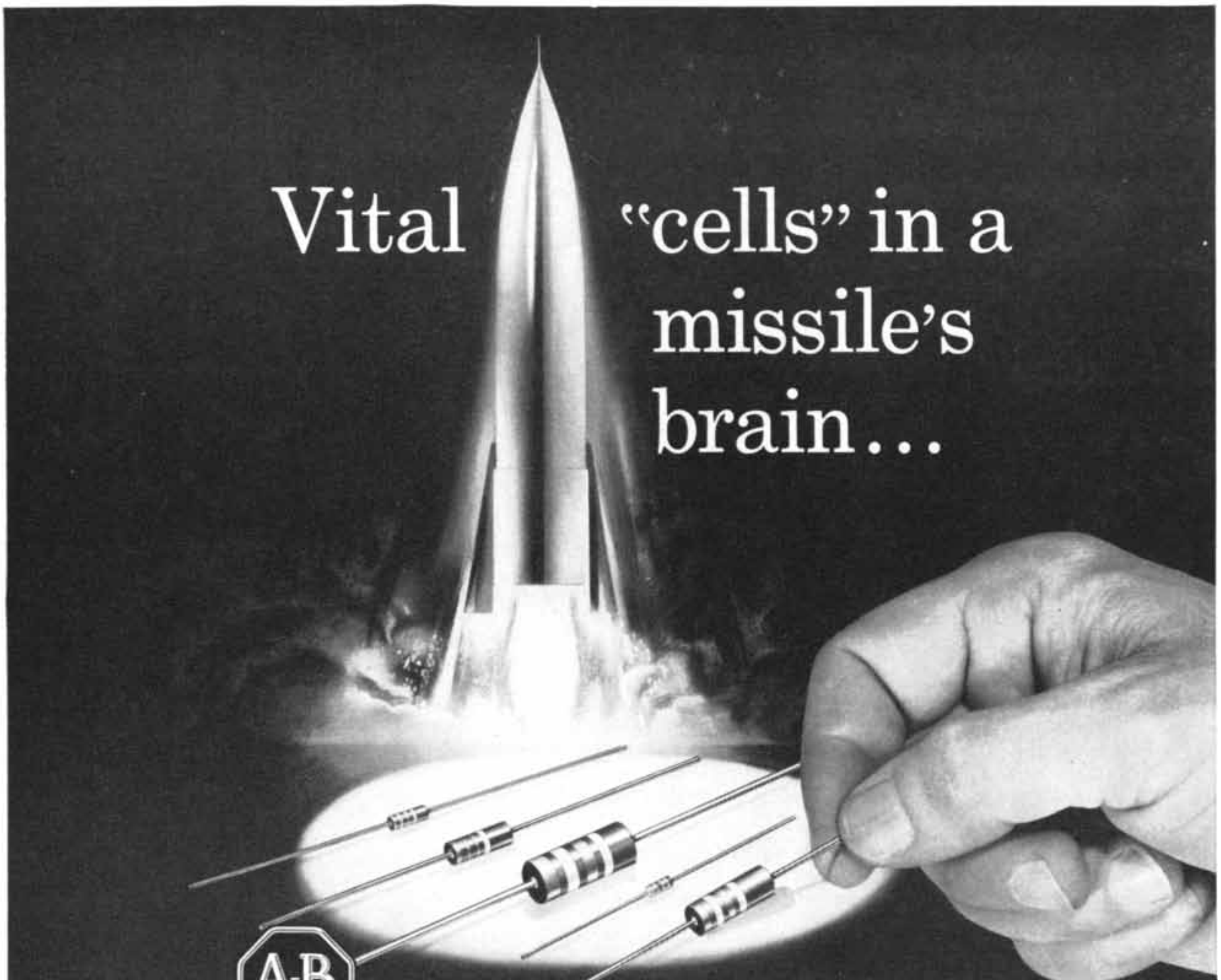
SLOW-MOTION RECORD of *Sabella spallanzanii* repeats the same monotonous pattern for days. Even beheading the animal (*arrow*) disrupted the pattern for only a few hours.

that the volume of water filtered through each net is rather more than a quarter of a liter. Another characteristic pattern that appears quite often in the writings of *Chaetopterus* seems to result from mild irritation, perhaps from some feature of the experimental setup. The animal that made the record at bottom right on the preceding two pages continually disturbed its water stream by little bursts of petulant kicking, and eight times, at intervals of about half an hour, it turned around so as to reverse its position in its tube, causing the slow wave pattern of the tracing.

Like the space patterns of anatomy, the time patterns of inherited routines are subject to natural selection and are adapted to the animal's way of life. This is clearly seen when we compare two species of the so-called feather-duster worms. These worms bear a crown of feathery tentacles that act as a living net to catch particles carried in the sea water. One species, *Sabella spallanzanii*, found embedded in gravel or attached to a hard object on the sea bottom, lives in a U-shaped tube in which one arm of the U is shorter than the other. Typically it drives water through its tube in a headward direction while the crown of tentacles is spread out, and then, when its mood changes, withdraws completely into its tube and pumps mainly in a tailward direction. One sees these behavior patterns over and over again in specimen after specimen of *spallanzanii.*

A second species, *Sabella pavonina*, prefers a muddy rather than a gravelly area. Its straight, non-U, tube runs deep into the mud, serving to anchor it more firmly. The inherited routines of this species consist solely of patterns of tailward pumping and never include reversal of the current. This is important because to drive water the other way would draw in mud and tend to clog the tube. So the difference of preferred habitat is connected not only with the difference between the U-tube of *spallanzanii* and the non-U of *pavonina*, but also with a difference in inherited routines. As a matter of fact, *pavonina* is perfectly capable of headward pumping if the necessity should arise—if, for example, it sucks something nasty into the upper end of its tube—but it never does so of its own accord.

We know nothing of the form in which behavior routines are inherited, or how they are stored for future use when not being performed. It is, however, worth noting that the worm's brain plays no part in their production. The crown of *Sabella* is quite vulnerable to



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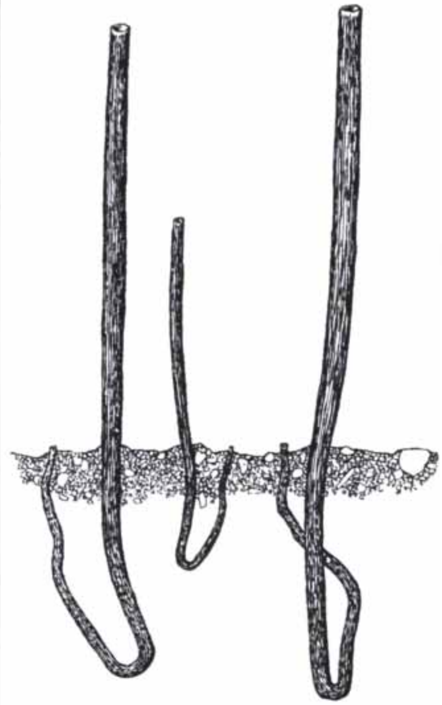
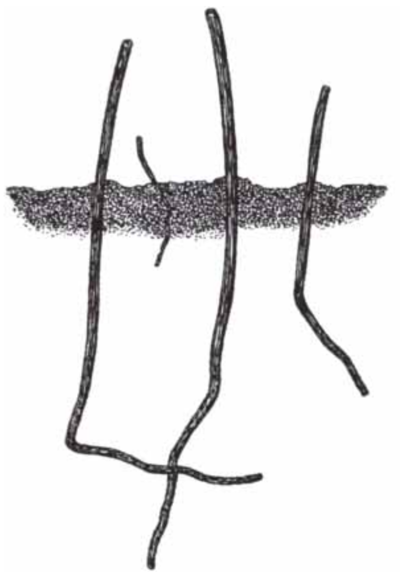


TUBES OF SABELLA are leathery and have a parchment-like root. At left are the U-tubes of *Sabella spallanzanii*, in which the

prowling predators when spread out in the sea water, and a worm may not always slip back into the tube quickly enough to escape a hungry fish. Fortunately a worm that has lost its head is able to grow a new one almost, but not quite, the same as the original. Under natural conditions more than half the worms show that they have had this experience at one time or another. During the slow-motion record at the bottom of page 138, the experimenter played the fish; I crept up with a pair of scissors and snipped off the entire head and crown with a short length of neck. It will be seen that the now-headless worm was put out, but only for a couple of hours; thereafter it calmly settled down to write the same old story. The resemblance between the complicated patterns traced by a decapitated *Sabella*, of either species, and those of a normal worm is remarkably close.

Even though the brain is unimportant, we can be sure that the patterns are not mere chains of reflexes. The tailward excursions of the lugworm look like reflex responses to a full rectum. Yet a lugworm can be kept in clean sea water, and after fasting for days, it some-



root returns to the surface of sand or gravel. At right are tubes of *Sabella pavonina*, which extend deeper into muddy sand.

times makes its regular excursions at normal intervals, though it has nothing in its rectum to discharge. Such experiments show that the lugworm has some kind of physiological clock in its nervous system that ticks spontaneously (if the worm is in the right mood) and compels it to go through its performances even in the absence of physiological need.

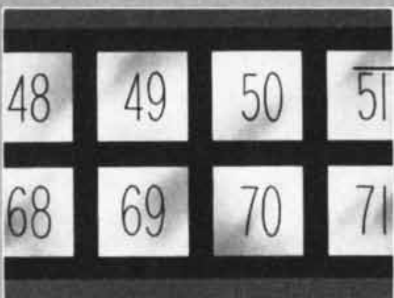
The clock that controls the lugworm's feeding has, in fact, been located. Under natural conditions the worm feeds in little bursts, each lasting for a few minutes, with a rest of a minute or so in between. In a glass tube of sea water with no sand to eat, the worms often make the same movements with about the same timing. If the front part of the gut—the esophagus—is removed from the worm and placed in a dish of sea water, it too exhibits this rhythm automatically. For a few minutes it is vigorously active, with waves of contraction running along it in regular sequence from the front end to the back; then it becomes quiet for a couple of minutes, and so on. One can show convincingly by appropriate experiments that the behavior of the esophagus is the determining cause of the intermittent feeding of the intact worm. When the esophagus is active, its activity spreads through the nervous system to most of the muscles of the body, affecting them in various ways and producing the complicated movements.

The rhythms of the lugworm can of course adjust themselves to suit external conditions. If the sand surface dries during low tide, the worms commonly cease to feed and defecate. The periodic excursions persist, however, and now serve as a means of aerial respiration, air being swept down into contact with the gills by the pumping motions. After a period of enforced oxygen lack, the excursions follow each other at unusually short intervals. But basically the rhythms are intrinsic.

A lugworm esophagus may be compared with that well-known classroom object the isolated heart of the frog. Even a little shred of heart muscle contracts rhythmically as long as it stays alive and healthy. The rhythmicity of the heart is as much a built-in feature as the anatomical structure of its cells. Similarly a lugworm esophagus, cut into pieces either lengthwise or across, shows the characteristic alternation of rhythmic activity and rest. Just as the heartbeat can be modified by factors external to it, such as hormones and nerves, so the rhythm of the esophagus is affected by changes in its surrounding fluid. By increasing the amount of magnesium in the fluid, the esophagus can be slowed up so that its outbursts of activity appear at regular intervals of over half an hour. How a clock of cellular dimensions can tick as slowly as this is indeed an intriguing problem. It is presumably related to many other problems of physiology, such as the exact mechanism of the heartbeat. Under certain abnormal conditions a heart may beat in bursts, very like the activity pattern of an isolated lugworm esophagus. Perhaps when the investigators of the vertebrate heart have found out how it beats, their answers may also explain the contractions of the lugworm esophagus.

The behavior of the lugworm is no less inherently spontaneous than the beating of the heart. The worm tends to express itself by generating characteristic patterns of events arranged in time, though the patterns may be interfered with, and more or less modified, by environmental influences. In other words, at the moment of fertilization, when it comes into existence, the lugworm acquires a blueprint for its body and a program for its life, though both are subject to environmental approval.

New packaged



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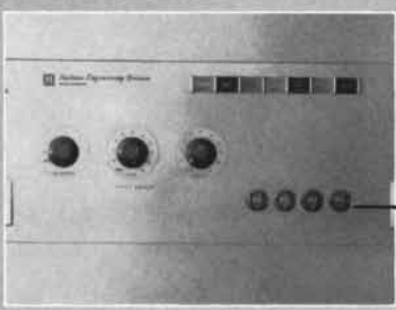

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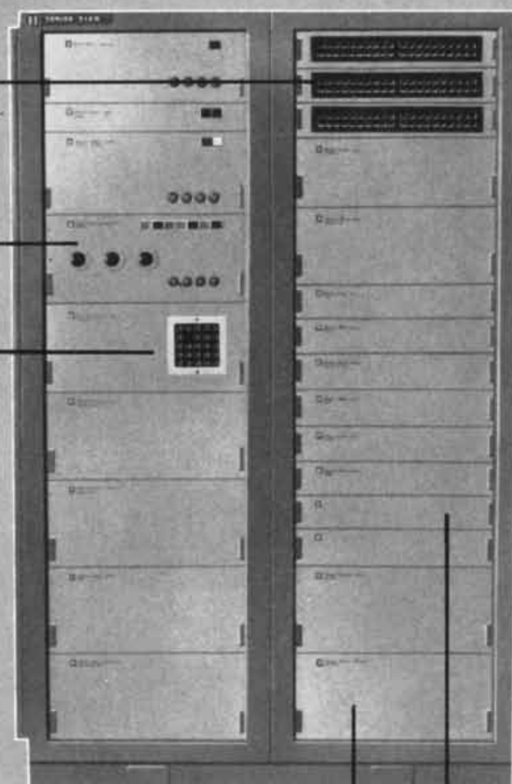

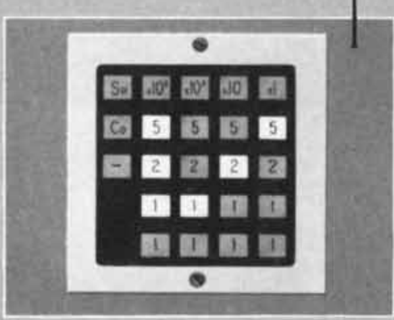

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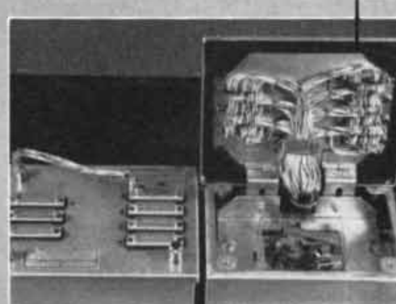

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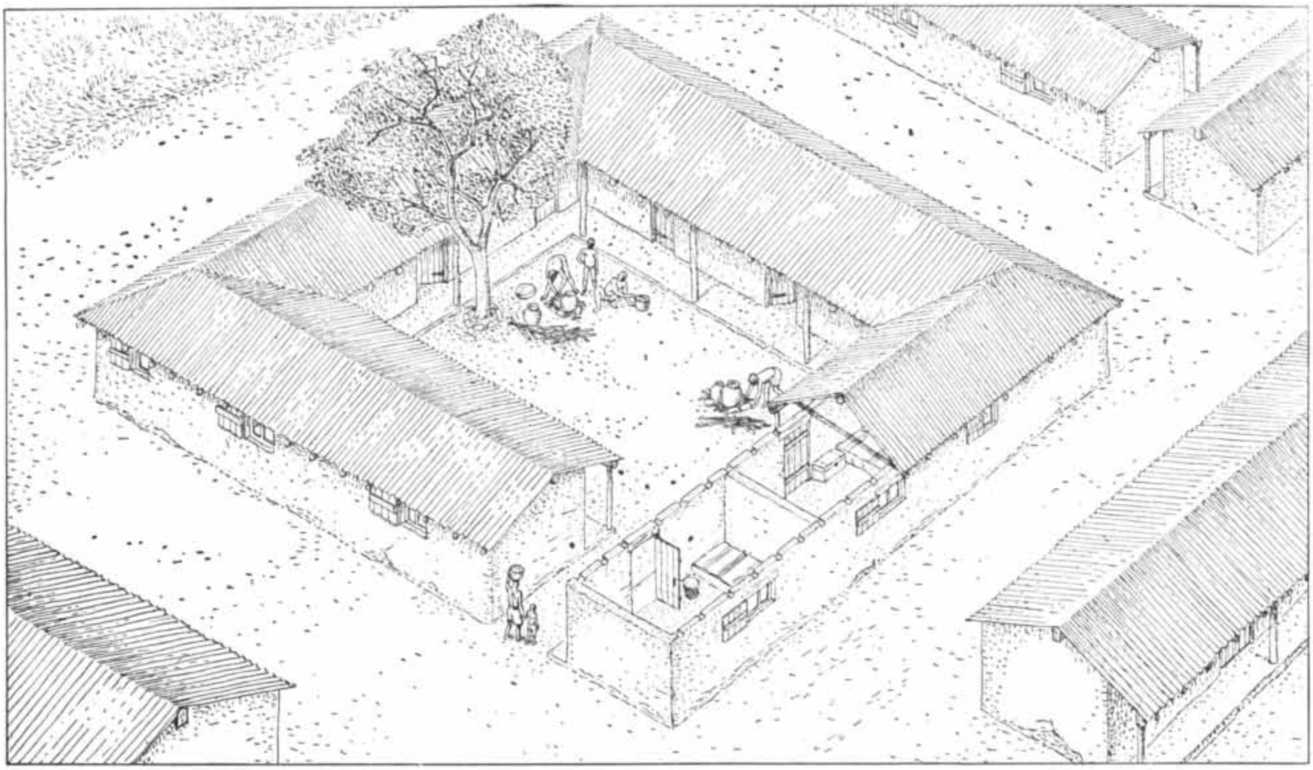
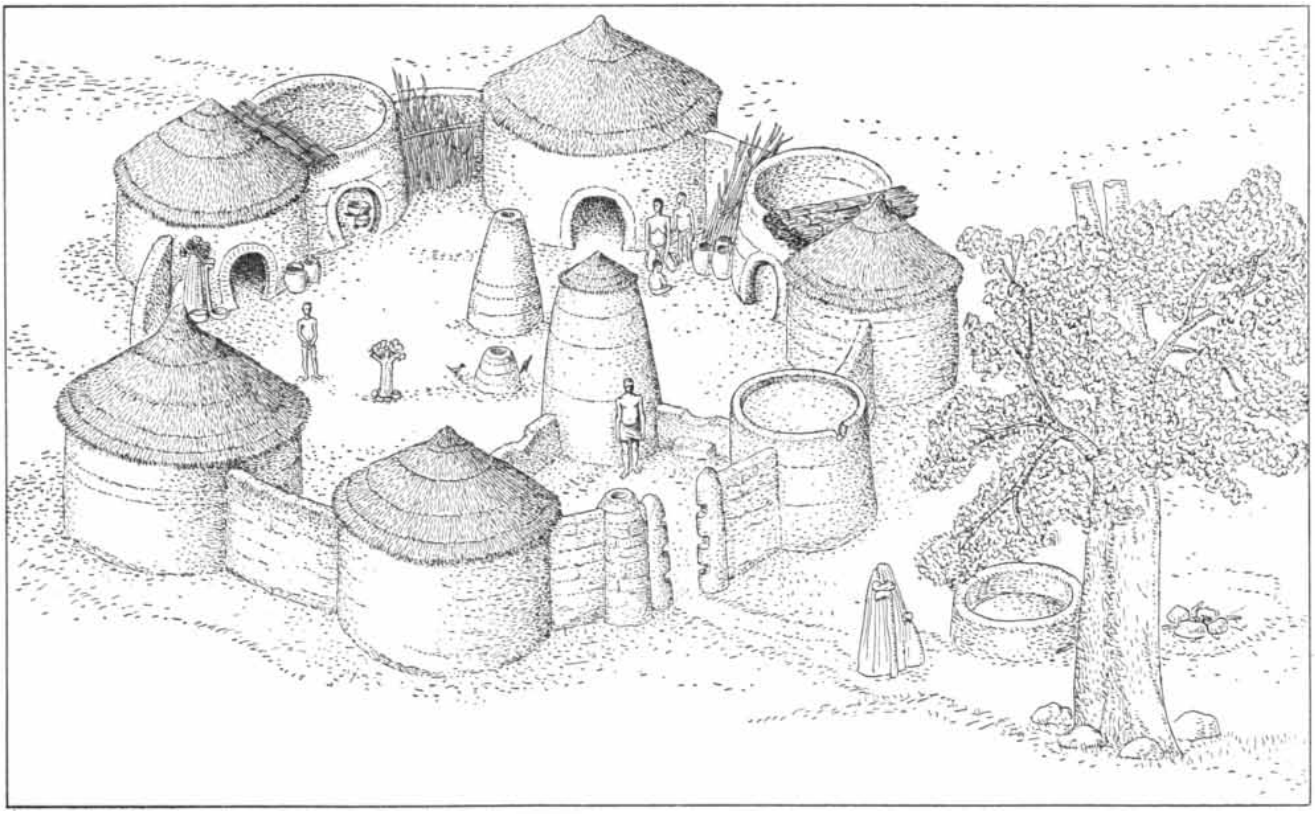


MATRILINEAL HOUSEHOLD is characteristic of the Ashanti tribe in Ghana, West Africa. A typical Ashanti household includes a grandmother, her sons and daughters and their children. Each adult occupies one room. Their spouses live apart from them in their own matrilineal households nearby. In this drawing part of the tin roof is removed, showing the interior of the adobe rooms.



PATRILINEAL HOUSEHOLD typifies the Tallensi tribe, also of Ghana. While more primitive than the Ashanti, they have more highly structured households. Outside the gate, by the sacred tree and conical ancestor shrine, is a social area for the men of the house. Inside the gate the patriarch of the household stands in the cattle yard, his special domain. To the right is the flat-roofed cattle shed where his ancestral spirits dwell. Behind him, at the hub of the homestead, is its granary, from which only he may dispense grain. Clockwise around the homestead, starting to the left of the gate, are a room for adolescent boys; the bedroom, pantry and unroofed dry-season kitchen of the patriarch's mother; and the bedroom, kitchen and pantry of his wife, himself and his children.

PRIMITIVE KINSHIP

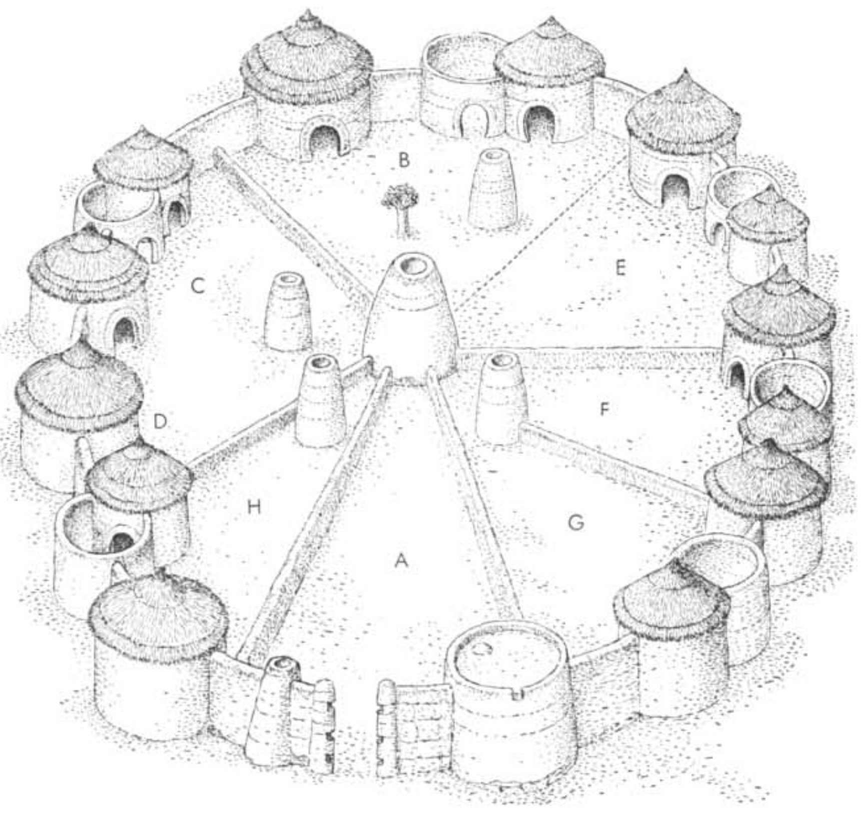
In most primitive societies the family is an organization far more complex than the family of Western civilization. This organization reflects the larger role played by the family in primitive cultures

by Meyer Fortes

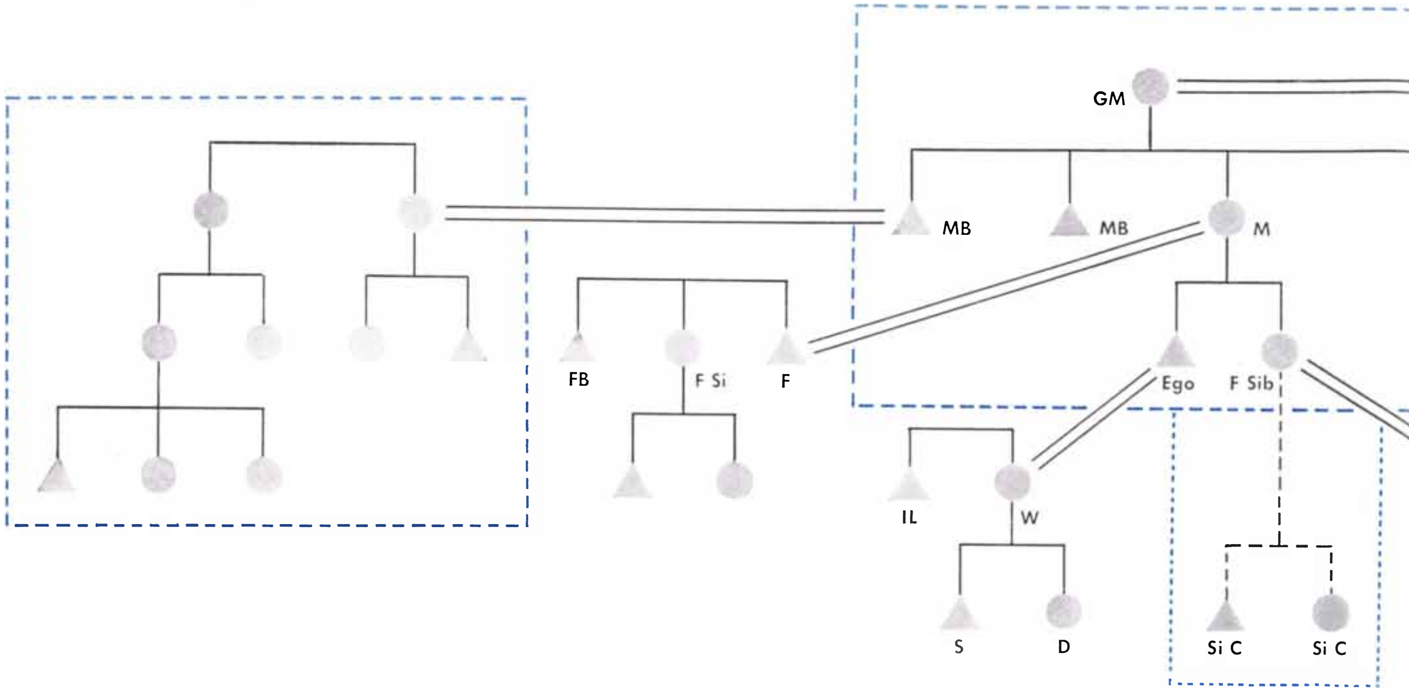
Ministers, political orators and editorial writers are apt to tell us that the family is the keystone of society. From the biological point of view it would indeed seem to be the ultimate social institution. The conjugal family—husband and wife and their children—gives social expression to the function of human reproduction. Early travelers from our civilization were sometimes shocked because they could find no obvious counterpart of our family among primitive peoples. When they found large communal households, inhabited by men, women and children having the most bizarre and sometimes downright indecent relationships to one another (in the terminology of our family), they took this as conclusive evidence that these cultures were barbaric.

We have come to know primitive peoples at closer range in recent years. What they have taught us has radically altered our judgment of their family organizations and given us an humbler understanding of our own. Primitive family types vary in their constitution, but they are always precisely structured institutions, embracing the primary loyalty and life activity of their large memberships and enduring from generation to generation. The exact prescription of relationships among members gives each individual a significantly defined connection to a wide circle of his kin. To the individual member, the family's property is the source of livelihood, its ancestors are his gods, its elders his government and its young men his defense and his support in old age. In simpler cultures (*e.g.*, the Australian aborigines) family and society are actually coterminous: all men are either kinsmen or potential enemies.

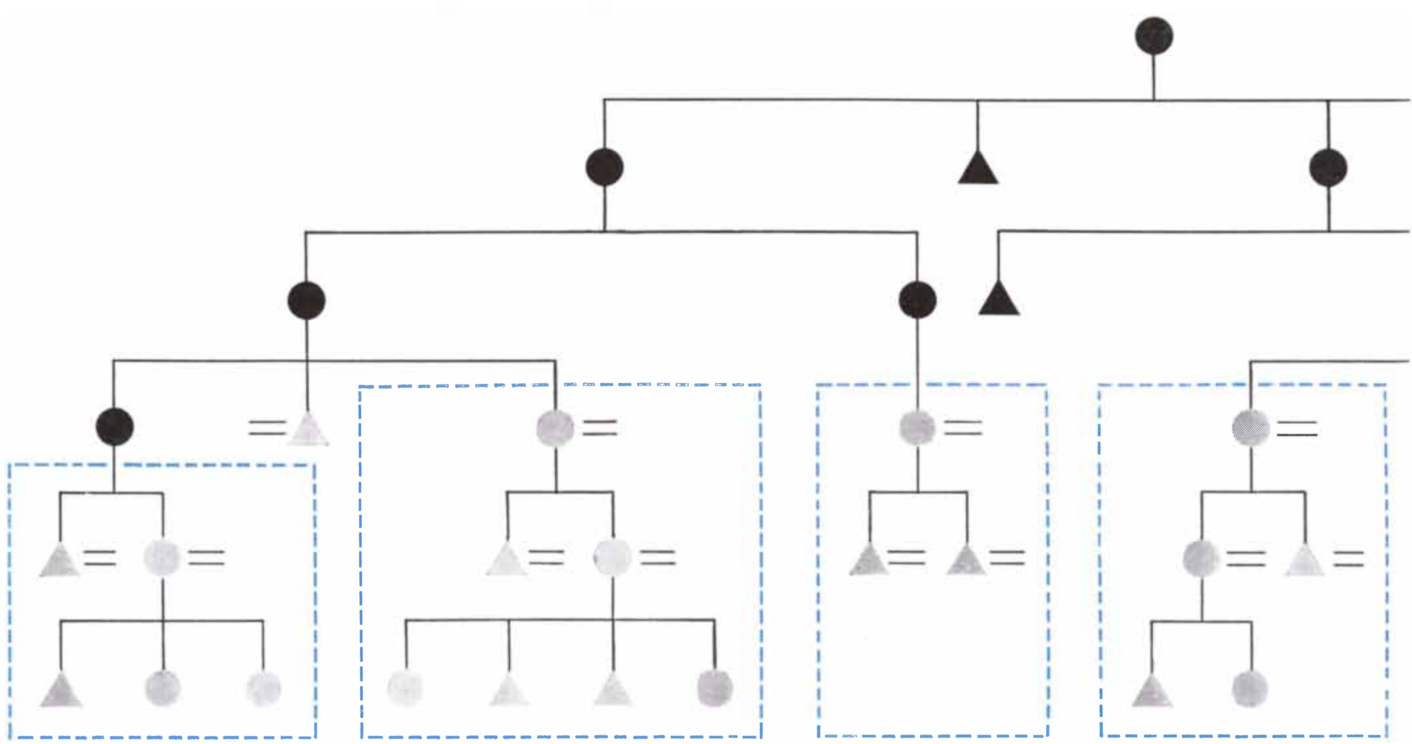
We, in contrast, are primarily citizens, not kinsmen. The family is organized anew with each marriage. It must share our allegiance with the many competing claims of our society: the loyalties we owe to the institutions that employ us, to our professional organizations, to political parties, to community and nation. A family of such reduced status and scope is, as a matter of fact, distinctly out of the ordinary as families go. The Hebrew families of the Bible and the Roman *gens* more closely resemble the extended family systems of contemporary primitive cultures than they do our own. Of all the primitive societies I know, the one that most closely resembles ours in isolating the conjugal family as the basic social unit is the Iban, a tribe of head-hunters in North Borneo. The vocabulary we employ to



TALLENSI DWELLING depicted in this schematic drawing is far more elaborate than the one shown in greater detail on the opposite page. It includes the patriarch's cattle yard (A); his senior wife's bedroom, pantry and kitchen (B); a similar unit for his second wife (C), including a hut (D) for her adult child, his second son; a unit for his third wife (E); his eldest son's domain, including units for the latter's first wife (F) and second wife (G); a unit for the third son (H). The basic Tallensi house plan can be expanded to any size. Large joint families of this kind are typical of primitive societies that are not nomadic.

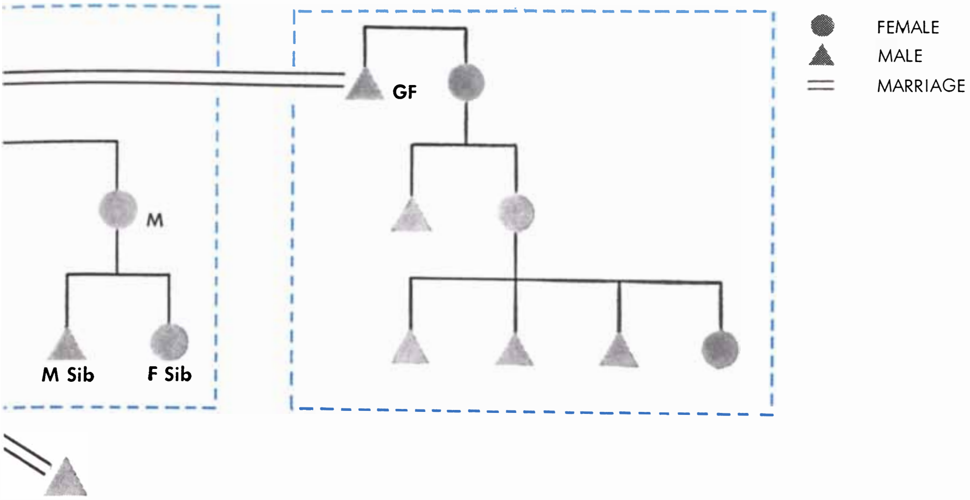


ASHANTI MATRILINEAL FAMILY is depicted in this family tree. The symbols are explained in the first key at right. The letters, which indicate the relations of each family member to the individual labeled "ego," are explained in the second key. Note that, according to the "classificatory" type of kinship terminology used by the Ashanti, "ego's" aunt as well as his own female parent is called "mother"; his aunt's children as well as his own brothers and sisters are called "siblings." "Ego's" own domestic household is shown in the broken colored rectangle at the center of the chart. Below this rectangle is a smaller one, representing a possible fourth

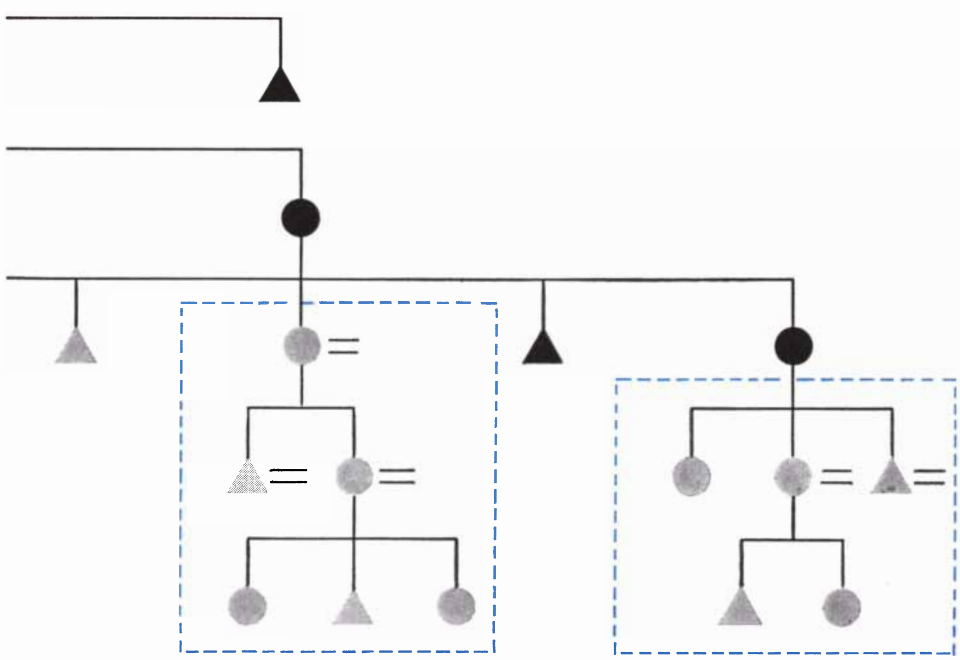


LIVING FEMALE
DECEASED FEMALE
LIVING MALE
DECEASED MALE
MARRIED MEMBERS

ASHANTI LINEAGE shown in this chart represents the common ancestry of six domestic families, traced through the female line (mothers and grandmothers, not fathers and grandfathers) to a single ancestress



generation in "ego's" family. The fourth generation, comprising his sister's children, will be his heirs. His own wife lives apart from him in another matrilineal household elsewhere in the village. His children are heirs not of himself but of his male affinal relations ("in-laws"), who share his wife's household. Also shown in this chart, in whole or part, are four households in which dwell spouses of other members of "ego's" family.



***(top)*. This "matrilineal" descent does not mean that Ashanti property and authority pass from mother to daughter; rather they descend from a woman's brother to her son.**

describe our kin—our uncles, aunts and cousins—beyond the immediate conjugal family fails to suggest the compelling ties that bind the kinship of peoples other than those of modern European and American civilization. Students of primitive kinship systems have found that they employ a terminology wholly unlike our own: the "classificatory" system, which groups relatives by status rather than sorting out their genetic interrelationships. It appears that all kinship systems obey certain universal principles governing the separation, inner unity and orderly sequence of generations. Viewed from the vantage point of such understanding, our family appears to be the much-curtailed form of a once far more elaborate and comprehensive organization.

Two "facts of life" necessarily provide the basis of every family: the fact of sexual intercourse is institutionalized in marriage; the fact of parturition is institutionalized in parenthood. Societies differ greatly, however, in which of these institutions they select as the more important. Our society selects marriage: the result is the conjugal family, centered upon a single marital relationship and the children it produces. Most human societies, however, rate parenthood above marriage. This results in the consanguineal family, centered upon a single line of descent.

Biologically our lineal inheritance derives equally from both sides of the family according to Mendelian law. Societies that prize lineage, however, restrict social inheritance either to the maternal or the paternal line. The social heritage—that is, property, citizenship, office, rank—passes either through the father or through the mother. "Patrilineal" descent (father to son) was the rule in ancient Rome, China and Israel, and occurs in many primitive societies. "Matrilineal" descent (mother's brother to sister's son) is common in Asia, Africa, Oceania and aboriginal America.

One matrilineal society that flourishes today is the ancient, wealthy and artistic kingdom of Ashanti in Ghana, West Africa. While European mores have made some inroads among the Ashanti, back-country Ashanti villages still keep to their strictly matrilineal ways. Let us consider how such a society works.

First of all, let us note that a matrilineal society is not a matriarchal society: it is not ruled by women. So far as I know there is not, nor has there ever been, such a thing as a genuine matriarchal government. In every preliterate society men, not women, hold the political, legal and economic power; the women usually remain legal minors all their lives, subject to the authority of their menfolk. Primitive peoples usually understand quite well why men, not women, must be the rulers. The women, they say, are incapacitated for warfare and the affairs of state by the necessity of bearing and rearing children. Many peoples, including the Ashanti, believe that women are magically dangerous to men during menstruation and after childbirth.

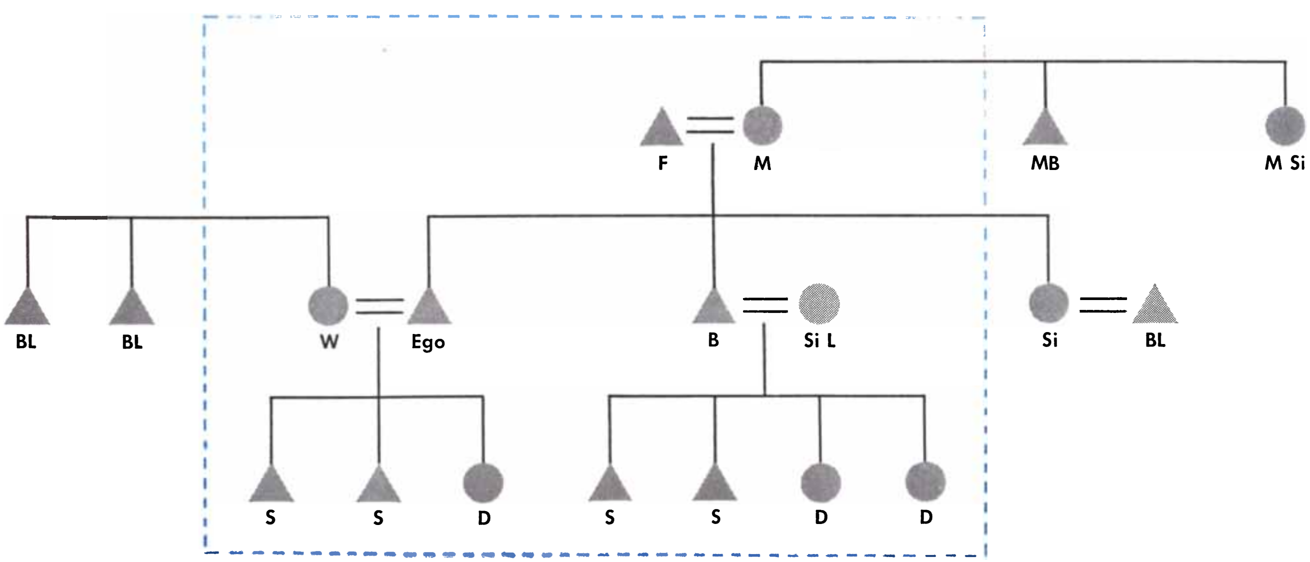
In describing the Ashanti kinship system I am going to use common English terms (like "aunt" and "cousin") rather than attempt to translate the native terminology. The typical Ashanti household consists of an old woman, her daughters, their children and one or two of her sons. The old woman, the daughters and the sons are all married, but where are their spouses? We can suppose that all of these people are on good terms with their husbands and wives; nevertheless they do not form part of the same household with them, because they do not belong to the same clan. The spouses all live nearby, in households belonging to their own clans. The legal head of the household is one of the old woman's sons; he inherited his role from his mother's brother, not his father; he will pass it on to his sister's son, not his own [*see illustration at bottom of preceding two pages*].

Among the Ashanti marriage is governed by strict moral, legal and religious rules. Yet it is clear that the Ashanti find the fact of descent much more important than the fact of marriage. That is why the households are formed by mothers and children rather than by husbands and wives. The lineage group to which the old woman and her children belong is united by the bond of common descent from an ancestress of perhaps the 10th generation before that of the youngest members. Through this ancestress the group traces its descent from an even more remote mythological ancestress: the progenitor of their clan, one of the eight clans into which the Ashanti people is divided.

It is considered a sin and a crime for members of the same Ashanti lineage to have sexual relations; by this token they must look for spouses of independent descent, that is, of a different clan. Since husband and wife commonly reside in separate households, they must live near each other if they are to have a normal marital relationship. More than 80 per cent of all marriages occur within the village community. Usually, therefore, one or two lineages of each of the eight clans is found in a village of average size.

The Ashanti rule of matrilineal descent has implications that reach far beyond the domestic household. Every Ashanti is by birth a citizen of the chiefdom to which his maternal lineage belongs. A man or woman can build a house freely on any vacant site in this chiefdom, and can farm any piece of unclaimed soil in the lands that it owns. An individual has no such rights in any other chiefdom. By the rule of matrilineal descent, a man can will no property to his own children; they belong to another household and another clan: his wife's. A man's heirs and successors are his sisters' sons. On his death his property and any position of hereditary rank he may hold pass automatically to his

B	BROTHER
BL	BROTHER-IN-LAW
D	DAUGHTER
Ego	SPEAKER
F	FATHER
M	MOTHER
MB	MOTHER'S BROTHER
M Si	MOTHER'S SISTER
S	SON
Si	SISTER
Si L	SISTER-IN-LAW
W	WIFE
●	FEMALE
▲	MALE
=	MARRIAGE



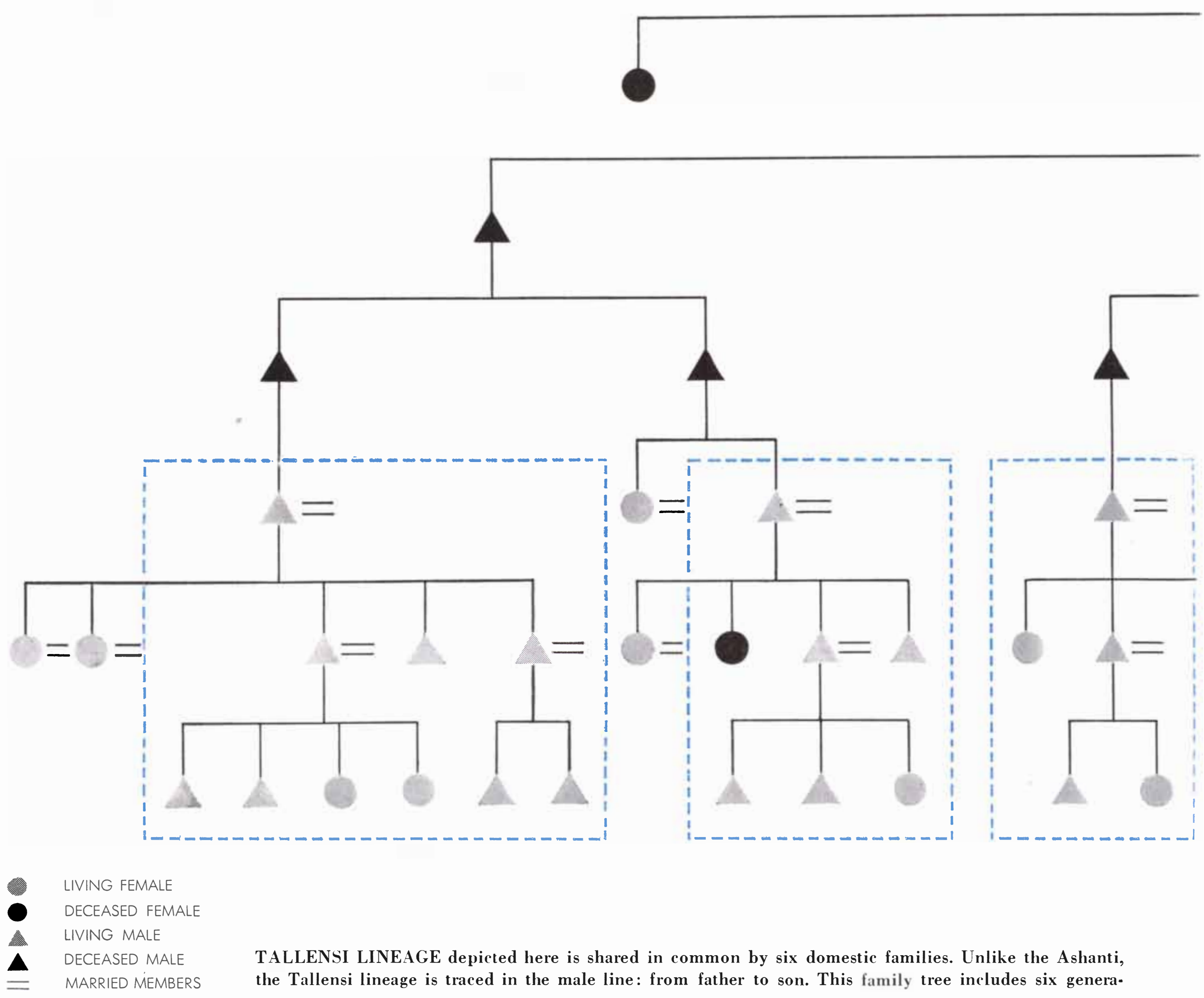
TALLENSI PATRILINEAL FAMILY differs from the Ashanti family (*see chart at bottom of preceding two pages*) in that it is a community of fathers, sons and their wives, not one of mothers, their brothers and their children, all living apart from their husbands and wives. It resembles the Ashanti family, however, in its use of classificatory terminology; *e.g.,* "ego" addresses his brother's children, as well as his own, as "son" or "daughter," a common practice with peoples who live in large joint households.

oldest nephew. If he wishes his own sons and daughters to benefit from his property, he must be content to make them gifts during his lifetime. They can accept his gifts only with the consent of his matrilineal heirs and of the elders in his lineage group. In the Ashanti tradition the individual comes under the authority of the mother's brother, not the father. It is the mother's brother whose consent is legally essential for a girl or boy to marry; he is also responsible for any costs that arise from divorce or other suits against them.

How do marriage and parenthood work out in such a system of kinship rules? It is undeniable that the Ashanti have delicate problems of marital adjustment. Both husband and wife must reach a compromise between their primary loyalties to matrilineal kin and their attachment to each other and to their children. When a man marries, he acquires legal rights to his wife's marital fidelity and to domestic services such as the regular provision of his meals. If a wife commits adultery, her husband can claim damages from the other man and apologies and a gift of placation from the wife, even if, as often happens, he does not divorce her. He can and will insist on divorce if his wife neglects her household duties or refuses to sleep with him. The husband is in turn obliged to provide food, clothing and general care for his wife and children. If he fails in these duties, his wife can divorce him. In fact, divorce is very common among the Ashanti. Usually it is free of acrimony, for it does not involve the splitting of a household.

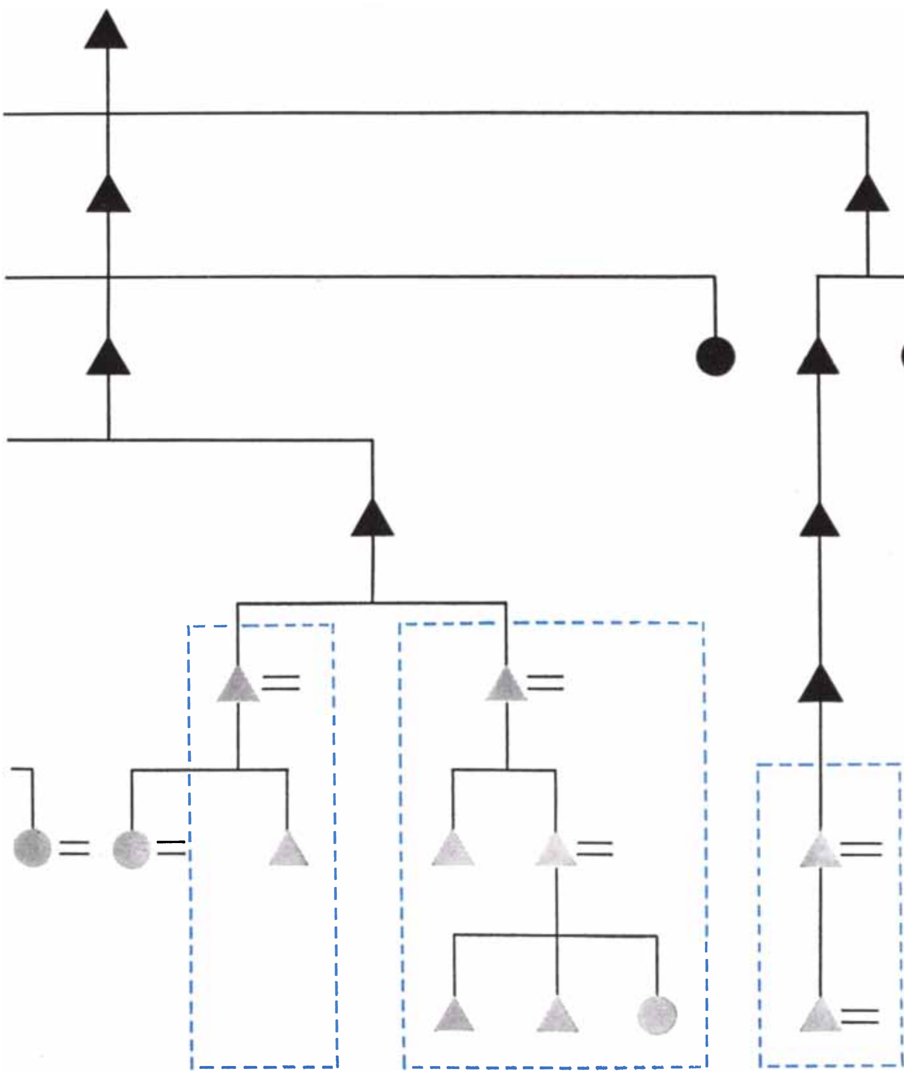
What an Ashanti man does not acquire by marriage is rights over his wife's reproductive powers, that is, over the children she bears him. These belong to her lineage, as opposed to his. An Ashanti man cannot demand help from his sons, for example in farming or in the payment of a debt, as he can from his sisters' sons. He can punish his nephew, but not his sons. He can order his nieces to marry a man of his choice, but not his daughter.

At the opposite extreme from the Ashanti are the Tallensi, who live nearby in Ghana's remote northern uplands. The Tallensi kinship and marriage sys-



TALLENSI LINEAGE depicted here is shared in common by six domestic families. Unlike the Ashanti, the Tallensi lineage is traced in the male line: from father to son. This family tree includes six generatem is the mirror image of that of the Ashanti. The Tallensi household is not matrilineal but patrilineal; it consists of a group of men, usually a man and his sons and grandsons, together with their wives and unmarried daughters. The men of this household and others in the immediate neighborhood all share the same patrilineal descent, which they can trace back in the male line to a single male ancestor [*see illustration on these two pages*]. Tallensi men share their land, are equally eligible for family offices and join in the worship of ancestral spirits. Like the Ashanti, the Tallensi are "exogamous"; their children must marry members of clans other than their own. Among the Tallensi, however, a woman joins her husband's household on marriage, because he has rights not only to her domestic services and marital fidelity, but also to her children. This is the crucial distinction between matrilineal and patrilineal systems.

Our Western way of reckoning kinship is neither matrilineal nor patrilineal. Rather, it is "bilateral" [*see illustration at bottom of next two pages*]. That is, we consider our mothers' kin to be as closely related to us as our fathers'. Nowadays we follow the same etiquette with both maternal and paternal relatives. Our terminology distinctly reflects the equality of our conjugal family system. Since we rate the conjugal (husband-wife) over the lineal (parent-child) bond, the paternal or maternal orienta-



tions, all derived from a single male. In each generation the women marry into other households and their children do not continue their lineage but that of their husbands.

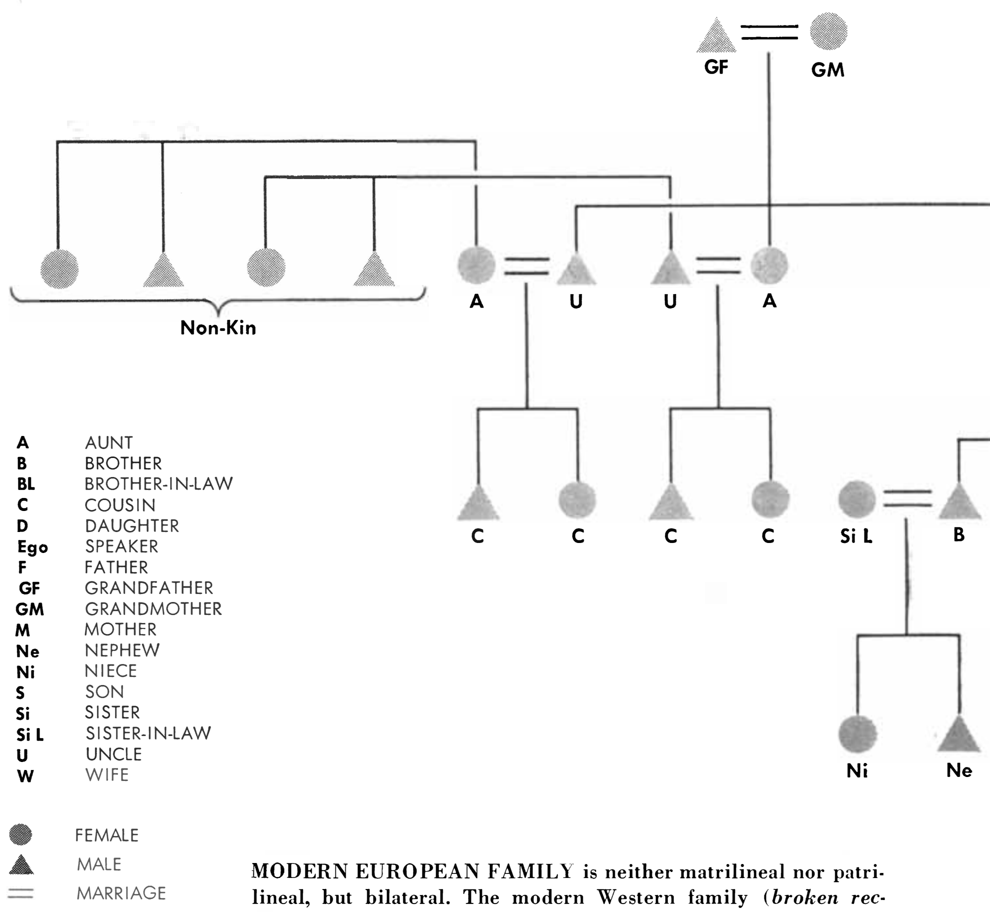
SEPARATION OF GENERATIONS from one another, a universal feature of kinship systems which serves to maintain the authority of seniors over juniors, is represented in this series of photographs. The photograph at left depicts the Tallensi custom of avoidance between a father (*center of photograph*) and his eldest son, who may not share his father's plate, although a younger son is shown

tion of the lineage becomes a matter of indifference. In naming our spouses' relatives we assimilate them to our own: a mother-in-law is a kind of mother, a brother-in-law is a kind of brother, and we treat them accordingly.

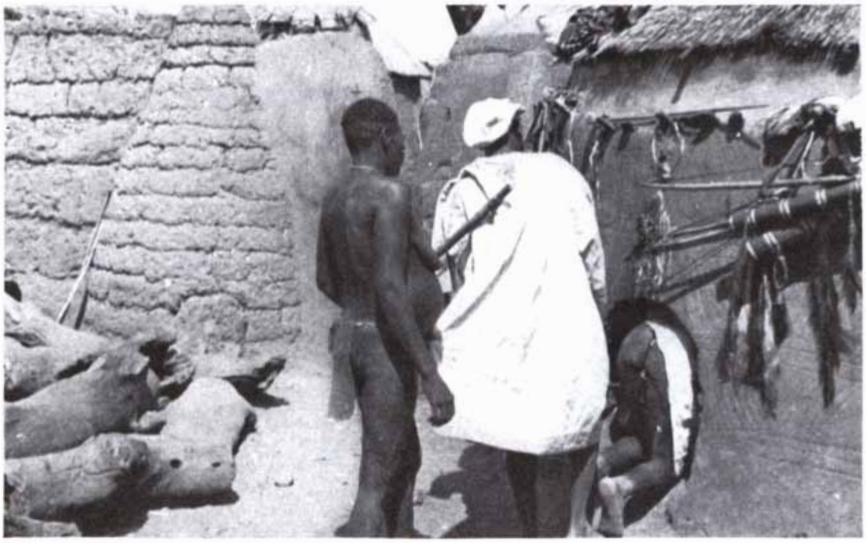
Our kinship terminology, like that of the Eskimos and a few other peoples, follows the so-called descriptive system. We have separate labels for each category of our kin, according to their generation, their sex and their linkage to us by descent or marriage. We distinguish our parents ("father" and "mother") from their male siblings ("uncles") and their female siblings ("aunts"). We have different appellations for our own siblings ("brother," "sister") and for our aunts' and uncles' children ("cousins").

Most primitive peoples use the entirely different labels of the classificatory system. This system often strikes Westerners as odd, although it is widespread among the peoples of mankind. Its principle is that in each generation all relatives of the same sex are addressed in the same way, no matter how remote the relationship. A sister and a female first- or second-cousin are all called "sister"; a father, an uncle and more distant male collaterals of their generation are called "father." A woman addresses her nieces and nephews, as well as her own offspring, as "my children." The nieces and nephews, as well as her own children, call her "mother." The Tallensi, the Swazi of South Africa and many other societies even use words for "father" with a feminine suffix added, to designate the sisters of all the men they address as "father." A Swazi calls his mother's brother a "male mother."

This terminology was recognized for the first time nearly a century ago by a great U. S. anthropologist, Lewis H. Morgan. His *Systems of Consanguinity and Affinity of the Human Family*, published in 1871, founded the modern study of kinship systems. Morgan and his followers believed that classificatory terminology had survived from an extremely primitive stage of social organization, in which a group of sisters would mate promiscuously with a group of brothers and would rear the offspring in common.

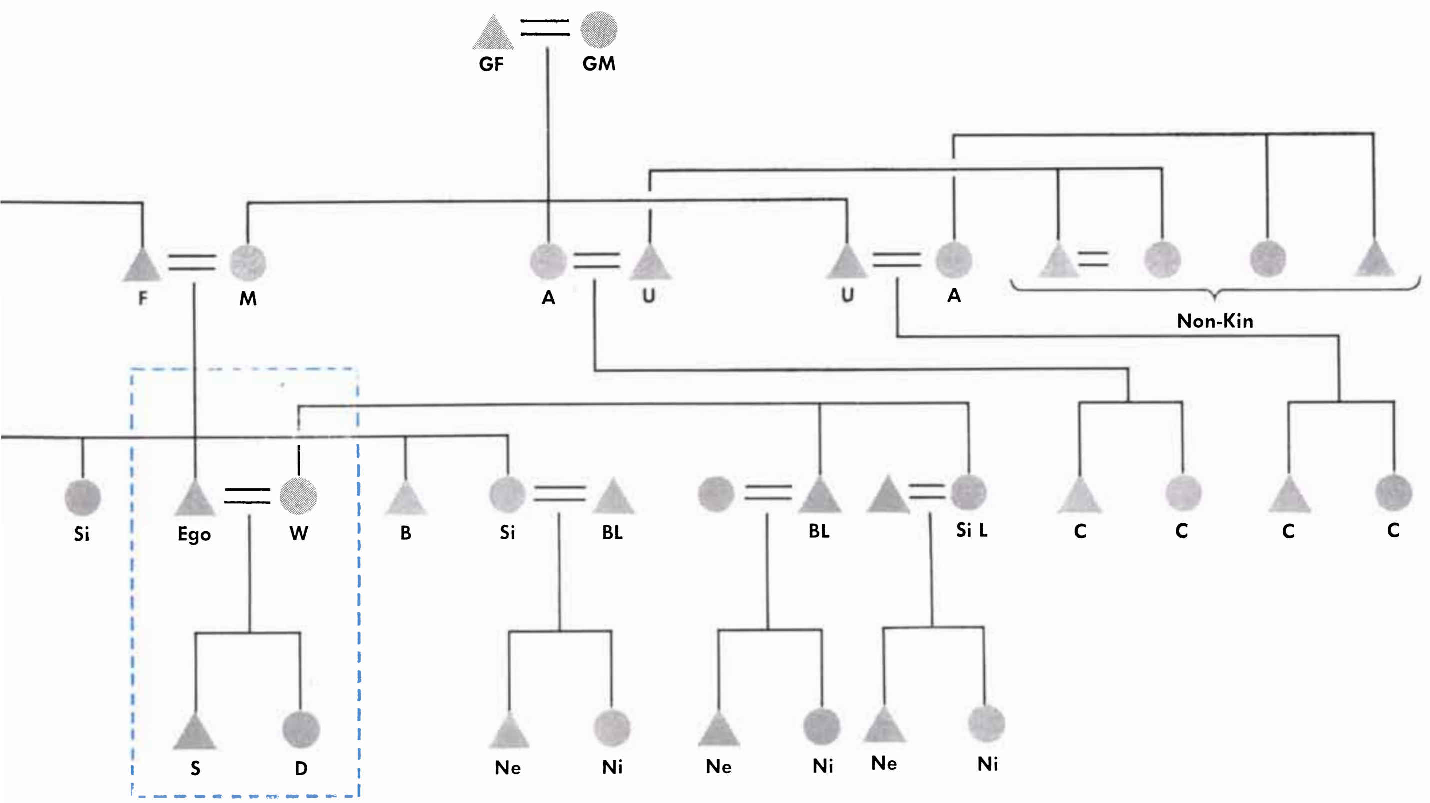


MODERN EUROPEAN FAMILY is neither matrilineal nor patrilineal, but bilateral. The modern Western family (*broken rec-*



doing so. The photographs at center and on the page at right show a Tallensi custom that illustrates the succession of juniors to the authority of their seniors. An eldest son whose father has died wears his father's tunic turned inside out. While his eldest sister clutches the garment, he marches around the homestead, then enters his father's cattle shed, thus canceling the avoidance taboo.

By now Morgan's theory of "group marriage" has been completely discredited. Modern anthropology has discovered far more cogent reasons for the existence of classificatory terminology. If a man calls all the male relatives of his generation "brother," it is not because at some remote period the promiscuity of the elder generation made it impossible to tell one's brother from one's cousin. The reason is that such generalized terminology expresses the deep sense of corporate unity in the extended family. A child in such a family knows very well which of the women of the household is his physiological mother. Like children anywhere in the world, he will love his real mother as he loves none of her sisters or female cousins. Yet in the joint family those sisters and cousins share his mother's duties to him,

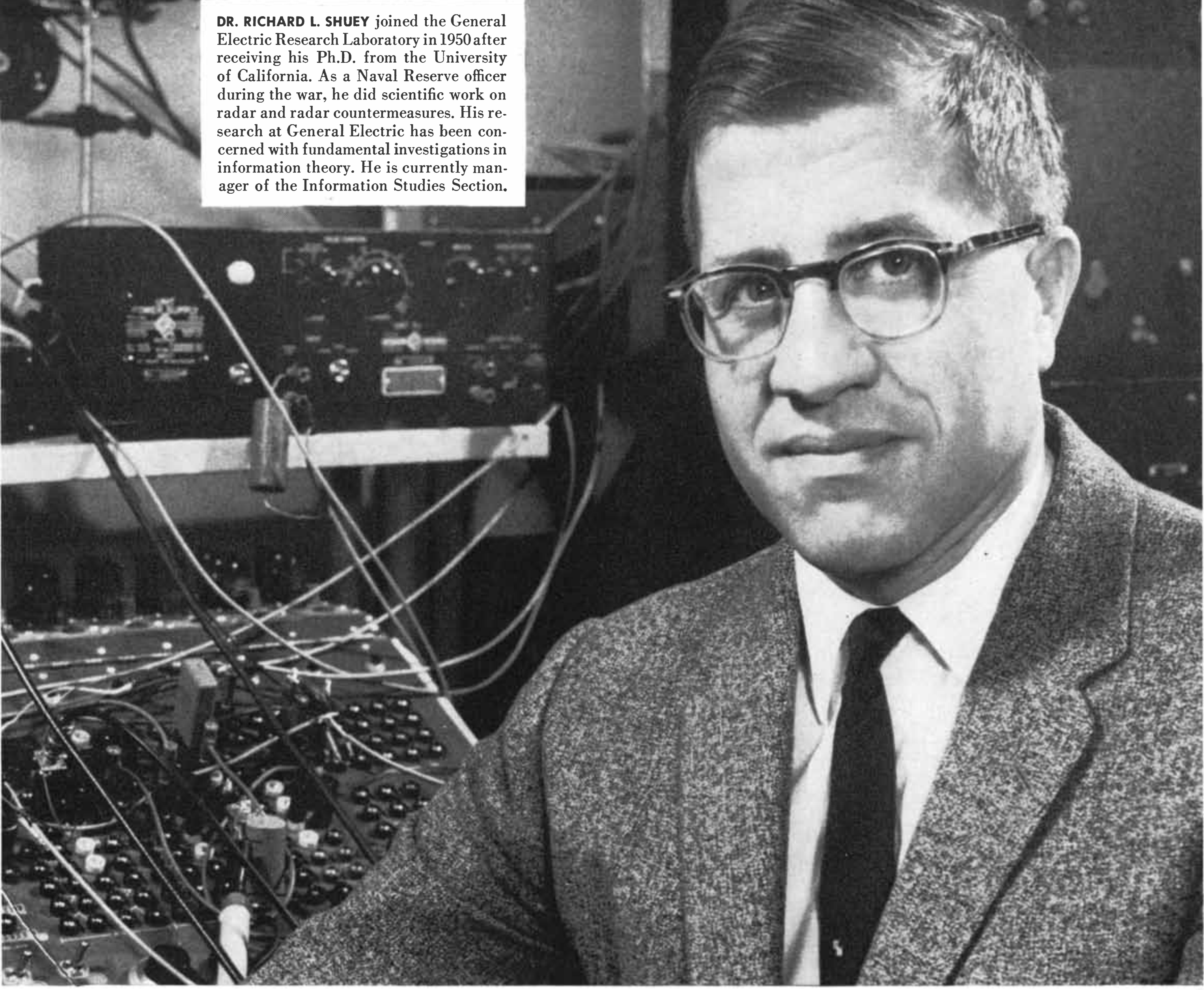


tangle) is smaller than the Ashanti or Tallensi and centered upon marriage, not lineage. Since neither maternal nor paternal lineage has exclusive importance, we acknowledge relatives on both sides and give them similar names (*e.g.*, "mother," "mother-in-law").

and he must observe the same code of politeness with each of them. If his real mother should die, another of the women he calls "mother" will replace her. The classificatory terminology binds together groups that share status and responsibilities. To people like the Ashanti and Tallensi the word "mother" has a social rather than a biological significance: it defines one rank in a complex family system.

The need to define relationships is crucial in every society, and all kinship systems have evolved in response to this need. We are indebted to A. R. Radcliffe-Brown, the distinguished British anthropologist, for the most satisfactory statement of the underlying principles. The first of these establishes a clear demarcation between successive generations. The elders are not only physiological progenitors of their young; they also protect and nurture them throughout childhood and provide their first training in the crafts, customs and morals of the tribe. This all-important relationship requires not only love on the part of the parents but also respect on the part of the children. Parental authority is incompatible with complete intimacy. Most societies banish everything sexual from the parent-and-child relationship; the universal taboo on incest between parent and child epitomizes the cleavage between elder and younger generations. Many societies enforce certain "avoidances" that help to maintain social distance between generations. The Tallensi, for example, forbid an eldest son to eat from his father's dish [*see illustrations at top of preceding two pages*]. Some central African tribes carry avoidance to extremes. One tribe, the Nyakyusa, requires fathers and children to live in separate villages. In the matrilineal Ashanti society, on the other hand, it is the uncle to whom children show respect (or at least resentful submission). Ashanti fathers are not figures of authority to their children and need not keep aloof from them. Indeed, the father's lack of authority over his children is compensated for by warm bonds of trust and affection.

Radcliffe-Brown's second principle is the so-called sibling rule of unity and loyalty among the members of a single generation. The unity among siblings (meaning cousins as well as brothers and sisters) is the converse of the first principle of separation between each generation of siblings and the next. Internally, of course, each generation is differentiated by sex and order of birth. Yet the rule generally prevails that siblings



DR. RICHARD L. SHUEY joined the General Electric Research Laboratory in 1950 after receiving his Ph.D. from the University of California. As a Naval Reserve officer during the war, he did scientific work on radar and radar countermeasures. His research at General Electric has been concerned with fundamental investigations in information theory. He is currently manager of the Information Studies Section.

Will machines ever "think"?

General Electric's Dr. Richard L. Shuey seeks new insight into the problems of information processing

TODAY'S computing machines frequently are described as "fast morons" — they do what they are told, and they do it with extraordinary speed. But will tomorrow's machines be capable of judgment without human guidance? Dr. Richard L. Shuey of the General Electric Research Laboratory believes that they will — when future, more sophisticated machines are given the capability of *self-organization*. While it is unlikely that man-made machines will ever duplicate all aspects of human intelligence, they will develop *their own criteria for decision making*, and in most cases will program their own operations.

Dr. Shuey and his associates are attacking these problems by using and combining knowledge from several areas of science. Mathematicians, electrical engineers, and physicists work side by side, and there is a growing interest in applying biological science to the theory of information processing.

The dramatic advances that are already being made in this area at General Electric typify the progress that can be made when scientists are provided the incentives, the tools, and the freedom to seek out new knowledge.

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share all things on equal terms. Frequently the sibling principle is generalized to include all tribesmen of the same generation. In East and West Africa this is institutionalized in the so-called age-grade system. The pastoral Masai, for example, initiate youths into their lowest "grade" of junior warriors every seven years, two successive grades forming a "generation set." Members of a set are classificatory brothers to each other and are classificatory fathers to the next set. Cattle-keeping and warfare are the tasks of the junior sets, while government is the prerogative of the senior sets.

The third principle of kinship, according to Radcliffe-Brown's scheme, accounts for the orderly succession of the distinct sibling groups in time: this is the rule of "filiation." Most societies, as we have seen, stress this rule more strongly than we do. Filiation is usually traced on strictly matrilineal or patrilineal lines. Occasionally the two modes are combined. In some African tribes the individual inherits land and political offices from his father, and livestock and religious-cult memberships from his mother. The bond of common filiation forms social groups that reach beyond the single household in time as well as space. These groups are often called clans. Frequently they are exogamous; as among the Ashanti and Tallensi, their members may not marry one another but must seek mates from other clans. This establishes "affinal" (in-law) relationships between clans and binds them into a still larger unit: the tribe.

What happens to kinship-based societies when industry, a money economy and Western education impinge on them? Recent investigation shows an increasing breakdown of both patrilineal and matrilineal family systems under such conditions. In their place bilateral systems similar to our own become established. The reasons are obvious. Industry and commerce require the individual to earn wages and to enter legal contracts not as a member of a family but on his own. Western law and education emphasize the responsibilities of individual citizenship and parenthood, as opposed to group citizenship and collective responsibility of kinfolk to children. In his legal and economic roles the individual separates from his kin group. The family constituted by marriage becomes his primary concern. In Africa and elsewhere, as people become industrialized, we are witnessing processes of social evolution analogous to those that shaped the much more limited institution that we call the family.

MATHEMATICAL GAMES

An inductive card game, and the answers to the "brain-teasers" in the May issue

by Martin Gardner

Most mathematical games, from ticktacktoe to chess, call for deductive reasoning on the part of players. In contrast, Eleusis, a remarkable new card game invented by Robert Abbott, a young New York writer, is an induction game. It should be of special interest to mathematicians and other scientists because of its striking analogy with scientific method and its exercise of precisely those psychological abilities in concept formation that seem to underlie the "hunches" of creative thinkers.

Eleusis is a game for three or more players. It makes use of the standard deck of playing cards. Players take turns at being the "dealer," who has no part in the actual play except to serve as a kind of umpire. He deals to the other players until one card remains. This is placed face-up in the center of the table as the first card of the "starter pile." To make sure that players receive equal hands, the dealer must remove a certain number of cards before dealing. For three players (including the dealer, who of course does not get a hand) he removes one card; for four players, no cards; five players, three cards, and so on. The removed cards are set aside without being shown.

After the cards are dealt and the "starter card" is in place, the dealer makes up a secret rule that determines what cards can be played on the starter pile. It is this rule that corresponds to a law of science; the players may think of the dealer as Nature. The dealer writes his rule on a piece of paper, which he folds and puts aside. This is for later checking to make sure that the dealer does not upset Nature's uniformity by changing his rule. For each player the object of the game is to get rid of as many cards as possible. This can be done rapidly by any player who correctly guesses the secret rule.

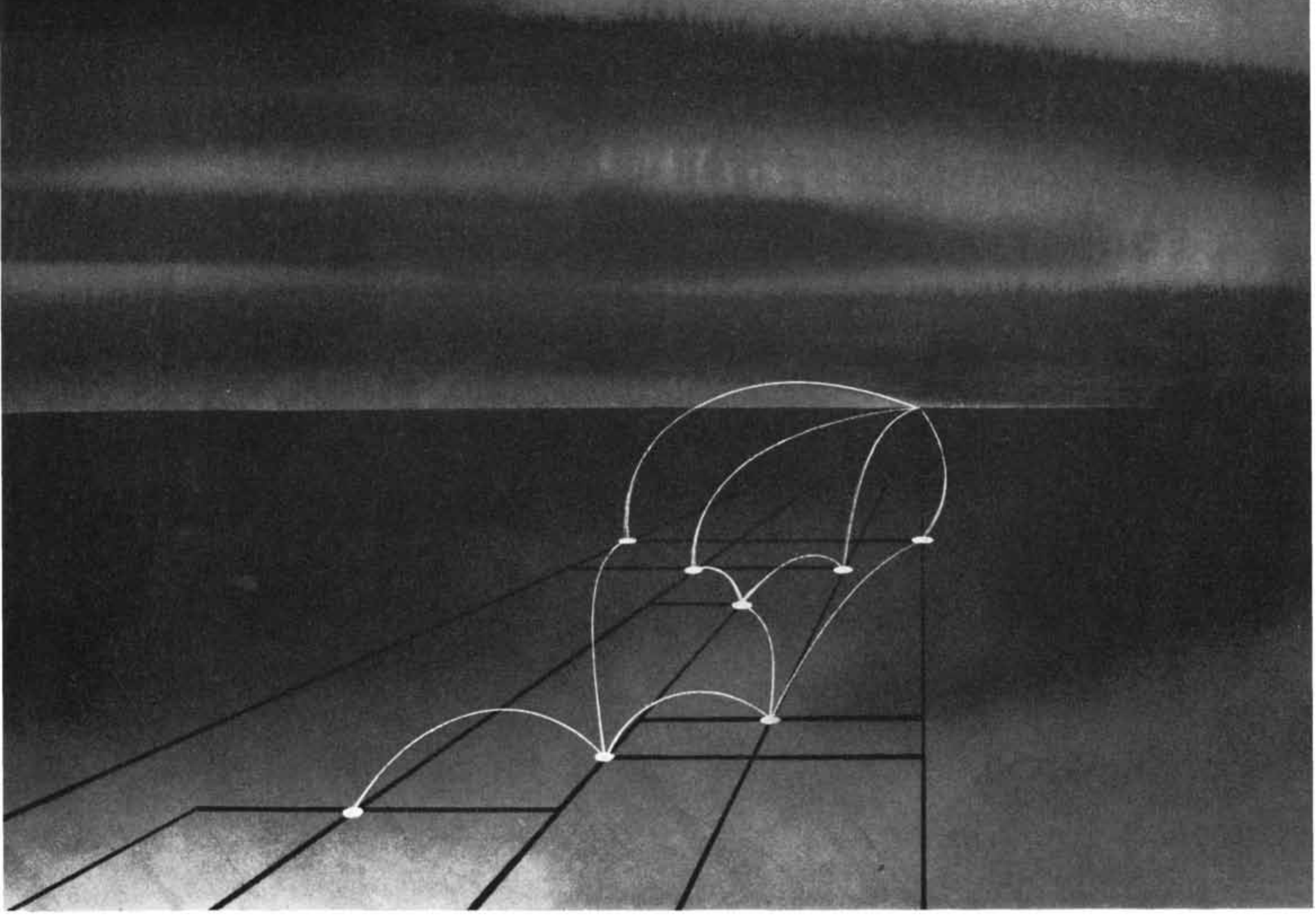
An example of a very simple rule is: "If the top card of the starter pile is red, play a black card. If the top card is black, play a red card." Beginners should limit themselves to extremely simple rules of this type, then move on to more complicated rules as their ability to play improves. One of the most ingenious features of Eleusis is that the method of scoring (to be explained later) puts pressure on the dealer to choose a rule which not everyone will guess quickly, but which is simple enough so that one player is likely to guess it ahead of the others and fairly early in the game. Here again we have a pleasant analogy. The basic laws of physics are difficult to detect, yet once they are discovered they usually turn out to be based on relatively simple equations.

After the rule is written, the "first stage" of the game begins. The first player takes any card from his hand and places it face-up on the starter card. If the card conforms to the secret rule, the dealer says "Right" and the card remains on the starter pile. If it violates the rule, the dealer says "Wrong." The player then takes back the card, places it face-up in front of him, and the turn passes to the next player on the left. Each player must play one card from his hand at each turn. His "mistake cards" are left face-up in front of him and spread slightly so that they can be clearly identified. The correctly played cards which form the starter pile are also fanned along the table so that all the cards can be seen. A typical starter pile is shown in the illustration below.

Each player tries to analyze the cards in the starter pile to discover the rule governing their sequence. He then forms a hypothesis that he can test by playing what he thinks is a correct card, or by playing a card he suspects will be rejected. The first stage of the game ends when all the cards in the players' hands have been played.

The dealer's score is now figured. It is based on how far the leading player (the person with the fewest mistake cards) is ahead of the others. If there are two players (not counting the dealer), the dealer's score is the number of cards in the leading player's mistake pile subtracted from the number of cards in the other player's pile. For three players, multiply the leading player's mistake

A typical "starter pile" for the game of Eleusis. What is the secret rule that determines the order of the cards?



Report from IBM Yorktown Research Center, New York

ORGANIZING A MAXIMAL-SPEED COMPUTER

In designing a computer suitable for extremely high information-processing rates, it becomes necessary to re-examine basic concepts of machine organization in the light of new devices, new programming techniques and new applications. This study is being conducted by a machine organization group at the IBM Yorktown Research Center.

Investigations into the principles of computers are leading to the design of a completely superconducting machine. Its computing speed and capacity will be so high that the finite velocity of propagation of electromagnetic signals becomes the limiting speed factor. Therefore, the design must not only provide for the unique properties of superconductors but must minimize the effects of information transmission delays. This will be accomplished by a machine organization which causes information to be confined in packets as it is processed through the machine, and by the use of miniature circuits. In addition, the machine will provide the facility for simultaneous or parallel calculations of different parts of a problem. Furthermore, whereas most machines have been synchronous (in that information flow is controlled by traffic signals operated by a common clock), methods of completely asynchronous operation are now being investigated.

A machine such as this superconductor computer may well lead to important theoretical advances in many scientific fields. This study is part of a broad research program in computer organization extending the mathematical theories of computers and their application to information processing systems of all kinds.

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cards by two, then subtract from the total of mistake cards belonging to the other players. For four players, multiply by three and do the same. For five players, the multiplier is four; for six the multiplier is five, and so on. The suits and values of cards do not enter into the scoring.

For example, suppose there are three players and the dealer. The mistake cards number 10, five and three. Twice three is six, which is taken from 15 to give the dealer a score of 9. This is recorded and the game goes into its second and final stage, during which the mistake cards are played.

The mistake cards remain fanned face-up on the table in front of each player, but a player may rearrange his cards if he wishes. Plays are made in turn as before, each player taking any card and putting it on the starter pile. The dealer tells him if it is right or wrong. If it is wrong, he replaces the card among his mistake cards.

The second stage ends when one player gets rid of all his cards, or when the dealer sees that it is impossible for more cards to be accepted on the starter pile. The slip of paper is now opened and the rule read. This corresponds in a sense to the mathematician's final deductive proof of a theorem that was first suggested to him by an inductive guess based on a set of particular observations. Other scientists are of course denied this final verification and must rest content with establishing their hypotheses to a high degree of probability. If the scientist accepts the pragmatic epistemology of, say, William James and John Dewey, he will not believe in the existence of the folded sheet of paper. The successful operation of his hypothesis will be the only meaning of its "truth." Or he may agree with Bertrand Russell and others that the truth of his theory is its correspondence with an external structure, even though he has no way of seizing the structure and unfolding it.

Players are now scored in a manner similar to the way in which the dealer was scored. Each takes the number of cards he holds, multiplies by the number of players exclusive of himself and the dealer, then subtracts the product from the total number of cards held by the other players. If the result is a minus number, he is given a score of 0. A bonus of 6 goes to the player who went out. If no one went out, it goes to the player with the fewest cards, and if two or more tie, the bonus is divided between them. For example, if there are four players (excluding the dealer) who hold two, three, 10 and no cards, their respective scores will be 7, 3, 0 and 21.

The deal passes to the left after each hand. The game continues until each person has been dealer twice; then the player with the highest score is the winner of the set.

If the rule is not applicable until two cards are on the starter pile, then the first card played is correct no matter what it is. If a rule involves numbers, the ace is 1, the jack 11, the queen 12 and the king 13. If it is permissible to "turn the corner" (continue in cyclic fashion: J-Q-K-A-2-3 . . .), the dealer must state this in his rule.

Rules should be avoided that restrict a player, on most of his turns, to less than a fifth of the cards in the deck. For example, the rule "Play a card with a value of one unit above the value of the top card" is not acceptable, because at each turn a player would be limited to only four cards out of the 52.

After writing down his rule, the dealer may, if he wishes, give a hint of it. He might say: "This rule involves the two top cards of the starter pile," or "This rule involves the suits." After the play begins, no further hints are permitted unless the play is very informal.

The following secret rules are typical, and are listed in order of increasing complexity.

1. Alternate even and odd cards.

2. The card played must have either the same suit or the same value as the card on top of the pile (as in the card game called Eights).

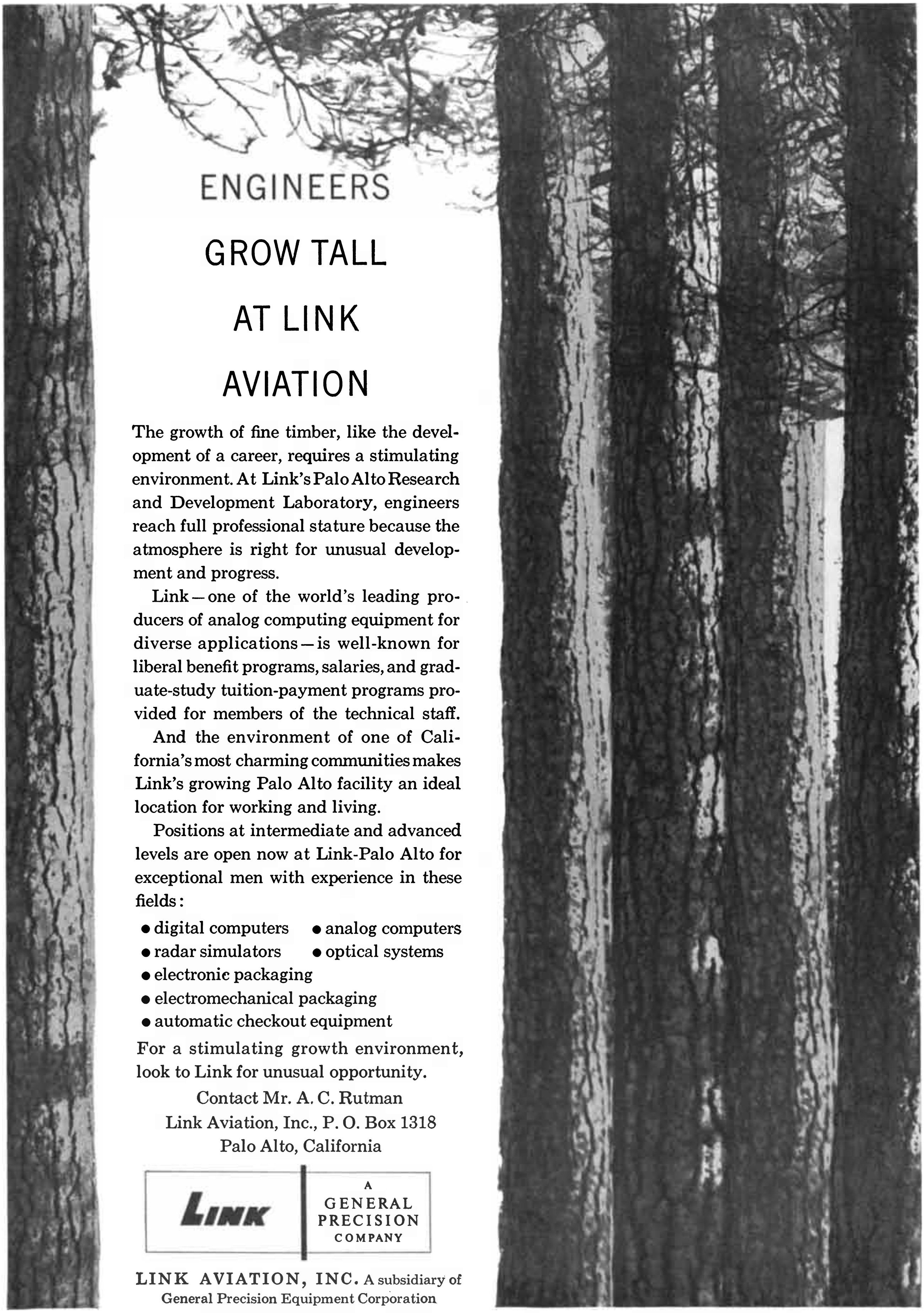
3. If the top two cards are of the same color, play a card from ace to 7. If they are of different colors, play a card from 7 to king.

4. If the second card from the top is red, play a card with a value equal to or higher than this card. If the second card is black, play a card of equal or lower value.

5. Divide the value of the top card by four. If the remainder is one, play a spade; if two, play a heart; if three, play a diamond; if zero, play a club.

If the players have some mathematical sophistication, the rules can of course be more advanced. The dealer, however, must always shrewdly estimate the skill of the players so that he can raise his score by choosing a rule that one player is likely to discover ahead of the others.

It is permissible to make up rules in which the players themselves are involved. (One thinks of the physicist whose apparatus influences what he is trying to observe, or the anthropologist whose investigation of a culture changes the culture.) For example, "If your last name has an odd number of letters, play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a color other than the color of the top card; otherwise play the same color." It would be unfair, however, for a dealer not to tell the players when a rule of this tricky type is used.

The complete rules for Eleusis have been printed by the Association of American Playing Card Manufacturers, 420 Lexington Avenue, New York 17, N.Y., and will be sent by the Association to any reader who sends a four-cent stamp to cover the cost of mailing.

The cards in the illustration on page 160 have been played according to a simple rule not mentioned in this article. The reader may enjoy puzzling it out before it is explained next month. Note that the first seven cards follow a pattern of alternate colors. This often happens in a game as well as in the history of science. Players have in mind a condition that is not really part of the rule, but they stick by it until an experiment proves that the rule is simpler than they suspected or that their successes were merely accidental.

The answers to last month's problems and to the question of two months ago about the doughnut are as follows:

1.

The following analysis of the desert-crossing problem appeared in a recent issue of *Eureka*, a publication of mathematics students at the University of Cambridge. Five hundred miles will be called a "unit"; gasoline sufficient to take the truck 500 miles will be called a "load"; and a "trip" is a journey of the truck in either direction from one stopping point to the next.

Two loads will carry the truck a maximum distance of 1 and 1/3 units. This is done in four trips by first setting up a cache at a spot 1/3 unit from the start. The truck begins with a full load, goes to the cache, leaves 1/3 load, returns, picks up another full load, arrives at the cache and picks up the cache's 1/3 load. It now has a full load, sufficient to take it the remaining distance to one unit.

Three loads will carry the truck 1 and 1/3 plus 1/5 units in a total of nine trips. The first cache is 1/5 unit from the start. Three trips put 6/5 loads in the cache. The truck returns, picks up the remaining full load and arrives at the first cache with 4/5 load in its tank. This, together with the fuel in the cache, makes two full loads, sufficient to carry the truck the remaining 1 and 1/3 units, as explained in the preceding paragraph.

We are asked for the minimum amount of fuel required to take the truck 800 miles. Three loads will take it 766 and 2/3 miles (1 and 1/3 plus 1/5 units), so we need a third cache at a distance of 33 and 1/3 miles (1/15 unit) from the start. In five trips the truck can build up this cache so that when the truck reaches the cache at the end of the seventh trip, the combined fuel of truck and cache will be three loads. As we have seen, this is sufficient to take the truck the remaining distance of 766 and 2/3 miles. Seven trips are made between starting point and first cache, using 7/15 load of gasoline. The three loads of fuel that remain are just sufficient for the rest of the way, so the total amount of gasoline consumed will be 3 and 7/15, or a little more than 3.46 loads. Sixteen trips are required.

Proceeding along similar lines, four loads will take the truck a distance of 1 and 1/3 plus 1/5 plus 1/7 units, with three caches located at the boundaries of these distances. The sum of this infinite series diverges as the number of loads increases; therefore the truck can cross a desert of any width. If the desert is 1,000 miles across, seven caches, 64 trips and 7.673 loads of gasoline are required.

2.

If Smith has two children, at least one of which is a boy, we have three equally probable cases: BB, BG, GB. In only one case are both children boys, so the probability that Smith's other child is a boy is 1/3. Jones's situation is different. We are told that his older child is a girl, so there are only two equally probable cases: GG, GB. Therefore the probability that the other child is a girl is 1/2.

If this were not so, we would have a simple method of guessing with better than even odds whether a flipped coin, covered by someone's hand, is heads or tails. We would simply flip our own coin. If it came heads we could reason: At least one of the two coins is heads, therefore the probability that the concealed coin is tails is 2/3. This reasoning is incorrect because we know *which* coin is heads. On the other hand, if someone flips two coins and informs you that at least one came up heads (picking this coin at random and not on a prespecified basis of naming the shiniest coin, the coin on the left and so on), you can bet that the coin is tails and in the long run expect to win two out of three times.

3.

The key to Lord Dunsany's chess problem is the fact that the black queen

...NEWS IS HAPPENING AT NORTHROP

Solving Problems of Manned Space Flight – at Northrop

by Welko E. Gasich

Director of Weapon System Development Engineering, Norair Division of Northrop Corporation, Hawthorne, California

Man in space. To put him there and return him safely to earth, no scientific breakthroughs are needed. It is now a problem of engineering. Engineers must solve lunar space challenges that include reliability, radiation, and human environment problems. Man himself must be trained for the environmental problems associated with either boost-glide or ballistic recovery. These are the areas in which the scientist and the engineer at Northrop are working today.

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Current papers by Northrop scientists and engineers include:

Lightweight High-Performance Military Aircraft—W. E. Gasich; Problems Associated with Injecting, Orbiting, Recovering A Man from Space Flight—Ralph Hakes.

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is not on a black square as she must be at the start of a game. This means that the black king and queen have moved, and this could have happened only if some black pawns have moved. Pawns cannot move backward, so we are forced to conclude that the black pawns reached their present positions from the other side of the board! With this in mind, it is easy to discover that the white knight on the right has an easy mate at Q3 (counting from the top of the board, which is really white's side), and reaches it in three moves. Black, however, delays the mate one move by playing his knight to KB6 (counting from bottom of board), then to K4, where it blocks the mate until it is taken by the white queen.

4.

Let n be the number of steps visible when the escalator is not moving, and let a unit of time be the time it takes Professor Slapenarski to walk down one step. If he walks down the down-moving escalator in 50 steps, then $n - 50$ steps have gone out of sight in 50 units of time. It takes him 125 steps to run up the same escalator, taking five steps to every one step before. In this trip, $125 - n$ steps have gone out of sight in 125/5, or 25, units of time. Since the escalator can be presumed to run at constant speed, we have the following linear equation that readily yields a value for n of 100 steps:

$$\frac{n-50}{50} = \frac{125-n}{25}$$

5.

In long division, when two digits are brought down instead of one, there must be a zero in the quotient. This occurs twice, so we know at once that the quotient is $x080x$. When the divisor is multiplied by the quotient's last digit, the product is a four-digit number. The quotient's last digit must therefore be 9, because eight times the divisor is a three-digit number.

The divisor must be less than 125 because eight times 125 is 1,000, a four-digit number. We now can deduce that the quotient's first digit must be more than 7, for seven times a divisor less than 125 would give a product that would leave more than two digits after it was subtracted from the first four digits in the dividend. This first digit cannot be 9 (which gives a four-digit number when the divisor is multiplied by it), so it must be 8, making the full quotient 80809.

The divisor must be more than 123 because 80809 times 123 is a seven-digit number and our dividend has eight digits. The only number between 123 and 125 is 124. We can now reconstruct the entire problem as follows:

```
        80809
124 | 10020316
       992
       ----
        1003
         992
        ----
         1116
         1116
```

6.

Several procedures have been devised by which n persons can divide a cake in n pieces so that each is satisfied that he has at least $1/n$ of the cake. The following system has the merit of leaving no excess bits of cake.

Suppose there are five persons: *A*, *B*, *C*, *D*, *E*. *A* cuts off what he regards as 1/5 of the cake and what he is content to keep as his share. *B* now has the privilege, if he thinks *A*'s slice is more than 1/5, of reducing it to what he thinks is 1/5 by cutting off a portion. Of course if he thinks it is 1/5 or less, he does not touch it. *C*, *D* and *E* in turn now have the same privilege. The last person to touch the slice keeps it as his share. Anyone who thinks that this person got less than 1/5 is naturally pleased because it means, in his eyes, that more than 4/5 remains. The remainder of the cake, including any cut-off pieces, is now divided among the remaining four persons in the same manner, then among three. The final division is made by one person cutting and the other choosing. The procedure is clearly applicable to any number of persons.

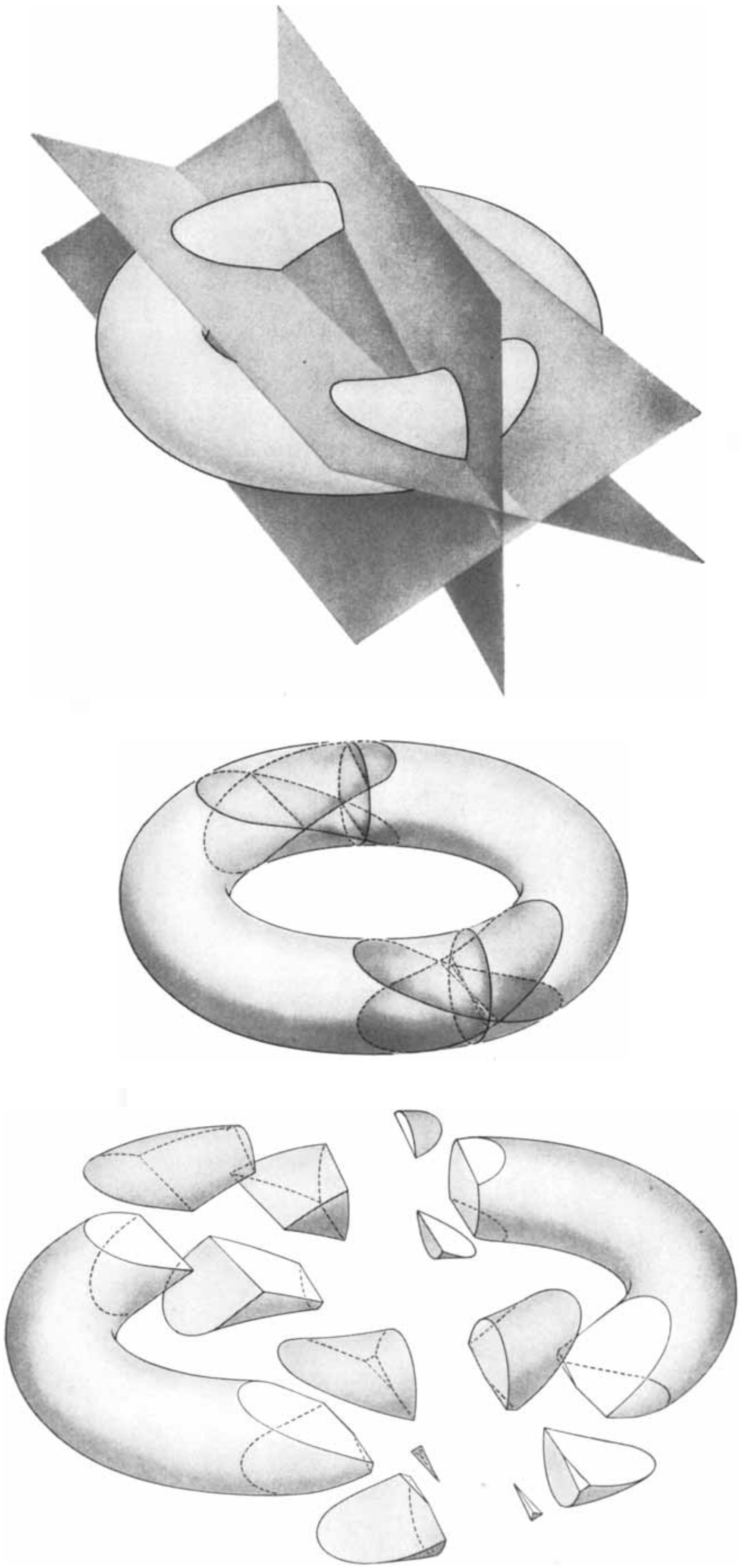
7.

The first sheet is folded as follows. Hold it face down so that when you look down on it the numbered squares are in this position:

2365	
1874	

Fold the right half on the left so that 5 goes on 2, 6 on 3, 4 on 1 and 7 on 8. Fold the bottom half up so that 4 goes on 5 and 7 on 6. Now tuck 4 and 5 between 6 and 3, and fold 1 and 2 under the packet.

The second sheet is first folded in half the long way, the numbers outside, and



How to slice a doughnut into 13 pieces with only three plane cuts

held so that 4536 is uppermost. Fold 4 on 5. The right end of the strip (squares 6 and 7) is pushed between 1 and 4, then bent around the folded edge of 4 so that 6 and 7 go between 8 and 5, and 3 and 2 go between 1 and 4.

8.

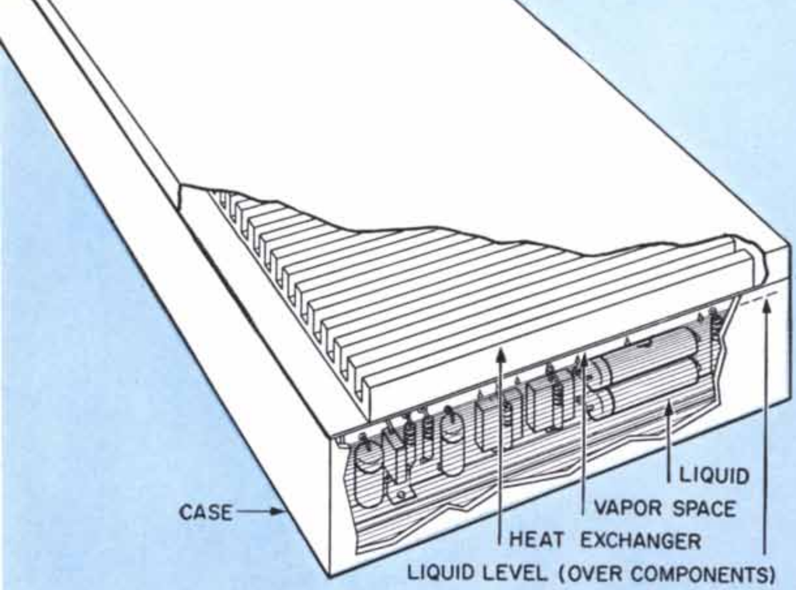
To determine the value of Brown's check, let x stand for the dollars and y for the cents. The problem can now be expressed by the following equation: $100y + x - 5 = 2\ (100x + y)$. This reduces to $98y - 199x = 5$, a Diophantine equation with an infinite number of integral solutions. Only one solution, however, meets the problem's condition that the value of y be less than 100. This solution is: $x = 31$ and $y = 63$, making Brown's check $31.63.

9.

Regardless of how much wine is in one beaker and how much water is in the other, and regardless of how much liquid is transferred back and forth at each step (provided it is not all of the liquid in one beaker), it is impossible to reach a point at which the percentage of wine in each mixture is the same. This can be shown by a simple inductive argument. If beaker *A* contains a higher concentration of wine than beaker *B*, then a transfer from *A* to *B* will leave *A* with the higher concentration. Similarly a transfer from *B* to *A*—from a weaker to a stronger mixture—is sure to leave *B* weaker. Since every transfer is one of these two cases, it follows that beaker *A* must always contain a mixture with a higher percentage of wine than *B*. The only way to equalize the concentrations is by pouring all of one beaker into the other.

The illustration at left shows how a doughnut can be sliced into 13 pieces by three plane cuts. A large number of correspondents sent correct solutions, but a majority failed to find that elusive 13th piece. At the time of writing, the clearest diagrams showing a correct manner of cutting were drawn by the Reverend Joseph B. Tucker, Joseph Raab, William Ross and Stephen Barr. Barr also sent a rigorous proof that 13 was the maximum. The formula for the largest number of pieces that can be produced with n cuts seems to be:

$$\frac{n^3 + 3n^2 + 8n}{6}$$



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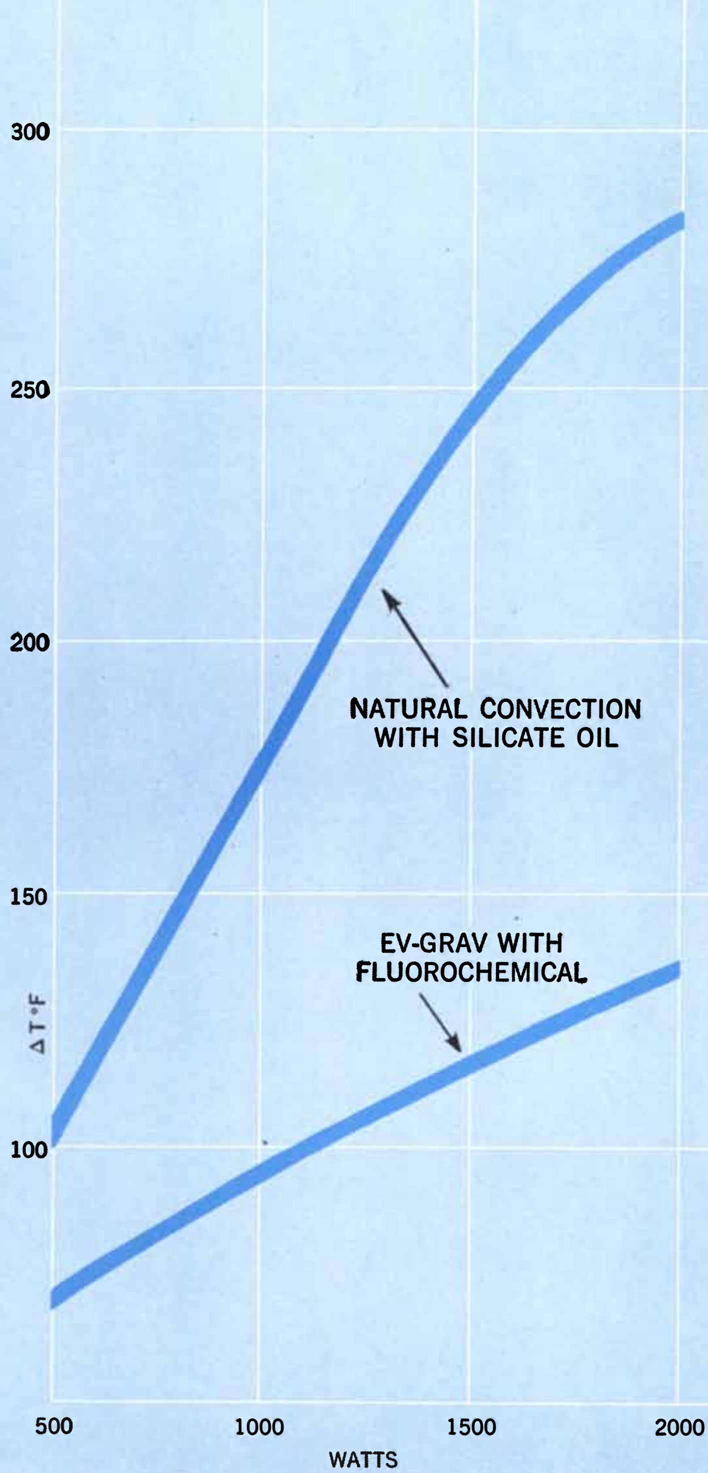

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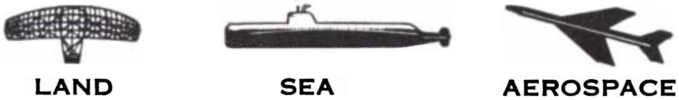

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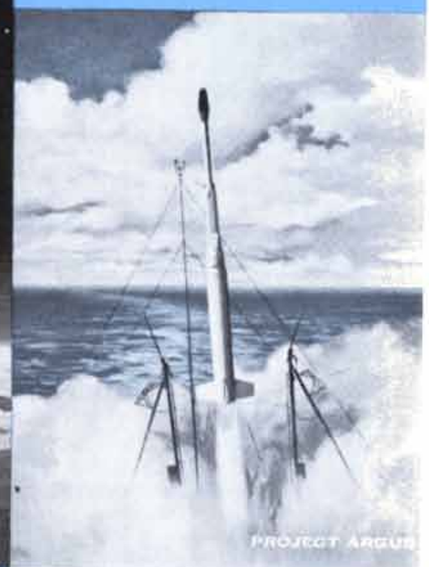

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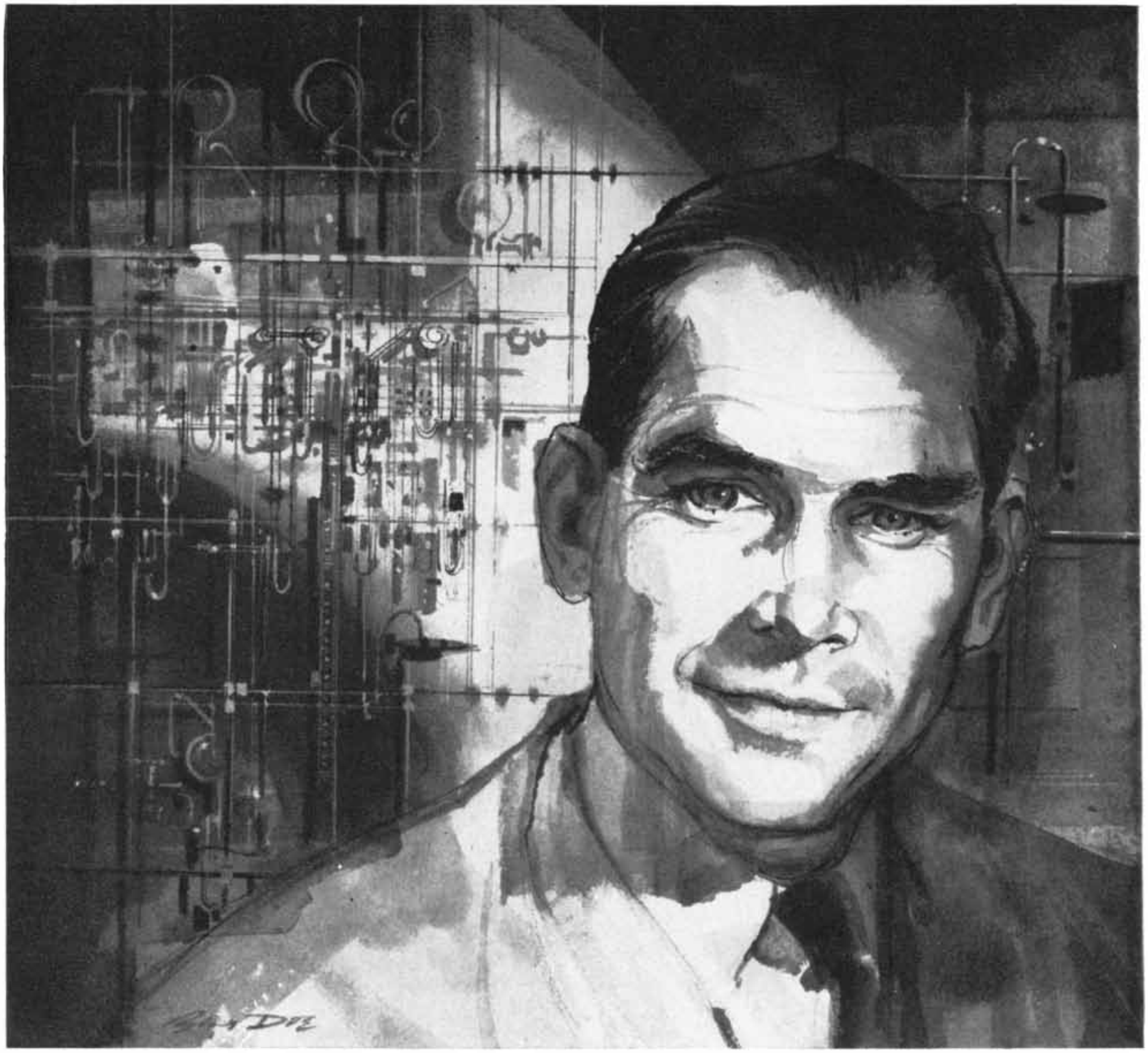


THE AMATEUR SCIENTIST

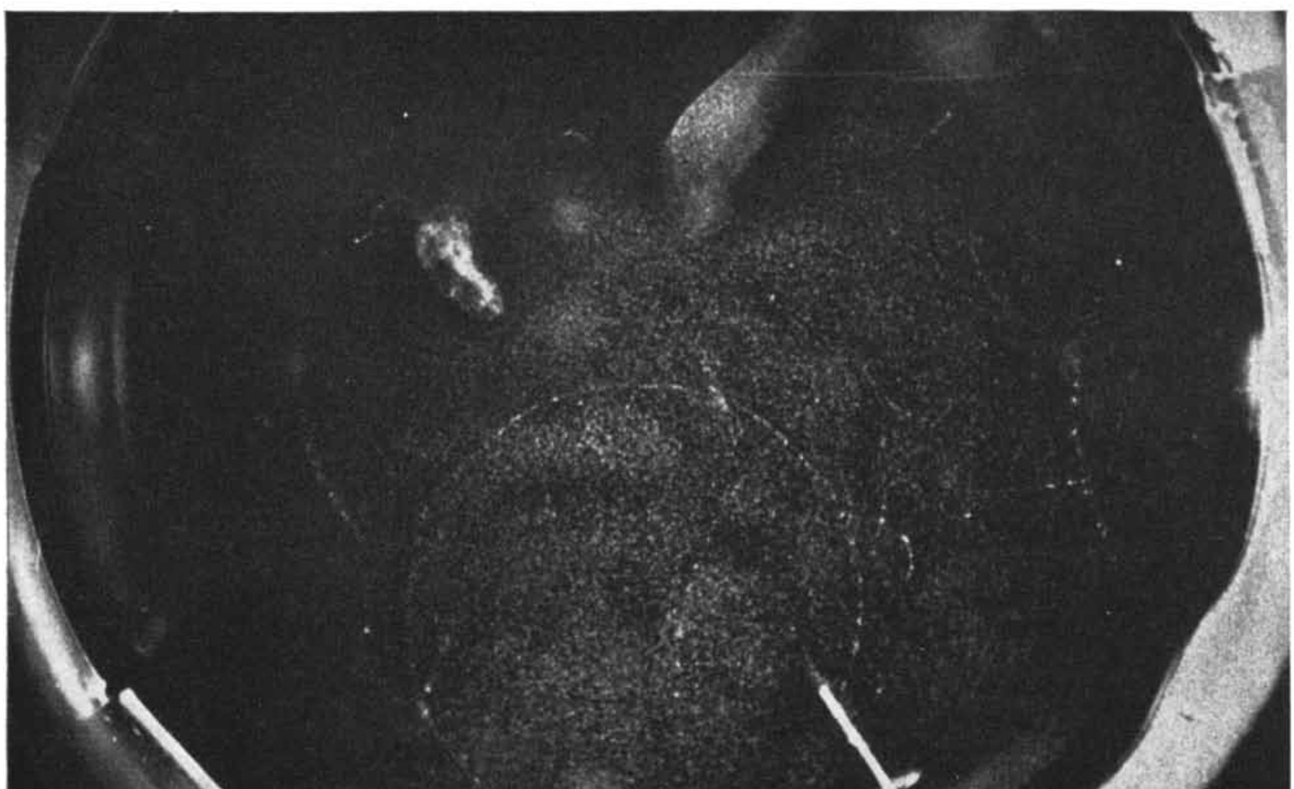
How to fit a diffusion cloud-chamber with a magnet and other accessories

Conducted by C. L. Stong

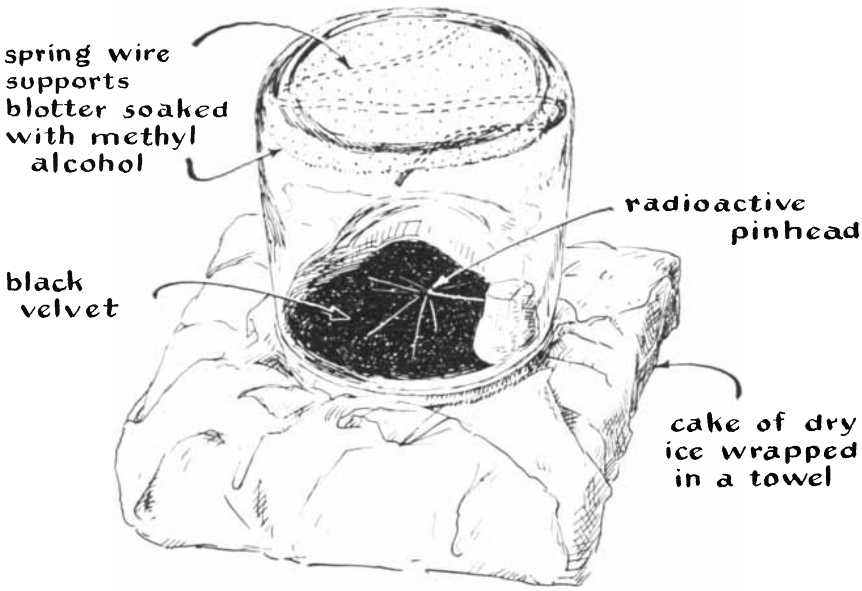
Amateurs who hanker to observe the decay of radioactive atoms and the behavior of subatomic particles often start out by making themselves a cloud chamber of the diffusion type. A simple diffusion chamber can be put together in less than five minutes from a glass jar with a screw cap, some alcohol of the rubbing variety and a small cake of dry ice. The jar is warmed, rinsed with alcohol, promptly capped and upended on the dry ice. In a minute or so, depending on the size of the jar, a vapor trail about the thickness of a hair will suddenly appear near the bottom of the chamber. Other trails will then follow at intervals of about 30 seconds. Most of the trails mark the paths of the electrically charged particles in cosmic radiation. In effect the trails magnify the width of the paths more than a trillion times.

Although a chamber made in this way stages a fascinating show, it will not satisfy the serious amateur for long. The tracks are not easy to see in ordinary light, and old tracks spread into wisps of cloud that soon clutter the view. Worse yet, the chamber stops working after a few minutes because condensation exhausts the alcohol vapor. To lengthen the operating period a pad saturated with alcohol may be fixed inside the glass top of the upended jar. Vapor evaporating from the pad will keep the chamber going for an hour or more.

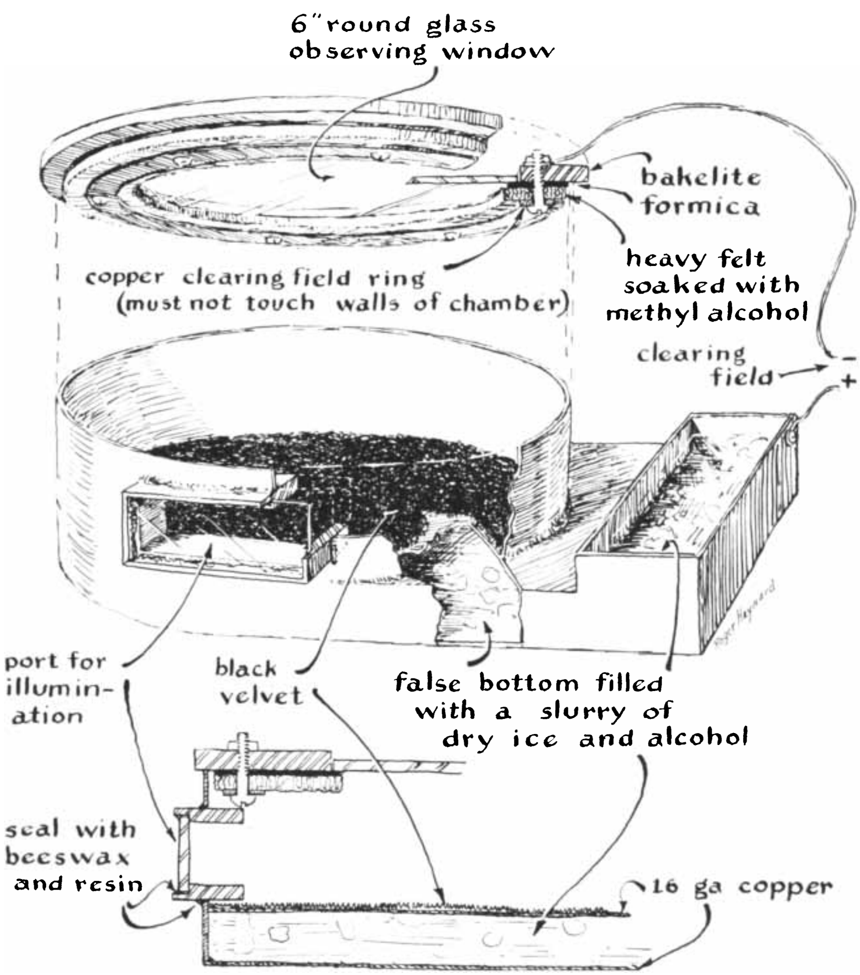
The tracks show up best when they are viewed in bright light and against a black background. A 35-millimeter slide-projector may be drafted as the light source; an effective background is provided by a scrap of black velvet fitted to the inside of the jar's screw cap. Old tracks can be cleared from the chamber by mounting a loop of wire just below



An amateur's photograph of the circular track of an electron in a magnetic field of 800 gauss



A diffusion cloud-chamber made with a glass jar



A diffusion cloud-chamber adapted for use with a magnetic field

the glass top and connecting it to the metal bottom through a voltage supply; when the voltage is turned on momentarily, the tracks disappear.

Other accessories may include a camera for photographing the tracks, mirrors set at angles to display the tracks in three dimensions, windows of flat glass to minimize optical distortion, and so on. The succession of improvements follow one another in such easy steps that a novice can find himself immersed in a full-blown hobby almost before he senses his involvement.

That is what happened to Gareth D. Shaw, a field engineer on duty in the Far East for the Bendix Aviation Corporation. His chamber is equipped with a full line of accessories for viewing and photographing tracks, plus other auxiliaries that enable him to identify particles and to determine their mass, charge, energy and velocity.

"All cloud chambers," writes Shaw, "are based on the fact that ions are created when charged particles move through a gas at high speed. Close encounters between the particle and an atom in its path dislodge an electron from the atom. The process forms two ions: the electron itself and the atom, now positive because it has lost a unit of negative charge. Either ion can disturb the delicate balance of electrical forces in a neighboring molecule of alcohol in the vapor state. On close approach to an ion the molecule acquires on the side facing the ion a charge that is opposite in sign to the charge of the ion. In consequence the molecule and the ion are mutually attracted. Other molecules in the vicinity react similarly. The ion thus acts as a center of condensation. When the temperature of the gas is below the dew point of the vapor, a droplet of alcohol quickly forms. A speeding particle leaves thousands of ions in its wake; the resulting droplets comprise the vapor trail.

"Two basic types of cloud chamber have been invented. They differ chiefly in the method used for cooling the gas below the dew point of the vapor. The first type, known as the expansion chamber, takes the form of a cylinder equipped with a close-fitting piston. When the piston is pulled down, the gas expands and its temperature drops. In the second type, the diffusion chamber, the gas is cooled by a refrigerant. When alcohol is used as the condensing vapor, a difference in temperature on the order of 150 degrees Fahrenheit is maintained between the top and bottom of the chamber. Alcohol evaporated near the top diffuses down through the air (or

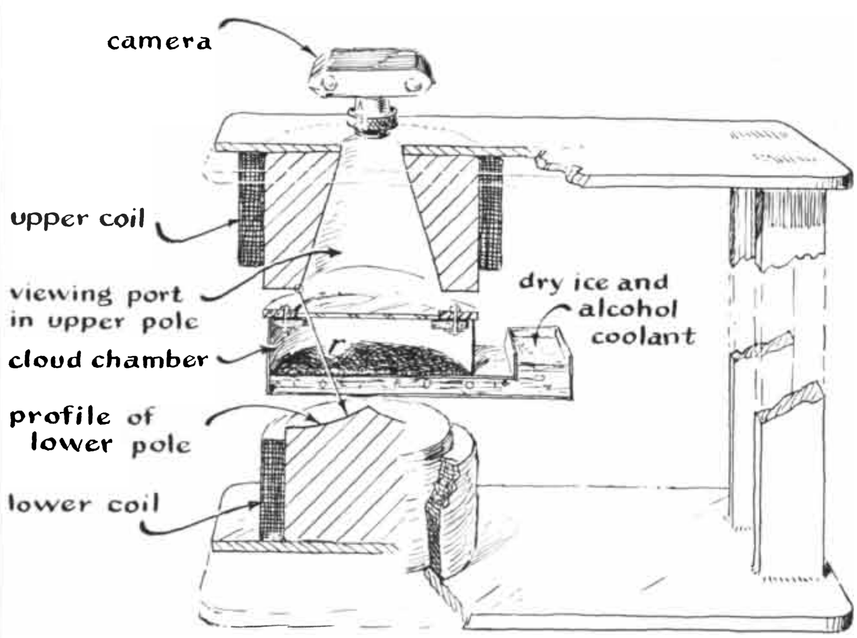
other gas) into the cold region; hence the name diffusion chamber. The amount of alcohol that can be held in the vapor state by a gas depends directly on the temperature. The cooler air near the bottom of the diffusion chamber has a lower capacity for vapor than the warmer air at the top. Thus an unstable condition arises when alcohol vapor diffuses into the cold region of the chamber. Any small body—for example, a particle of dust—will trigger condensation. The chamber is sealed against the outside air, however, and all the dust in the chamber when it goes into operation is soon carried to the bottom by droplets. Thereafter ions constitute the most likely centers of condensation.

"Dry ice also encourages condensation outside the chamber. This is why it 'smokes.' Water vapor naturally present in the air condenses around particles of suspended dust. The resulting fog can be a source of annoyance, particularly when one is attempting to photograph tracks. In the case of a simple chamber, such as the one shown in the accompanying illustration [*top of page 174*], fog can be minimized by covering the exposed surfaces of the ice with a towel. Chambers of more sophisticated design, such as one cooled by a slurry of dry ice and alcohol [*bottom of page 174*], should be insulated by a jacket of material like that used to cover steam pipes.

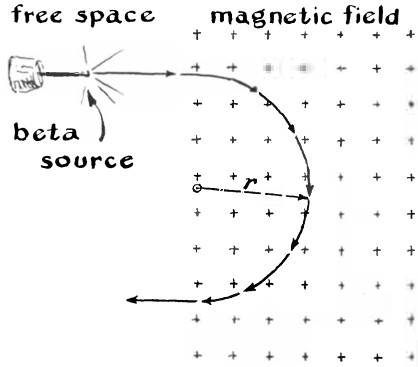
"The experimenter is interested in the size and shape of the tracks because they provide clues to the identity of the responsible particles. It is therefore important to minimize convection currents in the chamber by filtering as much heat from the light beam as possible. A small aquarium with flat sides makes a good filter. Most 35-mm. slide-projectors come equipped with heat filters and blowers. A pair of projectors may be needed to provide enough light for making photographs. Tracks show up best when viewed at an angle of about 130 degrees with respect to the light source.

"Photographs can be made inexpensively with a 35-mm. camera of *f*/3.5 aperture equipped with an auxiliary lens for close work. Lens openings range from *f*/3.5 to *f*/8 and shutter speeds from 1/10 to 1/100 second with film rated ASA 200. The photographs reproduced in this article were made with Kodak Tri-X film and developed in Kodak Microdol, a fine-grain developer. When the light source is relatively weak, a procedure known as 'pushing the film' is possible with this developer. The speed of the film is doubled by doubling the time in which the film is kept in the developer.

"Once the technique of operating the chamber has been mastered, the experimenter should consider adding a magnetic field to it. A chamber without a field is like a yardstick without inch marks—interesting but not very useful. When a charged particle moves at right angles to the direction of a magnetic field, it is acted upon by a force at right angles to both its direction and that of the field. If the field extends in the vertical direction, for example, and the particle moves from east to west, the particle is accelerated in the north-south



An electromagnet for a diffusion cloud-chamber



The path of an electron in a uniform field

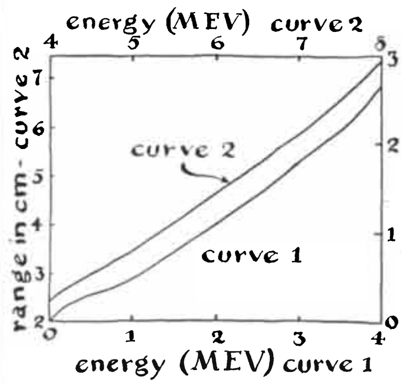
direction. As a consequence a particle that enters a uniform field follows a circular path [*see illustration above*]. The radius and direction of the path depend on the sign and magnitude of the charge on the particle, on the mass and velocity of the particle and on the strength and direction of the field.

"A suitable electromagnet can be constructed inexpensively from scrap steel, available in most communities from local industries or scrap dealers. My magnet consisted of two pole-pieces and a yoke made of a pair of plates separated by two rectangular members [*see illustration on opposite page*]. The pole-pieces were approximately five inches long. The upper one was machined to a diameter of nine inches and the lower one to a diameter of seven inches. Both were made of soft-steel shafting. In the upper pole-piece was machined a conical hole, which tapered from two inches at the top to five inches at the bottom. The hole provides a clear path for viewing and photographing the tracks. The lower pole-face was shaped to produce a uniform distribution of magnetic flux through the sensitive region of the chamber. The face of this piece is in the form of a shallow, curved cone. The inner edge of the upper pole-face coincides with the center of curvature of the lower pole-face. The radius of curvature in the case of my magnet is four inches ['*r*' *in the illustration*]. The pole-pieces are welded to the pair of soft-steel plates, each 3/8 inch thick, 10 inches wide and 18 inches long. The plates are welded in turn to the spacing members, also made of soft steel; each member is 1½ inch thick, two inches wide and 14 inches long. The spacers provide an air gap of four inches between the pole-faces.

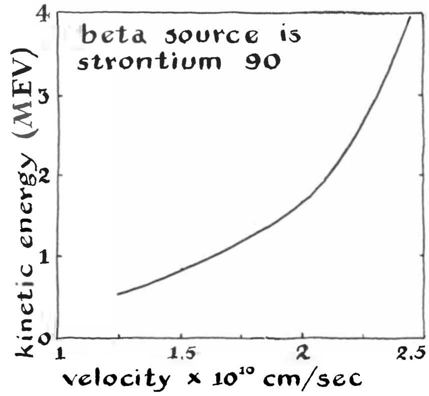
"Each of the two coils for energizing the magnet consists of 1,000 turns of No. 14 enameled copper magnet-wire, wound on wooden forms and wrapped with insulating tape. The coils require some 60 pounds of wire. The forms were made approximately 1/16 inch larger than the pole-pieces so that the coils could be slipped over the poles easily during assembly. The lower coil rests on the yoke plate and requires no fastening. The upper one is supported by an aluminum ring bolted to the upper pole. The magnet is energized by a six-ampere direct current at 100 volts, and is designed for a maximum duty-cycle of 15 minutes. Extended operation at six amperes results in overheating. The magnet produces a field strength of 1,000 gauss in the sensitive region of the chamber. Motor-generators of the type used for arc welding are suitable for powering the unit and can occasionally be picked up on the surplus market for a few dollars. An inexpensive power supply can also be assembled from surplus rectifier-units of the silicon-disk type.

"The coils must be interconnected so that the current flows in the same direction through each. When they are properly connected, the north end of a magnetic-compass needle will point to one pole-face and the south end to the other. A resistor of 1,000 ohms rated at 20 watts should be connected across the input terminals of the coils to dissipate the energy generated by the collapse of the magnetic field when the magnet is turned off. Without this resistor serious arcing will occur at the switch contacts. If a voltmeter or other instrument is connected across the coils, it should be removed before turning off the magnet; otherwise the sharp rise in voltage that accompanies the collapse of the field will damage the meter.

"When the magnet is ready for operation, the field strength must be measured in the region to be occupied by the sensitive part of the chamber. The current through the coils is adjusted as accurately as possible to six amperes and a note is made of the voltage at this value of current. The field is then meas-



Energy-range graph of alpha particles

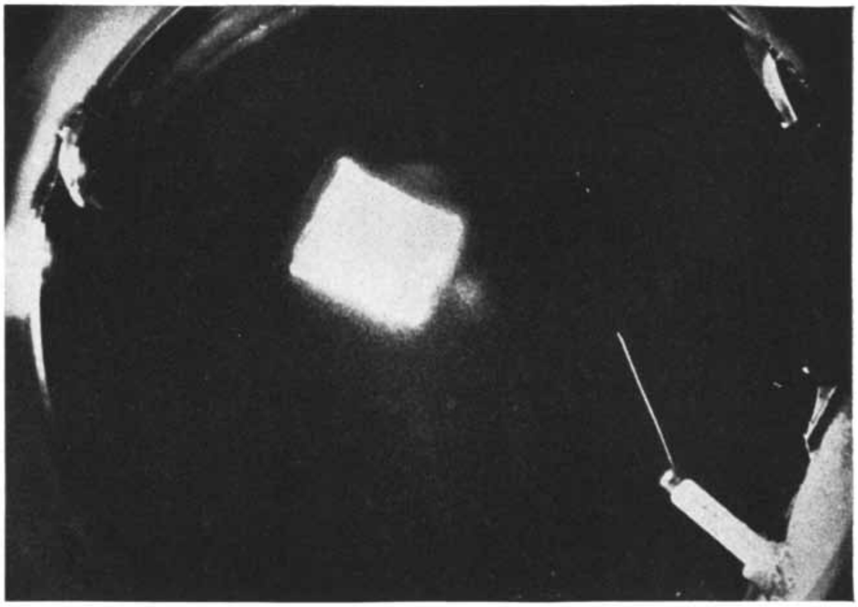


Energy-velocity graph of beta particles

ured (in gauss) with a fluxmeter. This measurement is made only once, so a fluxmeter may be borrowed from a local electric-power firm or the physics laboratory of a nearby school. If desired, the magnet may be calibrated for a series of current values.

"The experimenter will be well repaid in terms of convenience for care taken in constructing the chamber. One good design, which is made principally of sheet metal, provides two compartments. The lower one holds the refrigerant (a slurry of crushed dry ice mixed with alcohol), and also serves as the base for the upper compartment [*see illustration on page 174*]. Sheet steel may be used, but copper is recommended at least for the surface between the compartments because of its effectiveness as a conductor of heat. The upper chamber is closed by a lid that consists of an assembly of concentric rings and a disk of clear glass. The ring assembly supports the glass and includes an insulated ring of copper that serves as one electrode for applying an electric field across the chamber to clear it of old tracks. The ring assembly also incorporates a felt pad from which alcohol evaporates when the chamber is in operation. As an alternative scheme the wall of the chamber may be lined with a strip of blotting paper arranged so that its lower edge rests in the pool of alcohol at the bottom of the chamber. Fluid is drawn through the paper by capillary attraction, evaporates, condenses and returns to the pool for recirculation. The chamber may be supported within the magnet on a flat platform of nonmagnetic sheet metal (such as aluminum) attached to the lower pole. A bracket to support the camera in line with the opening should also be provided.

"To prepare the chamber for operation, crush enough dry ice into pea-sized lumps to fill the lower container. Do not handle the ice with your bare hands—a

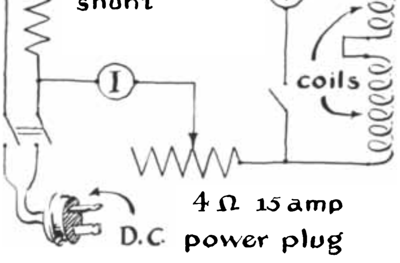


Vapor trail (lower right) *of an alpha particle*

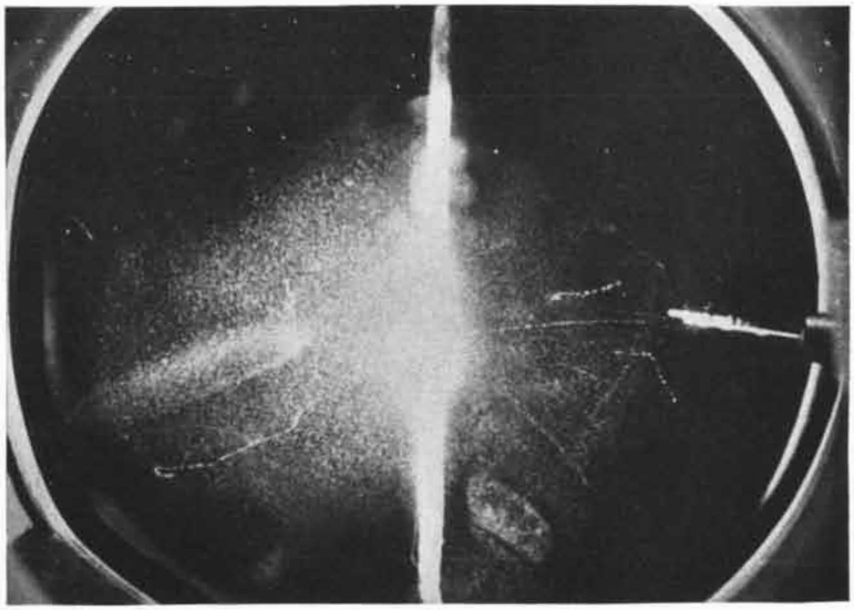
frozen finger is quite as painful as a burned one. Alcohol is next added *slowly* to the ice. Violent bubbling may occur until the temperature of the container drops close to that of the ice. Additional ice may be added from time to time as required. Next saturate the pad with alcohol and pour about a tablespoonful of alcohol into the chamber. Place the assembly in the magnet and apply power to the coils.

"Some of the trails in the chamber will now be curved. If the upper pole of the magnet attracts the north end of a magnetic-compass needle (which indicates that the direction of the magnetic flux is from the lower to the upper pole), electrons will follow a counterclockwise path. Relatively light particles of low energy that carry a positive charge will curve clockwise. The direction in which some particles move can be determined by inspection. Energy expended in the creation of ions during flight causes the particle to lose speed; more time is thus available for the transfer of energy near the end of flight. The heavier ionization is seen as a thickening of the track. The direction of flight is known, of course, when particles originate in a radioactive material deliberately placed in the chamber. The identity of some particles can also be determined by inspection. Alpha rays make relatively short, thick tracks; electrons and protons, thin ones. Mesons are usually so energetic that their flight is not perceptibly affected by a field of 1,000 gauss. Consequently their tracks appear thin and straight.

"It is interesting to analyze photographs of tracks and to calculate the speed, mass and energy of the responsible particles. The accompanying photograph [*page 173*], for example, shows the circular path of an electron ejected from a short stub of wire coated with radioactive material. Before the photograph was made, the current of the magnet was adjusted to generate a field strength at the chamber of 800 gauss. The momentum of the particle, expressed in units of 'magnetic rigidity,' is equal to the radius of its path multiplied by the field strength. The radius of this particular path is 3.09 centimeters. Thus the momentum of the particle is equal to 3.09×800, or 2,472, gauss-centimeters. With this quantity known, the velocity of the particle can be learned by doing just a little more arithmetic. The quantity representing the magnetic rigidity is combined with the ratio of the electron's charge to its mass (1.7588×10^7 electromagnetic units per gram) and the velocity of light (3×10^{10} centimeters per second) according to the accompanying formula [*see page 184*]. In this



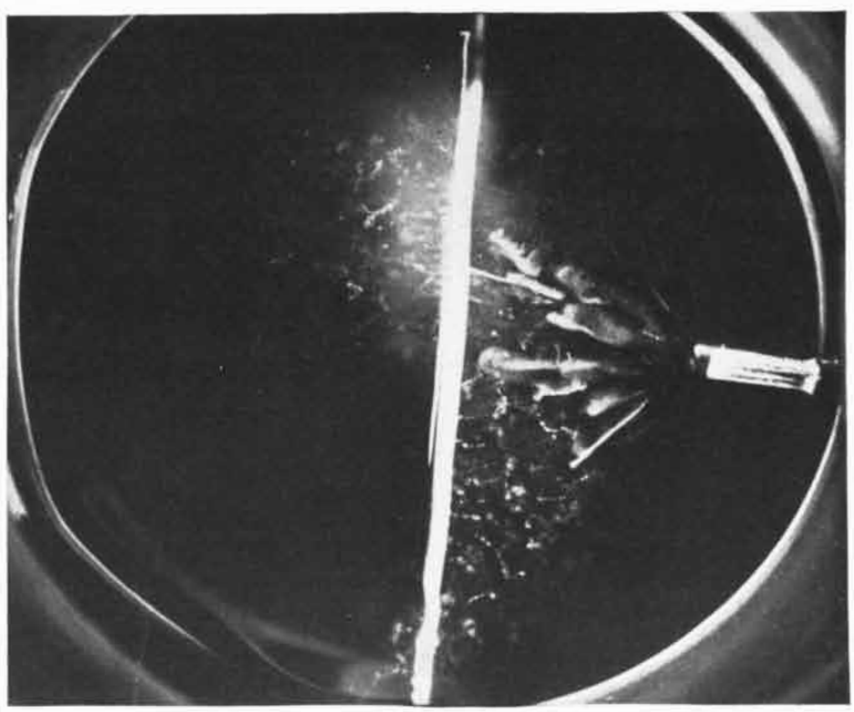
Circuit diagram for magnet coils



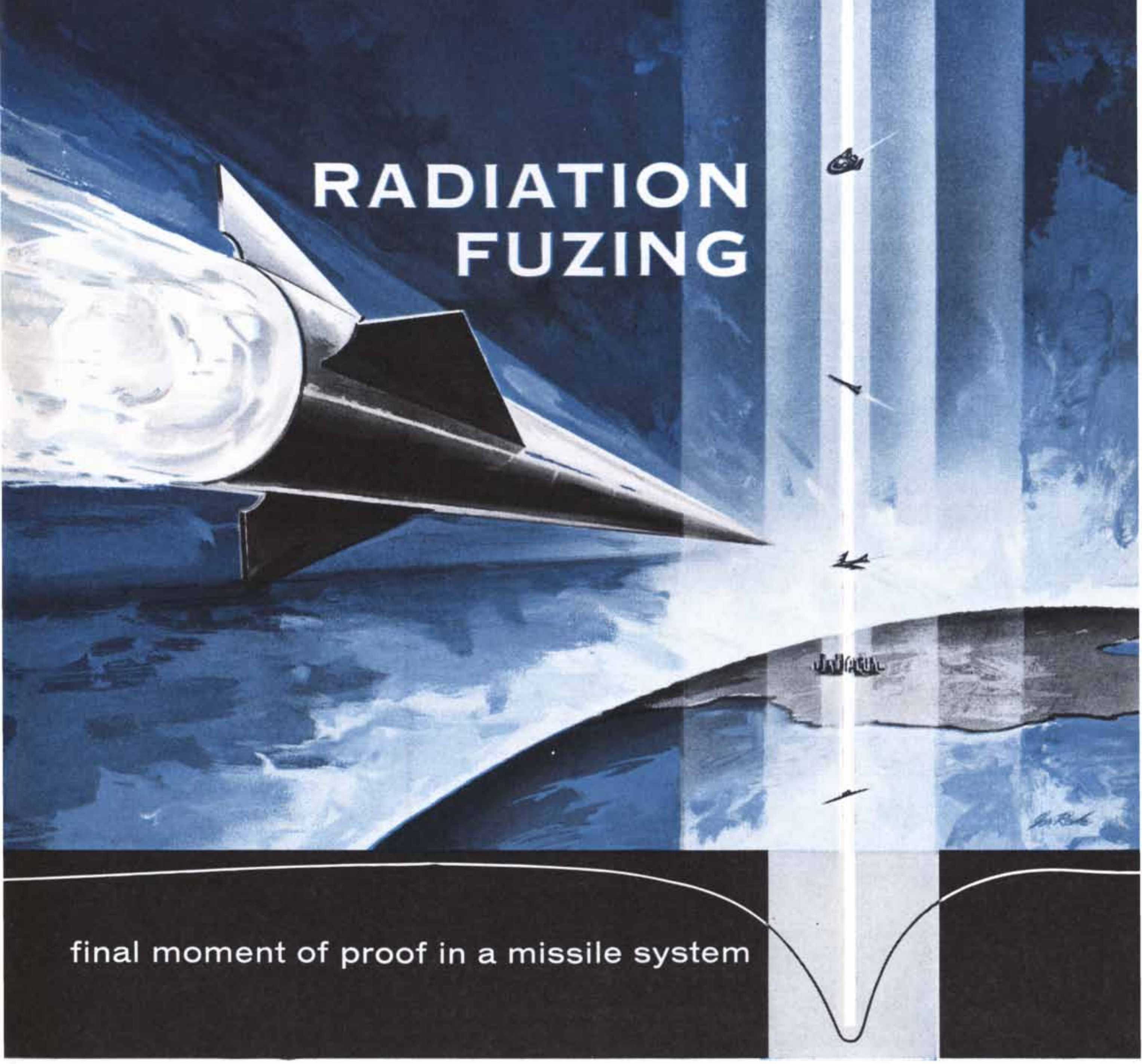
Beta particles penetrate a wax barrier in the diffusion chamber

case the velocity turns out to be 2.47 × 10^{10} centimeters per second. This is equivalent to about 153,000 miles per second, or 82.4 per cent of the velocity of light. The energy of the particle is found (in millions of electron volts) by squaring the ratio of the velocity of the particle to that of light and inserting the result in the second formula. The energy of the electron in this example was .394 million electron volts.

"An interesting property of matter can be observed by calculating the velocity and energy of a substantial number of electrons and plotting the result as a graph [*see illustration at top of page 178*]. Note how the curve bends up sharply as the speed of the particle approaches the velocity of light. This is in accord with the theory of relativity, which states that matter gains mass with velocity, and that the mass becomes in-



Alpha particles (heavy trails) *and electrons produced by X-rays leave tracks in chamber*



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"A similar graph can be drawn to show how the particle acquires mass with velocity. The mass of the electron at rest is known (it is 9.1×10^{-28} gram), and its velocity can be measured by means of the diffusion chamber. To find its mass at any velocity these values are inserted in Einstein's equation for relativistic mass [*third formula on this page*]. The rest is simple arithmetic.

"The curvature of alpha particles is difficult to detect with this apparatus because a magnetic field of 1,000 gauss exerts little influence on their relatively large mass (about 8,000 times that of the electron). The energy of alpha particles can be found by analysis of the tracks, however, because the length of the tracks depends on the rate at which the particles expend energy in ionizing atoms. Curves showing this relationship have been constructed from data acquired by observing numerous alpha-decay processes [*see illustration at bottom of page 178*]. To find the energy of an alpha particle, measure the length of its track in centimeters and refer to the curves. Care must be taken to enlarge the photographs accurately to full scale; errors in enlargement are preserved in the results.

"The classical formula for computing kinetic energy ($Ke = 1/2\ m\ v^2$) may be used for computing the energy of alpha particles because their velocity is so low that the relativistic mass effect may be neglected. This formula expresses energy in terms of ergs. To convert ergs into electron volts multiply by 6.25×10^{11}. The length of the alpha track depicted in the second photograph [*top of page 180*] is 3.1 centimeters, which according to the graph corresponds to an energy of 4.65 mev. From this value the formula for velocity gives a speed of 1.496×10^9 centimeters per second, or about 9,000 miles per second.

"The diffusion chamber invites numerous other interesting experiments. Air can be replaced by other gases, for example. In general it will be found that the quality of the tracks drops in proportion as the molecular weight of the gas falls below that of the vapor. The accompanying photograph of a beta track [*page 173*] was made in an atmosphere of oxygen.

"Gamma rays and X-rays dislodge electrons throughout the gas; the resulting tracks are characteristically erratic [*see illustration at bottom of page 182*]. In this case a particle source was included and appears at the right side of the picture together with a pattern of alpha tracks. The white strip across the center was made by a wax barrier, inserted to determine whether electrons could penetrate it. The broad, irregular masses in the vicinity of the alpha particles are wisps of cloud representing old tracks. These could have been cleared away by momentarily connecting a potential of from 45 to 90 volts across the electrodes of the chamber."

$$v_e = Hr \frac{e}{m_o} \sqrt{\frac{c^2 - v^2}{c^2}}$$

where:
v_e = velocity of electron in centimeters per second
Hr = magnetic rigidity in gauss-centimeters
$\frac{e}{m_o}$ = ratio of electron's charge to mass (1.7588×10^7)
c = velocity of light (3×10^{10} cm per sec)

$$T = 0.511 \left(\frac{1}{\sqrt{1 - \frac{v^2}{c^2}}} - 1 \right)$$

where:
T = kinetic energy in millions of electron volts
(with other quantities as previously defined)

$$m = \frac{m_o}{\sqrt{1 - \frac{v^2}{c^2}}}$$

where:
m = increased mass of particle in grams
m_o = rest mass of particle
(with other quantities as previously defined)

$$v_\alpha = \sqrt{\frac{2K}{m_o}}$$

where:
v_α = velocity of alpha particle
K = kinetic energy of alpha particle
m_o = rest mass of alpha particle

Formulae to determine nature of particles

BOOKS

Koestler on Kepler and the history of man's picture of the universe

by I. Bernard Cohen

The Sleepwalkers: A History of Man's Changing View of the Universe, by Arthur Koestler. The Macmillan Company ($6.50).

"In the index to the 600-odd pages of Arnold Toynbee's *A Study of History,* abridged version, the names of Copernicus, Galileo, Descartes and Newton do not occur." These words, with which the preface of *The Sleepwalkers* begins, exemplify both the tone and the purpose of Arthur Koestler's new book. He is concerned with "the gulf that still separates the Humanities from the Philosophy of Nature." Koestler prefers the latter expression to "Science," because it carries with it the "rich and universal associations" of the 17th century, the "days when Kepler wrote his *Harmony of the World* and Galileo his *Message from the Stars.*" In fact, the greater part of Koestler's book deals with the 17th century, the age known now for the "Scientific Revolution" but then for the "New Philosophy," which had as its aim not a revolution in technology but the "understanding of nature." Koestler regards the 17th century nostalgically as an age that still had a place in it for the universal man, and that had not seen either the present fragmentation of knowledge or the erection of "academic and social barriers" between the "Sciences" and the "Humanities."

One result of this "cold war," according to Koestler, is that there exist histories of the sciences but "no comprehensive survey of man's changing vision of the universe which encloses him," a deficiency that Koestler believes his own efforts to have remedied. He has not written "a history of astronomy, though astronomy comes in where it is needed to bring the vision into sharper focus; and, though aimed at the general reader, it is not a book of 'popular science' but a personal and speculative account of a controversial subject."

Koestler asks the reader to keep in mind that despite the time limit he has imposed—to begin with the Babylonians and to end with Newton—the subject was still so vast that to keep it "within manageable limits" he "could attempt only an outline." The result is thus "sketchy in parts, detailed in others, because selection and emphasis of the material was guided by my interest in certain specific questions, which are the *leitmotifs* of the book." These are two in number. First there are "the twin threads of Science and Religion, starting with the undistinguishable unity of the mystic and the savant in the Pythagorean Brotherhood." These threads run through history together, "falling apart and reuniting again, now tied up in knots, now running on parallel courses, and ending in the polite and deadly 'divided house of faith and reason' of our day." Koestler believes that a "study of the evolution of cosmic awareness in the past may help to find out whether a new departure is at least conceivable, and on what lines." Such a statement strongly suggests, as the text confirms, that what Koestler objects to is not merely the fragmentation of science but fragmented science itself, which has failed to achieve for man the goals that the 17th-century natural philosophers held to be the fruits of their inquiries.

The second *leitmotif* is the "psychological process of discovery," which Koestler conceives "as the most concise manifestation of man's creative faculty." He is equally concerned with "that converse process" which blinds man "towards truths which, once perceived by a seer, become so heartbreakingly obvious." Koestler calls this negative aspect of discovery a "blackout shutter" and observes its presence in scientific men of the highest genius: Aristotle, Ptolemy, Galileo, Kepler. It is suggested that a study of the greatest scientific men of the past shows that "while part of their spirit was asking for more light, another part had been crying out for more darkness." Koestler believes that to understand science one must be concerned with the character and personality of scientists, since "all cosmological systems . . . reflect the unconscious prejudices, the philosophical or even the political bias of their authors." Whether the subject be physics or physiology, "no branch of Science, ancient or modern, can boast freedom from metaphysical bias of one kind or another." This is Koestler's explanation for the fact that the evolution of science follows a bewildering series of zigzags rather than a simple and logical linear progression. And so we are led to Koestler's main theme: "The history of cosmic theories, in particular, may without exaggeration be called a history of collective obsessions and controlled schizophrenias; and the manner in which some of the most important individual discoveries were arrived at reminds one more of a sleepwalker's performance than an electronic brain's."

That it should be Arthur Koestler who has chosen this particular assignment may be an occasion for some surprise. His reputation, at least in this country, was made by the novel *Darkness at Noon,* in which he explored the psychological reasons for the confessions of old-line Bolsheviks in the Russian trials of the 1930s. Five years ago, however, Koestler decided to give up political matters for science. This decision was not quite as odd as it might seem; in pre-Hitler Germany Koestler had been science editor of the Ullstein chain of newspapers, and he had started his career as a science student in Vienna.

That his present writing on science should concentrate so much on the psychological aspects of scientific discovery is in keeping with Koestler's psychological approach to political problems. His *Insight and Outlook* dealt with questions similar in meaning but not in kind to those considered in *The Sleepwalkers.* His portrayal of conflicting attitudes in *The Yogi and the Commissar* may help to prepare the reader for his present reflections on the mysticism of the early cosmologists, as opposed to the hard-boiled positivism of modern science.

It will be apparent to anyone who picks up this book that Koestler has done a solid job of research. He provides a wealth of quotations from original source-material and buttresses them with references to some of the major results of historical scholarship. The very bulk of the book may deter some readers; it should be said at once that the narrative is fascinating and the style engaging and urbane. The author's personal prejudices and predilections will variously delight, enrage, stimulate, repel, attract, astound and titivate the scientist, the historian and the general reader. The book is stuffed with all kinds of recondite information about the lives of the early scientists and their contributions to the science of the universe. At the same time Koestler propagates old errors and adds new ones of his own; in general he presents a highly biased and/or inaccurate view of the nature and growth of science, and a distorted account of some of the major episodes in the history of astronomy.

Koestler is most successful in his discussion of Johannes Kepler, to whom about half *The Sleepwalkers* is devoted. One almost has the feeling that what began as a biography of Kepler ended up as a history of cosmology only by virtue of having Copernicus, Tycho Brahe and Galileo appear so that Kepler might be made a more sympathetic figure; and that a wholly inadequate account of ancient and medieval cosmology was added only to point up the originality of Kepler's contributions. Koestler claims that his own scholarly contribution lies mainly in the sections dealing with Kepler, "whose works, diaries and correspondence have so far not been accessible to the English reader; nor does a serious English biography exist." This is true, and it may be added that the only two major studies of Kepler's astronomy are all but inaccessible even to scientists and historians. Indeed, they were not consulted by Koestler.

Kepler makes an ideal subject for Koestler. Because one of Kepler's main concerns was the influence of the stars on the lives of men, he kept meticulous records of both the great and the minute events of his own life. How many biographers could begin, as Koestler does: "Johannes Kepler, Keppler, Khepler, Kheppler or Keplerus was conceived on 16 May, A.D. 1571, at 4:37 a.m., and was born on 27 December at 2:30 p.m., after a pregnancy lasting 224 days, 9 hours and 53 minutes. The five different ways of spelling his name are all his own, and so are the figures relating to conception, pregnancy and birth, recorded in a horoscope which he cast for himself." Koestler remarks: "The contrast between his carelessness about his name and his extreme precision about dates reflects, from the very outset, a mind to whom all ultimate reality, the essence of religion, of truth and beauty, was contained in the language of numbers."

Guided by Kepler's self-portrait, Koestler sketches for us the early years and education of a man who described himself as "born destined to spend much time on difficult tasks from which others shrunk." Quite early he became a Copernican, at a time when very few scientists had read that author's difficult exposition of a sun-centered system of the universe. But Kepler began his career more as an astrologer than a defender of Copernicus. His first job as teacher was marked by a prediction: From the stars he foresaw a very cold winter and an invasion by the Turks! Luckily for him he proved to be right about both. Although he knew that much of astrology was quackery, he remained convinced to his death that the stars and planets determine the fate of man.

Soon Kepler produced his first major work, the full title of which is: *A Forerunner to Cosmological Treatises, containing the Cosmic Mystery of the admirable proportions between the Heavenly Orbits and the true and proper reasons for their Numbers, Magnitudes, and Periodic Motions.* Kepler believed he had discovered why there are only six planets, and why they are placed as they are in the Copernican system. This discovery he considered to be a divine revelation, he being only the instrument directed by God's will and plan. Kepler's discovery relates numbers and geometry: six planets and five regular solids. He conceived that within the sphere containing Saturn's orbit there is inscribed a cube, within which is inscribed another sphere containing the orbit of Jupiter. Within the sphere of Jupiter is a tetrahedron containing the sphere of Mars; within the sphere of Mars is a dodecahedron containing the sphere of the earth; within the sphere of the earth is an icosahedron containing the sphere of Venus; within the sphere of Venus is an octahedron containing the sphere of Mercury. Given a certain thickness for the surface of each sphere, the distances in fact come out right. For the young Copernican, steeped in the Pythagorean ideal and convinced that everywhere in nature there are harmonies of number and shape, it was a significant stroke. To the end of his life Kepler considered it a more important discovery than the celebrated laws that bear his name.

It was Kepler's good fortune (he held it to be an act of divine Providence) that his book brought his skills in computation to the attention of Tycho Brahe. This Danish astronomer (for some reason Koestler insists on Frenchifying his name to "Tycho de Brahe") had reformed astronomy by making continuous rather than occasional observations of the planets, and by creating new instruments that made it possible to determine the planetary positions within less than eight minutes of arc. To appreciate what this figure means, one must recall that Copernicus had said that if he could ever predict the planetary positions within 10 minutes of arc, he would be as happy as Pythagoras was when he discovered his theorem. To Tycho, whose reforms made an exact science of astronomy, whose system of the world briefly became a rival of Ptolemy's and Copernicus's, and whose observations provided Kepler with the materials for his own deep discoveries, Koestler devotes an unilluminating pair of short chapters.

Using Tycho's observations of Mars, Kepler found his first two laws; these he published in his *New Astronomy*, which he described as "a physics of the sky, derived from investigations of the motions of the star Mars." Kepler's first law states that the planets move around the sun in elliptical orbits, one focus of the ellipse being occupied by the sun. His second law states that along this orbit each planet moves in such a manner that a line drawn from the sun to the planet sweeps out equal areas in equal times. Our modern assignment of the words "first" and "second" here suggests a logical progression: Is it not obvious that to determine the speed with which a planet moves along its orbit, and to compute the area swept out by a line drawn from sun to planet, there must be a prior determination of the shape of the orbit? But it is just this point that provides Koestler with a chief illustration of his central thesis. For the fact of the matter is that in this instance (though it is not unique in the development of science) the logical order of the discovery is just the reverse of the chronological order.

Kepler's *New Astronomy* gives us almost every stage in the development of his ideas—even calculations based on suppositions he later knew to be false. To the exhausted reader he says (in Chapter 16): "If thou art bored with this wearisome method of calculation, take pity on me who had to go through at least seventy repetitions of it, at a very great loss of time." By Chapter 19 he is at last willing to give up all the variations he had introduced into older hypotheses, and to approach his "goal according to my own ideas"; at last the reader could proceed to Kepler's own hypotheses. But 13 chapters later Kepler is still showing the consequences of physical assumptions, chiefly that some kind of *anima motrix* emanates from the sun, diminishes according to the inverse proportion of the distance and is active only in the plane of the planet's motion. In this way Kepler found the "second" law, knowing it was based on errors which he said "like a miracle . . . cancel out in the most precise manner." On this score Koestler remarks: "The correct result is even more miraculous than Kepler realized, for his explanation of the reasons *why* his errors cancel out was once again mistaken, and he got, in fact, so hopelessly confused that the argument is practically impossible to follow—as he himself admitted. And yet, by three incorrect steps and their even more incorrect defense, Kepler stumbled on the correct law. It is perhaps the most amazing sleepwalking performance in the history of science—except for the manner in which he found his First Law." In the course of this new adventure Kepler turned to an egg-shaped planetary orbit and repudiated the previously announced second law; he said that he regretted that the orbit was not "a perfect ellipse [for then] all the answers could be found in Archimedes's and Apollonius's work." Then by chance he suddenly found a clue to the fact that the orbit was indeed elliptical. He tells us: "I felt as if I had been awakened from a sleep." But search as he might ("until I went nearly mad"), he could never find "a reason why the planet preferred an elliptical orbit."

From antiquity up to the time of Kepler's book everyone was agreed that planetary motions were either circles or some combination of circles. No one was able to understand why a planet should move along an ellipse until Newton showed that this orbit was a consequence of a central force of gravitation dependent on the inverse square of the distance. It is not surprising that Kepler's contemporaries (including Galileo) never accepted elliptical orbits, if indeed they had ever heard of them. Koestler cannot forgive Galileo his treatment of Kepler. "In his works," says Koestler, Galileo "rarely mentions Kepler's name, and mostly with intent to refute him. Kepler's three Laws, his discoveries in optics, and the Keplerian telescope, are ignored by Galileo, who firmly defended to the end of his life circles and epicycles as the only conceivable form of heavenly motion." This statement is repeated a number of times with variations. Yet according to Koestler's own presentation even to find the first two laws within Kepler's *New Astronomy* is a heroic exercise. Moreover, the reader who has found them will quickly discover that they are based on false and untenable assumptions. Koestler writes: "The ellipse had nothing to recommend it in the eyes of God and man; Kepler betrayed his bad conscience when he compared it to a cartload of dung which he had to bring into the system as a price for ridding it of a vaster amount of dung. The Second Law he regarded as a mere calculating device, and constantly repudiated it in favour of a faulty approximation; the Third as a necessary link in the system of harmonies, and nothing more." If this is so, it is hardly surprising that Galileo did not accept Kepler's laws, even if he had succeeded in finding them within Kepler's prolix and confused presentation.

Koestler emphasizes the fact that Kepler was the first man to base astronomy on physics, even that he was the first man to make astronomy a causal physical science. But Koestler denies the reader equal insight into the relationship between Galileo's Copernican astronomy and Galileo's new science of dynamics. So the link between the work of Kepler and Galileo on the one hand and of Newton on the other is only half-presented. Koestler altogether gives Galileo a hard time. Kepler is "disarming"; according to Koestler, no one who met him "in the flesh or by correspondence could seriously dislike him." Galileo, in contrast, is characterized by "arrogance minus humility"; he is a man held in "aversion"; he is "ambiguous" and "subtle"; he confounds "freedom of thought" with "sophistry, evasion, and plain dishonesty." Galileo is condemned by Koestler on the ground that at the age of 70 he was frightened in the prison of the Inquisition, from which he was released (according to a report of the time) "more dead than alive." Koestler ascribes Galileo's "panic" to "psychological causes." Says Koestler: "It was the unavoidable reaction of one who thought himself capable of outwitting all and making a fool of the Pope himself, on suddenly discovering that he has been 'found out.' " But there is no reason whatever to believe that Galileo intended to make a fool of the Pope. I would submit that Galileo's panic (if he felt it at all) in a prison with that particular history needs no "psychological" explanation. That Koestler, who so sensitively described the thoughts of the prisoner Rubashov in *Darkness at Noon*, should find it necessary to invoke such an explanation is rather odd.

Why is it that Koestler can find no sympathy for Galileo, even in the trial room of the Inquisition? Koestler writes that although he has from early childhood retained "vivid impressions" of the "wholesale roasting alive of heretics by the Spanish Inquisition" (which is neither relevant nor exactly true), he finds "the personality of Galileo equally unattractive, mainly on the grounds of his behaviour towards Kepler." This absurd bias makes a travesty of the concluding portion of Koestler's book by forcing him to ignore or to belittle Galileo's profound contribution to physics and astronomy. All this because Galileo did not immediately answer Kepler's letters or accept his laws! Furthermore, Koestler makes it plain that his bias is not based "on affection for either party in the conflict" between Galileo and the Roman Church, but on his own personal "resentment that the conflict did occur at all." For Koestler the conflict was only in the nature of "a clash of individual temperaments," and not "a fatal collision between opposite philosophies of existence." Because of his belief in the "unitary source of the mystical and scientific modes of experience" and "the disastrous results of their separation," Koestler treats Galileo as the villain of his book.

The presentation of Copernicus is equally unsympathetic; the section devoted to his work is entitled "The Timid Canon." Koestler calls him "a stuffy pedant," lacking "the sleepwalking intuition of the original genius." Having "got hold of a good idea," Copernicus "expanded it into a bad system." I find myself wondering how different Koestler's book might have been if he had brought to bear on Copernicus the insight with which he portrayed the old Bolshevik Rubashov. Surely the reader would have been fascinated and rewarded by a thoughtful consideration of the mind of a man who stood at the threshold of the world of modern science and yet was not free of the shackles of his medieval heritage, who presented a new system of the world and yet knew that there was no physics to account for it.

Since Koestler presents Copernicus without understanding, it is hardly surprising that his account of the pre-Copernican period is a collection of platitudes. Indeed, he almost completely ignores astronomical and cosmological thought from Ptolemy to Copernicus, which has been considerably illuminated by recent scholarship. Because he finds Ptolemy "profoundly distasteful," Ptolemy's conceptions are reduced to "the work of a pedant with much patience and little originality, doggedly piling 'orb in orb.'" A handful of pages contemptuously dismiss the greatest achievement of ancient astronomy because of what is held to be an unforgivable failure to adopt the heliocentric system proposed by Aristarchus, a position in which Koestler finds it necessary to ignore the fact that Aristarchus's heliocentric astronomy was never worked out by its author but was only a suggestion whose implications were never—and could not possibly have been—realized. To go back farther in time, Koestler's presentation of the world of the Babylonians and the Egyptians reads as if it had been written decades ago, before serious investigation had made any dent in our ignorance of their respective astronomical systems. One must conclude that any statement in the book that does not refer to Kepler's life or writing must be taken with a grain of salt.

Koestler's epilogue contains the moral of his tale. It requires the whole saltcellar. He declares that the divorce of science from religion—the freeing of science from its "mystical ballast"—enabled it to "sail ahead at breathtaking speed to its conquest of new lands beyond every dream." The price paid for this rapid advance was that "it carried the species to the brink of physical self-destruction, and into an equally unprecedented spiritual impasse. Sailing without ballast, reality gradually dissolved between the physicist's hands; matter itself evaporated from the materialist's universe." This evil is imputed in the first instance to the villain of the book, Galileo, because it was he who "banished the qualities which are the very essence of the sensual world—colour and sound, heat, odour, and taste—from the realm of physics to that of subjective illusion." In the end the very "hard atoms of matter" have gone "up in fireworks; the concepts of substance, force, of effects determined by causes, and ultimately the very framework of space and time turned out to be as illusory as the 'tastes, odours and colours' which Galileo had treated so contemptuously." Says Koestler: "Compared to the modern physicist's picture of the world, the Ptolemaic universe of epicycles and crystal spheres was a model of sanity."

Koestler tries to make out that 20th-century physics is just like the pre-Keplerian cosmology. The fact that quantum mechanics works is for him irrelevant; it reminds him only of "Urban VIII's famous argument which Galileo treated with scorn: that a hypothesis which works must not necessarily have anything to do with reality for there may be alternative explanations of how the Lord Almighty produces the phenomena in question."

Koestler thus comes to the depressing conclusion of his reflections. Modern science—and here Koestler departs from cosmology to deal entirely with physics—is a "modern version of scholasticism." Koestler condemns the men of science for their reaction to what he calls "the phenomena of 'extra-sensory perception' " even as he bemoans the "rigorous banishment of the word 'purpose' " from the vocabulary of science. Science is divorced from faith, with the result that "neither faith nor science is able to satisfy man's intellectual cravings." Science, since the days of the villainous Galileo, has allegedly "claimed to be a substitute for, or the legitimate successor of, religion; thus its failure to provide the basic answers produced not only intellectual frustration but spiritual starvation." If only science could regain "its mystical inspiration," if only a new Kepler would arise to confute Heisenberg and Schrödinger, then the world might be better in some way. In the absence of a Kepler, Koestler concludes with the hope that the "muddle of inspiration and delusion, of visionary insight and dogmatic blindness, of millennial obsessions and disciplined double-think, which this narrative has tried to retrace, may serve as a cautionary tale against the *hubris* of science —or rather of the philosophical outlook based on it."

For me the most melancholy aspect of Koestler's conclusion is that it bears so little relation to the book which it serves as an epilogue. Five years of contemplation of the peculiar qualities of Kepler's mind, of the work of his predecessors and successors in the development of cosmology, have resulted only in an empty lament over 20th-century physics. So little has Koestler learned from his researches that the epilogue is actually based to a considerable degree on his earlier writings, borrowed, as he says, "without quotation marks."

Fortunately for the reader, Koestler is frank about his prejudices. And he has done his bit to correct the old-fashioned notion that science progresses only by orderly, logical steps. Science is an activity of human beings, and human beings do not always behave exactly the way history expects them to. There is no doubt that the scientific activity of man has wellsprings that we do not fully understand. When all is said and done, Koestler's eloquence in describing just how disorderly and illogical the progress of science can be may even outweigh his deficiencies as a historian.

Short Reviews

ARCHAEOLOGY AND THE OLD TESTAMENT, by James B. Pritchard. Princeton University Press ($5). THE ANCIENT NEAR EAST, edited by James B. Pritchard. Princeton University Press ($6). These two fine books by a foremost student of Old Testament literature and Biblical archaeology are prime examples of intelligent popularization. The first volume is an engrossing nontechnical account of how history as written in the Bible has been "changed, enlarged or substantiated" by the past century of archaeological work. Our understanding of this rich segment of man's cultural and religious heritage has been broadened not only by the finds in Palestine but also by discoveries—documents and monuments—in the "peripheral lands" of Mesopotamia, Egypt, Syria and Anatolia. Pritchard's text, supported by admirable illustrations, describes the excavations in modern Israel and Jordan, Baal and the religion of Canaan, the information gained about Assyria (Israel's enemy) from the digging in modern Iraq, myth in the ancient Near East, the laws and culture of Egypt and Babylon. The second book is an excellent anthology of texts and pictures drawn from two large volumes edited by Pritchard (one of them, *The Ancient Near East in Pictures,* was reviewed in these columns a few years ago), which are standard treatises on their subject. The texts include excerpts from the Gilgamesh Epic, the Descent of Ishtar to the Nether World, the Telepinus Myth, poems about Baal and Anath, the Code of Hammurabi, the Instruction of Amen-em-Opet, the Hymn to the Aton, Egyptian love songs, the inscription on the Moabite Stone, the Gezer Calendar, Assyrian, Egyptian and Babylonian documents describing military expeditions and sieges.

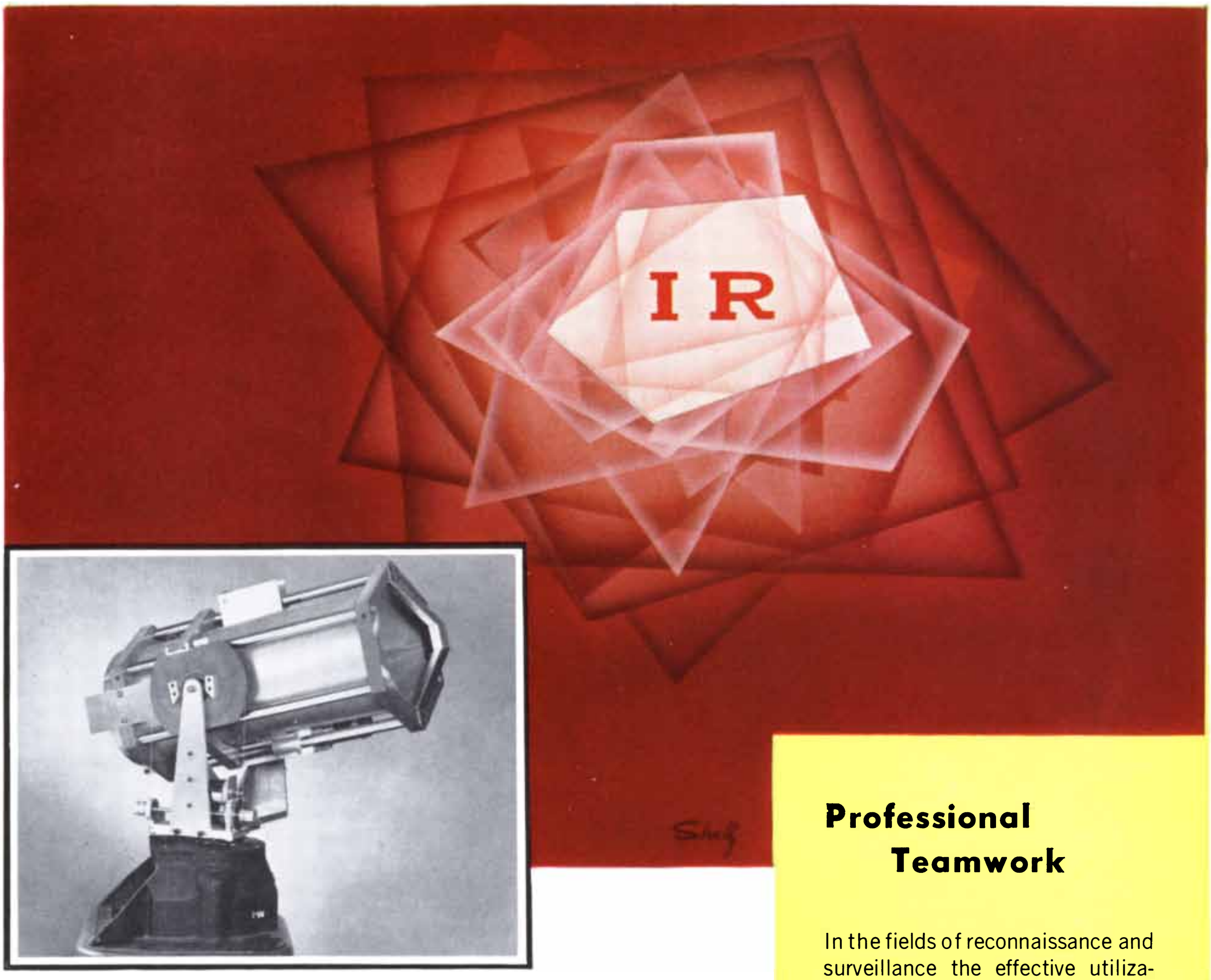
PSYCHOTHERAPEUTIC DRUGS, by Ashton L. Welsh. Charles C. Thomas ($4.75). The use of tranquilizers or ataractic drugs has soared in the last few years. In sales volume they are second, according to some reports, only to antibiotics and vitamins. The rising market for peace-of-mind pills, apart from being a most interesting social phenomenon, has broad and serious medical implications. What good are these various psychotherapeutic agents? What basis is there for the extensive claims made on their behalf by drug manufacturers? What are the known side effects of the continued use of such medicaments? The author of this book, a dermatologist and syphilologist on the staff of the University of Cincinnati, undertakes to answer these questions on the basis not only of his own clinical experience but also of data gathered from an extensive search of the medical literature. His monograph considers the five major groups of tranquilizers: the phenothiazines, the Rauwolfia alkaloids and their fractions, the substituted propanediols, the diphenylmethane derivatives, and the ureides and amides. The evidence is quite clear that the use of these drugs may involve many disagreeable and even dangerous toxic effects and side reactions, that all too often they are indiscriminately prescribed and taken. A very useful book, which all doctors ought to be required to read.

Of Stars and Men, by Harlow Shapley. The Beacon Press ($3.50). As man learns more about the universe the evidence mounts that he himself is incidental. In this sensitive and brilliant little book Shapley describes four "adjustments" in man's evolving thought about his relations to the total material universe. At first he and his small stamping ground were the whole world. Then, when he began to climb the hills to see what was on the other side, the horizon receded and a strange vagueness supplanted his notion of a snug and fixed domain. In time he became aware of the daily movements of the sun and the stars, and of the wandering planets. The earth, it appeared, was a sphere, turning on its track with the other heavenly bodies. Yet it was still thought to be the chosen central sphere of the universe, with man the crown of all living forms. In the 16th century the heliocentric concept supplanted the geocentric and forced a second adjustment; the earth had to yield its central position. But man could still cling to the treasured notion that he was the apple of the cosmic eye. A third change came with the realization that the sun is an ordinary star, a mere trifle in a huge galaxy of stars, and that the galaxy itself is one of millions. Thus human pride and self-assurance were eroded, though vanity continued to assert itself in the belief that man was unique even if his abode was not. Now, however, a fourth adjustment is required. Scientific workers have come up with pretty convincing evidence that whenever "the physics, chemistry and climates are right on a planet's surface, life will emerge, persist and evolve." This fact, coupled with certain observational facts of astronomy, forces us, says Shapley, to the realization that other planets very likely accompany some of the thousands of millions of stars that radiate energy capable of supporting life. Increasing knowledge has therefore not only dissolved the "subjective miraculous" and pierced deep into the "mystery of life," but has laid the basis for reasoned confidence in the theory that life is abundant and widely distributed throughout the universe. Asks Shapley: "What should be the human response" to this awesome circumstance? Frank Ramsay once commented on the physical universe in these words: "I don't feel the least humble before the vastness of the heavens. The stars may be large, but they cannot think or love; and these are qualities which impress me far more than size does." Our perspective is now changed. It is no longer a question of our competing with huge masses of incandescent gas and concluding comfortably and reasonably that they are mere outsize inanimate blobs, not worth a single living cell. Instead, we ourselves are "conceivably peripheral," not to be taken too seriously even among the animals and plants on our local planet, to say nothing of the possibilities of the richly endowed metagalaxy. Our philosophies and our religions must adapt themselves to this new view of the cosmos. And yet Shapley does not break entirely with Ramsay's view. He pleads for humility and hope, if not high confidence. There is much to learn, much to strive for, much we can accomplish through reason and imagination. If we are not alone, not even a chosen people, at least we can try to be equals among equals. Shapley's essay meanders and is uneven; its conjectures will not appeal to many cosmologists. But it is humane, courageous and fascinating writing.

THE FOLKLORE OF BIRDS, by Edward A. Armstrong (30 shillings); CLIMATE AND THE BRITISH SCENE, by Gordon Manley (25 shillings); MOUNTAIN FLOWERS, by John Raven and Max Walters (25 shillings); THE WORLD OF THE SOIL, by Sir E. John Russell (25 shillings). Collins. The New Naturalist Series in which these books appear is the best natural-history series being published today. In 10 years more than 40 volumes have appeared, many of them distinguished, and all of them solid contributions to biological literature for the general reader. Because the series is primarily concerned with the wildlife of Britain, only a few of the books have been published in the U. S.; among these are Alister Hardy's superlative *The Open Sea,* reviewed in these columns three years ago. This neglect is regrettable because the scientific content of the books, their clarity of presentation and the high quality of the illustrations (in black-and-white and in color) would assure them an appreciative audience in the U. S. despite the focus of attention on the British scene. The volumes listed above confirm the point. Armstrong's book traces to their origins in early cultures the magico-religious beliefs concerning a number of familiar birds: the swan, the raven, the owl, the robin and the wren. The history, from their beginnings in the "foggie dark sea of Antiquity," of various traditions and beliefs, of fables about weather-prophet birds, of such customs as breaking the wishbone, makes an engrossing tale, which is supported by a mass of data drawn from archaeology, anthropology, psychology, religious history and ornithology. Manley's subject is British weather in its infinite variety: Chaucer's "sweet April showers," London fogs, the famous English spring, the wild storms over the Channel, the smog over Liverpool, the redoubtable Scotch mist, the rain that falls and falls on Ireland, the windswept heights of the Pennines, the scant sunshine on Ben Nevis (about 750 hours a year). The volume by Raven and Walters is the first ever published on the wild flowers of British mountains. It is a true labor of love, the result of a collaboration between an amateur and a professional botanist (the amateur being an authority on Greek philosophy and a fellow of King's College, Cambridge) who have hunted flowers in the hills of Scotland, Wales, Ireland and the Lake District. While British mountain flowers do not provide so gorgeous a display as those of the Alps, they include many species of rare and gentle beauty that are lovingly described and discussed in this attractive volume. John Russell's monograph deals with how the soil was formed and how completed by organic matter; the living conditions for soil inhabitants; visible and invisible soil inhabitants from microorganisms to worms, slugs, snails, fungi and arthropods; man's control of the soil; the soil and the landscape; soil analysis and soil surveys. Discoveries made by soil scientists, chemists, physicists, biologists and geologists are very skillfully brought together in this authoritative and readable work by the former director of the Rothamsted Experimental Station, where much fruitful research has been performed on this complex and still little-known department of natural history. Many fine photographs.

AMERICAN VOTING BEHAVIOR, edited by Eugene Burdick and Arthur J. Brodbeck. The Free Press ($7.50). Why do people vote the way they vote? The editors of this heavy volume have collected essays by various students of voting behavior who report the latest researches in the field. The articles are not impressive. There are the usual weighty, long-winded demonstrations of the obvious: voters are prejudiced, irrational, neurotic, conformist, timid, stupid, suggestible; some persons vote like their fathers, some rebel and vote the opposite of their fathers; many voters simply don't care; some believe what they read but many never read; some are politically hypnotized by television—and so on and on. The statistical data are inconsequential; the writing is jargon-laden and pretentious. Among the few interesting pieces is Brodbeck's clever comparison of certain features of electioneering with psychotherapy. But on the whole this is just another bowl of thick social-science porridge, concocted of the trivial and the trite.

PROJECT SHERWOOD: THE U. S. PROGRAM IN CONTROLLED FUSION, by Amasa S. Bishop ($5.75); U. S. RESEARCH REACTOR OPERATION AND USE, edited by Joel W. Chastain, Jr. ($7.50); RADIATION BIOLOGY AND MEDICINE, edited by Walter D. Claus ($11.50); URANIUM ORE PROCESSING, edited by John W. Clegg and Dennis D. Foley ($7.50); THORIUM PRODUCTION TECHNOLOGY, by F. L. Cuthbert ($6.50); SOLID FUEL REACTORS, by Joseph R. Dietrich and Walter H. Zinn ($10.75); PHYSICAL METALLURGY OF URANIUM, by A. N. Holden ($5.75); BOILING WATER REACTORS, by Andrew W. Kramer ($8.50); FLUID FUEL REACTORS, edited by James A. Lane, H. G. MacPherson and Frank Maslan ($11.50); THE TRANSURANIUM ELEMENTS, by Glenn T. Seaborg ($7.50); SODIUM GRAPHITE REACTORS, by Chauncey Starr and Robert W. Dickinson ($6.50); THE SHIPPINGPORT PRESSURIZED WATER REACTOR, written by Personnel of the Naval Reactors Branch in the Atomic Energy Commission, of the Westinghouse Electric Corporation and of the Duquesne Light Company ($9.50). These volumes, prepared under the supervision of the Atomic Energy Commission, were presented in complete sets to the delegates to the Second International Conference on the Peaceful Uses of Atomic Energy, held at Geneva in September of



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last year. The 12 books offer a comprehensive review of atomic-energy technology in the last three years. Bishop's monograph gives a clear account of work done in the U. S. on thermonuclear reactions. Glossaries and excellent illustrations help to make this book understandable to the average reader. The other volumes in the series are addressed to specialists. A valuable and impressive record.

THE BIRDS OF ALASKA, by Iran Gabrielson and Frederick C. Lincoln. The Stackpole Company ($15). A massive natural-history compendium of some 900 closely printed pages describing the various species of birds of Alaska, their range, haunts and habits. The information is drawn from the files of the Wildlife Management Institute, from other literature (which is listed in an extensive bibliography) and from the observations of the senior author, who has made many field trips over the entire Alaskan territory, studying and collecting birds and gathering data on bird life from Eskimos, Aleuts and travelers in the Arctic. The book is illustrated by color plates of average quality; they cover only a small fraction of Alaskan birds, which is disappointing in a volume otherwise so complete.

FOUNDATIONS OF MATHEMATICS, by Carl H. Denbow and Victor Goedicke. Harper and Brothers ($6). A better-than-average textbook for the one-year course of college mathematics, which offers a brief survey not only of the usual bread-and-butter subjects but also of the philosophy of mathematics and of advanced topics of special interest such as group theory, the algebra of logic, and infinite sets. The authors have made no profound discoveries in pedagogy nor toppled any sacred monuments, but they sometimes have a nice fresh way of presenting old ideas and problems so as to make them clearer than usual and even exciting.

PERSPECTIVES IN VIROLOGY, edited by Morris Pollard. John Wiley & Sons, Inc. ($7). Twenty specialists report on recent progress in various fields of virological research. Some of the papers are exceptionally stimulating in suggesting new lines of research on the relation of viruses to cancer and other diseases. To counterbalance the accepted notion that all viruses are destructive to their hosts, René Dubos in a delightfully conceived scientific and historical paper entitled "Tulipomania and the Benevolent Virus" indulges himself in the "fantasy" that certain viruses are "now and then helpful" to other living organisms.

JET PROPULSION ENGINES, edited by O. E. Lancaster. Princeton University Press ($20). The latest volume in the High Speed Aerodynamics and Jet Propulsion series considers the principles and problems encountered in combining components to form a complete jet engine. The subjects covered include the history of rocket propulsion, basic principles of jet propulsion, the turbojet engine, the turboprop engine, the ramjet engine, intermittent jets, solid-propellant rockets, the ram rocket, jet rotors, atomic energy in jet propulsion.

Notes

THE PRINCIPLES OF SCIENCE: A TREATISE ON LOGIC AND SCIENTIFIC METHOD, by W. Stanley Jevons. Dover Publications, Inc. ($2.98). A paperback reissue of Jevons's celebrated work, first published in 1874. A new introduction by Ernest Nagel considers how much of this dissertation on the method and logic of the physical sciences is still of value to the scientist and philosopher. Despite many limitations, the *Principles*, says Nagel, "remains a richly instructive book."

THE MEANING OF MEANING, by C. K. Ogden and I. A. Richards. Harcourt, Brace and Company ($2.25). The well-known Ogden and Richards study of the influence of logic upon thought and of the science of symbolism is now issued in a paper-bound edition.

SEA SHELLS OF TROPICAL WEST AMERICA, by A. Myra Keen. Stanford University Press ($12.50). A descriptive listing of 1,650 species of marine mollusks from southern California to Colombia. Notes on geographic distribution, extensive bibliography, 1,500 illustrations, including 10 pages of color plates.

AUTOMATIC PROCESS CONTROL, by Donald P. Eckman. John Wiley & Sons, Inc. ($9). A study of automatic control with particular emphasis on process control. For engineers.

THE MENTALITY OF APES, by Wolfgang Köhler. Vintage Books ($1.25). Köhler's important book on animal psychology is issued in an inexpensive reprint.

A CENTURY OF MOUNTAINEERING, by Arnold Lunn. The Macmillan Company

($6.75). A most attractively illustrated memoir by a noted mountaineer celebrating the 100th anniversary of the famous Alpine Club, and recalling great climbing feats and climbers and the many controversies of mountaineering.

Planning of Experiments, by D. R. Cox. John Wiley & Sons, Inc. ($7.50). An account of the ideas underlying modern work on the statistical aspects of experimental design.

The Vertebrate Story, by Alfred S. Romer. The University of Chicago Press ($7). A radical revision of Romer's noted work *Man and the Vertebrates*, first published in 1933 and last revised in 1941.

Our Bible and the Ancient Manuscripts, by Sir Frederic Kenyon. Harper and Brothers ($6.95). A. W. Adams, an Oxford scholar, has completely revised this classical account, first published in 1895, of how the Scriptures have come to us, bringing it abreast of the most recent advances in knowledge by including the latest textual and archaeological discoveries. Forty-nine full-page plates. An engrossing book.

The Face of the Sun, by H. W. Newton. Penguin Books (85 cents). This compact Pelican furnishes an account of our knowledge of the surface of the sun, in particular the sunspots and their associated phenomena, from the time of Galileo to the International Geophysical Year.

The ABC of Relativity, by Bertrand Russell. George Allen & Unwin Ltd. (15 shillings). This very attractive, characteristically lucid primer first appeared in 1925 but has long been out of print. It is now reissued with numerous revisions by Felix Pirani.

Attic Red-Figured Vases, by Gisela M. A. Richter. Yale University Press ($5). Revised edition of a fine handbook on the activity of the Attic potteries.

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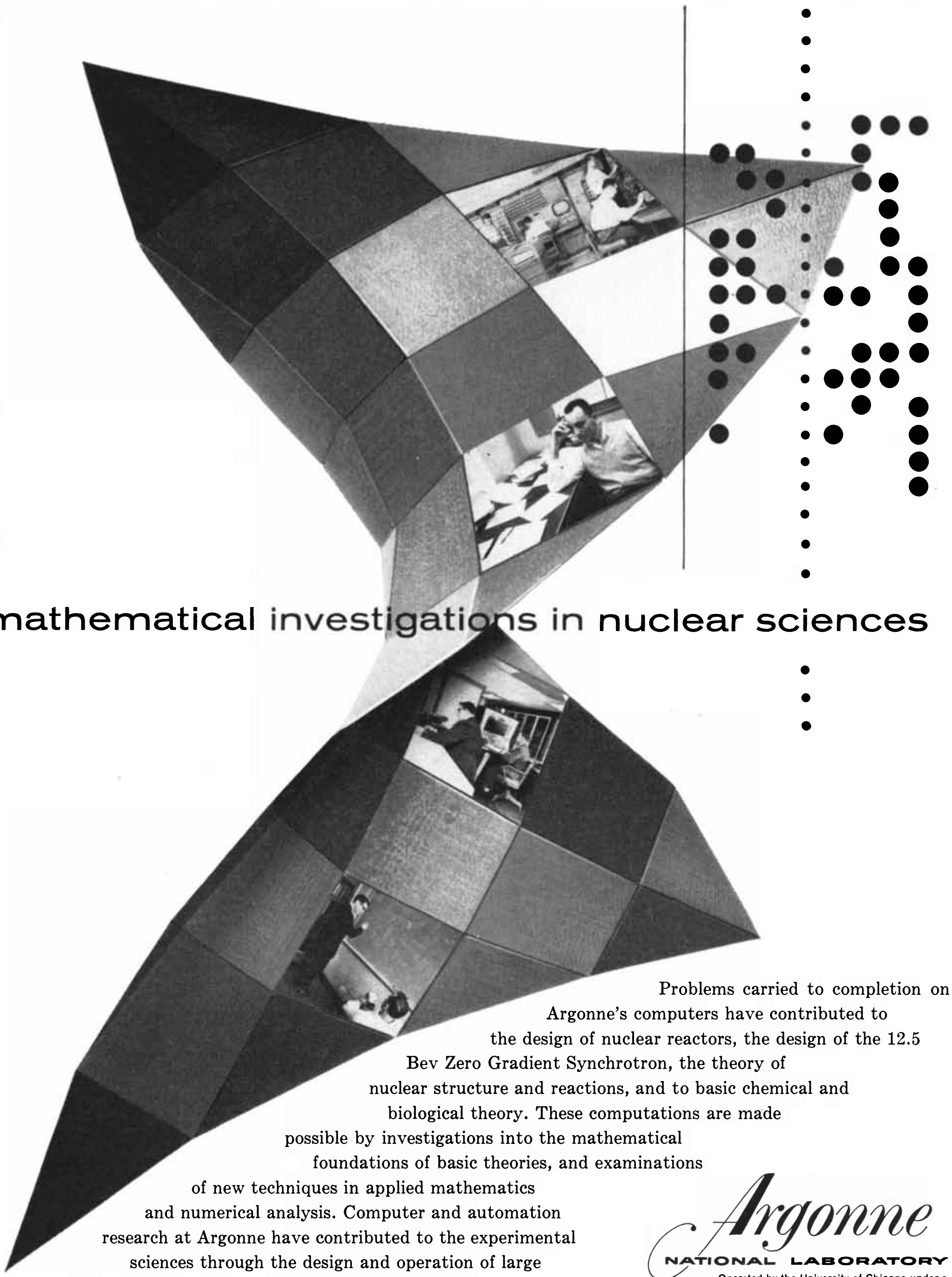

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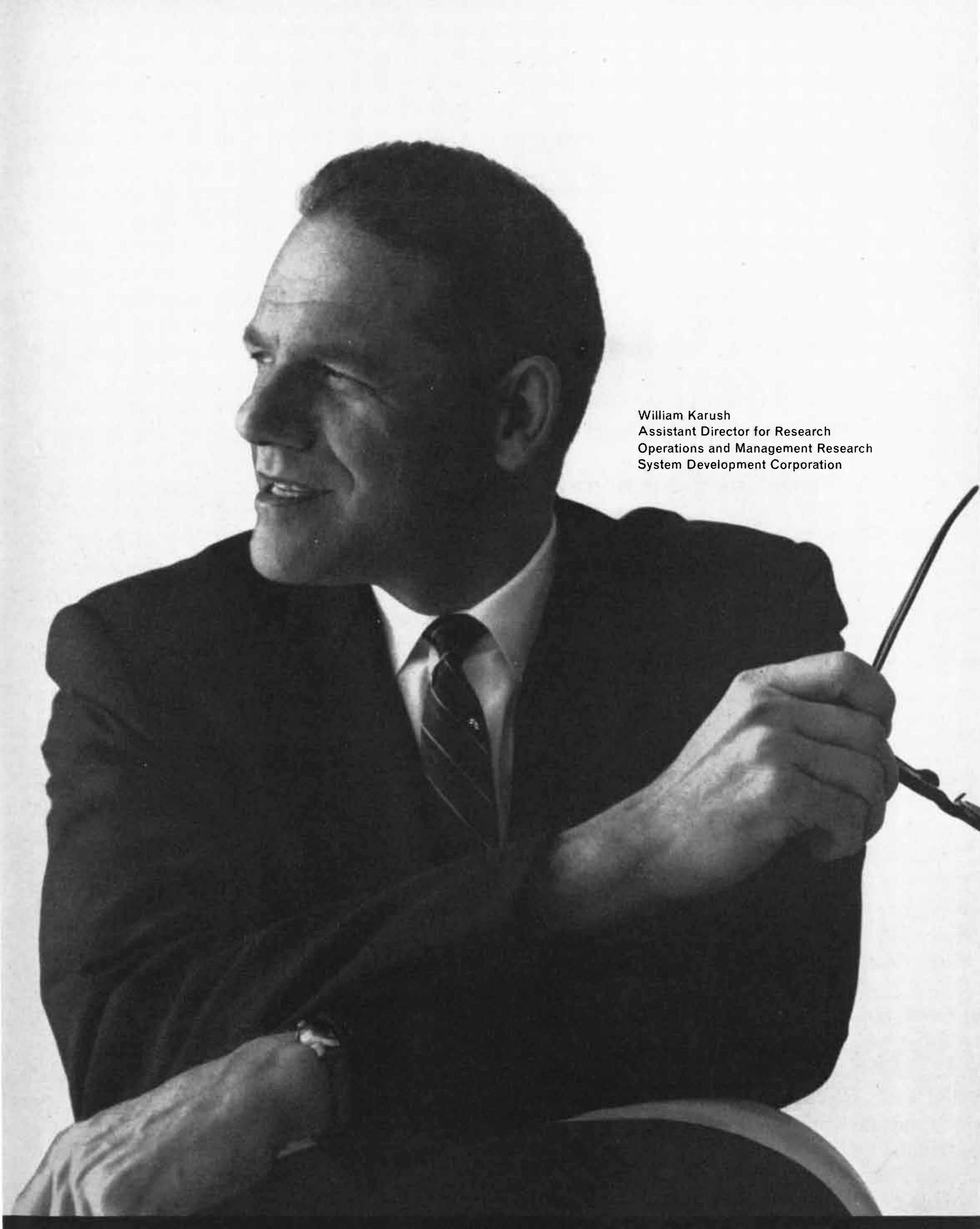
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