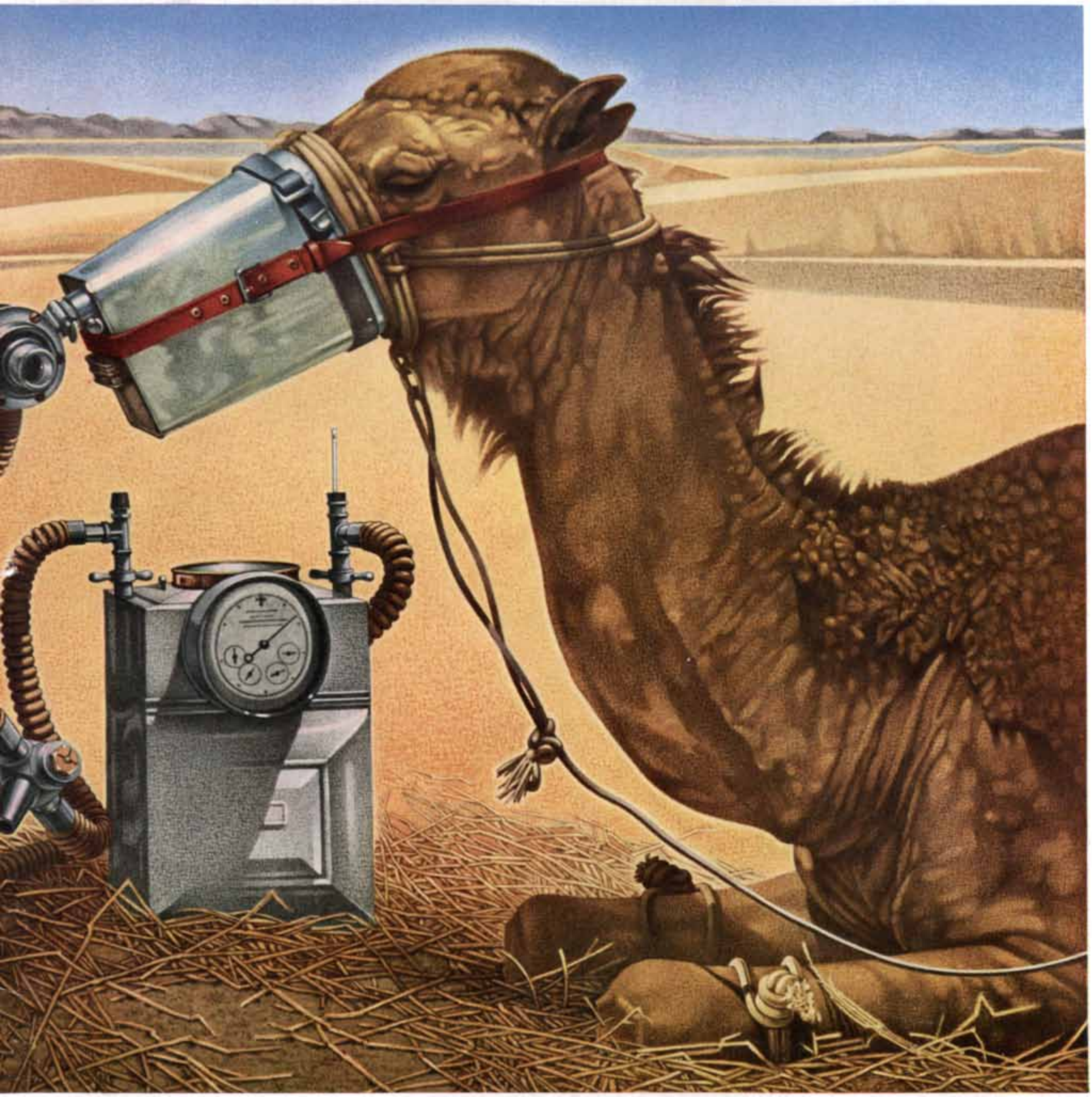
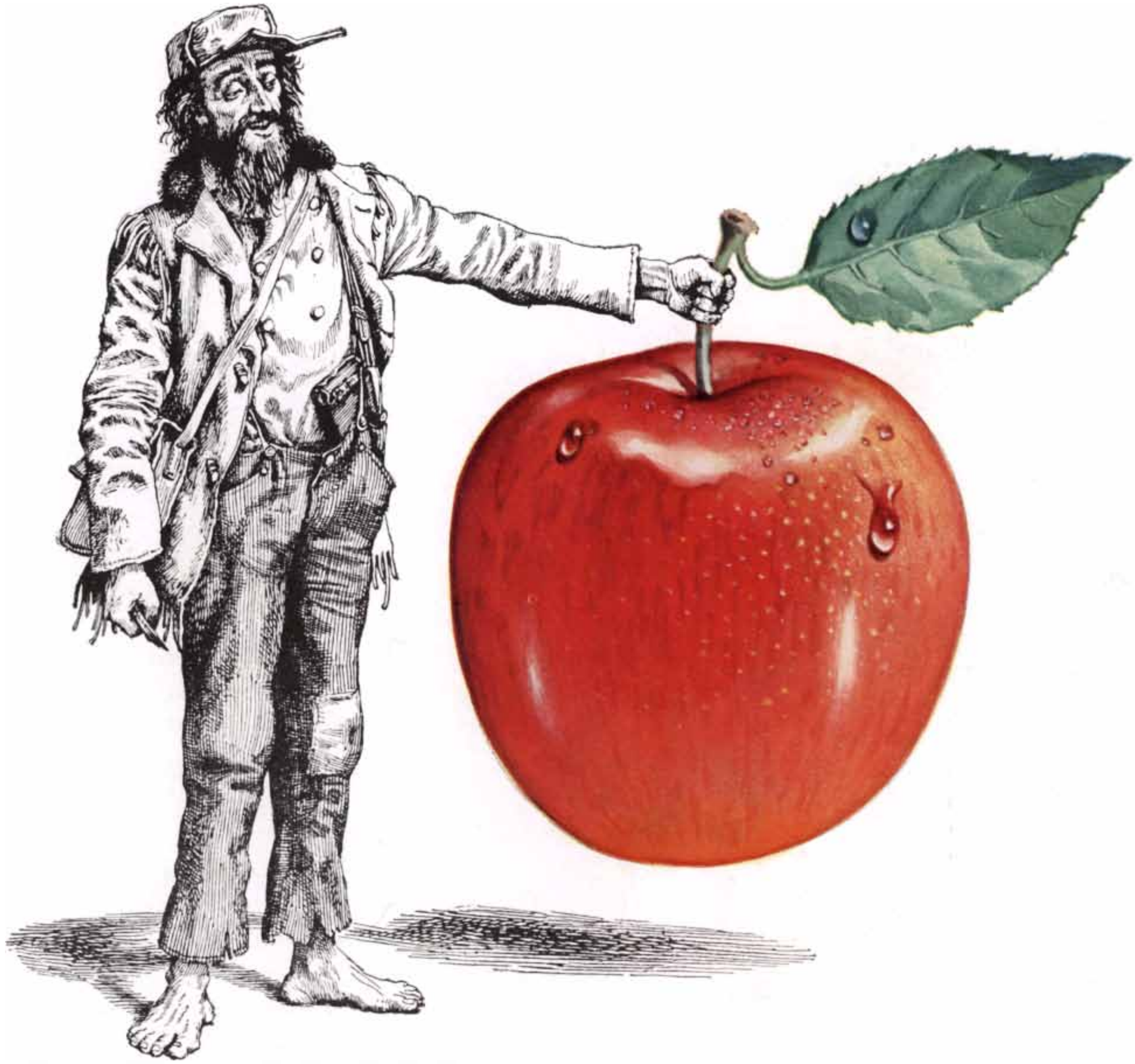
SCIENTIFIC AMERICAN

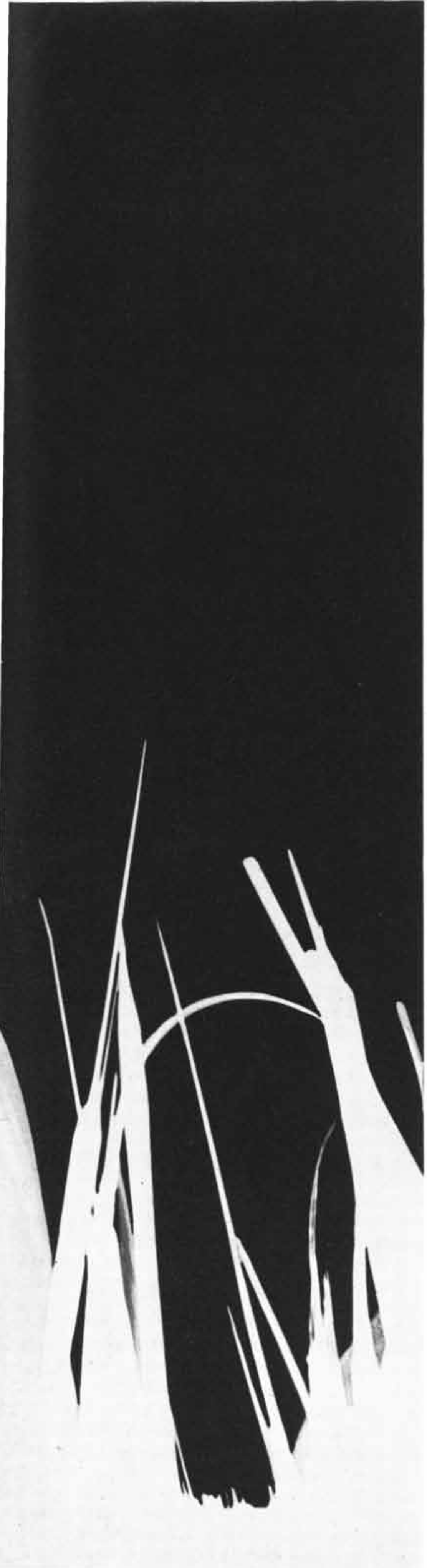


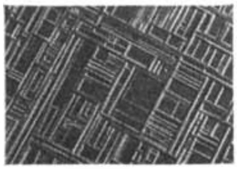
METABOLISM OF THE CAMEL

FIFTY CENTS

December 1959







Early Oxidation (750 x)

Oxide Whiskers (12,000 x)

Reduction of Oxide Products (2500 x)

Established 1845 SCIENTIFIC AMERICAN December, 1959 Volume 201 Number 6

ARTICLES

DEPARTMENTS

PUBLISHED MONTHLY BY SCIENTIFIC AMERICAN, INC., 415 MADISON AVENUE, NEW YORK 17, N. Y.

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THE COVER

The painting on the cover shows a camel being given a basal metabolism test with an apparatus made from, among other things, a gas meter (*lower left*). The test was made in experiments undertaken to study how the camel can go for long periods without water (*page 140*).

THE ILLUSTRATIONS

Cover painting by Rudolf Freund

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AN EXTRAORDINARY TRANSISTOR

This tiny silicon chip does something no other transistor can do. It achieves the speed of the fastest germanium plus having the superior temperature characteristics and reliability inherent to silicon. It is the Fairchild 2N706.

This extraordinary transistor was introduced to industry in August of 1959. Within two months, many thousands of units had been shipped and the 2N706 was being designed into highest performance computer circuits. No "blue sky" project, the 2N706 is applicable and extremely advantageous to all types of high speed computer logic.

The 2N706 is also extraordinary as a success story in people—solid-state physicists, physical chemists, metallurgists, electrical engineers, mechanical engineers and industrial engineers. Free flow of ideas and enthusiasm produced an accumulation of advanced semiconductor technologies at an unprecedented rate. From the beginning, only two years ago, the 2N706 was the goal. En route, these technologies resulted in the production of eight other silicon transistors. These devices have clearly established Fairchild as the leader in advanced semiconductor development.

Step by step, the Fairchild program was planned and held in focus by a top management team of advanced degree scientists. And now, this same program is being zeroed in on new targets, among them Esaki diodes and integrated solid-state circuitry. If yours is a relevant background and you like the way we work, why not drop us a line? We would like to hear from you.

FAIRCHILD
SEMICONDUCTOR CORPORATION

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OFFICIAL U.S.A.F. PHOTO
of the Atlas lift-off
at Vandenberg A.F.B.
on September 9, 1959.
This was the first official
firing by SAC crew to
test operational capability.

A memorable event in the Album of Space Technology

Many significant achievements will be added to those already recorded in the chronicles of military and scientific space technology. Many important milestones in the conquest of space will be passed. None, however, will surpass the realization of America's operational capability in Intercontinental Ballistic Missiles. The threshold of this phase of our national defense was passed on September 9, 1959, with the historic launch of an Atlas by a Strategic Air Command crew at Vandenberg Air Force Base, California. Measured by any standard no event could have been more timely... more rewarding.

Five years ago the free world had no functional ballistic missile rocket engines, no guidance systems, no nose cones, no tracking stations, no launching pads, no trained missile squadrons. Today all those who have contributed to this present state of operational reality may take justifiable pride.

In this effort, Space Technology Laboratories is also proud of its privilege in performing the functions of systems engineering and technical direction for the Air Force Ballistic Missile Division, in close and continuing cooperation with the Air Force Ballistic Missiles Center, Strategic Air Command-MIKE, and such major associate contractors as: Convair, a Division of General Dynamics Corp., for airframe, assembly and test; General Electric Co., and Burroughs Corporation for radio guidance; Arma, a Division of American Bosch Arma Corporation, for all-inertial guidance; Rocketdyne Division, North American Aviation, Inc., for propulsion; General Electric Co., for re-entry vehicle; and Acoustica Associates, for propellant utilization.

All have worked in concert, with vigor and dedication to the objective of providing the nation with this fundamental addition to its defense capability.

SPACE TECHNOLOGY LABORATORIES, INC.

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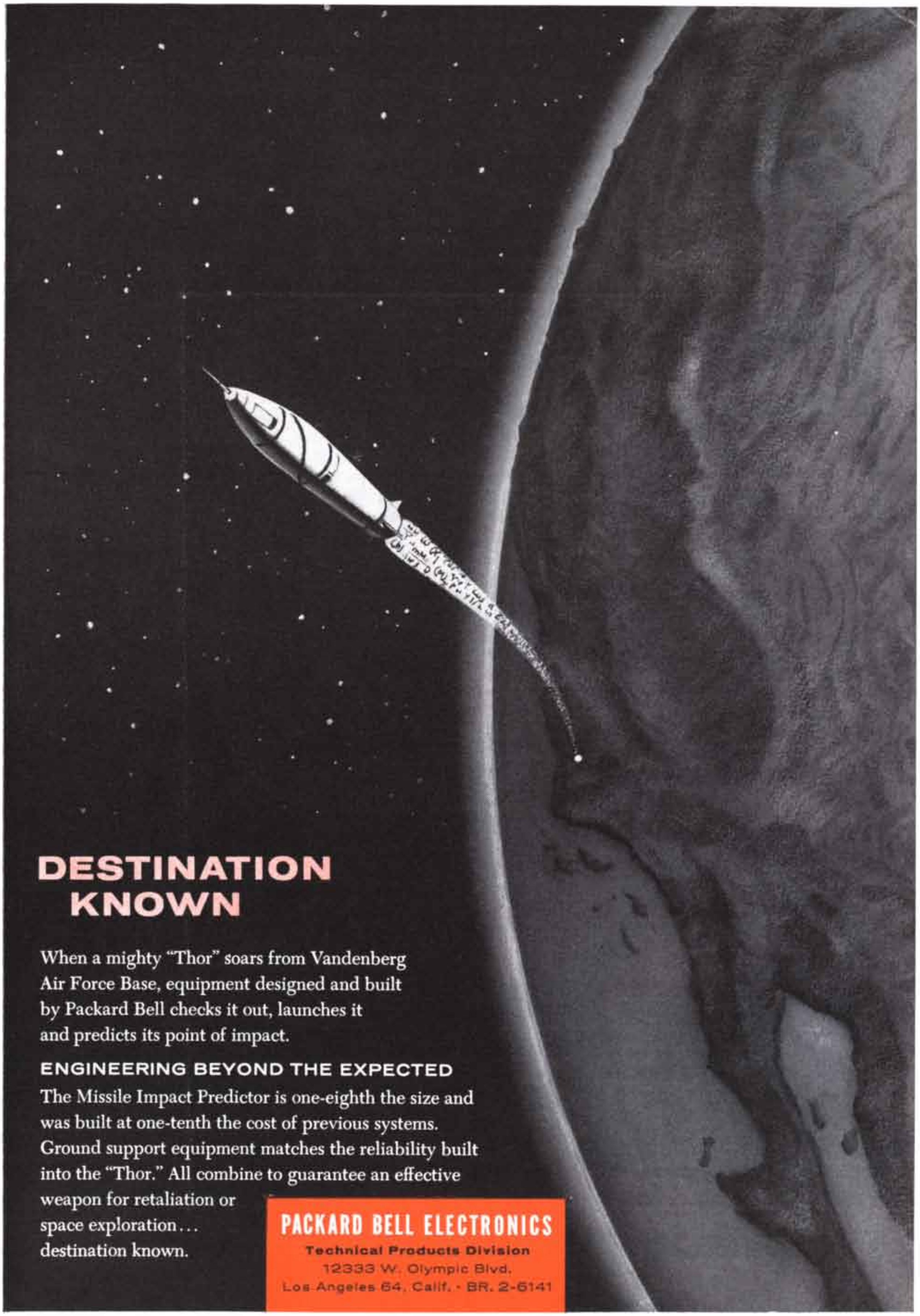
DESTINATION KNOWN
When a mighty "Thor" soars from Vandenberg Air Force Base, equipment designed and built by Packard Bell checks it out, launches it and predicts its point of impact.
ENGINEERING BEYOND THE EXPECTED
The Missile Impact Predictor is one-eighth the size and was built at one-tenth the cost of previous systems. Ground support equipment matches the reliability built into the "Thor." All combine to guarantee an effective weapon for retaliation or space exploration... destination known.
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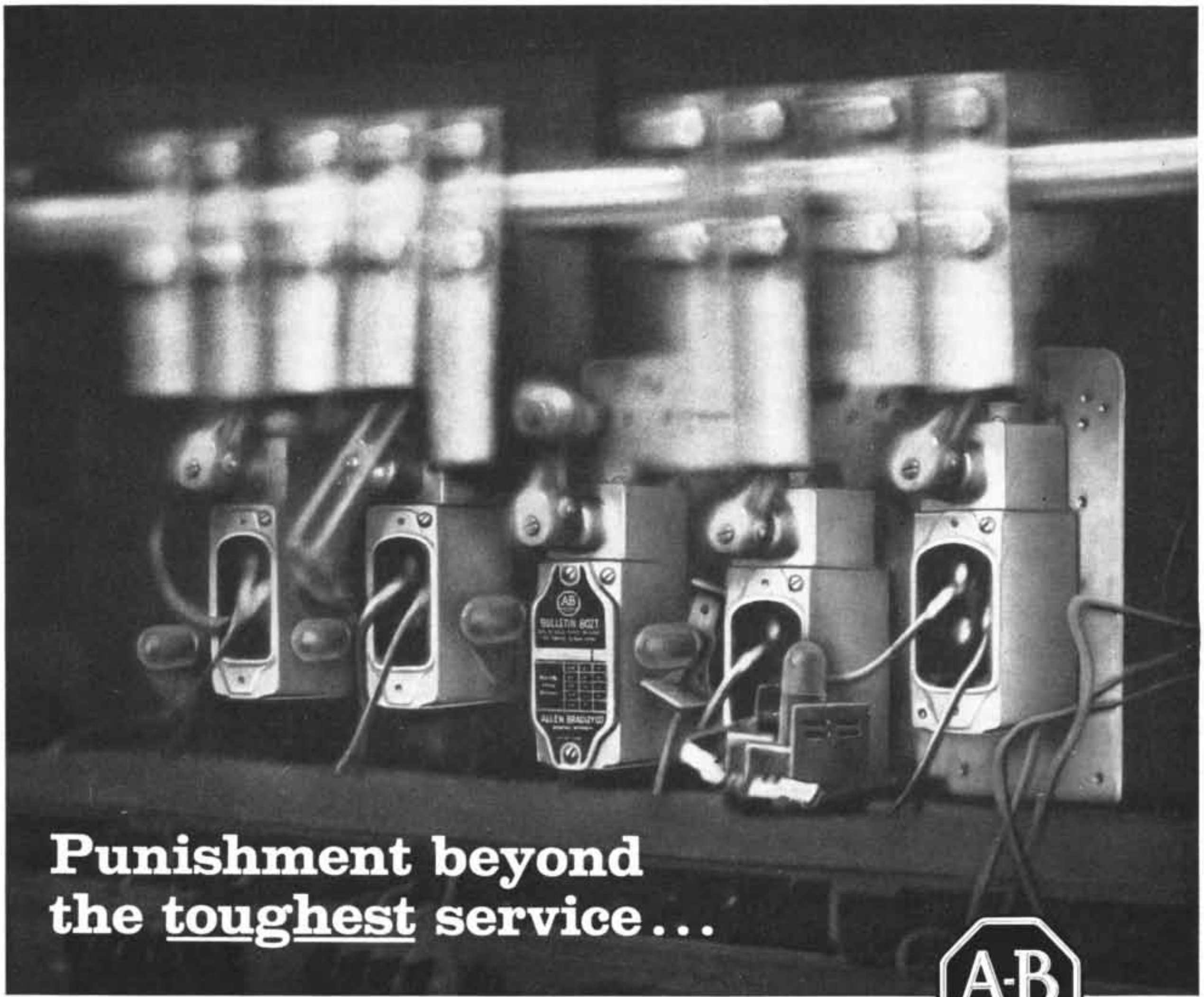

...these Allen-Bradley laboratory limit switch tests assure you more millions of trouble free operations

Almost faster than the eye can follow . . . these standard A-B limit switches undergo performance tests more severe than any service that could normally be expected. Allen-Bradley designs its apparatus to give "quality" performance in even the toughest applications. The operator, head design, and contact mechanism undergo these grueling tests for just one reason—to be certain that Allen-Bradley limit switches will deliver *more millions of reliable operations on the job!*

Every control device that carries the A-B trademark of quality is subjected to rigorous testing at every stage of production. It will pay you to insist upon Allen-Bradley—the *quality* line of motor control that gives you more for your money—in every way!

A FEW OF THE MANY VARIETIES IN THE A-B LINE OF LIMIT SWITCHES

Roller Lever	Fork Lever Type	Top Push Rod	Duplex Type

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EXTENSIVE DOW PRODUCTION FACILITIES FASHION VARIED NEW MAGNESIUM WARES

Coiled sheet, thin wall castings, many other production items are now available from Dow's big rolling mill, foundry and fabrication facilities.

Manufacturers on the alert for improved materials and production methods would enjoy a quick tour of the four Dow plants that turn out magnesium products. New ways of forming and fabricating magnesium now being practiced in these plants open up new areas of use for the lightweight metal.

TOOLING PLATE, extra flat, is annealed to eliminate residual stresses.

At the huge Madison, Illinois, rolling mill, for example, they're making magnesium sheet that doesn't require stress relief after welding. This is a major step forward in light metal technology and a boon to manufacturers using magnesium assemblies. Madison has also increased the maximum width of sheet to six feet. Five different sheet alloys, including elevated temperature alloys, are now available either flat or in coils.

To keep abreast of the rapidly increasing demand for precision jigs and fixtures, Madison keeps a close watch on the tolerances of Dow magnesium tooling plate. Typical flatness tolerances, for example, are 0.010 inches in any six feet. This means greater accuracy and less machining for users of Dow tooling plate. A mammoth 13,200 ton extrusion press, also located at Madison, is now turning out magnesium extrusions up to 30-inch circumscribed circle in size.

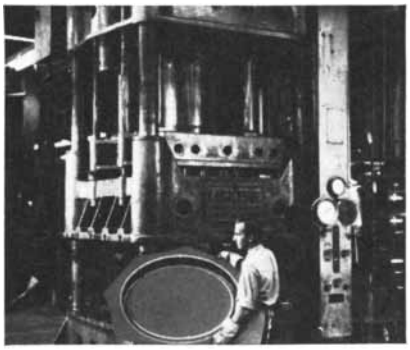
Over in Bay City, Michigan, interesting things are happening, too. At the well-equipped Dow magnesium foundry, largest in the U. S., sand and permanent mold castings of all sizes and shapes are being produced on a volume basis. Complete facilities are maintained for heat treatment, styrene DMI impregnation and chemical treatment. A well-staffed quality control team makes sure that all specifications are met or exceeded, and that the most modern equipment and techniques are fully utilized.

The Bay City foundry casts many complex and difficult designs. Large castings with walls as thin as 0.100 are now being produced. Other useful developments include cast-in tubeless passageways for use as hydraulic lines, special coring techniques for casting enclosed shapes and new magnesium casting alloys.

A new die casting plant is now on stream at Bay City. This facility houses the most advanced magnesium die casting equipment, including cold chamber metering units which automatically feed metal to the machines and contribute to unusually high production rates. To assure close alloy composition control in both die casting plant and foundry, a direct reading spectrometer provides frequent and precise analyses of the molten metal. Similarly, X-ray equipment is also available where radiography is needed in quality control.

The Dow fabrication plant, also in Bay City, offers capacity for volume work on magnesium assemblies. Here, too, developmental work on magnesium is constantly in progress. The plant is set up to handle large or small jobs, and plenty of both. Its activities include deep drawing, bending, spinning, stamping, piercing, machining, arc and spot welding, assembly, chemical treatment and painting. This plant has pioneered many "firsts" in magnesium production, such as hot drawing, spot welding and automatic welding.

DOW FOUNDRY offers production capacity for sand and permanent mold castings of all sizes.



LARGE DRAW PRESS at Dow's fabrication plant forms magnesium sheet in one operation.

WRITE TODAY for more information about Dow's magnesium production facilities. Request "Fabrication Brochure", "Foundry Brochure", "Die Casting Brochure" or all three. THE DOW METAL PRODUCTS COMPANY, Midland, Michigan, Sales Department 1351EQ12.

DOW

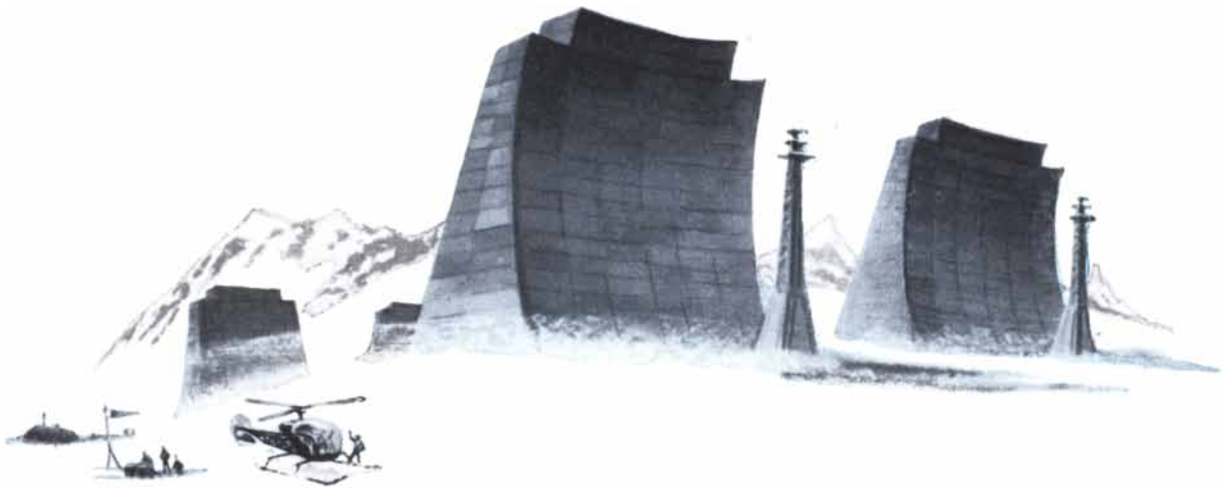
THE DOW METAL PRODUCTS COMPANY
Midland, Michigan
Division of The Dow Chemical Company

THE 'DO' LINE THAT TELLS AGGRESSORS, 'DON'T!'

Because the tropo scatter radio equipment of Radio Engineering Laboratories, Inc., has proved its worth in installations around the world, it is also specified for the U.S. Air Force's DEW-East—the vital DEW Line extension from the present terminal on Baffin Island 1,200 miles east to Iceland. Once again, Western Electric Co., Inc., has chosen REL apparatus for this "can do" communications system to bridge the gap of ice and open water, and overcome the plagues of atmospheric and electromagnetic disturbances.

It's the unequalled reliability of REL equipment which has made it the choice for eight of the nine major networks in operation or on order. In fact, more kilowatt miles of REL tropo apparatus are in use or on order than those of all other companies combined.

The hazards of snow, ice and weather that make construction of DEW-East stations so formidable for the men who build them, call for equipment with the same sturdiness, the background of experience, the same quality of "can do". That's REL. And that's why you'll want REL's help in solving your specialized radio problems.



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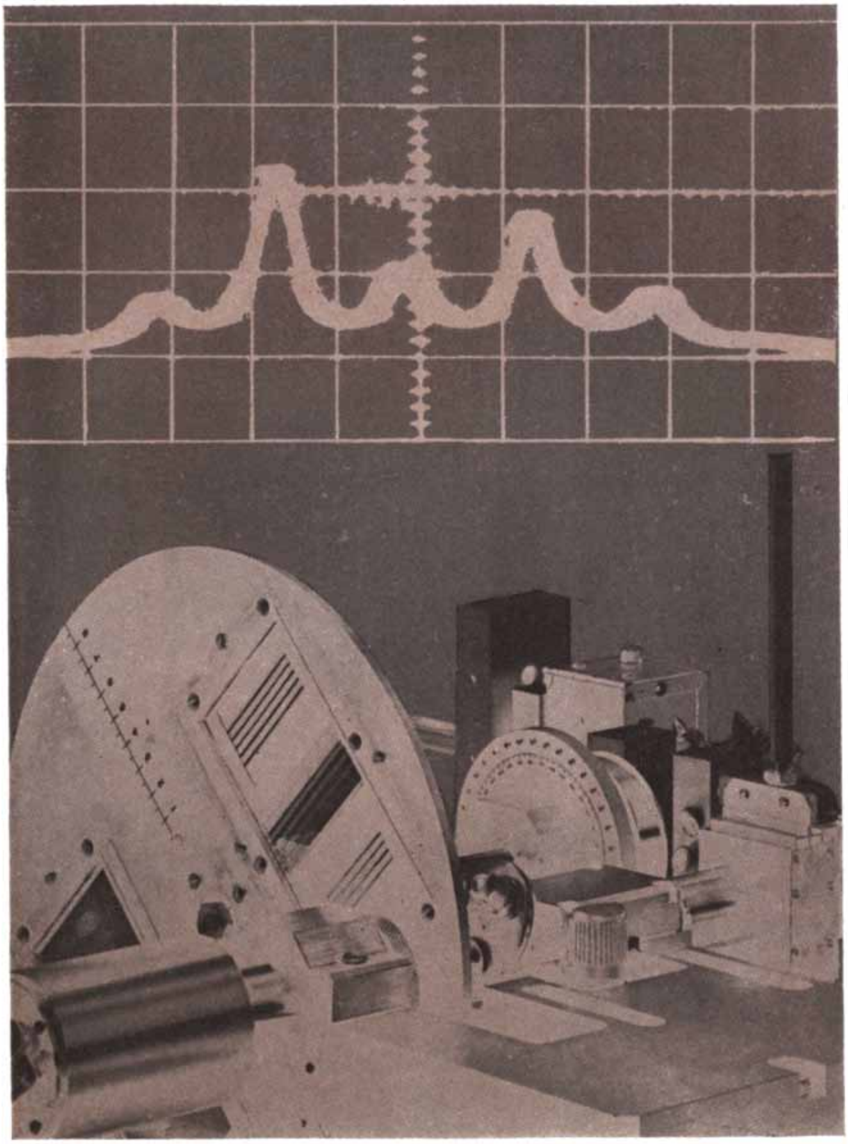
REL

Creative careers at REL await a few exceptional engineers. Address résumés to James W. Kelly, Personnel Director.



LETTERS

Sirs:

The Roman poet Lucretius did indeed believe, as B. J. Alder and Thomas E. Wainwright state in their article "Molecular Motions" [SCIENTIFIC AMERICAN, October], that "matter is composed of tiny particles called atoms [and] that the behavior of these particles is the key to understanding the properties of bulk matter." But Lucretius was in no sense the originator of this theory. He borrowed it from Epicurus, who flourished in Athens in the first part of the third century B.C.; and Epicurus had borrowed it, in turn, from the Thracians Leucippus and Democritus (*circa* 460-370 B.C.). If the "ancient hope of science," that the properties of macroscopic matter can be accounted for in terms of the behavior of its particles, must have a founding father, one of these philosophers (probably Democritus, since Leucippus's life is shrouded in mystery) is surely the best candidate for that honor.

The "dream" with which the name Lucretius is associated in the history of Western thought is not primarily that of giving scientific explanation of the behavior of matter—this for Lucretius was a foregone conclusion—but rather that of eliminating superstition and religion. To get rid of "this terror, this darkness of the mind" was his end in

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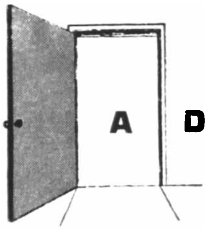


A DOOR IS OPENED... TO NEW USES FOR COLORED PAPERS

JUST OFF PRESS! *The Age of Reason for Color,* *featuring a treatise by color authority Faber Birren, discusses the advantages of tinted papers and related color inks.*

"If one faces the evident facts of human vision, it is no more plausible to conclude that a book, newspaper or magazine should be printed on white than to propose that they be printed on color!"

So writes Faber Birren—one of America's leading color authorities and a specialist in color psychology and research. The source? A new brochure featuring a treatise by Mr. Birren, *The Age of Reason for Color,* published by our National Aniline Division. It can be yours at the drop of a letter in your outbox.

Why black on white—only?

The purpose of this brochure is to point out the advantages to be found in the use of *tinted papers and related color inks.* But isn't *white* paper traditionally best, you may ask—proved by the test of time? Not necessarily, contends Mr. Birren. "Black on white admittedly has good legibility, but deep blue on pale yellow may be even superior."

Combatting eye fatigue

"In much printed matter involving 'sustained visual tasks'," continues the author, "lower contrast than black and white may make seeing not only easier but less fatiguing."

The Age of Reason for Color lets you test this for yourself. It is printed with special color inks on four differently tinted paper stocks to achieve varying degrees of contrast. As you read it, you can evaluate the readability of color combinations other than black and white. The specially designed Impact Book papers were developed by the Whiteford Paper Company.

You will also see the astonishing results obtainable by reproducing the same set of four-color process plates on each of the tinted papers.

More to it than legibility

Of course, there are more advantages in the use of colored papers than just improved readability or cutting down eye fatigue. There's the emotional—or psychological—use of color, and we think you'll enjoy Mr. Birren's scientific explanation of the emotional appeal that color can carry. It's a subject of particular interest to those engaged in the business of promoting or selling via the printed word and picture.

The brochure also contains an article contributed by the firm that printed it for our National Aniline Division. National is a major producer of dyes and pigments for the paper and printing industries—and of a full line of colorants for textiles, leather and almost anything else that needs color.

For a free copy of ***The Age of Reason for Color,*** just write, on company letterhead, to Allied Chemical Corporation, Department 129-S, 61 Broadway, New York 6, N. Y.

Allied Chemical

BASIC TO AMERICA'S PROGRESS

view, for without such purging man cannot live a life "worthy of the gods." Hence though Lucretius prized the atomic theory, he regarded it as a means. Democritus, on the other hand, prized it for its own sake, as truth, much as theoretical physicists prize it today.

CECIL MILLER

Department of Philosophy
Kansas State University
Manhattan, Kan.

Sirs:

As an interested reader of your department "Mathematical Games," I was happy to greet an old friend in the October issue: When a stick is broken at random, and the larger part is again broken, what is the probability of a triangle? I believe the construction you present, though elegant, gives an incorrect answer. The trouble is that the representative point in the triangle on page 174 is not uniformly distributed, so that a comparison of areas does not correspond to a comparison of probabilities. On page 636 of *Mathematics of Physics and Modern Engineering* (McGraw-Hill Book Company, Inc., 1958), evidence is presented that the probability is 2 log 2 minus 1, where log 2 is the log to the base *e* 2.718. . . . The same result is given by your triangle construction, when due account is taken of the nonuniformity.

If you wanted to illustrate the theme of your article, *viz.*, that even experts can go astray in probability theory, you could hardly have chosen a better example. So far as I know the wrong answer has been given ever since Henry Sinclair Hall and S. R. Knight started the ball rolling in the last century. You will be amused to note that the triangle construction *does* give the correct answer when two points are chosen at random, as in the first case you consider.

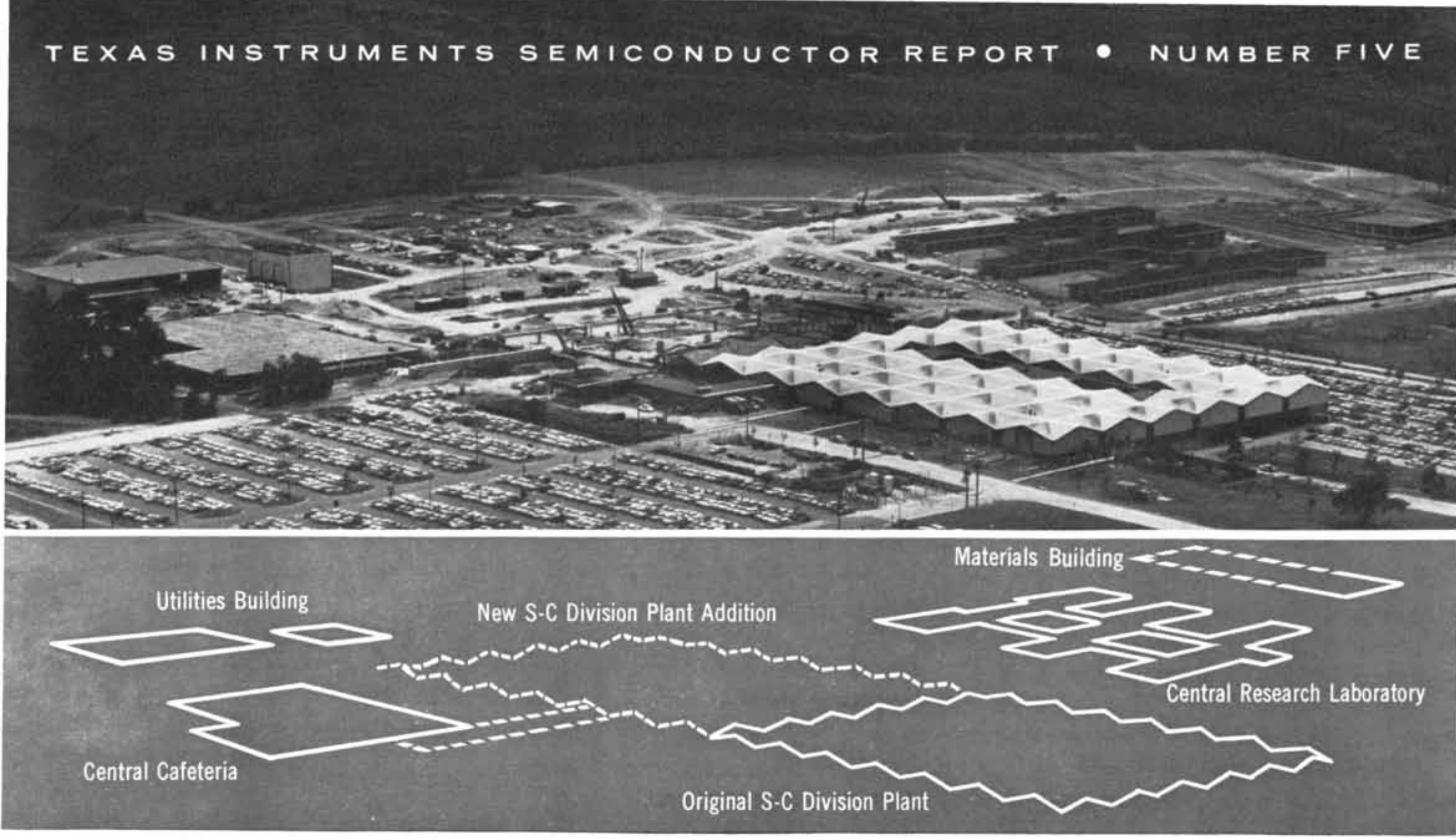
R. M. REDHEFFER

Department of Mathematics
University of California
at Los Angeles
Los Angeles, Calif.

Sirs:

May I congratulate you on Professor Briggs's discriminating review [SCIENTIFIC AMERICAN, October] of Sir Charles Snow's Rede Lecture and Sir Eric Ashby's little book? It is noteworthy, how-

TEXAS INSTRUMENTS SEMICONDUCTOR REPORT • NUMBER FIVE



The world's largest semiconductor plant ...now doubling in size!

By early 1960, more than 700,000 sq ft of plant space in Dallas will be devoted to the development and production of high quality semiconductor products by Texas Instruments. Although the original 310,000 sq ft plant — still the industry's largest — was completed only last year, growing mass-production requirements for TI semiconductors and components led to this additional expansion. This giant new plant will further serve TI goals of lowering semiconductor unit costs through high-volume production while rigidly maintaining high standards of reliability.

The Central Research Laboratory, located on the same 300-acre tract, houses creative personnel and facilities for basic research on semiconductors and related materials. Supporting buildings complementary to semiconductor development and manufacture scheduled for completion this year include a Materials building for the manufacture of high purity semiconductor and allied materials, a Utilities building and a Central Cafeteria . . . all integrated toward the production of semiconductors and components of ever increasing performance and reliability.

Only advanced facilities can produce advanced components.

These newest TI technological facilities are specifically geared to supply customer needs, both present and future, further insuring new and finer electronic components . . . in advance of user requirements.

Bedford, England semiconductor plant of Texas Instruments Limited. 32,000 sq ft facility is now in complete operation with a new 115,000 sq ft building, shown here, scheduled for completion in late 1960.

germanium and silicon transistors
silicon diodes and rectifiers
tan-TI-cap solid tantalum capacitors
precision carbon film resistors
sensistor silicon resistors

TEXAS INSTRUMENTS
INCORPORATED
SEMICONDUCTOR-COMPONENTS DIVISION
DALLAS, TEXAS

ever, that the historian reviewer did not mention Sir Eric's excursion into the history of universities or his view that they are likely to require stimulus from outside in order to bring about beneficent change.

Surely the sources of the bifurcation that have provided Snow with grist to his novelist's mill lie right in the universities. Academic theories of knowledge on which both scientists and humanists are brought up today are clearly contradicted by current trends in learning that lead to practical achievement. So the universities need to be reoriented to man, his ideas and his inventions. Reading of the *Scientific American* by more university professors, both scientists and nonscientists, might, I venture to suggest, help to generate a new academic outlook.

In the university each of the standard disciplines tends to occupy a museum that is becoming more and more costly to provide. For this reason alone most of the basic assumptions concerning academic functions today could, with advantage, come under scrutiny in the light of purposeful attitudes to living and reality. In particular, "technology" and "technique" might lose their role as catchwords and be judged by their intellectual function, since they may be essential for academic intellectual achievement even in fields of study that have been managed traditionally by means of a fluent pen or a good speaking voice.

The humanism of Ashby and Briggs can help only if translated into practical reforms in the universities.

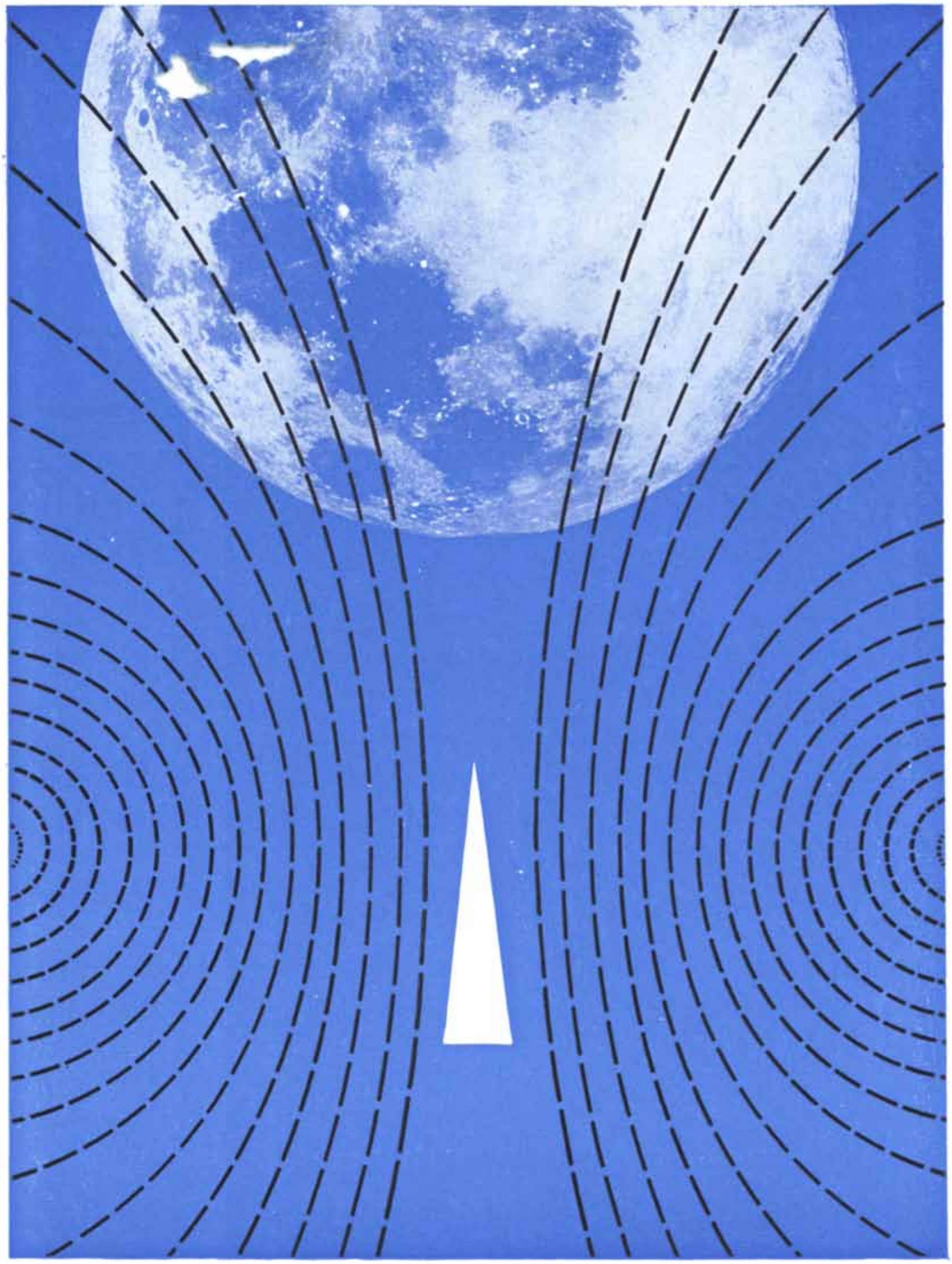
W. H. Watson

Head, Department of Physics
University of Toronto
Toronto, Canada

Errata

In the article "Life and Light" [Scientific American, October] the value of one mole of quanta was given as 7.02×10^{23} quanta. The correct figure is 6.02×10^{23} quanta.

The caption for the illustration on page 102 of the same article states that, upon absorbing light, the retinene molecule changes from the *trans* configuration to the *cis*. Actually the change is from *cis* to *trans*.



Avco's magnetic spaceflight—

When man first travels beyond the moon, the thrust may well be supplied by a new system of propulsion, based on principles of magnetohydrodynamics (MHD). This system uses a magnetic field to speed and expel ionized gas for power output. Magnetic thrust propulsion is a current project of the Avco-Everett Research Laboratory . . . working to extend the knowledge of man.

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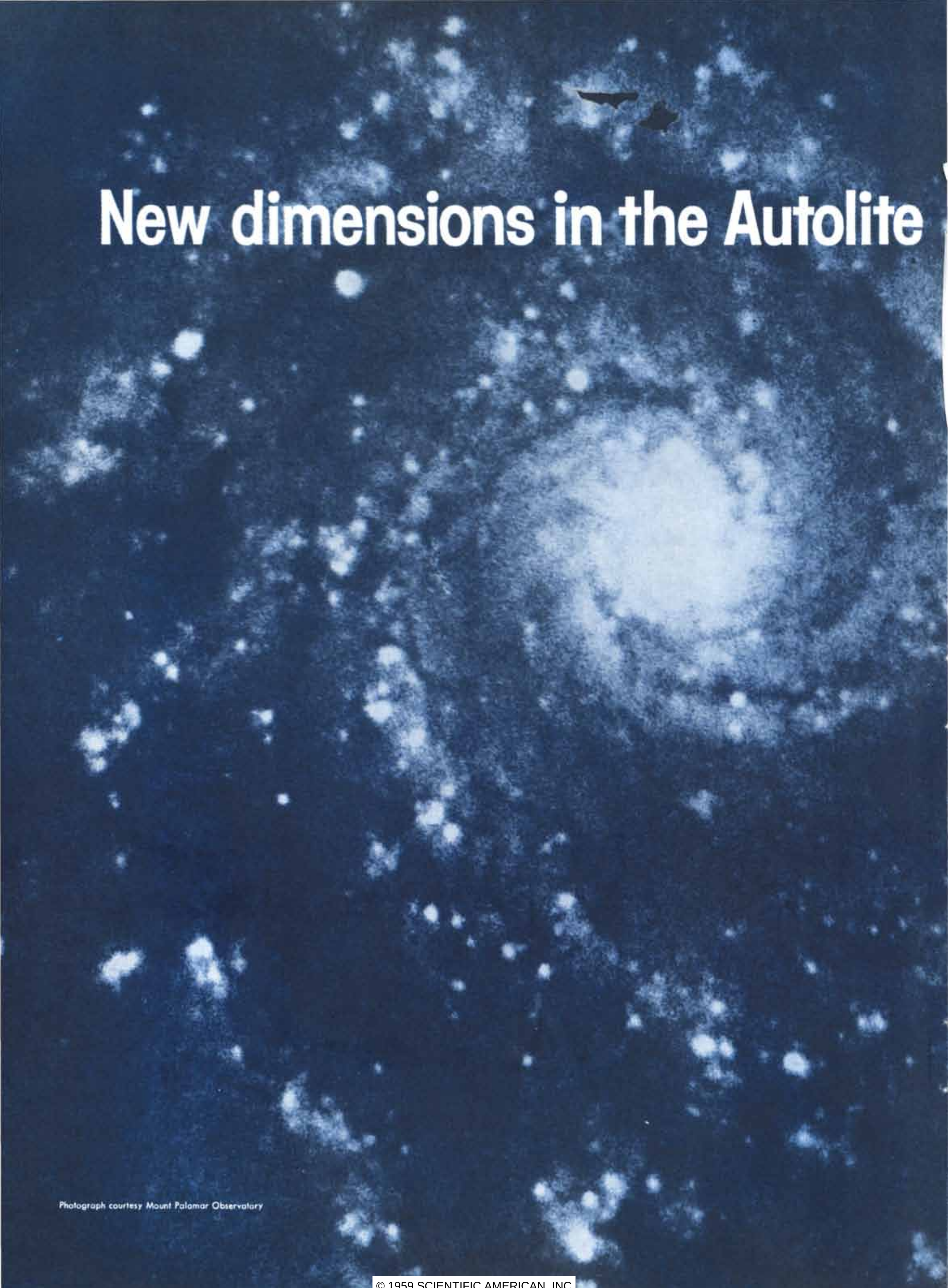
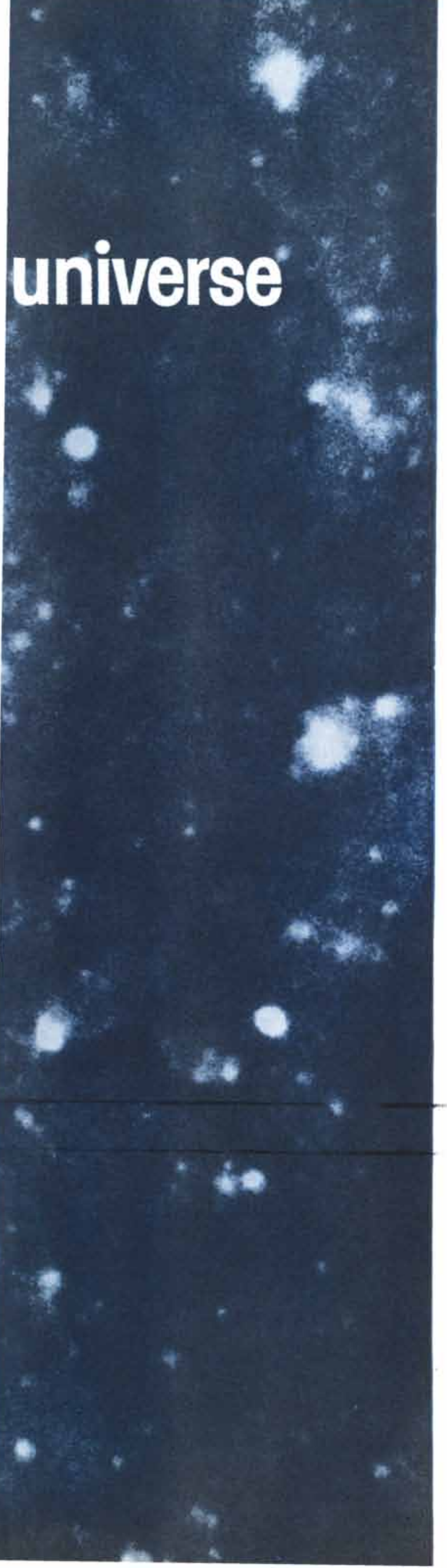

New dimensions in the Autolite
Photograph courtesy Mount Palomar Observatory


universe

We Have Taken the "Rare" out of "Rare Earths"

You Now Have a Wide Choice of Readily Available Materials

a report by Lindsay

We were thinking the other day of the progress we have made in taking the "rare" out of "rare earths." Even the "earth" in rare earth is not completely descriptive, either.

Actually, the name rare earths does fit these elements into the periodic system, for they are earthy when in the form of oxides. In this respect, they resemble the "earth" elements, aluminum being a good example. The "rare" came from the fact that those wonderful chemists of the last century thought that they were indeed rare, since the only supplies available were derived from quite rare and exotic minerals found then in a very few pegmatitic deposits in Norway.

Now, of course, you can buy rare earths in almost any size, shape and form. You can order in grams, ounces, pounds, and in many cases in carloads!

These elements have been described by other names such as "lanthanides" and "lanthanons." Technically, these are the elements lanthanum, atomic number 57, and the next fourteen elements in the periodic system. Thus, rare earths include all the elements from atomic number 57 to 71 (lanthanum to lutetium).

Due to some remarkable similarities in properties, the rare earths tend to occur together in nature. These same properties make it difficult to separate them in some cases. From the standpoint of availability of commercial materials, there are several choices.

THE RARE EARTHS

ATOMIC NUMBER	ELEMENT
39	Yttrium
57	Lanthanum
58	Cerium
59	Praseodymium
60	Neodymium
62	Samarium
63	Europium
64	Gadolinium
65	Terbium
66	Dysprosium
67	Holmium
68	Erbium
69	Thulium
70	Ytterbium
71	Lutetium
90	Thorium

Rare Earth Materials. The ore mineral commonly used as a source of rare earths is monazite. Rare earths extracted without any appreciable separation are marketed commercially as "rare earth" salts or materials. They contain these elements in about the same ratios as in the ore: roughly one-half cerium, one-quarter lanthanum, one-fifth neodymium, about five per cent praseodymium, and smaller amounts of the other rare earths. Being close to the starting material, "rare earth" salts are the most economical.

Cerium. Cerium is the most important single rare earth, relatively easy to separate and available in a rather complete range from commercial to high purity grades.

Didymium. Taking cerium out of the rare earth mixture leaves a collection of rare earths we call "didymium." Didymium materials, like cerium, are close to the starting ore, so costs aren't excessive.

High Purity Materials. *Lindsay* pioneered the first commercially installed ion exchange plant for the production of individually separated rare earths in purities up to 99.99%. These high purity materials are now readily available at prices which were unheard of only a few years ago.

Many applications. We have made remarkable progress . . . through the development of improved techniques for the separation of the rare earths, and expansion of production facilities . . . in taking the "rare" out of "rare earths." Needless to say we were compelled by considerable urgency to satisfy the rapid growth in demand by industry for many new uses.

• • •

We have prepared a revised edition of our technical data describing our rare earth, yttrium and thorium materials. Your request for the "Lindsay Binder" will bring you this collection of data promptly. If you have a specific idea or use in mind, let us know and our technical people will try to supply pertinent data.

We show you this photo of bulk handling of rare earth intermediates at our West Chicago plant to suggest that rare earth materials are produced in large tonnages. They are available for prompt shipment, some of them in carload quantities. Prices, incidentally, are surprisingly low.

PLEASE ADDRESS INQUIRIES TO

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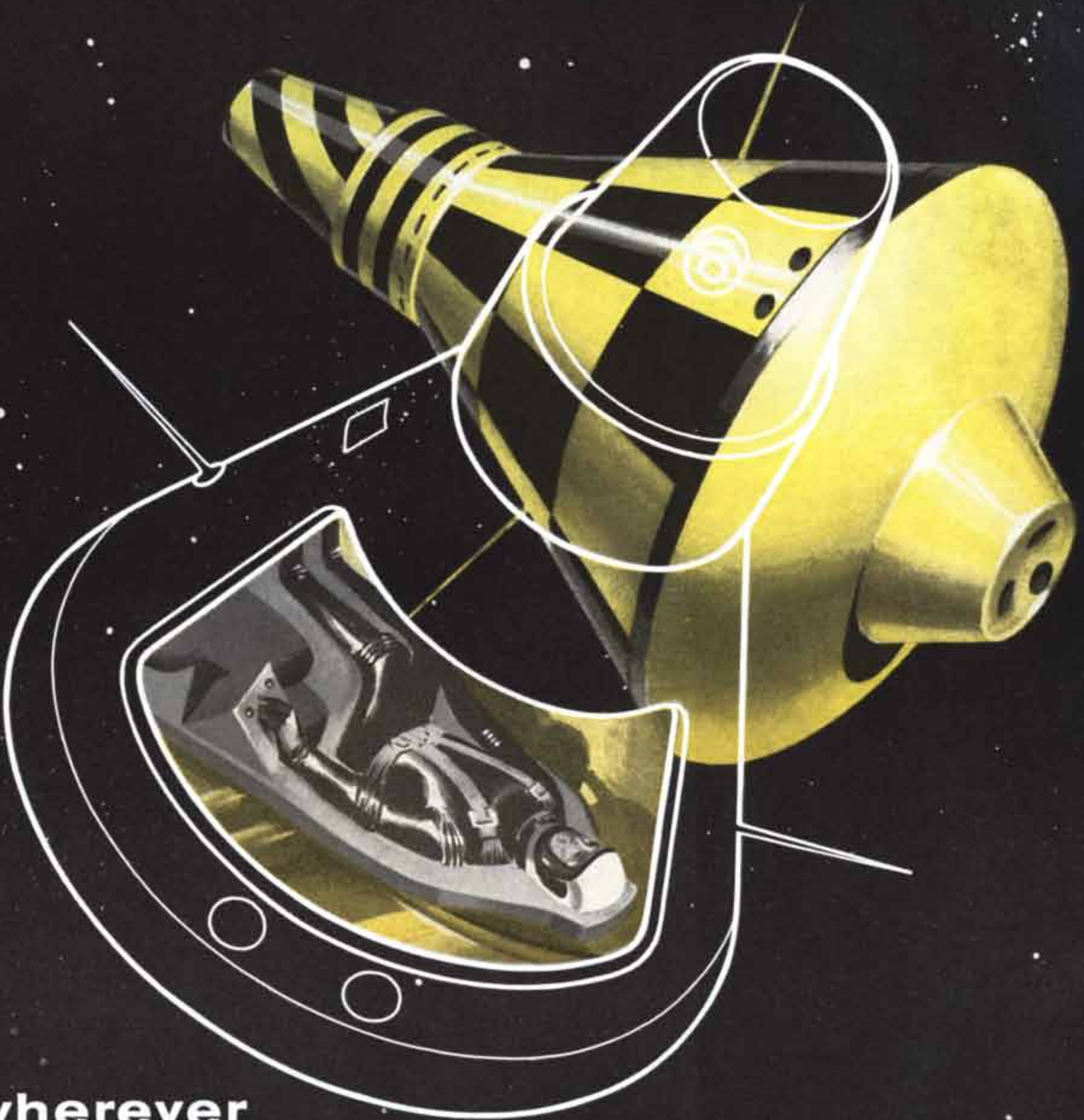

wherever there's electronics...

there's Transitron

Soon, one dependent man will be in a capsule, orbiting in outer space. This astronaut will rely on Transitron's semiconductors from launching pad into orbit and back under environmental extremes of temperature, radiation and acceleration. They'll help guide, communicate and record this historic adventure. At Transitron, more than 4000 skilled employees work exclusively to develop super-reliable silicon and germanium semiconductors. In rockets and missiles, as in radar, computers, atomic subs, communications, jets and thousands of other military and commercial applications — wherever there's electronics, there's Transitron, leading the field in advanced semiconductor reliability.

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Transitron

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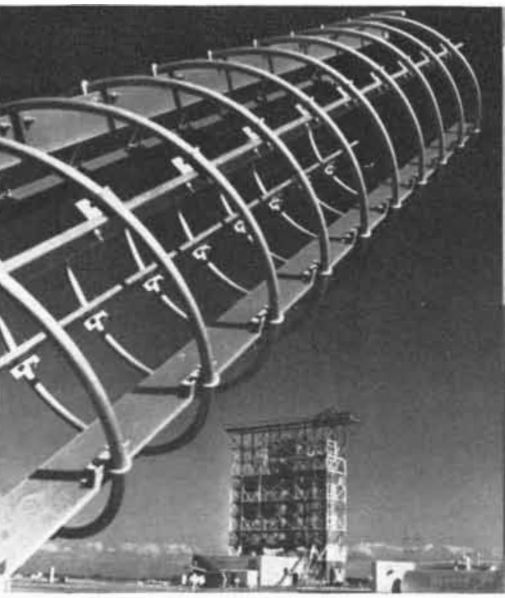
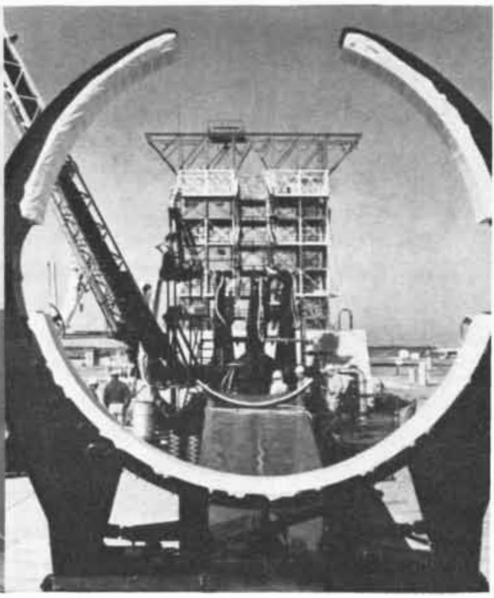
SALES OFFICES IN PRINCIPAL CITIES THROUGHOUT THE U.S.A. • CABLE ADDRESS: TRELCO

About the earthly side of Canaveral—Only recently, it spawned little more than snakes and other crawling creatures. Today, high flying birds are poised there, and because they can't jump off from sand, most of the Canaveral manpower and materials go into ground support equipment. And virtually all the steel material required can be purchased from one source—United States Steel. Whether we're talking about carbon steel, high-strength low-alloy steel, constructional alloy steel, or stainless steel, steel fence, electrical cable, wire rope or cement,

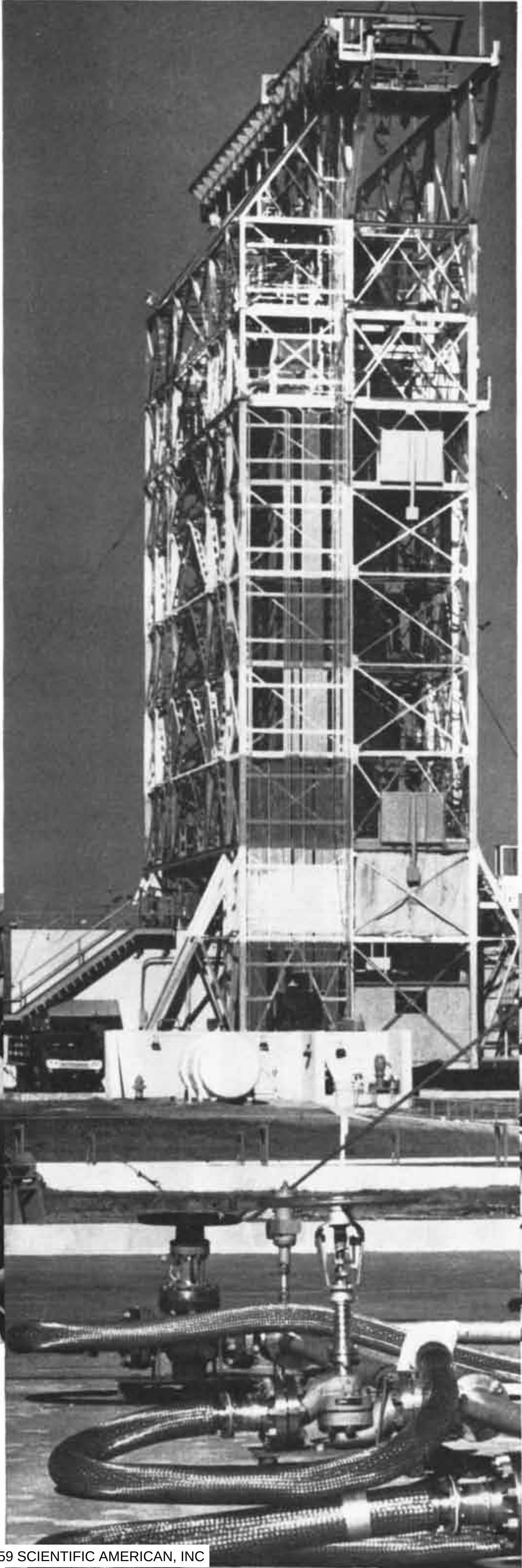


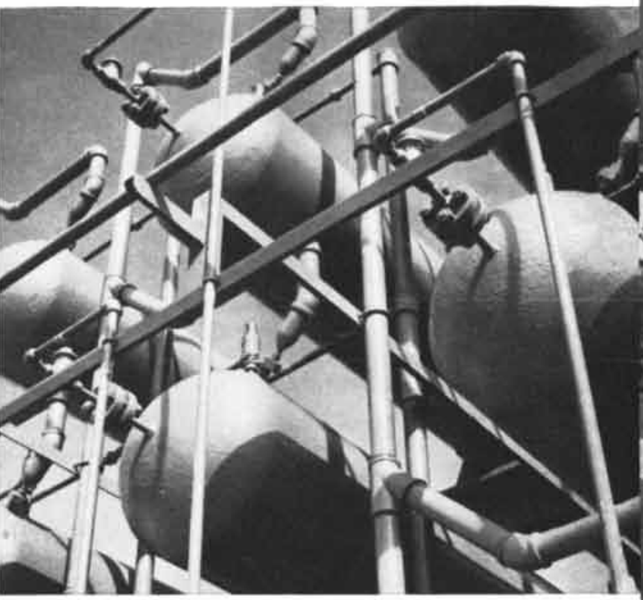
On this vertical oscillating radar tracking unit, every nut, bolt, and insulator collar is Stainless Steel. To the right, is a Stainless Steel fuel tank, and beyond that rises the U. S. Air Force Thor gantry tower, with a structural steel frame similar to a nine-story building.

The door to the U. S. Air Force Atlas blockhouse weighs 24 tons. It is solid manganese steel about eight inches thick. At X minus 15, the door automatically locks and it is blast-proof and vapor-proof.



The mobile transporter for the Thor is strong but light on its wheels because it was designed with weight-saving high-strength steels. Slanting to the left is the steel umbilical tower which carries Stainless Steel fuel lines and control lines.





These pressure vessels for the U. S. Air Force Bomarc A system are seamless steel cylinders about 20 inches in diameter and 26½ feet long. The cylinder walls are slightly more than an inch-and-a-half thick and will contain gas at pressure up to 4500 psi.

Stainless Steel pipes and Stainless Steel flexible tubing carry the fuel for the Thor complex. Fuel lines must be almost surgically clean to prevent explosions and assure proper flow. Inspectors check the lines with everything from microscopes to ultraviolet lamps. ▶

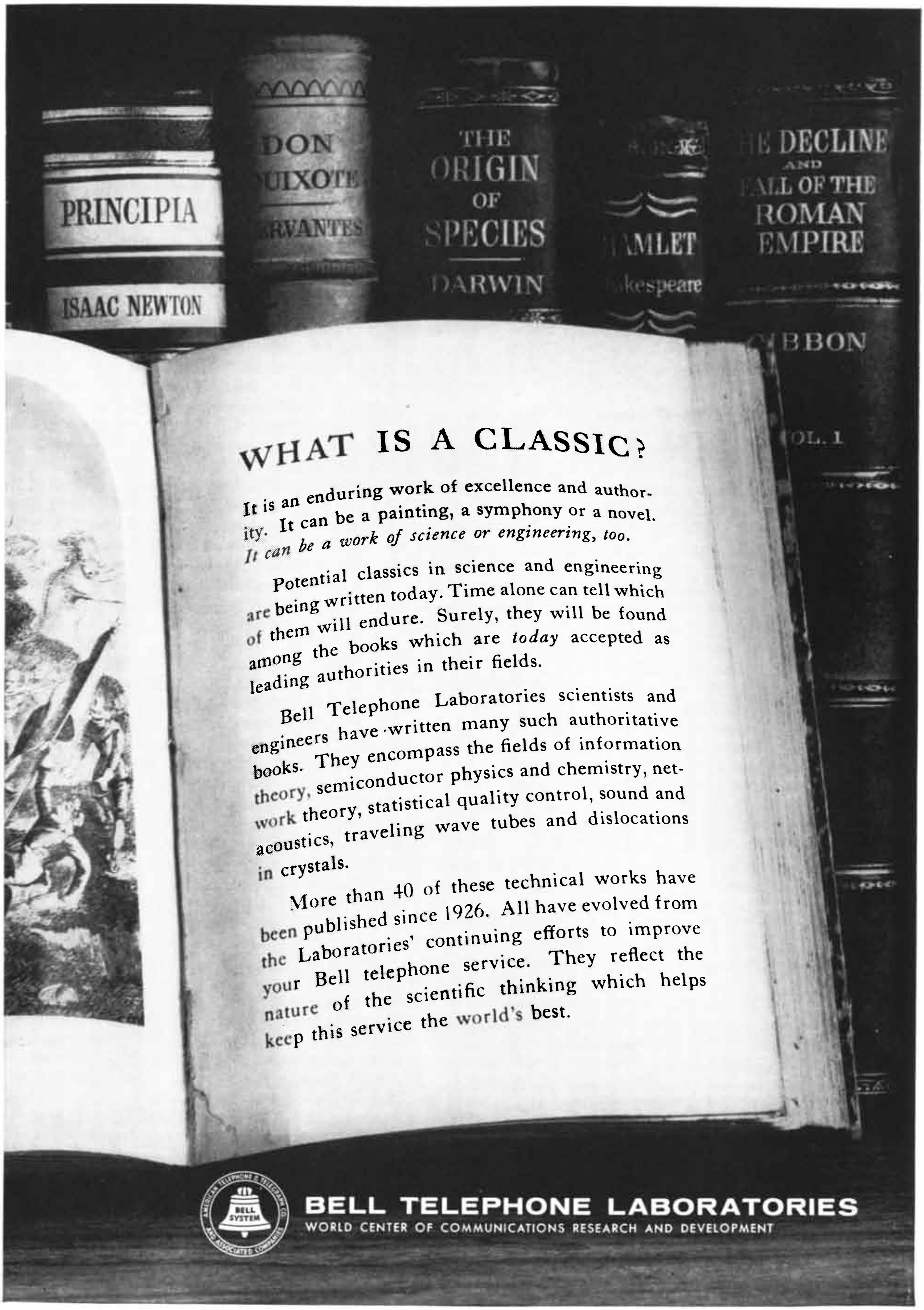
50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

DECEMBER, 1909: "This year's Nobel prizes will be distributed as follows: For physics, divided between Guglielmo Marconi and Prof. Karl Ferdinand Braun of Strasburg; for chemistry, Prof. Wilhelm Ostwald of Leipsic; for physiology and medicine, Prof. Emil Theodor Kocher of Bern; for literature, Selma Lagerlöf, the Swedish authoress. The Nobel prizes are worth about $40,000 each. Prof. Ostwald has become particularly well known as an investigator in connection with physical chemistry and chemical affinity. His researches have concerned, among numerous subjects, the electric conductivity of organic acids and the color of ions. Prof. Kocher is a Swiss surgeon. His special field is the thyroid gland."

"The Wright Company has recently been incorporated in New York for the manufacture of the Wright aeroplane in the United States. The company is capitalized at $1,000,000, Wilbur Wright being president. Among the directors are such men as Cornelius Vanderbilt, Howard Gould and August Belmont. The company will erect a factory at Dayton, Ohio, and will also have an aviation field where purchasers can be taught the operation of the machines. It is expected that many American sportsmen will soon become interested in aviation and own aeroplanes."

"At Mourmelon-le-Grand, France, on the 19th of November, Hubert Latham, in his birdlike 'Antoinette' monoplane, reached 410 meters (1,345 feet), thus making a new height record in a single-surface aeroplane. However, Louis Paulhan the next day made a new official record of 500 meters (1,640 feet), thus duplicating the height reached unofficially by Orville Wright at Potsdam. Besides this, Paulhan made a 55-minute flight from Mourmelon-le-Grand to Châlons and back, a distance of about 37 miles, in 55 minutes, or at an average speed of 40 miles an hour. In this flight he attained a height of nearly 1,000 feet, and at its termination glided to earth


PRINCIPIA
ISAAC NEWTON
DON
THE
ORIGIN
OF
SPECIES
DARWIN
DECLINE
AND
ROMAN
EMPIRE
WHAT IS A CLASSIC?
It is an enduring work of excellence and authority. It can be a painting, a symphony or a novel. *It can be a work of science or engineering, too.*
Potential classics in science and engineering are being written today. Time alone can tell which of them will endure. Surely, they will be found among the books which are *today* accepted as leading authorities in their fields.
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More than 40 of these technical works have been published since 1926. All have evolved from the Laboratories' continuing efforts to improve your Bell telephone service. They reflect the nature of the scientific thinking which helps keep this service the world's best.
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with his motor stopped from a height of about 700 feet."

"Within the next few months radium will be manufactured in London. Hitherto the world has had to depend upon Continental laboratories for its radium. The new factory has been constructed according to the requirements of Sir William Ramsay, who has devised a method of radium extraction which will, it is claimed, enormously reduce the time now needed for the elimination of the nonradioactive elements of pitchblende."

"Five miles of the Panama Canal have been opened to navigation. This includes the channel from the point in the Bay of Panama, where the water is 45 feet deep at mean tide, to the wharves at Balboa. Steamships are using this part of the canal daily."

"On the 8th instant Earl Gray, Governor General of Canada, and several other prominent Canadians visited Dr. Alexander Graham Bell's laboratory at Beinn Behreagh, near Baddeck, N. S. A demonstration was given of a new hydroplane boat, which rose completely out of the water in a short run of a few hundred feet. It is expected to use this boat beneath an aeroplane, so as to make possible the ascent from water."

"The gyroscope is an old and familiar toy which has always been a source of speculation. Renewed interest has been taken in the device within the past two years on account of two very interesting successful applications to practical uses, by Dr. Schlick and by Mr. Brennan. Dr. Schlick has mounted a large, steam-driven gyroscope in the hold of a 20-foot torpedo boat to prevent rolling in water. Mr. Brennan has built a locomotive that will run on a single rail and maintain its equilibrium above it by using two motor-driven gyroscopes. So far, however, no extended use of the devices has developed."

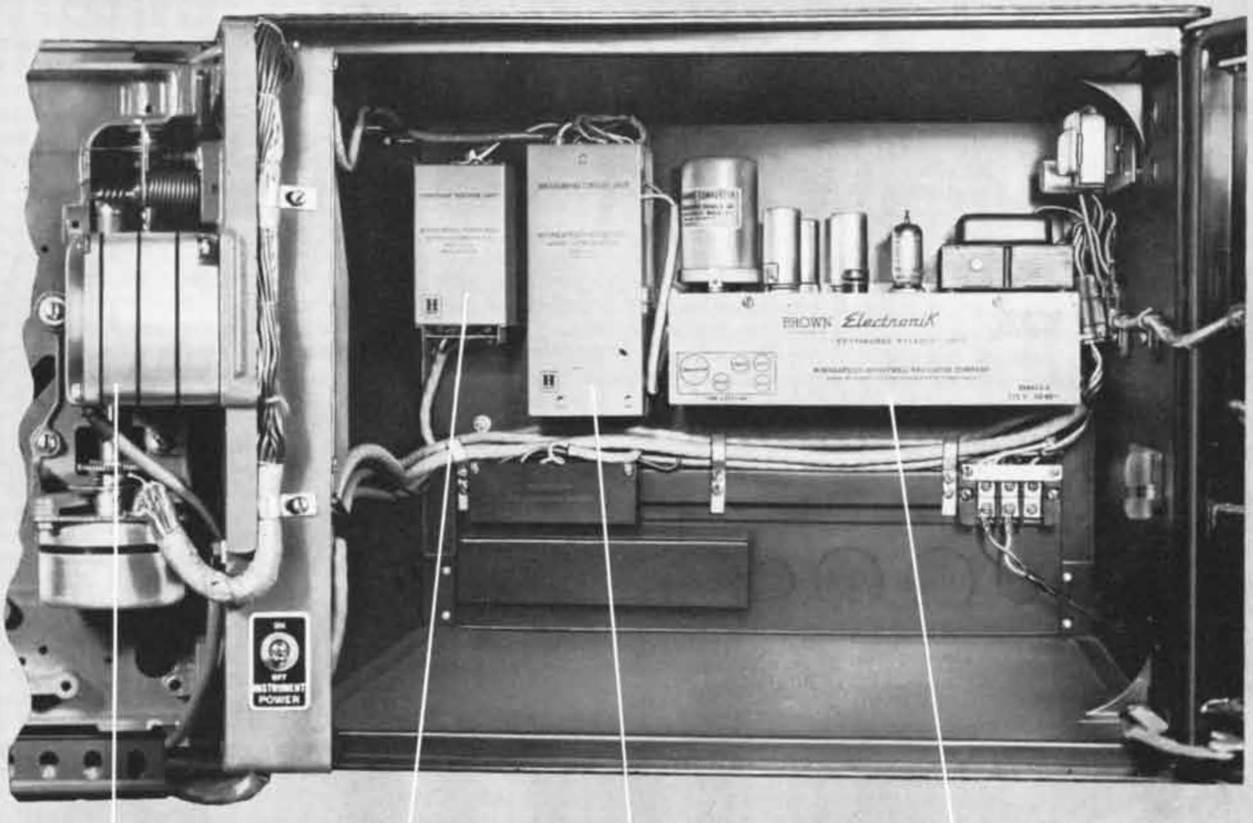
Scientific American.

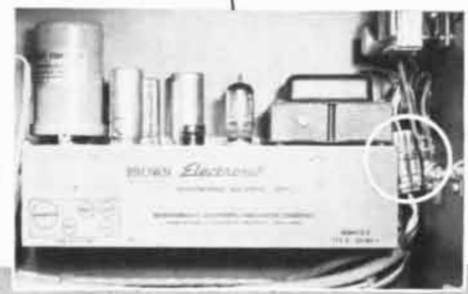
DECEMBER, 1859: "Some years ago we published an account of the first discovery of the gorilla, the largest of all the monkey family; and last year we gave an account of the arrival in England of the remains of one of these rare animals in a state of putrefaction. M. du

Chaillu, a gentleman who was sent to Africa by the Philadelphia Academy of Sciences, has now returned, bringing with him several skins and skeletons of the gorilla, which are now on exhibition in New York City. He says that the statements made by Professor Owen, on the authority of those who caught his specimen, in regard to the intelligence of the animal, are greatly exaggerated; that it does *not* use a club as a weapon, but is in fact simply a brute. It is among the most formidable of animals, its arms being as large as some men's legs. One specimen in M. du Chaillu's possession measures eight feet, three inches from tip to tip of its fingers when its arms are extended."

"The Boston *Journal* publishes the following interesting information in reference to the whale fisheries:—'In 1834 the whole number of vessels engaged in this business was about 700, of which 400 were American and 300 were foreign; so that 25 years ago, American enterprise was ahead of the rest of the world as four to three. In 1859 the whole number is estimated at 900, of which 661 are American and 239 foreign, showing American enterprise still more in the ascendant. In the value of the catch the increase is still greater, being about $12,300,000 in 1859 against $4,500,000 in 1834. Of the ships employed in this business, from this country, nearly four fifths are owned in and fitted from Massachusetts ports.' "

"Aluminum, the metal of which we have heard so much during the past few years, does not appear to be about to realize the brilliant expectations which were formed at the time of its first successful production in quantity, by St. Clair Deville. In its pure state it approaches somewhat to the color of silver; but it is found nearly impossible to free it from the certain foreign matters which become alloyed with it during the process of production. Aluminum is now sold in London for about $15 an ounce, being nearly as costly as gold, but, in consequence of its small specific gravity, an immensely larger bulk is given in an ounce of aluminum than in an ounce of gold. When aluminum becomes cheap, its nontarnishing property will bring it at once into varied and extensive use for many articles of domestic economy—tea utensils, spoons, knives and forks, door-knobs, &. Verily, a millennium of housekeeping may not be far distant, for M. Deville has prophesied that aluminum will ultimately be cheaper than silver."





Servo Motor has sectional housing, leakproof oil wick, printed circuits for simplified servicing. Any major part can be replaced in 2 minutes.

Constant Voltage Module—Uses Zener diodes and an ambient temperature compensator to replace standardizing mechanism.

Measuring Circuit Module—Contains easily-changed range spool panels and vernier adjustment. Range is changed simply by replacing screw-clip panels of fixed resistors.

Amplifier Module—Quick-connect design permits fast, easy removal for servicing and replacement. Circle shows quick connect plug.

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New modular design...

makes *ElectroniK* potentiometers easier to use and maintain

Now, four great new features add new operating and servicing ease to all *ElectroniK* circular and strip chart potentiometers.

- **New servo and chart drive motors are sectionalized so that any major part can be replaced in two minutes.**
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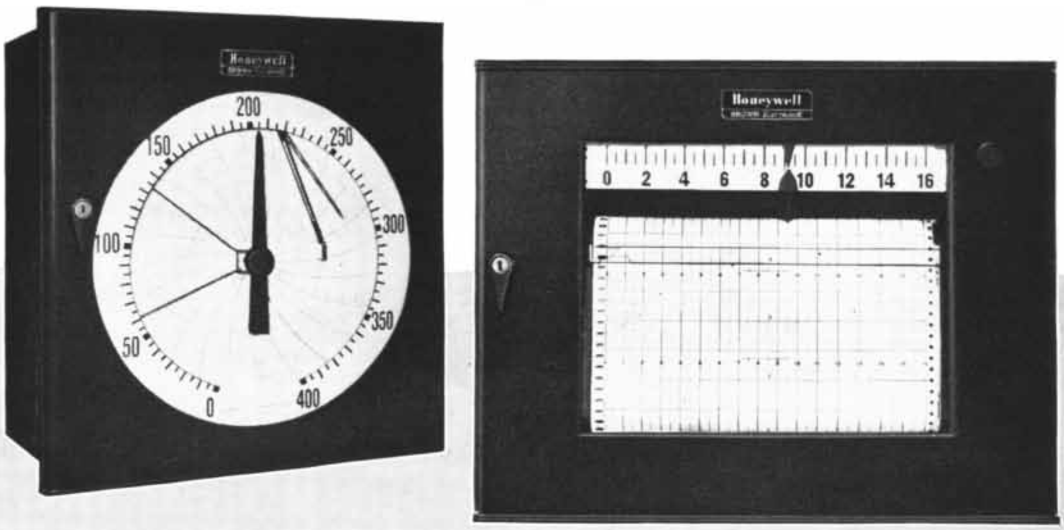
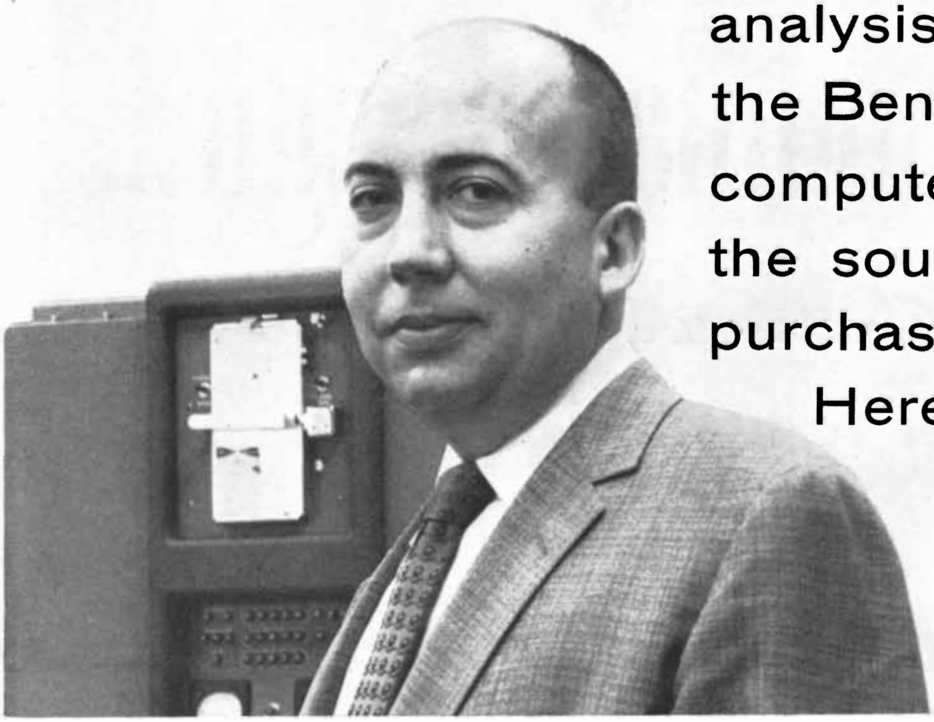


"Our detailed analysis proved the Bendix G-15 computer the soundest purchase. Here's why"



ROBERT C. MEISSNER,
PRESIDENT,
MEISSNER ENGINEERS, INC.
CHICAGO, ILLINOIS

Over 200 firms are enthusiastic users of the Bendix G-15 computer. Many, like the consulting engineering firm of Meissner Engineers, Inc., are involved in the heavy construction industry. Before purchasing, Meissner meticulously studied all medium-scale computers. "Only the G-15 gives us the *speed*, *expandability*, *price*, and *ease of operation* we require," says Mr. Meissner.

Mr. Meissner continues:

Speed: "The G-15 is faster than other computers in its price range, and for many problems gives us the answers we need in less than 1% of the time required by manual methods."

Expandability: "The variety of accessories for the G-15 is a very important feature. As we developed and expanded our applications, we added magnetic tape units, punched card equipment, and other special accessories."

Ease of Operation: "Our engineers find the G-15 Intercom 1000 programming system easy to master. It permits them to write versatile programs which can handle practically all of our problems."

The G-15 is the leader in its field for many other reasons as well: A price much lower than any other medium-scale computer, a built-in, magazine-loaded photoelectric paper tape reader, and tape punch as standard equipment, an active user's group that shares hundreds of proven programs, and fast, nationwide service.

G-15's are being applied successfully in a great many fields — business data processing, scientific and engineering calculations. Write us your specific problems.

Bendix® Computer

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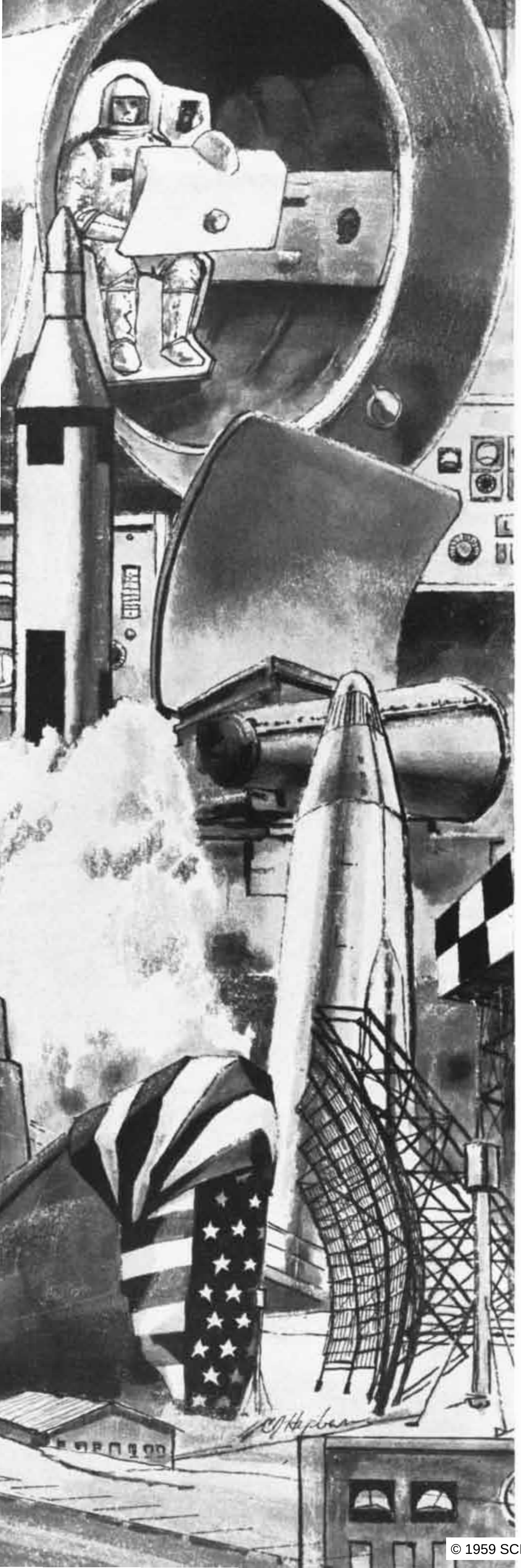

General Electric moves to provide a more effective

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Top systems management, technical talent are concentrated in Defense Systems Department with a charter geared to modern defense needs for:

- **Systems-oriented management**
- **Pinpointed authority, responsibility**
- **Full back-up resources**

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RICHARD L. SHETLER
General Manager
Defense Systems Department

Richard L. Shetler is General Manager of the Defense Systems Department. One of the Company's outstanding system managers, Mr. Shetler's experience has included responsibility for some of the longest range radar systems ever built in this country.

SYSTEMS CAPABILITY

Accelerating technological change, coupled with the increased complexity and wider variety of choice of weapons and weapons systems, has profoundly altered the defense requirements on industry.

In line with this requirement, General Electric's Defense Systems Department, headquartered in Syracuse, New York, draws together under one roof, the systems capabilities and long-range planning functions required to draw on all of General Electric to provide the total solution to specific defense problems of the military departments of the Department of Defense and other government agencies.

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The Defense Systems Department is a unique department within General Electric's Defense Electronics Division. Completely systems-oriented, DSD has no need for equipment design or fabrication facilities. While it determines the specifications to be met, the Defense Systems Department assigns design and fabrication functions to other General Electric departments or to some subcontractors among the 45,000 suppliers to General Electric.

But overall responsibility to the customer for the complete weapon or support system always remains within the Defense Systems Department. This responsibility is fulfilled through the Department's

- Systems-oriented program management
- Competent systems engineering
- Continuous program evaluation
- Efficient specification and procurement

These specific capabilities permit the Department to deliver the total system requirement on time, with the right quality, and at the specified price.

AUTHORITY, ACCOUNTABILITY

As the focal point within the Company for a specific system effort, the Defense Systems Department program manager has complete responsibility and accountability plus the authority necessary for the timely execution of the particular program.

OUTSTANDING COMPETITIVE ADVANTAGES

The Defense Systems Department offers its customers outstanding qualifications for meeting total prime and support system requirements including long-range planning and feasibility studies. For example, it has . . .

Demonstrated systems competence: Recent examples include the highly successful radio-command guidance system for the USAF's ATLAS ICBM which precisely guided the Atlas into orbit around the earth on December 18, as part of Project SCORE.

Full back-up resources: The full range of General Electric's scientific, engineering and manufacturing skills supports DSD capabilities.

For example, the Company's research and development programs, carried on by over 100 laboratories at an annual cost of 300 million dollars, provide the depth of knowledge for vital technological break-throughs.

For more information—or for a copy of brochure GED-3760, describing the Department's defense systems capabilities—write to R. L. Shetler, General Manager, Defense Systems Department, P.O. Box 457, Syracuse, New York. 226-1

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THE FIRST mobile air conditioners produced for cooling electronic equipment in jet aircraft were designed, developed and produced by the Electric Machinery & Equipment Division of American Electronics. Today nearly 1500 of these rugged, reliable ground support units are in use at U.S. military installations throughout the world. They supply conditioned air for the electronic equipment in the aircraft during ground check calibration and servicing ...they maintain exact air temperatures, under pressure, regardless of ambient temperatures or climatic conditions. Top reliability is essential.

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are but one product of the engineering talent and manufacturing know-how at the Electric Machinery & Equipment Division. Mobile power support carts for ground check of aircraft, missile and weapons systems have been designed and built which deliver as many as eight regulated power outputs of extremely close tolerances in various voltages and exact frequencies. Electronic and mechanical support equipment including towing vehicles, erectors and trailers are also manufactured by the Division. With this proven experience, this Division of AEI is prepared to meet all of your needs for ground support ...from equipment to an entire support program. Write for our new 24 page Ground Support brochure. Please address Electric Machinery & Equipment Division, American Electronics, Inc., 2112 N. Chico Ave., El Monte, California.

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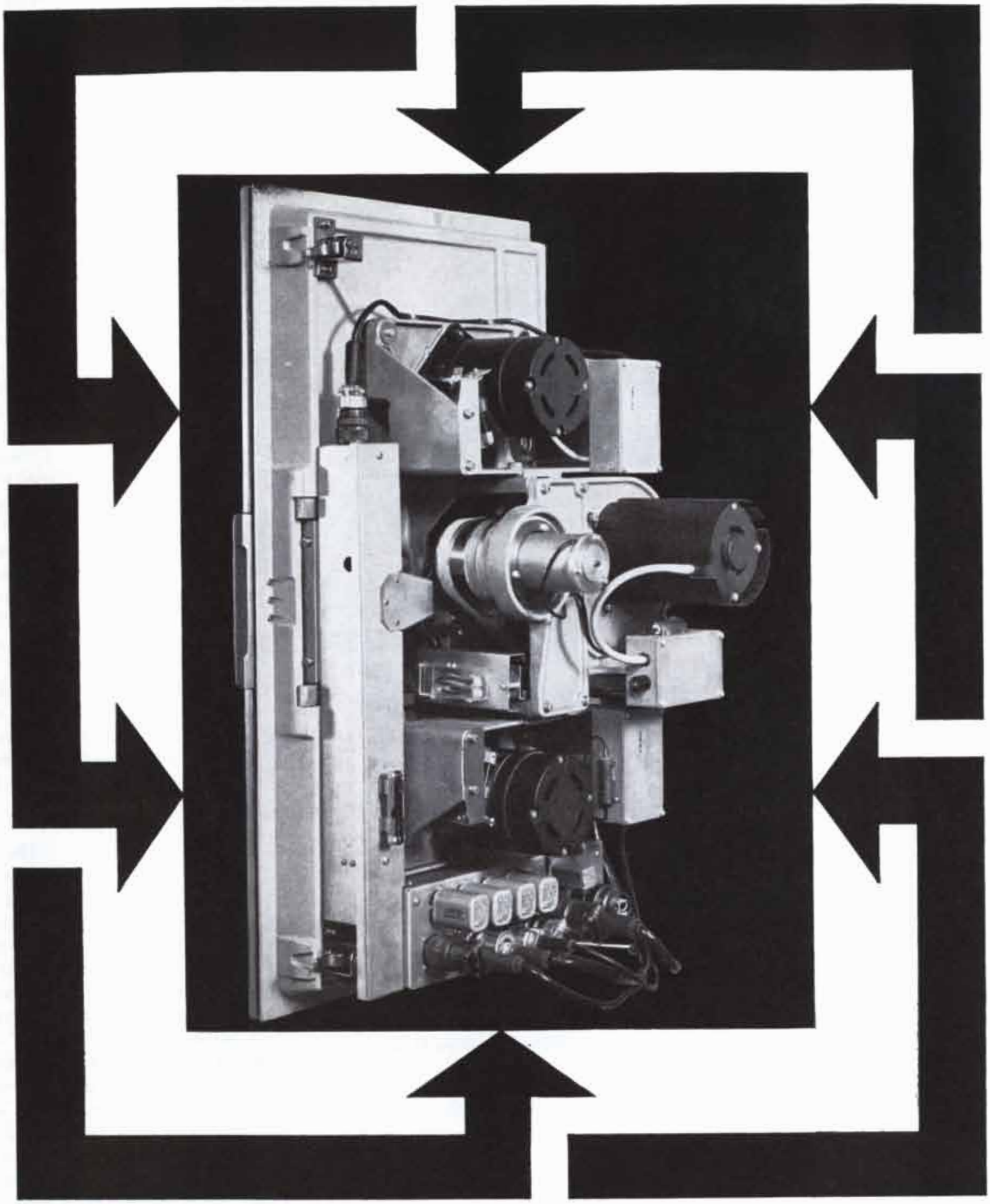

AMPEX PRECISION NOW 'LOCKED IN'

Lose the precise alignment of tape guiding and driving components in an instrumentation recorder and you lose the fine edge of designed-in performance. As alignment is lost, flutter and skew set in.

In the new Ampex FR-100B analog recorder, the possibility of misalignment—even under conditions of shock and vibration incidental to shipment or installation—is now eliminated by a framework of three precision castings with machined 'V' mating surfaces that lock all critical parts into a single rigid unit. The result: an instrumentation recorder with built-in performance and reliability that stays built in.

Other advanced features: 1. A unique electrical hold-back system keeps tape tension constant within narrow limits, reducing flutter and eliminating mechanical feedback of speed variations. 2. Modular plug-in amplifiers and power supplies give quick versatility for direct, FM carrier, PDM, and NRZ digital recording. 3. Front-panel, four-speed switching over a six-speed range from 1⅞ to 60 ips allows flexibility in selecting upper frequency limit for maximum tape economy.

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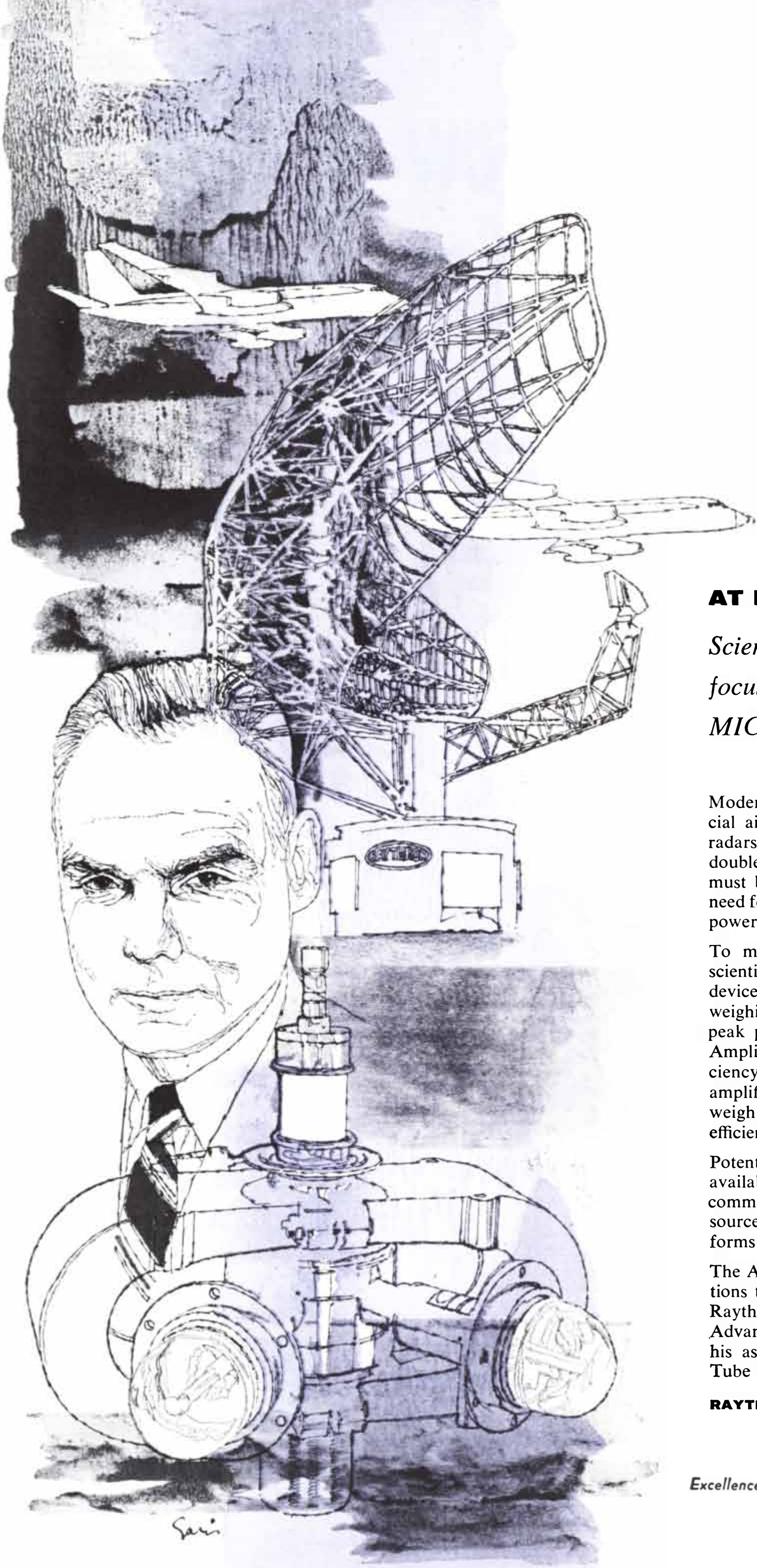
AMPEX
CORPORATION

THE AUTHORS

MAHLON B. HOAGLAND ("Nucleic Acids and Proteins") is assistant professor of medicine at the Harvard Medical School. A native of Boston, Hoagland entered the same institution in 1943, intending to become a surgeon. After being ill for two years with tuberculosis, he obtained his M. D. degree in 1948. "As a recuperative interlude," he reports, "I began doing research at Harvard's Huntington Memorial Hospital under Joseph C. Aub. I intended to return to medicine, but very soon became deeply absorbed in a study of the carcinogenic properties of beryllium and decided to stay in biochemical research." Hoagland became interested in the problem of how cells synthesize materials, and spent a year with K. U. Linderstrom-Lang in Copenhagen and another year with Fritz A. Lipmann at Massachusetts General Hospital, studying protein structure and biological energy-transfer mechanisms. Then he returned to the Huntington Hospital, where he engaged in a study of protein biosynthesis with Paul C. Zamecnik.

GIOVANNI LILLIU ("The Proto-Castles of Sardinia") is professor of Sardinian antiquities and director of the Institute of Sardinian Antiquities and Sardinian Studies at the University of Cagliari in Sardinia. He is also head of the faculty of letters at the University. He was born in Sardinia 45 years ago and took his degrees in letters and archaeology at the Italian School of Rome. His archaeological research has covered all aspects of his native island's ancient civilization, though he has specialized in the stone towers he describes in his article. He is director of the magazine *Studi Sardi* and has for 10 years been inspector of antiquities of the island. In May of this year he directed an Italian archaeological expedition on the Spanish island of Majorca that started the excavation of a village of the Bronze and Iron ages.

VINCENT P. DOLE ("Body Fat") has since 1952 been a member of the Rockefeller Institute and a senior physician in the Rockefeller Institute Hospital. He was born in Chicago in 1913 and took his M. D. degree at Harvard Medical School in 1939. After finishing his internship in July, 1940, Dole joined the laboratory of Donald D. van Slyke at the Rockefeller Institute, studying blood



AT RAYTHEON –

Scientific imagination focuses on MICROWAVE POWER

Modern defensive systems and commercial air traffic control networks demand radars of ever-increasing range. Yet to double its range, a radar's output power must be increased sixteen-fold. Thus the need for microwave amplifiers of immense power and high efficiency.

To meet these requirements, Raytheon scientists developed a unique microwave device – the Amplitron. Typical models weighing 90 lbs. generate five million watts peak power – 15 kilowatts average. The Amplitron achieves unprecedented efficiency of as high as 80%. Conventional amplifiers of comparable output would weigh almost 1,000 lbs., operate at 40% efficiency.

Potentially, 100 megawatts peak power is available from the Amplitron. Uses: space communication, super-power radar, energy sources to hold aloft "sky stations"–platforms situated miles above the earth.

The Amplitron is typical of the contributions to scientific progress made by such Raytheon men as W. C. Brown, Manager, Advanced Development Laboratory and his associates at Microwave and Power Tube Division.

RAYTHEON COMPANY, Waltham, Mass.

Excellence in Electronics RAYTHEON

proteins and shock. He continued this work under van Slyke during World War II as a member of the Naval Medical Research Unit, and learned to study diseases in terms of biochemical changes in blood and in tissues. He believes that obesity can be described in chemical terms and that biochemists are not far from that goal. Dole has studied patients with high blood pressure as well as those suffering from obesity, and at present he is investigating the circulation of the fatty acids in the body in the hope of finding the answer to the problem of obesity.

BART J. BOK ("The Arms of the Galaxy") is director of the Mount Stromlo Observatory in Australia and professor of astronomy at the Australian National University. A native of Hoorn in the Netherlands, he was educated at the universities of Leiden and Groningen. He came to Harvard University in 1929 as a fellow in astronomy and joined the faculty there in 1933. When he left in 1957 to go to Australia, he was Robert Wheeler Willson Professor of Astronomy. His major interest has always been the structure of the Milky Way. The center of our galaxy is best seen from the Southern Hemisphere, and Bok was in charge of installing the Baker-Schmidt telescope at Harvard's Boyden Station in South Africa. He studied the southern skies there in 1950 and 1951.

LEJAREN A. HILLER, JR., ("Computer Music") is a chemist and composer who holds the position of assistant professor of music at the University of Illinois. He was born in New York City in 1924 and studied at Princeton University, where he received his Ph.D. in chemistry in 1947. While there he also studied electrical engineering, and took courses in composition with Milton Babbitt and Roger Sessions. He did chemical research for E. I. du Pont de Nemours at Waynesboro, Va., from 1947 until 1952, when he joined the chemistry faculty at the University of Illinois. In his research there he employed the ILLIAC computer and, since he had never stopped composing music, he began to think that a computer could be used to study musical problems. By 1958 he had acquired an M.A. in music and switched to his present post with the School of Music, where he teaches musical acoustics and experimental composition. He is now setting up a laboratory for electronic music.

MARCUS REINER ("The Flow of Matter") has since 1949 been professor of applied mechanics and head of the

Israel Institute of Technology. He was born in Austria and holds the degree of doctor of technical sciences from the Technische Hochschule of Vienna. Before World War I he designed bridges in Austria, and during and after the war he headed a special Austrian army unit for the reconstruction of steel bridges. In 1922 he joined the Department of Public Works of the British Government in Palestine, and devoted two decades to the design of reinforced-concrete structures. He visited the U. S. in 1928 and again as a research professor at Lafayette College and a lecturer at Princeton University in 1931. He made a third visit to the U. S. this year. He has published many technical papers in structural engineering, hydrodynamics, theory of elasticity, flow of homogeneous liquids and air, and applied mathematics.

KNUT SCHMIDT-NIELSEN ("The Physiology of the Camel") is professor of physiology in the department of zoology at Duke University. He studied the camel when he led an expedition of four scientists to the Sahara Desert in 1953 and 1954, while on a Guggenheim fellowship. He has long been interested in the water metabolism of animals, as indicated by two previous articles in SCIENTIFIC AMERICAN: one ("The Desert Rat") in collaboration with his wife in July, 1953, and the second ("Salt Glands") in January of this year. He was born in Norway and holds degrees from the University of Copenhagen. In addition to his work in physiology, he has done research in biochemistry and analytical chemistry. He studied for four years in Copenhagen under August Krogh, Nobel laureate in physiology, and married Krogh's daughter. The Schmidt-Nielsens came to this country in 1946. They worked at Swarthmore College, Stanford University and the University of Cincinnati before they went to Duke in 1952.

JOHN TYLER BONNER ("Differentiation in Social Amoebae") is professor of biology at Princeton University. He was born in New York City in 1920 and took his degrees at Harvard University. During World War II he did research in the Aero Medical Laboratory at Wright Field, and afterward was a junior fellow at Harvard. Bonner joined the faculty at Princeton in 1947. He started his research on social amoebae as an undergraduate under William H. Weston, and has been studying these life forms ever since. This is his fifth article for SCIENTIFIC AMERICAN.

The legendary Firebird, the Phoenix, rose young and strong again and again from flames . . . This is the new Norton Firebird — symbol for the exciting new fused materials made in Norton's electric furnaces.

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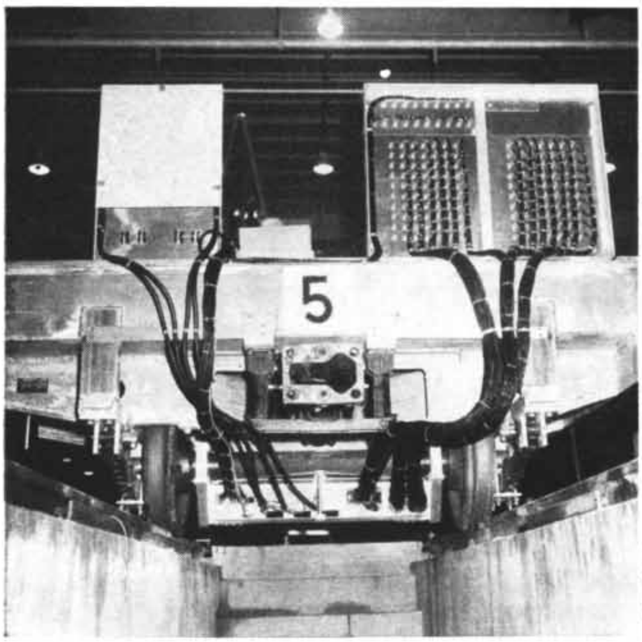

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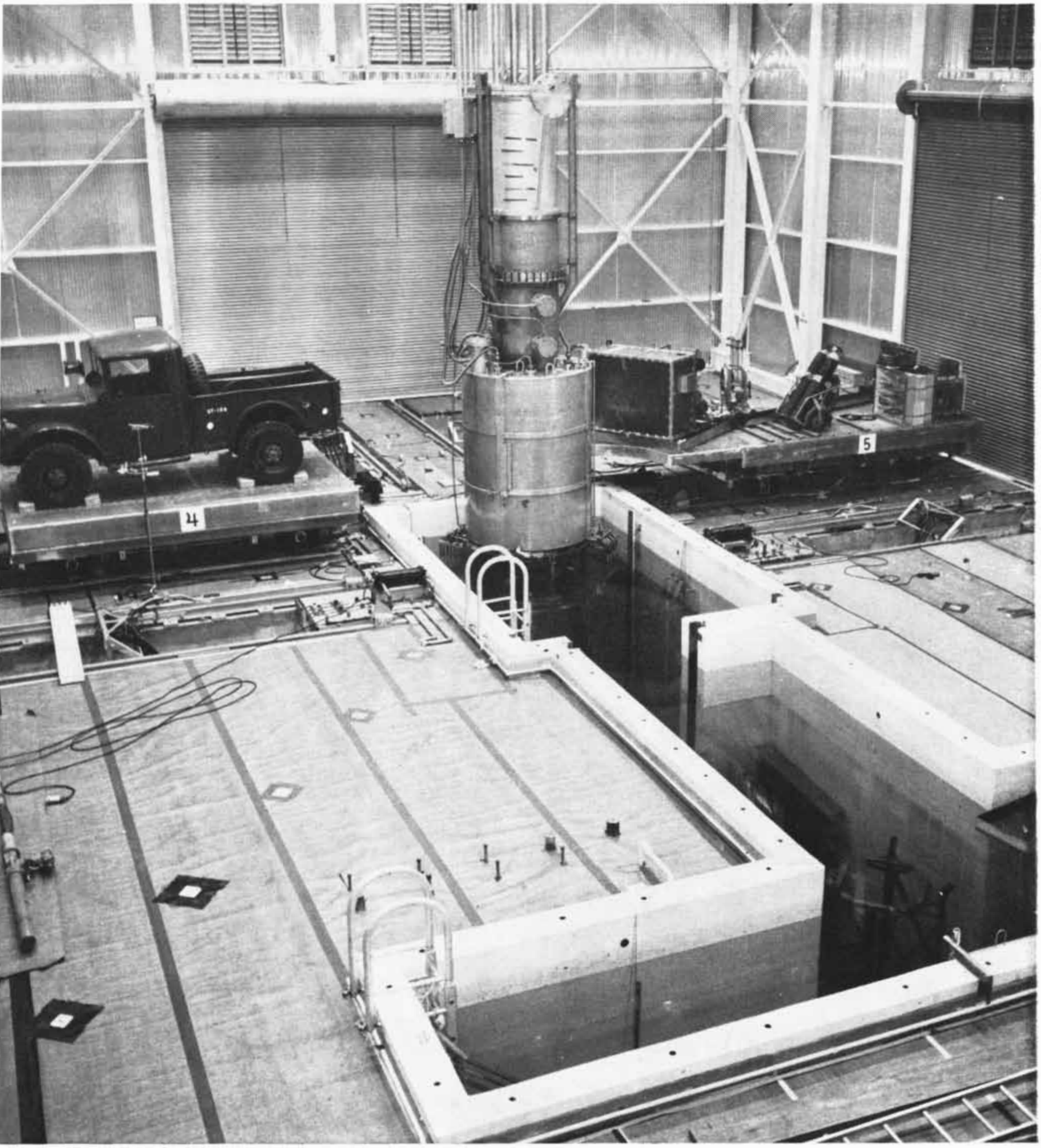

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Jean Baptiste Fourier...on mathematical analysis

"Its chief attribute is clarity; it has no symbols to express confused ideas. It brings together the most diverse phenomena and discovers hidden conformities which unite them. If matter evades us, such as the air and light, because of its extreme thinness, if objects are located far from us in the immensity of space, if man wishes to understand the performance of the heavens for the successive periods which separate a large number of centuries, if the forces of gravity and of heat be at work in the interior of a solid globe at depths which will be forever inaccessible, mathematical analysis can still grasp the laws of these phenomena. It renders them present and measurable and seems to be a faculty of the human reason destined to make up for the brevity of life and for the imperfection of the senses; and what is more remarkable still, it follows the same method in the study of all phenomena; it interprets man in the same language, in some measure to affirm the unity and simplicity of the plan of the universe and to make still more manifest the immutable order which rules all natural matter."

—*Théorie analytique de la chaleur,* 1822.

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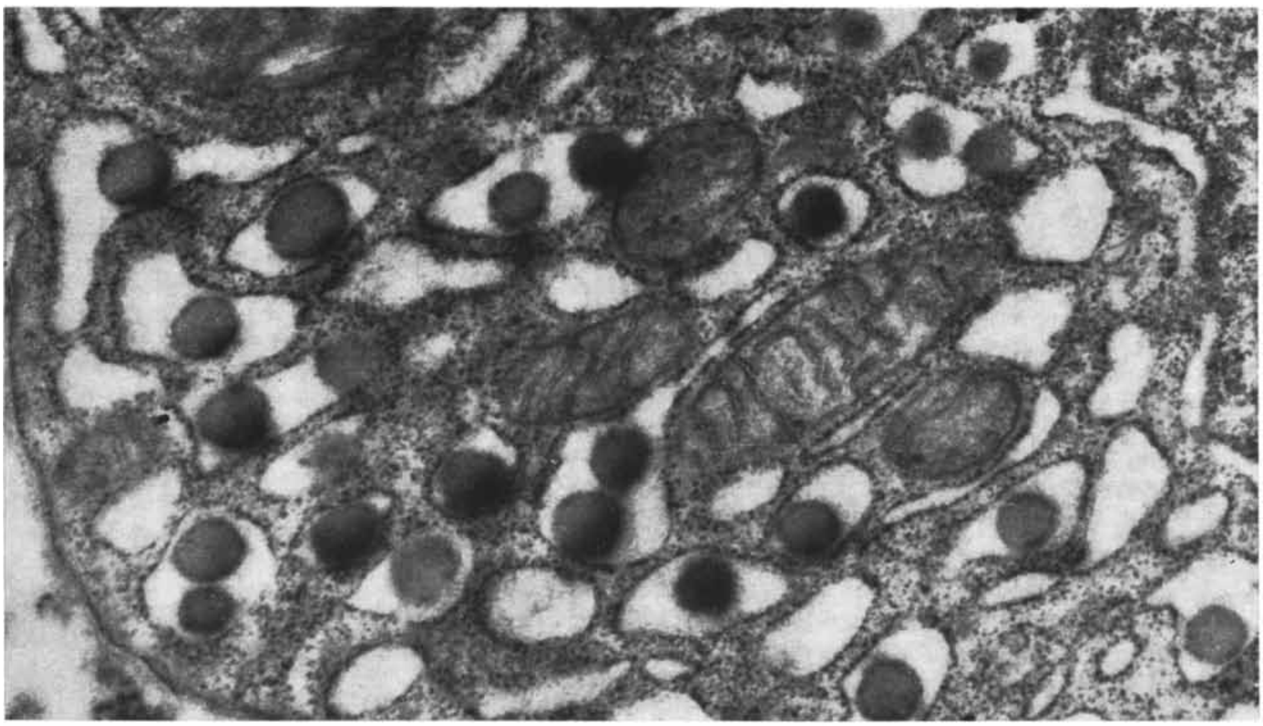
Nucleic Acids and Proteins

The nucleic acid molecules inherited by the living cell bear the plan of all the cell's protein molecules. It now appears that another kind of nucleic acid plays a key role in translating the plan into protein

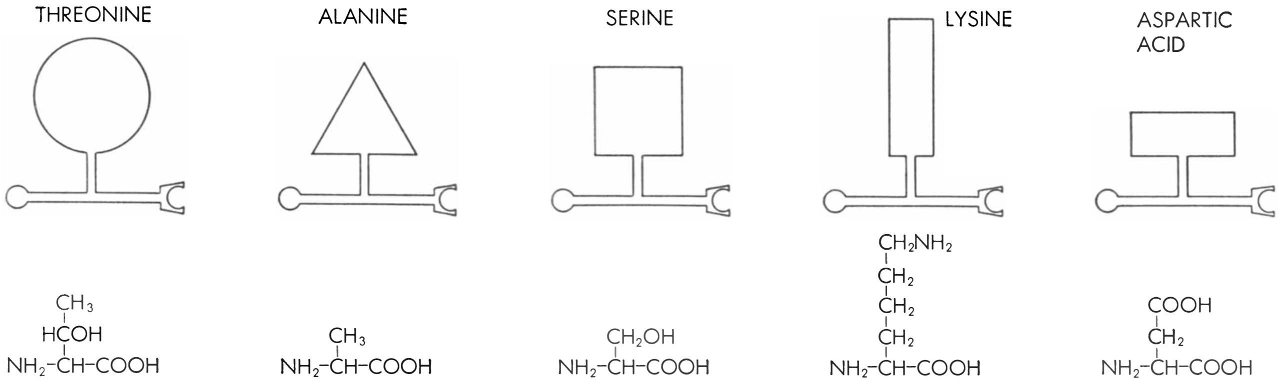
by Mahlon B. Hoagland

The blink of an eye, the beat of a heart, the ordered advance from embryo to adult—in short, all the simple and the complex workings of living matter—are the result of the coordinated interplay of many hundreds of different protein molecules. Proteins are the substratum of our form and function; of what we are and what we do. Our living machinery—skin, muscle, bone, blood vessels, internal organs—is made of protein. Enzymes, the cogs on which the machinery within each cell turns, are protein molecules. The individuality of each living being is the manifestation of the uniqueness of its own particular array of protein molecules. It is small wonder that the central problem of biochemistry today is: How do organisms make their protein?

As readers of SCIENTIFIC AMERICAN



SYNTHESIS OF PROTEIN is dramatically depicted in this electron micrograph, which enlarges some 39,000 diameters the interior of a cell from the pancreas of a guinea pig. The large dark bodies are protein (in this case digestive enzymes) that the cell has made. The lighter areas surrounding them are sections of a network of canals. The small dark particles are ribosomes. The four large gray bodies at right center are mitochondria. The micrograph was made by George E. Palade of the Rockefeller Institute.



FIVE AMINO ACIDS, of the 20 that exist, are abstractly represented by the building blocks at the top. Below each block is a symbolic ball-and-socket device that works like a plastic "poppet" bead. At bottom are the chemical formulae of the amino acids.

are aware, a growing army of investigators has attacked the problem over the past decade, and a plausible mechanism of protein synthesis has begun to emerge. Some steps in the complex sequence of chemical events are still hypothetical, the products of imaginative theorizing. But experiment is steadily filling in the theoretical outline. Even if (as is likely) the current ideas should turn out to be wrong in some particulars, they will have been invaluable as a guide to further research.

Recently my colleagues and I uncovered a series of reactions that appears to help bridge a serious gap in the sequence. In this article I shall try to show how they fit into the total picture of protein synthesis.

In broadest terms that picture is as follows: The master plan, which tells an organism how many and what kinds of proteins to build, is contained in the substance of its genes: deoxyribonucleic acid (DNA). Passed down from generation to generation through the vast reaches of evolution, specific giant molecules of DNA maintain the continuity of living matter, ensuring that an elephant continues to be an elephant and a mosquito a mosquito. A second type of large molecule, ribonucleic acid (RNA), carries the instructions from the genes to the building sites, where it directs the assembly of proteins.

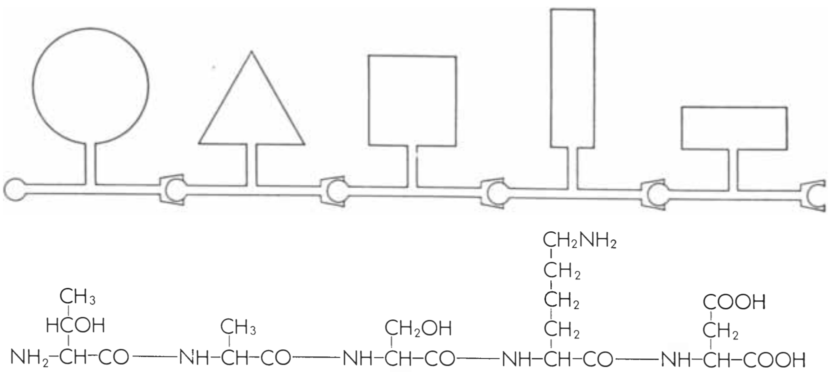
The factory in which all these operations are carried out is the individual living cell. Electron-microscope studies have shown that cells are not formless blobs of protoplasm, but have an intricate anatomy [*see illustration on preceding page*]. In the cytoplasm (that part of the cell which lies outside the nucleus) there is a fine network of membranous canals lined with small, dense particles called ribosomes. As their name implies, ribosomes consist largely of RNA, and they are known to be the end of the assembly line, where protein molecules are actually fabricated. The beginning of the line is in the nucleus, which contains all of the cell's DNA. Another group of cytoplasmic bodies, known as mitochondria, provides energy for the manufacturing process in the form of the substance adenosine triphosphate (ATP).

Let us examine the elements of this microscopic chemical plant in greater detail. Protein molecules, the end product, are long chains made up of smaller molecules, the amino acids. There are 20 different amino acids, all having an identical group of atoms that forms a sort of backbone, but differing in the side groups attached to it. The backbones can join end to end by means of a linkage known as the peptide bond. We can think of amino acids as "poppet" beads of different shapes that can be snapped together to make a variety of strings [*see illustrations above*]. A protein molecule may contain 100 or more amino acid units. What distinguishes one protein molecule from another, giving each its marvelous uniqueness, is the number and kind of its amino acid units and the order in which they are strung together. We might think of an organism as a book whose immutable form and content are uniquely determined by the organized accumulation of sentences (proteins) it contains, this in turn depending on the number, kind and order of letters (amino acids) in each sentence. Thus in trying to explain how genes determine the way specific proteins are made we must look for a mechanism that inserts the right amino acids in just the right places in the string.

Turning to DNA, the genetic material, we find another chain molecule, but one made up of only four different units. These units, called nucleotides, also have a common backbone structure that can join chemically end to end. Attached to the backbones are any of four different side groups, which in this case have an added feature. The spatial arrangement of the side-group atoms is such that they form two complementary pairs. One member of each pair can nest with the other. For diagrammatic purposes the nucleotides can be represented as blocks [*see illustration on opposite page*]. As J. D. Watson, now of Harvard University, and F. H. C. Crick of the University of Cambridge first showed, DNA molecules are double-stranded structures. The nucleotides of one strand face those of the other in complementary pairs, with the backbones outermost [*see top illustration on page 58*]. When a cell divides, the two strands of its DNA molecule separate and a new complementary chain builds up on each one. Hence for every original molecule there are now two, identical with the original, one going to each of the daughter cells. Because only one nucleotide can fit at a given position anywhere in either chain, the duplication is highly accurate.

In all these pairing reactions the materials must be brought close enough together for chemical bonds to form. Enzymes generally perform this function in cells. Arthur Kornberg and his colleagues, now at Stanford University, have in fact found enzymes that will synthesize new chains of DNA, provided an already formed chain is present. For this work Kornberg has just shared the 1959 Nobel prize in physiology and medicine.

In nature DNA molecules are helical strands, rather than the straight chains shown in the illustration. But since the



AMINO ACIDS ARE JOINED in a protein chain. At top the shapes are joined ball to socket. The formulae at bottom show the actual peptide linkages, between COOH and NH_2.

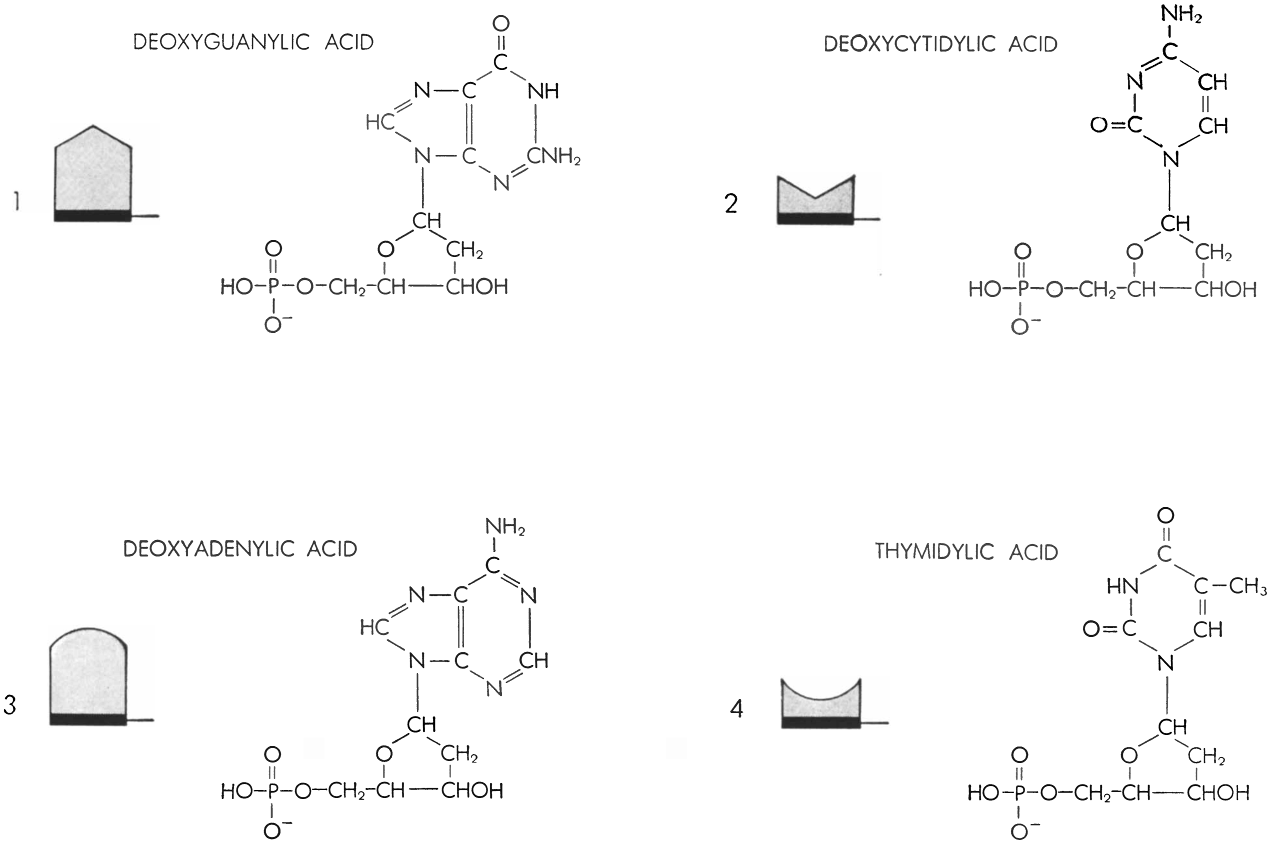
helical structure does not affect our argument, we will omit it for the sake of simplicity.

RNA is very similar to DNA. It too is made up of four repeating units with a common backbone, and two of its side units are complements of the other two. The backbone is different, having an extra hydroxyl (OH) group which is indicated in our diagrams as a small knob. Three of the nucleotides are the same as those of DNA, and the fourth, though different, has essentially the same pairing properties and hence is given the same block shape.

From a number of brilliant investigations over the past few years, certain facts about DNA have been established. First, we know that DNA, by itself, transmits genetic information in organisms that contain it. (In a few organisms that do not have DNA this function seems to be performed by RNA. No living form lacks both nucleic acids.) Second, the genetic information-content of DNA is arranged in a linear order along the molecule. Third, a mutation, which appears to be a change in a small segment of the DNA chain (perhaps the deletion or substitution of a single nucleotide), results in a small change in the amino acid composition of a single protein. Thus it seems highly probable that the specific order of nucleotides in DNA molecules determines in a fairly direct way the specific order of amino acids in protein.

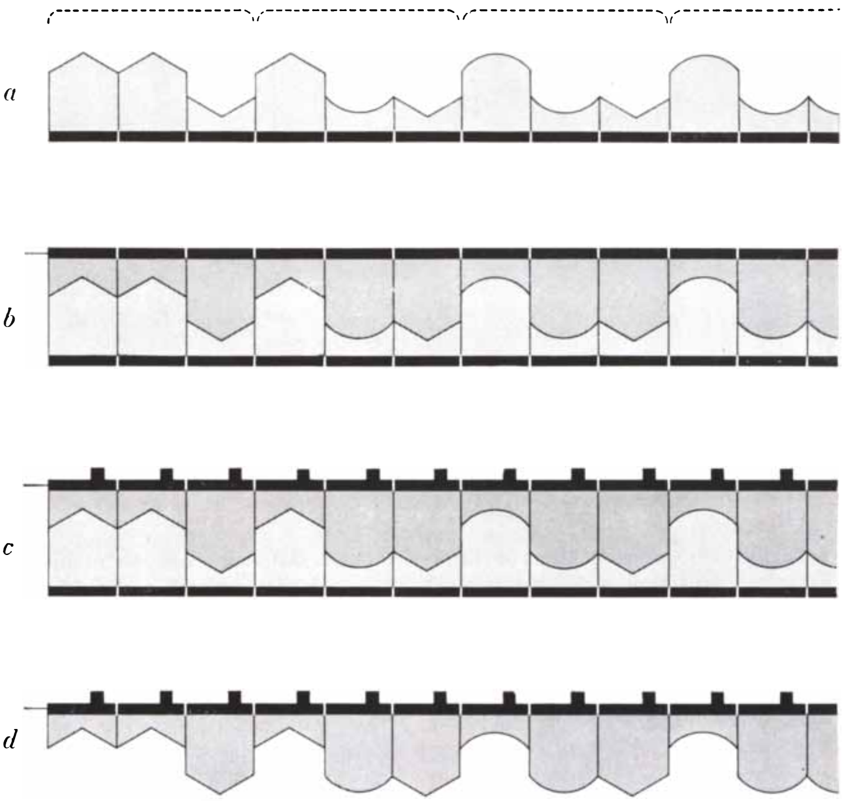
It has also been found, however, that cells from which the nucleus, and hence the DNA, has been removed can continue to synthesize proteins for a while. Indeed, most protein synthesis takes place in the ribosomes, which, since they are located in the cytoplasm, are physically separate from the DNA but contain some 80 per cent of the cell's RNA. Isolated ribosomes can even be made to build protein in a test tube, by fortifying them with certain enzymes from the soluble portion of the cell in which they are normally bathed.

It would appear, therefore, that the linear genetic information in DNA is first translated into linear information in the closely similar RNA molecules,



FOUR NUCLEOTIDES that make up deoxyribonucleic acid (DNA) are similarly represented by building blocks. The black section at bottom of each block denotes backbone structure by which nucleotides are joined. At right of blocks are their formulae.

and that RNA directly controls protein synthesis in the ribosomes. How might all this be accomplished?



SYNTHESIS OF DNA begins with a single strand of the normally two-stranded molecule (*a*). Nucleotides then assemble themselves along this strand to reconstitute the other (*b*). Presumably by a similar process (*c*) a strand of DNA can assemble a strand of ribonucleic acid, or RNA (*d*). The knobs along the RNA backbone represent hydroxyl (OH) groups.

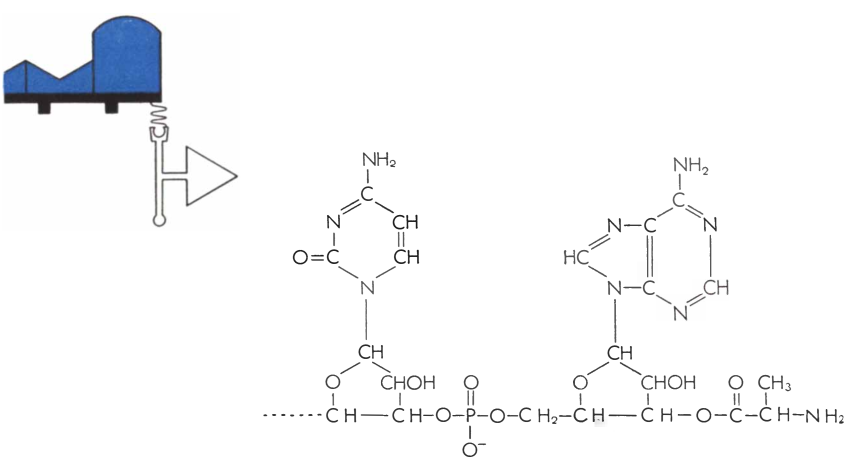
First of all, we must explain how the four component units of DNA (and RNA) can determine the order of 20 units in protein molecules. One ingenious solution has been suggested by Crick, J. S. Griffith and L. E. Orgel of the University of Cambridge. Taking the nucleotide blocks in groups of three, they were able to form 20, and only 20, distinct and nonoverlapping sequences [*see illustration on opposite page*]. (To grasp what is meant by overlapping, one may consider the digit sequences 121 and 213. Joined together, they are 121213. The third, fourth and fifth digits are also 121, and hence could be confused with the opening triplet. Among the 20 nucleotide triplets no such ambiguities can occur.) Thus from the magic number four of DNA it is possible to code the magic number 20 for the beads DNA must arrange. Each triplet of nucleotides corresponds to one of the 20 different amino acids.

Linking the nucleotide triplets end to end in any desired order will produce a chain coded for any specified sequence of the 20 beads. Another arrangement of the triplets would give a second DNA molecule coded for another bead sequence, and so on. Every organism presumably contains as many different DNA molecules as it has unique proteins. (Or, alternatively, if the DNA is a single long chain, it would have the proteins coded consecutively along its length.) The DNA may be thought of as master dies or templates from which the proteins are manufactured. In the nucleus the templates are stored as bundles of double complementary strands. In cell division the double strands separate and each half assembles on itself a new complementary partner.

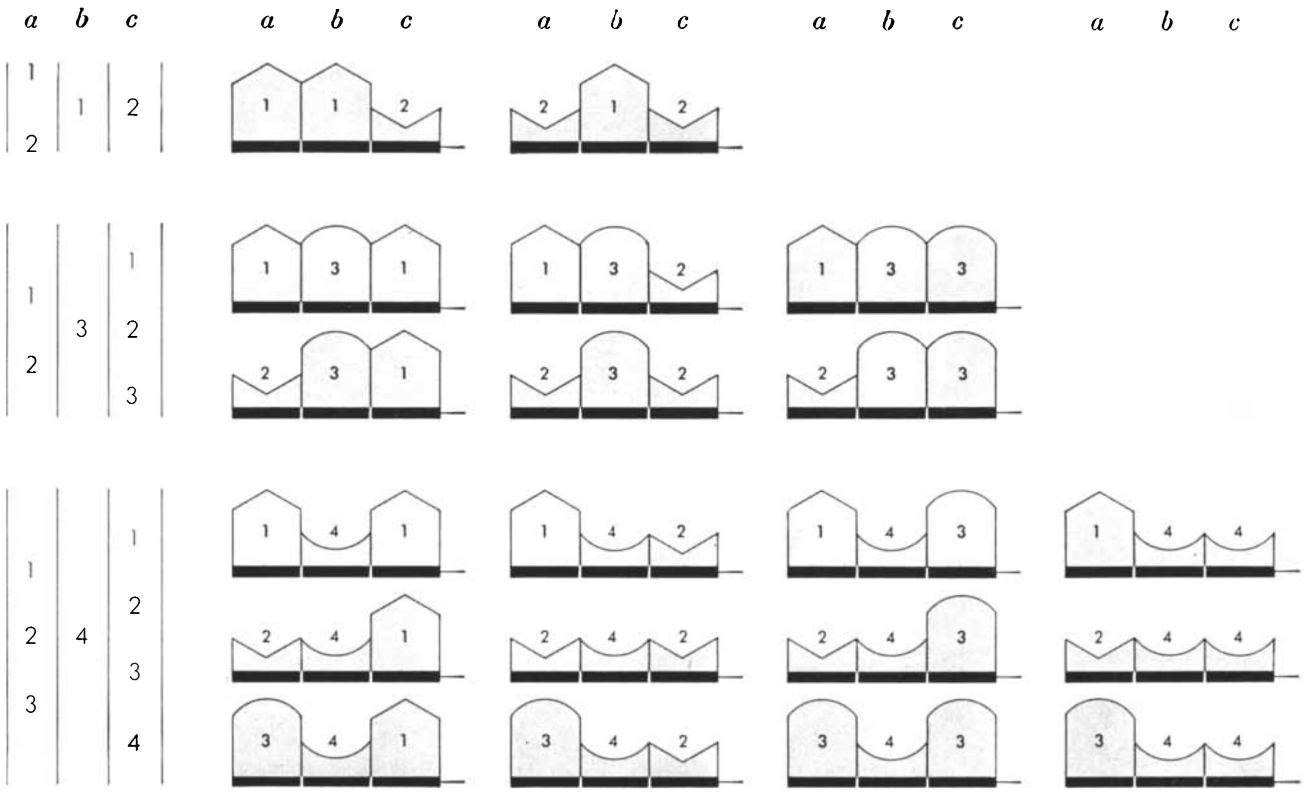
It is now a simple matter to envision each strand of DNA laying down along its length a series of RNA nucleotides, creating a set of working dies identically coded for the amino acid beads. The master DNA-templates are thus preserved as a stable source of genetic information. Although the replication of RNA from DNA in such a manner is pure speculation at the moment, evidence is growing that RNA is indeed synthesized in the nucleus. Furthermore, although ribosomes can make protein in the absence of the nucleus, once the RNA in the ribosomes is used up or artificially destroyed, the process stops. Recent experiments indicate that putting back the nucleus restores the cell's ability to synthesize protein. Apparently the nucleus rebuilds the ribosomes.

Assume, then, the RNA chains have been assembled, carrying the code for the amino acid sequences. Now we come to an embarrassing impasse in the theory. How do the amino acid beads "recognize" their appropriate triplets on the RNA surface? We can discern no structural or chemical correspondence between the ordered triplets and the 20 beads. The information is there but the mechanism for using it appears to be lacking.

Recently a group in our laboratory at



TRANSFER RNA is a third species of nucleic acid that appears to convey amino acids to "template" RNA. Its molecules end in the nucleotide adenylic acid, which forms a high-energy bond with an amino acid. At bottom right is the formula of the last two nucleotides of transfer RNA with the amino acid alanine attached. At top left is corresponding symbol.



TRIPLETS OF NUCLEOTIDES along a strand of DNA or RNA possibly represent a code for the amino acids. Each triplet is a combination of three of the four nucleotides. Only these 20 triplets can be put together without ambiguity due to overlapping. At left is a shorthand notation for the 20 combinations. The two nonambiguous triplets that can be assembled from two nucleotides are at top; the six that can be assembled from three nucleotides, in middle; the 12 that can be made from four nucleotides, at bottom.

Harvard University stumbled on some exciting new phenomena that seem to resolve the difficulty and open the way to probing much more deeply into the protein-building machinery. Paul C. Zamecnik, Mary Louise Stephenson, Jesse F. Scott and I discovered quite by accident that amino acids attach to RNA *before* they are linked together to form protein. To our surprise the RNA that binds the amino acids turned out to be not the plentiful template material of the ribosomes, but a small chemical fraction of the soluble part of the cytoplasm. This RNA, consisting of relatively small molecules, was called "soluble RNA." Now it is becoming known as "transfer RNA" because of its role in protein synthesis, which further experiments soon revealed. With the invaluable assistance of Liselotte I. Hecht, who joined us at this time, we followed up the lead and found that before amino acids appear in protein each amino acid attaches to a specific location on the soluble RNA molecules.

The reaction takes place in the soluble fraction of the cell that bathes the ribosomes, and will also proceed in the test tube quite independently of ribosomes. It requires energy, which it obtains from the universal energy source in cells: adenosine triphosphate (ATP). Once the compounds of RNA and amino acids are formed, they can be isolated from the tissues and purified. If they are then incubated with fresh ribosomes, the amino acids rapidly disappear from the transfer RNA, enter the ribosomes and condense with other amino acids to form new protein.

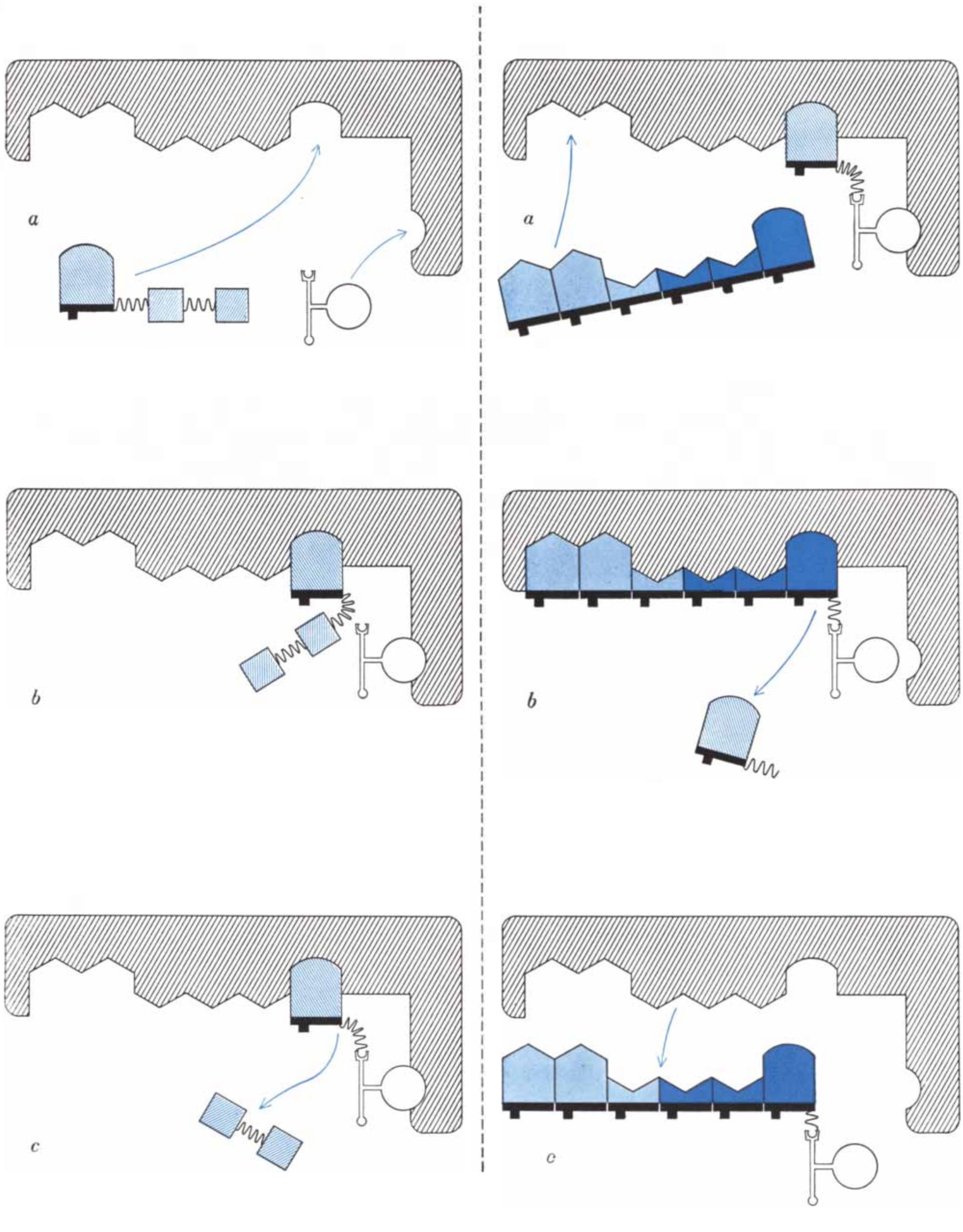
Workers in a great many laboratories throughout the world have since studied transfer RNA and its reactions. It has been found in all types of cells, from those of bacteria to those of mammals. We now know that there is a separate transfer RNA molecule for each amino acid, and that the amino acid attaches to the end of the nucleotide chain.

It looks very much as if these observations contain the key to the coding mechanism. The simplest interpretation of the data is that, by attaching to transfer RNA, amino acids receive an identity that can be recognized by the RNA templates in the ribosomes. Presumably some of the nucleotides in the transfer molecule fit against a complementary set on the template chain. In this way transfer RNA would link each amino acid to its own specific triplet.

As these ideas were percolating through our heads we learned that Crick had anticipated them on theoretical grounds. He had suggested that amino acids might attach to an "adaptor" molecule consisting of a triplet of nucleotides complementary to the appropriate group in the template. Here was one of those rare and exciting moments when theory and experiment snapped into soul-satisfying harmony. Although transfer RNA is not a triplet (it consists of 50 to 100 nucleotides), it seems highly probable that it contains a few nucleotides whose order determines on the one hand the amino acid with which it reacts and on the other the place where it fits on the RNA template of the ribosome.

Perhaps the reader is wondering why, if an amino acid can join with a triplet in the transfer molecule, it cannot hook directly to a triplet in the large RNA chain. The answer is that the transfer molecule has a free end that serves as a point of attachment. In template RNA the triplets have no free ends.

As we have said, the joining of an



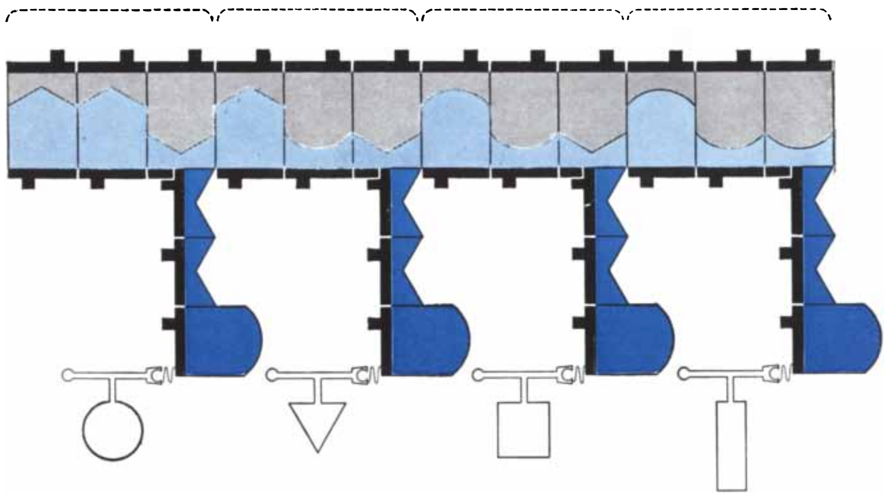
TRANSFER RNA AND AN AMINO ACID are thought to be joined by these steps. In steps *a* and *b* at left an amino acid (*bottom right*) and a molecule of adenosine triphosphate, or ATP (*bottom left*), take their places at appropriate points on an enzyme molecule (*hatched structure*). In *c* the phosphate groups of ATP (*squares*) drop off and the remaining adenylic acid is joined to the amino acid by a high-energy bond (*symbolized by a spring*). The same enzyme is also shaped to fit a specific molecule of transfer RNA. At right the molecule (shortened for diagrammatic purposes) joins the enzyme (*a*), displacing the adenylic acid from ATP and forming a bond with the amino acid (*b*). The complex of transfer RNA and amino acid then drops away from the enzyme (*c*).

amino acid to transfer RNA requires energy: the amino acid must be "activated" before it can react. Furthermore it must retain its energy for the eventual linkage in the protein molecule. Amino acids can no more snap together spontaneously than can poppet beads. They both need a push.

The activation mechanism, which was discovered independently by the author and by Paul Berg at Washington University in Saint Louis several years ago, is a reaction between the amino acid and an energy-rich ATP molecule. ATP consists of one of the RNA nucleotides, called adenylic acid, with a pair of phosphate groups attached. It is the phosphate bond that contains the energy of activation. In the activation reaction the amino acid replaces the two phosphate groups, the energetic bond remaining.

As always, in order for the reaction to take place the substances must be brought close together in the proper spatial relationship. This is accomplished by means of an enzyme that acts as a mechanical jig, holding the amino acid and ATP in place [*see illustration on opposite page*]. There are 20 different enzymes, each shaped to accommodate a specific amino acid. When the reacting molecules are located in the jig, the amino acid joins the adenylic acid and the phosphate groups drop away. The combination remains fixed in the enzyme matrix.

Berg and other workers have proved that the same enzymes that activate amino acids also catalyze their reactions with transfer RNA. Therefore we can assume that each enzyme contains a section shaped to fit the specific nucleotide triplet corresponding to the amino acid it holds. We do not know where the triplet is located along the transfer RNA molecule, but we do know that all such molecules terminate in the same three groups: two cytidylic acids and, at the end, an adenylic acid. For the sake of convenience our diagrams show the identifying triplet attached directly to the terminal group of three nucleotides [*see right side of illustration on opposite page*]. Actually they may be some distance apart on the string.



FINAL STEP IN ASSEMBLY of protein molecule may be the attachment of complexes of transfer RNA and amino acids to the template-RNA chain. Each identifying triplet in the transfer RNA finds its unique complement on the template. The terminal triplets are at right angles to the template, bringing amino acids close enough to snap together.

In any event it is not hard to visualize the sequence of chemical events. An enzyme holding a particular activated amino acid has a site adapted to a specific nucleotide triplet. When a transfer RNA molecule containing that triplet encounters the enzyme, it fastens onto the jig. This brings the end of the RNA chain into contact with the amino acid. The terminal adenylic acid on the chain replaces the adenylic acid of the activating ATP, and the amino acid is hooked onto its proper transfer agent. Now the whole combination drops away and the enzyme is free to repeat the cycle.

When attached to transfer RNA, the amino acid is still in an activated state. This is due to the influence of the hydroxyl group on the RNA backbone, which DNA does not have. Thus only RNA, and only the end of an RNA chain, can qualify as an intermediate carrier of activated amino acids.

With the help of 20 different enzymes each amino acid is made recognizable to the template by linking it to a specific triplet of nucleotides on the transfer RNA. We suggest that this triplet locates itself on a complementary triplet in the ribosomal RNA [*see illustration above*]. In hooking on, the terminal group of the transfer RNA presumably bends at right angles, forming extension arms that bring the amino acids close together. Finally, the activated amino acids snap together to make a protein molecule. Then the transfer RNA drops off the template and recycles.

Amino acid activation, attachment of amino acids to transfer RNA and the final building of protein in ribosomes are well-established biological facts. Our model attempts to fill the gaps between these steps without violating chemistry. It is a hypothesis. As such it is valueless unless it suggests further lines of investigation, and this it does. For one thing, the model predicts that somewhere in the chain of nucleotides of transfer RNA there is a code determining which amino acid becomes attached to it. In many laboratories research workers are trying to isolate pure types of transfer RNA from the natural mixture. Then they will take the molecules apart, nucleotide by nucleotide, to determine whether the code indeed exists and, if so, where it is. Transfer RNA may well be the Rosetta Stone that will decipher the language of the gene!

If transfer RNA is an adaptor, at least part of it (and that part bearing the code) must accompany the amino acid into the ribosomes during the course of protein synthesis. By tagging the molecules of transfer RNA with radioactive atoms we can follow their fate. Preliminary studies in our laboratory show that at least the terminal nucleotides of transfer RNA molecules do accompany the amino acids. By labeling other parts of the molecule we hope to get more information on this important question. The model also predicts that RNA of the ribosomes can be synthesized using DNA as a template. Many laboratories are attempting to see if this actually happens.

After such matters are settled there will remain still deeper questions. How does the cell administer the over-all activity of its complex machinery? What turns this wonderful chemical factory on and off at exactly the right times in the life of the organism? How does the control process go astray in malignant cells? It is problems like these that make biochemistry one of the great adventures of our era.

OLD AND NEW CASTLES dominate the Sardinian plain near Barumini. Atop the conical hill in the background are the ruins of a medieval castle. In the foreground, with its village around it, is the Su Nuraxi nuraghe, which dates from the 11th century B.C.

SU NURAXI NURAGHE is seen from the air. One of the finest examples of Sardinian proto-castle, it was besieged and destroyed by the Carthaginians in the sixth century B.C., some three centuries before the Roman conquest. Su Nuraxi was excavated in 1951.

The Proto-Castles of Sardinia

During the second and first millennia B.C. the inhabitants of Sardinia built thousands of conical stone towers. Called nuraghi, they show the influence of early Greek civilization

by Giovanni Lilliu

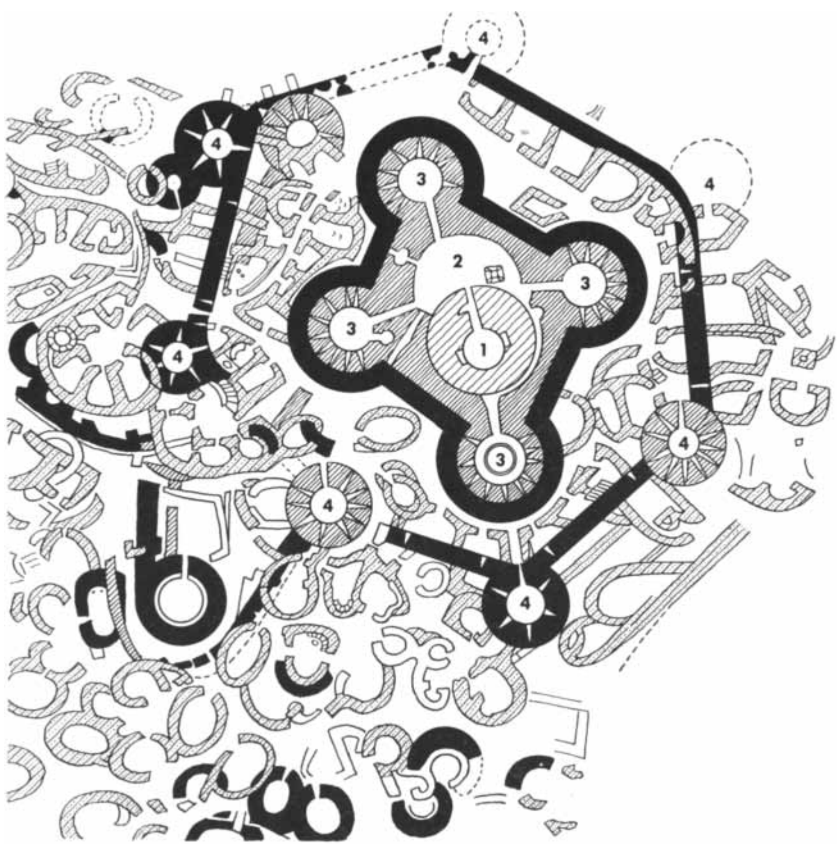
On the island of Sardinia, off the west coast of Italy, stand the ruins of some 6,500 stone towers. These massive truncated cones, built without mortar, once stood 50 to 65 feet high and were held erect by the sheer weight of their roughly shaped stones. Laid in circular tiers and stepped back from the bottom of the tower to its flat top, the stones enclosed one to three beehive-shaped vaults, each not more than twice as wide as its surrounding wall; when a tower contained two or three vaults, they were stacked vertically. It is not only the structure of the towers but also their number that impresses the beholder: they stand an average of one or two for each square mile of the island.

The towers of Sardinia were wonders of antiquity. Timaeus, a perceptive Greek historian of the fourth century B.C., thought they were linked with the Mycenaean civilization that preceded the classical Greek culture in the eastern Mediterranean. The vaults within recalled the domed *tholoi*, or burial chambers, of Mycenaean Crete. His surmise was echoed in myths that credited the towers to Daedalus, the Cretan hero who had soared away into the sky on wings of his own making. Daedalus, it was said, had brought this style of building to Sardinia, and after him the towers were called *daedaleia*. Native legend in Sardinia regarded the towers as monuments of an early, happier era when the island was governed by wise and powerful men who had come from distant Spain. From Norax, the name of one of these heroes, comes the modern term for the ruins: *norake*, which is Italianized to *nuraghe* (plural: *nuraghi*).

Contemporary philology traces the word back still farther to the pre-Indo-European *nurra*, which means "heap" or "cavity" and so aptly describes both the shape of the exterior and the domed chambers in the interior of the towers. But perhaps the Romans had the best name for the nuraghi. They called them *castra*, or fortresses. This term reflects the Romans' first-hand experience with the towers, gained in the conquest of Sardinia that began in 231 B.C.

Taking account of the density of nuraghi on the Sardinian landscape along with their military function, archaeologists have begun to reconstruct the life and history of the people who built them. To us no less than to the ancients these structures seem more the work of heroes than of men. On this margin of the ancient world there was achieved a state of social efficiency and a release of creative human vigor that Sardinia is experiencing anew only today.

The earliest ruins on the island, antedating the westward flow of Mycenaean



PLAN OF SU NURAXI NURAGHE indicates how it grew. To the early tower (1) were later added the bastion and towers (3) enclosing a courtyard (2) and well. Outer defenses (4) were built still later. The older huts of the surrounding village are indicated in black. The remaining hatched structures were built after the nuraghe had fallen to Carthaginians.

SORO NURAGHE is one of the most primitive. Originally 65 feet high, it was built in second half of second millennium B.C.

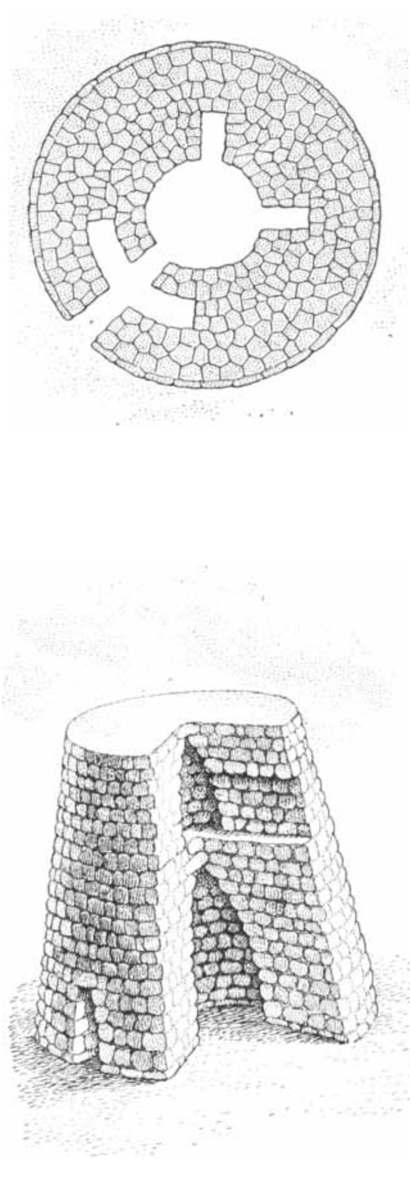
influence, show that the Sardinians had already achieved a considerable degree of engineering skill. They erected great rectangular structures, raising huge stones by placing them on wooden rollers and hauling them up inclines of packed earth. Under the influence of Mycenaean style they learned to set the stones in circular tiers, producing the stepped, conical structure of the nuraghi. The stability of the circular tiers, in which the stones hold one another in place by the opposition of their masses, made it possible to build towers to imposing heights. In the beehive chambers within, the stepped tiers of stone also perpetuated in Sardinia the tholoi of early Bronze Age Crete.

The link with Mycenaean civilization has been confirmed in recent years by the discovery of bronze ingots in several nuraghi. These ingots, stamped with letters in the Mycenaean "Linear B" script, indicate that the structures date back to the middle of the second millennium B.C. The dating has been verified by measurement of radioactive carbon in a wooden beam from one of the towers; the beam yielded a date of 1270 B.C., plus or minus 200 years. These were the centuries, from about 1500 to 1100 B.C., when Aegean commerce penetrated westward as far as England and the Aegeo-Asiatic peoples dispersed around the shores of the Mediterranean in the aftermath of the Trojan war. Other relics—weapons, pottery, certain treatments of bronze, various religious motifs—further confirm the Mycenaean influence. But the conclusive evidence is in the structure of the nuraghe itself: the domed vault of the inner chamber, so reminiscent of the tholoi. The Mycenaeans had built their burial chambers below the ground. By combining this style with their own command of the art of masonry, the Sardinians made a fortress-residence for the living out of a tomb for the dead.

The nuraghi built during this early period stand alone and single-towered. In many of them one enters the tower through a low, narrow doorway, obviously designed to place an intruder at a disadvantage. The passage through the thick wall to the first chamber flares upward and inward to allow maximum dispersion of the light from outside as well as to give sentries room for defensive action. Within the circular chamber, about 14 feet in diameter, one stands enclosed in the dim, echoing silence of the windowless masonry, eight or more feet thick, and looks upward 24 feet to the ceiling of the vault. A stairway starts a few feet above the chamber floor and spirals upward within the wall toward the chamber above. The first step of this stairway can only be reached by a ladder—another defense measure.

Upon climbing the stairs one enters a chamber identical with the first but smaller, perhaps nine or 10 feet in diameter and 18 feet high, and dimly illuminated through a small window. Above, in some nuraghi, there was a third chamber, shaped like the other two but proportionately smaller. These have universally fallen to the processes of time. But one must have emerged from the gloom of the third chamber onto a broad open terrace resting upon wooden beams that jutted out over the sloping exterior walls. Around the edge of the terrace were openings through which great stone balls could be loosed upon the heads of attackers at the base of the tower. These openings probably represent the first appearance in Mediterranean architecture of the "machicolations" that were to become a feature of medieval castles.

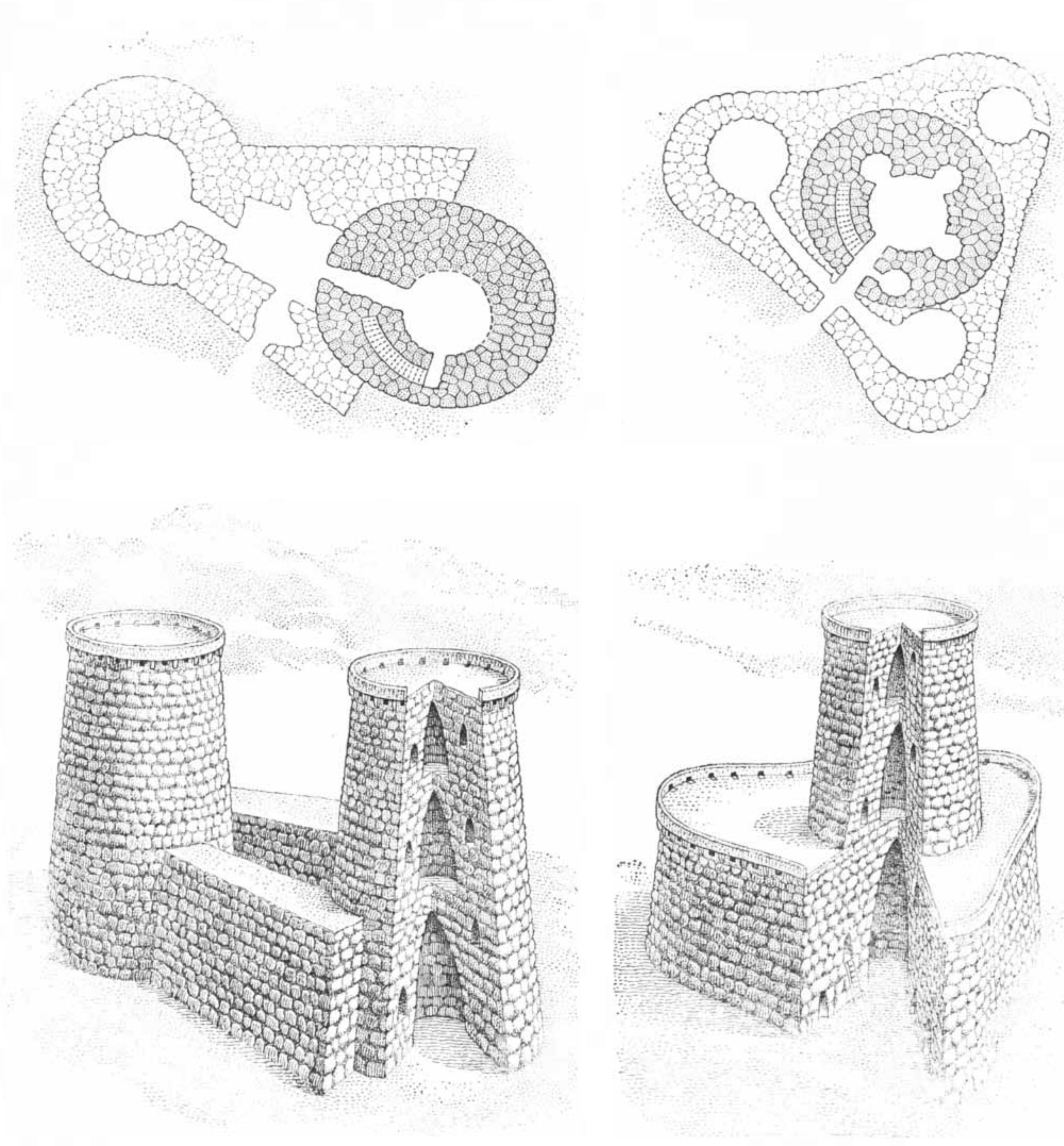
By the beginning of the first millennium B.C. these archetypal nuraghi were already wrapped in legend that held them to be monuments of a golden age. Their great number and scattered distribution tell us that the Sardinians had not achieved an urban culture. They lived upon the land—warrior-herdsmen and farmers organized in clans. Each clan had its own nuraghe, which fur-



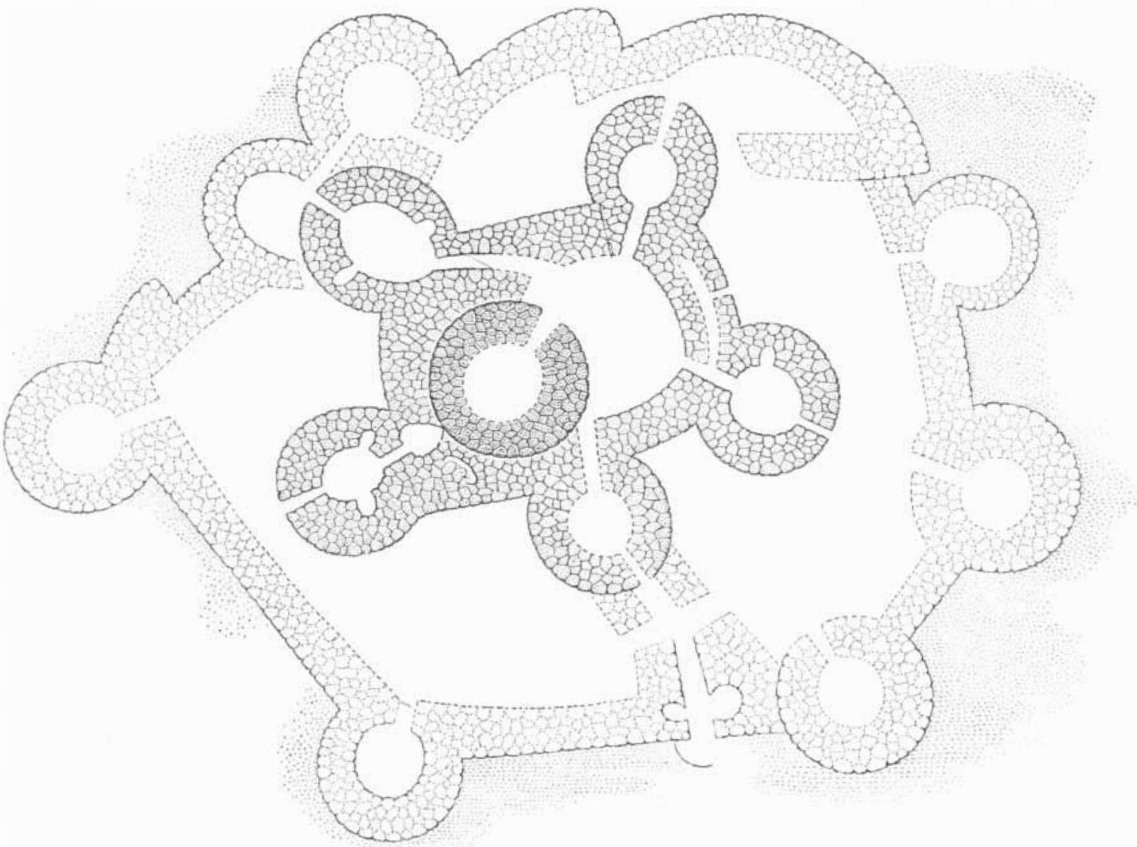
NURAGHI DEVELOPMENT is depicted in these illustrations and the one on page 66. Early single towers, shown in plan and elevation at left, were one to three stories high nished refuge to its members, their dependents and their slaves in times of conflict, and probably served as the habitation of the chief. To guard the pastures and grain fields, the towers were built preferably on heights. They stand often within sight of one another and always close to springs and rivers. The orientation of their doorways, to the south-southeast, shows that even then the inhabitants felt the scourge of the mistral: the cold, prevailing northwest wind of the Mediterranean basin.

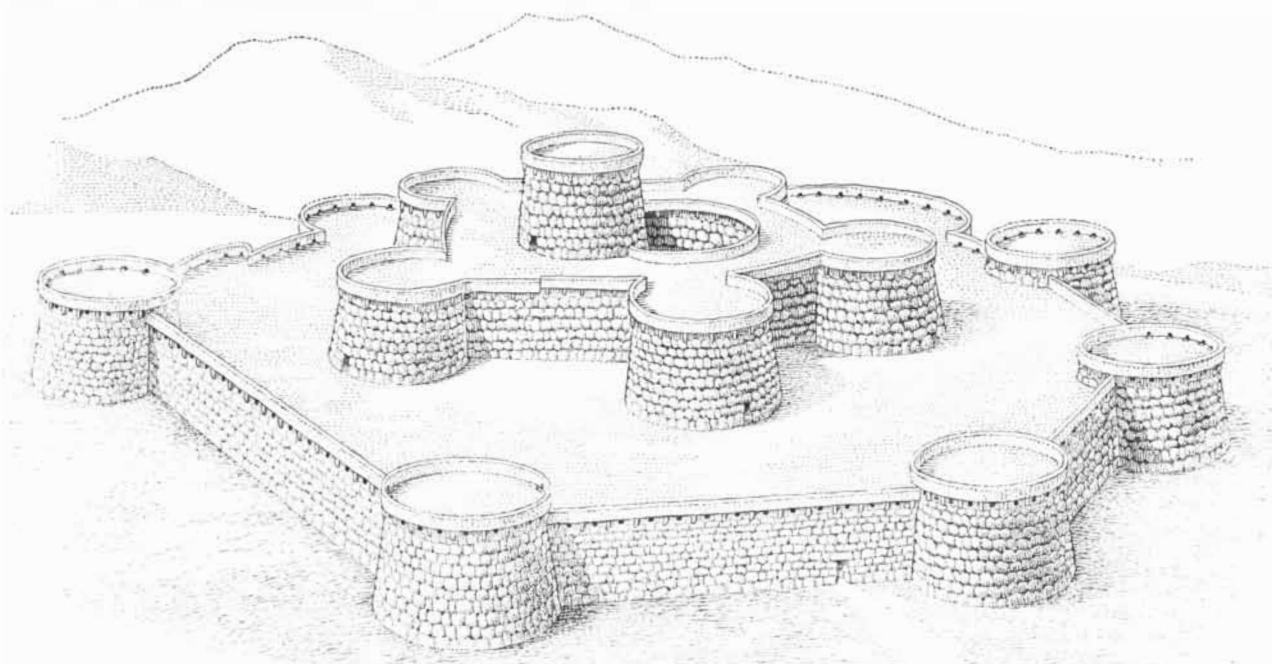
The nuraghi are densely concentrated in the central part of Sardinia, where the land is most suitable for grazing and in the western part, where the island's best ports are located. Here they provided strongholds for the defense of the island against invasion from overseas as well as for inter-clan warfare. It was probably the threat of invasion (there had been suspicious landings of ships from Syria and Etruria and exploratory parties from Greece) that brought nuraghe architecture to its climax after 1000 B.C., in the early Iron Age.

The more ambitious structures of this period indicate that the independent



with throwing platforms at the top. Early in the Iron Age the platforms were elaborated into machicolated terraces, and curtain walls joined the single towers (*middle*). Sophisticated design of tower at right includes rooms opening off main chamber, niche for sentry opposite stairway entrance, and living quarters in bastion towers. Small openings around chambers are stairway built into wall. Evolving simultaneously with nuraghi shown here were others throughout the island with many-towered bastions (*next page*).





PEAK OF NURAGHI EVOLUTION is embodied in the Orrubiu nuraghe at Nuoro. The keep, or main tower, and its bastions are encompassed by a broad terrace and heavy outer walls. The entire edifice was surrounded by a glacis, or slope, which forced attackers to climb uphill to reach the fortress. Unrestored upper portions of the Orrubiu nuraghe are shown in this reconstruction.

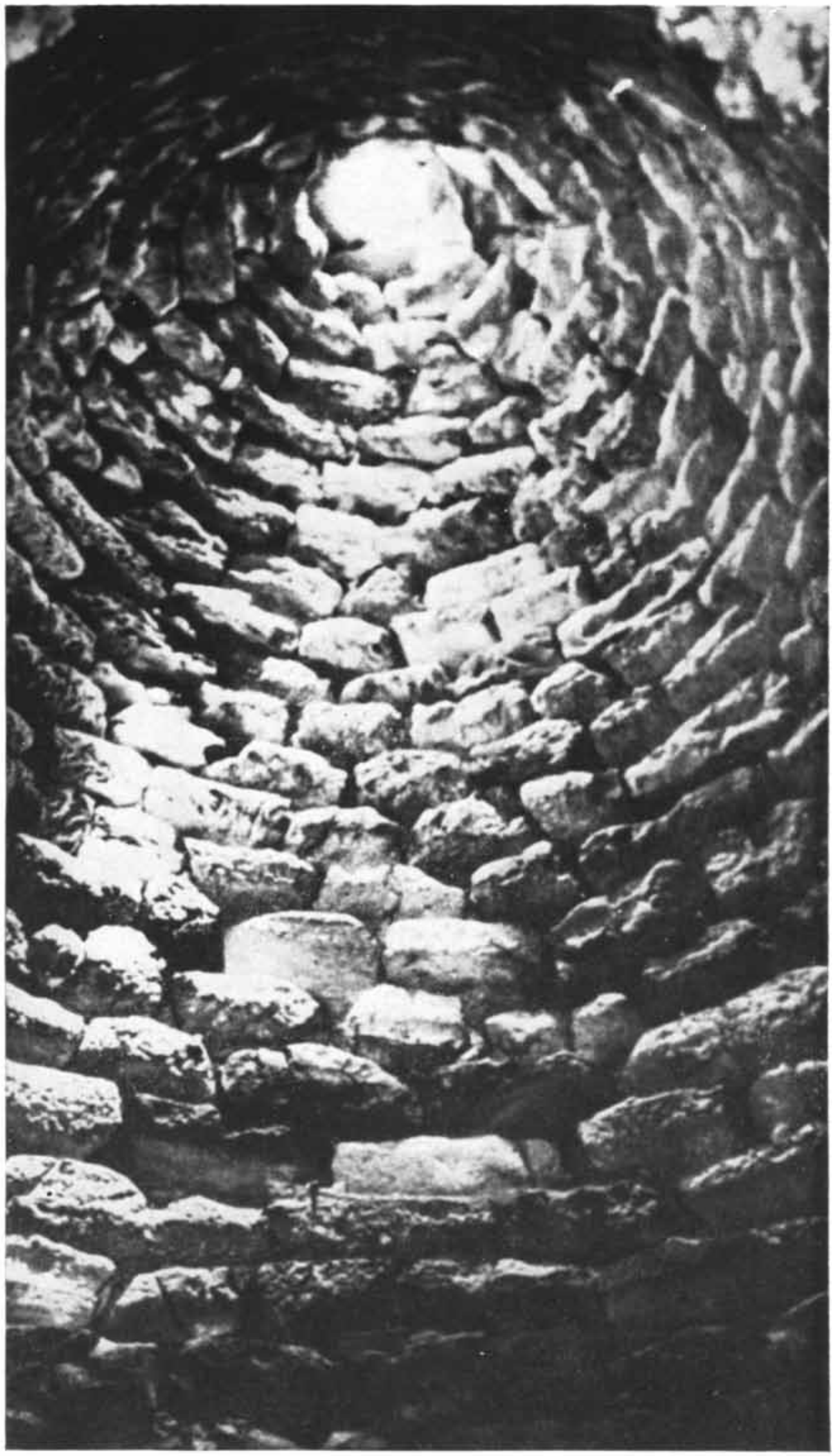
clans must have combined in some measure of unity for larger effort in the common defense. Massive triangular walls were thrown up around the central tower, providing courtyards, corridors and dwelling chambers. Double towers appeared, linked by walls. The space in the ground-floor chambers inside the larger towers was enlarged by three symmetrically placed caverns in the surrounding wall, accommodating an augmented garrison and larger stores. To the right of the entrance a recess in the wall provided a vantage for a sentry, from whence he could strike the unshielded flank of an invader. Opposite was the entrance of the stairway, which still spiraled upward inside the masonry of the thicker wall. This twisting, yard-wide passage could be easily defended at each turn. Often the towers and the walls were pierced by embrasures from which missiles could be launched.

The nuraghe at Barumini represents the peak achievement of this movement and shows clearly the succession of the distinct periods of development. Here the projecting terrace atop the principal tower rested on great stone corbels, or brackets, instead of on wooden beams. During the ninth century B.C. a large quadrangular wall was built with a tower at each corner, the whole enclosing a courtyard. Terraces reached out from the inner bastion to the outer towers. Later still, at the time when the island came under invasion from Carthage, the outer walls were faced with six or more feet of masonry, the better to resist a new weapon: the Carthaginian battering ram. Exploring the fortress in detail, one finds other evidences of a mature military art devoted to passive defense—dropping platforms, blind angles, narrow passageways, trapdoors, sentry posts and acoustic passages.

This formidable structure and others that approach it in size and elaboration may be regarded as true, thoroughgoing castles comparable to those of the Middle Ages. We must imagine them as the residence of a petty monarch and his garrison, consisting of as many as 200 to 300 men. Finds of stone and metal (both bronze and iron) testify that the men were armed with bows, slings, swords and other weapons representative of the armament of their period. Such bastions and their military organizations dominated the surrounding countryside and the villages huddled at their feet. In time of peril the entire population could take refuge behind the castle walls.

There are also nuraghi that may have been simply the habitations of shepherds and farmers, even though their Cyclopean construction suggests a grander purpose. These edifices complete the picture of a culture in which the larger structures represent the aristocratic and warlike aspect. Despite the derivation of their interior design from the Mycenaean burial vaults, there is no evidence that the nuraghi were built to serve as tombs or temples.

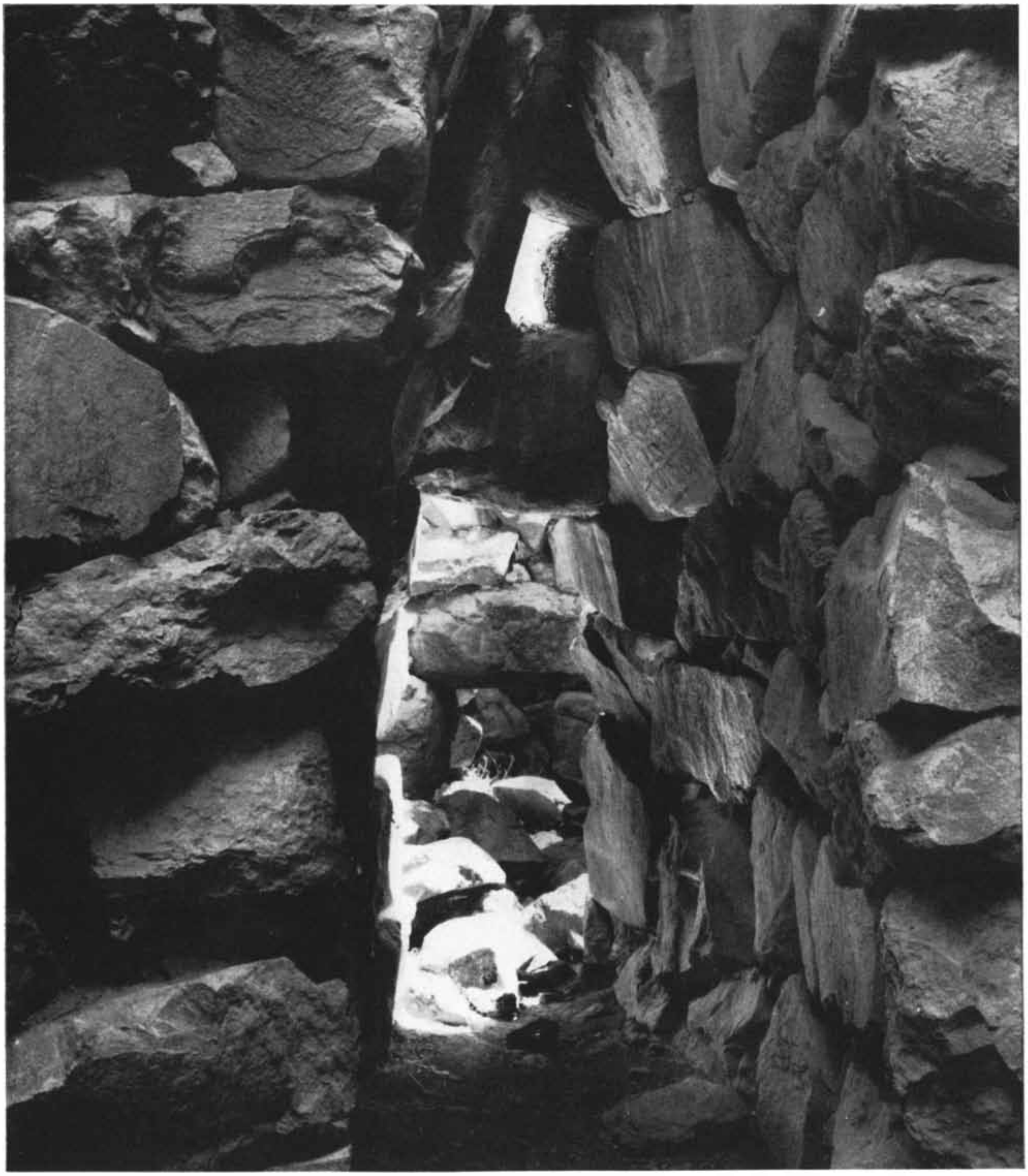
The Sardinian civilization, dominated and fragmented as it was by petty monarchs secure in their nuraghi, never evolved beyond the warrior-pastoral



INFLUENCE OF MYCENAEAN CIVILIZATION is evident in the nuraghi chambers. Beehive-shaped construction was characteristic of the *tholoi*, the burial chambers of Crete.

state. In its disunity the island was prey to invaders from the great urban cultures overseas. At last, in the sixth century B.C., came the Carthaginians. Under their repeated and persistent sieges, even Barumini fell. The fortress was reduced, the surrounding village burned and the population scattered. For three centuries the Carthaginians held the island in thrall and then lost it to the Romans.

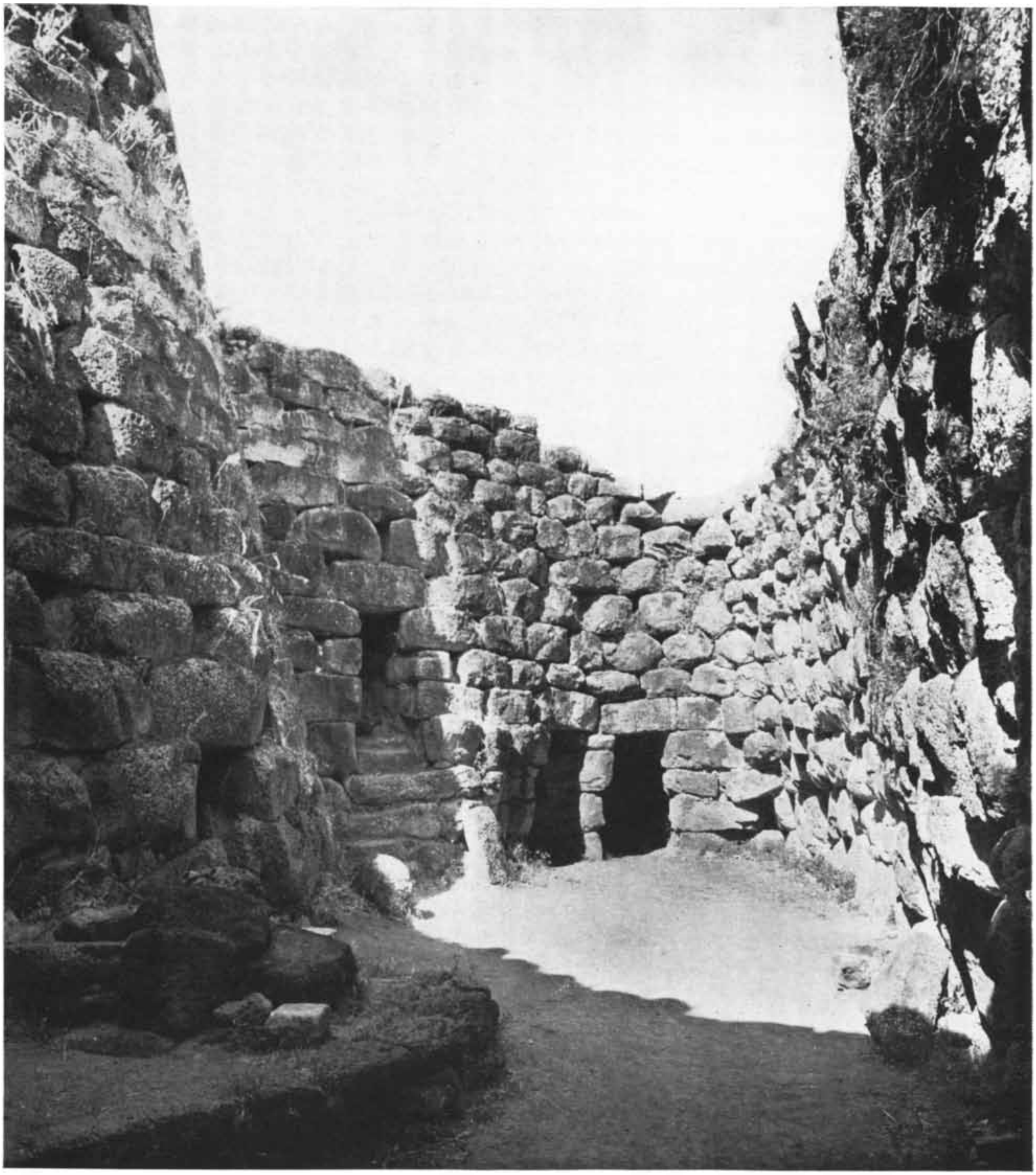
The last nuraghi were built during this period in the border zones between the mountains, still held by Sardinians, and the western lowlands, in possession of Carthage. Classical historians, writing of this period, describe a new kind of native fortress, the "cavern" or "hide-out" nuraghe. These were scarcely the splendid constructions of the past. Built in caverns and caves, hidden in the woods or tucked into rock formations, the pseudo-nuraghi were little more than flat-roofed subterranean corridors built



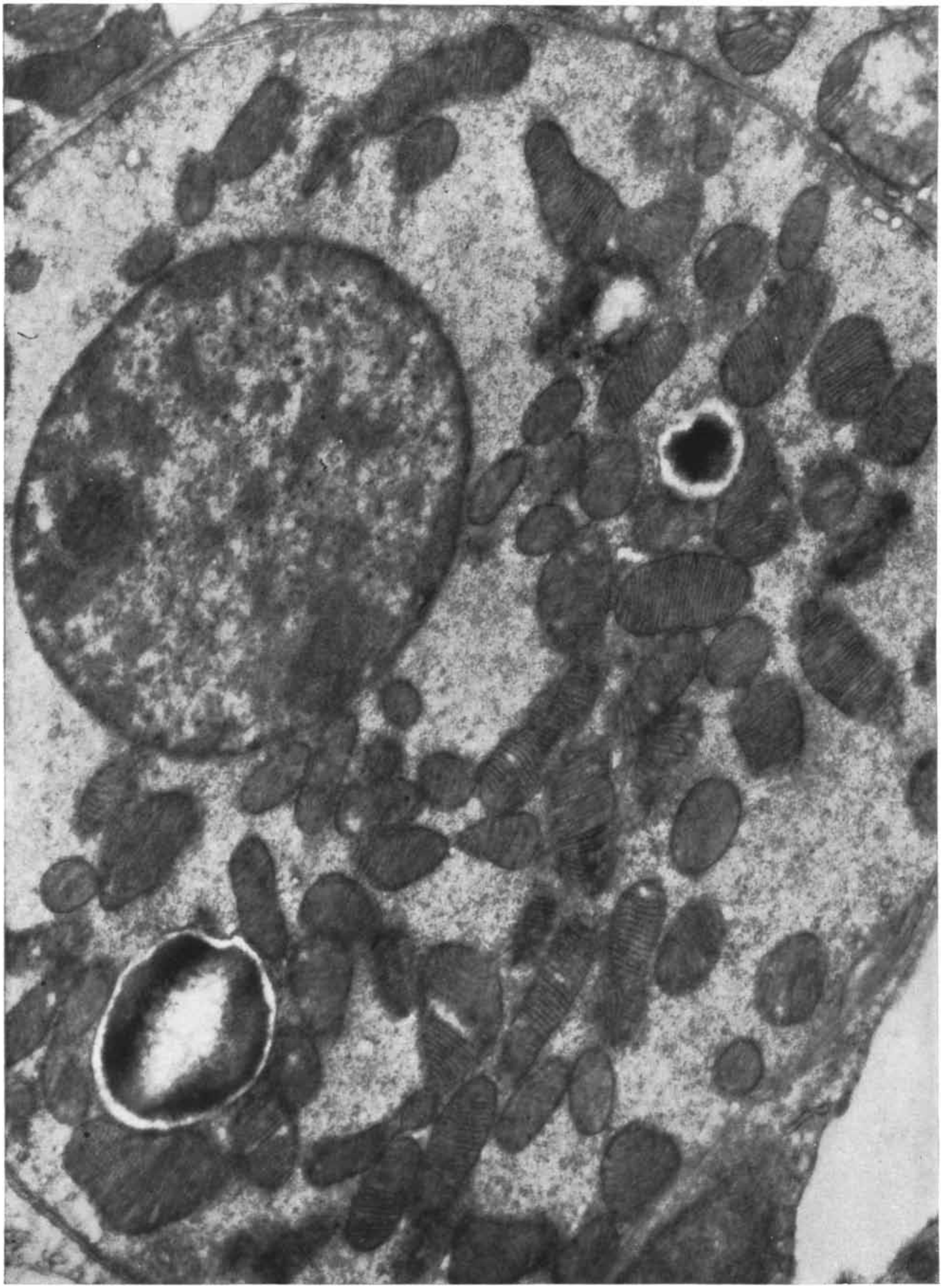
MASSIVE CONSTRUCTION OF THE NURAGHI is evident in this detail of the entrance to the Domu s'Orku nuraghe. The angular construction is characteristic of the most primitive towers. The view is looking outward from the chamber on the ground floor.

on a quadrangular or horseshoe plan. The native population, seeking to defend the last breath of their liberty, concealed themselves in these refuges and deployed from them in guerrilla forays. They continued their bitter resistance for generations until at last the Roman legions, with the aid of mastiffs brought from Italy especially for this purpose, tracked them to their lairs.

These last nuraghi were but a reminder of departed grandeur. At the most they embodied a transient impulse of proud defiance, the ideal of a barbarous world of shepherds and warriors forever fighting among themselves and closed against the world outside. When the Romans finally prevailed, the refugees returned to the sites of their devasted villages. But they continued to resist cultural domination by their conquerors and clung to the memories and customs of their old civilization, which had been free and not without glory.



COURTYARD OF SANTU ANTINE NURAGHE has a well *(left foreground)* and entrances to bastion chambers *(rear)*. Rising at left is the main tower of the tri-lobed nuraghe which, except for the courtyard, is of the type depicted at the right on page 65.



FAT-CELL CYTOPLASM is rich in mitochondria, the numerous small structures magnified 20,000 times in this electron micrograph. They make fat, droplets of which are at lower left and upper right. Large structure is cell nucleus; line near top is cell wall.

BODY FAT

Far from being relatively inert stored material, fat tissue plays a central role in human metabolism, producing fat and constantly releasing it to be used as fuel by the working cells of the body

by Vincent P. Dole

Most fat people make repeated efforts to reduce, only to regain the lost weight within a few months. The typical overweight person knows as much about calorie-counting as a physician does, and yet cannot stay thin. The consistent failure of dietary treatment demands a critical look at the assumption that obesity is simply the result of habitual overeating.

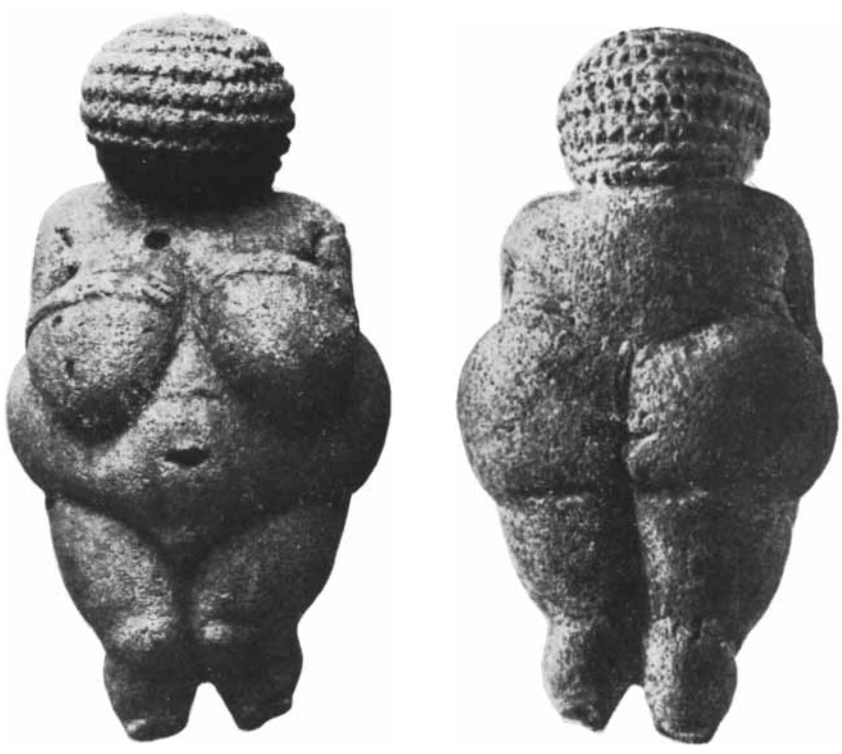
Several studies have thrown doubt on this notion. It has been found that some fat people remain overweight while adhering to a diet consisting of normal quantities of food. A number of individuals who have succeeded in reducing have regained weight while eating less than do average persons of the same age, height and sex. Such individuals use less energy than average for the upkeep of the body and for muscular work; they metabolize at subnormal rates.

The finding that some people can gain weight without eating more than comparable people of normal weight does not mean that fat persons are able somehow to defy the basic laws of physics and accumulate body mass without ingesting it. The word "overeating," like its companion word "overweight," implies a comparison between the individual in question and average persons of the same age, height and sex. This point deserves emphasis because many writers have confused the issue by reasoning in a circle. They define overeating as an intake of food greater than the quantity of matter excreted from the body. By definition, therefore, anyone who gains weight must overeat, even if he consumes a subnormal quantity of food. Overeating is identified with weight gain, and no attempt is made to explain the processes involved.

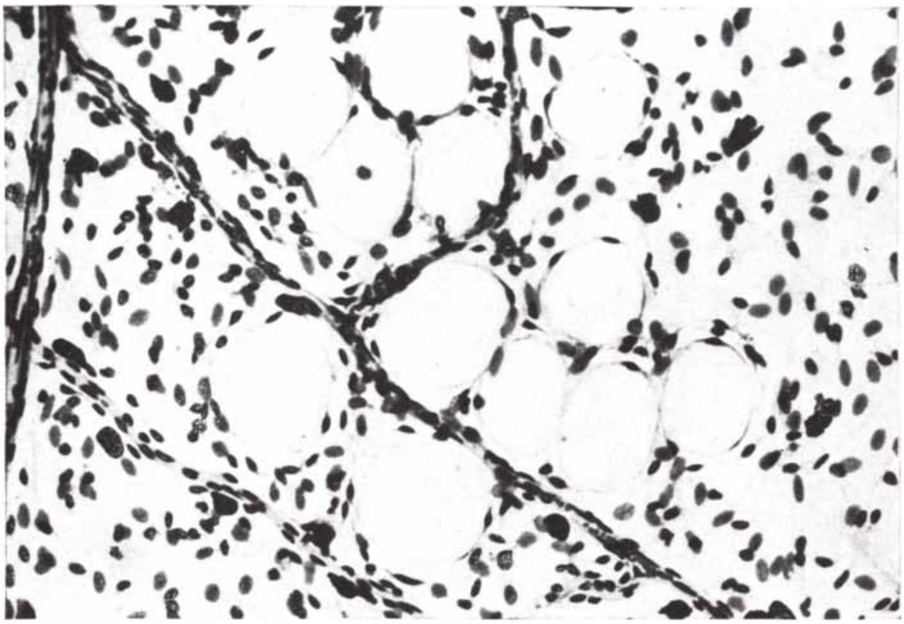
If obesity is to be understood, these processes must be recognized. Recent studies have shown that fat tissue is more than a storage depot for excess food. It lives and participates actively in the metabolism of the body. It converts a substantial part of dietary sugar and starch to fat even when a person is at constant weight. It throttles the flow of energy in the body by adjusting the outflow of fatty acids to the needs of working cells. It responds to hormones, which integrate its performance into the coordinated working of the body. Since all of these processes in fat tissue are affected by obesity, a theory of the disease based entirely on overeating seems inadequate.

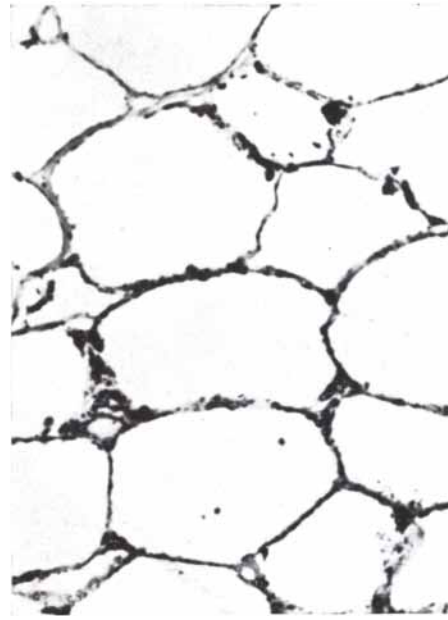
The high incidence of obesity also suggests that this disease is more than a simple dietary problem. People gain weight on many different kinds of diet. Obesity occurs in the wealthy and sedentary class of every race. Even the mummies of ancient Egypt show numerous skin wrinkles that preserve the evidence of marked obesity during life.

The most ancient example of obesity is the so-called Venus of Willendorf, a figurine from the early Stone Age that



VENUS OF WILLENDORF, named for the Austrian village where it was found, is a limestone statuette from the Stone Age. The figure, shown almost actual size, is thought to represent fertility. Its stylized features also approximate those of a modern fat woman.





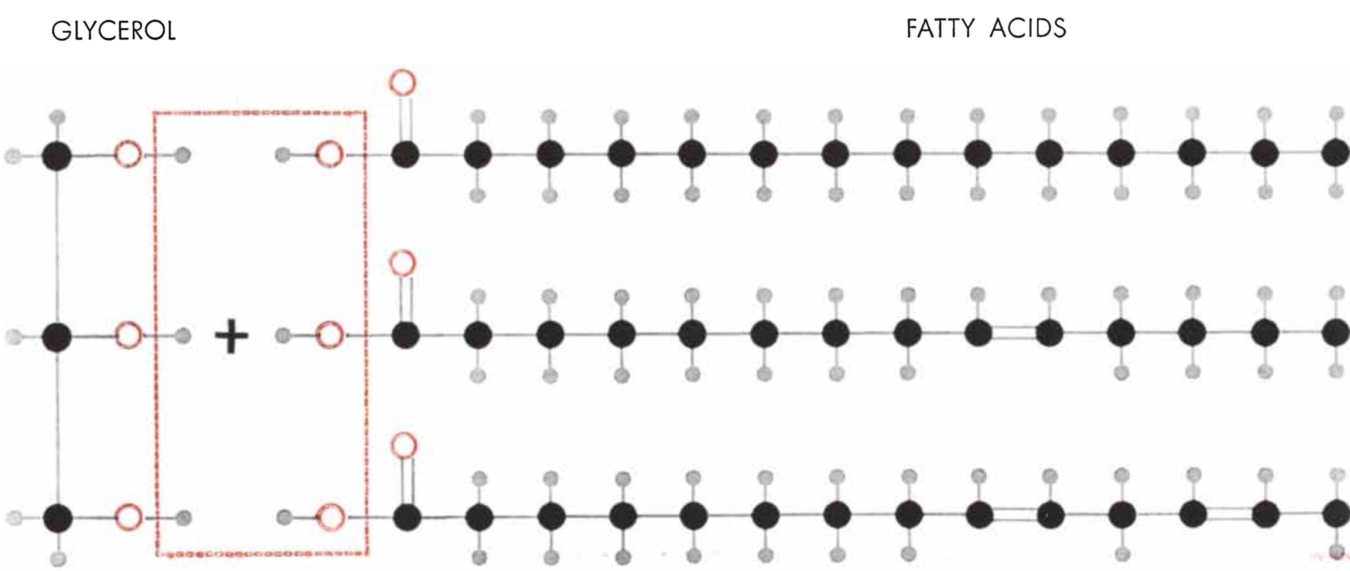
FAT CELLS IN CONNECTIVE TISSUE (enlarged 275 times) are open circles in photomicrograph at left. Dark spots are nuclei of other types of cells, and diagonal tubes are capillaries containing red blood cells. Center photomicrograph shows fat cells (enlarged

antedates the development of agriculture by some 10,000 years. The people who created the Venus lived as hunters, moved with the seasons, ate mammoths and other animals, undoubtedly gorged when food was available and starved when game was scarce. Their way of life and dietary habits were utterly different from ours, and yet the ancient Venus resembles the present-day middle-aged fat woman.

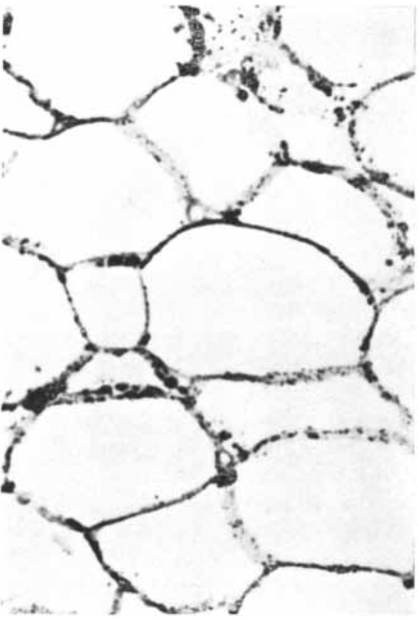
Today's counterpart of this figurine usually gives a history of being thin when married (and sometimes brings a wedding picture to prove it), and then of gaining weight with each successive pregnancy. The metabolic processes of the human body have not changed much in a few thousand years; the response of fat tissue to age and hormonal changes was undoubtedly much the same then as now.

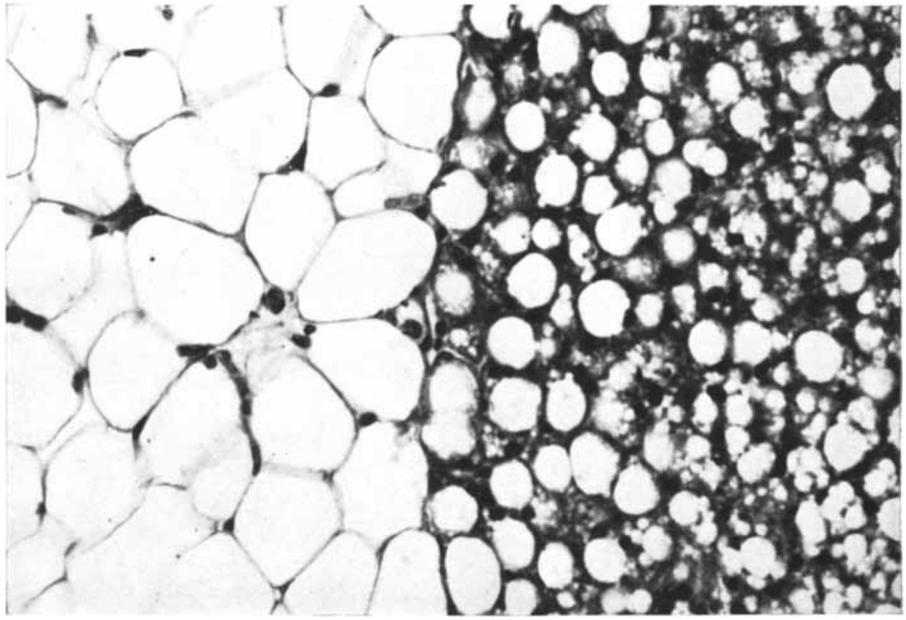
Most people ignore body fat unless, like the Stone Age Venus, they have too much of it. Actually fat is a major component of the normal body, accounting for about 15 per cent of the total weight of a young adult and a higher percentage in an older person. A healthy body maintains a constant proportion of fat, and restores this proportion if weight is lost.

The maintenance of body fat relates in part to its structural and mechanical functions. Fat is a chemically stable substance, liquid at body temperature, distributed over the surface of the body to serve as a heat insulator and as a protec-



TRIGLYCERIDE IS FORMED from three fatty acids and a glycerol molecule by splitting off three water molecules (*in colored rectangle at left*). The glycerol and fatty acids then join at three oxygen atoms (*red circles*), which are the ester bonds. Palmitic acid is saturated with hydrogen atoms (*gray*), having no double bonds between carbon atoms (*black*); because of this it is a solid





550 times) from an animal that had been starved, then fed. Granules are glycogen, which is made into fat. In photomicrograph at right (enlarged 375 times) white-fat cells from a rat are seen with smaller brown-fat cells, which have more cytoplasm and are more active.

tive cushion. Internally it surrounds and supports delicate structures such as the eyes, kidneys, joints and intestines. In starvation, however, its function as a fuel takes precedence. Despite its structural importance, almost all of the body fat can be mobilized and burned in an emergency.

Considered as an energy store, the body fat of an average young man represents about 100,000 calories (12 kilograms of fat tissue with a caloric value of eight calories per gram), roughly the amount of energy expended in a month of normal life. With unlimited drinking water available, a healthy person can survive even longer than a month without food; he becomes lethargic and expends less energy, burning less and less fat each day. An obese person on a low-calorie diet often shows a similar fall in metabolism, despite the fact that his body may contain a year's supply of energy. His weight loss may stop, even when he is still overweight and taking in a subnormal amount of food. These results do not support the theory that a fat person is really normal but overfed.

PALMITIC ACID

OLEIC ACID

LINOLEIC ACID

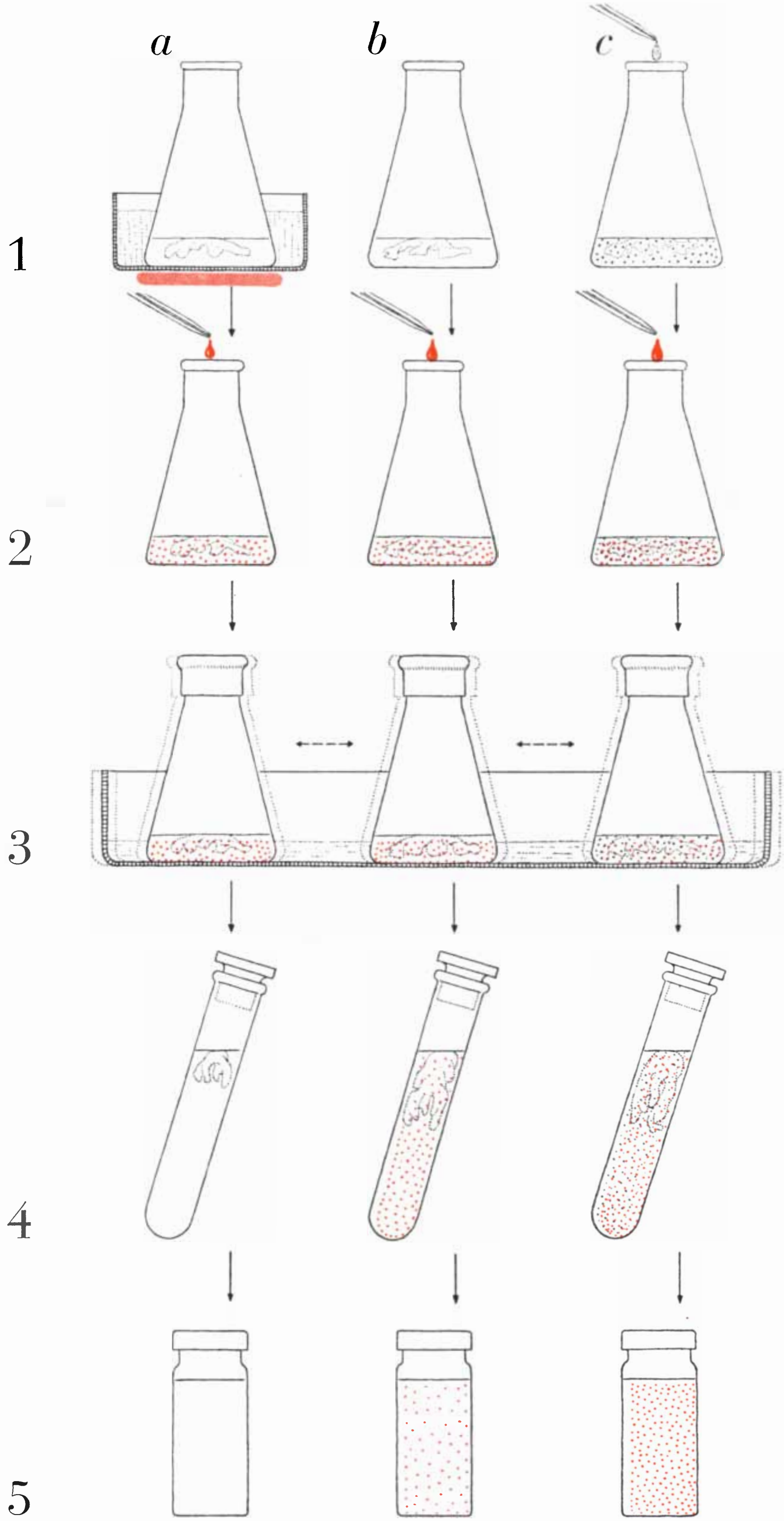
at body temperature. Oleic acid has one double bond between carbon atoms; linoleic, two. Both are unsaturated and thus liquid.

The overfeeding theory of obesity had been based on the assumption that fat tissue serves only as a reservoir for excess calories. The theory made no distinction between fat tissue (the fatty parts of the body) and fat (the substance stored in the tissue), because the cellular part of the tissue seemed negligible. About 95 per cent of the total tissue-weight is due to the substance fat, which is certainly not a living material comparable to protoplasm. Of the 5 per cent remaining, more than half is structural: connective-tissue strands and blood vessels. Living cells in fat tissue thus account for about 2 per cent of the weight, and of this small percentage a portion must be assigned to blood cells, which are only visitors and not part of the tissue itself.

It seemed hardly possible that the minute quantity of living cells in fat tissue could have much influence on the metabolism of the body. Nevertheless recent studies have shown that this is the case: working protoplasm is present in fat tissue, but in an unfamiliar form. First consider a typical cell in an organ such as the liver. It has a roughly spherical shape, with a nucleus in the center surrounded by a zone of highly organized cytoplasm. Within the cytoplasm small structures called mitochondria serve as focal points of energy conversion. Near the mitochondria lie droplets of fat, either being formed or consumed as fuel.

Now imagine that the droplets of fat in the cells grow enormously and fuse into a single drop still contained within the cytoplasm. Suppose that the size of each drop becomes 50 times as large as the original cell. Obviously the cytoplasm surrounding such a drop would be stretched out to almost vanishing thinness; the nucleus of the cell would be flattened and pushed to one side. On examination, a tissue containing these cells would appear to be only a foamlike assembly of fat droplets. The living part of it would have become almost invisible.

This describes the usual condition of fat tissue as seen with the light microscope. Without special methods of examination the cellular part seems negligible. However, if an animal is first starved and then fed, so that the fat cells are seen in the process of refilling themselves, the rims of living cytoplasm show a dense accumulation of granules. These granules contain glycogen, a car-



EXPERIMENTS DETERMINE ACTIVITY OF FAT TISSUE in synthesizing fat. In step 1 isolated tissues are placed in nutrient solution. Bottle at 1*a* is heated to inactivate enzymes, and serves as control. At 1*c* insulin (*black dots*) is added. In step 2 radioactive glucose (*colored dots*) is added. At 3 bottles are agitated for three hours. At 4 the fat is extracted. At 5 fat extract is tested to see how much of the radioactive glucose has been changed into fat, and thus how much synthesis has occurred in the pieces of fat tissue. Control (*column a*) is not radioactive. Tissue in column *b* has made radioactive fat, and that in *c* even more.

bohydrate material that serves as an intermediate in the synthesis of fat from sugar.

Recently the electron microscope has permitted a more detailed study of fat-cell cytoplasm. The so-called brown fat of rodents—a highly cellular variety of fat tissue that lends itself to this type of study—exhibits many large mitochondria associated with fatty droplets. The abundance of mitochondria means that the cells probably consume energy at a rapid rate, because these elements are consistently associated with high-energy metabolism in other tissues. Ordinary fat tissue (sometimes called white fat) similarly shows abundant mitochondria and cytoplasmic granules when it is examined in suitable preparations. The recent studies thus provide evidence that fat tissue is an active living structure, although it is greatly diluted by the stored fat it produces.

Biochemical studies have added even more direct evidence on this point. Isolated pieces of fat tissue consume oxygen and, like other living systems, utilize chemical energy to drive various chemical reactions in a specific direction, the main process in this instance being the conversion of the glucose to fat. This process of synthesis shows the expected sensitivity to changes in the environment of the tissue. If a fresh piece of fat tissue is placed in a nutrient broth, synthesis proceeds in the cells only at body temperature; it can be speeded by the hormone insulin or blocked by the destruction of cellular enzymes.

A good way to demonstrate the synthesis of fat is to supply radioactive glucose in the nutrient solution. If radioactivity appears in the fat molecules after incubation, and if this labeling of the molecules can be speeded or blocked by various agents that affect the functioning of living cells, then it can be concluded that the fat cells have converted glucose into fat.

In a typical experiment fat tissue is removed from the abdominal cavity of a rat, divided into several parts and distributed into flasks containing nutrient solution with a tracer amount of radioactive glucose. Insulin is added to some flasks; other flasks, serving as controls, are heated to destroy cellular enzymes. All the flasks are incubated for three hours. At the end of this time the fat in the tissue is extracted, washed to remove any residue of the original radioactive glucose, and analyzed to determine how much radioactivity is present in the fat. Such an experiment shows that, even without added insulin, fat tissue can synthesize fat; the piece of tissue treated with insulin synthesizes much more, while the heated piece synthesizes none.

Insulin not only promotes synthesis; it also favors the retention of fat in tissue. Before the stored fat molecules are released from the cell, they are split into their constituent fatty acids. To the chemist the term fat means a family of molecules formed by the union of fatty acids with glycerol. Fatty acids are chains of 16 to 20 carbon atoms with hydrogen atoms attached, ending in an acid group. Glycerol is a three-carbon unit with a site of attachment for a fatty acid on each carbon. The chemical binding of three fatty acids onto glycerol—a process called esterification—yields a triglyceride, or, in common usage, fat. Splitting these bonds yields glycerol and a mixture of nonesterified fatty acids, abbreviated NEFA. Fat tissue releases NEFA, although it stores the fatty acids in chemical combination as triglyceride. To study the discharge of fat from storage, one therefore measures the quantity of NEFA released from fat tissue under various conditions. Adding insulin to a piece of fat tissue, as in the experiment on synthesis, reduces the output of NEFA from the tissue.

The work with insulin has led to similar investigations of other hormones. At least three hormones act on isolated pieces of fat tissue. Prolactin, a pituitary hormone associated with milk production in the living animal, increases the synthesis of fat in fat tissue. The pituitary hormone ACTH, or some closely related substance, stimulates the output of NEFA in the tissue.

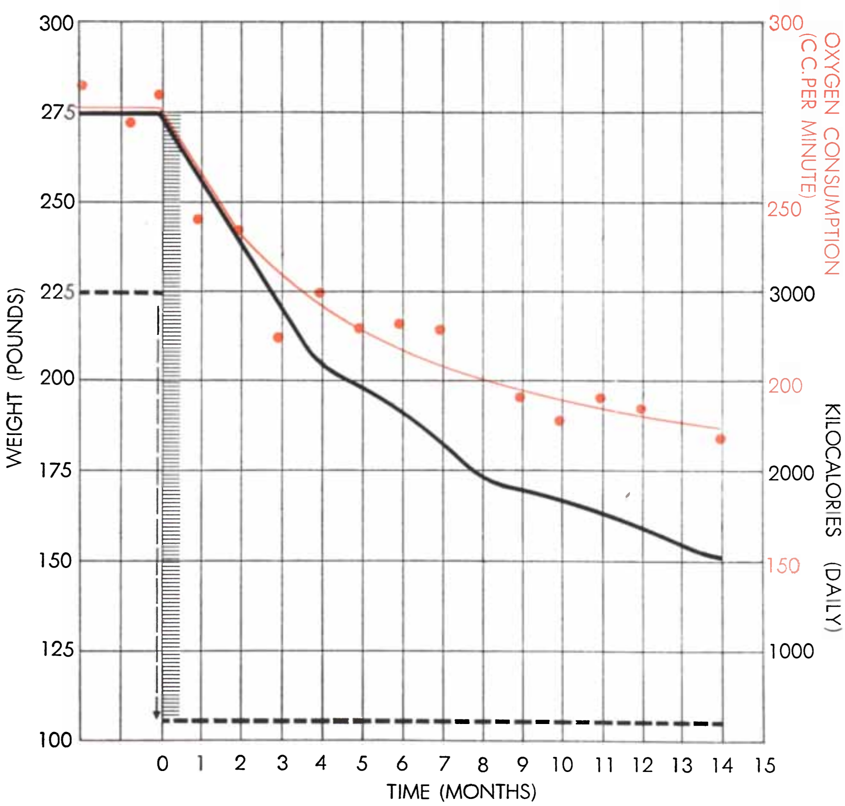
The third of these hormones, adrenalin, also promotes the release of NEFA. Fright or anger causes a discharge of adrenalin, and, as a result, induces an outpouring of NEFA into the bloodstream. It seems reasonable to assume that this release of chemical energy provides fuel for emergency use. Possibly the action of adrenalin contributes to the disturbances of metabolism caused by the emotional stresses of modern life.

In many respects, however, the action of hormones on fat tissue in the body remains a mystery. Sex hormones obviously govern the distribution of fat, since the distinctive contours of men and women are fatty in nature and are affected by castration. When men and women are emaciated, their outlines differ hardly at all. The adrenal steroids, chemically related to the sex hormones, also appear to be involved in some cases of obesity. The thyroid hormone accelerates metabolism and causes loss of weight even when an unlimited amount of food is available. None of these hormones has as yet been shown to act on isolated pieces of fat tissue. Possibly they act indirectly in the body, for instance by changing the sensitivity of fat tissue to insulin or adrenalin.

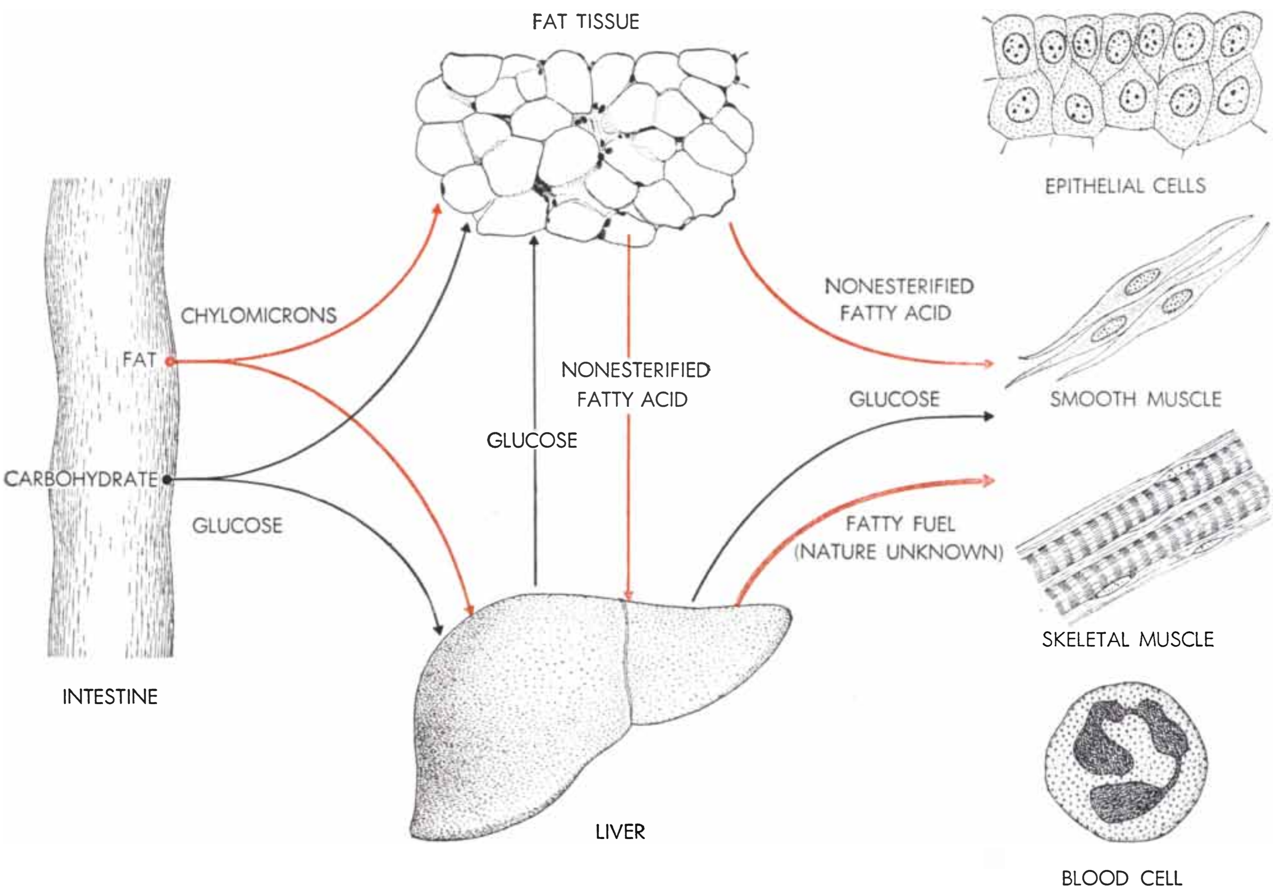
These findings have thrown light on some puzzling reactions of fat tissue in the body. In diabetes, for example, the fat tissue seems to be involved in two different ways: The middle-aged fat individual with mild diabetes often is obese, and is benefited by a reducing diet, while the individual with severe diabetes tends to lose weight rapidly and, if not treated with insulin, dies emaciated. The gain of weight in the first kind of diabetic, and loss of weight in the other, can be attributed to imbalance between the synthesis and release of fat. Both kinds of individual suffer from a block in utilization of glucose; probably both fail to synthesize fat from glucose at a normal rate. They differ, however, in the rate at which their tissues release fat. The obese person mobilizes fat slowly for utilization by his working cells, while the severe diabetic floods his body with a fatal load of fatty acids from excess release.

In addition to processing starches and sugars, the fat tissue also plays a role in the metabolism of fat ingested in the diet. It stores dietary fat and, according to present theories, mixes these molecules with fat synthesized from the carbohydrates. After mixing, the two fats appear to share a common function. The mixture leaves the tissue in response to hormonal demands, and provides fuel for the working cells. If this theory is correct, it explains why carbohydrate and fat—chemically quite different substances—serve equally well as food for the body. In either case much of the food energy reaches the working cells in the form of fat. The conversion of sugar to fat in the fat tissue thus enables cells in the muscle and other tissues of the body to operate on a standard fuel despite wide variations in diet.

The protoplasm of fat cells must be remarkably active, according to this theory, because carbohydrate often provides more than half of the dietary calories. Consider a normal young man of athletic build. At a weight of 80 kilograms (176 pounds) he probably has



METABOLISM DROP IN DIETING PATIENT is shown on this chart. A 20-year-old girl, she was five feet, six inches tall and weighed 275 pounds. She remained at constant weight for two months on daily diet of 3,000 calories. Then she was put on a diet of 600 calories a day for 14 months (*scale at right and broken line*). Her weight dropped to 150 pounds (*black curve and scale at left*). Her basal metabolism (*oxygen consumption, shown by colored dots, line and scale at right*) decreased to low values, accompanying loss of weight.



PATHS OF FAT AND CARBOHYDRATES in the body are shown schematically in this diagram. Colored arrows indicate route of fat and fatty materials; black arrows show path of sugars. Fat tissue synthesizes nonesterified fatty acids for fuel and for processing by the liver. That organ incorporates the acids into complex lipoproteins, which may carry fatty fuel to working cells (*at right*).

about 12 kilograms (26 pounds) of fat tissue in his body, and of this weight the fat cells account for less than 2 per cent, or 240 grams. His diet might contain 400 grams of sugar, or its equivalent in starch, providing 1,600 calories per day. If his fat cells convert only half of the dietary sugar to fat, they synthesize roughly their own weight in fat every 24 hours.

The weight factor is also of interest in relation to the efficiency of energy storage. The two main energy-yielding reactions in the body are the combination of carbon and oxygen to make carbon dioxide, and of hydrogen and oxygen to make water. Since the air provides oxygen, there is no need to store this element in the body. Therefore fat, consisting of about 88 per cent carbon and hydrogen, approaches maximum efficiency as a storage material. Its favorable energy-to-weight ratio permits birds and insects to fly, and other animals to travel long distances in search of food. When man runs his automobiles and other machines on petroleum, he is simply making use of an ancient biological discovery.

The analogy between combustion engines and the body goes further. Both systems burn fatty material and utilize the energy to do work. Both eliminate waste products, and remain at constant weight only if the quantity of matter eliminated just equals the quantity received as fuel. The analogy breaks down, however, when it is examined in detail. If an excess of fuel is poured into a machine, nothing much happens to the performance of the engine. But in the body the quantity of fat held by the fat cells affects the cellular processes of synthesis and release; the biological engine is sensitive to the quantity of energy in storage. The body, driven by hunger, seeks to maintain a definite state of nutrition. The machine remains indifferent to the state of the fuel tank until it is out of gas.

To sum up, fat tissue is a living part of the body structure and not simply a tank to hold excess calories. The cells in this tissue contain some of the most active protoplasm in the body. They synthesize fat from sugar and release the fuel on demand. Apparently these steps are essential for a normal utilization of food energy.

People differ in their content of body fat, because of differences in the activity of their hormones. Since this is the case, it is a fallacy to specify a single ideal weight for all adults of given height, age and sex. The desirable amount of body fat should be defined in terms of the jobs done by this tissue, rather than by arbitrary standards of appearance or by insurance statistics. Undoubtedly a lean, vigorous body is healthier than a fat one, but it does not follow that starvation provides a specific cure for obesity. Not every fat person is simply an overfed normal one.

Many people who tend to be overweight in middle age eat too much and exercise too little. For them the remedy is clear. With moderation in diet and increased activity they can lessen the danger of such diseases as arteriosclerosis and diabetes, which frequently occur in fat people. But the truly obese person, grossly overweight despite all efforts at dietary control, suffers from a disease that present-day medicine cannot remedy.

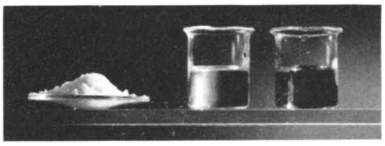
Kodak reports on:

"Ektalith," a word which will catch on ... special lubricants without diplomatic maneuvering ... the bright prospects and stable bases of photography

Camera weds duplicator

There are many thousands of offset duplicators in offices. We have worked out new materials and equipment which enable them to start in two minutes, turning out in quantity first-rate enlargements or reductions of anything drawn, written, or printed, including microfilm records. If you require relatively few copies, you don't even need an offset duplicator. Write a note to Eastman Kodak Company, Graphic Reproduction Division, Rochester 4, N. Y., and ask where in your locality you can see a demonstration of the *Kodak Ektalith Method.*

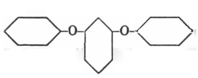
600°F is tougher than 350°F



To demonstrate how passably these two liquids and this solid perform as oxidation-, corrosion-, and radiation-resistant lubricants for gears and bearings operating up to 600°F in flying objects and other up-to-date kinds of machinery must have taken a tidy chunk of government money. We can cluck like a frugal taxpayer, since only a pittance found its way into our pockets.

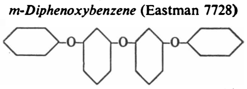
Now that the pure, undoctored, unsubstituted meta-linked polyphenyl ethers are revealed to rate high for chemical sturdiness, lubricity, and retention of the liquid state over a broad temperature range, we find it in our hearts to enable the experimenter to acquire them in a small, quiet commercial transaction without diplomatic maneuvering.

For $8.80 for 25 grams



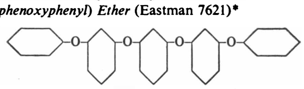
m-Diphenoxybenzene (Eastman 7728)

For $18.45 for 10 grams



Bis(m-phenoxyphenyl) Ether (Eastman 7621)*

For $12.45 for 10 grams



m-Bis(m-phenoxyphenoxy)benzene (Eastman 7815)

Perhaps one of our markets for these polyphenyl ethers will be for use as foils against which to demonstrate the superiority of new classes of lubricants as yet unrevealed, just as the polyphenyl ethers stand up for many hours to conditions that devastate 350°F lubricants to stiff sludges or vapors in minutes. Two decades ago, when we were in the high-vacuum business and considered ourselves pretty smart in diffusion pump liquids, we developed some phlegmatic esters that now serve as the goats for the polyphenyl ethers to beat.

Small, quiet transactions are the mainstay of the Eastman Organic Chemicals Department of Distillation Products Industries, Rochester 3, N. Y. (Division of Eastman Kodak Company). Our current "List No. 41" will tell you of our organic chemical wares, some 3700 of them.

*There has been some 40° to 800°F talk about this one.

Factory Photos

headlined the first column of *The Wall Street Journal* on the penultimate morning of last summer,

Firms Spur Camera Use To Solve Test, Sales, Production Problems

"Industry sources expect retail sales of equipment and supplies for industrial photographic use will reach some $250 million this year, up from about $100 million five years ago," the story said. (That's a very short time ago. These very discourses have been appearing for six years in this periodical.)

Feeling well disposed toward *The Wall Street Journal*, we laid it aside and took action to maintain the trend. Of "supplies" that *The Wall Street Journal* mentioned, none is older than photographic plates—our original product. For the love of challenge, we decided to get ready for the printer a chart that would put the photographic plate right into the spearhead of photography's onslaught on current technology.

The chart is now ready. You may have a copy with our compliments for your photo department wall. Indicate interest to Eastman Kodak Company, Special Sensitized Products Division, Rochester 4, N. Y. It takes 29" x 16½" to set out enough information about our 75 species of plates to permit industry and technology some intelligent basis for choice. You will receive the chart accompanied by a little pamphlet on dimensional stability entitled "Physical Characteristics of Kodak Glass Plates." Gist of the pamphlet's message: if there were no such thing as the glass photographic plate, it would be necessary to invent it.

Useful Invention concerning bases to carry photographic emulsion has, in all candor, taken place; we would be fools to ignore it. Instead of ignoring it, we have been busy for the past several years setting up the newest, smoothest-running process and plant for the manufacture of polyester film base. Last month, convinced in our own good time of the advantages to the user in our own methods of making and orienting the polymer, we released its product for sale. It will suit technologists who have learned to prefer Kodak emulsions, yet require low thermal coefficient of expansion, extreme resistance to tearing, indifference to the effects of humidity change on flatness and dimensional change, and/or inertness to most organic solvents. Though polyester cannot match glass in any of these attributes, it has about half the temperature response and much less than half the humidity response of cellulose ester at its best, and it provides a great many square yards of image on a very small weight and thickness of support. Nor does a sheet of it make an unpleasant noise when dropped.

The first emulsion to go on what we call *Estar Base* is one yielding very high density and very high contrast without imposing the usual severe demands of such photomechanical emulsions in precision of exposure and processing. For help in locating a dealer who stocks this *Kodalith Ortho Film, Type 3* (*Estar Base*), write Eastman Kodak Company, Graphic Reproduction Division, Rochester 4, N. Y.

Next month *Kodagraph Autopositive Film* (*Estar Base*) reaches the dealers. In this, light falling on the film through a yellow filter undoes the effect of a factory pre-exposure, so that the result is a positive image. Since the technique is much used for preparing intermediates of engineering drawings, the dimensional constancy and extraordinary durability of the new base will be a great boon.

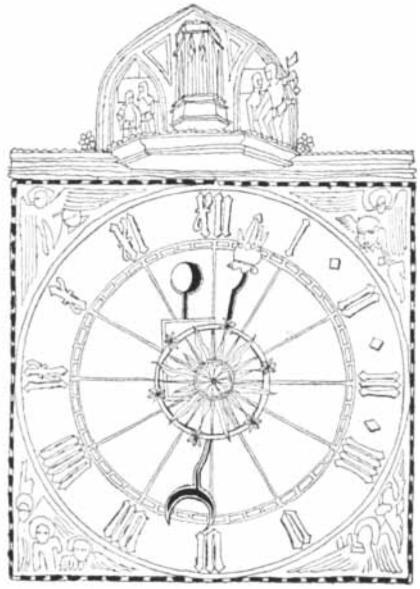
These, obviously, mark only the beginning of *Estar Base.*

You know something? $250 million a year is peanuts.

Prices quoted are subject to change without notice.

Kodak
TRADE MARK

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



SCIENCE AND

The Nobel Prizes

Two biochemists and two physicists in the U. S. and a physical chemist in Czechoslovakia are the winners of the 1959 Nobel prizes in science, each equivalent to $42,606.

Severo Ochoa of New York University and Arthur Kornberg of Stanford University, described in their citation as "two of the best biochemists of the present time," shared the physiology and medicine prize for "discoveries of the mechanism in the biological synthesis of ribonucleic acids (RNA) and deoxyribonucleic acids (DNA)." These substances are thought to play a central role in transmitting genetic information from generation to generation, and in directing the synthesis of protein molecules in living cells [see "Nucleic Acids and Proteins," page 55].

According to present theories DNA is the substance of the genes. It consists of a long, double-stranded molecule made up of combinations of four similar units called nucleotides. When a cell divides, the strands are thought to separate, each assembling on itself a new complementary strand. Kornberg and his colleagues, then at Washington University in Saint Louis, discovered a bacterial enzyme that can join nucleotides together into DNA molecules outside the living cell. Obtained from the bacterium *Escherichia coli*, the enzyme is known as polymerase. When added to a mixture of nucleotides, together with a small amount of DNA to serve as a "primer," it produces DNA apparently identical to the priming molecules. Thus the mechanism by which DNA supposedly reproduces itself in the cell has been demonstrated in the test tube. Kornberg has not shown that his synthetic DNA is biologically active, but he is now working on the problem.

DNA is found only in the nucleus of the cell. RNA is found outside the nucleus in the cytoplasm, but it is thought that it is made in the nucleus and moves out to the cytoplasm to direct the assembly of protein molecules. Ochoa and his co-workers have synthesized RNA in the test tube with the aid of the enzyme polynucleotide phosphorylase, obtained from the bacterium *Azotobacter vinelandii*. Again with the help of some primer material they can make molecules consisting of various combinations of the four basic nucleotides, as well as simpler chains containing a single nucleotide. At present Ochoa is trying to purify the enzyme in order to study its action in greater detail.

The physics award went to the co-discoverers of the antiproton: Emilio Segrè and Owen Chamberlain of the University of California. For 25 years physicists had been confident that the antiproton existed; they saw that P. A. M. Dirac's theory of the electron, which had successfully predicted the existence of the antielectron, or positron, should also apply to the proton (and to all other elementary particles). They knew what properties to look for: The antiproton would have the same mass as the proton and an equal but opposite (negative) charge. When it collided with a proton, the two particles would disappear in a mutual annihilation, releasing energy in the form of gamma rays. The antiproton would be produced in a high-speed particle collision, its creation requiring a particle with an energy of about six billion electron volts (Bev).

It was precisely this requirement that the University of California's six-Bev proton accelerator, the Bevatron, was designed to meet. When the machine was ready, a team headed by Segrè and Chamberlain set out to make and detect antiprotons. They bombarded a copper target with six-Bev protons. By an elaborate and ingenious system of bending- and focusing-magnets, counters and timers, they sorted the subatomic debris resulting from the collision and unequivocally identified antiprotons. Shortly afterward they also demonstrated the mutual annihilation of antiprotons and protons in photographic emulsions.

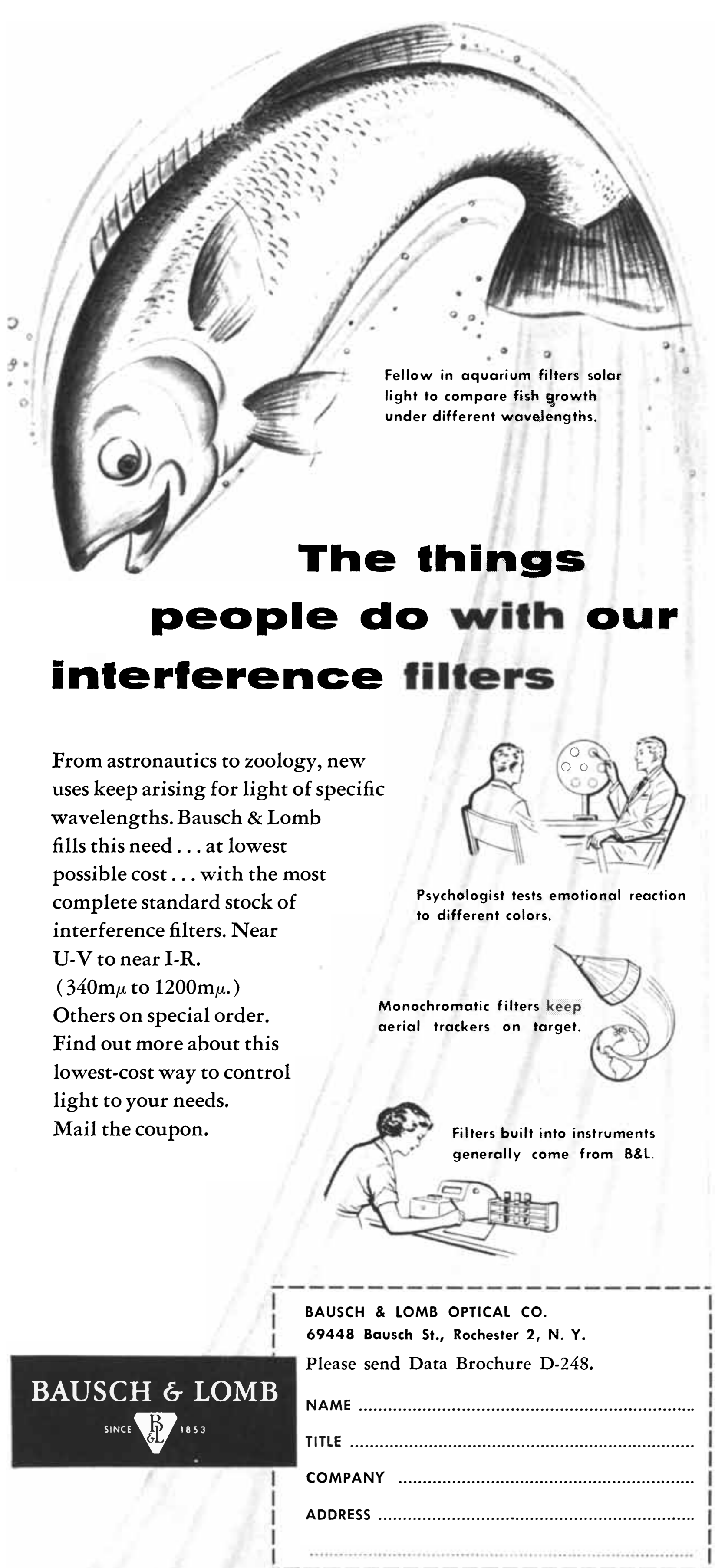
Jaroslav Heyrovsky, director of the Polarographic Institute in Prague, won the chemistry prize for his invention in 1922 of the analytical technique known as polarography. His apparatus consists of an electrolytic cell containing a large electrode and a very small one. Chemical reactions between the small electrode and the atoms or molecules under study determine the current that flows through the cell. As the voltage is increased the current increases up to a point and then levels off at a "limiting" value. This happens when the molecules react as fast as they diffuse to the electrode from the solution. The size of the limiting current depends on the concentration of molecules and their diffusion rate. The voltage at which the electrode reaction takes place depends on the type of molecule. Hence polarography is a method for both quantitative and qualitative analysis. It is fast and convenient, and is applicable to a very wide range of substances down to low concentrations.

The Back of the Moon

Man's first blurred view of the other side of the moon suggests that current theories of the origin and history of our natural satellite may require revision. Photographs taken by the Soviet space vehicle that passed within 5,000 miles of the moon appear to indicate that the topography of the moon's hitherto unobservable hemisphere is considerably less varied than that of its familiar face.

The Soviet vehicle, launched on October 3, crossed the moon's orbit some three days later. Shortly thereafter, in response to radio signals from earth, it pointed its two cameras at the moon and made the photographs. They were developed in the vehicle and were radioed back to the earth; one of them was released in Moscow on October 27.

The photograph showed nearly three quarters of the hidden part of the moon's surface (irregularities in the moon's motion make about 60 per cent of its surface accessible to direct observation). It revealed a number of sizeable craters as well as a mountain range of peculiar topography. Its most conspicuous fea-



ture, however, was the paucity of conspicuous features.

U. S. experts were reluctant to comment in detail on the photograph until they had seen clearer prints. Several of them also pointed out that the monotonous topography might be an illusion because at the time the photograph was made the sun's light was striking the back of the moon at an angle that would "wash out" much topographic detail. In at least one major feature, however, the back of the moon seems to differ radically from the front. Shadows on the surface appear to show a long mountain range (Soviet workers have christened it the Soviet Mountains) that resembles mountain chains on earth rather than other lunar mountains.

Terrestrial mountains are thought to have been thrown up by slow currents in the earth's plastic mantle and by volcanic action. Lunar mountains, by contrast, seem without exception to have been formed by the impact of meteorites, leading selenologists to conclude that the moon's interior has been cold and rigid during most of its history. The new mountain range indicates that this conclusion may have to be modified.

Soviet astronomers have named several other features revealed by the photographs. Apart from the Soviet Mountains and a large crater which they have christened the Moscow Sea, they have adhered to the tradition by which craters have been named after scientists or explorers, and larger features have been given poetic designations. They have named craters after Konstantin E. Tsiolkovsky, the Russian rocket pioneer; Mikhail V. Lomonosov, the 18th-century Russian poet and scientist; and the late French physicist Frédéric Joliot-Curie. A large, dark area at the edge of the photograph has been named the Sea of Dreams.

Radiation Compromise

A long-standing disagreement between U. S. authorities and those of other nations as to safe limits of radiation exposure for the general population was settled last month.

The U. S. National Committee on Radiation Protection and Measurement, a nongovernmental group of about 40 experts, has been recommending that the maximum permissible exposure of the population at large be set at a 10th of the corresponding value established for radiation workers. Meanwhile the International Committee on Radiation Protection has called for a figure of a 100th of the permissible occupational

THIS IS GLASS

A BULLETIN OF PRACTICAL NEW IDEAS FROM CORNING

NEW! A MIRROR THAT MAKES HEAT TO BEAT SLEET

You're jockeying a big trailer-truck along a winding road in New England. It's winter and you run into a real storm—a mixture of snow, rain, sleet. You flip a switch and . . .

Your outside rear-view mirror is *clear* in a matter of minutes. From a heavy coating of ice to *all* clear is only a matter of five minutes, even at −20°F.

The mirror, as you might guess, isn't just ordinary glass. It's one of Corning's PYREX brand glasses, and on its surface is an electrically conductive coating that's permanently fired in.

This coating (a metallic oxide) is what turns your mirror into a *heating* element when a current is applied. The heat melts ice and snow, prevents fog or drizzle from freezing on the surface.

If you use EC (electrical-conducting) glass for self-defrosting mirrors you get a bonus, since the coating also provides a non-glare surface.

But don't go away just because you gave up dreaming about driving a truck-and-trailer years ago. This PYREX® electrical-conducting glass comes in a wide choice of applications.

For example, there are some enterprising people who build radiant heaters, both portable and permanent, around such glass panels.

Comfort, safety, and convenience are the big selling points. Comfort because a panel of EC glass is an area *heat* source putting out long waves. Safety because there are no exposed wires or moving parts. Convenience since you have no burning, no need to do extensive remodeling in order to install it.

These same reasons have made PYREX brand radiant heating units attractive to industry—for heating, drying, curing, baking.

And, if you turn a panel of this glass *around*, it becomes an infrared reflector you can see through—blocking heat but still passing about 75% of the visible light.

Facts? Ask for PE-34, a 4-page data sheet, and/or PE-60, all about industrial heating units. Please use the coupon.

CHROMATOGRAPHY COLUMNS —COILED, READY FOR TOIL

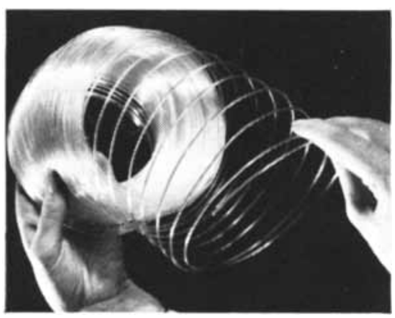
Till now, those analysts using capillary coils were hung on the horns of two displeasing alternatives: Theycould use a coil of synthetic material with a low heat ceiling. Or they could "roll their own" stainless alloy tubing which is fairly expensive.

"Till now," we say, for starting today such men can get PYREX brand glass capillary columns, already wound; coils that will perform at high temperatures; coils that are bargain priced in the light of their many advantages.

Like all PYREX labware, these coils are corrosion resistant. Their glass-smooth surfaces offer little resistance to gas flow, make coating and cleaning simple as can be.

Like all PYREX labware, these have the outstanding advantage of transparency—the analyst can be sure the inner surfaces of his coils are properly coated.

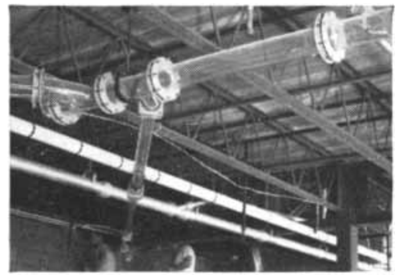
Coils can be had in standard lengths of 100, 200 or 300 feet, wound on 2″ or 3½″ centers. I.D.'s of the $\frac{1}{16}$-inch capillary tubing are 0.010″ or 0.020″. Specials will be made on request.



PYREX chromatographic columns like this one come already wound, ready for coating. They are heat resistant, chemically stable, modestly priced.

If you would like all the specs—and prices—we refer you to the coupon for a copy of Supplement No. 8 to PYREX Labware Catalog LG-1.

If you would like to see the rest of our chromatographic line—tubes, plain or graduated, with stopcocks or needle valves, write for LG-1.



PLUMBING FOR POSTERITY

An increasingly popular fixture in labs, hospitals, schools, chem plants, and photo-engraving shops is the glass drainline.

With good reason. Glass drainlines are fashioned from PYREX brand glass No. 7740.

This is the glass that ends your worries about corrosion. For example, if you were disposing of waste hot hydrochloric acid, your PYREX pipe would still be around at the end of 200 years.

And glass is smooth; very little chance for block-up in the pipe. If such does occur, however, you can spot the exact point and take corrective action, without having to take down the whole system.

In fact, almost anything made from PYREX brand glass No. 7740 will be around for quite a while because this glass is able to cope with thermal shock and physical knocks, too.

Available in many forms—tubing, rod, pipe, plate, and all kinds of shapes.

Fill in the gaps in your files with these basic references: PE-30, all about glass drainlines; IZ-1, design considerations in glass. Any or all, free. Use the coupon.

MORE ON PYROCERAM*

Developments in our new crystalline materials made from glass are treated at length in the third Pyroceram Progress Report. See coupon.

*Trade Mark

CORNING MEANS RESEARCH IN GLASS

CORNING GLASS WORKS 49 Crystal St., Corning, N. Y.

Please send me: ☐ PE-34, Corning Flat Glasses; ☐ PE-60, Heating Units; ☐ LG-1, PYREX Labware; ☐ Supplement No. 8 to LG-1; ☐ PE-30, Drainline Manual; ☐ IZ-1, Design Manual; ☐ Pyroceram Progress Report No. 3.

Name...Title..........................

Company...

Street...

City...................................Zone............State..................

dose. Following a meeting in Munich last summer the international group issued a report proposing a maximum of a 10th "for individuals in the population at large." The report urged, however, that for "planning purposes" the average exposure be restricted to a 100th. If matters are arranged so that no individual receives more than a 10th of the occupational dose, the Committee hopes and expects that the average exposure for the entire population will in fact turn out to be much smaller.

No official action has yet been taken by the new Federal Radiation Council, set up by the President last summer to establish standards of safety. Members of this Council are the secretaries of Defense and of Health, Education and Welfare and the chairman of the Atomic Energy Commission.

Radio Bands for Astronomy

Heeding the pleas of radio astronomers and scientific societies both in this country and abroad, the U. S. delegation to the current 84-nation conference of the International Telecommunications Union in Geneva has asked that 17 radio bands be reserved for radio astronomy. Originally the U. S. had requested that only the frequency band from 1,400 to 1,427 megacycles (where the hydrogen in space emits its signals) be reserved for astronomical studies ["Science and the Citizen," November].

Astronomers quickly became alarmed over the possibility that the remaining bands in the cosmic radio-spectrum would be allocated for commercial or military use. Because of the extreme sensitivity of radio telescopes, interference from a transmitter anywhere on the earth can effectively jam signals of the same frequency emitted by sources in space. The change in the U. S. position was warmly praised by radio astronomers, who felt that it helped to set a precedent that would protect their young discipline from the inroads of expanding radio communications.

Solar Reversal

Map makers who have been plagued by minor anomalies in the earth's magnetic field may console themselves that they are not faced with the problem of charting the face of the sun. Harold D. Babcock of the Mount Wilson and Palomar Observatories has confirmed his observation that the magnetic poles of the sun have exchanged places within the past two years. Should a similar switch occur on the earth, all compasses

would point south instead of north. Still more curious is his finding that the reversal took place one pole at a time, giving the sun two north poles for several months.

Solar magnetism has troubled astrophysicists for a long time. Despite the size of the sun, its magnetic field is no stronger than the earth's. The strength of the field fluctuates sharply, sometimes becoming too weak to detect. The over-all field is much weaker than the powerful localized magnetic fields that accompany sunspots. With their magnetic axes perpendicular to the surface, the sunspot fields in the Southern Hemisphere of the sun are polarized opposite those in the Northern Hemisphere; this polarity is known to reverse itself every 11 years.

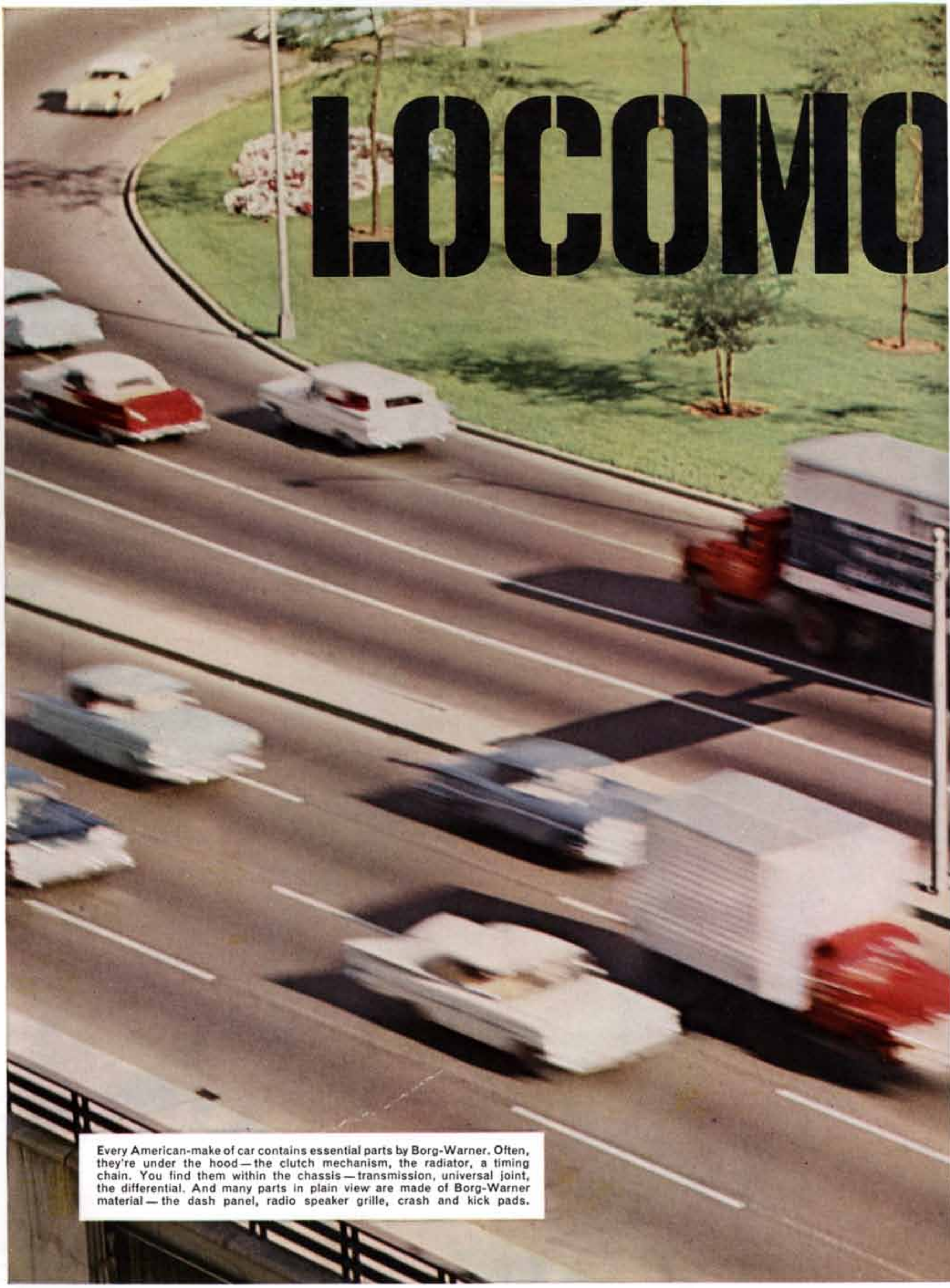
The reversal of the sun's magnetic poles and the magnetic cycle associated with sunspots suggest to Babcock that the two hemispheres of the sun act "semi-independently" of each other. Vast currents of hot gas beneath the surface of the sun may interact with the over-all magnetic field to produce these strange effects.

The Sea Lamprey Defeated?

The sea lamprey, the eel-like bloodsucking parasite that invaded the upper Great Lakes two decades ago and all but exterminated the commercially important lake trout, is now being brought under control by chemical means, according to the joint U. S.-Canadian Great Lakes Fishery Commission. Trout are so scarce in the lakes, however, that the job of restocking will be tremendous.

The sea lamprey has always been capable of living in fresh water, but did not move into the upper Great Lakes until the 1930's [see "The Sea Lamprey," by Vernon C. Applegate and James W. Moffett; Scientific American, April, 1955]. The catch of trout in Lake Michigan, Lake Huron and Lake Superior declined from 15.5 million pounds in 1938 to 1.5 million pounds in 1958.

Since 1951 the U. S. Fish and Wildlife Service has used electrically charged barriers to trap sea lampreys in the streams where they spawn. Although the barriers destroyed large numbers of lampreys, they did not bring the parasite under control. Chemical methods, however, seem capable of defeating the lamprey. After some 6,000 substances had been tested in the laboratory, a successful field trial was conducted in 1957. The Fishery Commission is now using



Every American-make of car contains essential parts by Borg-Warner. Often, they're under the hood — the clutch mechanism, the radiator, a timing chain. You find them within the chassis — transmission, universal joint, the differential. And many parts in plain view are made of Borg-Warner material — the dash panel, radio speaker grille, crash and kick pads.

TION

BY BORG-WARNER

A revealing look at the many ways in which a vigorous corporation helps you get from place to place

Ours is a nation of over 80 million vehicles—everything from automobiles to ambulances, from taxis to tractors, from cross-town busses to cross-country trucks. And Borg-Warner Corporation makes parts that help keep these wheels rolling.

Take the automobile. We've been working hand-in-hand with the manufacturers of cars since the running-board era. Over the years, our search for better automotive components has produced exactly that—like the first standard transmission and an improved automatic transmission, development of a universal joint and a spin-resistant differential. Today, we're busy researching still better products into reality—for the models of '62, '66, '70.

Every Borg-Warner part that goes into an automobile is, in itself, quite a remarkable piece of machinery—and it's made of *more* than metal. In Detroit, Flint and Lansing and in Kenosha and South Bend, car-makers know that Borg-Warner delivers parts with built-in *quality*.

Borg-Warner Corporation contributes to far more than the automotive industry alone. We supply parts to the aviation and oil industries. We make industrial machinery, farm equipment and products for the home. We're deeply involved in national defense. And, in each area of Borg-Warner's activity, *you and your family* are the final beneficiaries.

B-W

BORG-WARNER

200 South Michigan Avenue • Chicago 4, Illinois

It's a better product when Borg-Warner makes it

OFF AN ASSEMBLY LINE at the Warner Gear Division plant come automatic transmissions which, by action of your fingertip, transmit power from engine to axle.

SMOOTH OPERATION of engine depends on a perfectly balanced clutch—assured in a Borg & Beck Division clutch by tests on this sensitive, specially designed machine.

READY FOR SHIPMENT by Mechanics Universal Joint Division: drive shafts and universal joints with fewer parts for easier assembly and service.

TINY AS IT IS, the Spring Division's full-phasing one-way sprag clutch is vital to the smooth, reliable performance of a modern automatic transmission.

"EXCLUSIVE ROLLER ACTION of this clutch," says an engineer of the Rockford Clutch Division, "requires less foot-pedal pressure from the driver of a truck or a bus."

FLUID TORQUE CONVERTER, built with the superior engineering of Long Manufacturing Division, delivers a smooth flow of power from the very instant of acceleration.

OTHER DIVISIONS AND SUBSIDIARIES serving the automotive industry: Borg & Beck do Brasil, S.A. • Borg-Warner Ltd. (England) • Borg-Warner (Australia) Ltd. • Calumet Steel • Franklin Steel • Ingersoll Products • Ingersoll Steel • Long Manufacturing Company Ltd. (Canada) • Marbon Chemical • Marvel-Schebler Products • Morse Chain Company • Morse Chain of Canada Ltd. • Warner Automotive • Warner Gear Company Ltd. (Canada) • York

WHAT BORG-WARNER MEANS TO YOU!

Behind the wheel or beside the driver? City boulevard or country highway? Commuting to work or vacation-bound? Mechanical-minded or not? You experience the joy of a comfortable ride, the anticipation of a safe journey, the assurance of dependable and responsive machinery—thanks, in part, to essential automotive products made by the divisions and subsidiaries of Borg-Warner Corporation.

fluorinated nitrophenol, which kills lampreys but not valuable fish. Since 1957 the Commission has been concentrating on saving a breeding stock of trout in Lake Superior. Now it plans to release the chemical in the other two upper lakes. Although it will take years to restore the trout population, it is expected that the trout will once again support a substantial fishing industry.

Indestructible Detergents

Synthetic detergents, which resist both artificial and natural water-purification processes, are creating a public-health problem in some places by coming out of the tap in "purified" drinking water, according to Jesse M. Cohen, a U. S. Public Health Service chemist.

At a recent meeting sponsored by the American Public Health Association, Cohen said that although synthetic detergents have been known for only 25 years, 3.8 billion pounds were consumed in the U. S. last year, as compared with 1.3 billion pounds of ordinary soap. The latter is completely responsive to both artificial and natural sewage-treatment. Cohen said that concentrations of detergents in drinking water as low as .8 parts per million are easily detected by the fact that they foam at the faucet. In addition to polluting drinking water, detergents carry phosphate compounds that promote the growth of algae, which also contaminate the water.

Much effort is being devoted to removing detergents during sewage treatment. Detergent manufacturers, reports Cohen, are working to change their products so that the microorganisms that break down sewage can also break down the detergents. He suggests that new compounds made from sucrose will replace the present petroleum-based detergents. The sucrose detergent, now reaching commercial production, is readily decomposed by sewage-disposal microorganisms.

Power from Plasma

The current revival of research interest in such historically neglected electrical generators as fuel cells and thermoelectric devices has now spread to another obscure power source: the plasma generator. This device produces electric power directly from a gaseous jet of electrons and positive ions, and possesses an inherent thermal efficiency of from 40 to 50 per cent. A research group at the Aerosciences Laboratory of the General Electric Company has built an experimental model that generated a

kilowatt of electrical power during a five-second test.

The plasma generator operates on the principle of induction discovered by Michael Faraday in 1838, when he observed that an electrical conductor moving across a magnetic field generates a current. Faraday himself demonstrated the special "magnetodynamic" application of the principle represented in the plasma jet. By measuring the voltage induced by the motion of the brackish Thames through the earth's magnetic field, he obtained a crude reading of the flow-rate of the river.

In the plasma generator a powerful electromagnet provides a field much more intense than the earth's, and the gently flowing Thames is replaced by a plasma jet blasting through a quartz nozzle. The nozzle, roughly the size and shape of a cigarette package, is sandwiched between the poles of the magnet. As the ions in the plasma rush through the nozzle, they cut magnetic lines of force and spiral toward the nozzle wall, where they are drained off as current by two graphite electrodes.

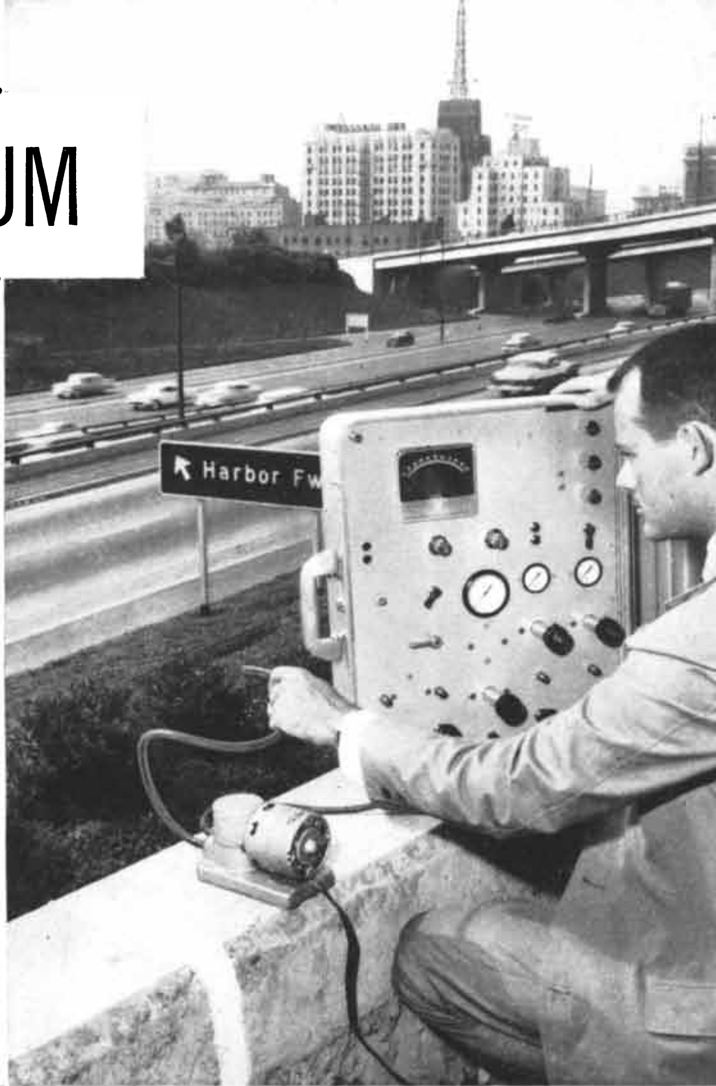
The size and performance of the research model fall short of the theoretical ideal. With a magnet weighing 600 pounds and the plasma heated to 8,000 degrees Fahrenheit, its efficiency proved extremely low. The General Electric workers nonetheless believe that within two years they can build a lighter, more compact model capable of operating in the 5,000-degree environment of a rocket exhaust. In a two- or three-second burst, they say, such a generator could produce enough power to transmit a strong signal from a space vehicle.

Writing in the British journal *Research*, R. G. Voysey of the British Ministry of Power rates the magnetodynamic plasma generator as less promising than a similar device that he classifies as electrodynamic. An electrodynamic generator works like an ion rocket in reverse. Where the rocket accelerates hot gases by means of grids carrying an attractive charge, the generator decelerates the plasma by funneling it through a nozzle containing repulsively charged grids. The work done in moving the plasma against the electric field is converted to electrical energy when the ions reach a collecting grid near the nozzle exit.

Voysey observes that various types of plasma generators have been patented in several countries in the past. But there was little hope of building a practical model, he says, until efforts to harness thermonuclear reactions during the past few years yielded new insights into the behavior of plasmas.

THE P-E SPECTRUM

news of advanced systems and instruments from Perkin-Elmer

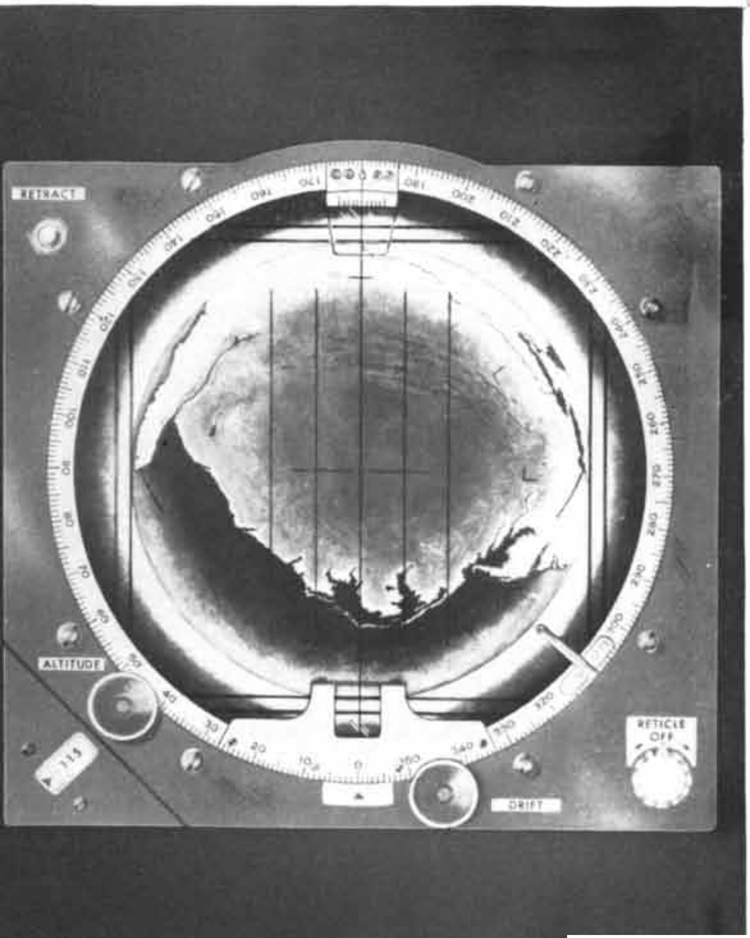


NEW PORTABLE INSTRUMENT DETECTS HYDROCARBON TRACES IN ATMOSPHERES AND GASES

Traces of hydrocarbons and many other organic vapors in the atmosphere or in gases can be detected rapidly and easily with a new instrument costing less than one-third that of conventional equipment. This Hydrocarbon Detector, developed by Perkin-Elmer, is a self-contained portable unit. It is suitable for monitoring air pollution or lower explosive limits of atmospheres, and can also serve as a leak or impurity detector in lab, field or processing systems.

Such organic compounds as hydrocarbons, aldehydes, ketones, amines and alcohols are determined when present in concentrations as low as 0.1 parts per million. There is no interference from common backgrounds — water vapor, oxygen, nitrogen, CO_2 and rare gases. Response time is less than two seconds.

Heart of the novel device is the Flame Ionization Detector, recently incorporated in Perkin-Elmer's gas chromatographic instruments. Its principle: A metered quantity of sample is exposed to a hydrogen flame in an enclosed chamber. Combustibles are ionized to effect changes in current flow in a surrounding electrical field. These changes are proportional to the sample's total organic carbon content. Results are read out on Detector's meter or an attached milliamp or millivolt recorder.



MERCURY ASTRONAUT WILL CALCULATE POSITION WITH UNIQUE PERISCOPE SYSTEM

The Mercury space capsule will bear man around the world in some 90 minutes — a far cry from Jules Verne's 80 days. To solve the difficult problem of determining his position quickly and accurately, the Astronaut will have a unique periscope system designed and built by Perkin-Elmer for the McDonnell Aircraft Corporation, prime contractor for the National Aeronautics and Space Administration's Project Mercury, Manned Orbital Space Flight Capsule.

The system will present its information on an 8″ screen showing, at orbital altitude, a 1,700-mile-diameter area of the earth. An optional altimeter which measures this diameter as displayed on the screen will give the Astronaut his altitude.

For navigational purposes, other indices will measure the angle made by the sun or moon with the longitudinal axis of the capsule, its position above the earth's surface, capsule attitude and drift angle. Thus, if the automatic reentry control system malfunctions, the Astronaut can use the periscope to determine when to fire retrograde rockets to slow the capsule to safe reentry speed.

* * * *

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SPIRAL GALAXY resembling our own is NGC 5194, shown in this photograph made with the 200-inch telescope on Palomar Mountain. Cosmic dust appears as dark wisps at the insides of the arms. The bright blob at bottom is NGC 5195, a companion galaxy.

THE ARMS OF THE GALAXY

Astronomers have long believed that our galaxy is a giant spiral. By combining new optical techniques and radio evidence, they are now beginning to prove it

by Bart J. Bok

Once every 200 million years the sun completes one revolution about the center of our galaxy. To an observer in another galaxy ours would appear as a flattened disk of stars, gas and cosmic dust 80,000 light-years in diameter. In the neighborhood of the sun, about halfway between the center of the galaxy and its edge, the disk is only about 5,000 light-years thick; in the center the disk bulges out to about three times this thickness.

Only a fraction of the galaxy is visible from the earth. The view of even the largest telescopes is obscured by the clouds of dust floating in the central plane of the galaxy; in this plane it is impossible to see farther than 20,000 light-years. In other directions we can perceive galaxies millions of light-years away, many of which have handsome spiral patterns. For years most astronomers agreed that our galaxy also has a spiral structure, but there seemed to be no way of proving it.

We tried to tackle the problem by brute force. By counting stars and sorting them according to their brightness, their color and their spectral lines, we attempted to detect statistical "bumps" or patterns of star distribution that might suggest spiral arms. These studies failed so conclusively that in my lectures during the 1930's I often stated that I had no hope of seeing the structure problem solved during my lifetime.

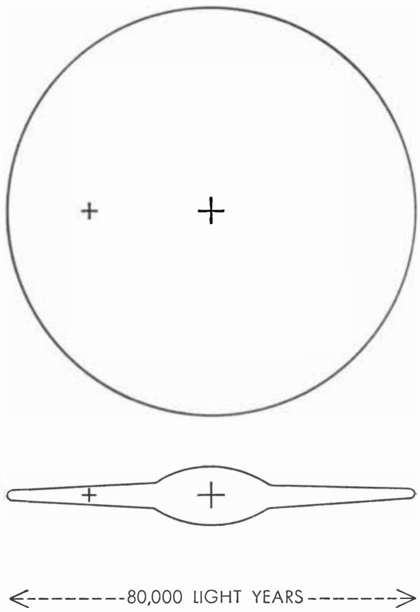
Then came the break-through. In the middle and late 1940's Walter Baade of the Mount Wilson and Palomar Observatories demonstrated that the best way to determine the structure of our galaxy was to find out what kinds of stars most clearly marked the arms of other galaxies. With the 100-inch telescope on Mount Wilson and later with the 200-inch on Palomar Mountain, Baade examined the spiral of the nearby Great Nebula in Andromeda. By skillfully manipulating color filters and fast, red-sensitive photographic emulsions he was able to show that luminous blobs of gas—the so-called emission nebulae—traced out the arms of the Andromeda spiral like a string of street lamps.

Soon additional spiral tracers were found, including cepheid variable stars with long periods of pulsation, clumps of young stars known as galactic clusters, and even the troublesome cosmic dust, which was observed to accumulate at the inner edges of spiral arms [*see illustration on opposite page*]. The most interesting tracers proved to be the hot, blue-white supergiant stars, classified (according to their color and spectral characteristics) as O or B stars. These stars, which follow the spiral arms quite closely, are truly mighty radiators, many of them being 10,000 to 100,000 times brighter than the sun. Because they are visible for great distances through the cosmic haze, Baade advised his fellow astronomers that to map the arms of our galaxy they had only to locate its bright O and B stars, measure their distances from the earth and plot their positions accurately on a chart.

The Optical Model

A vigorous search for the supergiants was quickly pressed by W. W. Morgan and his colleagues at the Yerkes Observatory of the University of Chicago. The task of measuring distances accurately was complicated by the fact that such stars are often found in loose groups or "associations" which are embedded in clouds of gas or are partially hidden by drifts of cosmic dust. These drifts, lying in the line of sight between the star and the earth, act like red filters, dimming and reddening the light passing through them. Because we measure the distance to a remote star by applying the law that the intensity of light diminishes inversely with the square of the distance, the "space reddening" caused by dust makes the star appear farther away than it really is.

We can nonetheless determine the distances to partially obscured stars with fair accuracy. We first measure the star's spectral lines, then estimate its true color on the basis of its spectral classification. The difference between the true color and the measured apparent color indi-

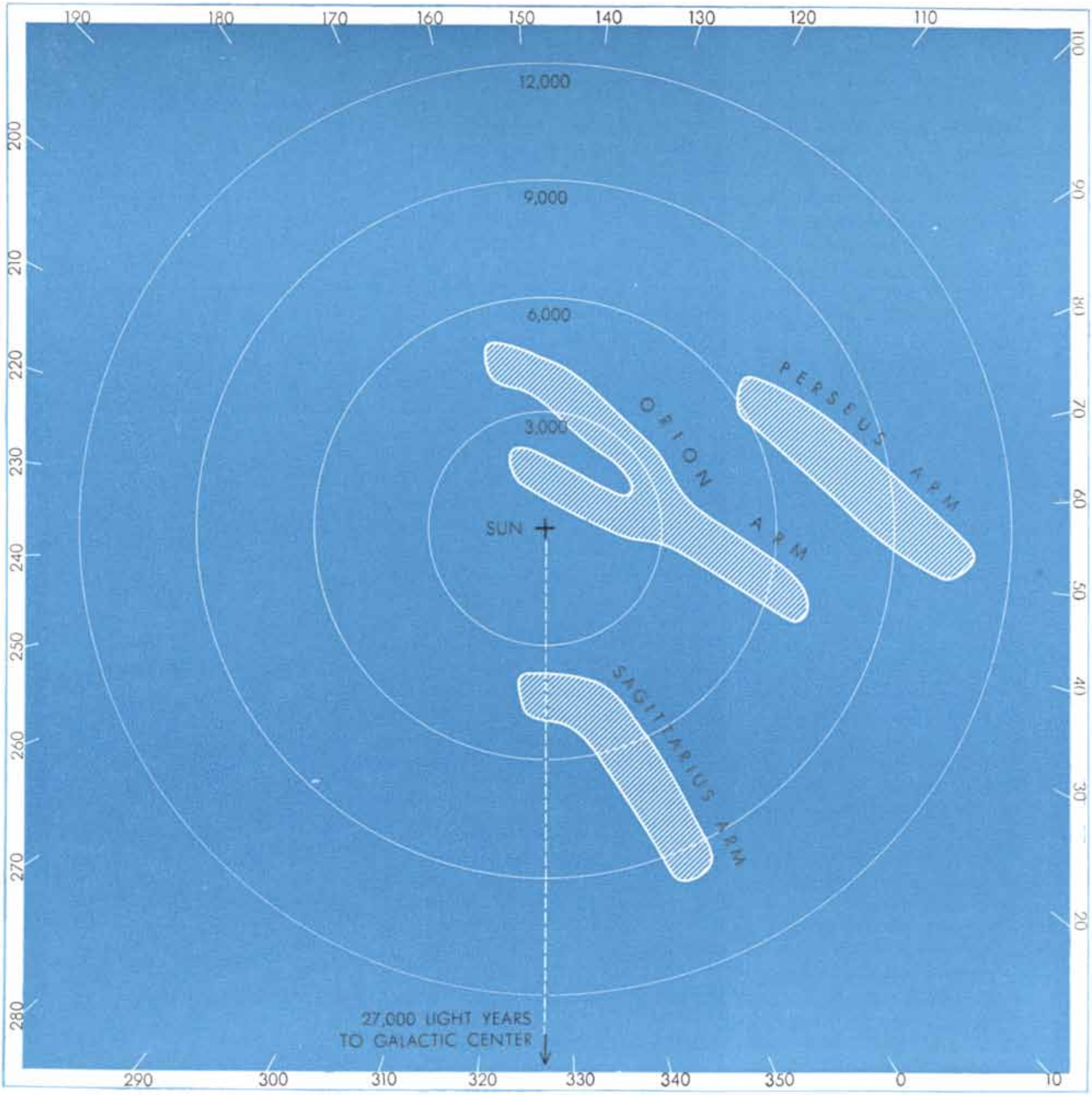


OUR GALAXY, seen from above (*top*) and from the edge (*bottom*), appears as a bulging disk in this schematic diagram. The larger cross indicates the center of the galaxy; the smaller one, the position of the sun.

cates the amount of cosmic dust that lies between the star and the observer. Once this is known we can determine the distance to the star by adding an appropriate correction factor to the inverse-square law.

Using this method, Morgan and his associates Stewart Sharpless and Donald Osterbrock accumulated enough information by the end of 1951 to draw a tentative diagram of the spiral arms in the neighborhood of the sun. When they presented their model at the Cleveland meeting of the American Astronomical Society, its impact on the assembled astronomers was impressive. Here, for the first time, the spiral structure of the galaxy began to unfold.

The model showed that a giant spiral arm extends from the direction of the constellation Orion, enfolds the sun and its planets and swerves off in the general direction of Cygnus. Morgan later called this the Orion Arm. A second arm, well separated from the first and 5,000 to 7,000 light-years farther from the center of the galaxy, was named the Perseus Arm because the famous double star-cluster in Perseus is the most prominent object within it. In the direction of the constellation Sagittarius, Morgan found a few nebulae and associations outlining a possible third arm, located about 5,000 light-years closer to the galactic center than the Orion Arm. Because he had no data for the Southern Hemisphere, Morgan was unable to trace the full extent of the Sagittarius Arm, but he suspected that it was connected to a section of an arm that lay in the direction of the constellations of Carina and Centaurus, near the Southern Cross.

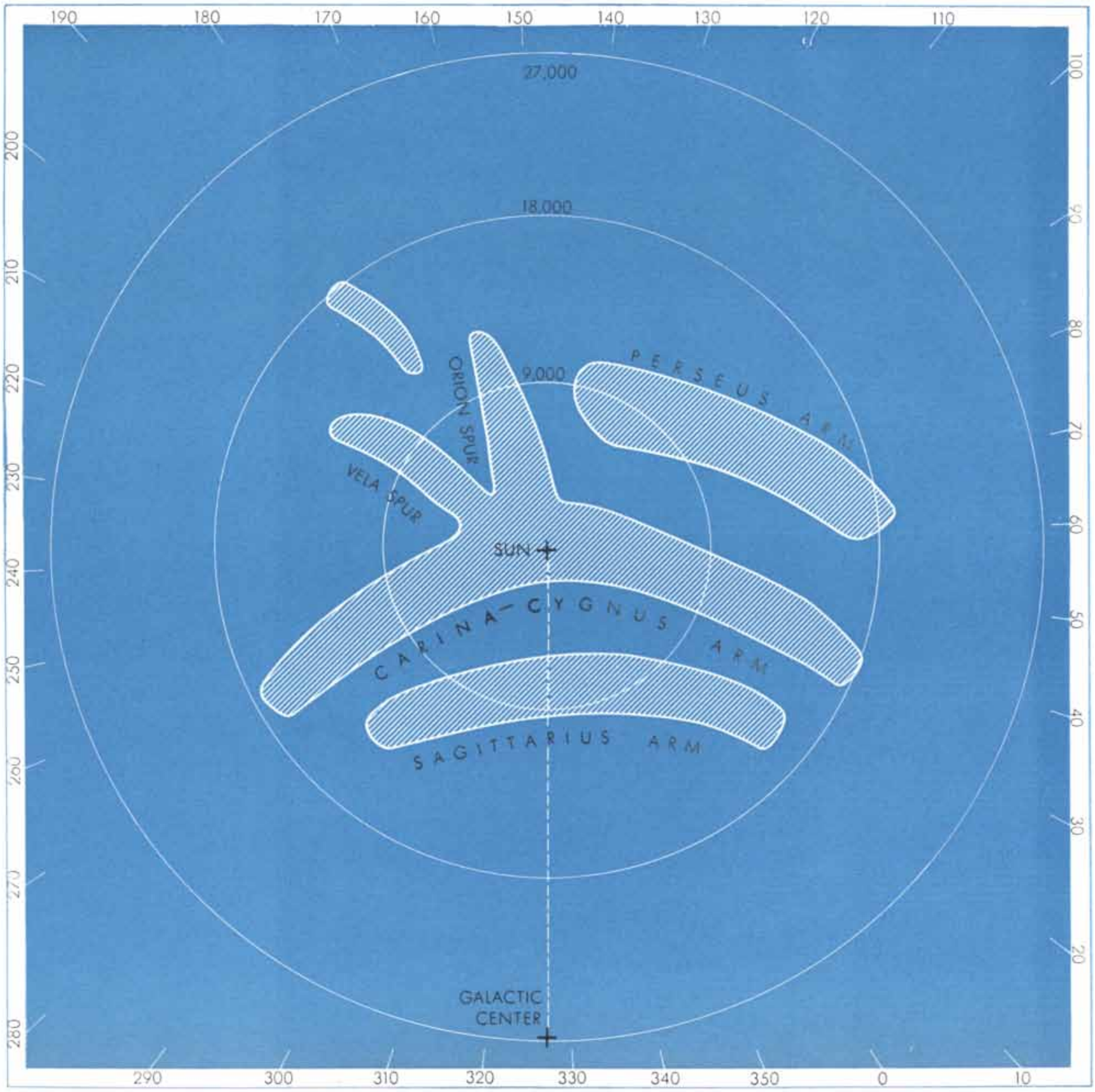


EARLY OPTICAL MODEL traced the structure of the spiral arms near the sun. The numbers around the edge of the map indicate degrees of longitude in the plane of the galaxy. Numbered circles show distance from the sun in light-years. Dotted line shows direction of the galactic center. This drawing is based on the model proposed in 1952 and 1953 by W. W. Morgan of Yerkes Observatory.

After Morgan had presented his dramatic paper there was every hope that the rest of the galaxy's spiral structure might soon be charted, but it quickly became apparent that great difficulties lay ahead. Even with the new method it seemed impossible to map more than our immediate galactic neighborhood; there still appeared to be no way to penetrate more than 20,000 light-years into the cosmic haze. It was a happy coincidence that at just about that time the new techniques of radio astronomy provided a research tool that extended the search for spiral arms to areas apparently closed to optical observation.

The 21-centimeter radio signals emitted by interstellar clouds of neutral (un-ionized) hydrogen in our galaxy were first detected in 1951 by Harold I. Ewen and Edward M. Purcell of Harvard University. The relatively long wavelength of the signals enables them to penetrate clouds of cosmic dust, opening up vistas in all parts of the galaxy—and beyond. By 1952 it had also become clear that the signals were an excellent spiral tracer, since neutral hydrogen is at least 10 times more plentiful in spiral arms than in the "empty" regions between them. By measuring signal strength and slight shifts in wavelength we can locate the hydrogen clouds and hence the spiral arms.

The story of the 21-centimeter studies of spiral structure has been told by earlier articles in this magazine, most recently by Gart Westerhout of the Leiden Observatory in the Netherlands [see "The Radio Galaxy"; SCIENTIFIC AMERICAN, August]. The Leiden group, which includes J. H. Oort, H. C. van de



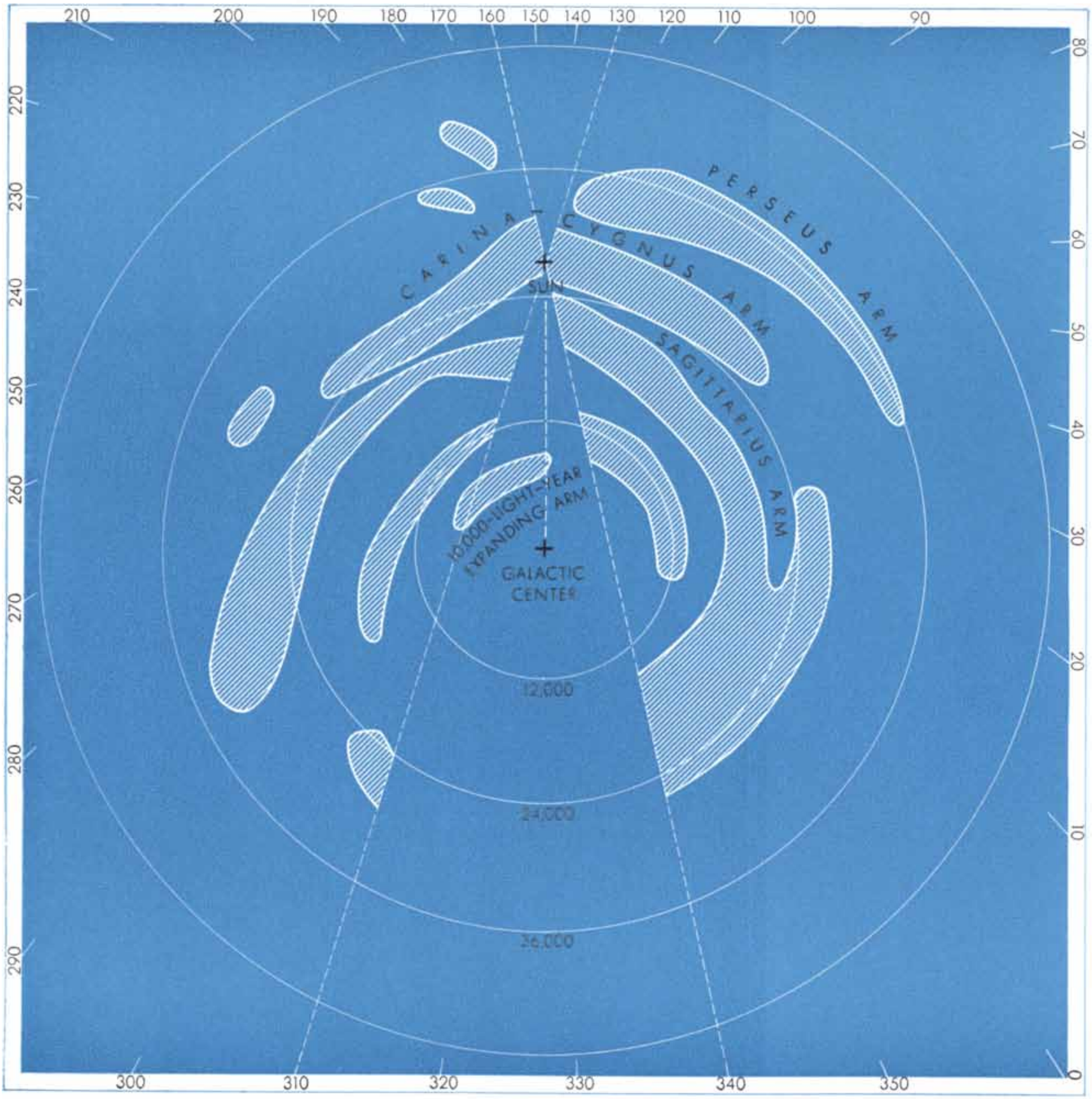
NEW OPTICAL MODEL shows the same region as the earlier model, but here the Orion Arm appears only as a short spur branching from a larger feature: the Carina-Cygnus Arm. In addition, the spiral arms in this model are almost circular, forming an angle of about 80 degrees with a line to the galactic center (*broken line*); the corresponding angle in the earlier model is about 55 degrees.

Hulst, C. A. Muller and M. Schmidt as well as Westerhout, has logged most of the basic observations in the Northern Hemisphere. In the Southern Hemisphere the principal investigators have been F. J. Kerr, J. V. Hindman and C. S. Gum of the Commonwealth Scientific and Industrial Research Organization in Australia. The combined results have made it possible to trace the spiral arms with fair precision to a radius of 25,000 light-years from the sun, and to obtain a picture of the over-all pattern to even greater distances. As the illustration below indicates, radio data have even made it possible to map the arms on the side of the galaxy opposite the sun.

The Model Revised

Up to this point I have told a success story, with Baade, Morgan and the radio astronomers in the Netherlands and Australia as the heroes. In 1953 Morgan presented a revised map of the nearby spiral arms that he believed was fairly complete, except for the Carina region [*see illustration on page 94*]. It looked as though we were making rapid progress. But as more data became available, the mapping of spiral features became increasingly difficult. Spiral tracers were found in low concentrations for thousands of light-years in every direction, making it necessary to extricate the major arms from a confused picture.

To complicate matters further, the radio data, which were expected to support the optical picture, instead contradicted it. In fact, the two pictures conflicted so sharply that Hugh M. Johnson, now working with us at the Mount



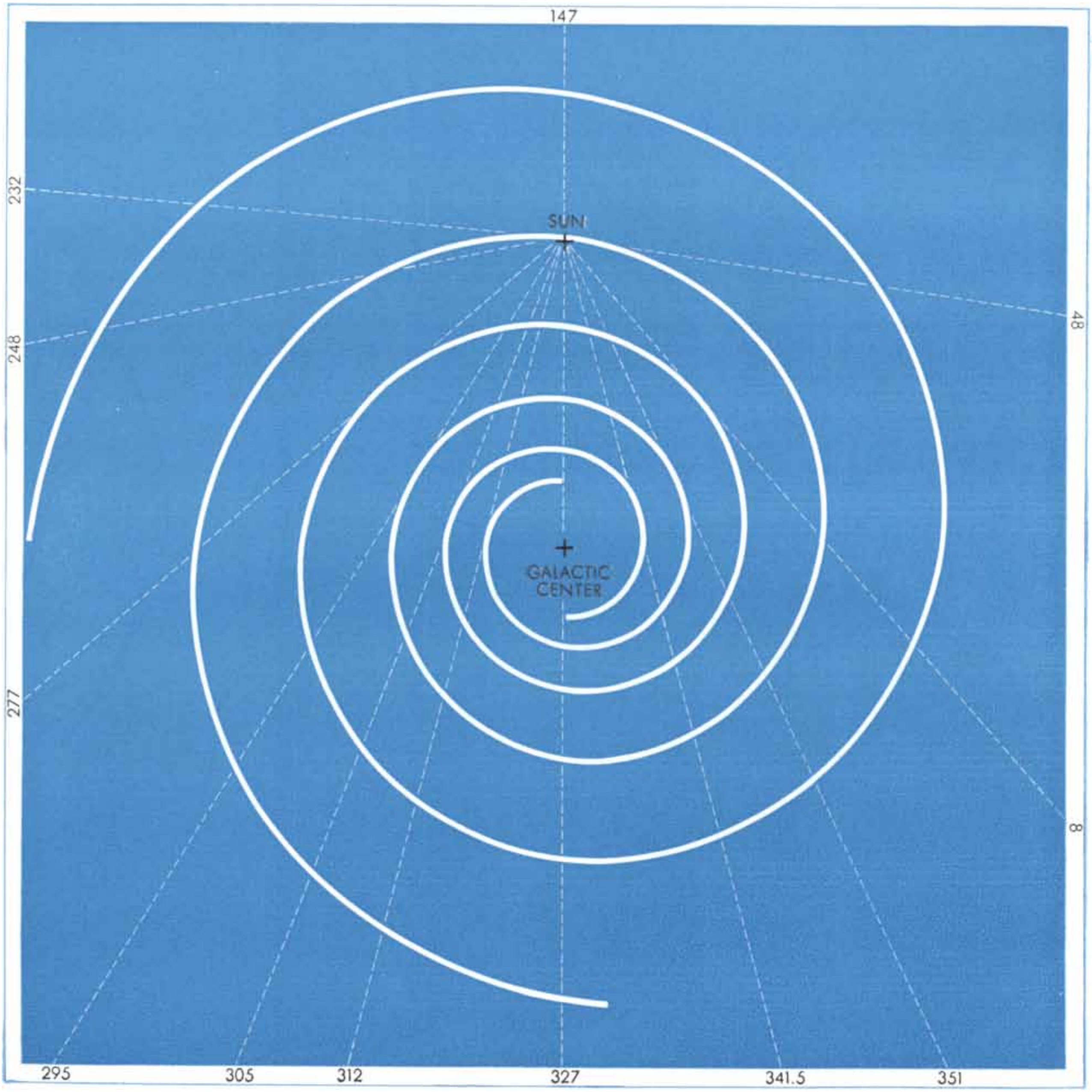
RADIO MODEL of the galaxy was made by charting the 21-centimeter signals emitted by interstellar hydrogen. The coordinates of this chart and the one opposite indicate degrees of galactic longitude in the plane of the galaxy. The numbered circles show distance from the sun in light-years. Data for the fan-shaped areas from longitudes 130 to 160 degrees and from 310 to 340 degrees are inconclusive because most of the gas in these areas moves perpendicular to our line of sight, making its red-shift unobservable.

Stromlo Observatory, commented that they hardly seemed to represent the same phenomena. I believe that this conflict can be resolved by modifying the optical model presented by Morgan as shown in the illustration on the preceding page.

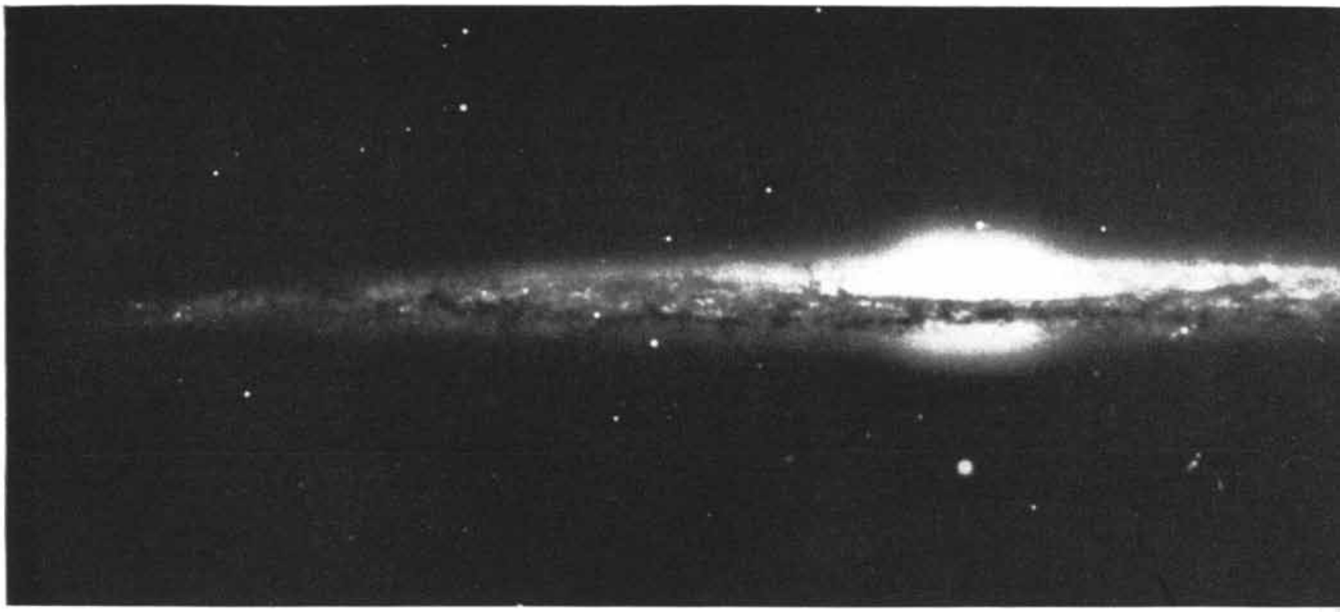
I have two reasons for suggesting the change. The first concerns the over-all shape of the spiral arms. In Morgan's diagram they are almost elliptical, forming an angle of 55 degrees with a line drawn to the center of the galaxy. But photographs of other galaxies show that their spiral arms are more nearly circular, forming an average angle of 80 degrees with the center line. The same picture emerges in 21-centimeter maps of our galaxy, though we must bear in mind that the 21-centimeter picture is a preliminary one and subject to revision.

Further radio evidence that the spiral arms are nearly circular has been presented by B. Y. Mills of the Commonwealth Scientific and Industrial Research Organization. Mills has made an extensive survey of the radio brightness of the southern sky at a wavelength of 3.5 meters, and has found strong signals emanating from the central plane of the galaxy. The signals are strongest in the direction of the galactic center and diminish in intensity on either side of it. They remain constant along the plane of the galaxy for 10 to 20 degrees, then drop sharply to a lower level and remain constant for another 10 to 20 degrees. According to Mills, the sharp decreases in signal strength coincide with the edges of spiral arms.

From his results Mills has constructed a tentative diagram of the over-all spiral pattern of the galaxy [*see illustration*



SCHEMATIC RADIO MODEL was proposed by B. Y. Mills of the Commonwealth Scientific and Industrial Research Organization in Australia. Mills drew his tentative diagram of the over-all spiral structure of the galaxy after analyzing radio signals having a wavelength of 3.5 meters. The dotted lines show the line of sight from the sun to the edges of the major spiral arms; no details are shown. The arms in this model and the one opposite are roughly circular, in excellent agreement with the optical model shown on page 95.

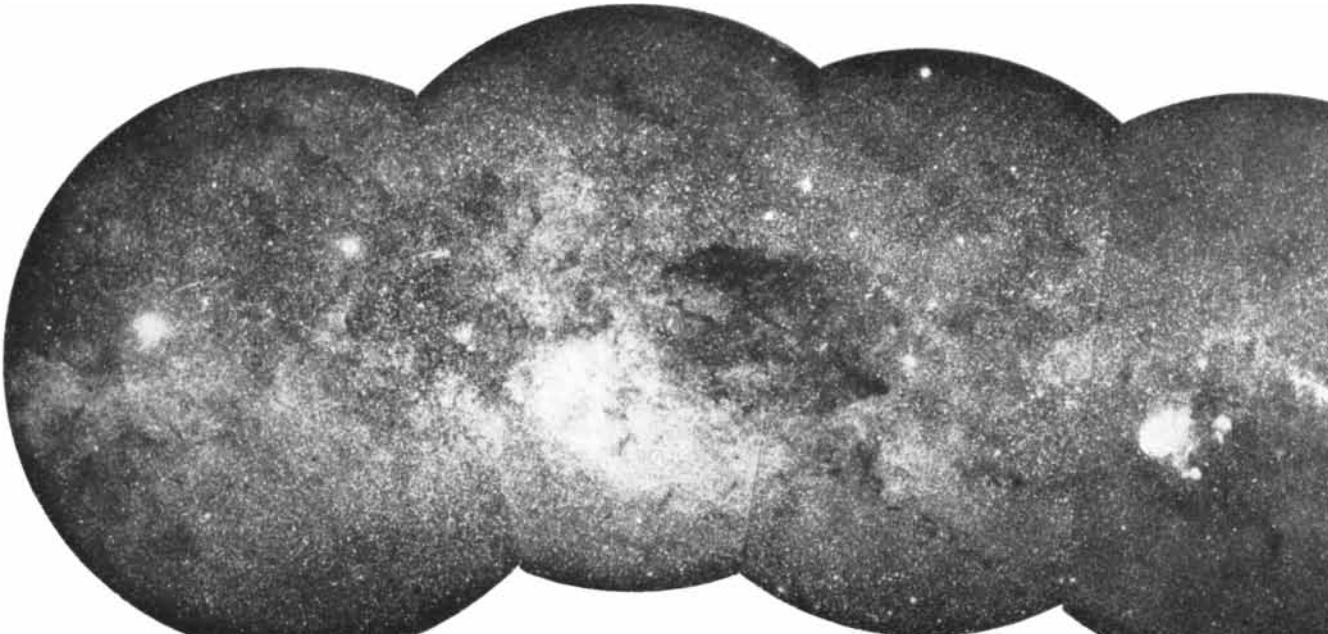


EDGE-ON VIEW of the spiral galaxy NGC 4565 shows the characteristic thin disk of gas and dust lying in the central plane of the galaxy. The dust is visible as a dark band against glowing mass of stars. Our own galaxy would probably appear slightly less flat-

on preceding page]. Although this diagram agrees rather well with the new optical model, Mills's approach is at best a generalized one, and does not reveal fine structural details. The true spiral pattern is doubtless complicated by many minor spurs protruding from the major spiral arms.

My second reason for proposing a revision of Morgan's model is that in mapping his Orion Arm, Morgan ignored the long stretch of spiral arm extending from the sun toward Carina and Centaurus. Yet there is no other section of the Milky Way in which we are so obviously looking along a major spiral feature. The arm can be followed for a distance of 15,000 light-years from the sun and is studded with great numbers of spiral tracers: O and B supergiants and associations, young galactic clusters and emission nebulae. And no other region of the Milky Way is so rich in long-period cepheid variables.

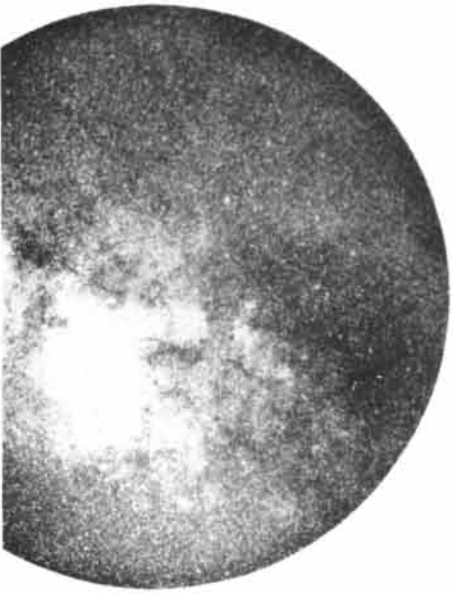
Observers in the Southern Hemisphere have long recognized the importance of the Carina Arm, but Morgan and others in the Northern Hemisphere have tended to ignore it. One exception is van de Hulst, who has proposed a galactic model very similar to mine, in which the Carina Arm gets the attention it so richly deserves.



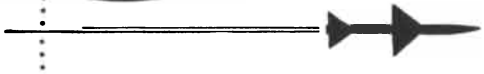
PART OF CARINA-CYGNUS ARM appears in this composite photograph of the Southern Milky Way. The circular section at far left contains the bright stars Alpha and Beta Centauri. The dark clouds in the second and third sections are known as the Coal Sack. The Southern Cross appears at the top of the third section, and the bright clouds in the section at far right form the Eta Carinae Nebu-

tened. The photograph was taken with the 200-inch telescope on Palomar Mountain.

In the new model the Carina and Cygnus arms unite to form the major spiral feature: the Carina-Cygnus Arm. This arm, which contains the sun, replaces the Orion Arm pictured in Morgan's diagram. It now appears that the Orion Arm is not an arm at all but merely a short spur lying partly outside the plane of the galaxy and extending away from the sun to the south. Another spur extends toward the south-



la. The photographs were taken with the eight-inch Schmidt telescope located at the Mount Stromlo Observatory in Australia.



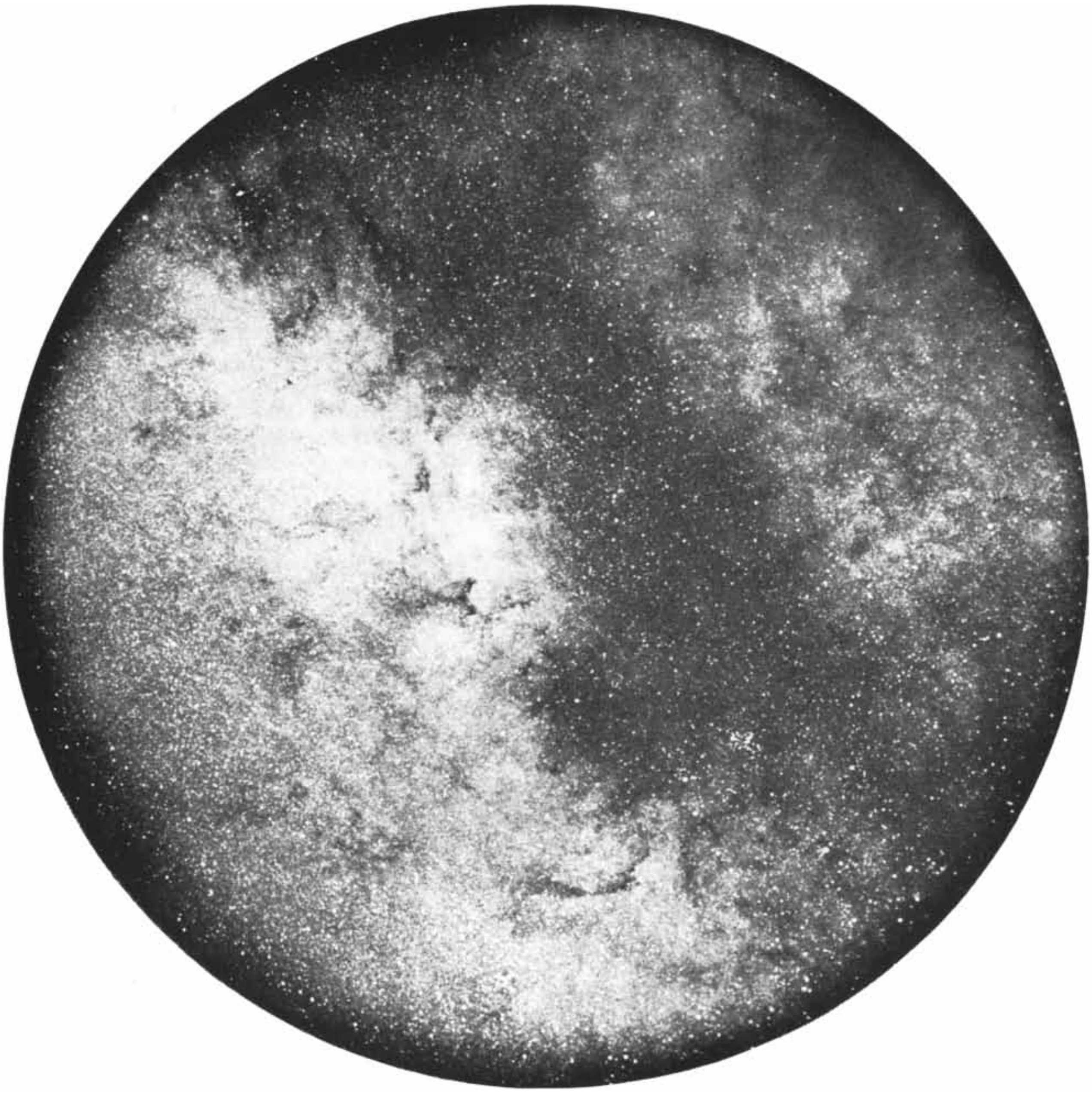
ern constellations of Vela, Puppis and Canis Major, and in the new model is called the Vela Spur.

Absorption Lines

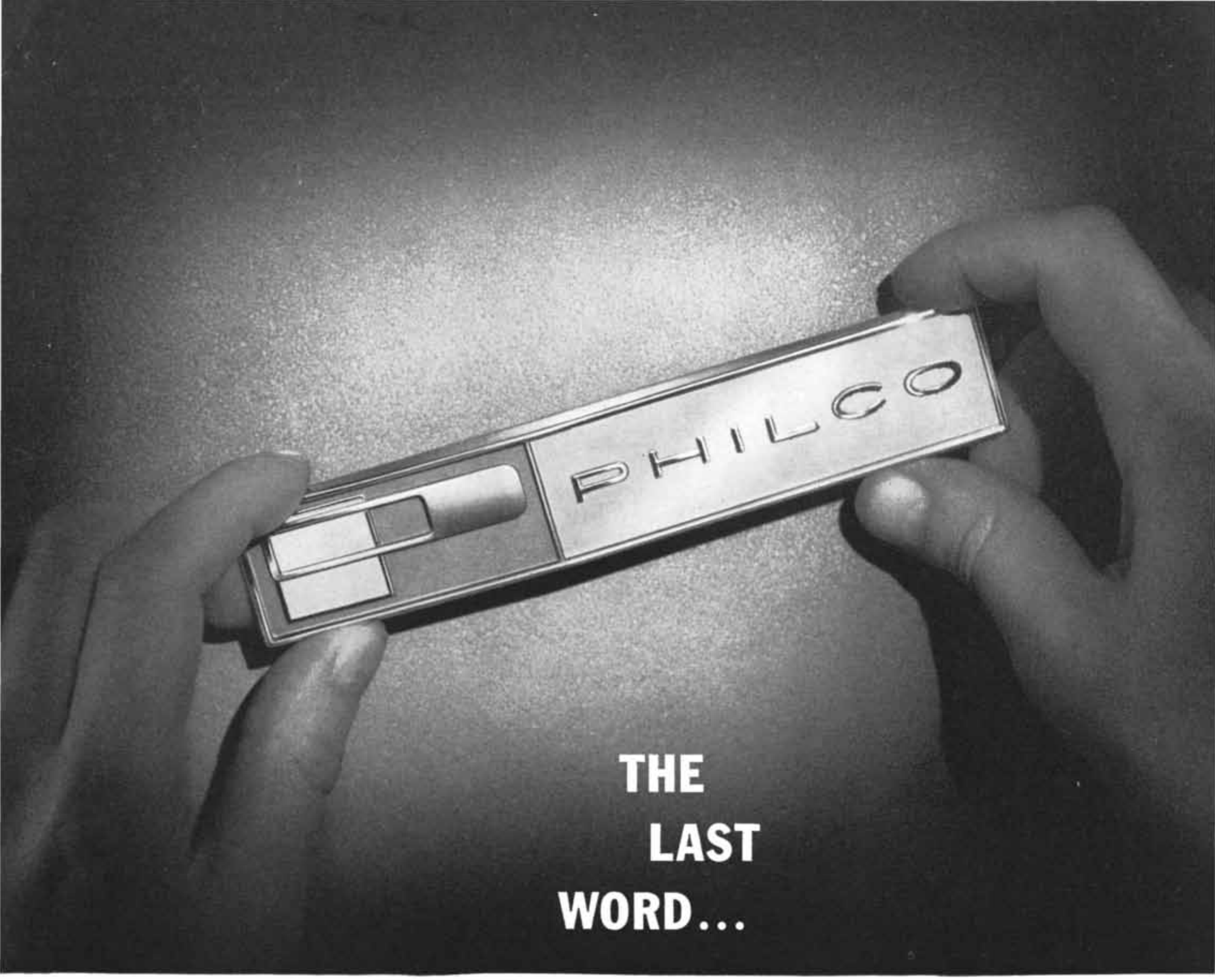
In years to come the disparity between the optical and radio models of the galaxy should be further reduced by a number of other techniques that have proved reliable in tracing spiral arms. One such technique is the study of interstellar absorption lines. Clouds of interstellar gas are known to block light of certain wavelengths, producing dark lines in the spectra of remote stars. Because the lines are sharp and narrow they are easily distinguished from the rather fuzzy absorption bands produced by the star's own atmosphere. Observed from the earth, many distant stars have multiple or split absorption lines. The spectrum of one star, for example, has seven such lines, caused presumably by seven separate gas clouds between it and the earth.

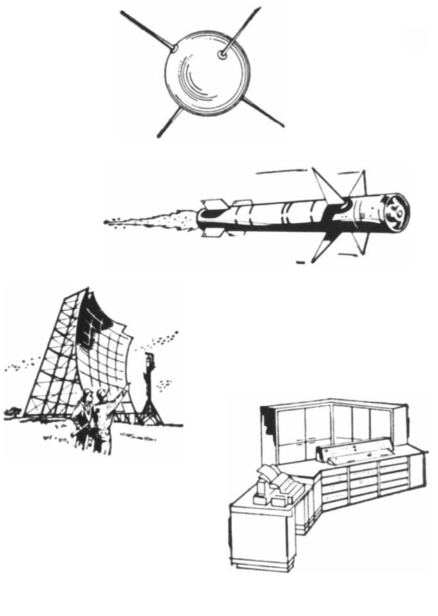
Guido Münch of the California Institute of Technology has shown that the split lines enable us to locate the gas clouds responsible for them. We begin by measuring how much each component of the absorption line has been shifted from its normal position. If the cloud is moving toward us, the line will be shifted to a slightly shorter wavelength; if the cloud is moving away, the wavelength will be longer. From this shift we can calculate each cloud's motion with respect to the earth, its rate of rotation around the center of the galaxy and hence its distance from the sun.

Using this method, Münch derived the distances of a number of clouds and found that they fell into two belts: one



THE CENTER OF OUR GALAXY lies hidden behind the interstellar dust clouds extending from the upper left to the lower right of this infrared photograph. The photograph was taken with the eight-inch Schmidt telescope at the Mount Stromlo Observatory.





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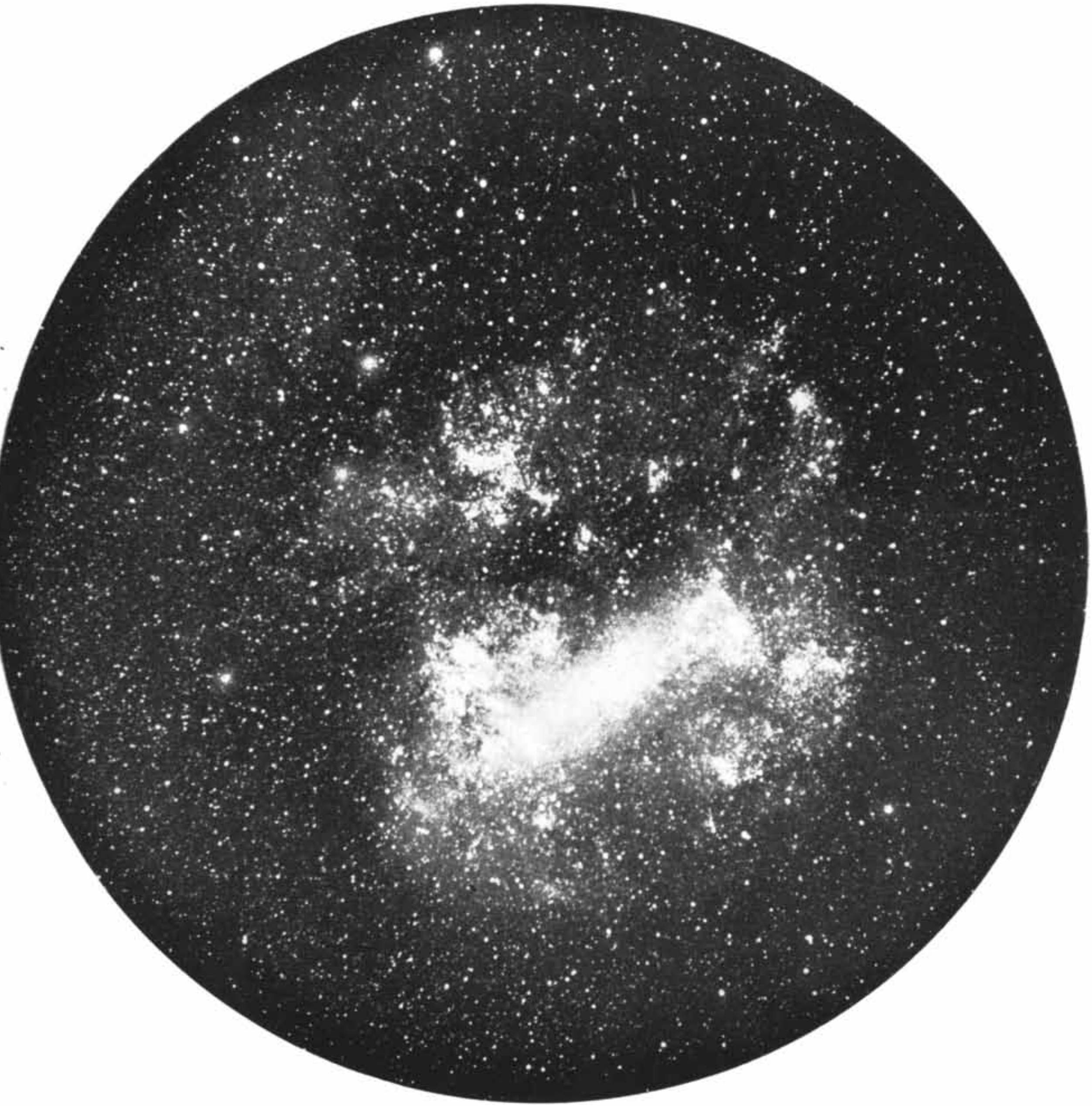
corresponding to the Carina-Cygnus Arm; the other, to the Perseus Arm. Further work along these lines looks quite promising, especially in the Southern Hemisphere, where great opportunities await astrophysicists with powerful spectrographs.

Still another method of observing spiral arms was discovered some 10 years ago by John S. Hall and W. A. Hiltner at the Yerkes Observatory. They noticed that the light from stars lying in the plane of the galaxy is polarized. The polarization is probably produced by clouds of slightly magnetized particles of cosmic dust aligned by giant magnetic fields. Extensive observations in the Northern Hemisphere by Hall and Hiltner and in the Southern Hemisphere by Elske van P. Smith at the Boyden Station at Bloemfontein, South Africa, indicate that the magnetic fields are associated with spiral arms. Magnetic lines of force appear to stretch along these arms like long rubber bands.

Evolution of the Galaxy

The spiral arms that we observe today were probably formed rather recently and, cosmically speaking, may be rather short-lived. Most of the stars that serve as spiral tracers probably condensed from the interstellar gas in their vicinity less than 100 million years ago, a very short interval in cosmic time. If we define the cosmic year as the time required for the sun to complete one revolution around the galactic center, then the earth and the sun have existed for about 25 cosmic years. The oldest stars in our galaxy are about twice that age, while the very youngest may have ages of less than a 100th of a cosmic year.

The spiral arms, gaseous envelopes filled with stars and dust, are apparently doomed to a brief existence by the law of gravity. Because of the great



YOUNG GALAXY, the Large Magellanic Cloud, shows at best only an incipient spiral structure. This photograph of one of the two nearest galaxies (the other is the Small Magellanic Cloud) was made with the eight-inch Schmidt telescope at Mount Stromlo.

attraction exerted by the massive core of the galaxy, sections of spiral arm closer to the core should complete their revolutions faster than those at greater distances. In a few cosmic years the difference in rotation rates would render the galaxy's former spiral pattern unrecognizable.

But we should not assign too much importance to purely gravitational arguments. If these forces were the only ones controlling the gaseous arms, the arms would probably never have been formed in the first place; and if they came into existence by some freakish accident, they would have been dissipated in short order. It is highly probable that although gravity is the major force controlling the orbits of stars in the galaxy, it acts in conjunction with magnetic forces in controlling the shape and movement of the gaseous spiral arms.

Apparently these magnetic forces can preserve the spiral pattern more or less intact until the gas in a given arm is exhausted by the condensation and evolution of new stars. The new stars at first lie neatly embedded in the arm, but after one or two cosmic years they begin to migrate from their original positions, smearing out the original spiral pattern. The vague patterns still traceable among the older stars in our galaxy may well be the last remnants of fossil spiral arms that disappeared a few cosmic years ago.

The Origin of Arms

We have almost no information as to how the arms were formed. One clue may lie, however, in the motion of the interstellar gas clouds. According to the estimates of Oort, van de Hulst and Westerhout, the neutral atomic hydrogen in these clouds represents about 2 per cent of the total mass of the galaxy. Ionized atomic hydrogen (dissociated protons and electrons) adds about a twentieth of this amount; other gases, including helium and molecular hydrogen, probably also make a small contribution. The gas forms a wafer-thin disk, 1,200 light-years thick and 100,000 light-years in diameter, in the central plane of the galaxy.

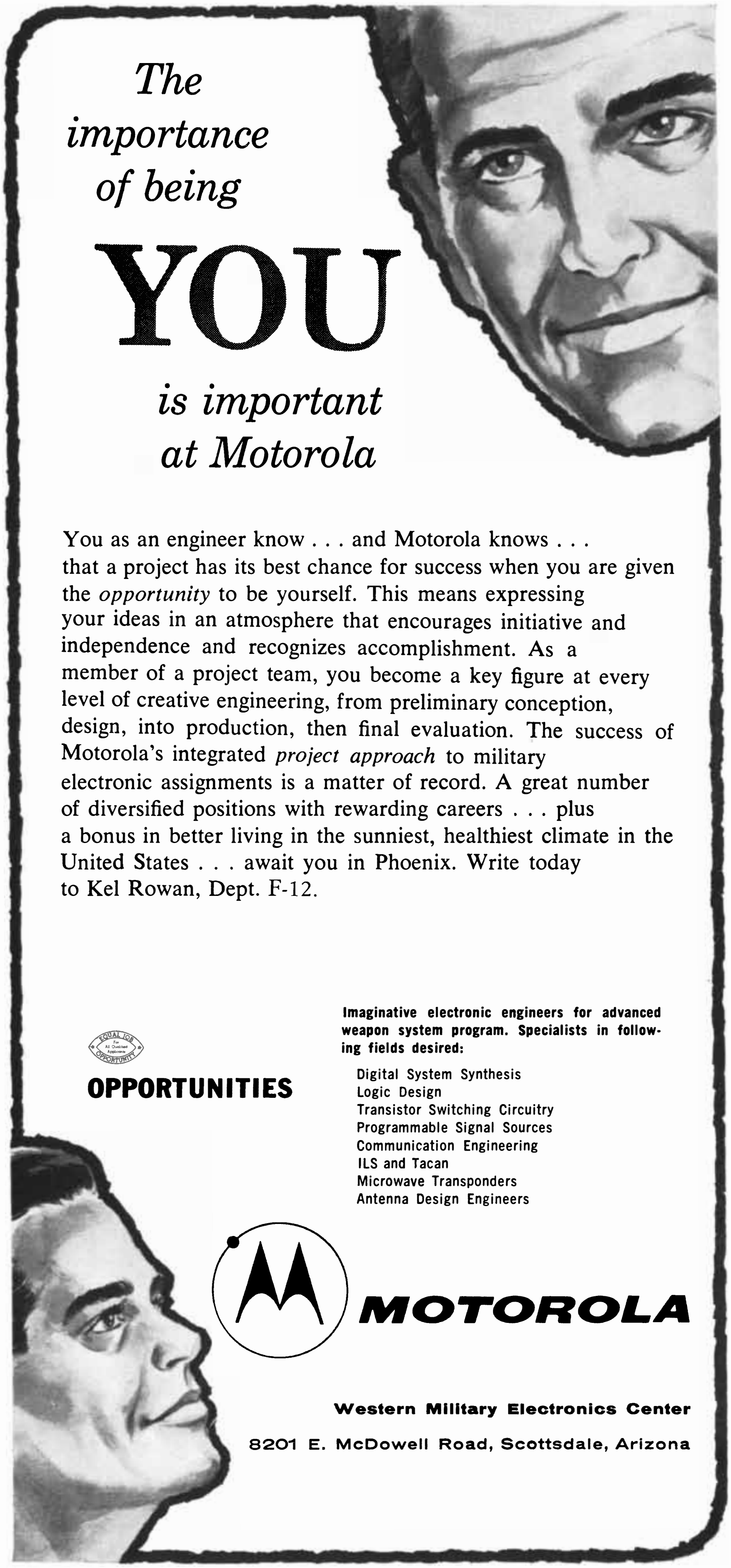
The hydrogen in the disk expands outward from the center of the galaxy at velocities ranging from 30 to 100 miles per second. This expansion may be influenced by gravitational forces set up by the galactic nucleus, but it seems more likely that it is directed by other forces—probably magnetic—that prevent the gas from being flung outward in all directions. Some of the expanding gas appears to be concentrated in an arc 10,000 light-years long, called the "10,000 light-year expanding arm." This arm is moving outward from the center of the galaxy at a rate of 30 miles per second [*see illustration on page 96*].

From here on everything becomes speculation. Oort and his colleagues have estimated that expanding arms transport roughly one solar mass of matter per year from the nucleus to other parts of the galaxy. This redistribution adds up to 200 million solar masses per cosmic year, a quantity of matter so enormous that we may well ask: Where does it all go?

The radio observations of the 10,000 light-year arm provide a tentative answer. If the arm is accompanied by a magnetic field, it will tend to move outward as a unit, slowing down as it proceeds farther from the galactic center. The outer arms of the galaxy apparently move outward at velocities greater than three miles per second, or 3,000 light-years per cosmic year. As the galaxy evolves further, its arms will continue to expand, and the 10,000 light-year arm may successively come to resemble the Sagittarius, the Carina-Cygnus and the Perseus arms.

The vast amount of material flung outward from the galactic center raises another question: How does the nucleus replenish its enormous reservoir of gas? There seem to be two possibilities. One is that the gas is supplied by eruptions from some of the many stars in the galactic nucleus. This hypothesis holds so far as it goes, but we have no idea of what kinds of stars might provide the necessary eruptions. A more attractive possibility is that new gas enters the nucleus from the galactic halo, a huge sphere of very thin gas that surrounds the galaxy. The halo is shaped by weak magnetic fields; perhaps these forces tend to pull the gas toward the galactic center, where it is caught by other magnetic fields and pushed outward in puffs resembling smoke rings. The rings, of course, are spiral arms.

So little is known about the magnetic fields that prevail in the halo and the nucleus that fanciful hypotheses like these may survive for a while. I present them mainly to show how far we still are from an understanding of the forces that control the structure of galaxies. The final solution to the problem of spiral structure will probably come from coordinated optical and radio studies of our galaxy, where detailed features obscure the over-all pattern, and of nearby spiral galaxies, where the pattern is clearly visible in all its majesty.



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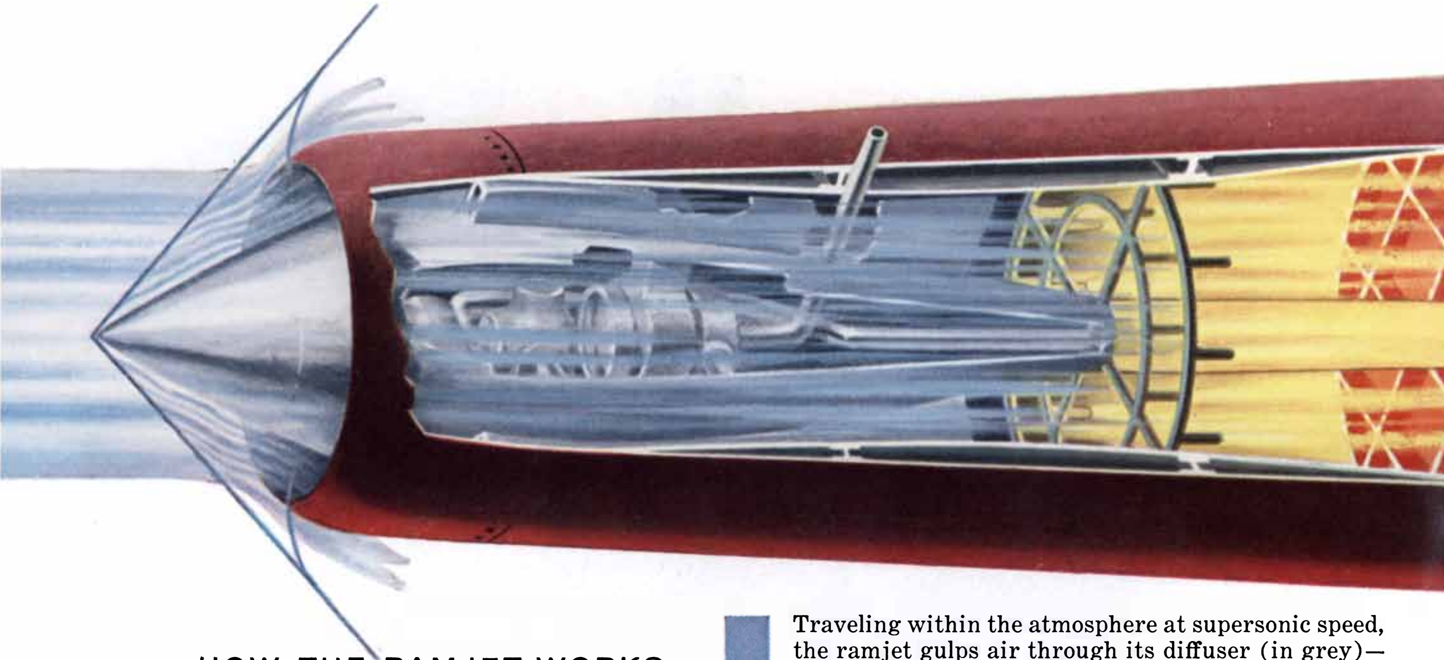

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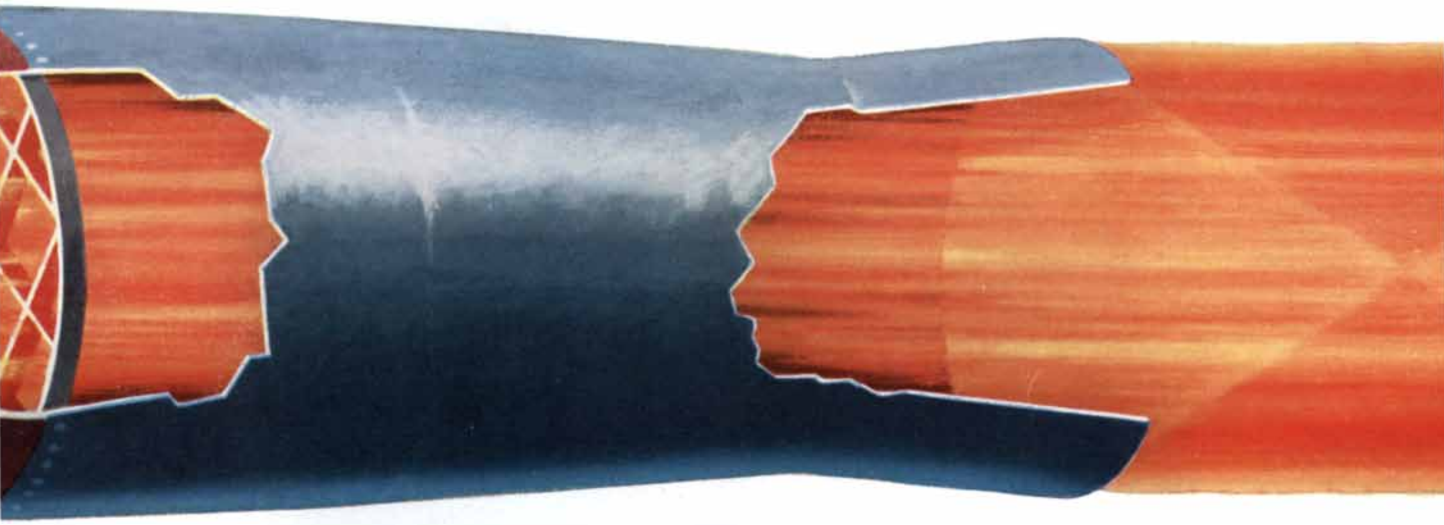

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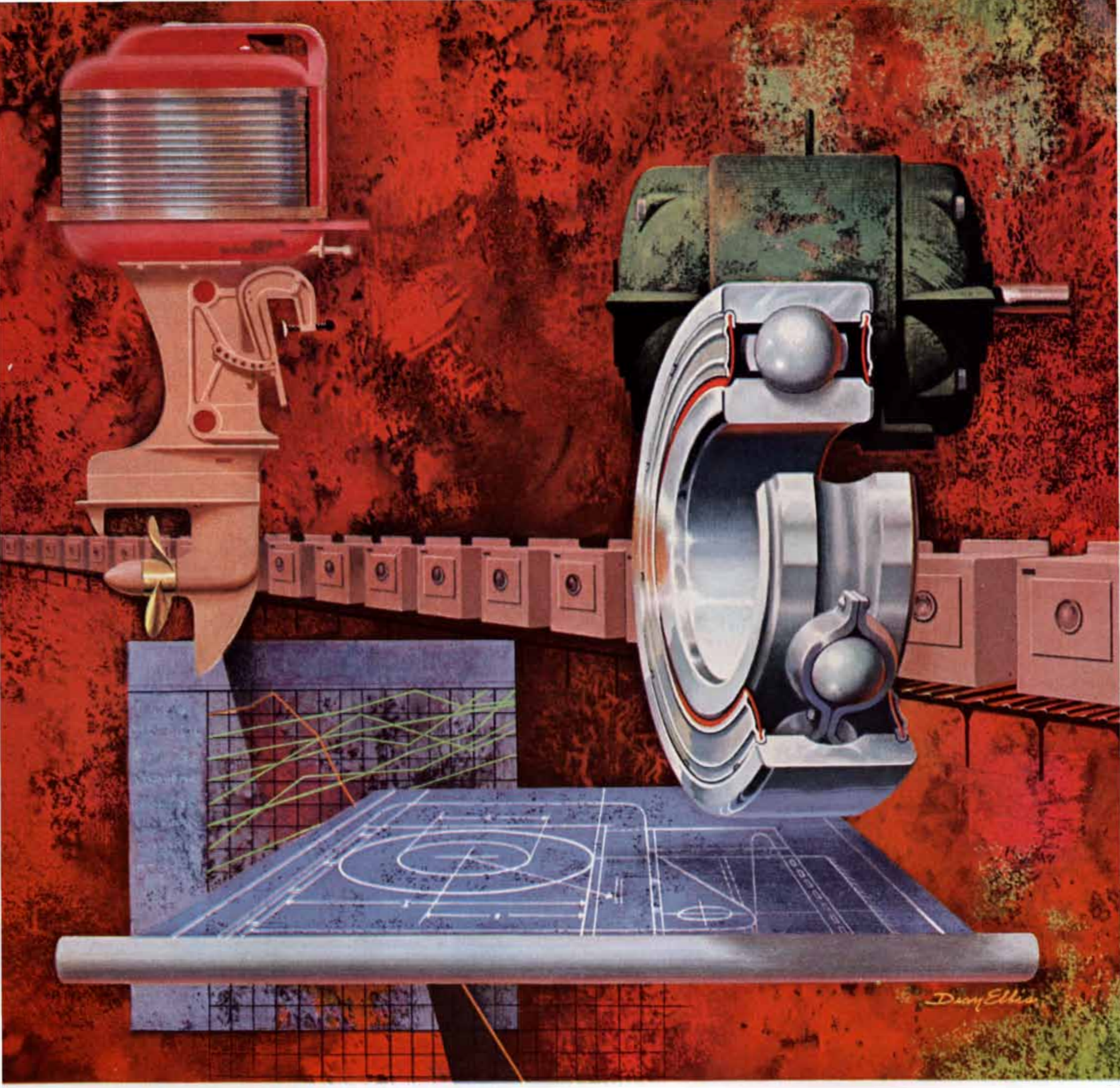

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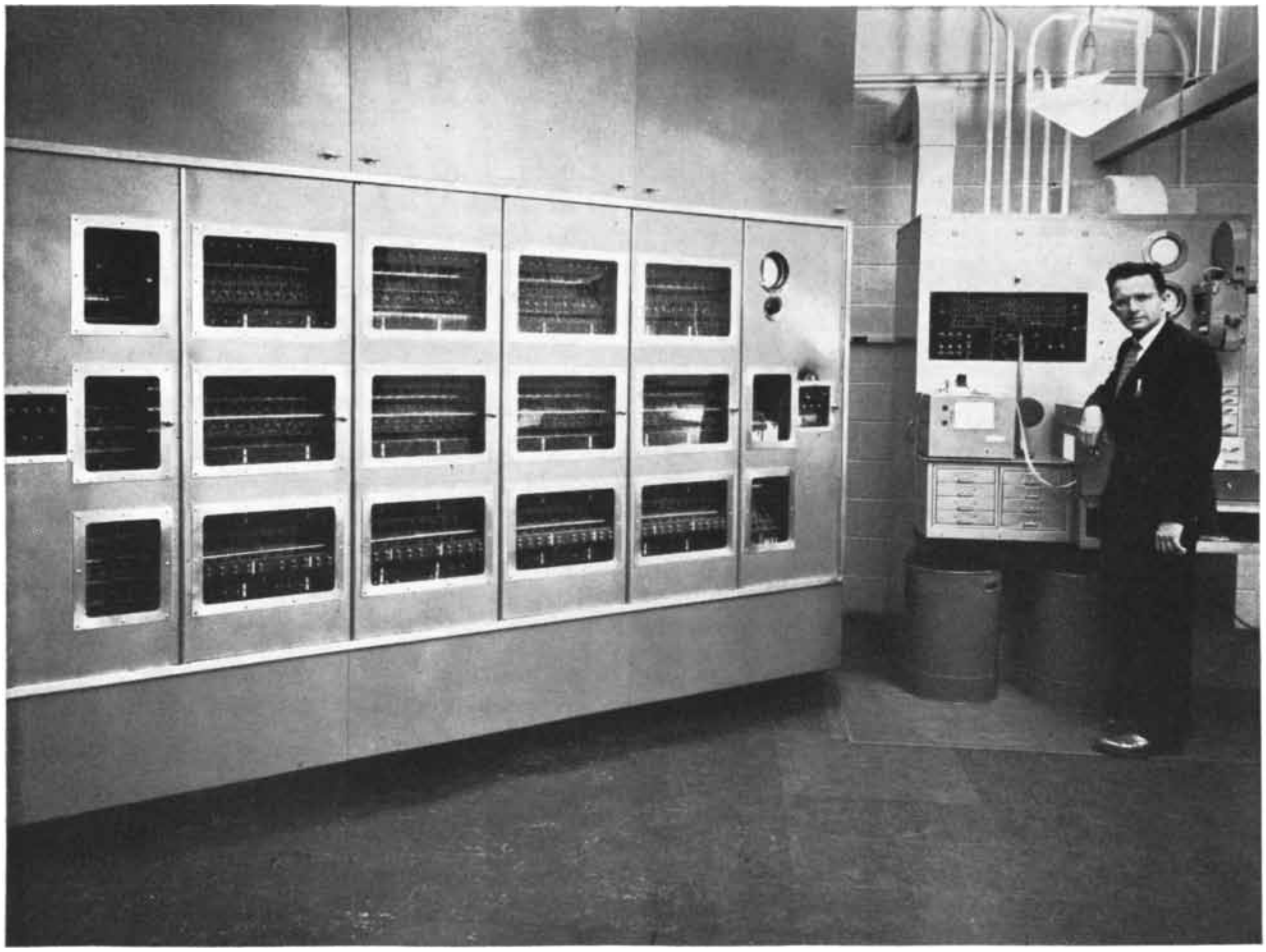
COMPUTER MUSIC

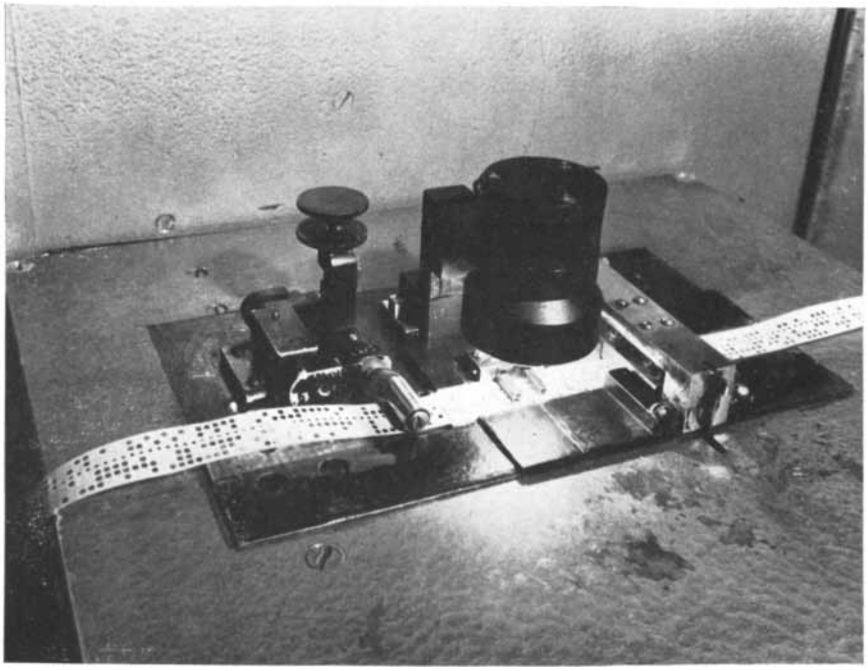
Information theory makes possible the programming of a computer to compose music. The process by which the machine does so throws light on musical structure and on the methods of human composers

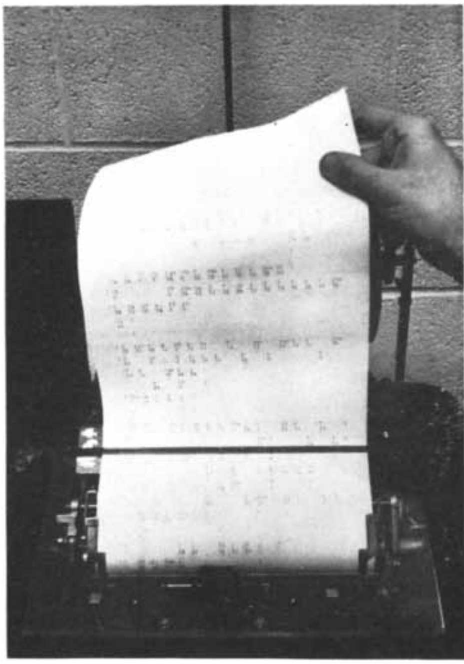
by Lejaren A. Hiller, Jr.

Can a computer be used to compose a symphony? As one who has been engaged in programming a large digital computer to produce original musical compositions, I can testify that the very idea excites incredulity and indignation in many quarters. Such response in part reflects the extreme view of the 19th-century romantic tradition that regards music as direct communication of emotion from composer to listener—"from heart to heart," as Wagner said. In deference to this view it must be conceded that we do not yet understand the subjective aspect of musical communication well enough to study it in precise terms. The appreciation of music involves not only psychological needs and responses but meanings imported into the musical experience by reference to its cultural context. On the



"ILLIAC" DIGITAL COMPUTER at the University of Illinois was used for the experiments in composition described in this article. It has "composed" hundreds of simple melodies as well as more complicated musical structures. At right is the author.





COMPUTER'S MUSICAL OUTPUT is punched into paper tape shown at left, which is then run through a teletype machine to produce sheets of letter-number combinations (*center*). These are then decoded by hand into conventional musical notation (*right*).

other hand, music does have its objective side. This can be defined as existing in the score as such, quite apart from the composer and the listener. The information encoded there relates to such quantitative entities as pitch and time, and is therefore accessible to rational and ultimately mathematical analysis.

In recent years the "physics of music" has disclosed much that is mathematical in music. It reveals how sound waves are formed and propagated, how strings, membranes and air columns vibrate and how timbre depends upon complex wave-structure; it has provided universal standards of frequency and intensity, and clarified the rationale of musical scales. In its most compact form, acoustics reduces the definition of musical sound to a plot of wave-form amplitude versus time. The groove of a phonograph record, for example, contains only this information and yet yields a believable reconstruction of an original musical sound.

Acoustics, however, deals primarily with isolated elements of music and has thus far said relatively little about how these elements may be combined in a musical composition. Musicians have devised various nonmathematical systems for analyzing the structure of compositions. More recently they have begun to draw upon a new branch of applied mathematics known as information theory as a means of clarifying this aspect of musical communication.

Information theory relates the "information content" of a sequence of symbols (be they letters of the alphabet or musical notes) to the number of possible choices among the symbols. Information content thus resembles entropy or the degree of disorder in a physical system. The most random sequence has the highest information content; the least random (or most redundant) has the lowest. The apparent paradox in this statement derives from the definition given the term "information" in the theory. As Warren Weaver has observed, the term "relates not so much to what you *do* say as to what you *could* say" [see "The Mathematics of Communication," by Warren Weaver; SCIENTIFIC AMERICAN, July, 1949]. Information in this sense is not the same thing as meaning, and information theory is concerned more with the reliability of communication systems than it is with problems of meaning. Thus, it can be seen, the general inquiry into communication is confronted with the same dualistic question of form and meaning that faces the study of musical communication. Weaver encourages us to believe, however, that information theory has cleared the way toward "a real theory of meaning."

Music, sometimes defined as a compromise between chaos and monotony, appears to the information theorist as an ordered disorder lying somewhere between complete randomness and complete redundancy. This viewpoint accords well with much of traditional musical esthetics. As early as the fourth century B. C. the Greek writer Aristoxenus noted that "the voice . . . does not place the [musical] intervals at random, . . . for it is not every collocation but only certain collocations . . . that distinguish the melodious from the unmelodious." The composer, employing what Stravinsky has called "the great technique of selection," introduces redundancy into his relatively random materials in order to organize them into a "meaningful" pattern.

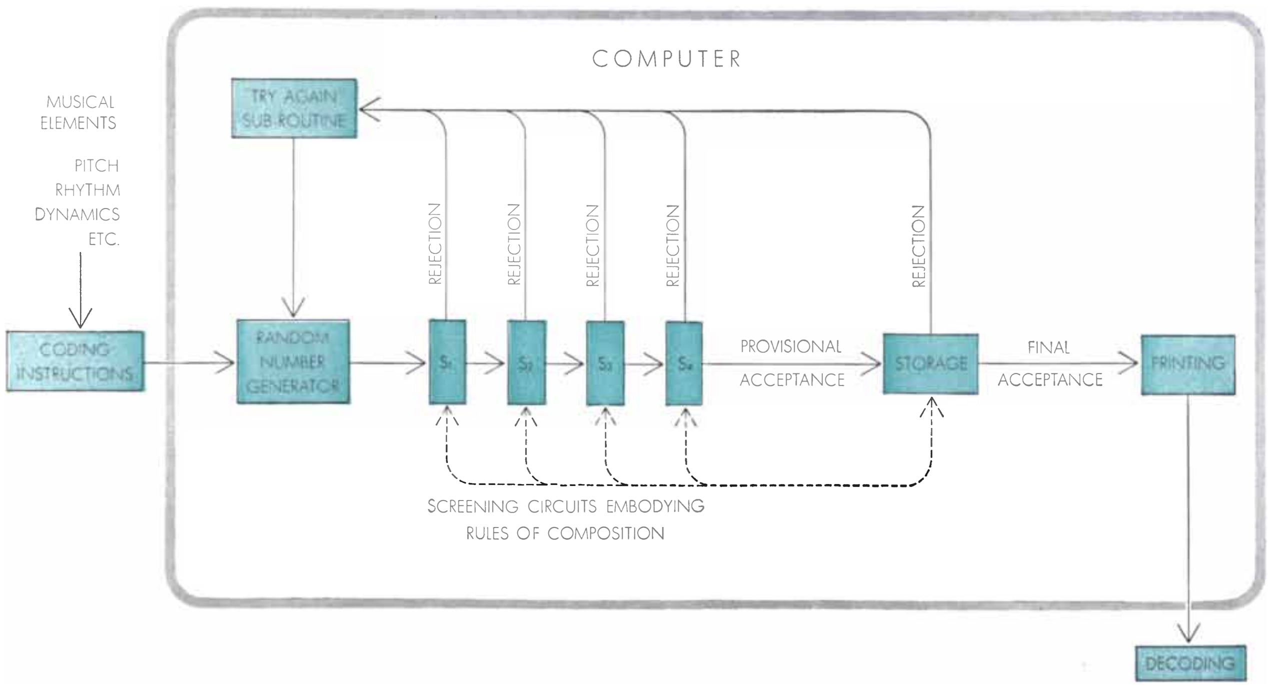
To be sure, meaning is as difficult to define in music as it is in every other kind of communication. But musical sounds are not, as words are, primarily symbols of something else; the meaning of music is peculiarly dependent upon its own structures as such. The study of musical structures by information theory should open the way to a deeper understanding of the esthetic basis of composition. We may be able to respond to Stravinsky's injunction and cease "tormenting [the composer] with the *why* instead of seeking for itself the *how* and thus establish the reasons for his failure or success."

From the analytical standpoint, the esthetic content of music can be treated in terms of fluctuations between the two extremes of total randomness and total redundancy. The significant fluctuations manifest themselves not only between one composition and another but also among elements or sections of the same

Future experiments may develop a method for automatic decoding and printing. Music publishers, who now use much expensive hand labor, would welcome such a technique.

composition. To take a very simple example, the "dominant 7th" chord GBDF is highly redundant under the rules of conventional harmony, because it will most frequently be followed by the chord CEG. The "diminished 7th" chord G# BDF, by contrast, is far less redundant, for it can be followed with equal probability by any one of a dozen-odd chords. Or consider the "sonata form" of organization which classical composers typically employed for the first movements of their longer compositions. In this musical structure the "exposition," in which the composer sets forth the themes, is fairly redundant (that is, predictable); the "recapitulation," in which he restates them, is even more so. The intervening "development," in which the themes are broken up, recombined and shifted through a number of keys, is far less redundant than either. As a final example, the stylistic device of modulation (key-shift) shows a fairly steady decrease in redundancy over the past 200 years. Mozart employed a limited number of rather standardized modulations. In Chopin and Brahms the modulations are more extreme and occur more frequently and less predictably. Wagner and Debussy modulate so freely that the listener often loses any immediate and unequivocal sense of key. Many modern composers have abandoned the concepts of key and modulation altogether and in this dimension approach complete randomness.

By standards such as these it is possible, at least in theory, to construct tables of probabilities describing a musical style, such as Baroque, Classical or Romantic, and perhaps even the style of an individual composer. Given such tables, one could then reverse the process and compose music in a given style. The task of composition would start from the random condition with choices among musical elements all equally probable. The introduction of redundancy in accord-



COMPUTER "COMPOSES" by a process of which the general features are here shown schematically. The machine generates random integers which are then screened by computational circuits that are arithmetical analogues of rules of composition. If circuits reject an integer, the "try again" circuit automatically produces a new one. Integers accepted by the screening circuits are stored in the memory until the composition is complete; memory and screening circuits are joined by feedback linkages symbolized by broken arrows. If the machine cannot complete a sequence without breaking the rules, it clears its memory and begins anew.

ance with a particular scheme of probabilities would extract order from chaos. It is not to be thought, however, that order is the sole criterion of beauty; as the musicologist Leonard B. Meyer has observed, "Some of the greatest music is great precisely because the composer has not feared to let his music tremble on the brink of chaos."

A few years ago Richard C. Pinkerton of the University of Florida employed this method to produce a simple "tune maker." He derived his probability tables by averaging the probabilities in a collection of nursery tunes [see "Information Theory and Melody," by Richard C. Pinkerton; SCIENTIFIC AMERICAN, February, 1956]. As he noted, however, this method produces only banal tunes. If more interesting music is desired, criteria other than simple averages must determine the probabilities.

A number of composers, both classical and contemporary, have produced more sophisticated musical structures embodying mathematical or quasi-mathematical "programs" that reflect an explicit concern with order and disorder. Especially illuminating are the extreme types of such structures: random music and totally organized music.

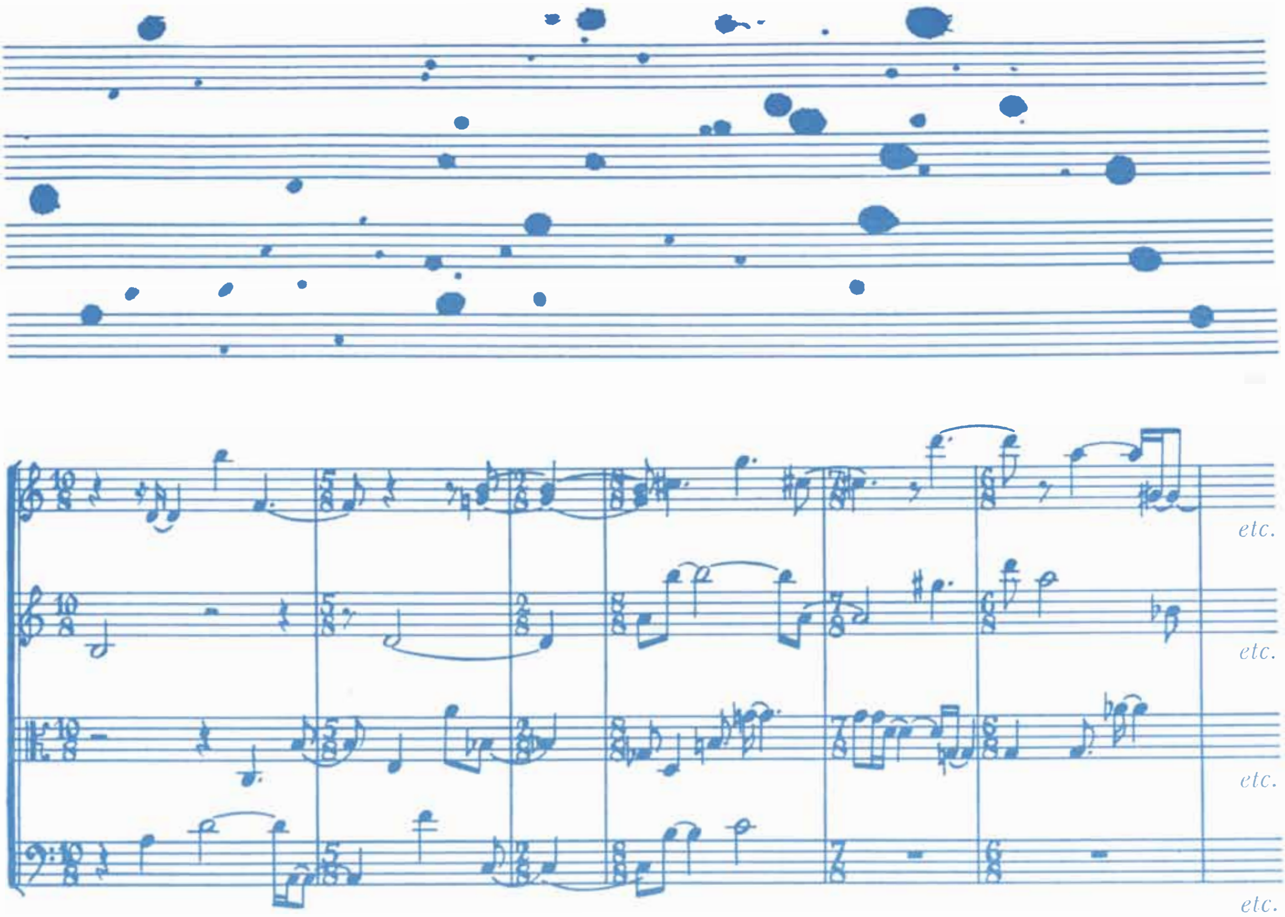
In its literal sense, pure random music is equivalent to "white noise"—the undifferentiated hissing sound made up of all possible audible frequencies occurring at random time intervals. It can be "composed" on any good high-fidelity set simply by turning the volume control high and thereby amplifying the random motions of electrons and ions in the tubes. At the opposite pole, the unvarying dial tone of a telephone provides a good example of totally organized music. Obviously neither extreme has much to offer the listener. To obtain sufficient variation in texture the composer must move away at least a little from total randomness or total redundancy.

Perhaps the simplest method of composing "almost random" music is to spatter ink from a brush on a page of blank music paper. By adding stems to the spots and then selecting the meters of successive measures by picking cards from a deck, one obtains random music that is sometimes playable if not harmonious [*see illustration on opposite page*]. A second and rather well-known example of chance music is Mozart's "A Musical Dice Game." This piece, one of many similar "compositions" produced as parlor games in the late 18th century, consists essentially of several dozen assorted measures of music, the order of which is determined by rolling dice. A more modern random work, "Imaginary Landscape" by the American composer John Cage, is "scored" for 12 radios and thus derives a strong element of randomness from regional and temporal variations in radio programs. Moreover, the score itself, which specifies the tuning of each radio and changes in volume, is based on chance numbers derived from an ancient Chinese book of oracles. Cage composes by several other chance methods, including "the observations of imperfections in the paper on which I happen to be writing" and the random shuffling of score pages just before performance.

John R. Pierce of Bell Telephone Laboratories, an authority on information theory, has demonstrated other approaches to the composition of simple "probability music." In one, a sequence of chords is chosen by means of dice rolls and a table of random numbers; in another, a series of volunteers each contributes a measure. A number of European composers have produced more elaborate random music electronically by causing random sequences of electrical signals to trigger sequences of tones.

Like random music, highly organized music does not lack historical precedent. A notable example is the "isorrhythmic" music of the 14th and 15th centuries, which was based on abstract formulations that took precedence over conventional rules of harmony. Among contemporary composers, Cage has produced what is probably the most perfect example of the genre in his composition "4:44," which consists of four minutes

"FIRST SPECIES COUNTERPOINT" composed by ILLIAC (*top*) is compared with a portion of the motet "Adoramus Te Christe," composed in the same style by Palestrina (*bottom*). The computer produced monotonous rhythms here because its program contained no provision for varying rhythms until later experiments. The computer music is taken from "Illiac Suite for String Quartet," by Lejaren A. Hiller, Jr., and L. M. Isaacson. Copyright 1957 by New Music Editions; assigned to Theodore Presser Company, 1959.



RANDOM MUSIC can be "composed" by spattering ink from a brush onto blank music paper (*top*). When the spots are transcribed (*bottom*), the horizontal distance between them defines their time value. Meters are obtained by drawing cards from a deck.

and 44 seconds of silence. Other contemporary composers have produced less totally organized but more audible pieces by composing according to invariant sequences of numbers. Each number is associated with musical elements such as pitch, rhythm, dynamics and orchestration. This method of composing evolved out of Arnold Schönberg's 12-tone technique. Once belabored as rigid and ultra-mathematical, Schönberg's works seem hardly "programmed" at all when compared with those of his "descendants." Karlheinz Stockhausen's "Zeitmasse" is an example of recent programmed music available on phonograph records. Its elaborately organized structure is not readily discernible by ear alone, so that it does not sound very different from the general run of modern compositions.

The concept of mathematically programmed music easily leads to the notion of composition by computer. In 1955 Leonard M. Isaacson and I began a series of experiments in composition with ILLIAC, the high-speed digital computer at the University of Illinois. In due course we completed four groups of experiments, the results of which we have sampled in the "Illiac Suite for String Quartet."

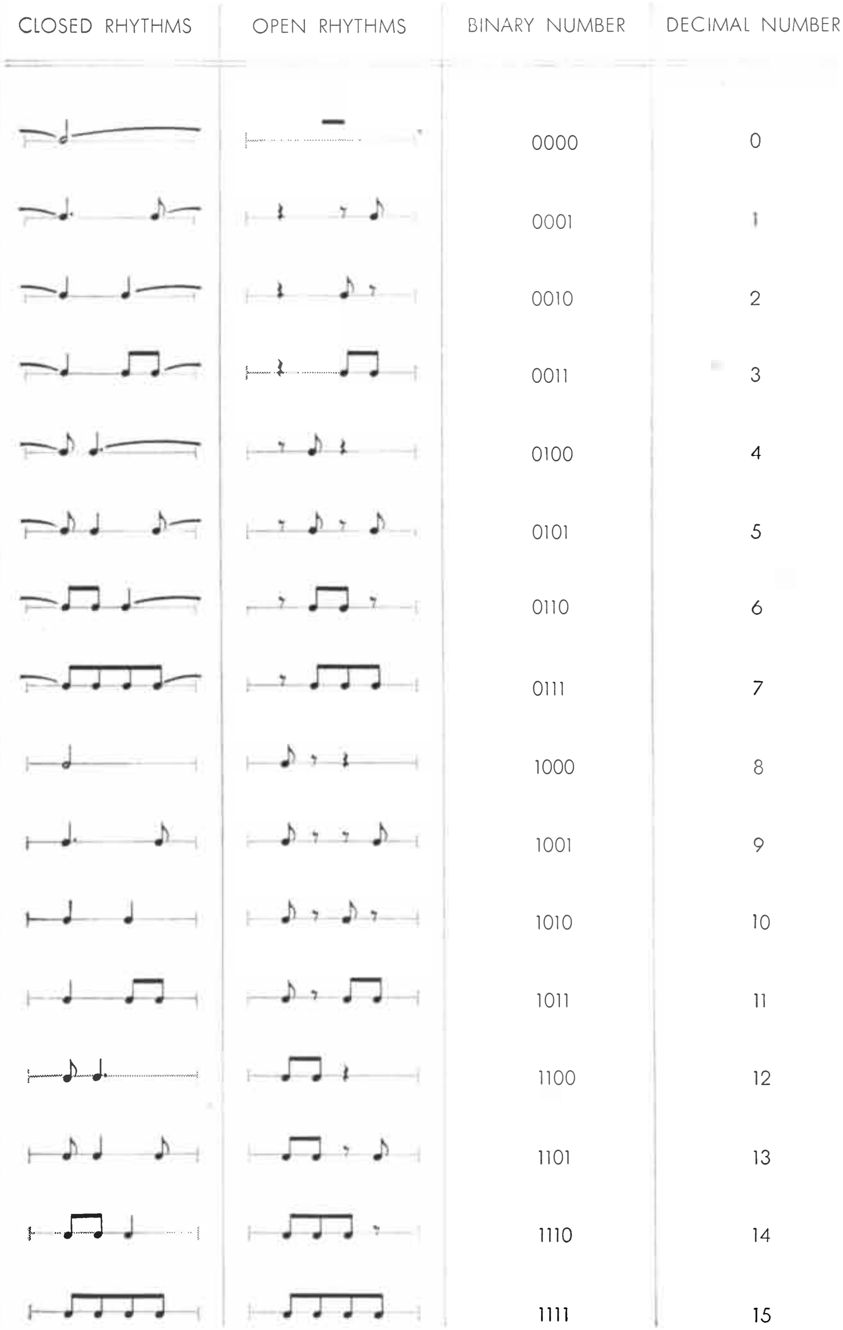
As our first step we set the computer to composing simple melodies. To this end we programmed the machine to generate random integers by a technique borrowed from the "Monte Carlo" method, which physicists have devised to solve certain problems involving multiple probabilities. Random integers from 0 to 14 represented the tones ("white notes" only; no sharps or flats) in a two-octave range of the C-major scale. To introduce redundancy we screened the integers by feeding in additional programming instructions; these embodied arithmetical analogues of rules of composition governing "permissible" sequences of notes. We selected the rules from the elaborate injunctions for "strict first-species counterpoint," a formalized musical idiom based on the methods of such 16th-century composers as Palestrina.

Integers that passed the screening procedure were stored in the computer's "memory" until the machine had completed a melody by returning to C, the note with which it had begun. The complete melody was then printed on perforated tape, from which it could be transcribed into conventional musical notation [*see illustrations at top of pages 110 and 111*]. Rejection of an integer automatically triggered a "try again" program that generated a new integer. The machine continued "trying" until it produced a satisfactory note or until it "concluded" (after 50 unsuccessful trials) that no such note existed, that is, it had "written itself into a corner," as human composers sometimes do. In the latter case it cleared the incomplete melody from its memory and began afresh from C.

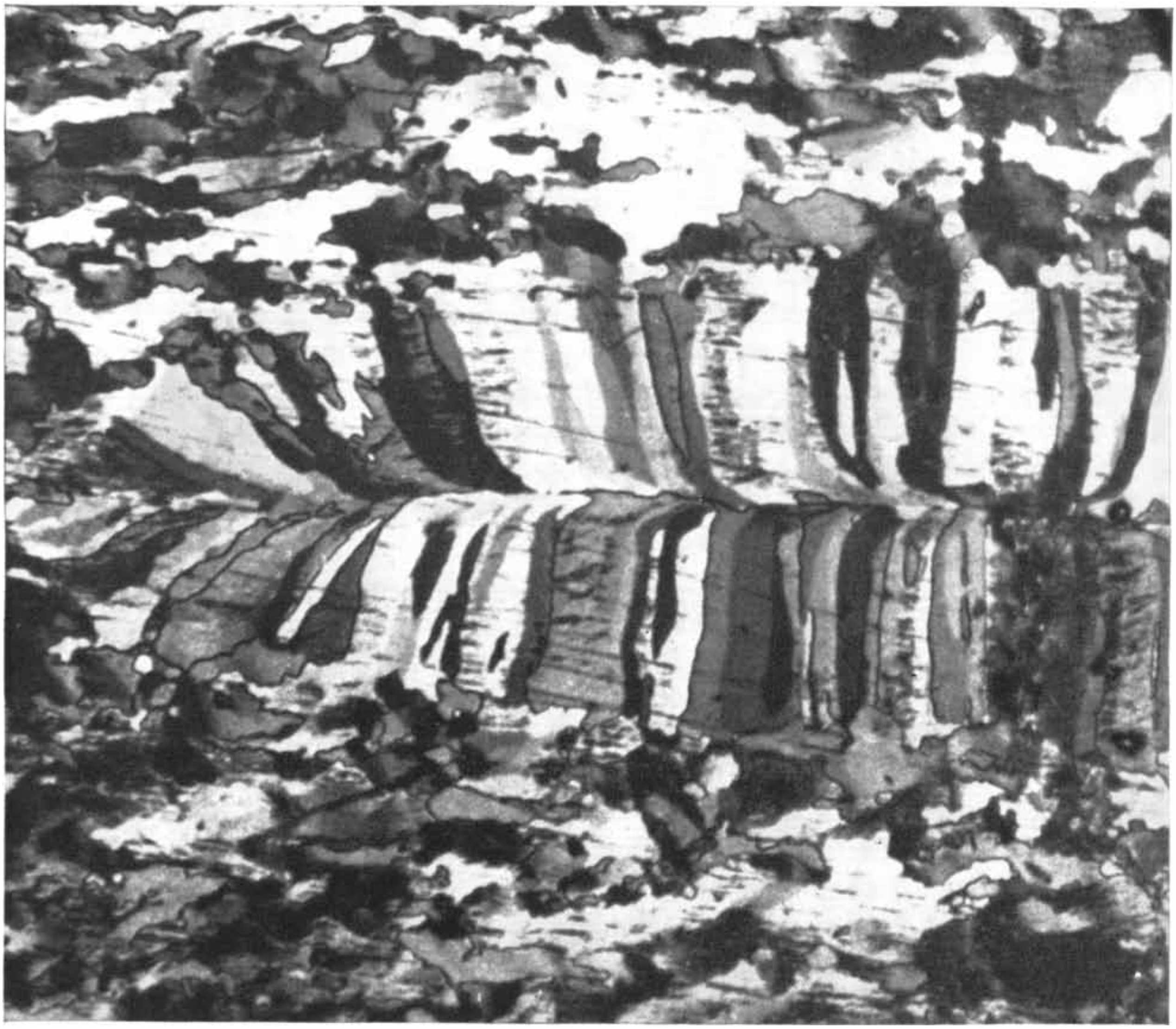
In the course of an hour's operation the machine produced several hundred melodies from three to 12 notes long. It was then programmed to produce two-voice counterpoint—two melodies at once—incorporating for this purpose four more instructions that screened out dissonances between the voices. The addition of still other instructions enabled the machine to produce four-voice counterpoint. The more elaborate programs produced more trials and "erasures," but the machine still composed copiously.

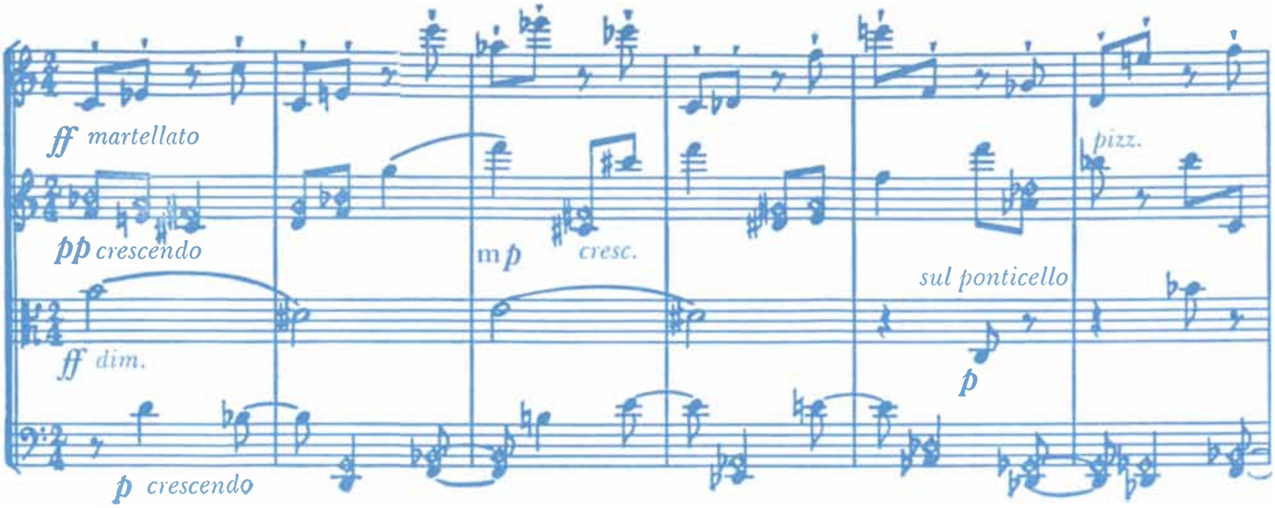
For our second experiment we devised additional screening instructions embodying the entire set of 14 rules of strict first-species counterpoint. The machine was first set to turning out random "white-note" music in four voices; randomness was then made to yield to redundancy in small increments by feeding in the screening instructions one by one. The complete set of instructions yielded counterpoint of fair quality, strongly reminiscent, if one ignores a certain monotony in rhythm, of passages from Palestrina.

In Experiment III we sought to find ways of producing the rhythmic and



RHYTHMIC CODING for the computer is based on 4/8 meter (chosen arbitrarily) with the eighth-note as the smallest rhythmic unit. All rhythms possible under these restrictions can be expressed as binary numbers equivalent to the decimal numbers from 0 to 15. Random choice determines the order of rhythmic patterns and selects "closed" or "open" form.





RANDOM CHROMATIC MUSIC produced by the computer (*top*) resembles the compositions of some extreme modern composers. The introduction of redundancy in melody, rhythm and playing instructions produces a more ordered texture (*middle*) that suggests passages from Bartok. Samples of computer music from "Illiac Suite," Copyright 1957, New Music Editions; assigned to Theodore Presser Company, 1959. Shown below is a passage from the first movement of Bartok's "First String Quartet." Copyright 1929 by Universal Editions; renewed 1956. Copyright and renewal assigned to Boosey and Hawkes Inc. Reproduced by permission.

dynamic variety that the earlier compositions lacked. A simple method gave us a considerable variety of rhythm. With 4/8 time as the meter and the eighth-note as the smallest rhythmic unit, all the rhythmic patterns possible under these restrictions were coded in binary digits (that is, numbers expressed by 1 and 0, representing the "on" and "off" positions of a relay). Thus 1111 represented four eighth-notes; 1110, two eighth-notes followed by a quarter-note; 1010, two quarter-notes, and so on. The resulting series of permutations formed a sequence of binary numbers equivalent to the decimal numbers 0 to 15 [*see illustration on page 114*]. Since rhythms in music do not normally shift with every measure, rhythmic redundancy was introduced by a second series of random numbers that programmed the machine to repeat a particular rhythm up to 12 times. To this "horizontal" redundancy in the melodic line of the individual voices another binary code added "vertical" redundancy among the four voices. Here 0000 indicated that all four voices would be rhythmically independent, 1111 called for the same rhythm in all voices, and so on. Similar methods introduced patterns of dynamics (*forte, crescendo*, and so on) and variations in playing instructions (*legato*, *tremolo*, *pizzicato*, and so on).

Since the object was to produce a type of music less imitative than strict counterpoint, the machine was first permitted to write entirely random chromatic music (including all sharps and flats). The result was music of the highest possible entropy content in terms of note selection on the chromatic scale, and thus it was strongly dissonant. With the minimal redundancy imposed by feeding in only four of the 14 screening instructions, the character of the composition changed drastically. While the wholly random sections resembled the more extreme efforts of *avant garde* modern composers, the later, more redundant portions recalled passages from, say, a Bartok string quartet [*see illustration on opposite page*]. The experiment concluded with some exploratory studies in Schönberg's 12-tone technique and similar compositional devices.

Experiments II and III thus developed the contrasts between two widely different styles, that of the 17th and that of the 20th century. One style is highly restrictive and highly consonant but sounds quite simple; the other sounds dissonant, much more complex and difficult to decipher. The contrast underlines an important musical moral: Simplicity of style and hence accessibility

"MARKOFF CHAIN" MUSIC is composed by selecting intervals between successive notes according to a shifting table of probabilities. During the first two bars, the probability of unison (the "zero" interval) is 1; that of all other intervals, 0. The music necessarily remains on the same note. After each two bars the probabilities shift according to the scheme shown on page 120. From Experiment IV of "Illiac Suite for String Quartet," copyright 1957, New Music Editions; assigned to Theodore Presser Company, 1959.

bear an inverse relationship to freedom of choice. The simpler the style, the more severe the restrictions and the higher the degree of redundancy. By the same token, music that sounds simple may well be more difficult to write. In the freer style the difficulty involved in making the best choices among the larger number of alternatives is offset by the fact that more of the available alternatives are permissible. Each choice, in other words, is less significant to the total effect.

In Experiment IV the objective was the synthesis of music from purely mathematical rules—a style of composition peculiarly appropriate to a computer. To this end the computer was programmed to select the intervals between successive notes according to a table of probabilities instead of at random. Moreover, the probabilities themselves were made to shift in accordance with so-called Markoff probability chains. For example, in the first specimen of this music the "zero" interval (unison) had an initial "weight" of one while all the other intervals had a weight of zero. All voices perforce remained on the same note. After two bars the octave interval was given the weight of one and the weight of unison increased to two (unison was thus twice as probable as the octave). The fifth was the next interval added, and the respective weights of the three intervals, in order of appearance, became three, two and one. Two bars later the fourth interval was added with weights of four, three, two and one now assigned, and so on until all possible intervals had been added [*see illustrations on opposite page and on next page*].

When the computer had composed under the instruction of a number of similar Markoff programs, the probabilities were programmed to depend partly upon the last choices made. Thus if the last interval was a fifth, the probability of that interval would drop sharply and the probabilities of the others would rise. Another rearrangement linked the choice of interval to the opening note of the sequence. This latter relationship is of particular interest because it bears on the problem of tonality, the factor in conventional music by which the notes of the scale acquire individual significance because of their relationship to the keynote. The suppression of tonality, even to the point of abandoning it completely (atonalism), constitutes perhaps the most characteristic trend in "serious" music during the past 50 years.

We discovered with interest that the sound of "tonal" Markoff music closely resembled that of the "atonal" species, though its mathematical basis was quite different. Indeed, large sections of Experiment IV, though based on wholly abstract formulae, sounded much the same as Experiment III, which was generated under relatively unrestricted conditions. These correspondences suggest that if the structure of a composition exceeds a certain degree of complexity, it may overstep the perceptual capacities of the human ear and mind.

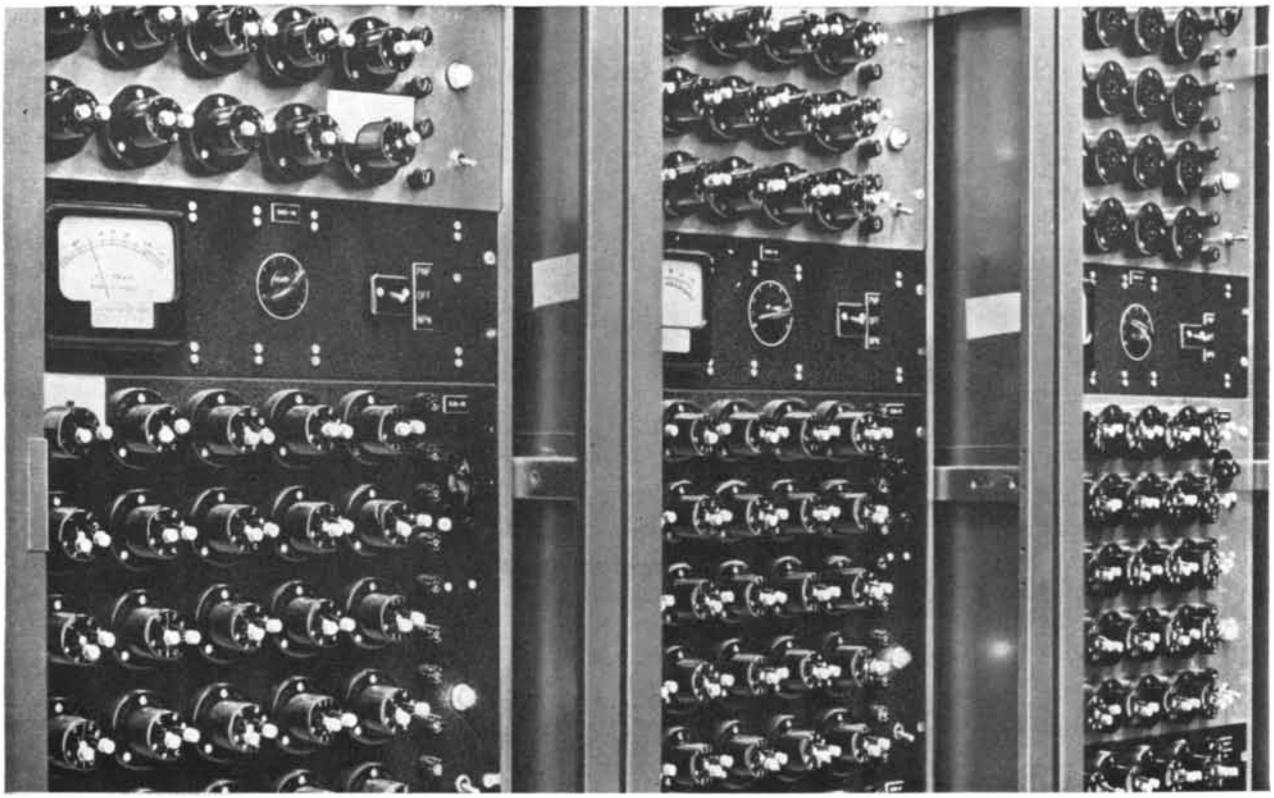
Since completing the "Illiac Suite," our efforts have been devoted to more complicated problems of musical structure, the solutions to which may yield a "Second Illiac Suite." As against the rather fragmentary music thus far obtained, the objective is to produce compositions in relatively lengthy conventional forms, such as theme and variation and four-part fugue. The computer will also be put to work on "totally organized" music as well as more complex Markoff chains. These and similar experiments involving a precisely specified degree and type of uncertainty should provide some quantitative criteria for judging the effect of order-disorder fluctuations in music.

A far more elaborate project is suggested by the question that began this discussion: Can a computer be used to compose a symphony? In principle, there seems to be no reason why it cannot. The computer program would have to be far more elaborate than any we have yet devised. Whether the results would justify the necessary labor is another story. With a program of reasonable length, the machine could be made to produce, say, a 42nd Mozart symphony, which would prove to be a representative but almost certainly undistinguished work. So long as the human programmer collaborates in the undertaking, the computer cannot be regarded as a truly independent composer. On the other hand, so long as the input to the computer includes some variant of the Monte Carlo method, the programmer cannot precisely specify the output of the machine. Thus the machine may be said to "compose," or at least to "improvise" within the limits set by its program.

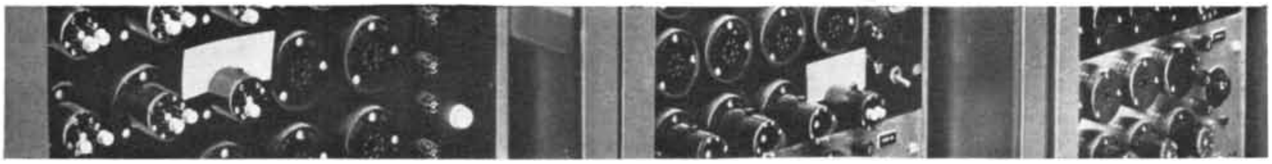
The computer can also be used to make an original contribution to our understanding of the structure that underlies the esthetic qualities of music. As I remarked earlier, these qualities are perceived largely through the articulation of musical forms and can therefore be most fruitfully explored via the investigation of the technical problems of composition. The computer has already proved its value in this line of investigation, and in future studies we plan to explore more deeply its application to problems of musical analysis.

	a		*b*		*c*		*d*		*e*		*f*		*g*		*h*		*i*	
INTERVALS	W	P	W	P	W	P	W	P	W	P	W	P	W	P	W	P	W	P
UNISON	1	1.00	2	.67	3	.50	4	.40	5	.33	6	.29	7	.25	8	.22	9	.20
OCTAVE	0	.00	1	.33	2	.33	3	.30	4	.27	5	.24	6	.21	7	.19	8	.18
FIFTH	0	.00	0	.00	1	.17	2	.20	3	.20	4	.19	5	.18	6	.17	7	.16
FOURTH	0	.00	0	.00	0	.00	1	.10	2	.13	3	.14	4	.14	5	.14	6	.13
MAJOR 3RD	0	.00	0	.00	0	.00	0	.00	1	.07	2	.09	3	.11	4	.11	5	.11
MINOR 6TH	0	.00	0	.00	0	.00	0	.00	0	.00	1	.05	2	.07	3	.08	4	.09
MINOR 3RD	0	.00	0	.00	0	.00	0	.00	0	.00	0	.00	1	.04	2	.06	3	.07
MAJOR 6TH	0	.00	0	.00	0	.00	0	.00	0	.00	0	.00	0	.00	1	.03	2	.04
MAJOR 2ND	0	.00	0	.00	0	.00	0	.00	0	.00	0	.00	0	.00	0	.00	1	.02
MINOR 7TH	0	.00	0	.00	0	.00	0	.00	0	.00	0	.00	0	.00	0	.00	0	.00
MINOR 2ND	0	.00	0	.00	0	.00	0	.00	0	.00	0	.00	0	.00	0	00	0	.00
MAJOR 7TH	0	.00	0	.00	0	.00	0	.00	0	.00	0	.00	0	.00	0	.00	0	.00
TRITONE	0	.00	0	.00	0	.00	0	.00	0	.00	0	.00	0	.00	0	.00	0	.00

SHIFTING PROBABILITIES governing one species of Markoff chain music are shown in part here; colored letters key the columns of the table to sections of the music shown on page 118. The probabilities (P) of the intervals are defined by their "weights" (W), which shift according to a simple arithmetical formula. Markoff music has been composed by several similar schemes.



At this moment, 30,000 transistors are on test at General Electric



Among the more than 30,000 transistors you will find right now on General Electric's cycled life-test racks are Series 2N43 PNP germanium devices dating back to 1952.

Each of these 2N43's has clocked at least 40,000 hours of operating life. This represents five years of "power-on" operation without failure. And the "old" 43's still live on!

Since 1952, General Electric Company has produced and thoroughly tested well over 20-million transistors. A quarter-million of these devices have been subjected to from 1000 to 10,000 hours of maximum-rated-power.

Life testing is but one of many exacting product quality-assurance criteria *all* General Electric semiconductor products must meet. For example, on an average, 16 separate quality-level tests . . . electrical, mechanical, environmental, as well as life . . . are given every General Electric transistor.

Through its system of stringent quality control, General Electric strives to continuously raise the stability/long-life reliability goals for semiconductor products—to the ultimate benefit of the user, the industry and the country at large.

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Semiconductor Products Department, Electronics Park, Syracuse, New York

THE FLOW OF MATTER

Everything flows, including solids such as concrete and steel. The exact way in which a material flows is of practical concern to the technologist and a difficult problem for the physicist

by Marcus Reiner

"The mountains flowed from before the Lord," sang the prophetess Deborah (*Judges* 5:5). The English scholars who prepared the King James version of the Bible apparently could visualize only liquids as flowing, and they translated the Hebrew word for "flowed" as "melted." But the change was unnecessary. On God's time-scale even solid rock can flow. In the span allotted to us poor mortals the process is almost, but not quite, unobservable. By exceedingly accurate measurements we too can perceive rocks "creep" when they are subjected to large enough forces.

Indeed, we realize that the Greek philosopher Heraclitus was right when he declared that "everything flows." Today the flow of matter is the subject of a separate and lively scientific discipline. Apart from its interest as a challenging theoretical problem, the phenomenon of flow touches virtually every aspect of our technology. Construction engineers must be able to predict how soil will be squeezed away beneath the foundations of a building, and how steel and concrete beams will gradually stretch or warp under steady loads. Chemists design plastics that can be extruded into useful shapes. Bakers want a dough that works smoothly under their kneading and rolling machines. Airplane builders need to know how lubricating oil flows through an engine, and air across a wing.

Although a real understanding of flow has been achieved only quite recently, the beginnings of the story go back to the earliest days of physics. Isaac Newton was one of the first to consider the problem of fluid motion. An unconfined liquid (or gas) will flow whenever a force, no matter how small, is applied to it. However, the motion is resisted by viscosity, "the lack of slipperiness of the parts of the liquid," as Newton put it. The equations of viscous flow were worked out by the French physicist Louis Navier and the English mathematician George Stokes early in the last century. Essentially they postulated that the rate of flow is directly proportional to the force and inversely proportional to the viscosity. For example, consider the three fluids air, water and castor oil. Water is about 50 times as viscous as air. If it takes one minute to pump a given quantity of water through a certain pipe, an equal pressure will push through the same amount of air in a little over a second. Castor oil, 1,000 times more viscous than water, would take almost a day to complete the same movement. In each case doubling the pressure would double the rate of flow.

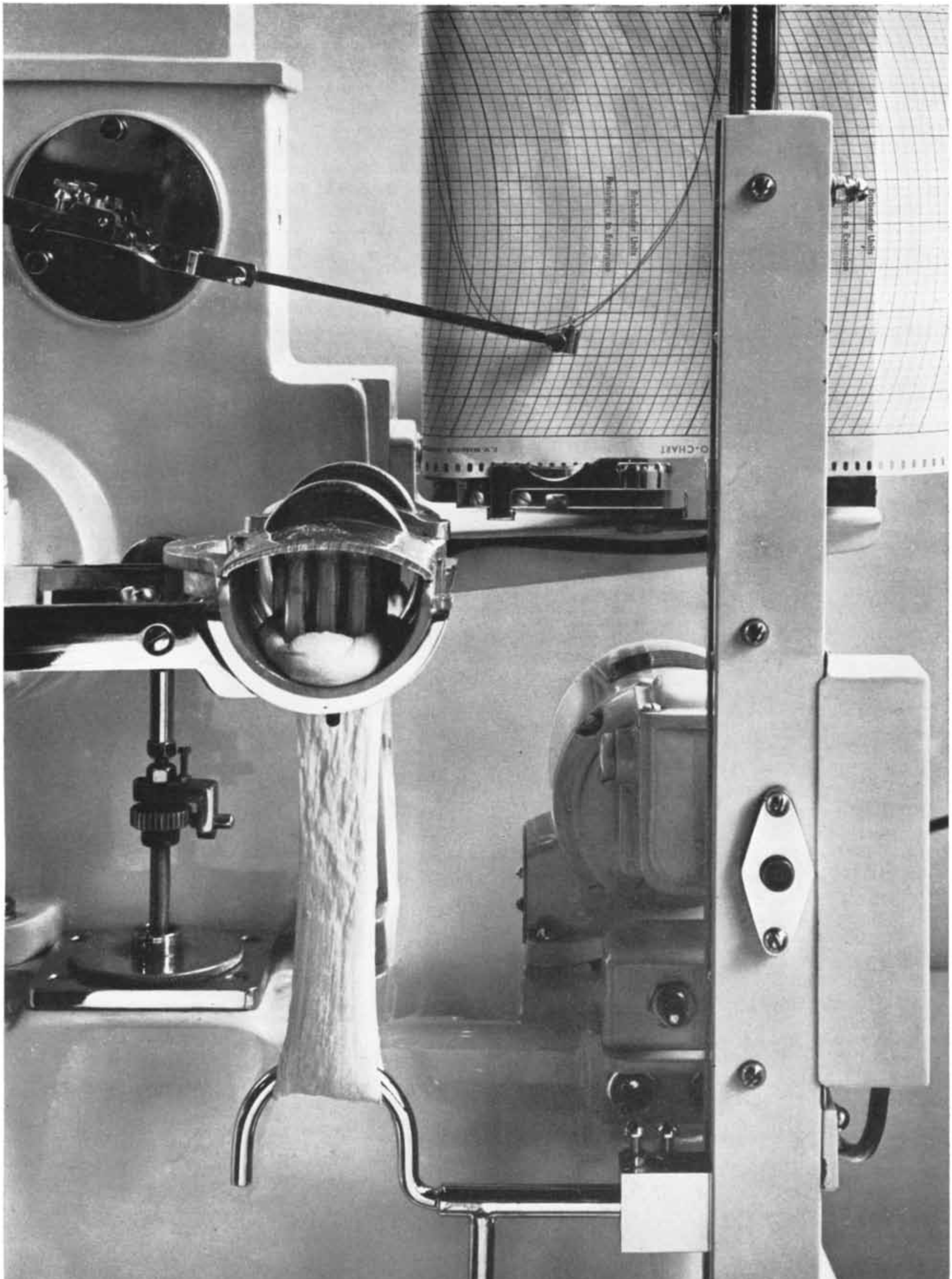
As to solids, their most obvious property, and the first to be studied quantitatively, is not that large forces make them flow but that small forces do not. Under a small force a solid body is distorted, but when the force is removed, the body regains its original shape. Robert Hooke, a contemporary of Newton, discovered the fundamental law of this elastic behavior: that the amount of distortion is proportional to the force applied.

Of course if the force is big enough, the distortion goes beyond the so-called yield point, and the body can no longer recover. Such a permanent change of shape is known as plastic deformation, which is really another way of saying flow. In 1868 the French physicist Henri Edouard Tresca demonstrated that very high pressures could force metallic lead to flow through tubes. From these experiments Tresca's countryman, Barré de Saint-Venant, was able to develop a theory of the plastic flow of metals.

Here, until 40 years ago, matters rested. Physicists and engineers thought in terms of two types of material: fluids, which flow no matter how small a force is applied to them; and plastic solids, which flow only if the force exceeds a critical amount known as the yield stress. The classification was apparently clear-cut. There seemed to be no difficulty in distinguishing between the flow of water, say, and of mild steel, or even of very viscous castor oil and very soft lead.

Then, in 1919, a seemingly routine problem in industrial chemistry thoroughly muddied this classical picture. E. C. Bingham of Lafayette College in Easton, Pa., was concerned with the properties of ordinary house paint. A good paint should spread easily under the brush, and should then flow enough to obliterate the brush marks. Consisting of pigments suspended in oil, paints were naturally considered viscous liquids. The requirements of "brushing" and "leveling" qualities evidently called for a low viscosity. However, a satisfactory paint must fulfill another requirement: brushed onto a vertical wall, it must not run off under the force of its own weight before it dries. This seemed to call for a high viscosity. Bingham came to realize that this apparent contradiction arose from a misconception of the problem. In order for the paint to stay put on the wall it was not enough that it flow slowly; it must not flow *at all*. In other words, it must be a solid! To be sure, it is a solid with very low yield-stress, so that the gentle pressure of the brush is enough to make it flow. Bingham published his findings under the title "Paint, a Plastic Material and Not a Viscous Liquid."

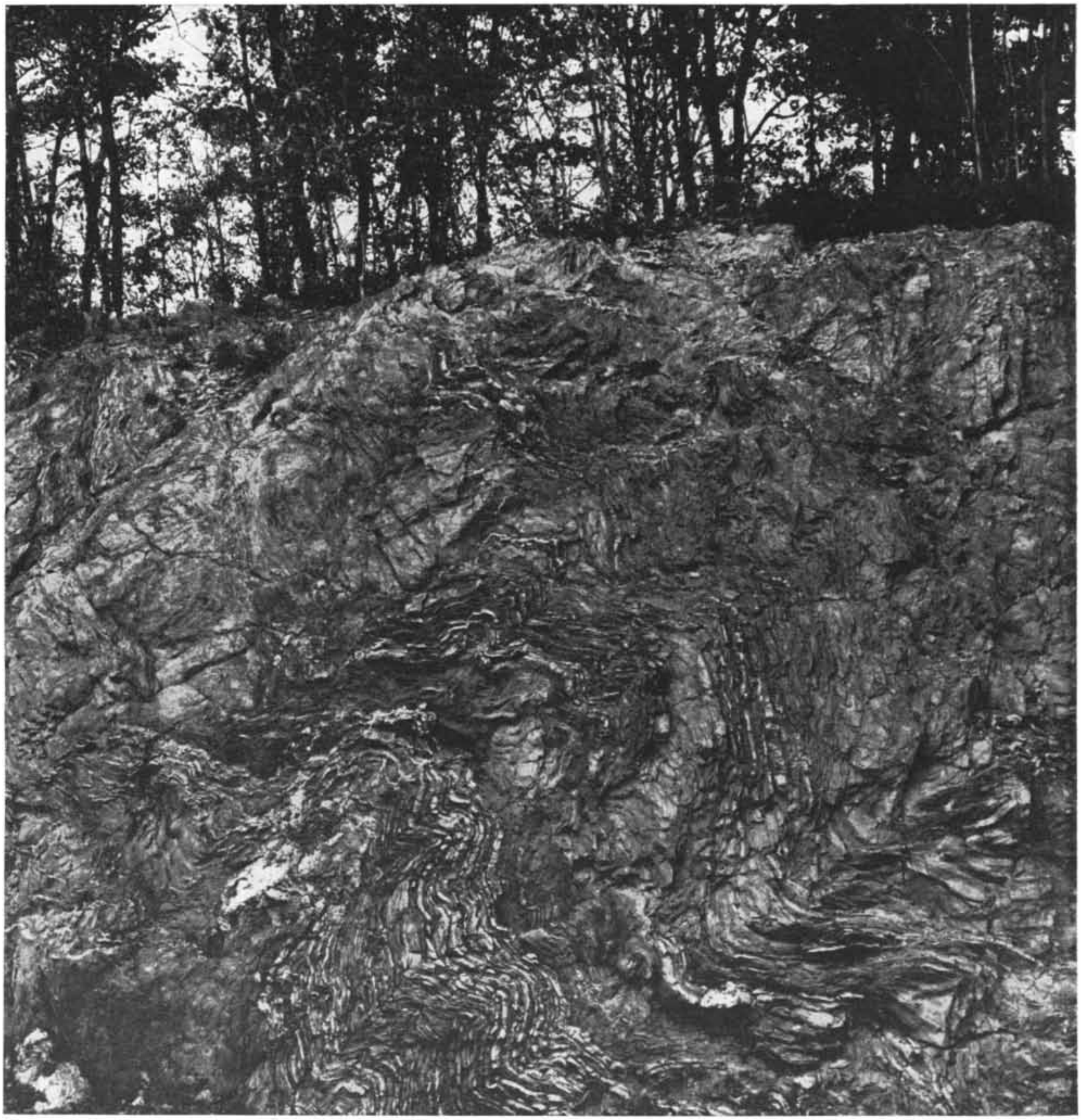
Surveying the classical ideas on flow, Bingham found them quite inadequate



DOUGH IS MADE TO FLOW in "extensograph" of C. W. Brabender Instruments Inc. The dough is held in clamp in center and stretched by hook at bottom. The curve on the graph at upper right indicates that the dough has good flow properties for baking bread.

to describe the behavior of substances like paint, and the new plastics, ceramics, lubricants, rubber products and so on that the chemical industry was beginning to produce. He and his colleagues then set out to develop a modern theory. At the same time, unaware of these developments in the U. S., I was working on the same problem in faraway Palestine. Over the next few years we became acquainted with one another's studies, and a number of international meetings were held. A peculiar feature of the early meetings was that, although they were attended mostly by chemists, the subject matter would have been more interesting to physicists. Finally, in 1948, it was decided to set up a new society for the study of deformation and flow, which would attract workers from all the allied fields. Named the Society of Rheology, after the Greek word for flow, it has just held its 30th-anniversary meeting at Lehigh University in Bethlehem, Pa.

Although the laws of rheology are essentially mathematical, they can be visualized with the help of some simple mechanical models. Rheologists themselves have formed the habit of thinking in terms of their models. This attitude, now largely out of style in physical sciences, harks back to the last century, when British physicists especially tried to picture abstract concepts such as the electromagnetic field and the ether by means of ropes, pulleys, springs and other such devices. Often these contrivances were considered to go beyond



FLOW OF ROCK is dramatically demonstrated by this formation laid bare by a highway excavation near New York City. These rocks originated with sediments deposited at the bottom of the sea in the Older Paleozoic Period of some 400 million years ago. Between 20 million and 50 million years later, when the sediments had become rock, they were plastically folded as the sea bottom sank downward.

Outdoor Christmas decorations shown here were manufactured by General Plastics Corporation, Marion, Indiana. The flat sheets of Tenite Butyrate from which these displays were vacuum-formed were also extruded by General Plastics Corporation.

Butyrate

gives the gift of long life to giant outdoor Christmas decorations

Street displays made of tough, weather-durable Tenite Butyrate plastic help communities spread Christmas cheer for many years

When you need a plastic with long outdoor life, you find a ready answer in Tenite Butyrate.

Its durability has been proved by displays like these and by hundreds of other applications in many different fields, including such products as automobile taillight lenses, marine buoys, outdoor signs and oil-field pipe.

Yet, the outstanding weatherability of Tenite Butyrate seldom is the sole reason for its use. Rather, it is Butyrate's *combination* of properties that usually dictates its choice for a specific job.

The Christmas decorations shown here are an ideal illustration of how Butyrate's properties can be mated to the demands of a specific use.

Outdoor durability certainly is an important consideration for these decorations. Exposed to weather extremes ranging from sub-zero Alaska to sunny Florida, they must be able to endure in any location, showing excellent resistance to cracking, crazing or "aging."

They must also be tough enough to take the abuse of repeated installation and dismantling, plus the hazards of storing and transporting.

Butyrate satisfies these requirements... and other specifications of the manufacturer, such as availability in a crystal-like, clear-transparent formulation, resistance to yellowing by sunlight, and a high surface luster.

Fabricating advantages, too, complement the service excellence of Butyrate. Because of the ease with which extruded sheet of Butyrate can be vacuum-formed over inexpensive molds on fast-cycle machines, production costs are kept at a minimum. Even decorating costs are low; for the multicolored patterns are applied by silk-screening the inside face of the display before forming, thus protecting the printing from the weather and preserving a naturally glossy exterior. Subsequent fabricating operations such as trimming, punching, stapling, riveting or grommeting are easy to carry out without danger of crazing or cracking.

If you'd like to consider Tenite Butyrate for one of your material needs, let us hear from you. We'll be glad to discuss your application in confidence, and help you evaluate the suitability of Butyrate. For this assistance or for more information, write EASTMAN CHEMICAL PRODUCTS, INC., subsidiary of Eastman Kodak Company, KINGSPORT, TENNESSEE.

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Much of United Aircraft Corporation's success may be attributed to its ability to determine the genuinely significant areas of technology before committing valuable talent and resources.

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Projects at Missiles & Space Systems share this same heritage of significance as we move into a new era of astronautics. If you are interested in joining a new organization destined shortly to demonstrate its significance, contact John North.

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East Hartford, Connecticut

mere analogy; their inventors thought they represented the actual structure of the physical world. So also with rheological models. If we think of the molecules of a material as having elasticity, for instance, then a spring may not only be an analogue for the behavior of the material, but a real element of its internal structure.

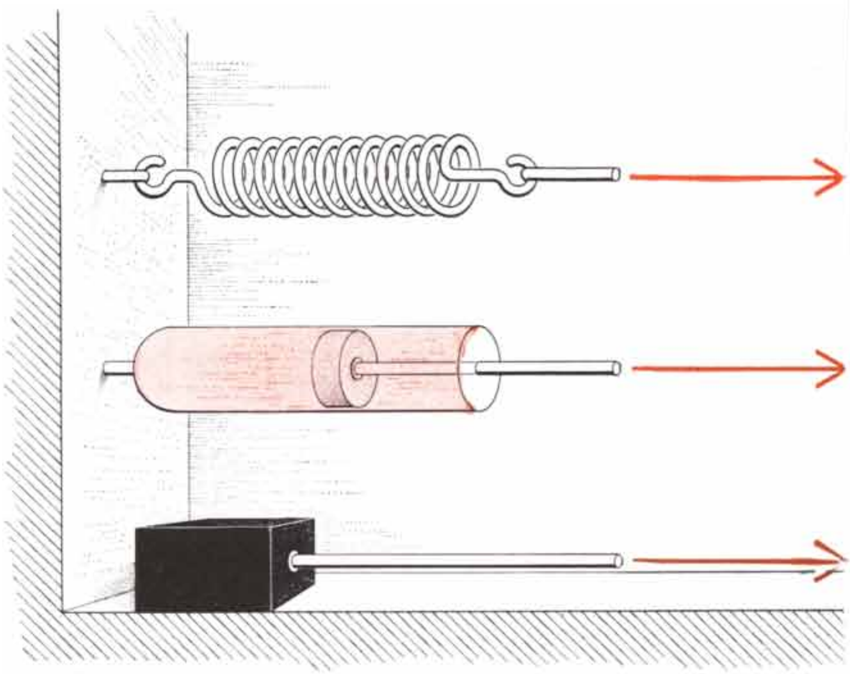
In any case the models are built up from just three elementary mechanisms [*see illustration below*]. The first, called a Hooke body, is a helical spring rigidly supported at one end. It represents, of course, the elastic behavior of bodies. When a force is applied at the free end, the spring extends. When the force is removed, it goes back. The amount of the extension depends on the size of the force.

The second element is called a Newton body, and represents pure viscous flow. It is a "dashpot"—a tube filled with oil, in which a loosely fitting stopper can move as a piston. Pulling or pushing the stopper causes it to move through the liquid at a definite rate, proportional to the force. As soon as the force is taken off, the motion stops, and the plunger stays just where it is.

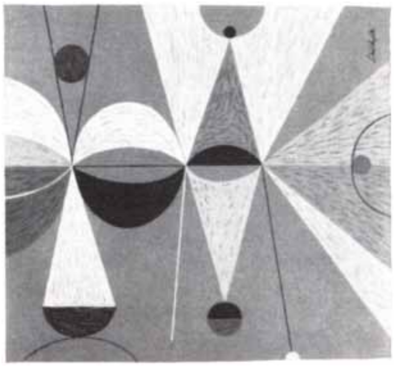
Finally there is the Saint-Venant body, a model of classical plastic flow. It consists simply of a weight resting on a horizontal tabletop. In order to move the weight the friction between it and the table must be overcome. A force too small to do this has no effect. A sufficiently large force moves the weight across the table. Again, when the force is removed, the weight comes to rest in a new position.

Actually the Saint-Venant body is a defective model. It accurately represents the phenomenon of yield stress, but not the true motion when the yield point is exceeded. A steady force large enough to set the weight in motion would in fact cause it to move faster and faster once it got started. But plastic flow, once it has been set up, resembles viscous flow in that a steady force produces a constant rate of movement. To remedy this shortcoming we can hook up a weight and a dashpot in parallel [*see illustration at left on next page*]. Then the weight determines the behavior below the yield point and the dashpot determines the motion of flow.

This is precisely what Bingham did in his analysis of paint, and the combination is known as a Bingham body. See how nicely it demonstrates the kinship as well as the difference between various materials. To represent paint we would envision a light weight with smooth surfaces, resting on a smooth table. The dashpot might contain a rather light oil. A very small force would be enough to start the body moving, and it would then flow quite easily. Lead, on the other hand, would be conceived as a heavy, rough weight on a rough surface, together with a dashpot containing very



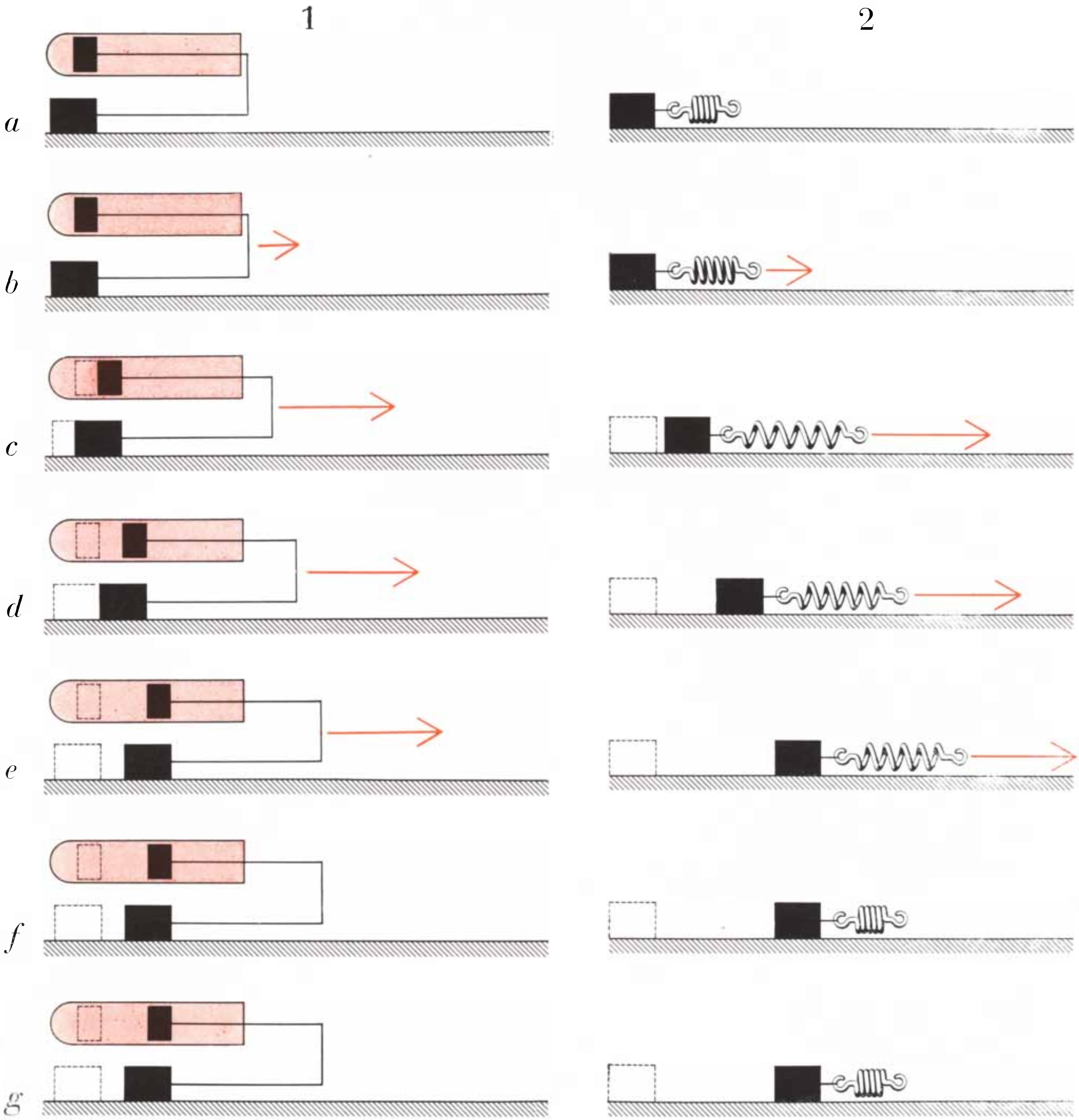
BASIC MECHANISMS of rheological models are the Hooke body, a spring (*top*); the Newton body, a dashpot (*middle*); and the Saint-Venant body, a block that resists being pulled because of friction. Action of each body under the influence of a force is described in text.



thick oil. Now the yield stress is high, and the flow comparatively sluggish.

As the reader will have anticipated, different combinations can be put together to suit a variety of problems. In brushing on paint, or squeezing toothpaste from a tube, or drawing wires from steel rods, we will probably care only about the properties of yield and flow, represented by the Bingham model. Suppose, however, we are concerned with the behavior of soil under a building foundation. Then its elastic deformation below the yield point would also be important. To represent it we hook a spring in series with a weight [*see illustration at right below*]. A small force merely stretches the spring; a large one moves the weight as well. This arrangement is sometimes called a Prandtl body, after the German physicist Ludwig Prandtl.

Two more of the fundamental "bodies" of rheology were invented long before the discipline was born, by Lord Kelvin and James Clerk Maxwell. They did not describe the structures in terms of our elementary units, but it is possible to do so. Kelvin was thinking about the



MODELS FOR RHEOLOGICAL BEHAVIOR, made up of various combinations of the mechanisms depicted on the preceding page, include the Bingham body (*column at left*), the Prandtl body (*column second from left*), the Kelvin body (*column third from left*) oscillations of metal wires. As a model he proposed a sponge made of perfectly elastic material, whose holes were filled with a viscous liquid. He pointed out that in a static experiment, such as stretching the sponge with a steady force, the model would be perfectly elastic: its elongation would be proportional to the force, and it would return to its original shape when the force was removed. On the other hand, in a dynamic experiment—for example, rapidly stretching and compressing the sponge—the viscous flow of the contained liquid would absorb energy, and the body would behave like rubber or jelly. Kelvin's model turned out not to apply to oscillating wires, but it does describe quite well a type of soil containing large grains of silt embedded in fine clay.

In rheological terms a Kelvin body is represented by a spring in parallel with a dashpot [*see illustration at left below*]. It is an elastic solid whose reactions are not instantaneous, but are retarded by the viscous dashpot.

A Maxwell body also is made of a spring and a dashpot, but the two are hooked up in series [*see illustration at right below*]. It reflects the fact that

3

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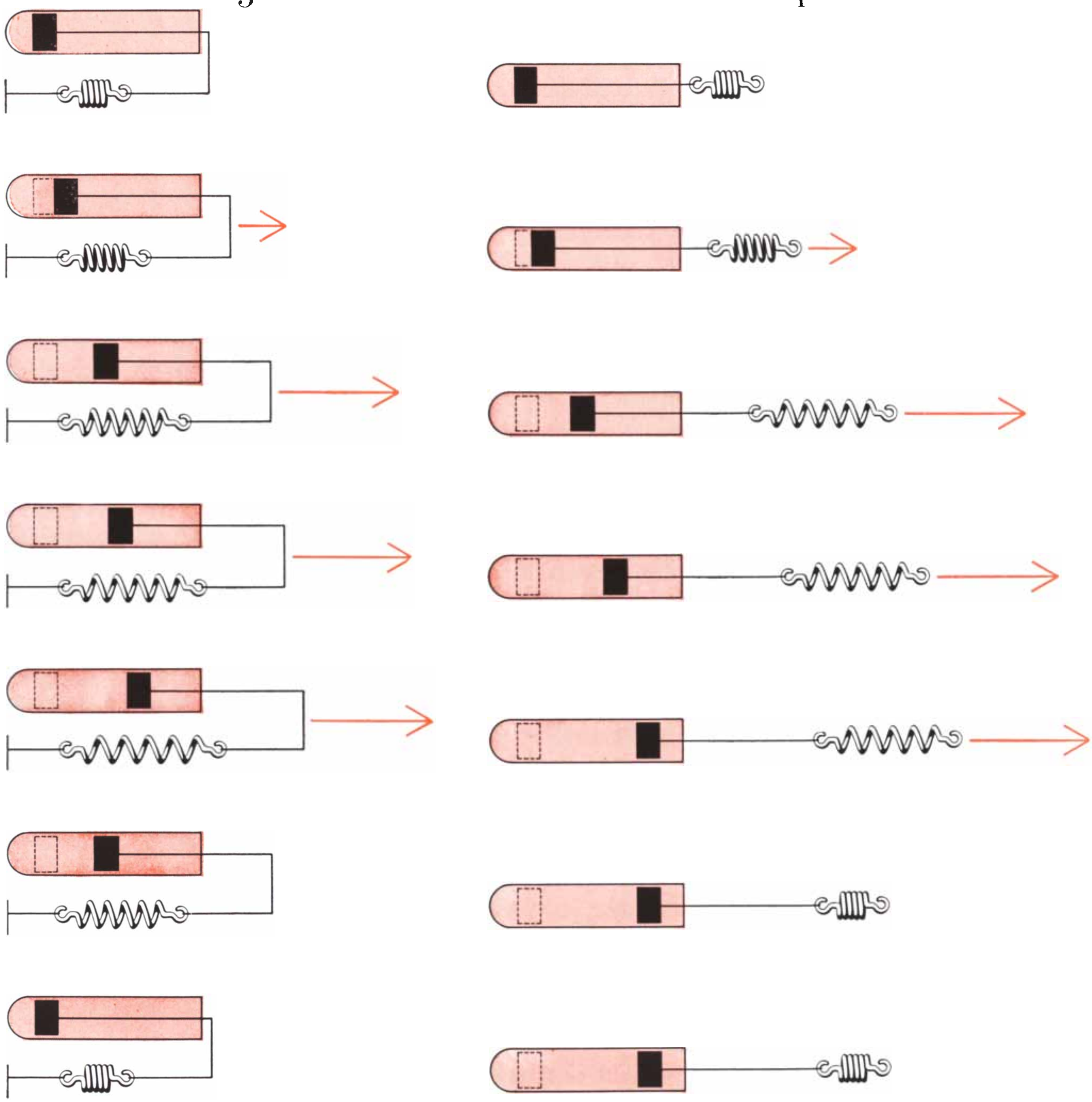
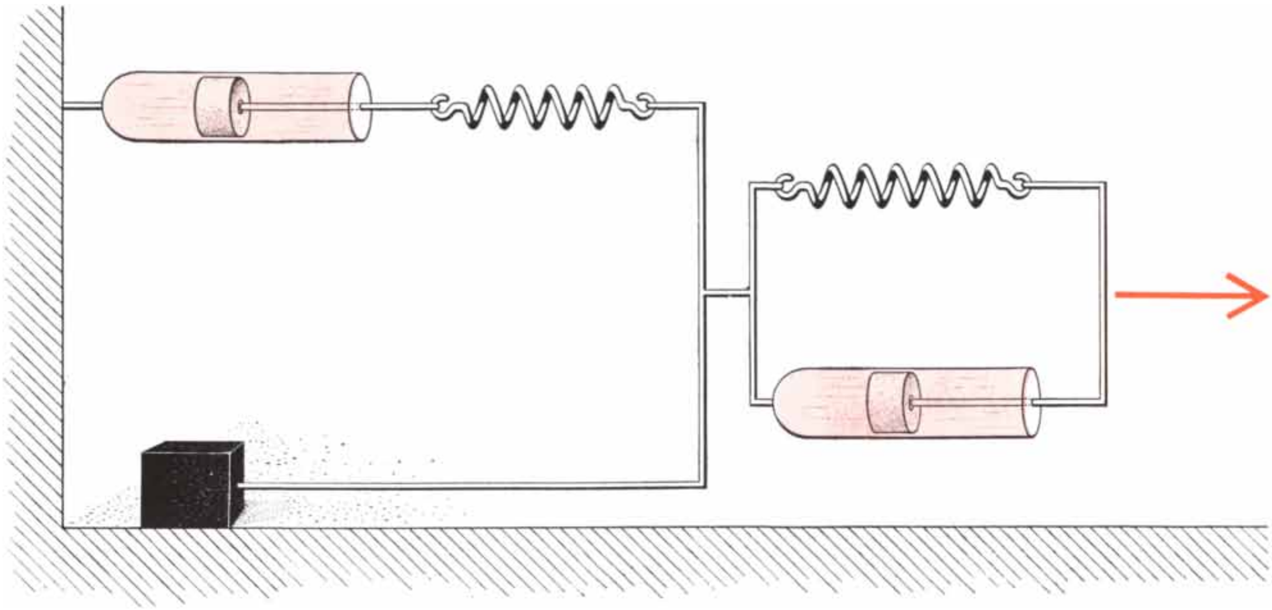


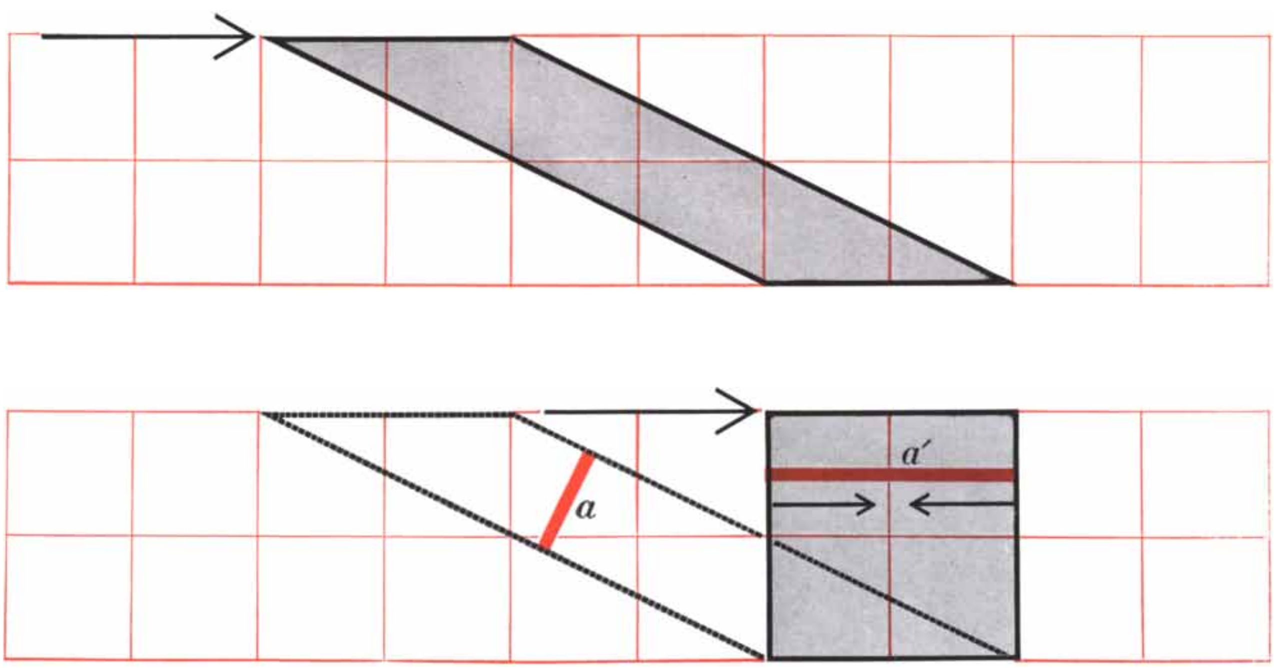
and the Maxwell body (*column at right*). Successive drawings in each column show the behavior of these bodies under the influence of an applied force. Broken rectangles indicate original position of weight or piston; black rectangles, position at a given instant.



COMPLEX FLOW OF DOUGH is represented by this intricate combination of rheological models. The model consists of a Maxwell body (*top left*) in parallel with a Saint-Venant body (*bottom left*), which are then connected in series with a Kelvin body (*right*).

fluids—even ideal gases, which Maxwell himself was studying—may have elasticity as well as viscosity. If we pull on the model, the spring extends at once, and the piston begins traveling behind it. Thus we may think of the Maxwell body as a liquid that can be strained (*i.e.*, that can have its shape changed) elastically. If we keep the model stretched at a certain length, the piston continues to move until the elastic strain disappears. We can say that the elastic stresses, or forces, in the liquid have "relaxed" in the time required by the piston to complete its motion.

But there is another way of looking at it. Imagine a rather weak spring attached to a dashpot containing extremely viscous oil. If the spring is pulled out and then quickly released, it will return almost exactly to its original position. The plunger will hardly have moved at all. Now the body looks like an elastic solid. Depending on the viscosity we assign to the dashpot, it might be hours, weeks, even centuries before the fluid properties become apparent. From this point of view the everyday qualitative difference between a solid and a liquid becomes only a quantitative difference,



SHEARING ACTION results in geometrically nonlinear flow. A block with slanted sides (*diagram at top*) is pushed by a shearing force to an upright position (*diagram at bottom*). The original distance between its sides, *a*, has now increased to the distance *a′*. Thus the block is stretched sideways and is under tension, as is indicated by the two arrows that point inward from its sides.

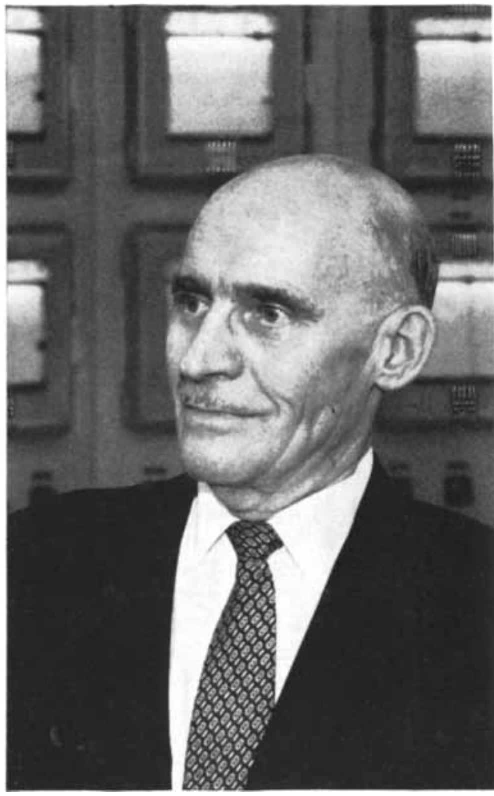
Their problem:

To control an entire electric power system with a computer on an economic basis

Names of these scientific Americans:

E. D. Early, Vice President
Southern Services, Inc.

H. W. Page, Manager of Power Supply
Florida Power & Light Co.



E. D. Early

As so often happens when a significant technological advance is made, workable solutions to this problem were conceived independently in widely separated locations—and at about the same time.

Back in the late 1940's, much theoretical work had been done by a number of men in an effort to use computers for automatic economic generation control on electric power company systems. The most difficult part of their problem consisted of reducing a thousand-odd power system operating variables to a mathematical expression which lent itself to electronic computation. On the basis of their efforts, two outstanding operating engineers made the contributions which led directly to practical computer-control.

One was E. D. Early, then Manager of the Southern Company Power Pool, which consists of four separate power companies covering a four-state area in the South. He succeeded in developing an analog method of obtaining the incremental cost of power delivered for each unit on the system—including the effect of both incremental generating costs, and incremental transmission losses associated with delivering power to the load centers. He succeeded where others had failed because of his ingenious use of the power system itself, in effect, as part of computer feedback — an arrangement which greatly simplified computer design. As a result, he was the first by some two or three years to actually install a workable computer (the famed "Early Bird") and use it for economic system control. This computer —the world's first incremental cost computer for delivered power—accelerated interest in cost computers. Since its installation in 1954, additional control equipment has been incorporated in the "Early Bird" to provide for automatic economic loading of steam units, thus making the computer part of a closed loop arrangement.

The other engineer was H. W. Page, Manager of Power Supply, Florida Power & Light Company. In 1948, when Page was associated with Ebasco Services as a consultant on power system operating problems, he made a study of the rapidly expanding Florida P & L transmission system. In addition to showing F P & L how transmission losses could be incorporated into its manually-calculated plant loading schedules, Page and two associates* were able to derive the "coordination equation" which made computer-control of the system practicable. This equation was presented in a widely-acclaimed AIEE paper in 1949, and today is utilized by a Desired Generation Computer in the Miami control center of the F P & L system. Not only does this computer provide closed-loop control of the system on a cost basis, but it also plots graphic answers to the many anticipated loading problems which occur as power is exchanged with neighboring utilities, generating units are taken off the line for maintenance, etc.

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depending on the relation between the time of relaxation and the time of observation. If we could sit and watch Deborah's mountains for a few million years, we might also see them flow [*see illustration on page 124*].

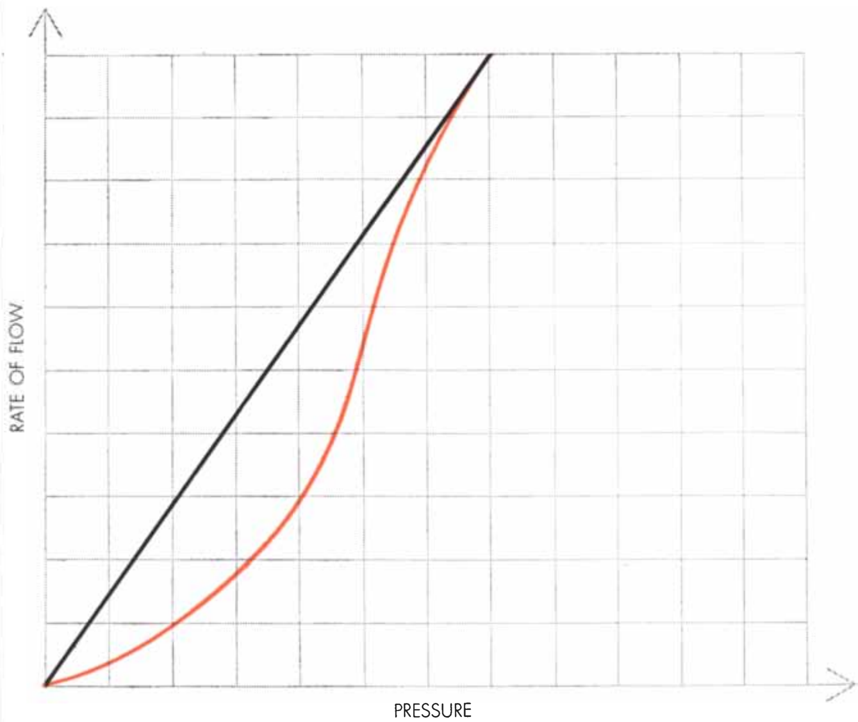
By combining the basic models in various ways, extremely complicated types of rheological behavior can be represented. The most elaborate case yet studied is the flow of dough. According to the British investigators R. K. Schofield and G. W. Scott-Blair, dough acts as if it were made of a Maxwell body in parallel with a Saint-Venant block, both joined in series to a Kelvin body [*see top illustration on page 132*]. I leave it to the reader to picture for himself the strange movements that this model can perform.

Of course we do not suppose that dough is really the most complicated of all materials. On the contrary, every substance should be considered to have all possible rheological properties in greater or lesser degree. Their relative prominence will depend on the conditions under which the substance is examined. So far it is dough that has been observed under the most diverse circumstances.

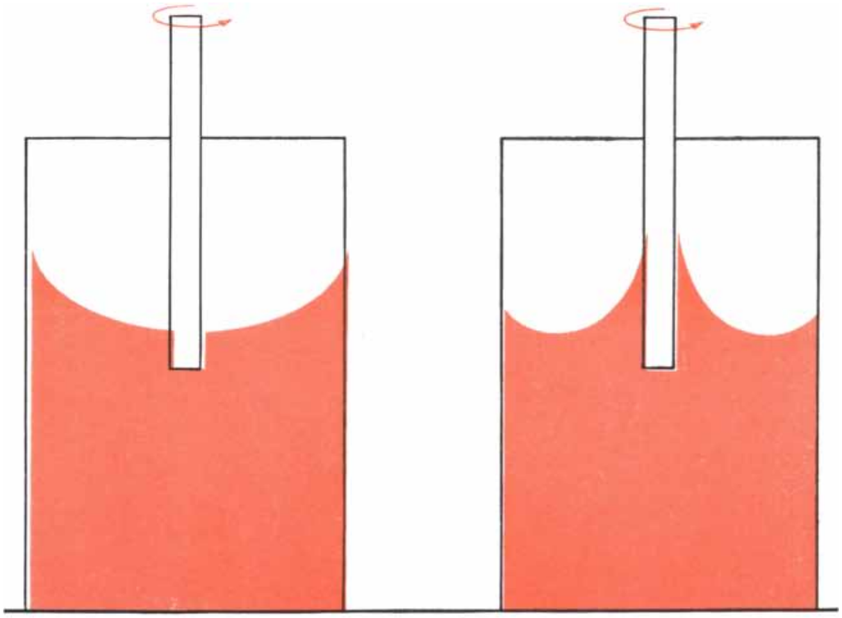
The types of behavior we have considered so far, complex as they are, nevertheless share a certain underlying mathematical simplicity: they are all "linear." By this we mean that effects are directly proportional to causes. The two basic types of motion, viscous and elastic, are themselves assumed to be linear, as we have indicated. In elasticity the amount of stretch (or other change in shape) is proportional to force; in viscosity the rate of flow is proportional to force. The various combinations of these simple cases are also linear.

Unfortunately real materials are not always linear, a fact that first turned up in the study of liquids such as blood and solutions of rubber. Homogeneous liquids—water, alcohol, toluene, oil—and true solutions such as sugar in water have constant viscosity. Their rate of flow is directly proportional to the pressure. But when we force blood to flow through a tube, we find that doubling the pressure, for example, may triple or quadruple the rate of flow. In other words, its viscosity under large forces is less than under small forces. The plot of flow against force is no longer a straight line [*see illustration below*]. Liquids whose viscosity varies in this way are suspensions or dispersions—mixtures of different types of material.

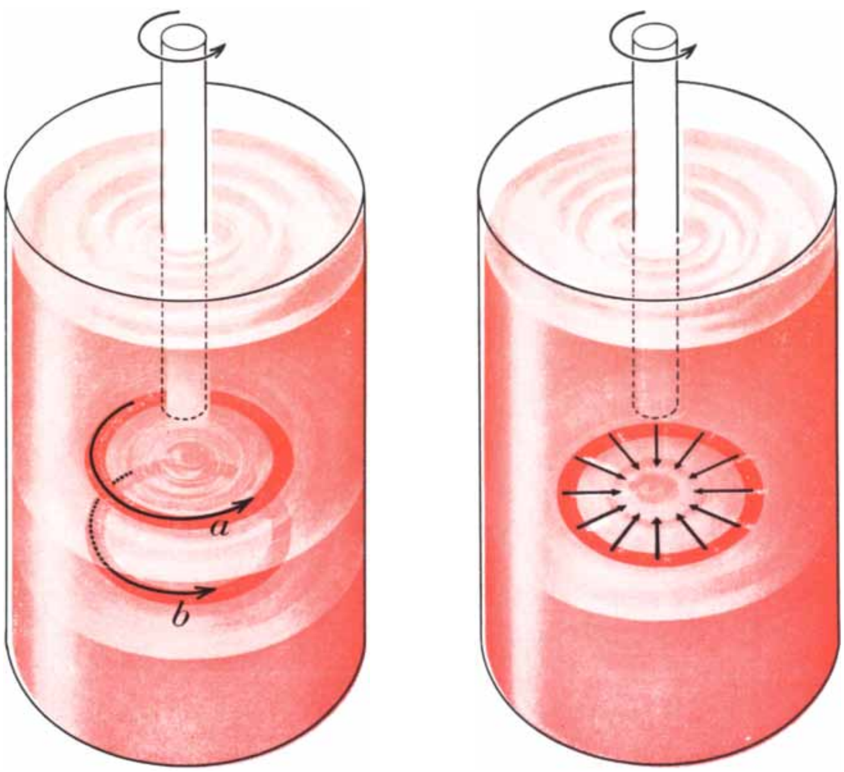
We believe that their behavior is due to the effect on their internal structure of the deformation known as shear. Any liquid flowing through a tube moves faster in the center than near the walls. This difference in the rate of motion



VISCOSITY PLOT of a Newtonian liquid is a straight line. The rate of flow is directly proportional to the pressure applied. A non-Newtonian fluid has a curved graph indicating that the viscosity of the fluid changes with different rates of flow (or different pressures).



WEISSENBERG EFFECT is illustrated by the drawing at right. At left a Newtonian liquid reacts to circular stirring by moving down at the center of the vessel and up near the walls. A liquid obeying the Weissenberg effects climbs up the stirring rod rather than down.



WEISSENBERG EFFECT is explained by shear elasticity. Rotation of liquid is faster in plane *a* than in plane *b* (*left*); therefore the liquid is sheared circularly. Because of elasticity the circular flow-line (*right*) is under tension along its length. Hence it acts like a stretched rubber band and tries to squeeze the liquid in toward the center of the vessel.

of adjacent layers is shearing action. In suspensions, shear presumably alters the internal arrangement of the constituents, making them flow more easily at higher rates of shear. Thus if the suspension consists of long, thin particles in a liquid, shearing might tend to align the particles in a common direction.

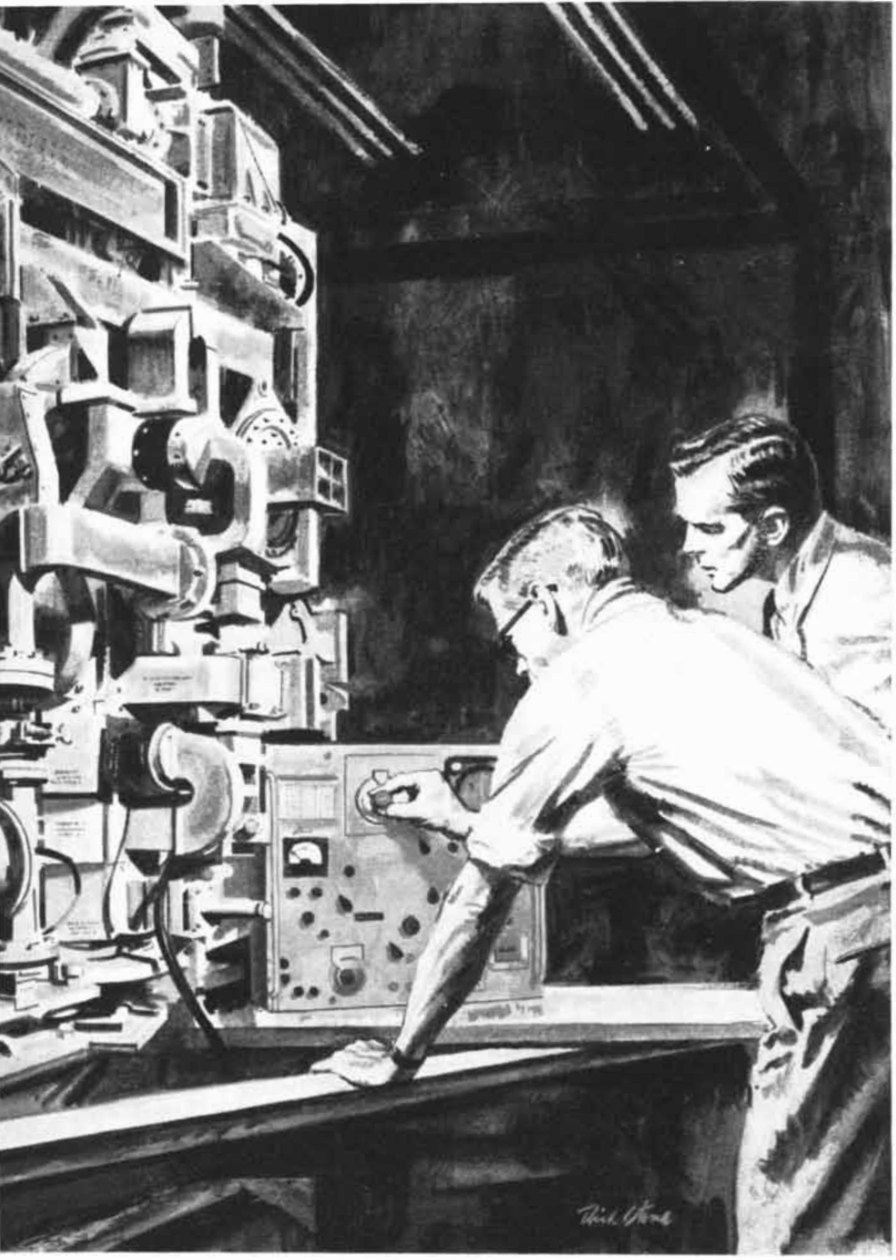
Whatever the exact mechanism, the phenomenon depends on the physical structure of the material, and hence is called physical nonlinearity. Liquids that behave in this way are called non-Newtonian.

Although the basic model elements—spring, dashpot and block—are not ideally suited to represent a non-Newtonian liquid, it is possible to combine them in such a way that they will simulate its action. Thus it seemed until fairly recently that all possible types of rheological behavior could be analyzed in terms of the three basic elements. Then, during World War II, Karl Weissenberg in England discovered some totally new and strange effects (which I, at the same time, predicted from theoretical considerations).

Experimenting with napalm and other viscous materials he saw these liquids do things that were simply impossible according to the standard theories. An investigator observing these motions for the first time, Weissenberg wrote, "would hardly believe his eyes."

We will mention just one example of the Weissenberg effects. Think of what happens when a rotating rod, like the shaft of a soda-fountain mixer, is lowered into a liquid. The liquid is set into rotation and, under centrifugal force, tends to move outward toward the walls of its container. The net result is to push the liquid down in the center, around the rod, and up toward the walls [*see illustration at left at the top of this page*]. When Weissenberg tried this [*illustration at right*], he saw his liquid climb *up* the rod!

The search for an explanation of such phenomena has demonstrated that some fundamental processes, supposedly well understood, are more subtle than they seem. For our purposes we need consider only the case of "simple" shear elasticity. Imagine an elastic block with slanting sides and a horizontal top and bottom [*see bottom illustration on page 132*]. The bottom is held fixed, and a horizontal force is applied to the top, pushing the block until its sides are upright. In describing the condition of the block, we now say it contains shear stresses that push back against the applied force and tend to



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bring the body back to its original shape.

But there is more to it. If we compare the distance between the sides in the two positions, we realize that they are farther apart after the deformation than before. In other words, shearing has stretched the block horizontally, and it is under tension, as if a stretched spring connected its sides. The tension is parallel to the original shearing force.

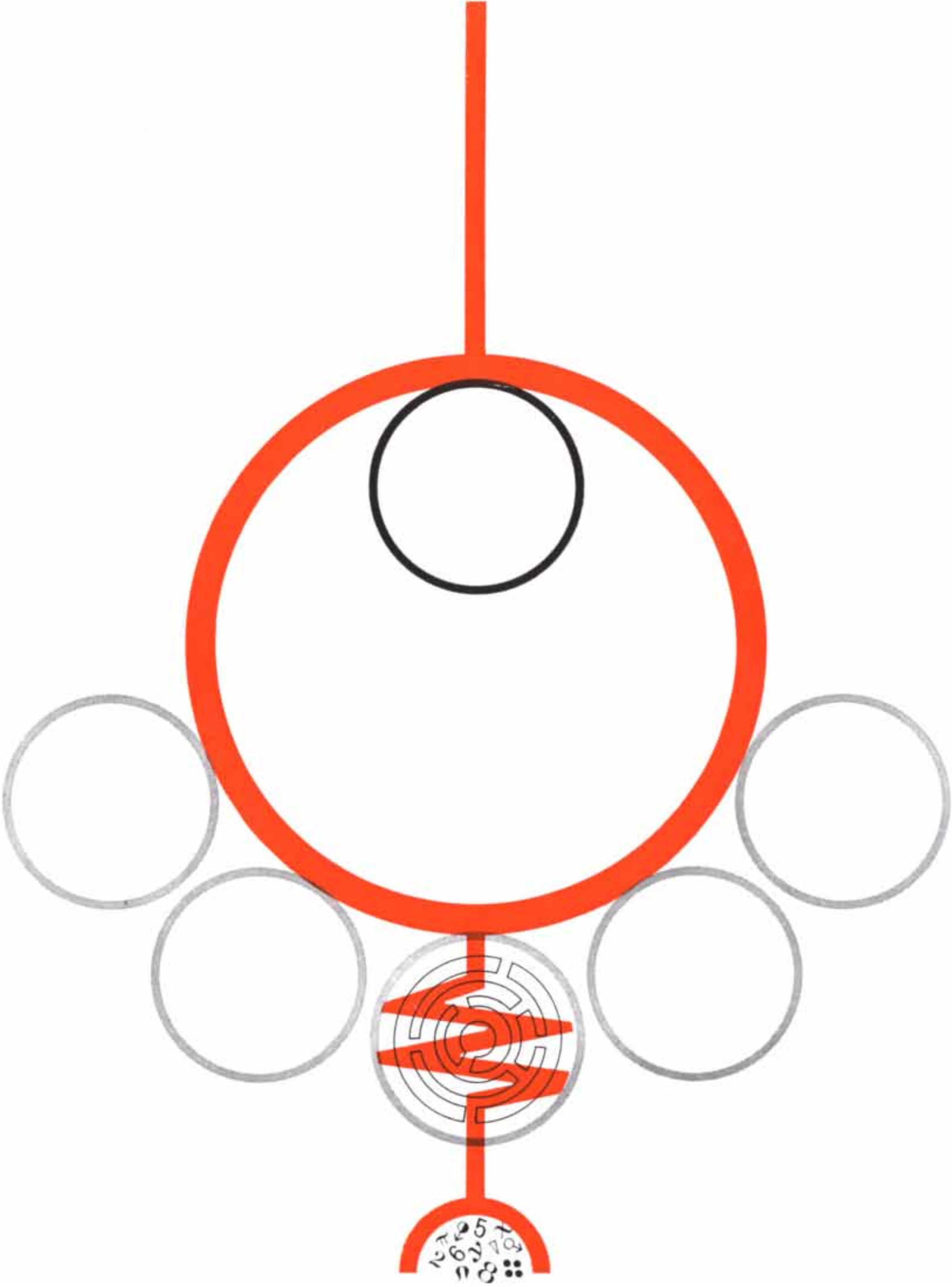
Now a liquid set into rotation by a rod is sheared, because the higher layers tend to move faster than the ones below [*see bottom illustration on page 136*]. Here the shear is circular. If the liquid has elasticity, there will be tension in the same direction as the shear, as there was in the block. Therefore a circular flow-line acts like a stretched elastic band, tending to shrink down, forcing the liquid inward and up the rod.

This effect is not linear. It depends on the geometry of the deformation; hence it is called a geometrical nonlinearity. We now realize that, like other rheological properties, geometrical nonlinearity is shared by all materials to some extent. We can find it if we know how to look.

Recently I discovered a dramatic confirmation of this. If Heraclitus declared that everything is fluid, we can now say everything is solid—even air! In brief, I have found that air too has shear elasticity and can be made to act in the same way as the liquids we have just been discussing. The experimental setup consists of two parallel circular plates, one spinning and the other stationary. The stationary plate has a hole in the center to which is connected a pressure gauge. When the plates are about one millimeter apart, the air between them, set into rotation, tends to fly out because of centrifugal force. The gauge registers a drop in pressure. Now if we move the plates slowly closer, the pressure is gradually restored. At last, when the gap is only about a hundredth of a millimeter, the air is squeezed inward and through the hole, and the pressure jumps above normal.

The disks make a new kind of air pump. Moreover, if there is no hole in the stationary disk, the compressed air forms a very low-friction bearing. Both of these applications are now under development.

It is fair to say that not all authorities agree with my interpretation of this effect. Some have attempted to "save" the Navier-Stokes equations and to derive the result for a strictly Newtonian fluid with no shear elasticity. I believe, however, that my case is now pretty well proved. Thus rocks are liquid, air is solid and things are not what they seem.



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The Physiology of the Camel

How does the camel survive for weeks without drinking? Studies in the Sahara Desert have exploded some old legends and have elucidated the animal's remarkably parsimonious water economy

by Knut Schmidt-Nielsen

The camel's ability to go without water for long periods is proverbial. Naturalists since Pliny the Elder have ascribed this talent to a built-in reservoir on which the animal can draw in time of need. Thus the English zoologist George Shaw wrote in 1801: "Independent of the four stomachs which are common to the ruminating animals, the Camels have a fifth bag which serves them as a reservoir for water. . . . This particularity is known to Oriental travelers, who have sometimes found it necessary to kill a Camel in order to obtain a supply of water."

Such tales appear even in modern zoology textbooks (though some writers have shifted the camel's reservoir from its stomach to its hump). There is remarkably little evidence for them. A few years ago I became interested in camel physiology and leafed through every book on the subject I could find. I accumulated a large amount of information on the camel's anatomy, its diseases and its evolution, but discovered that scientific knowledge of its water metabolism was almost nonexistent.

The camel's tolerance for drought is real enough. It can travel across stretches of desert where a man on foot and without water would quickly die of thirst. This fact poses some interesting questions for the physiologist. No animal can get along completely without water. Land animals in particular lose water steadily through their kidneys and from the moist surfaces of their lungs; mammals cool themselves in hot surroundings by evaporating water from their skins or oral membranes.

Desert animals have evolved a variety of mechanisms to minimize these losses. The kangaroo rat, for example, produces urine which contains so little water that it solidifies almost as soon as it is excreted. The animal avoids the heat and thus decreases evaporation by passing the daylight hours in a relatively cool burrow [see "The Desert Rat," by Knut and Bodil Schmidt-Nielsen; Scientific American, July, 1953].

The camel can hardly escape the heat by burrowing. Does it emulate the desert rat by excreting a highly concentrated urine? Does it store water in its stomach, or anywhere else? For that matter, just how long can a camel go without water?

Our laboratory at Duke University was obviously no place to seek answers to these questions. Accordingly my wife and I, together with T. R. Houpt of the University of Pennsylvania and S. A. Jarnum of the University of Copenhagen, undertook to study camels in the Sahara Desert. The information we were seeking was not only of scientific interest but might also be of practical importance. In many arid lands the camel is the chief domestic animal. It serves not only as a beast of burden but also as a source of milk, meat, wool and leather. A better understanding of camel physiology might benefit the economy of these areas, which include some of the most poverty-stricken regions on earth.

The expedition required a year's planning, because we had to be completely independent of outside supplies in setting up our desert laboratory. Late in 1953 we arrived at the oasis of Béni Abbès, located in the desert south of the Atlas Mountains. To many Americans the word "oasis" suggests a few date palms clustered around a well. Béni Abbès, however, is a community of several thousand people. Its location over an underground river flowing down from the mountains ensures water for drinking and some irrigation.

Camels are valuable beasts in the Sahara, and we had considerable difficulty in securing animals for experimental purposes. With the aid of our native assistant, Mohammed ben Fredj, I managed after considerable haggling to purchase one animal and later to rent two others. Meanwhile we sought to track down the source of some of the abundant camel folklore.

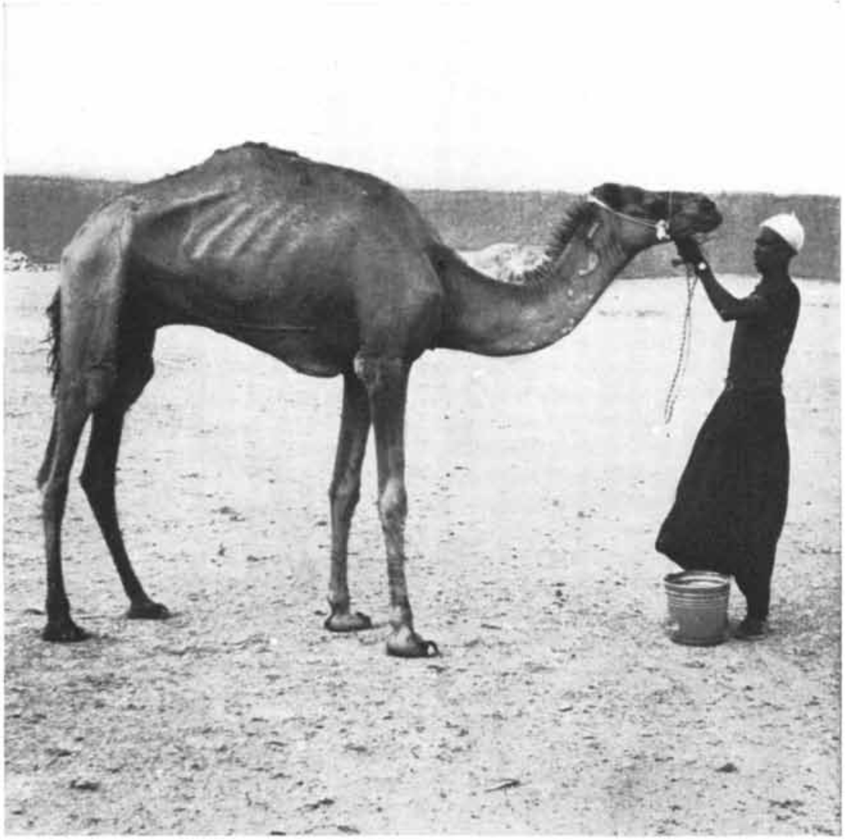
Explorers have often reported that their camels have gone without water for as long as several weeks. Is this possible? Under certain circumstances it is. Much desert exploration has been conducted in winter, because the desert summers are unbearably hot. During the winter the camel can often meet its need for water by browsing on bushes and succulent plants, which flourish after a rain and contain considerable water. Indeed, we found that in the Sahara grazing camels are not watered at all in winter. Some that had not drunk for as much as two months refused water when we offered it to them. When we examined such animals that had been butchered for meat, we found that all their organs contained the normal amount of water.

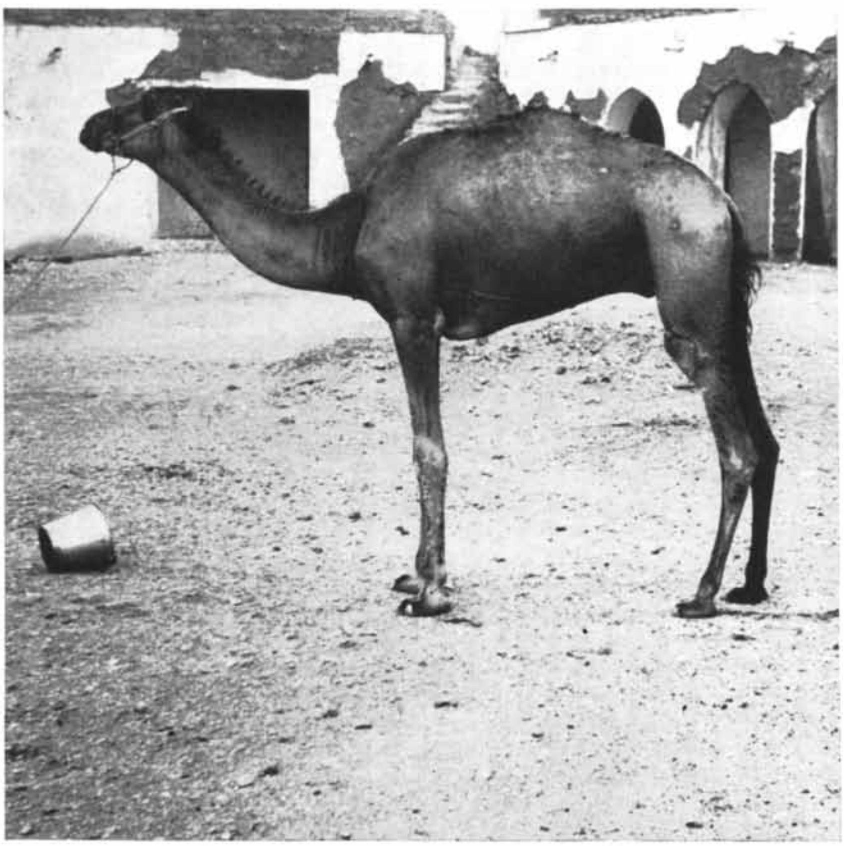
Thus the camel's drought tolerance in winter seems entirely ascribable to its diet. Even a man would have no difficulty in abstaining from drinking in cool weather if he fed largely on juicy fruits and vegetables. During the winter months the only way to dehydrate a camel is to restrict it to a fodder of dry grass and dried dates (not the soft, sweet dates of the grocery but a hard, fibrous and bitter variety). Even when we kept our camels on this completely dry diet, they could go for several weeks without drinking, though they lost water steadily through their lungs and skin and through the formation of urine and feces. We were able to measure these losses quite accurately simply by weighing the beasts, because unlike most animals deprived of water they continued to eat normally and thus did not lose weight in the usual sense. When we finally offered them water, they would in a few minutes drink enough to bring their weight back to normal. In no case did they drink more water than they had previously lost. Evidently they were not storing up a surplus but replacing a deficit.

Our studies of butchered camels supported this conclusion; we could find no evidence for special water-storing organs. The camel's first stomach, or rumen, does have pouches that are not found in the stomachs of other ruminants. These pouches have been called water sacs by some investigators, but their total fluid capacity is only about a gallon, and they contain coarsely masticated fodder rather than water. The main part of the rumen and the other stomachs contained considerable fluid, but less than the stomachs of other ruminating animals do. Chemical analysis revealed the similarity of the fluid to digestive juices; in salt content it resembled blood rather than water. Though it could furnish no significant reserve of water for the camel, it might well save the life of a thirsty man. The stories of travelers who killed their camels for water may thus be true. However, a man would have to be terribly thirsty to resort to such an expedient, because the fluid is usually a foul-smelling greenish soup. As for other possible sites of water storage, we found that neither the hump nor any other part of the animal's body contained an unusual quantity of fluid.

The tale that the camel stores water has probably gained color from the animal's remarkable capacity for rapid and copious drinking. During a later experiment one of our camels drank more than 27 gallons of water in 10 minutes. Camels are always watered before a long desert journey, and if they have not been watered for some days they will drink greedily. The uncritical observer could easily conclude that the animals are storing water in anticipation of future needs.

Some writers have alleged that the camel's fatty hump, though it contains no water reservoir, nonetheless provides the animal with a reserve of water as well as of food. Their logic is simple enough. All foods contain hydrogen and therefore produce water when they are oxidized in the body; the desert rat obtains all its water from this source. Fat contains a greater proportion of hydrogen than any other foodstuff and yields

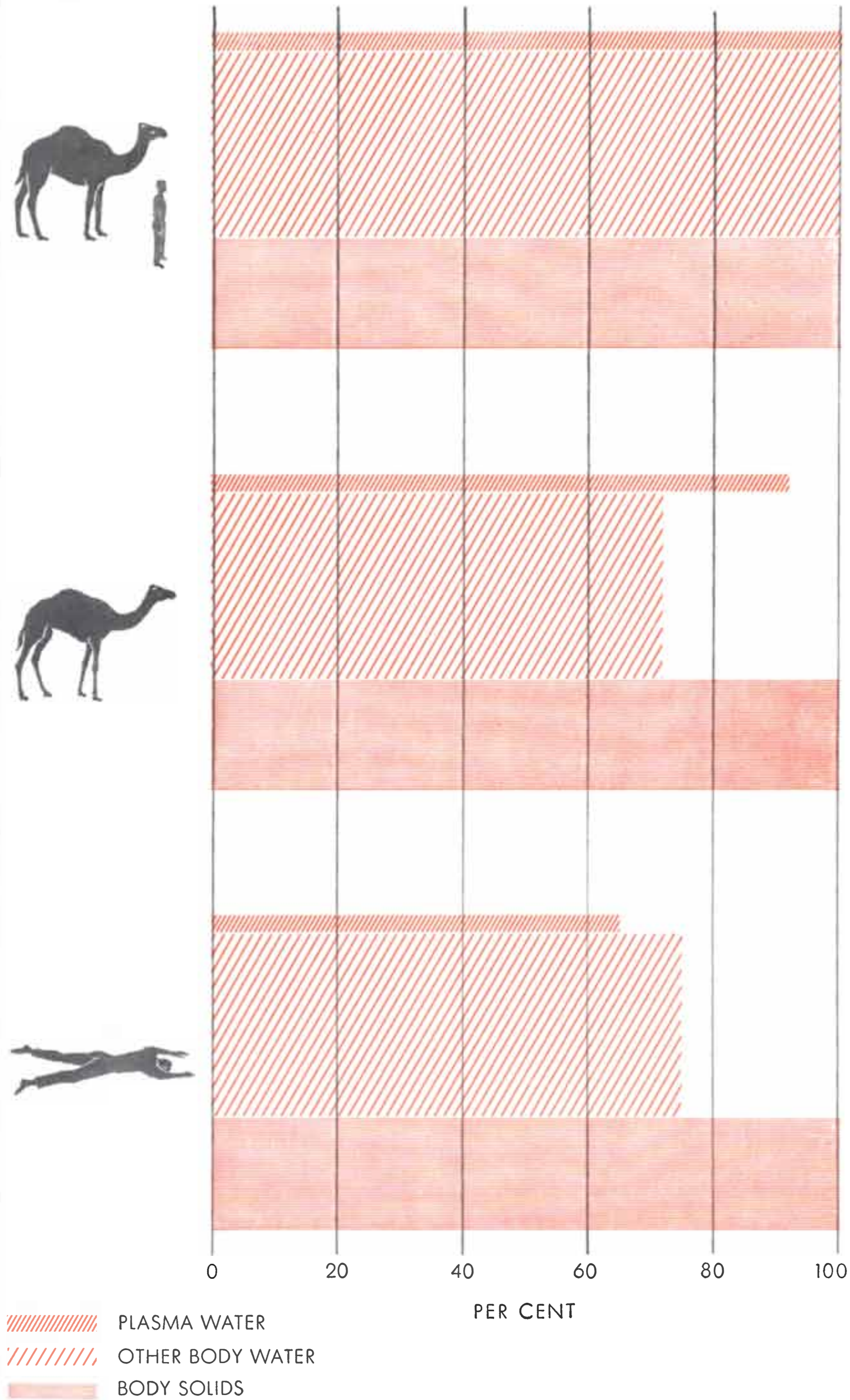




CAMEL CAN LOSE WATER amounting to more than 25 per cent of its body weight. A dehydrated camel (*top*) appears emaciated but can still move about; a similarly dehydrated man would be unconscious or dead. The animal can quickly drink back its water losses and resume its normal appearance (*bottom*). Photographs were made about 10 minutes apart.

a correspondingly larger amount of water: about 1.1 pounds of water for each pound of fat. Thus a camel with 100 pounds of fat on its back might seem to be carrying 110 pounds—more than 13 gallons—of water. But in order to turn the fat into water the camel must take in oxygen through its lungs; in the process it loses water by evaporation from the lung surfaces. Calculation of the rate of loss indicates that the animal will lose more water by evaporation than it can gain through oxidation.

If the camel possesses no special re-



CAMEL SURVIVES DEHYDRATION partly by maintaining the volume of its blood. Under normal conditions (*top*) plasma water in both man and camel accounts for about a 12th of total body water. In a camel that has lost about a fourth of its body water (*center*) the blood volume will drop by less than a 10th. Under the same conditions a man's blood volume will drop by a third (*bottom*). The viscous blood circulates too slowly to carry the man's body heat outward to the skin, so that his temperature soon rises to a fatal level.

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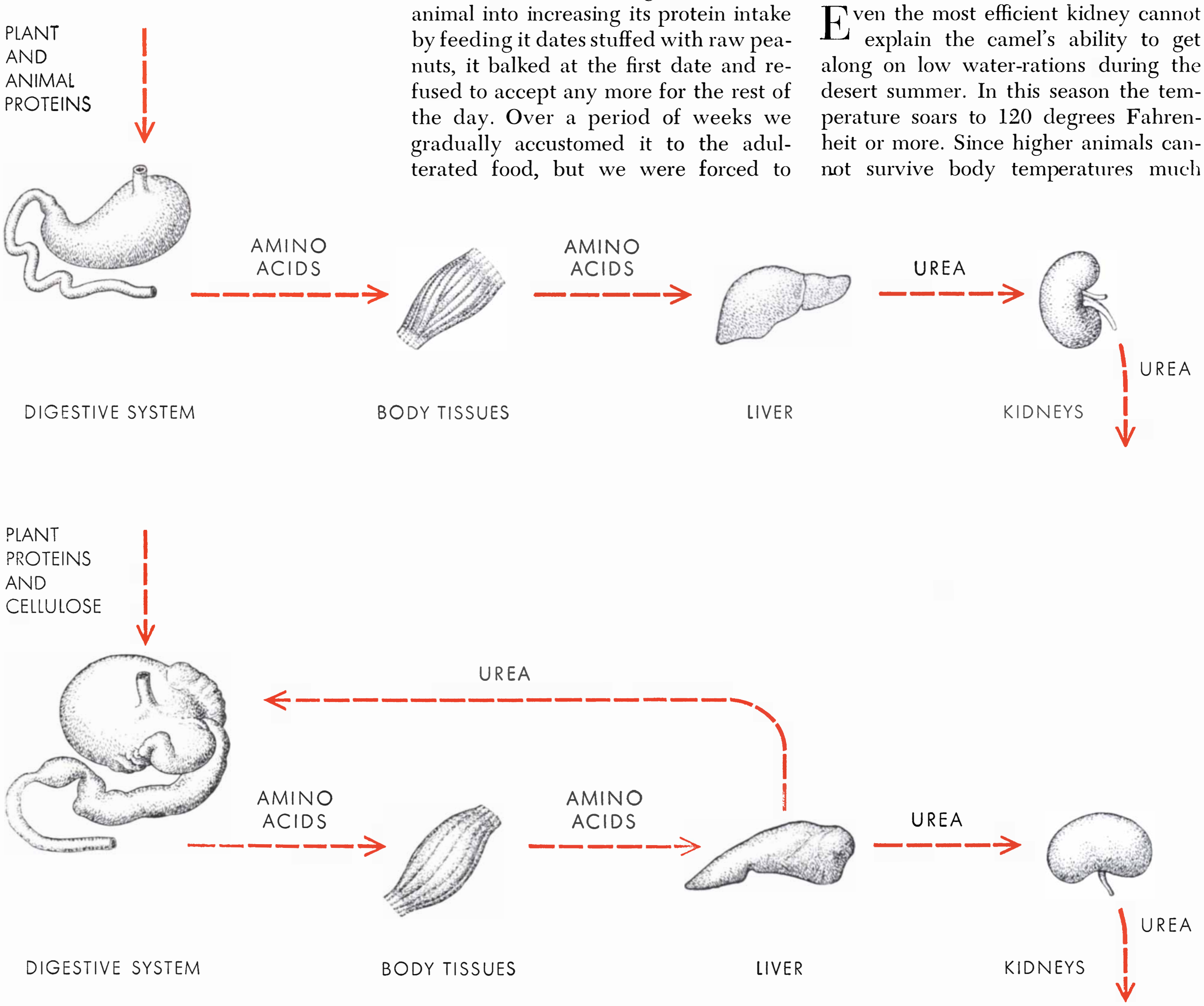
In engineering and manufacturing AMF has ingenuity you can use... **AMERICAN MACHINE & FOUNDRY COMPANY** serves of water, it must have evolved methods for economizing on water expenditure. Its kidney functions in particular seemed worth investigating. All vertebrates rely on the kidney to rid their bodies of nitrogenous wastes (in mammals primarily urea). Few animals can tolerate any accumulation of these substances in the body. The kangaroo rat conserves water by eliminating a urine very rich in urea, and we were not surprised to find the camel following its example. When we kept our camels on dry fodder, their urine output declined and its urea content rose. In the case of one young animal, however, the urea output dropped sharply along with the volume of urine. The animal did not retain the urea in its blood, because the concentration of urea in the blood plasma also fell. Even the injection of urea into the bloodstream did not raise its concentration in the urine.

Further work revealed that the low level of urea had to do with nutrition rather than water conservation. The dry fodder contained too little protein to meet the nutritional needs of a young and growing camel. Under these circumstances the animal was apparently able to reprocess "waste" urea into new protein. From recent studies of sheep we have found that they share the camel's ability to use nitrogenous compounds over and over again. Experiments with cows by other investigators suggest that these ruminants may husband nitrogen in the same manner [see "The Metabolism of Ruminants," by Terence A. Rogers; SCIENTIFIC AMERICAN, February, 1958].

To determine the maximum efficiency with which the camel can excrete urea, we tried to put one of our camels on a high-protein diet. Unfortunately the camel's taste in food is exceedingly conservative. When we sought to trick the animal into increasing its protein intake by feeding it dates stuffed with raw peanuts, it balked at the first date and refused to accept any more for the rest of the day. Over a period of weeks we gradually accustomed it to the adulterated food, but we were forced to abandon the experiment when we found that we had exhausted the entire stock of peanuts in the oasis!

The kidney of the desert rat has a remarkable capacity for concentrating not only urea but also salt, and one would expect the camel's kidney to operate with similar efficiency. We were not able to test this hypothesis because neither the fodder nor the local wells contained much salt. We were told, however, that camels in other areas could and did drink "bitter waters" containing enough magnesium sulfate (epsom salt) to sicken a man. Camels in coastal regions were said to browse on seaweed along the shore; these plants would of course have a salt content equal to that of sea water. It seems quite possible that the camel can approach the performance of the desert rat, whose efficient kidney permits it to drink sea water without harm.

Even the most efficient kidney cannot explain the camel's ability to get along on low water-rations during the desert summer. In this season the temperature soars to 120 degrees Fahrenheit or more. Since higher animals cannot survive body temperatures much



UNUSUAL NITROGEN METABOLISM helps the camel to get along on low-grade fodder. In man (*top*) nitrogenous metabolic wastes are constantly excreted in the form of urea. In the camel (*bottom*) urea may return via bloodstream to the stomach, where in combination with broken-down cellulose it is reprocessed into new protein. Sheep and perhaps cattle husband nitrogen similarly.

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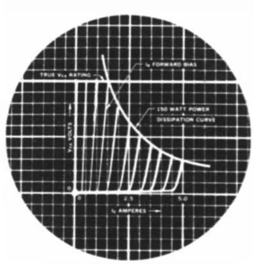

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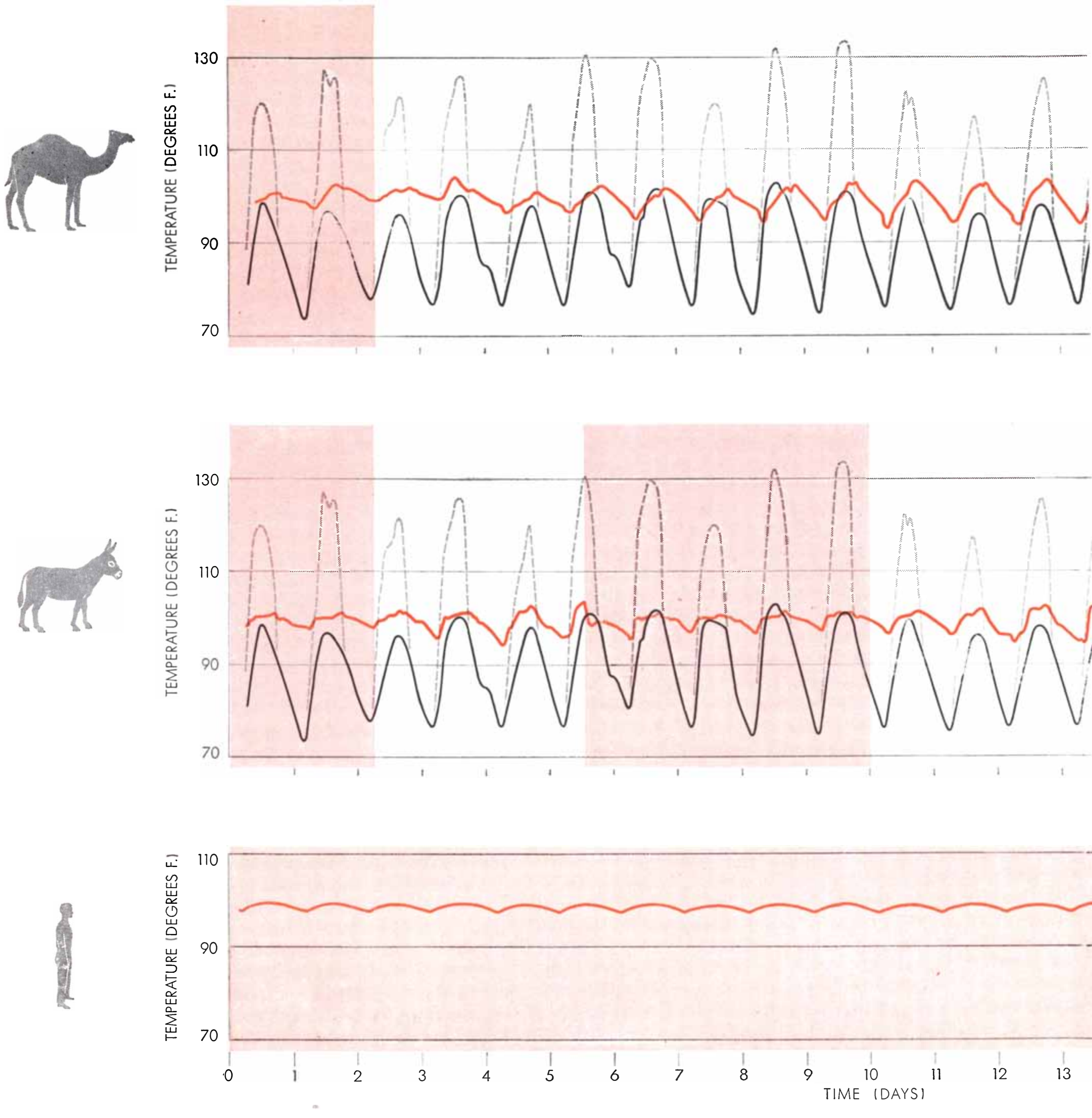
over 100 degrees, they must either seek shelter, as do many small desert creatures, or cool themselves by evaporation of water from the mouth (panting) or from the skin (sweating). On a hot desert day a man may produce more than a quart of sweat an hour.

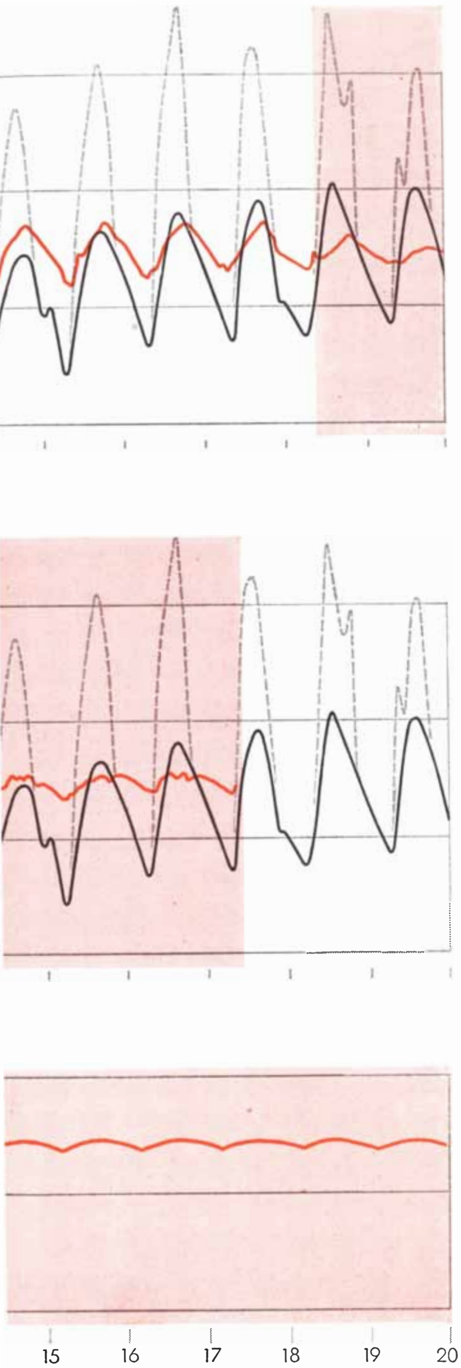
A man losing water at this rate rapidly becomes intensely thirsty. If the loss passes 5 per cent of his body weight (about a gallon), his physical condition rapidly deteriorates, his perceptions become distorted and his judgment falters. A loss of 10 per cent brings on delirium, deafness and insensitivity to pain.

In cool surroundings a man may cling to life until he has lost water up to 20 per cent of his body weight. In the desert heat, however, a loss of no more than 12 per cent will result in "explosive heat death." As the blood loses water it becomes denser and more viscous. The thickened blood taxes the pumping capacity of the heart and slows the circulation to the point where metabolic heat is no longer carried outward to the skin and dissipated. The internal tempera-

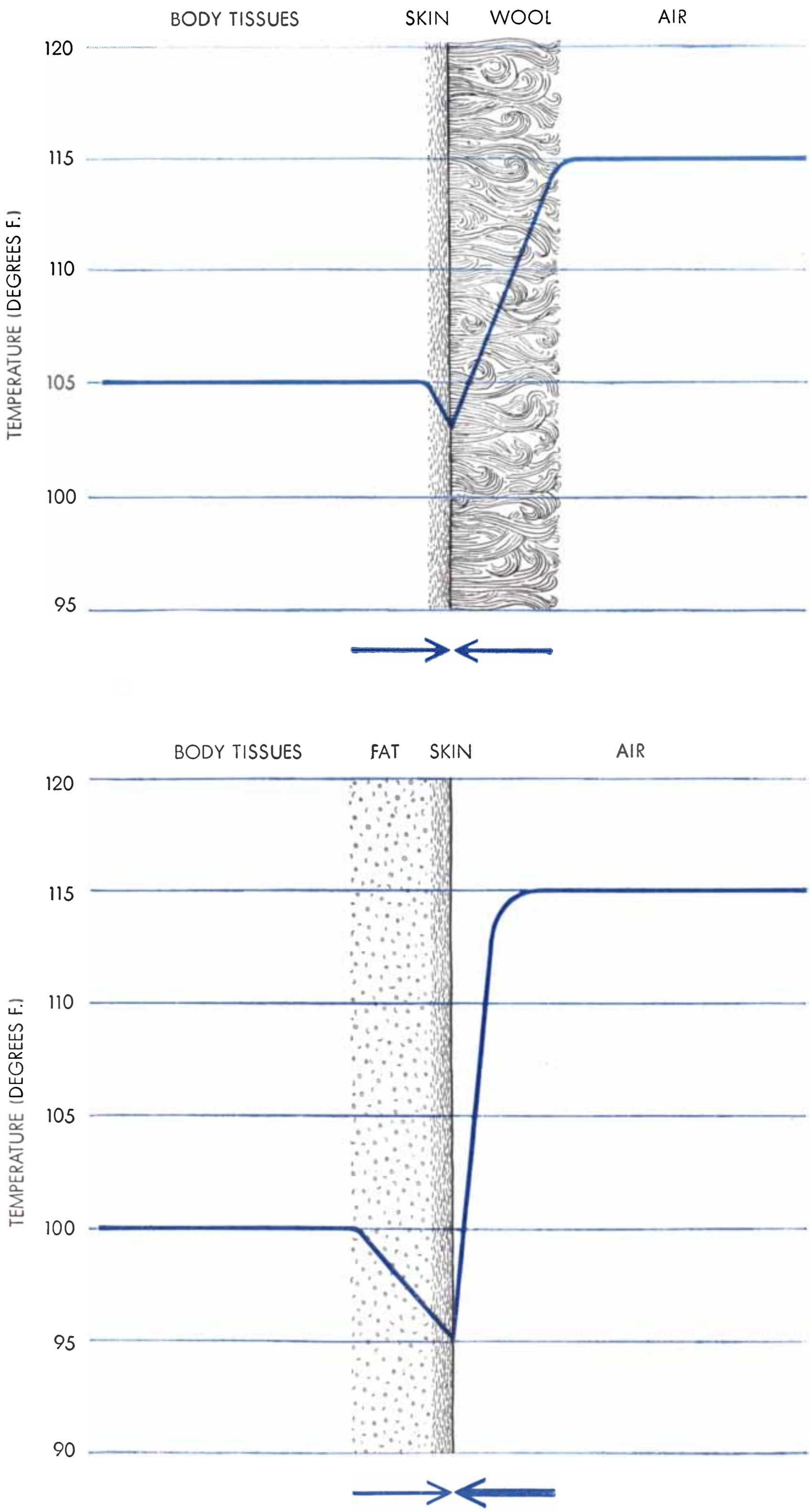


"FLEXIBLE" BODY TEMPERATURE partly accounts for the camel's ability to conserve water. Colored curves show variations in body temperature for a camel and a donkey over a 20-day period during the desert summer; a typical temperature curve for a man is shown for comparison. Solid gray curves show variations in air temperature during the same period; the broken curves indicate the additional heat load due to radiation from the sun and ground. The camel's temperature can rise to 105 degrees before the animal begins to sweat freely; during the night its temperature drops as low as 93 degrees, thereby delaying the next day's rise. The camel ture of the body suddenly increases, and death quickly follows.

How does the camel fare under similar conditions? We kept one camel without water for eight days in the heat of the desert summer. It had then lost 220 pounds—about 22 per cent—of its body weight. It looked emaciated; its abdomen was drawn in against its vertebrae,



survived though watered (*shading*) only at the beginning and end of the period. Donkey, with a less flexible temperature, sweated more and drank more often. In the desert summer man must drink every day.



HEAT FLOW IN CAMEL AND MAN is compared in these schematic cross sections of a small portion of body surface. Colored curves show temperature; heat flow, suggested by arrows, increases with the slope of the curves. Camel (*top*) can eliminate heat from its body with an average skin temperature of about 103 degrees; its wool slows the heat flow from the environment. Man (*bottom*), with a lower body temperature and an insulating layer of fat beneath the skin, must maintain a lower skin temperature (that is, must evaporate more sweat) to obtain the same flow of heat from his interior. The lack of insulation between his skin and the air raises heat flow from the air, necessitating still more evaporation.

its muscles were shrunken and its legs were scrawny and appeared even longer than usual. But even though the animal would not have been able to do heavy work or travel a long distance, it was not in serious condition. It had no difficulty in emptying bucket after bucket of water and quickly recovered its normal appearance. Later experiments showed that camels can lose more than 25 per cent of their body weight without being seriously weakened. The lethal limit of dehydration is probably considerably higher, but for obvious humanitarian reasons we did not attempt to determine it.

How does a camel that has lost water amounting to a quarter of its body weight—more than a third of the water in its system—manage to avoid the explosive heat death that would overtake a man long before this point? It can do so because it maintains its blood volume despite the water loss. We were able to calculate the blood volume before and after dehydration by injecting a nonpoisonous dye into the bloodstream and measuring its concentration when it had become evenly distributed. In the case of a young camel that had lost about 11 gallons of water the reduction in blood volume was less than a quart. The water had been lost not from the blood but from the other body fluids and from the tissues.

One might suppose that the camel has some special physiological mechanism for maintaining its blood volume. In theory, however, a man should be able to do the same thing. When he lacks water, the osmotic pressure of the proteins in his blood plasma should draw it from the rest of his body. Since this does not happen, the real question is not how the dehydrated camel maintains its blood volume but why a dehydrated man does not.

The camel not only tolerates dehydration much better than a man but also loses water much more slowly. One reason is that it excretes only a small volume of urine—in summer often as little as a quart a day. The animal saves much more water, however, by economizing on sweat.

In the burning heat of the desert an inanimate object such as a rock may reach a temperature of more than 150 degrees F. A camel in such an environment, like a man, maintains a tolerable body temperature by sweating. But where the temperature of the man remains virtually constant as the day grows hotter, the temperature of the camel increases slowly to about 105

degrees. As the temperature of the camel rises, the animal sweats very little; only when its temperature reaches 105 degrees does it sweat freely. The camel's elevated temperature also lessens its absorption of heat, which of course depends on the difference between the temperature of its body and that of the environment.

The camel lowers the heat load on its body still further by letting its temperature fall below normal during the cool desert night. At dawn its temperature may have dropped as low as 93 degrees. Thus much of the day will elapse before the animal's body heats up to 105 degrees and sweating must set in. As a result of its flexible body temperature the camel sweats little except during the hottest hours of the day, where a man in the same environment perspires almost from sunrise to sunset.

These remarkable temperature fluctuations—about 12 degrees for the camel as against two degrees for a man—might seem to indicate a failure of normal heat regulation. This, however, is not so. The camel's body temperature never rises above 105 degrees. Moreover, if the camel has free access to water, the fluctuations are much smaller: about four degrees, comparable to the fluctuations during the cool winter months.

These findings may have implications for animal husbandry in the tropics. Cattle breeders have long sought ways of adapting the highly productive European dairy and beef animals to hot climates. In the process they have generally assumed that animals whose body temperature rises in hot weather will adapt poorly to heat. Although this assumption is often correct, the camel's example suggests that the reverse may sometimes be true.

People in desert areas and outside them have long appreciated the excellent insulating properties of camel hair. The camel employs camel-hair insulation to lower its heat load still further. Even during the summer, when the camel sheds much of its wool, it retains a layer several inches thick on its back where the sun beats down. When we sheared the wool from one of our camels, we found that the shorn animal produced 60 per cent more sweat than an unshorn one. To Americans, who wear light clothing during the summer, the idea that a thick layer of wool is advantageous in the desert may seem unreasonable. The Arabs, however, typically dress in several layers of loose clothing, frequently made of wool. I have seen a nomad returning from the desert shed one thick wool burnous after another. We ourselves quickly learned that Arab dress was more comfortable than "civilized" garments.

The camel's hump also helps indirectly to lessen the heat load on the animal. Nearly all mammals possess a food reserve in the form of fat, but in most of them the fat is distributed fairly uniformly over the body just beneath the skin. In having its fat concentrated in one place the camel lacks insulation between its body and its skin, where evaporative cooling takes place. The absence of insulation facilitates the flow of heat outward, just as the insulating wool slows the flow of heat inward.

To clarify the relative importance of insulation and temperature fluctuation in lowering the camel's need for water, we repeated several of our experiments on a donkey. Because the donkey, like the camel, is a native of the arid lands of Asia, it should presumably have developed similar devices for conserving water.

We found that the donkey could tolerate as much water loss as the camel—up to 25 per cent. The donkey, however, lost water three times more rapidly than the camel does; thus it could not go as long without drinking. In one experiment a camel went for 17 days without drinking, while the donkey had to be watered at least once every four days. The difference in water loss seems partly due to the fact that the body temperature of the donkey is more stable than that of the camel. The donkey begins to sweat when its temperature has risen only slightly. Furthermore, the donkey's coat is quite thin in comparison with the camel's and thus does not provide so effective a barrier against heat from the environment.

The donkey outdoes the camel in one respect: its drinking capacity. A camel that has lost 25 per cent of its body weight can drink back the loss in about 10 minutes; a donkey can perform the same feat in less than two minutes. A man drinks much more slowly; after a day in the desert he will not completely make up his water losses for several hours or until he has eaten (when he tends to drink with his food).

The drinking capacity of both camel and donkey doubtless came about by evolutionary adaptation in the wild state. Water holes are rare in an arid land, and predators often lie in wait near them. The animal that can quickly replenish its water losses and depart is likely to live longer than one that must linger by the water to satisfy its needs.

Differentiation in Social Amoebae

Certain amoebae gather to form a mass of spores and a stalk. The way in which spore cells and stalk cells segregate may shed light on how the cells of many-celled organisms differentiate into various types

by John Tyler Bonner

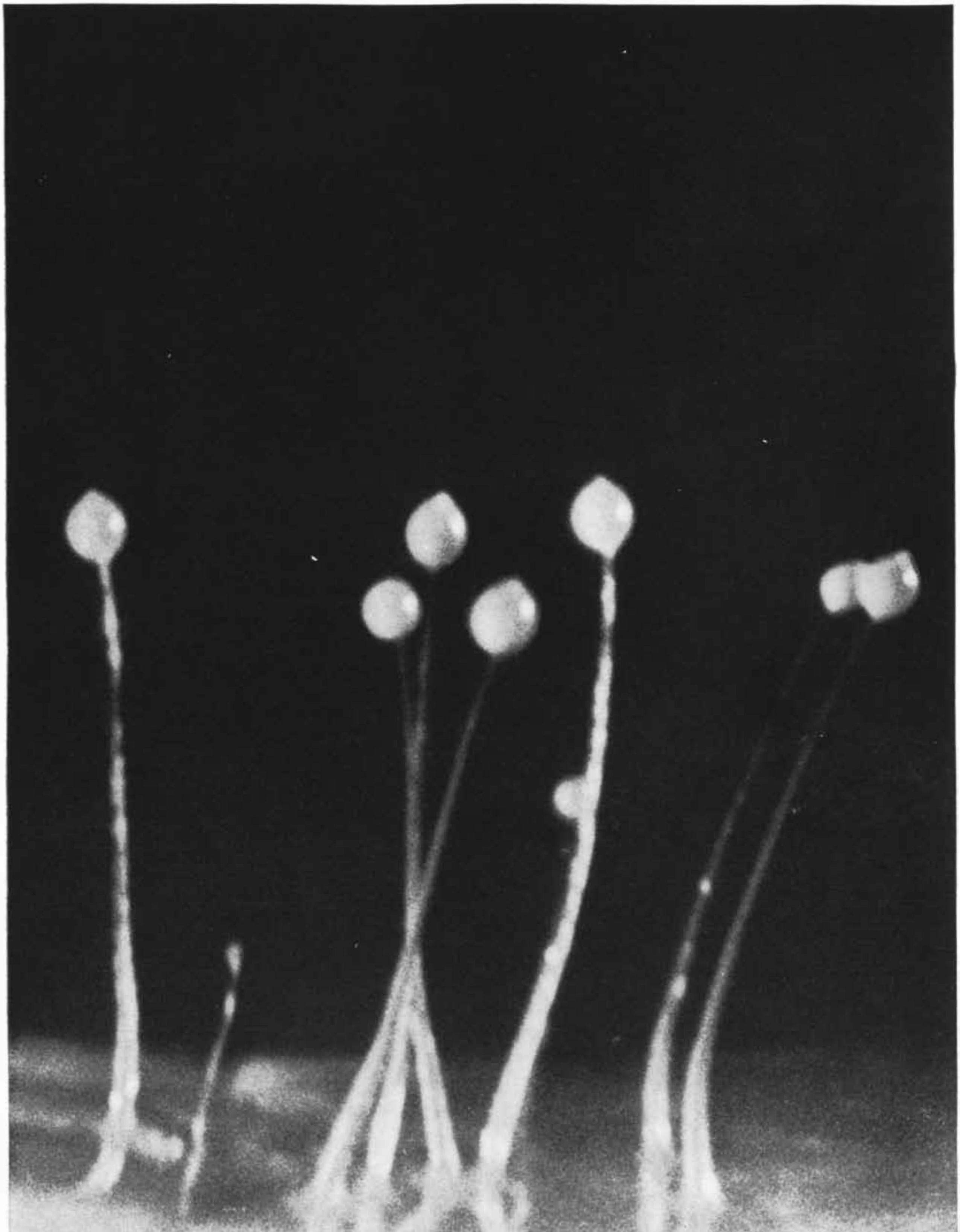
Recently I was asked to talk to two visiting Russian university rectors (both biologists) about the curious organisms known as slime molds. Communication through the interpreter was somewhat difficult, but my visitors obviously neither knew nor really cared what slime molds were. Then, without anticipating the effect, I wrote on the blackboard the words "social amoebae," a title I had used for an article about these same organisms some years ago [see "The Social Amoebae," by John Tyler Bonner; SCIENTIFIC AMERICAN, June, 1949]. The Russians were electrified with delight and curiosity. I described how individual amoebae can come together under certain conditions to form a multicellular organism, the cells moving into their appropriate places in the organism and differentiating to divide the labor of reproduction. Soon both of my guests were beaming, evidently pleased that even one-celled animals could be so sophisticated as to form collectives.

Of course there are other reasons why slime molds hold the interest of biologists. The transformation of free-living, apparently identical amoebae into differentiated cells, members of a larger organism, presents some of the same questions as the differentiation of embryonic cells into specialized tissues. In the budding embryo, moreover, cells go through "morphogenetic movements" which seemingly parcel them out to their assigned positions in the emergent organism. The only difference is that the simplicity of the slime molds provides excellent material for experiments.

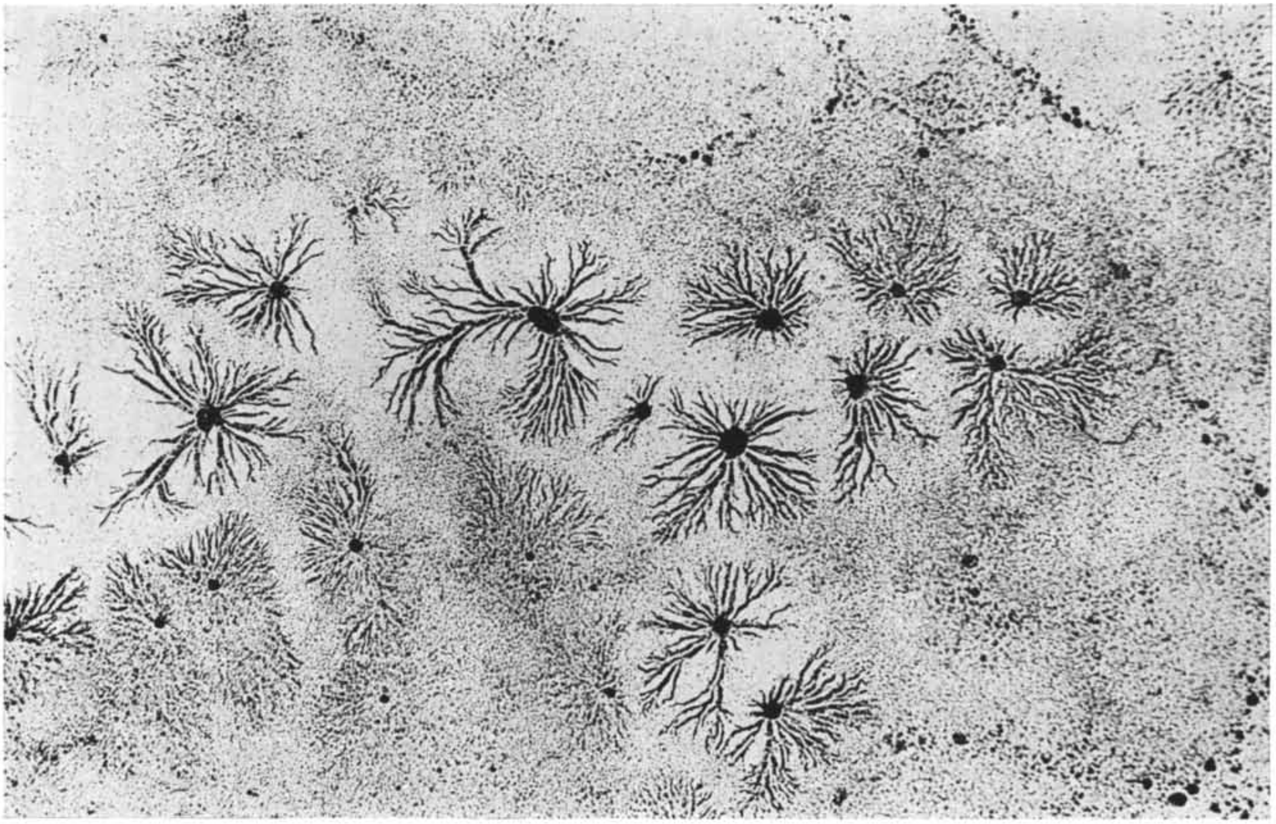
The slime-mold amoebae, inhabitants of the soil, do their feeding as separate, independent individuals. Flowing about on their irregular courses they engulf bacteria, in the manner of our own amoeboid white blood cells. At this stage they reproduce simply by dividing in two. Once they have cleared the food away, wherever they are fairly dense, the amoebae suddenly flow together to central collection points. There the cells, numbering anywhere from 10 to 500,000, heap upward in a little tower which, at least in the species *Dictyostelium discoideum*, settles over on its side and crawls about as a tiny, glistening, bullet-shaped slug, .1 to two millimeters long. This slug has a distinct front and hind end (the pointed end is at the front) and leaves a trail of slime as it moves. It is remarkably sensitive to light and heat; it will move toward a weak source of heat or a light as faint as the dial of a luminous wrist watch. As the slug migrates, the cells in the front third begin to look different from the cells in the two thirds at the rear. The changes are the early signs of differentiation; eventually all the hind cells turn into spores—the seeds for the next generation—and all the front cells cooperate to make a slender, tapering stalk that thrusts the mass of spores up into the air.

To accomplish this transformation the slug first points its tip upward and stands on end. The uppermost front cells swell with water like a bit of froth and become encased in a cellulose cylinder which is to form the stalk. As new front cells arrive at the frothy tip of the stalk they add themselves to its lengthening structure and push it downward through the mass of hind-end cells below. When this process, like a fountain in reverse, has brought the stalk into contact with the surface, the continued upward migration of pre-stalk cells heightens the stalk lifting the presumptive spore cells up into the air. Each amoeba in the spore mass now encases itself in cellulose and becomes a spore. The end result is a delicate tapering shaft capped by a spherical mass of spores. When the spores are dispersed (by water or by contact with some passing creature such as an insect or a worm), each can split open to liberate a tiny new amoeba.

What mechanism brings the independent slime-mold amoebae together in a mass? More than a decade ago we found that they are attracted by the gradient of a substance which they themselves produce. In our early experiments we were unable to obtain cell-free preparations of this substance (which we named acrasin); cells actively secreting it were always necessary to start an aggregation. Later B. M. Shaffer of the University of Cambridge got around this barrier in an ingenious experiment. He took water that had been near acrasin-producing cells (but was itself free of cells) and applied it to the side of a small agar block placed on top of some amoebae. The amoebae momentarily streamed toward the side where the concentration of acrasin was higher. Shaffer found that the water must be used immediately after it is collected in order to achieve this effect, and that it must be applied repeatedly. He therefore concluded that acrasin loses its potency rapidly at room temperature. The loss of potency, he showed, is caused by enzymes that are secreted by the amoebae along with acrasin; when he filtered the fluid through a cellophane membrane to hold back the large enzyme molecules, he was able to secure a stable preparation of acrasin. Presumably the enzymes serve to clear the environment of the substance and so enhance the establishment of a gradient in the concentration of acrasin when it is next secreted. Maurice Sussman and his



SPHERICAL MASSES OF SPORES of the social amoeba *Dictyostelium discoideum* are held aloft by stalks composed of other amoebae of the same species. When the spores are dispersed, each can liberate a new amoeba. The stalks are about half an inch high.

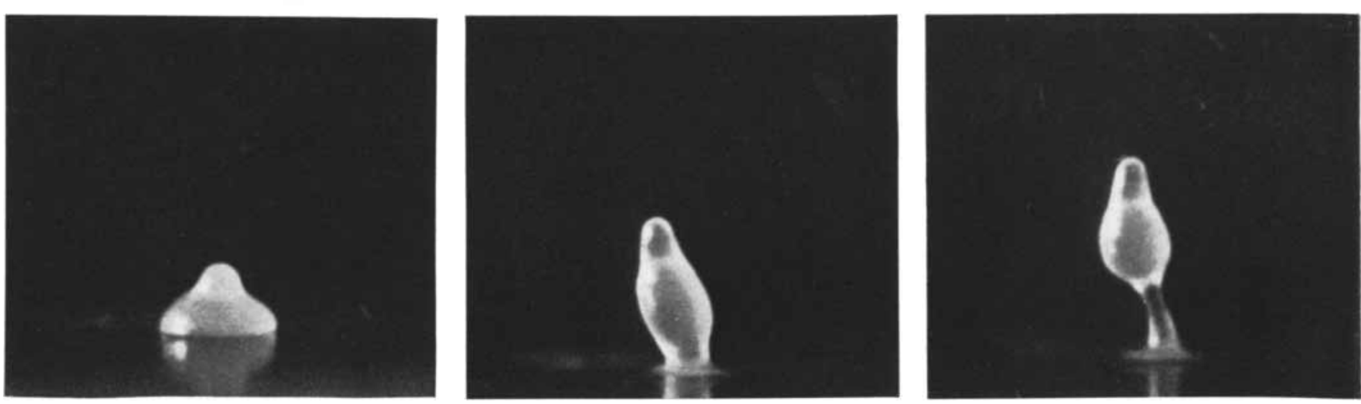


AGGREGATING AMOEBAE of *Dictyostelium discoideum* move in thin streams toward central collection points. Each of the centers comprises thousands of cells. This photograph and facing one were made by Kenneth B. Raper of the University of Wisconsin.

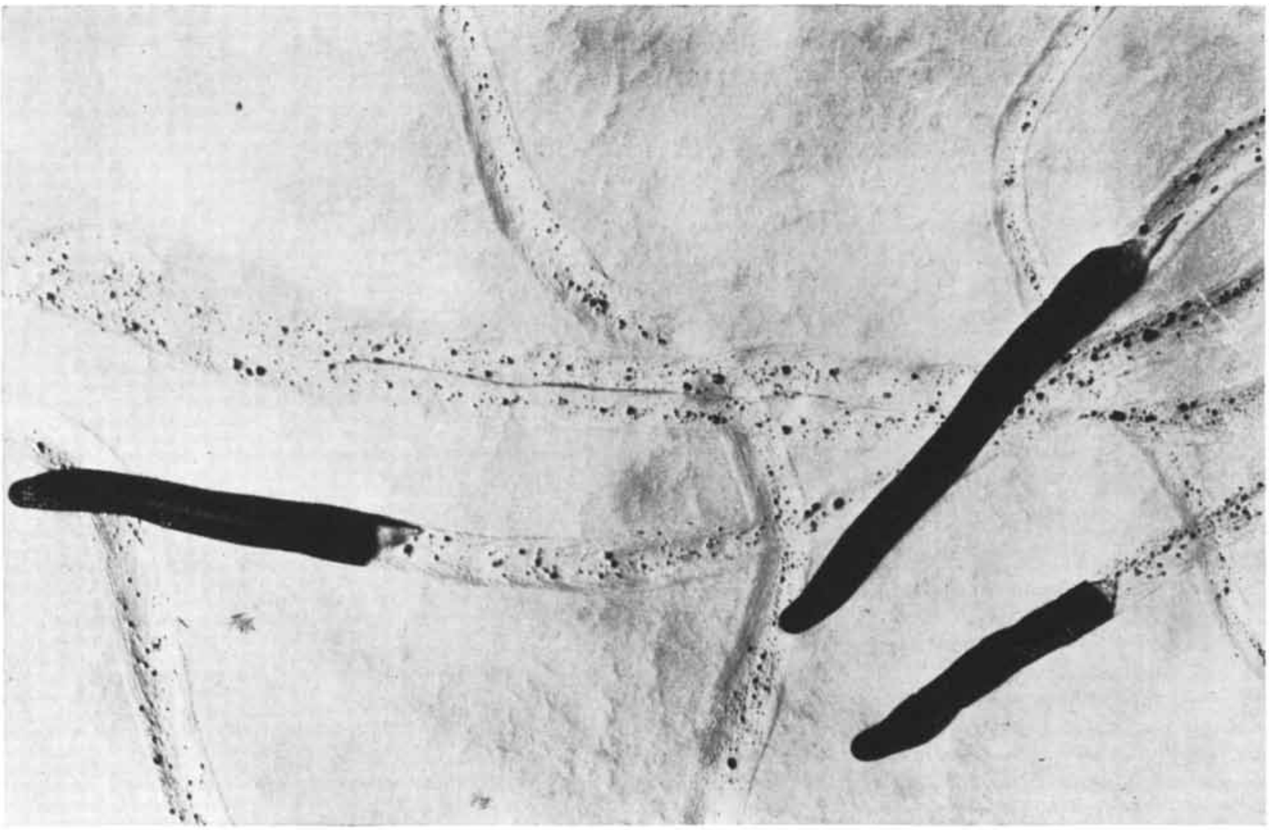
co-workers at Brandeis University in Waltham, Mass., have confirmed Shaffer's work and are now attempting the difficult task of fractionating and purifying acrasin, steps leading toward its identification.

Meanwhile Barbara Wright of the National Institutes of Health in Bethesda dropped a bombshell. She discovered that urine from a pregnant woman could attract the amoebae under an agar block just as acrasin does. The active components of the urine turned out to be steroid sex hormones. This does not necessarily mean that acrasin is such a steroid. Animal embryologists were thrown off the track for years when they found that locally applied steroids induce the further development of early embryos. Only after much painful confusion did it become clear that steroids do not act directly on the embryo, but stimulate the normal induction substance. We must therefore consider the possibility that the steroids act in a similarly indirect manner on the amoebae. The purification of acrasin will, we hope, soon settle the question.

From observations of the cells during aggregation, Shaffer has come to the interesting conclusion that the many incoming amoebae are not responding to one large gradient of acrasin but to relays of gradients. That is, a central cell will release a puff of acrasin that produces a small gradient in its immediate



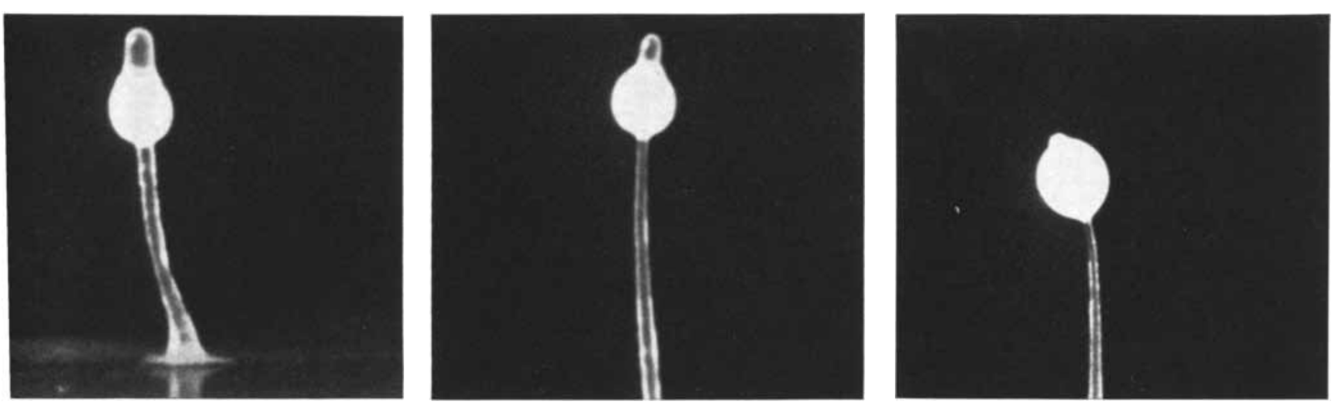
DEVELOPMENT OF THE FRUITING BODY of a slime mold is shown in this series of photographs made at half-hour intervals. At far left the tip cells are starting to form a stalk. In the next two pictures the stalk has pushed down through the mass to the



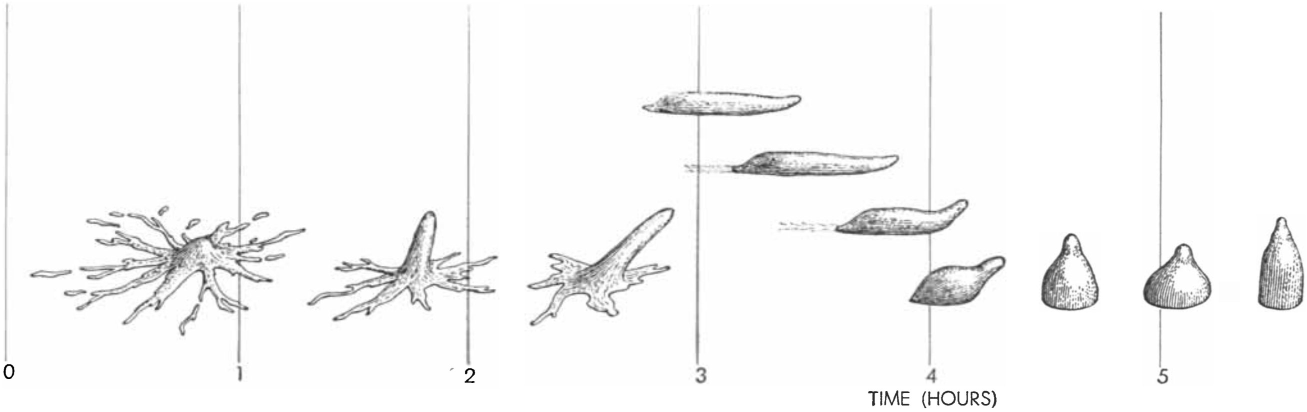
MIGRATING SLUGS of *Dictyostelium discoideum* leave trails of slime behind them as they move. The photographs in this article appear in *The Cellular Slime Molds*, by John Tyler Bonner, and are reproduced with permission of Princeton University Press.

vicinity. The surrounding cells become oriented, and now produce a puff of their own. This new puff orients the cells lying just beyond, and in this way a wave of orientation passes outward. Time-lapse motion pictures show the amoebae moving inward in waves, which could well represent the relay system. If this interpretation is sound, then the rapid breakdown of acrasin by an enzyme plainly serves to clear the slate after each puff in preparation for the next. The cells do not depend entirely on acrasin for orientation; once they are in contact they tend to stick to one another and the pull-tension of one guides the cells that follow. This is a special case of contact guidance, a phenomenon well known in the movements of embryonic cells of higher animals.

After the amoebae have gathered together, what determines their position within the bullet-shaped slug? One might assume that the cells that arrive at the center of the heap automatically become the tip of the slug, and that the last cells to come in from the periphery make up the hind end. If this were the case, chance alone would determine whether a cell is to become a front-end cell and enter into the formation of the stalk, or a hind-end cell and become a spore. If, on the other hand, the cells rearrange themselves as they organize into a slug, then it is conceiv-



surface and is starting to lift the cell mass. In the fourth picture the spores have formed their cellulose coats, making the ball more opaque. In the last two pictures the spore mass moves up to the very top of the stalk, as the stalk itself becomes still longer.



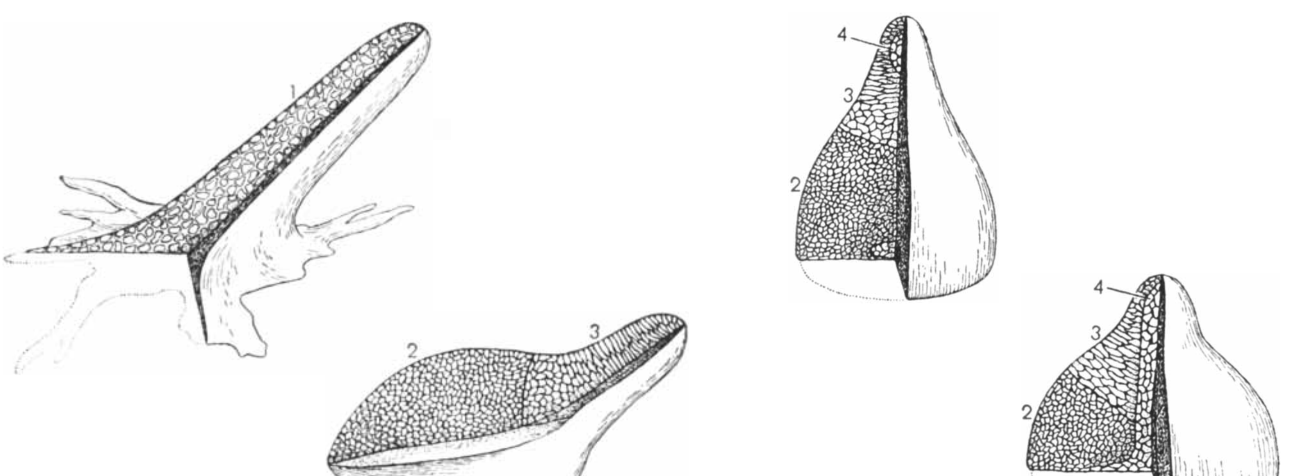
LIFE CYCLE OF A SLIME MOLD, typified by *Dictyostelium discoideum,* involves the aggregation of free-living amoebae into a unified mass (*first three drawings*), then the formation of a slug which moves about for a time (*next four drawings*) and finally

able that the front end might contain selected cells, differing in particular ways from those in the hind end. I am embarrassed to say that in 1944 I presented some evidence to support the idea that their chance position was the determining factor—evidence that, as will soon be clear, was inadequate. It is some comfort, however, that I was able to rectify the error myself.

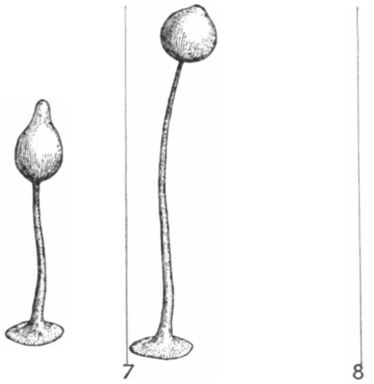
The first faint hint that the cells do redistribute themselves in the slug stage came when we repeated some experiments first done by Kenneth B. Raper of the University of Wisconsin. We stained some slugs with harmless dyes and then grafted the hind half of a colored slug onto the front half of an unstained slug. The division line remained sharp for a number of hours, just as Raper had previously observed. But later we noticed that a few stained cells were moving forward into the uncolored part of the slug. In the reverse graft, with the front end stained, a similar small group of colored cells gradually migrated toward the rear end of the slug. Still, the number of cells involved was so small that it could hardly be considered the sign of a major redistribution. Next we tried putting some colored front-end cells in the hind end of an intact slug. The result was a total surprise: now the colored cells rapidly moved to the front end, traveling as a band of color up the length of the slug.

Here was a clear demonstration that the cells do rearrange themselves in the slug and that there is a difference between the cells at the front and hind ends. The difference between front-end and hind-end cells—whatever its nature—was confirmed in control experiments in which we grafted front-end cells to the front ends of the slugs and hind-end cells to the hind ends; in each case the cells maintained their positions.

It looked as if front-end cells were selected by their speed; the colored cells simply raced from the rear end to the front. When we placed hind-end cells in the front end, they traveled to the rear, outpaced by the faster-moving cells, which again assumed their forward positions. We tried to select fast cells and slow cells over a series of genera-



CUTAWAY DRAWINGS of five stages show how the cells change. At the end of aggregation all cells appear the same (1), but in the slug they are of two types (2 and 3). The cells near the tip (3) gradually turn into stalk cells (4) and move down inside the

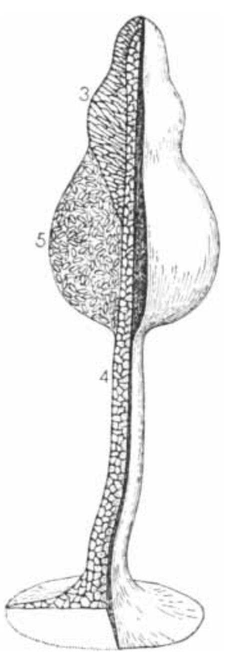


the development of a fruiting body (*last six drawings*). Times are only approximate.

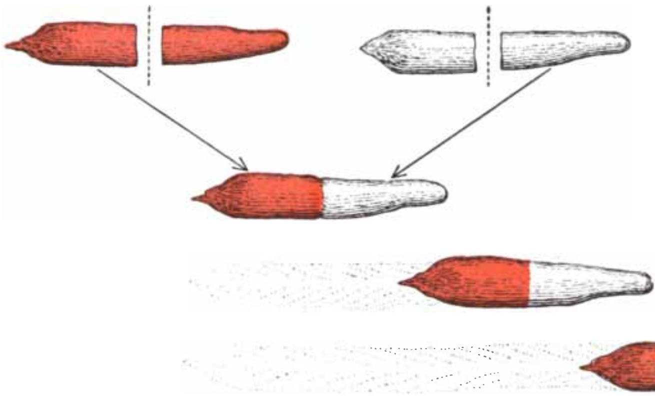
tions to see if speed was a hereditary trait, but after selection the cultures showed no differences from one another or from the parent stock.

Quite by accident a new bit of evidence turned up in an experiment designed for totally independent reasons. Instead of using the fully formed slug we stained amoebae colonies in the process of aggregation and made grafts at this stage by removing the center of the stained group and replacing it with a colorless center, or vice versa. In either case the resulting slug was always uniformly colored, indicating a rapid reassortment of the cells during the formation of the slug.

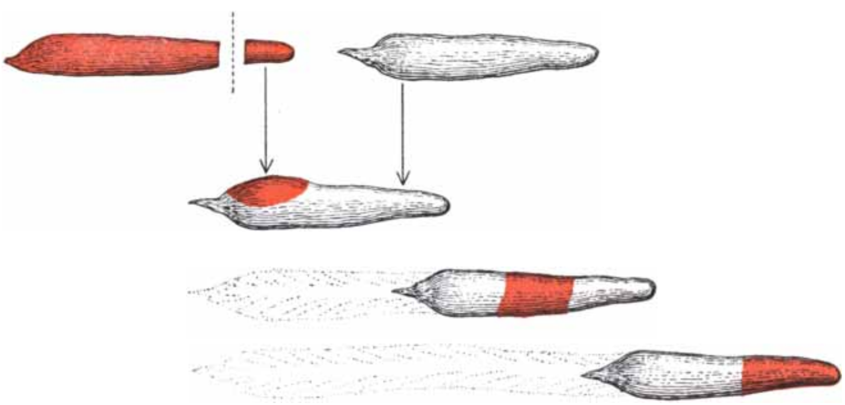
The evidence for a rearrangement of



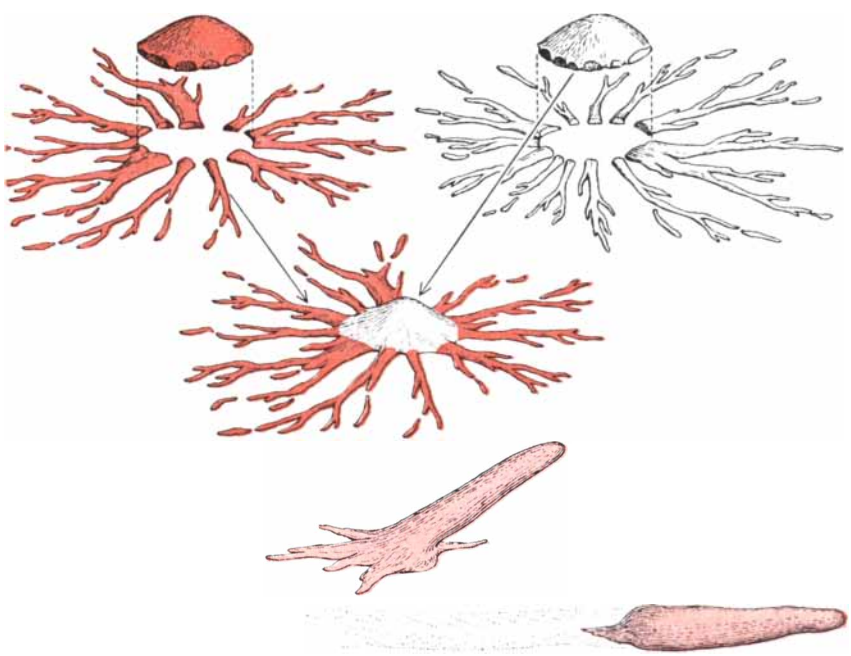
mass. The others (2) become spores (5) as the growing stalk lifts them into the air.



GRAFTED SLUG composed of the hind end of a stained slug and the front end of an unstained slug retains a sharp line of demarcation between the parts even after several hours.



COLORED TIP taken from a stained slug can be inserted into the hind part of an intact slug. The colored cells then move forward as a band until they again are at the front tip.



COLORED AGGREGATE in which the center has been replaced by a colorless center produces a uniformly colored slug, indicating that the cells are rearranged as the slug forms. The experiment illustrated in these drawings was originally performed by Kenneth B. Raper.

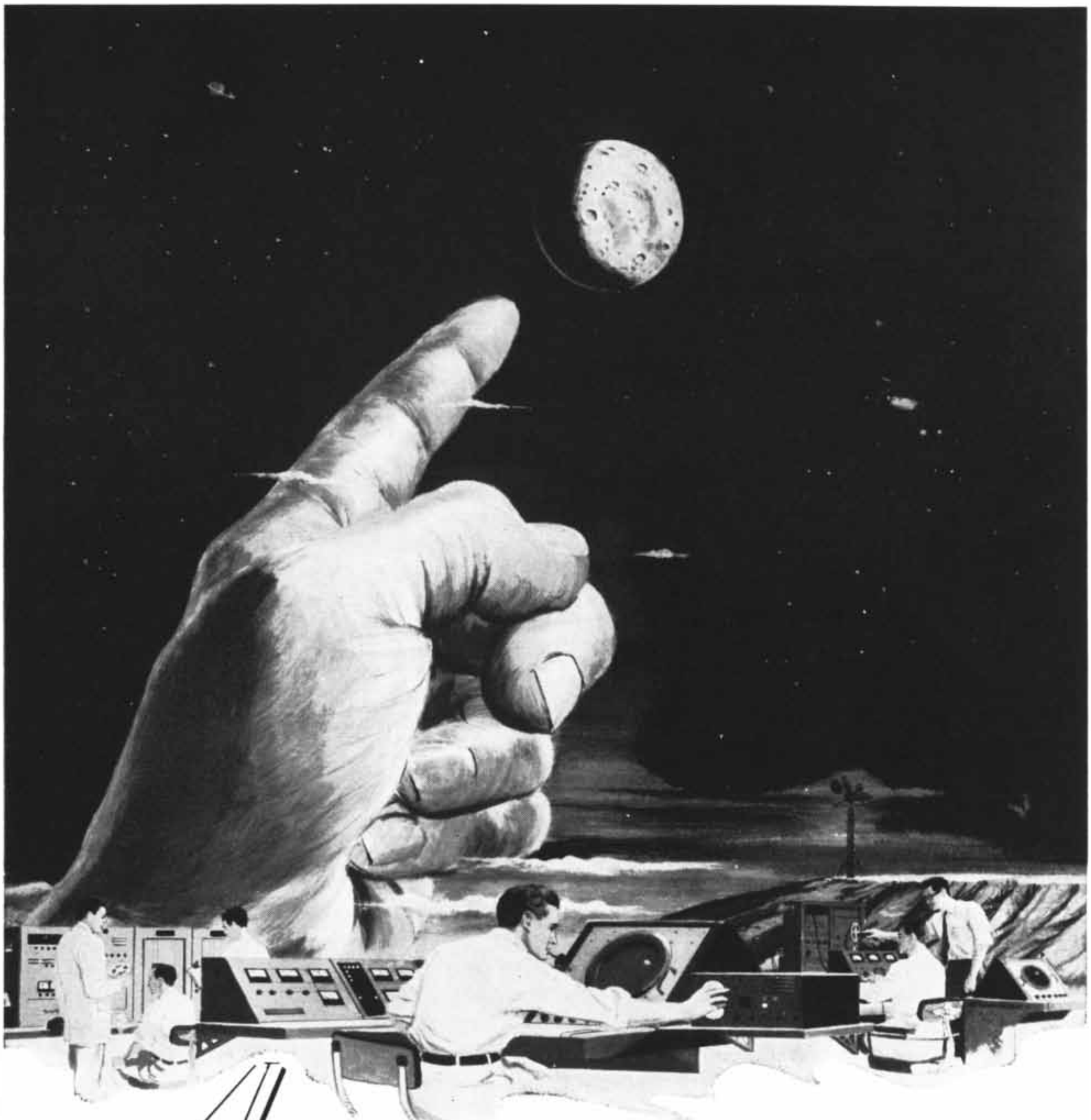
cells was becoming impressive, but I felt uneasy about the reliability of tests with dyes because such tests had led me into my earlier error. We needed to confirm our results by a different method.

At about this time M. F. Filosa, who was working in our laboratory on his doctoral dissertation, discovered that many of our amoeba cultures contained more than one genetic type. By isolating and cultivating single cells of each type he was able to obtain pure strains that displayed various recognizable abnormalities—in the way they aggregated, in the shape of their slugs or in the form of their spore masses [*see illustration on page 160*]. The discovery of these strains furnished natural "markers" for identifying and following cells.

Of course there remained one technical problem: How could the individual cells be identified? Fortunately Raper had shown some time earlier that each fragment of a slug that has been cut into pieces will form a midget fruiting body. Spores derived from the several fragments can then be cultured individually. The amoeba from each spore will give rise to many daughter amoebae which can be scored for mutant or normal characteristics as they proceed to form slugs and fruiting bodies.

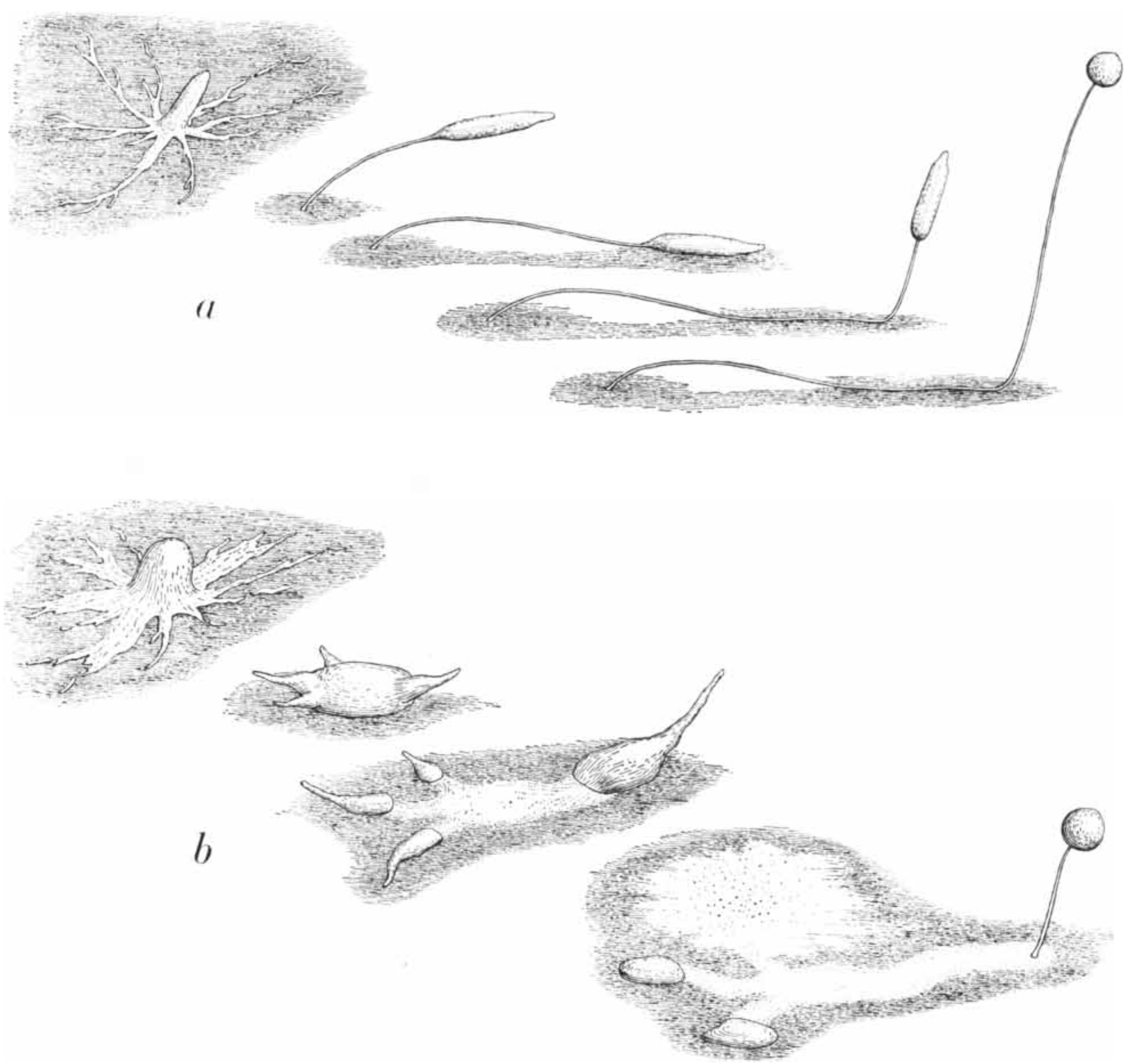
In one experiment we started with a culture of cells in the free-living feeding stage, into which was mixed 10 to 15 per cent of mutant cells. If we were to find a higher concentration of one type of cell in one part of the resulting slug, then we could conclude that there had been a rearrangement. We allowed the cells to form a slug and cut it up into three parts. Upon culturing the individual spores produced by each part, we found that the hind third had 36 per cent mutant cells, the middle third 6 per cent and the front third 1 per cent. Nothing could be more clear-cut; obviously the cells sort themselves out in a way that brings the normal cells to the front end of the slug. In another experiment, with a larger percentage of mutant cells in the mixture, hind and middle fractions contained 91 per cent mutant cells, and the front end only 66 per cent. Further experiments, including some with other species of slime mold, all led to the same conclusion. During the process of slug formation some cells are more likely to reach the front end than others, and the position of a cell in the slug does not merely depend upon its chance position before aggregation.

One must assume that certain cells move to the front because they travel the

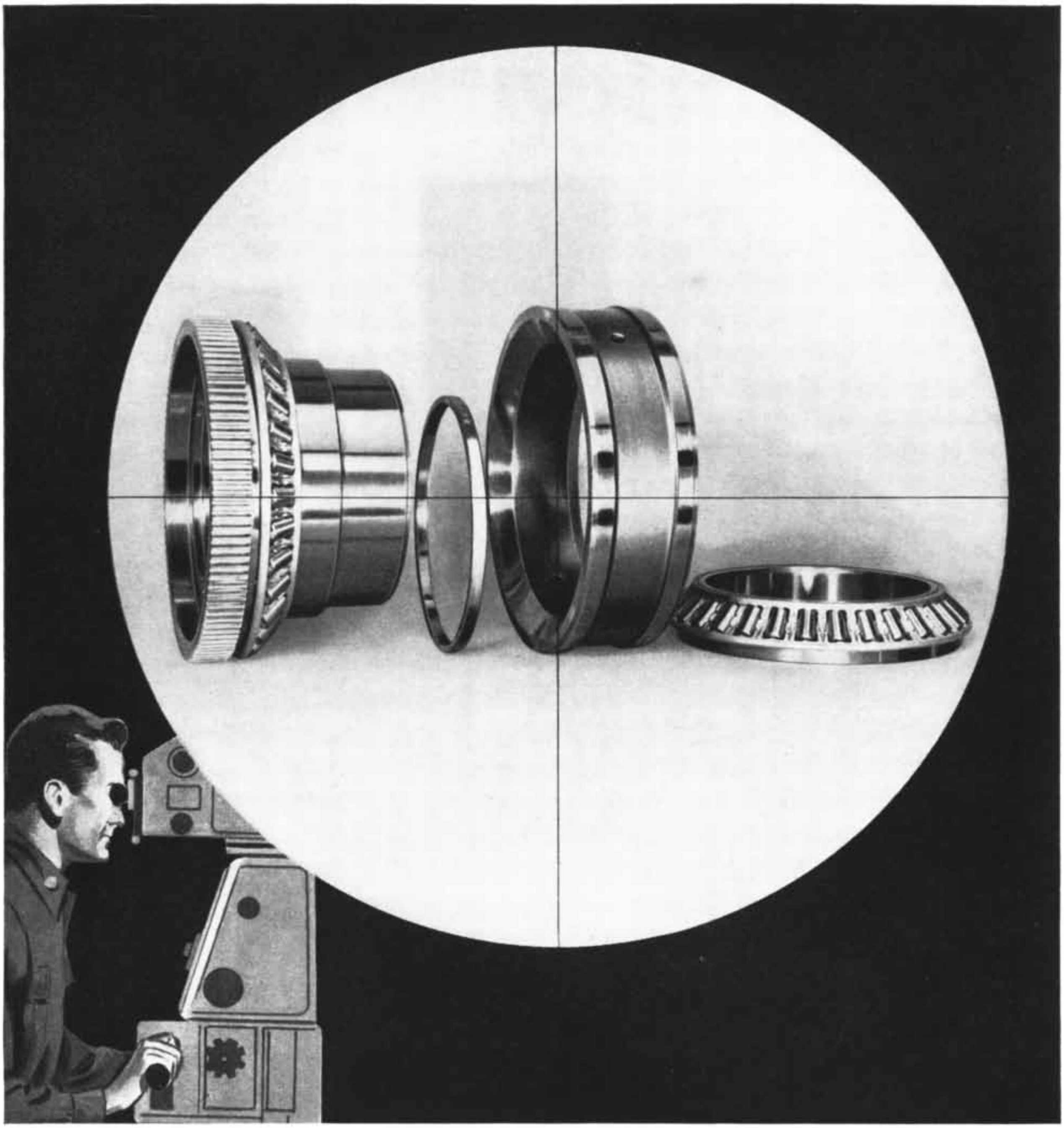


fastest, while the other, slower cells are left behind in the rear end of the slug. Considering the different fates of the front and rear cells, however, it is natural to wonder whether there are any other discernible differences between the front and hind cells. Size is one of the easiest qualities to measure, and comparison of spores from the front and rear portions showed that cells of the front segment are larger. From this it might be concluded that the fastest cells are the largest. But size is related to many other factors; some evidence indicates that cells in the front end divide less frequently than those in the hind regions, and this could affect their size. The possibility of a correlation between size and speed can only be settled by further experiment and observation.

But one fact is inescapable. The cells that tend to go forward are not identical with those that lag behind. Do the differences ultimately determine which cells become stalk cells and which will be spores? The most obvious deduction is that among feeding amoebae roughly a third are presumptive stalk cells, and the rest are predestined to be spores. This interpretation is clearly false, however, because then it would be impossible to explain how a single fragment of a cut-up slug can produce a perfect miniature fruiting body. The cells in the hind piece, which would normally yield spores, recover from the surgery that isolates them from the large slug, and one third of these presumptive spore cells proceed to form the midget stalk. This remarkable accommodation to a new situation is also exhibited by



NORMAL AND MUTANT STRAINS of ***Dictyostelium mucoroides*** **are contrasted in these drawings. The normal form (*a*) aggregates in thin streams, and its slug remains anchored by a thin stalk. The "MV" mutant (*b*) aggregates in broad streams and produces a starfish-like slug which then breaks up into smaller slugs. The stalk of the mutant is usually shorter than that of normal strain.**



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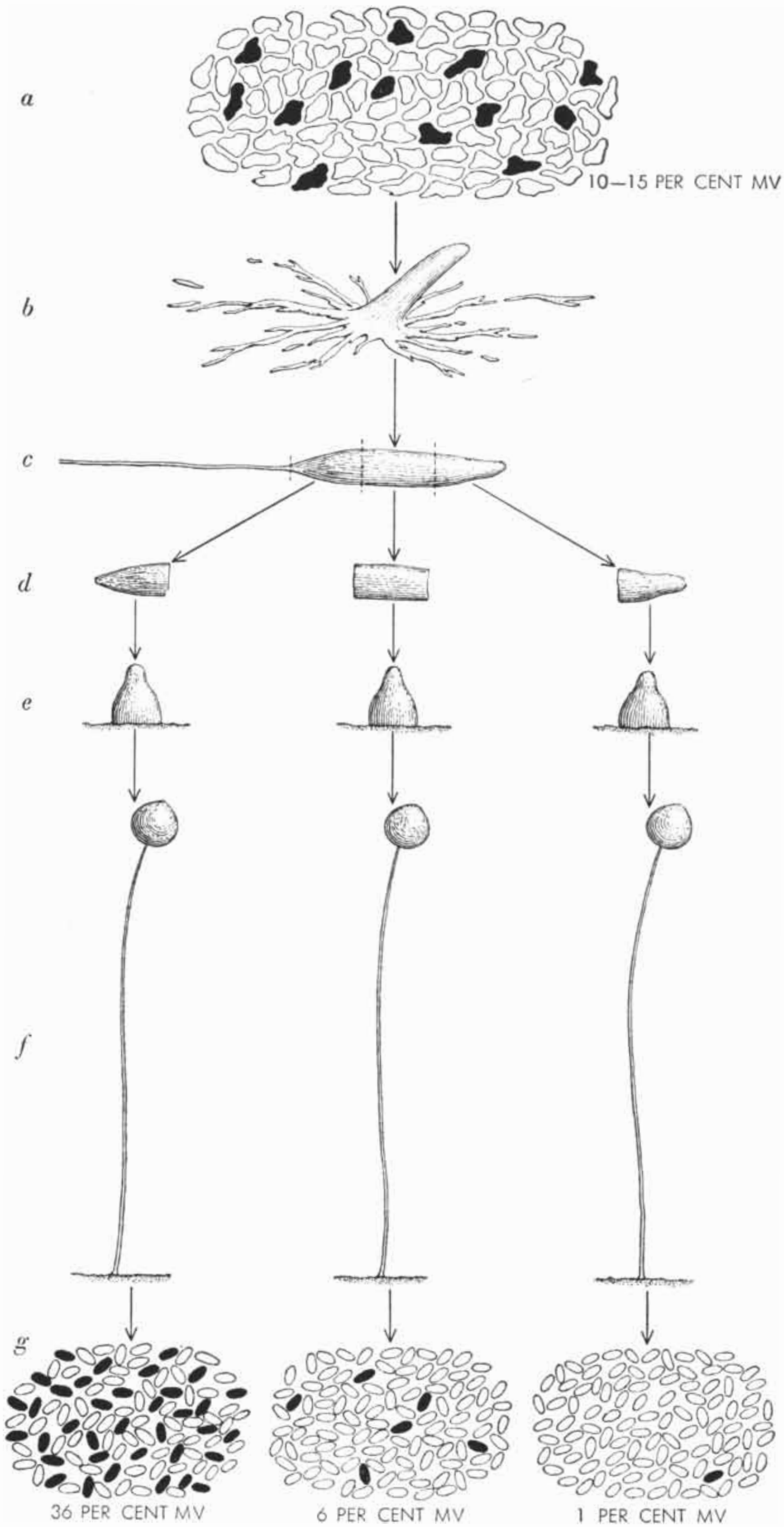

REDISTRIBUTION OF CELLS was proved in an experiment in which MV mutant cells (*black*) were randomly mixed with normal cells at feeding stage (*a*). The cells aggregated (*b*), and the resulting slug (*c*) was cut into three parts (*d*). Each part produced a fruiting body (*e* and *f*). Spores of each were then identified (*g*) by culturing them separately. The concentration of mutant cells was markedly higher in spores from the hind part of the slug.

many types of cells in embryos and in animals capable of regenerating limbs and organs.

A more reasonable way to explain the relation between sorting-out and differentiation is to visualize the aggregating amoebae as having all shades of variation in characteristics between the extremes found at the ends of the slug. As they form a slug the cells place themselves in such an order that from the rear to the front they display a gradual increase in speed, in size and perhaps in other properties not yet measured. Thus each fragment of a cut-up slug retains a small gradient of these properties. It is conceivable that the gradient, set up in the process of cell rearrangement, actually controls the chain of events that leads the front cells to form a stalk and the hind cells to become spores. For the present, however, this is only conjecture.

At this point let me emphasize that the sorting-out process is not unique to slime molds. Recently A. A. Moscona of the University of Chicago and others have found that if the tissues of various embryos or simple animals are separated into individual cells, the cells can come together and sort themselves out [see "Tissues from Dissociated Cells," by A. A. Moscona; Scientific American, May]. For instance, if separate single pre-cartilage cells are mixed with pre-muscle cells, the cartilage cells will aggregate into a ball and ultimately form a central mass of cartilage surrounded by a layer of muscle. By marking the cells in a most ingenious way Moscona showed that there was no transformation of pre-cartilage cells into muscle cells or vice versa; each cell retained its original identity but moved to a characteristic location. In animals, then, sorting-out appears to be a general phenomenon when the cells are artificially dissociated. Since the movement in slime molds is part of their normal development, this raises the challenging question whether such sorting-out occurs in the normal development of animal embryos as well.

One must concede that slime-mold amoebae do profit by collectivization: the aggregate can do things the individuals cannot accomplish alone. In the amoebae's society, however, all are not created equal; some rise to the top and others lag behind. And then there is this distressing moral: Those that go forward with such zest to reach the fore are rewarded with sacrifice and destruction as stalk cells. It is the laggards that they lift into the air which survive to propagate the next generation.

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MATHEMATICAL GAMES

Diversions that clarify group theory, particularly by the weaving of braids

by Martin Gardner

The concept of "group," one of the great unifying ideas of modern algebra and an indispensable tool in physics, has been likened by James R. Newman to the grin of the Cheshire cat. The body of the cat (algebra as traditionally taught) vanishes, leaving only an abstract grin. A grin implies something amusing. Perhaps we can make group theory less mysterious if we do not take it too seriously.

Three computer programmers—Ames, Baker and Coombs—wish to decide who pays for the beer. Of course they can flip pennies, but they prefer a random decision based on the following network-tracing game. Three vertical lines are drawn on a sheet of paper. One programmer, holding the paper so that his friends cannot see what he is doing, randomly labels the lines A, B and C [*see illustration at left below*]. He folds back the top of the sheet to conceal these letters. A second player now draws a series of random horizontal lines—call them shuttles—each connecting two of the vertical lines [*see second illustration below*]. The third player adds a few more shuttles, then marks an X at the bottom of one of the vertical lines [*see third illustration*].

The paper is unfolded. Ames puts his finger on the top of line A and traces it downward. When he reaches the end of a shuttle he turns, follows the shuttle to its other end, turns again and continues downward until he reaches the end of another shuttle. He keeps doing this until he reaches the bottom. His path [*traced in color in the fourth illustration*] does not end on the X, so he does not have to buy the drinks. Baker and Coombs now trace their lines in similar fashion. Baker's path ends on the X, so he picks up the tab. For any number of vertical lines, and regardless of how the shuttles are drawn, each player will always end on a different line.

A closer look at this game discloses that it is based on one of the simplest of groups, the so-called permutation group for three symbols. What, precisely, is a group? It is an abstract structure involving a set of undefined elements (a, b, c . . .) and a single undefined operation (here symbolized by .) that pairs one element with another to produce a third. The structure is not a group unless it has the following four traits:

1. When two elements of the set are combined by the operation, the result is another element in the same set. This is called "closure."

2. The operation obeys the "associative law": $(a.b).c = a.(b.c)$

3. There is one element e (called the "identity") such that $a.e = e.a = a$

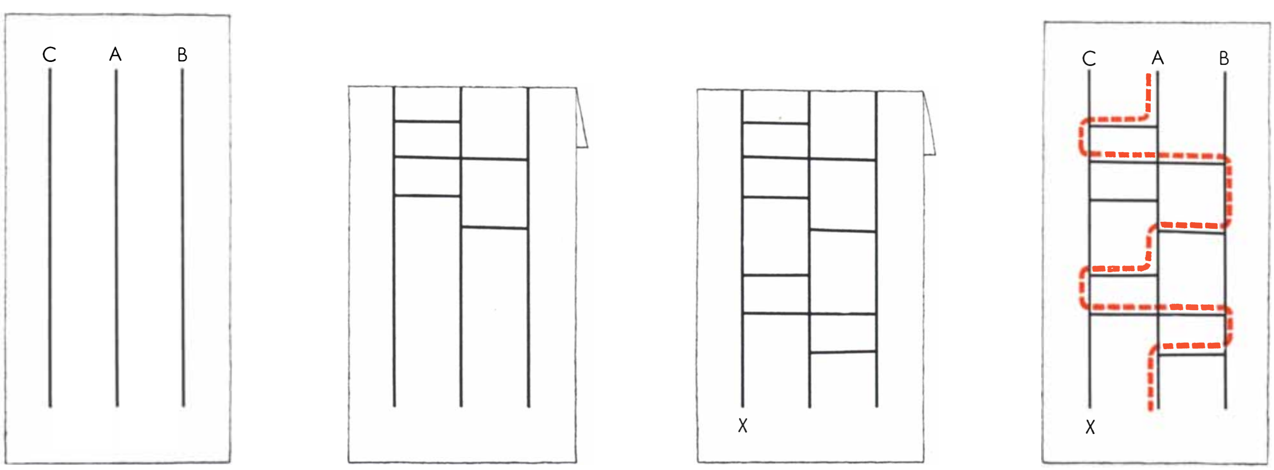
4. For every element a there is an inverse element a' such that $a.a' = a'.a = e$

If in addition to these four traits the operation also obeys the commutative law ($a.b = b.a$), the group is called a commutative or Abelian group.

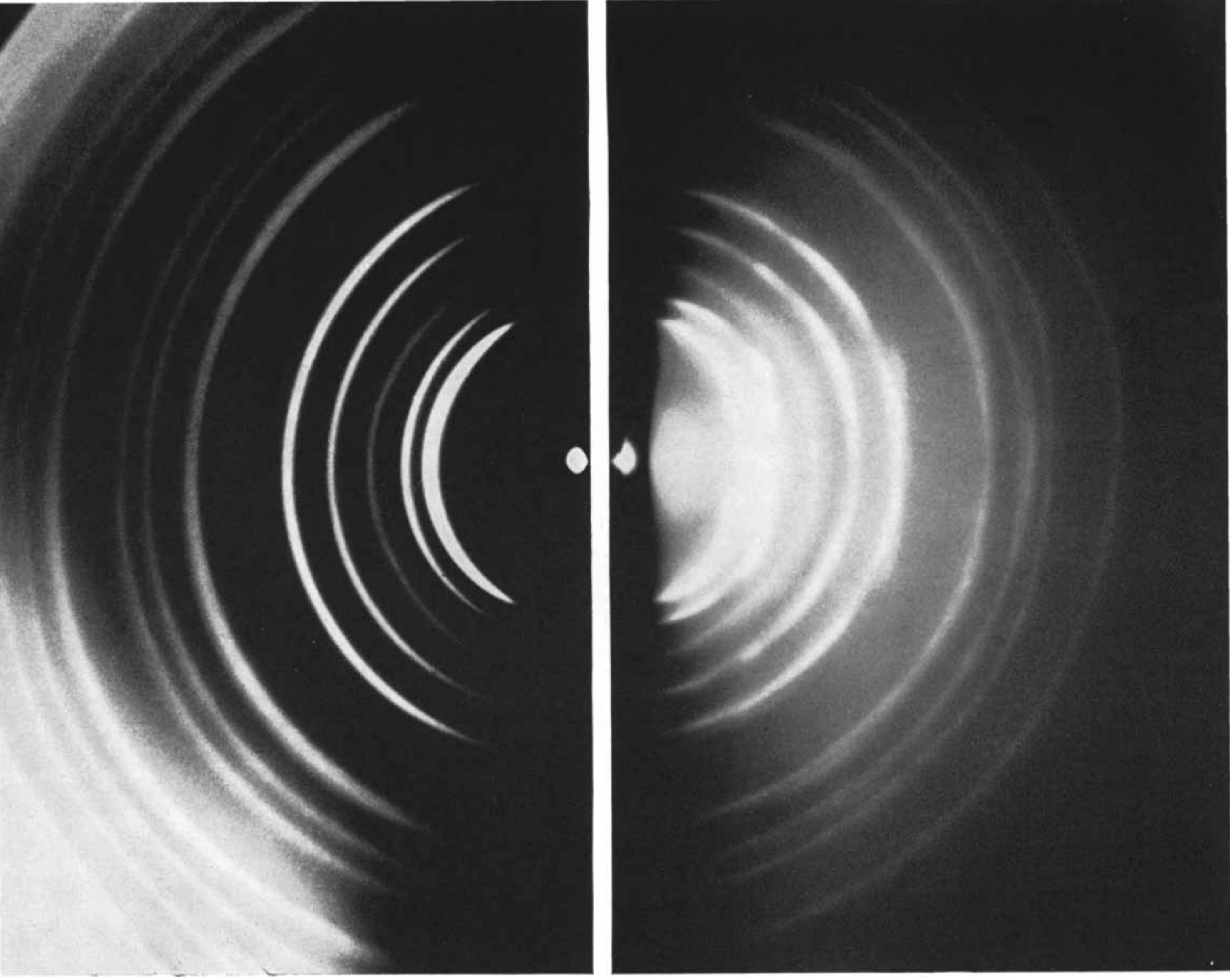
The most familiar example of a group is provided by the integers with respect to the operation of addition. It has closure (any integer plus any integer is an integer). It is associative (adding 2 to 3 and then adding 4 is the same as adding 2 to the sum of 3 and 4). The identity is 0 and the inverse of a positive integer is the negative of that integer. It is an Abelian group (2 plus 3 is the same as 3 plus 2). The integers also form an Abelian group with respect to multiplication, but here the identity is 1 and the inverse of an integer is its reciprocal (*e.g.*, the inverse of 5 is 1/5). The integers do *not* form a group with respect to division: 5 divided by 2 is 2½, which is not an element in the set.

Let us see how the network game exhibits group structure. The top illustration on page 169 depicts the six basic "transformations" that are the elements of our finite group. Transformation p switches the paths of A and B so that the three paths end in the order BAC. Transformations q, r, s and t give other permutations. Transformation e is not much of a change; it consists of drawing no shuttles at all. These six elements correspond to the six different ways in which three symbols can be permuted. Our group operation, symbolized by . , is simply that of following one transformation with another; that is, of adding shuttles.

A quick check reveals that we have



The network-tracing game



Report from IBM — *Yorktown Research Center, New York*

MAGNETIC EXPLORATION ALONG THE CRYSTAL AXIS

How does the orientation of crystallites within a thin metallic film relate to its magnetic properties? This is the question under study by a group of scientists at Zurich, Switzerland—one of the laboratories coordinated from the IBM Yorktown Research Center.

Electron-diffraction permits the investigation of the crystal structure of thin magnetic films prepared by evaporation in vacuum. In particular the orientation of the numerous small crystals in a polycrystalline film can be detected. The uniform distribution of density along the rings in the left-hand picture results from a random distribution of crystal axes, whereas the arcing of the rings at the right indicates a preferred orientation, known as fiber texture. Alignment of the axes of the individual crystallites contributes to the film's magnetic anisotropy—the variation of magnetic energy with different directions of magnetization.

Techniques for producing predictable anisotropy in thin films and for measuring magneto-crystalline relationships are among the goals of the present work. Thorough understanding of all factors influencing the magnetic anisotropy is mandatory for the development of optimal operation of magnetic thin film logic and memory devices. Mastery of anisotropic films may thus offer a promising route to greater capabilities in tomorrow's computers.

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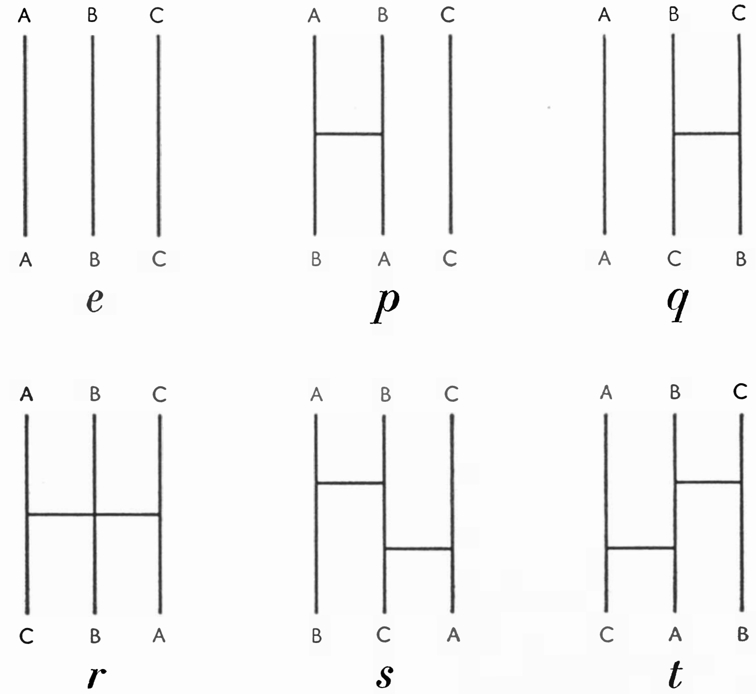

The six elements of the network-game group

here a structure with all the properties of a group. It has closure because no matter how we pair the elements we always get a permutation in the order of the paths that can be achieved by one element alone. For example, $p.t = r$ because p followed by t has exactly the same effect on the path order as applying r alone. The operation of adding shuttles is clearly associative. Adding no shuttles is the identity. Elements p, q and r are their own inverses, and s and t are inverses of each other. (When an element and its inverse are combined,

	e	*p*	*q*	*r*	*s*	*t*
e	*e*	*p*	*q*	*r*	*s*	*t*
p	*p*	*e*	*s*	*t*	*q*	*r*
q	*q*	*t*	*e*	*s*	*r*	*p*
r	*r*	*s*	*t*	*e*	*p*	*q*
s	*s*	*r*	*p*	*q*	*t*	*e*
t	*t*	*q*	*r*	*p*	*e*	*s*

Results of pairing elements in the network-game group. Broken line indicates $r \cdot s = p$

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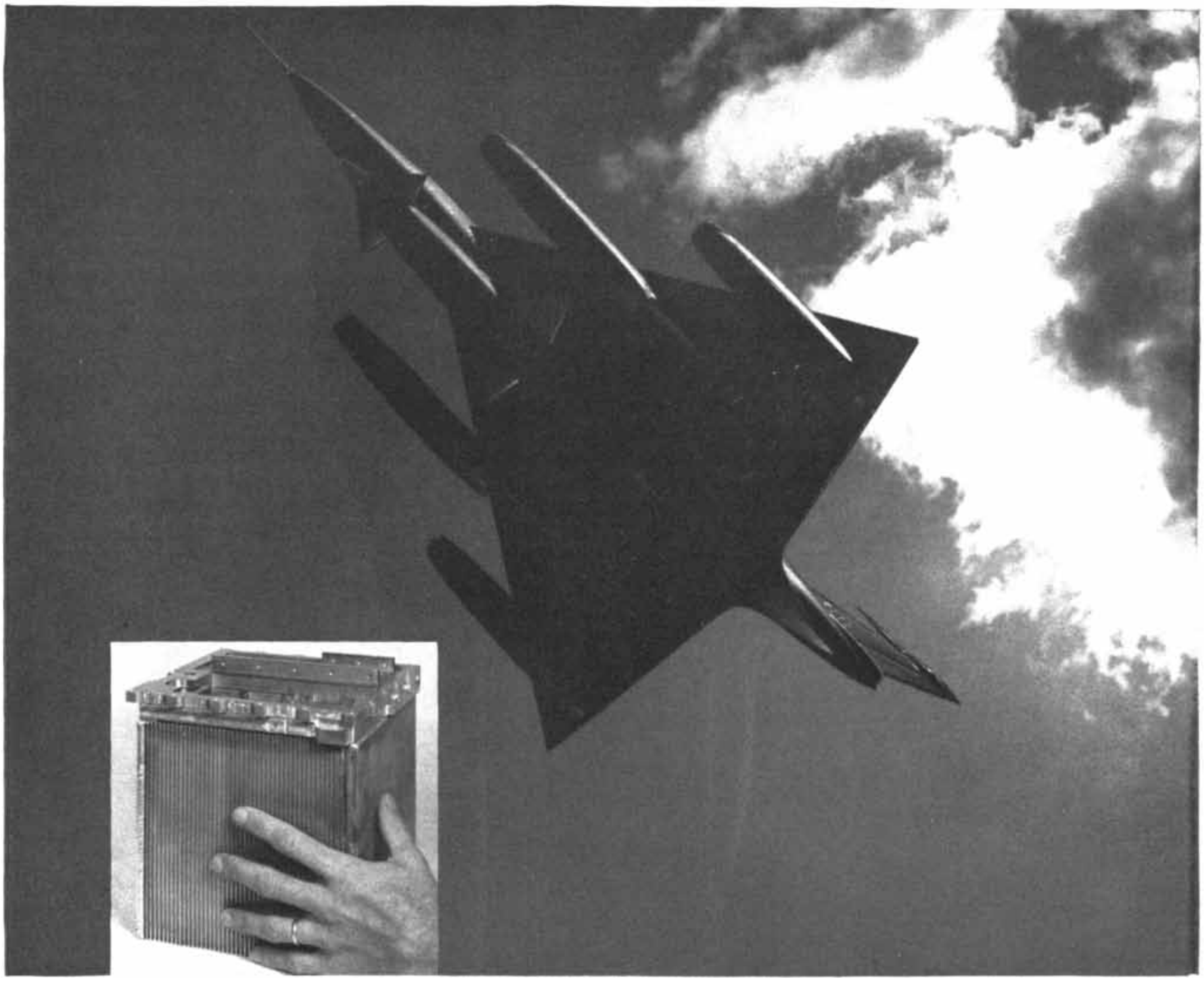

COMMUNICATIONS SYSTEM POWER UNIT

POWER... IN THE SPAN OF A MAN'S HAND...

This remarkably small 1 KW linear power amplifier (entire unit is approximately the size of an 8½″ cube) was developed by the Communications Division of Hughes Aircraft for the U. S. Air Force B-58 bomber.

With a blend of 3M Company's FC-75 and FC-43 as a dielectric coolant, the amplifier provides all the high-power output required by this huge aircraft's HF communications system, yet withstands all military environments at temperatures from −55°F. to +200°F. Here's why: the circuitry of the amplifier is immersed in this non-corrosive, non-flammable inert fluid which protects it against internally generated heat through a highly efficient evaporative cooling process. There are no hot spots, and a uniform temperature is maintained throughout.

By using FC-75 and FC-43 in this way, Hughes Communications Division engineers were able to achieve a "compression in volume of a factor of 6" when developing this amplifier for use in an area where space is at a premium. Other areas of application now under investigation include submarines and ground base systems.

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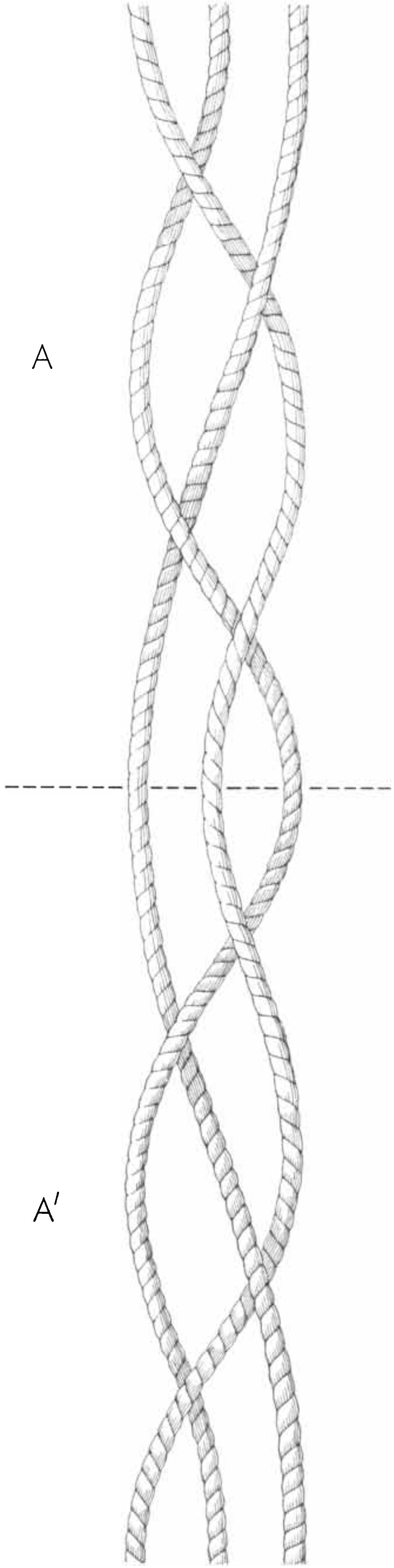
the result is the same as drawing no shuttles at all.) It is not an Abelian group (*e.g.*, *p* followed by *q* is not the same as *q* followed by *p*).

The bottom illustration on page 169 provides a complete description of this group's structure. What is the result of following *r* with *s*? We find *r* on the left side of the table and *s* at the top. The intersection of column and row is the cell labeled *p*. In other words, shuttle pattern *r* followed by shuttle pattern *s* has the same effect on path order as pattern *p*. This is a very elementary group that turns up in many places. For example, if we label the corners of an equilateral triangle, then rotate and reflect the triangle so that it always occupies the same position on the plane, we find that there are only six basic transformations possible. These transformations have the same structure as the group just described.

It is not necessary to go into group theory to see intuitively that the network game will never permit two players to end their paths on the same vertical line. Simply think of the three lines as three ropes. Each shuttle has the same effect on path order as crossing two ropes, as though forming a braid. Obviously no matter how you make the braid or how long it is, there will always be three separate lower ends.

Let us imagine that we are braiding three strands of a girl's hair. We can record successive permutations of strands by means of the network diagram, but it will not show how the strands pass over and under one another. If we take into account this complicating topological factor, is it still possible to call on group theory for a description of what we are doing? The answer is yes, and Emil Artin, a distinguished mathematician now at the University of Hamburg, was the first to prove it. In his elegant theory of braids the elements of the group are "weaving patterns" (infinite in number), and the operation consists, as in the network game, of following one pattern with another. As before, the identity element is a pattern of straight strands—the result of doing nothing. The inverse of a weaving pattern is its mirror image. The illustration at right shows a sample pattern followed by its inverse. Group theory tells us that when an element is added to its inverse, the result is the identity. Sure enough, the two weaving patterns combined prove to be topologically equivalent to the identity. A tug on the end of the braid in the illustration and all strands pull out straight. (Many magic tricks with rope, known



Braid A is the mirror image of A′

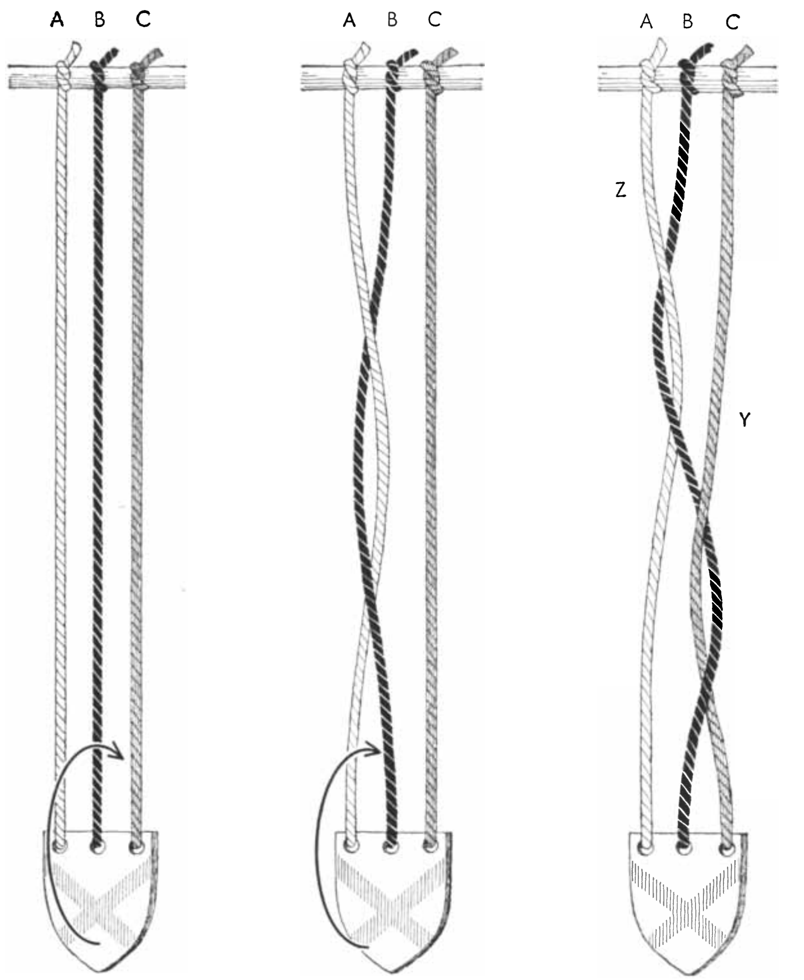
in the trade as releases, are based on this interesting property of groups.) Artin's theory of braids not only provided for the first time a system that classified all types of braids; it also furnished a method by which one could determine whether two weaving patterns, no matter how complex, were or were not topologically equivalent.

Braid theory is involved in an unusual game devised by Piet Hein of Copenhagen, several of whose mathematical recreations have been discussed in this department. Cut a piece of heavy cardboard into the coat-of-arms shape depicted below. This will be called the plaque. Its two sides must be easily distinguished, so color one side or mark it with an X as shown. Punch three holes at the square end. A two-foot length of heavy but flexible cord (sash cord is excellent) is knotted to each hole. The other ends of the three strands are attached to some fixed object like the back of a chair.

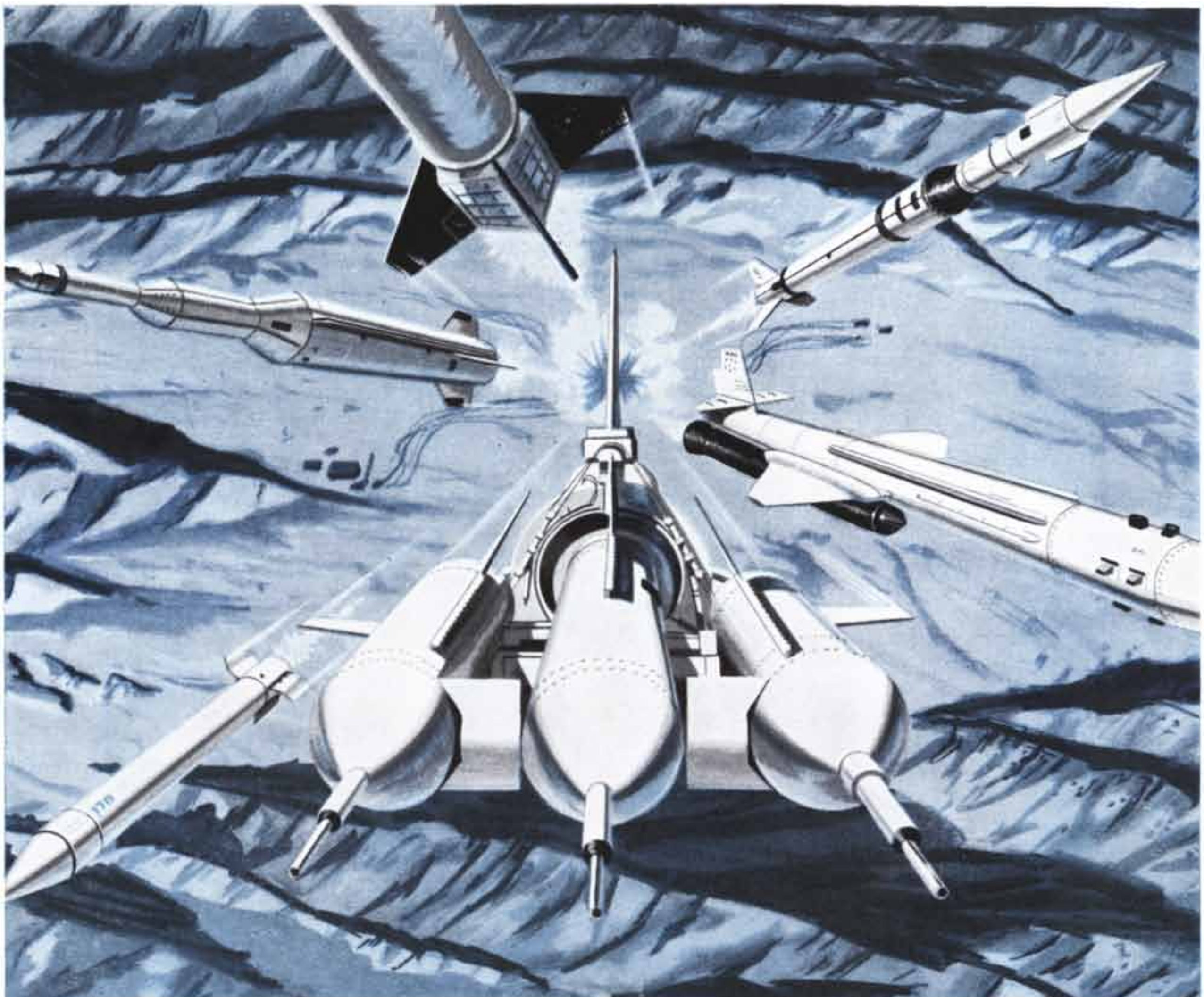
You will find that the plaque can be given complete rotations in six different ways to form six different braids. It can be rotated sidewise to the right or to the left; it can be rotated forward or backward between strands A and B; it can be rotated forward or backward between strands B and C. The second illustration below shows the braid obtained by a forward rotation through B and C. The question arises: Is it possible to untangle this braid by weaving the plaque in and out through the strands, keeping it horizontal at all times, X-side up, and always pointing toward you? The answer is no. But if you give the plaque a second rotation, in any of the six different ways, the result is a braid that *can* be untangled by weaving the plaque without rotating it.

To make this clear, assume that the second rotation is forward between A and B, creating the braid shown in the third illustration. To remove this braid without rotating the plaque, first raise C at the spot marked Y and pass the plaque under it from right to left. Pull the strings taut. Next raise A at the spot marked Z and pass the plaque under it from left to right. The result is that the cords pull straight.

The following surprising theorem



Rotation at left produces braid in center; rotation in center, braid at right



RADIOSONDE X-17 WALLOPS ISLAND ROCKET CREE SPAEROBEE X-7

ELECTRICAL CONNECTORS FOR TEST AND RESEARCH MISSILES

Ideas are the payload aboard these vehicles. From the wealth of data they radio back to recording stations, concepts grow to maturity or become stepping stones to further advance.

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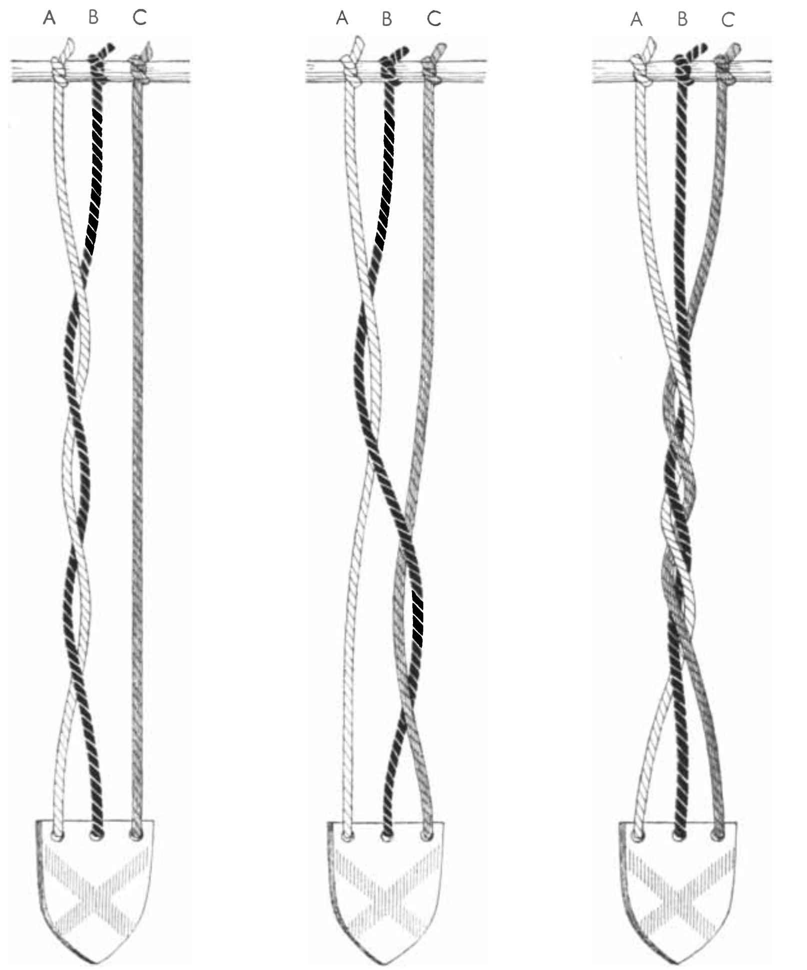
holds for any number of strands above two. All braids produced by an *even* number of rotations (each rotation may be in any direction whatever) can always be untangled by weaving the plaque without rotating it; braids produced by an *odd* number of full rotations can never be untangled.

It was at a meeting in Niels Bohr's Institute for Theoretical Physics, more than 25 years ago, that Hein first heard this theorem discussed by Paul Ehrenfest in connection with a problem in quantum theory. A demonstration was worked out, by Hein and others, in which Mrs. Bohr's scissors were fastened to the back of a chair with strands of cord. It later occurred to Hein that the rotating body and the surrounding universe entered symmetrically into the problem and therefore that a symmetrical model could be created simply by attaching a plaque to *both* ends of the cord. With this model two persons can play a topological game. Each holds a plaque, and the three strands are stretched straight between the two plaques. The players take turns, one forming a braid and the other untangling it, timing the operation to see how long it takes. The player who untangles the fastest is the winner.

The odd-even theorem also applies to this two-person game. Beginners should limit themselves to two-rotation braids, then proceed to higher even-order braids as they develop skill. Hein calls his game "tangloids," and it has been played in Europe for a number of years.

Why do odd and even rotations make such a difference? This is a puzzling question that is difficult to answer without going more deeply into group theory. A hint is supplied by the fact that two rotations in exactly opposite directions naturally amount to no rotation. And if two rotations are almost opposite, prevented from being so only by the way certain strings pass around the plaque, then the tangle can be untangled by moving those same strings back around the plaque. M. H. A. Newman, in an article published in a London mathematical journal in 1942, says that P. A. M. Dirac, the noted University of Cam-



Three problems of braid disentanglement

STEPS IN THE RACE TO OUTER SPACE

Nuclear Rocketship

Despite the sky-high transportation costs, Lunar manufacturing should prove economically viable. With unlimited Solar power, controlled atmospheres and advanced automation, a considerable commerce could be realized in delicate instruments, rare minerals, reactor cores and other items that might be more efficiently processed or produced in the Moon's perfect vacuum.

To supply the Moon colonists, and to carry their production back to Earth, special rocketships will be developed.

Nuclear energy is the most promising source of propellant power. The ship shown here utilizes nuclear fission for heat and hydrogen gas as a working fuel. From pressurized tanks, the gas is fed through a heat exchanger, expanded, and expelled for the motive thrust.

When the craft leaves Earth, it carries only enough gas for a one-way trip. For, by extracting hydrogen and oxygen from Lunar rocks, Moon settlers will be able to refuel the rocketship for the return voyage. This will permit smaller fuel tanks on the craft and larger payloads.

Inertial navigation systems will play an increasing role in the exploration of outer space. ***ARMA***, now providing such systems for the Air Force ATLAS ICBM, will be in the vanguard of the race to outer space. ***ARMA*** . . . Garden City, N. Y. A Division of American Bosch Arma Corp.

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Solution to last month's card problem

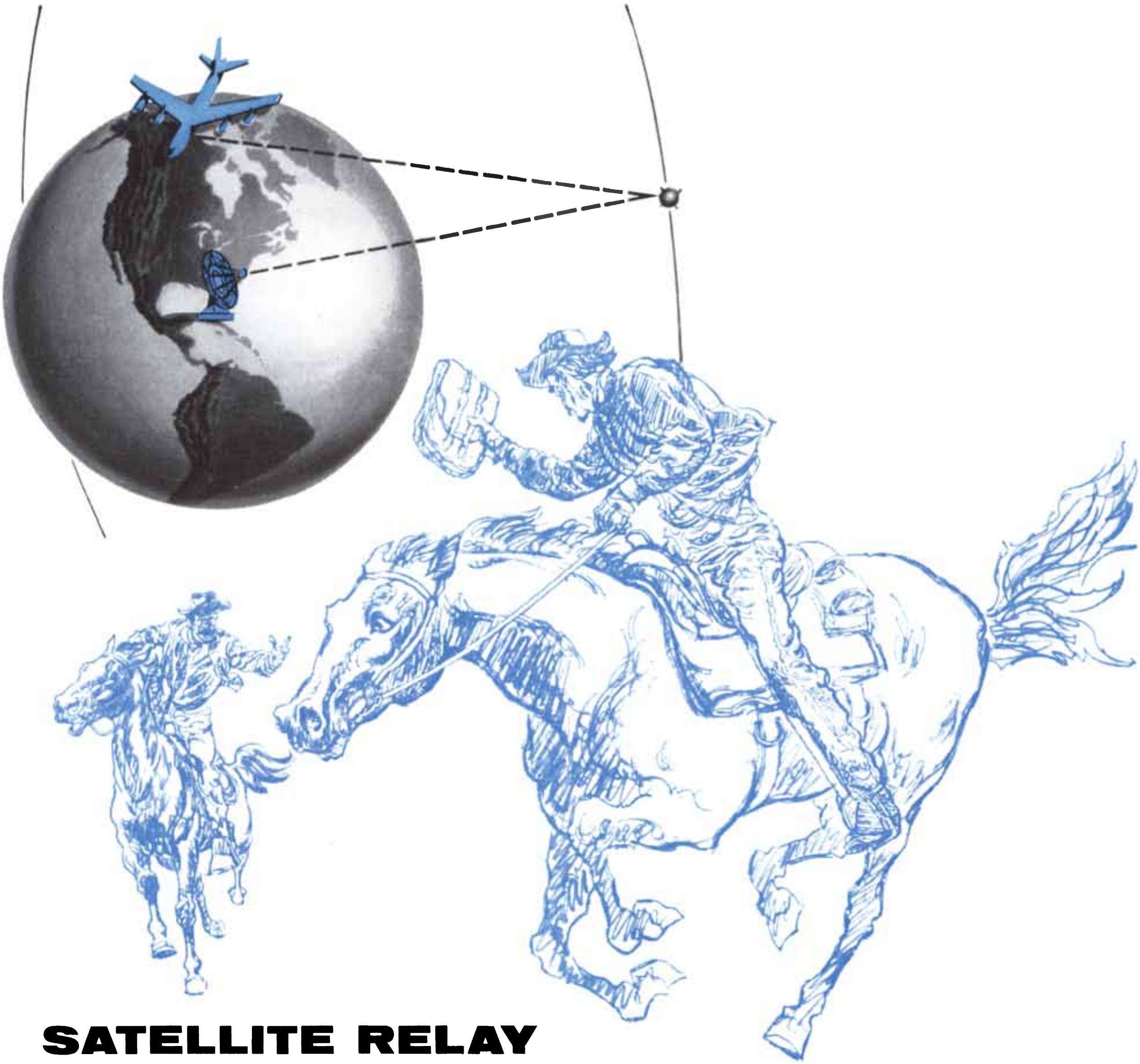
bridge physicist, has for many years used the solitaire form of this game as a model "to illustrate the fact that the fundamental group of the group of rotations in 3-space has a single generator of the period 2." Newman then draws on Artin's braid theory to prove that the cords cannot be untangled when the number of rotations is odd.

You will find it a fascinating pastime to form braids by randomly rotating the plaque an even number of times, then seeing how quickly you can untangle the cords. Three simple braids, each formed by two rotations, are shown in the illustration on page 174. The braid on the left is formed by rotating the plaque forward twice through B and C; the braid in center, by rotating the plaque forward through B and C and then backward through A and B; the braid at right, by two sidewise rotations to the right. Readers are invited to determine the best method of untangling each braid. Answers will be given in the next issue.

Following a practice inaugurated last December, I close with a cryptic Yuletide message. To find it, you must permute properly all the letters (that is, form an anagram) of the following sentence: MANY A SAD HEART CAN WHISPER MY PRAYER.

Unfortunately permutation group theory is of no help here, but the puzzle is not nearly so hard as it looks.

Last month readers were asked to form a square with the 16 highest playing cards so that no value or suit would appear twice in any row, column or two main diagonals. One solution is given in the illustration above.



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Other space age projects at the Bendix Systems Division include magnetohydrodynamics, highly reliable radiation-resistant communication equipment, interpretation and prediction of infrared reconnaissance, new satellite stabilization techniques, and communication methods to penetrate the ionized shock layer surrounding hypersonic vehicles. Additional projects involve satellites for weather and ground infrared reconnaissance, and for radio navigation.

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THE AMATEUR SCIENTIST

About experiments that demonstrate the function of the thyroid gland

Conducted by C. L. Stong

An amateur who likes to perform biological experiments is unlikely to turn to those involving hormones. The endocrine glands which produce these "chemical messengers" in the animal body comprise a complex system that is poorly understood even by endocrinologists. It would also seem that hormones themselves are not available for amateur experimentation. Actually this is not so. A number of animal hormones can now be obtained without prescription and at modest cost. With them the amateur can perform relatively simple experiments that will give him a deeper understanding both of animal physiology and of physiological method.

One such experiment has been designed by Robert Lawrence, a physician at Kings County Hospital in New York City, and Henry Soloway, a student at the State University of New York College of Medicine. They write:

"The human body can be likened to an engine. Structures such as the heart, lungs and kidneys are essential to its operation. If any of these organ systems breaks down, the engine stops. Other structures control the rate at which the engine operates; they are analogous to the flywheel, governor and throttle. These include the endocrine-gland complex, comprised of such organs as the pituitary, thyroid, adrenals, pancreas and gonads.

"The product of certain of these glands, such as the adrenals or the pancreas, is essential to life. Their destruction by injury or disease leads to death unless the missing hormones are supplied to the body artificially. The destruction of others, such as the thyroid or gonads, need not result in death, but depriving an animal of them can seriously alter various body structures and functions such as skin texture and color, the growth and distribution of hair, the sex drive, the rate at which the organism grows, and so on.

"Unlike other glands, those of the endocrine complex elaborate and liberate chemical substances directly into the bloodstream. Known as hormones, these substances include insulin, estrogen, cortisone, testosterone and thyroxin. Once secreted into the circulation they act throughout the body to control the rates of its various processes.

"Obviously the glands can function at three levels: optimal production, overproduction and underproduction. The experiment we shall describe is designed to demonstrate the reaction in a group of experimental animals when the thyroid gland is made to function at each of these three levels.

"The thyroid gland is located just below the Adam's apple. It elaborates the iodine-containing hormone thyroxin, which helps to control the animal's rate of metabolism. Our experiment employs the dried and powdered thyroid gland, which contains active thyroid hormone. The preparation may be purchased from the General Biological Supply House of 8200 South Hoyne Avenue in Chicago. A 10-gram bottle, sufficient for this experiment, is priced at 95 cents.

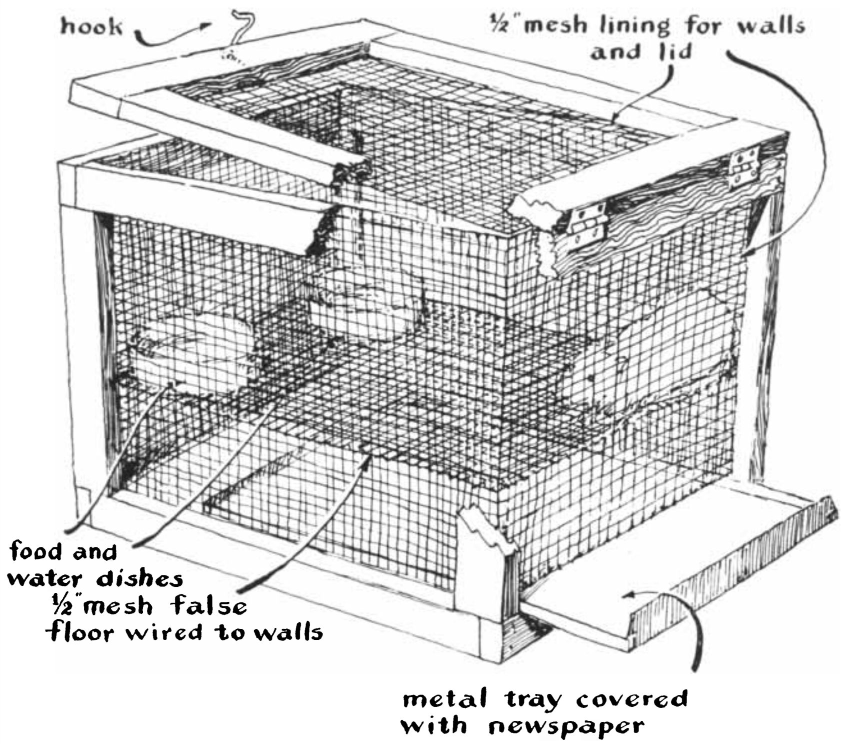
"In addition to thyroxin, the experiment requires a second compound: 6-n-propyl 2-thiouracil, usually called PTU. When administered in sufficient quantity, this compound will render the thyroid gland almost completely incapable of producing thyroxin. By using either of the two preparations it is possible to inhibit the action of the experimental animal's thyroid and so reduce its natural supply of thyroxin far below the optimal level. Then, by administering the thyroid powder, one can raise the thyroxin level to any desired amount. The animal is physiologically unable to distinguish between thyroxin produced by its own thyroid gland and that administered to it. This so-called inhibition-replacement technique enables the experimenter to observe the broad spectrum of effects that accompanies variations in the activity of the thyroid gland. The amount of thyroxin needed to restore normal function in an animal with a nonfunctioning thyroid gland will be measured, and records will be made of how the various levels of simulated thyroid activity modify the body's responses to certain abnormal physiological states.

"The experiment requires 20 male albino rats, each weighing between 45 and 50 grams. These can be procured either through firms specializing in biological supplies or from pet stores. It is inadvisable to mix male and female rats in the experiment. The use of females rather than males also complicates the experiment, because the hormones involved in the ovarian cycle interact with other hormones in a regular manner that tends to make the analysis of the experiment difficult. It is also inadvisable to perform the experiment with guinea pigs, because in these animals the thyroid normally functions at a very low level.

"The experimental rats should be divided into four groups of five each. The individuals in each group should be selected so that their weights are as similar as possible. The groups are placed in four cages, which should be approximately 12 inches high, 12 inches wide and 18 inches long. All-metal construction is recommended, but wooden frames covered with half-inch wire mesh are satisfactory. The cages should be equipped with floors of wire mesh so that urine and feces can fall through the wire into a shallow pan.

"The reliability of the experimental results will depend heavily on how the animals are maintained during the period of the experiment. The cages must be kept scrupulously clean and out of drafts. Laboratory rats are more susceptible to disease than their untamed cousins.

"When a rat is in a cold environment, its nervous system senses the loss of heat and communicates the need for energy to the thyroid. The gland thereupon liberates additional thyroxin, which in turn increases the rate at which food is 'burned.' Since the objective of the experiment is to observe the effects that



Cage for housing experimental rats

accompany various levels of thyroxin in the blood independent of environmental factors, the room housing the rats must be maintained at a uniform temperature. If possible, the temperature should be held within the range of 69 to 72 degrees Fahrenheit. The animals should be exposed to natural daylight occasionally, but the cages must be protected from direct sunlight because the eyes of albino rats contain little pigment and are easily injured by strong light.

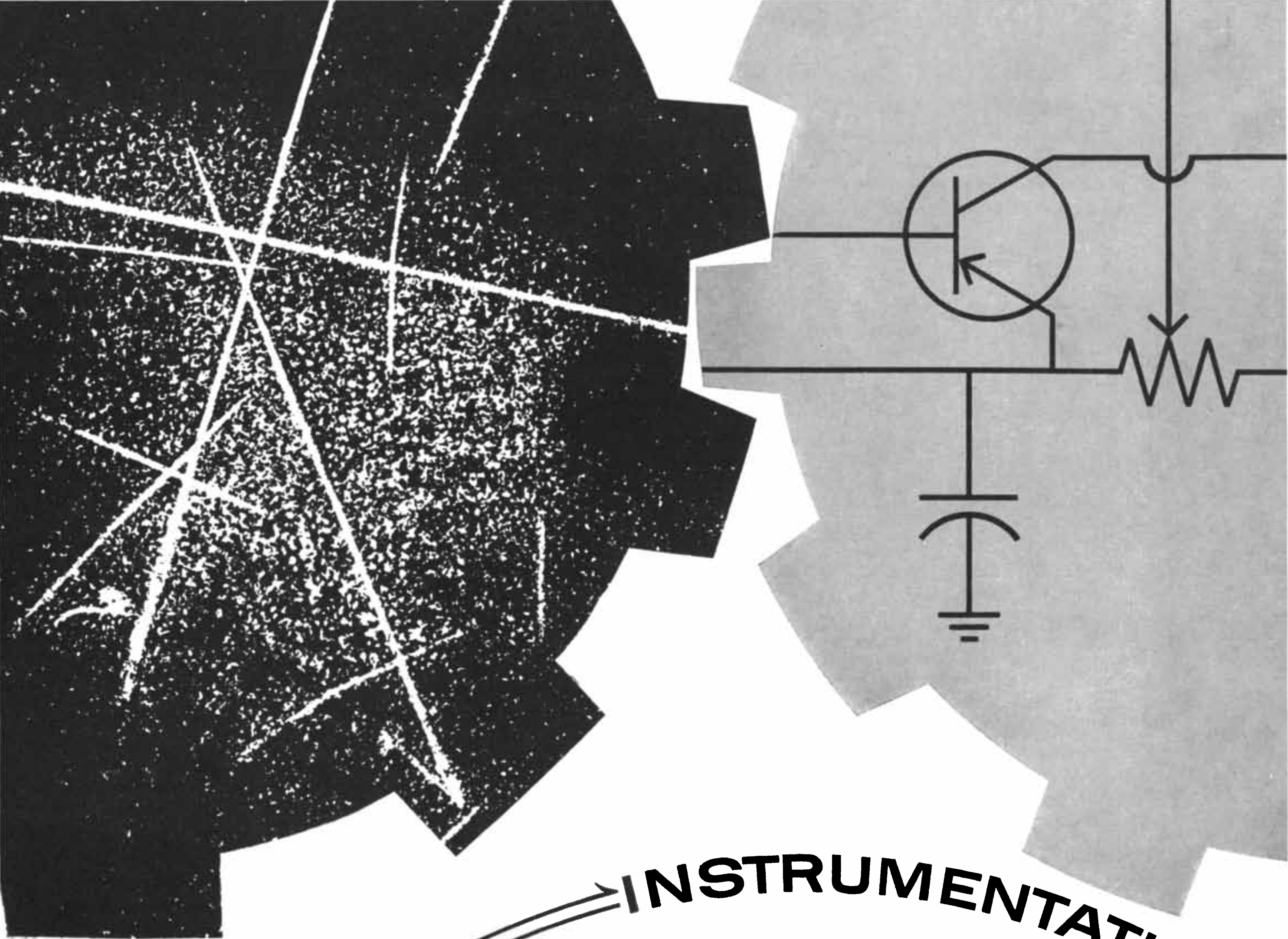
"Each cage should be equipped with a water-dispenser. An automatic dispenser can be made from a pint bottle, an elbow of glass tubing, a short length of rubber tubing and a rubber stopper perforated with a hole the same diameter as the rubber tubing. The end of the glass elbow is inserted into the tubing, which is pushed through the hole in the stopper. The stoppered bottle is filled and upended so that a small air space remains at the top, and is mounted so that the glass tube is vertical inside the cage. It is advisable to polish the exposed end of the tube in a gas flame to prevent the rats from cutting themselves.

"PTU can be obtained from the Lederle Laboratories in Pearl River, N. Y. A bottle containing 100 five-gram tablets is priced at $2.61. Amateurs can purchase the substance, however, only through a recognized scientific institution, school or board of education.

"PTU is administered in the drinking water. The required .02-per-cent solution is made by dissolving .4 gram of PTU (eight tablets) in two quarts of boiling water. (PTU does not dissolve readily in cold water.) After cooling, the solution may be stored in a stoppered bottle from which the water bottles are replenished as required. One group of rats, which is reserved as a control, receives plain tap-water. The other three groups receive the PTU solution.

"The dried-thyroid powder containing the hormone is administered with the rat's food. From the strictly scientific point of view this technique leaves something to be desired, because it is impossible to control the dosage accurately. One can predict neither the precise quantity of food that will be eaten nor the amount of thyroxin absorbed from the digestive tract. Ideally an accurately measured solution containing the pure hormone would be injected under the skin. Pure thyroxin is costly, however, and injection is inconvenient. In this experiment it is permissible to sacrifice some accuracy for a gain in convenience.

"Each of the four experimental groups receives a diet that varies only in its concentration of thyroid powder. A standard ration is stocked by most biological supply-houses and is relatively



RESEARCH ⇄ INSTRUMENTATION

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inexpensive. Most experimenters prefer to work with the prepared food unless a diet is required that is deficient in some particular element. For those who prefer to make up their own rat food, the accompanying recipe is recommended [*see table below*].

"Because the object of the experiment is to show the effects of normal, high and low thyroid activity, two groups of rats receive the stock ration to which no thyroid powder is added. One of these is the control group. It receives plain food and water. The second is the group to be deprived of thyroxin. It receives PTU and plain food. The remaining two groups receive medication in both food and water. The first receives PTU and just enough thyroxin to restore its normal complement of the hormone. It has been calculated that the addition of three parts of thyroid powder to 1,000 parts of stock ration almost exactly replaces the amount of thyroxin that would be liberated naturally. If all goes well, the biological functioning of this group should closely match that of the control group. The fourth group will simulate the effects of an overactive thyroid. Excessive thyroxin is administered: 12 parts of thyroid powder to 1,000 parts of stock ration.

"The prescribed diets should be prepared in bulk and stored in appropriately labeled boxes from which individual food dishes are filled as required. A 50-gram rat will consume on the average about seven grams of food per day. The food dishes should be about two inches high and should have steep sides to prevent spillage. They should be anchored to the floors of the cages and kept filled, because the capacity of a rat's stomach is small. Consequently the animals will eat almost continuously.

"The experiment gets under way as soon as the rats have been placed in their cages and supplied with medicated food and water. Each animal should have been marked for identification either by an ear punch or a dye and listed on an individual record sheet with column headings for body length, weight, oxygen consumption and general comments, including a description of hair condition.

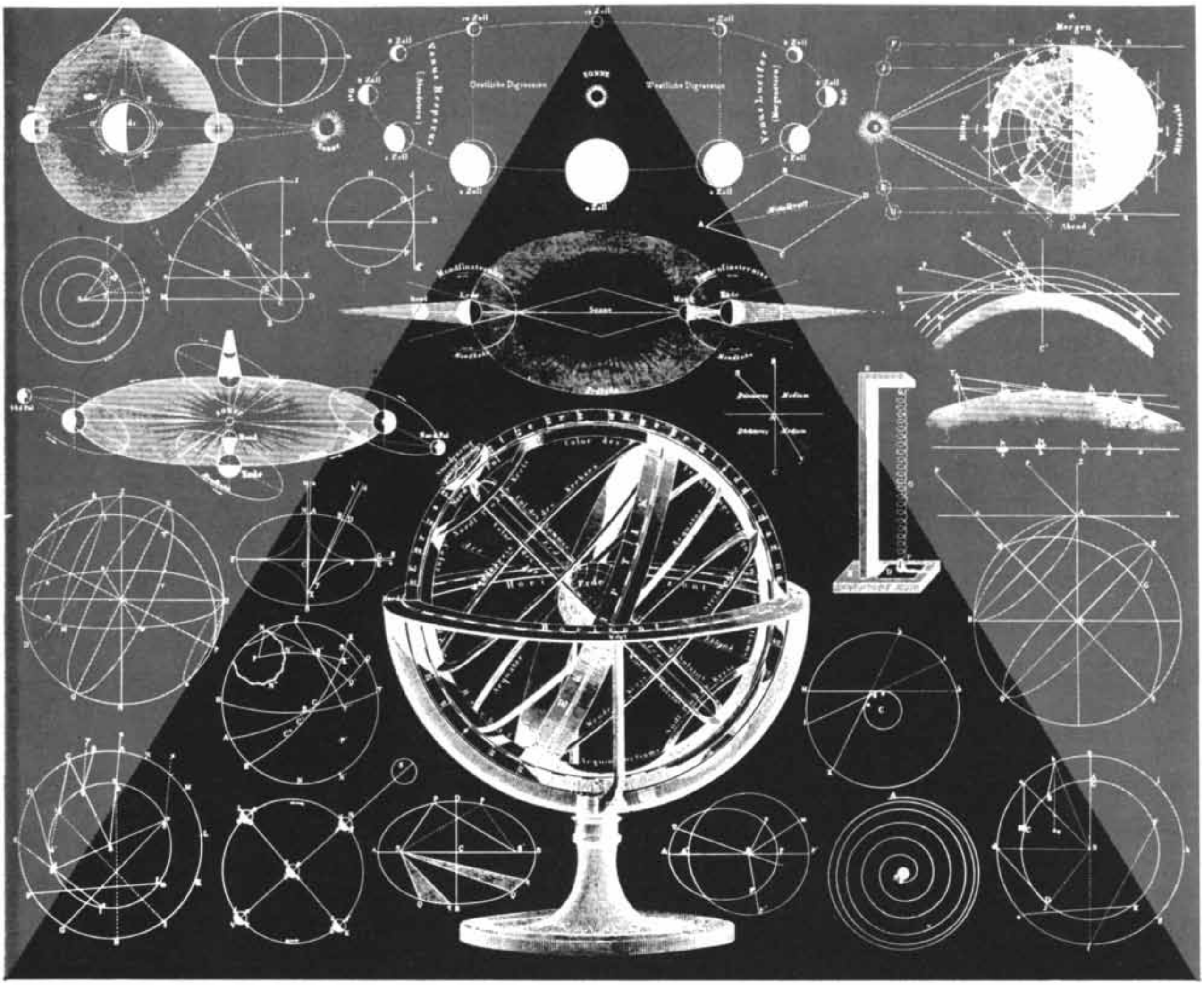
"As previously mentioned, thyroxin influences the animals' metabolism. The effect can be observed indirectly by means of a number of tests based on one or more of the end products of the metabolic process. The test selected for this experiment measures the rate at which the animals consume oxygen. As described in this department [see "The Amateur Scientist"; SCIENTIFIC AMERICAN, August, 1957], the apparatus consists of a large, stoppered jar containing the animal together with approximately eight ounces of soda lime (calcium hydroxide and sodium hydroxide). A graduated pipette serves as a port to connect the air in the jar with that in the room.

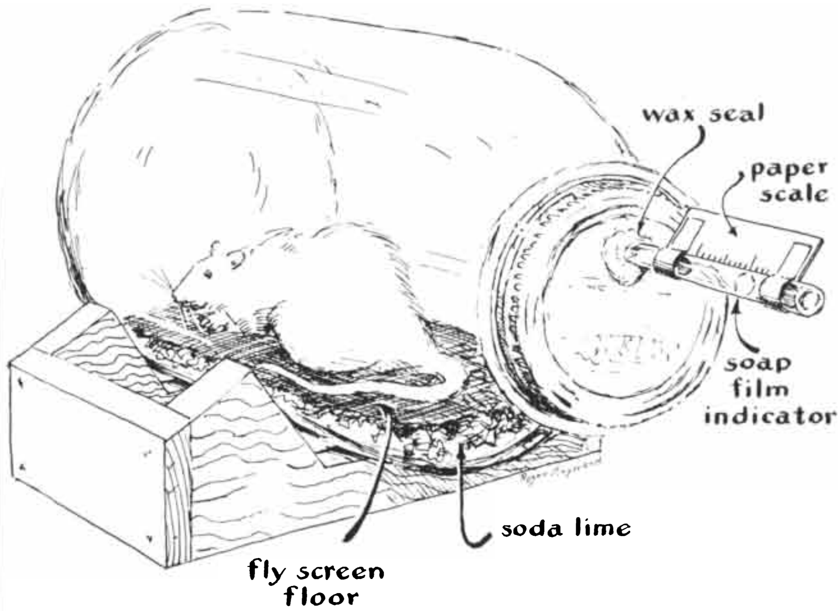
"Carbon dioxide is exhaled by the animal and absorbed by the soda lime. Oxygen is absorbed by the animal from the inhaled air. Consequently air pressure inside the jar drops, and air from the room flows into the jar through the graduated pipette. This flow can be accurately measured by closing the end of the pipette with a film of soapy water. Air flowing into the tube from the room pushes the film, which serves as a pointer, ahead of it. Graduations indicate the internal volume of the tube at two points: one at five cubic centimeters and the other at zero c.c.

"The time required for the soap film to move from the zero graduation to the five-c.c. graduation is a function of the animal's metabolic rate. Measure this interval with a stop watch marked off in hundredths of a minute. Make three runs, add the three stop-watch readings, divide the sum by three and divide the resulting quotient into .3. The result represents the consumption of oxygen in liters per hour. Next square the recorded weight of the animal, find the cube root of the result and divide it by 1,000. This gives the approximate surface area of the animal in square meters. The ratio of the oxygen consumption per hour to the surface area is a measure of

NUTRIENT	AMOUNT (PARTS)
WHOLE-WHEAT FLOUR	21
YELLOW CORN MEAL	21
WHOLE-OAT FLOUR	20
WHOLE-MILK POWDER	20
LINSEED OIL MEAL	10
CASEIN	3
YEAST	3
CALCIUM CARBONATE	1
SODIUM CHLORIDE	1

Recipe for a rat's diet





Apparatus for determining the oxygen consumption of rats

the animal's metabolic rate. This figure should be recorded in the appropriate column.

"The jar should be fitted with a floor of wire mesh to prevent the animals from coming into contact with the soda lime, as shown in the accompanying drawing [*above*]. Because soda lime reacts with the atmosphere, the spent chemical should be replaced with a fresh charge before tests are begun.

"The oxygen-consumption rate of each animal should be measured when the rats are put in their cages, and once every three days afterward during the 15-day period of the experiment. Ordinarily a correction factor for variations in atmospheric pressure and temperature is taken into consideration when computing the rate of oxygen consumption, but this may be omitted in the present experiment because the correction is small in comparison with experimental errors. If the initial rate of oxygen consumption of any rat varies more than 25 per cent from the average of those in all groups, the animal may be considered abnormal and should be replaced.

"A significant drop in oxygen consumption will follow the administration of PTU, although the drug requires about nine days completely to inhibit the action of the thyroid gland. The effect will be most apparent in Group III, which receives no replacing thyroxin. If Group II assimilates the foreign thyroxin, its reactions will match those of the control group (Group I) and the amount of oxygen consumed by the two groups will be similar. In contrast, the consumption rate of Group IV will increase sharply, demonstrating the simulated effect of an overactive thyroid.

"The length and weight of each animal should be recorded at least as frequently as the rate of oxygen consumption. At the conclusion of the test run it is interesting to plot all data as graphs. Weight, growth and oxygen consumption for experimental and normal animals should be plotted as three separate graphs. The curves representing Group I and Group II should be similar. If not, then either the replacement dose was not correct in amount or the animal failed to assimilate the drug as anticipated. The hypothyroid group (those deprived of thyroxin) should show the lowest gain in weight and the hyperthyroid group the highest gain. The completed graphs illustrate the general influence of the thyroid gland on metabolism and growth under constant environmental conditions. The same inhibition-replacement technique can also be used to show how the thyroid helps the animal to cope with changes in its environment as well as how it modifies the action of selected vitamins, minerals and hormones other than thyroxin. It is interesting, for example, to investigate the role of the thyroid in helping an animal adapt to a cold environment.

"The four groups of rats are placed in an air-conditioned room (about 60 degrees F.) for three hours with water but without food. The oxygen-consumption test is then made. If the test proceeds normally, the results should show that the thyroids of the control animals respond to the temperature stimulus by stepping up the rate of oxygen consump-

tion, suggesting an increased rate of thyroxin production. This implies that the thyroid plays an important role in helping warm-blooded animals to maintain constant internal temperature, a fact with important clinical implications. Patients with underactive thyroids feel unbearably cold at temperatures that are only mildly uncomfortable to most persons, a symptom that disappears when they are treated with the appropriate thyroid preparation.

"The experiment can be varied to study the effect on related hormones and assorted dietary deficiencies. One variation requires seven groups of experimental animals. One group is reserved as a control. Three groups are treated as in the experiment described: one with PTU, the second with PTU plus a replacement dose of thyroid powder and the third with PTU plus a large overdose of thyroid powder. The remaining three groups receive precisely the same treatment plus daily injections of growth hormone. By comparing the slopes of the resulting rate-of-growth curves it will become apparent that growth hormone has little effect in the absence of a functioning thyroid gland. For the most interesting results the animals used in this experiment should be selected at the age when the normal rate of growth has become almost imperceptible. Similar experiments based on the inhibition-replacement technique can be designed for investigating vitamin-deficient and mineral-deficient diets. Materials for these, as well as the growth hormone experiment, can be purchased from the General Biological Supply House, mentioned earlier."

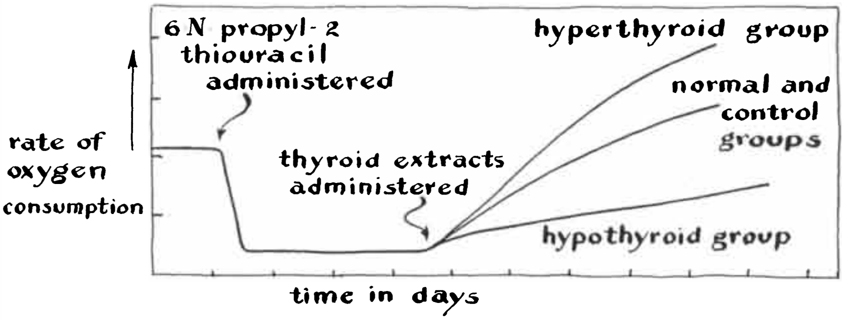
Frank Hughes, an amateur telescope-maker of Wausau, Wis., submits the design for a machine to grind and polish small telescope mirrors that approaches the ultimate in simplicity.

"Lately I have been turning my attention to grinding and polishing machines," he writes, "and have been looking for ways to lop off little pieces here and there without spoiling the basic mechanism. The result is a device so simple that it scarcely justifies the name 'machine.'

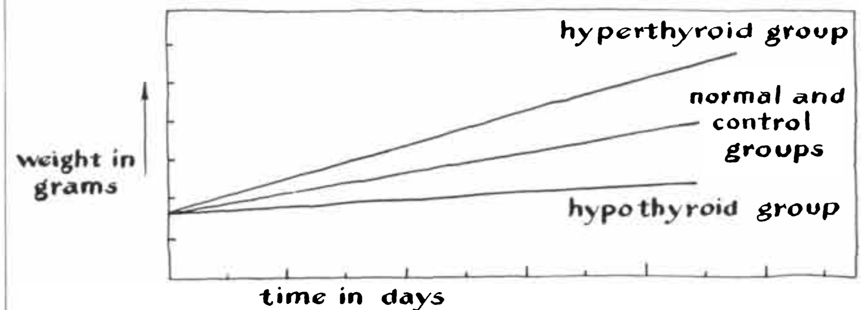
"Imagine a turntable on which a disk of thick glass, the 'tool,' is mounted. The surface of the mirror to be worked is placed on the tool with wet abrasive between the two. The mirror blank is loosely confined by three stationary buffers spaced at 120 degrees. If the tool, mirror and turntable are concentric and the buffers do not make contact with the edge of the mirror (which has been

edge-ground to a circle), the tool and mirror will simply rotate with the turntable. No work will be accomplished. If the turntable and tool are now offset by a fraction of the radius of the mirror, the mirror will be rotated by the tool against two of the buffers and will be abraded. Similarly, if the tool has been coated with pitch and rouge, the mirror will be polished. The polish will divide sharply, however, where the edge of the tool touches the mirror, and the resulting figure will suffer. If the tool is now offset on the turntable, the mirror will be pushed irregularly by the buffers with respect to the tool in a nonrepetitive path, the axial amplitude of which can be altered as desired. A turntable speed of about 30 revolutions can be used. The variables include the horizontal relationship of the turntable, the position and size of the triangle formed by the buffers and the eccentricity of the tool on the turntable. The turntable of my prototype is driven by a low-speed motor of an old ironing machine, and the buffers consist of three wooden slats fastened to the workbench. No cranks, no levers, no belting!"

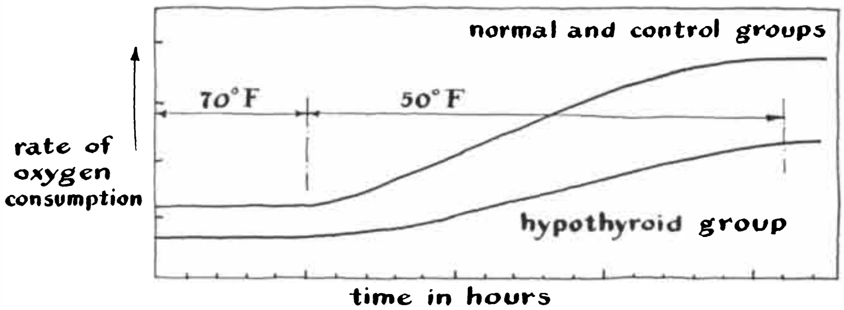
David A. Whitmore of Natick, Mass., writes: "I read with interest George W. Ginn's description of the transistorized telescope drive in 'The Amateur Scientist' for October. He is to be complimented on a remarkably good design. Being a transistor-circuit engineer, however, I must mention two errors that appear in the schematic circuit-diagram. First, there must be a connection between the junction of the two .5-microfarad capacitors nearest the CK 722 transistor and the base of that transistor. Second, and not so obvious, is the value of the collector resistor in the second stage (the General Electric 2N 188 A transistor). This should be 470 ohms, not 470 K as shown."



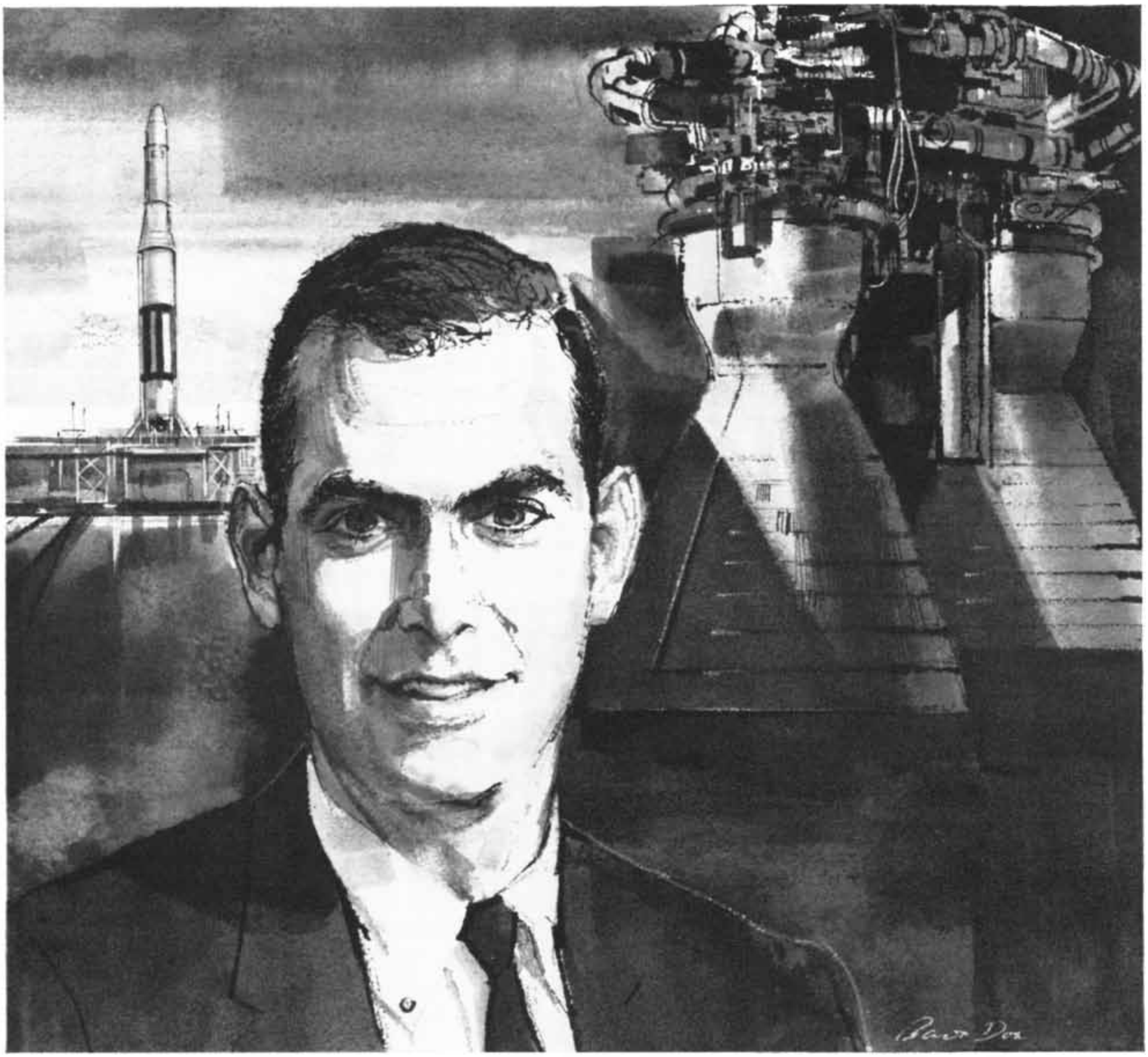
Graph showing the effect of thyroid activity on rat metabolism



Graph showing the effect of thyroid activity on growing rats



Graph showing the influence of the thyroid in maintaining body temperature in rats



BOOKS

The tortured life of Blaise Pascal, one of the great minds of all time

by James R. Newman

BLAISE PASCAL: THE LIFE AND WORK OF A REALIST, by Ernest Mortimer. Harper & Brothers ($4).

Did religion consume Blaise Pascal? Did it lead him to immolate the intellect, to forsake reason for faith? He stands out for his achievements even in the century of genius in which he lived; yet how much more, one wonders, might he have accomplished had he not wasted himself on theological sterilities and on religious quarrels? In one of Nietzsche's eloquent polemics against Christianity it is Pascal whom he holds up as a tragic victim of the ravages of religion: "What is it that we combat in Christianity? That it aims at destroying the strong, at breaking their spirit, at exploiting their moments of weariness and debility, at converting their proud assurance into anxiety and conscience-trouble; that it knows how to poison the noblest instincts and to infect them with disease, until their strength, their will to power, turns inwards, against themselves—until the strong perish through their excessive self-contempt and self-immolation: that gruesome way of perishing, of which Pascal is the most famous example."

No doubt Pascal's struggle with himself, his attempt to reconcile religious faith with the spirit of geometry, and his final justification of religion on a nonintellectual basis cost him dear. He was not a saint by nature. He had ferocious energy and a fiery temper (his sister Jacqueline tells us he had *une humeur bouillante*); he was a man of passion in his arguments, his friendships, his scientific exertions, his religious beliefs. He had a passion even for self-torture. But there are other facts which cast doubt on the opinion that Pascal sacrificed his magnificent creative powers to his God. They are set forth in this lucid, insightful biography by Ernest Mortimer, an English clergyman.

The subtitle of Mortimer's book is "The Life and Work of a Realist," and he endows the word realist, as a British reviewer has said, with its full breadth of meaning. Two of his major points should be mentioned at the outset. The first is that it is simply untrue that Pascal abjured science and society after his conversion in 1654. Over the years his religious interests deepened, but until the very end of his life he clung to his "free-thinking friends" and retained his scientific curiosity. The second point is that Pascal held facts to be no less sacred than faith. He believed in sense-data as a source of knowledge and truth; he recognized that the contradictory impressions of nature are no excuse for mystery-mongering; he respected the power of the intellect and reason to enlarge the "gates of perception" upon the universe. In all this he was a modern thinker. He was no less modern, it can be argued, in believing that the emotions are another gate of perception. It was he who said that the heart has its reasons which reason knows nothing of; modern psychology and psychoanalysis have also said it, but not so well.

Pascal was born at Clermont in Auvergne on June 19, 1623. His father, Etienne Pascal, was a well-to-do high public official (a judge and tax commissioner) who was to rise even higher. Blaise's mother, who came of a family of prosperous merchants, died at the age of 30, leaving him, aged three, an elder sister Gilberte and a younger sister Jacqueline.

The boy was sickly and precocious. The nature of his illness is not fully known (a witch was said to have been partly responsible), but an anatomical anomaly discovered after his death was probably a contributing factor. Of the two apertures in a baby's skull that should knit in the early weeks of life, one had never properly closed, and the other had clamped or overlapped so as to form a bony ridge. Pascal suffered from headaches all his life. His precocity served him better. His family was bound close by natural affection and by bereavement; they loved him and recognized his exceptional powers. Blaise was "encouraged rather than forbidden to stare."

On the death of his wife Etienne Pascal resolved to be father, mother and tutor to his children. They had their governess, but he alone gave them their formal education. His instruction, says Mortimer, was remarkable for its paternal self-denial, its eccentricity, rigor and patience; also for its fruits. He scorned "the sort of pedagogy which he had suffered himself"; he had his own theories of teaching and did not hesitate to practice them. His principal maxim, Gilberte tells us, "was to hold the child always above his work," not to rush him or overload him. Instruction was by easy conversation. The object was to quicken the child's interest, to let natural curiosity about language, about the things around him guide the direction and emphasis. It was time enough for a child to learn Latin when he was 12, when he could do it more easily. "By good fortune," Pascal wrote to a friend in later years, "for which I cannot be too grateful, I was taught on a peculiar plan and with more than fatherly care."

Etienne had a bent for mathematics, and decided to make that subject "the coping stone of his plan." Not until he was 16, after he had learned Latin, Greek, history and geography, was Blaise to be introduced to geometry. Meanwhile books on mathematics were not allowed in the house and the subject was not discussed in the daily conversational instructions. But the boy had

EDITOR'S NOTE

Each December since 1949 this department has reviewed a number of books about science for younger readers. The reviews begin on page 201.

secretly made his own way. One day when he was 12 his father came upon him surrounded with diagrams, "so absorbed that he still thought himself alone." He had been trying to work out for himself the principles of geometry, calling straight lines "bars" and circles "rounds," and he was now trying to prove that the three angles of a triangle add up to two right angles. (Another version of the story is that he had rediscovered the whole of Euclid up to the 32nd proposition of the first book, but there is no evidence that this is so.) Etienne forgot his theoretical scruples and was overcome with pride and joy.

Admirable though it was, Blaise's education had its gaps. History and literature were sketchily imparted; the natural sciences even more sketchily. Fortunately Blaise was not overburdened with theology; for the time being elementary religious teaching was enough. But he was soon to come out into the world and to glimpse new horizons of learning, including both science and theology.

When he was eight, the family had moved to Paris. Etienne had rented a house in the Rue de Tisseranderie (which, it is delightful to learn, was intersected by the Street of the Two Doors, the Street of the Bad Boys, Cock Street and the Street of the Devilish Wind) and had entered into the life of this marvelous city. He now had few professional duties and could give even more time to the education of his children. He was a sociable man, with a taste and talent for natural science, and he found friends with whom he could share his interests. Social groups in which the arts and sciences were discussed seriously "but outside academic settings" were a feature of the time. He was close to Guillaume Montory, the leading actor of the day, and to Charles Dalibray, the poet; the fashionable circles of literature and art were open to him. More important was his membership in the Abbé Bourdelot's group, which included, among others, the aging but still lively mathematician and physicist Père Mersenne ("a bold, capacious, untidy and extraordinarily vivacious mind"), who managed to reconcile his support both of Galileo and orthodox theology; the gifted but prosaic mathematician Gilles Personne de Roberval (who, it is told, saw a performance of *Le Cid* and complained that he could not see what it proved); the brilliant young engineer Pierre Petit; and Gérard Desargues, who invented projective geometry and introduced the method of perspective. Blaise was allowed, while still a child, to accompany his father to the séances of this group and was even encouraged to utter his own ideas. He was much influenced by Desargues, not only in mathematics but also in a concern, which the older man felt deeply, for improving the education and lightening the labors of plain workmen.

Pascal's first contribution to mathematics, composed at the age of 16, was his celebrated theorem. He had read Desargues' writings and had recognized as no one else had the worth of Desargues' method. His little *Essay on Conic Sections*, which acknowledged his debt to Desargues, described a property common to all conic curves that is invariant under projection and section: If any six points on the curve are joined by straight lines and the sides of the resulting hexagon are prolonged beyond the curve, the three pairs of opposite sides will intersect at three points that lie on one straight line.

The theorem was widely praised, but not by the great Descartes. In reply to Mersenne's enthusiastic letter he wrote: "He seems to have copied Desargues. I cannot pretend to be interested in the work of a boy." It is true Desargues' treatise suggested the property, but Pascal "isolated and proved it." It was a beautiful piece of work in its own right, and not merely a feat of precocity.

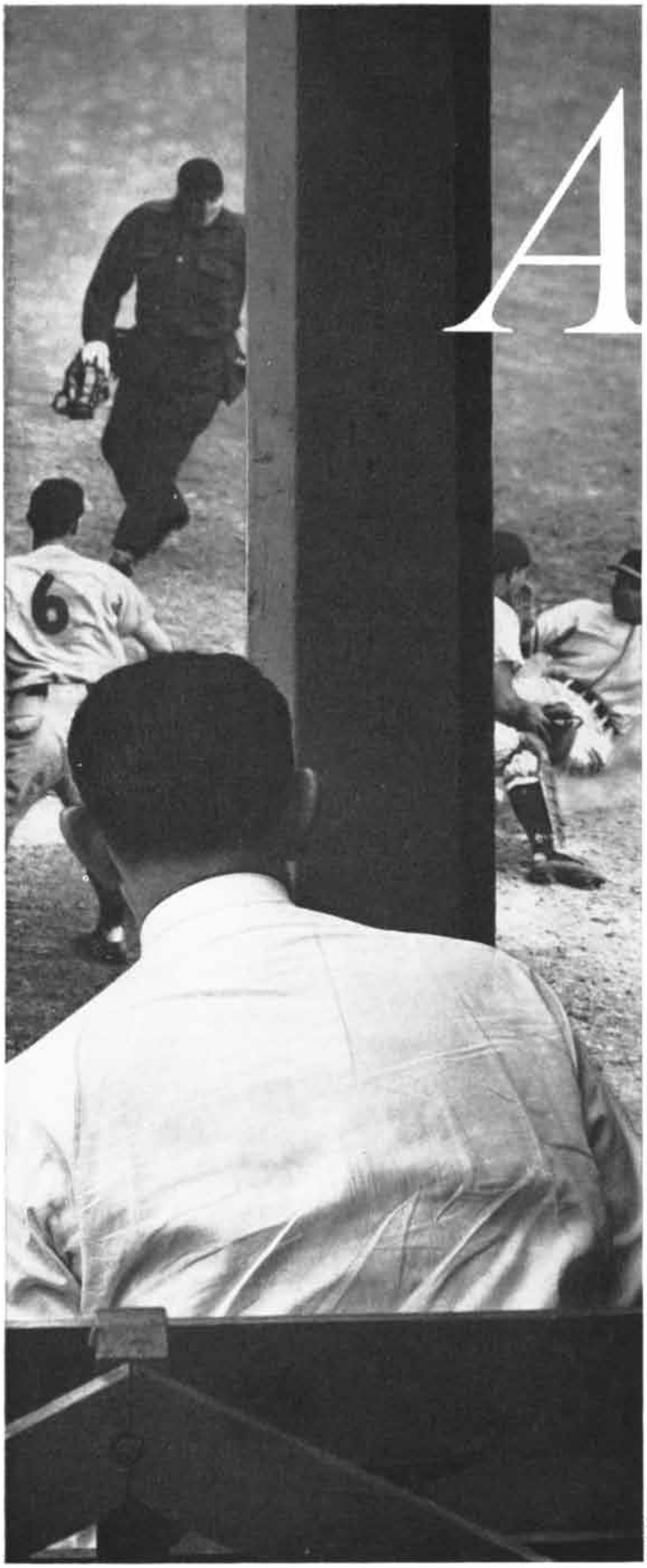
And now Pascal was no longer a child. The eight years in Paris had been "intensely formative." He was mastering Latin, beginning Greek, "absorbing paternal disquisitions on philosophy at mealtimes." He had met leading scientific thinkers; he had had his first taste of *la vie mondaine*. His energy matched the fecundity of his intellect; it is said, for example, that he followed up his theorem on conics with some 400 corollaries. Mathematics was unquestionably his great passion; he put his whole spirit into it. He reserved mathematics, to be sure, for his leisure moments; because it came easy to him he may have regarded it as a self-indulgence. But like the young Bertrand Russell he hoped to find in mathematics the solace and perfection of eternal truth.

In 1640 the Pascals moved to Rouen, Etienne having through the favor of Cardinal Richelieu been awarded the important but unpopular post of tax assessor for that city. There they remained for seven years. For Blaise it was a period of "much hard work, a religious awakening and the beginnings of a profound spiritual dilemma."

Etienne's job was backbreaking; in addition to various administrative chores he had the task of reassessing the taxes of 18 townships, which meant, among other things, copying endless columns of figures. "I never get to bed before two o'clock," he wrote Gilberte. The spectacle of his father's drudgery put an idea into Blaise's head. Why not make a machine to do the donkey calculations? During the first year at Rouen he conceived a mechanism that would perform all the operations of arithmetic; it would have a device for carrying digits from one column to the next, and another for recording the result. With the help of local craftsmen he worked on the idea. Some 50 experimental models were constructed over five years, and in 1645 he had his machine. It was the size of a glove box, simple in appearance, portable and workable. (It is believed that this very machine is now in private hands in the south of France.) Pascal hoped to get rich on the invention and staked a claim for a patent; by 1652 a standard model was in production and was placed on sale at 100 livres. His hopes were not realized. The manufacturing costs were too high, and the invention of logarithms cut the demand for the machine. Yet it was the first of all computers; as Gilberte writes in her life of her brother: "He reduced to mechanism a science which is wholly in the human mind." Now Blaise began to be referred to as *le grand M. Pascal*.

His concern with religion was growing, but it was still far from pervading his thoughts. The drama and poetry of the day did not appeal to him. He disliked and distrusted their emotional influence; he found them artificial and stilted. He read in philosophy and was attracted to the ancient Stoic writings and to Epictetus. What he admired was the value they placed on fortitude and duty, the high notion that man's fate is in his own power, that no outside force can crush him. But it was a "fatal flaw," he believed, to make man the complete master, to leave no place for God. Stoicism was too self-assured, too filled with self-pride, too apt "to greet the unseen with a sneer."

When his computer was finished, a new interest came to Pascal. On a visit to Rouen, Pierre Petit brought news of experiments in Florence two years before in which Evangelista Torricelli had demonstrated that we live at the bottom of a sea of air and that air has weight. Torricelli had taken a glass tube closed at one end, filled it with mercury and covered the open end with his finger; when he inverted the tube, placed the open end in a bowl of mercury and removed his finger, the liquid in the tube did not fall into the bowl but sank only part of the way down the tube and re-



mained mysteriously suspended. "I assert," he wrote, "that the force [holding up the mercury in the tube] comes from without [and that the mercury stands] in a column high enough to make equilibrium with the weight of the external air which forces it up."

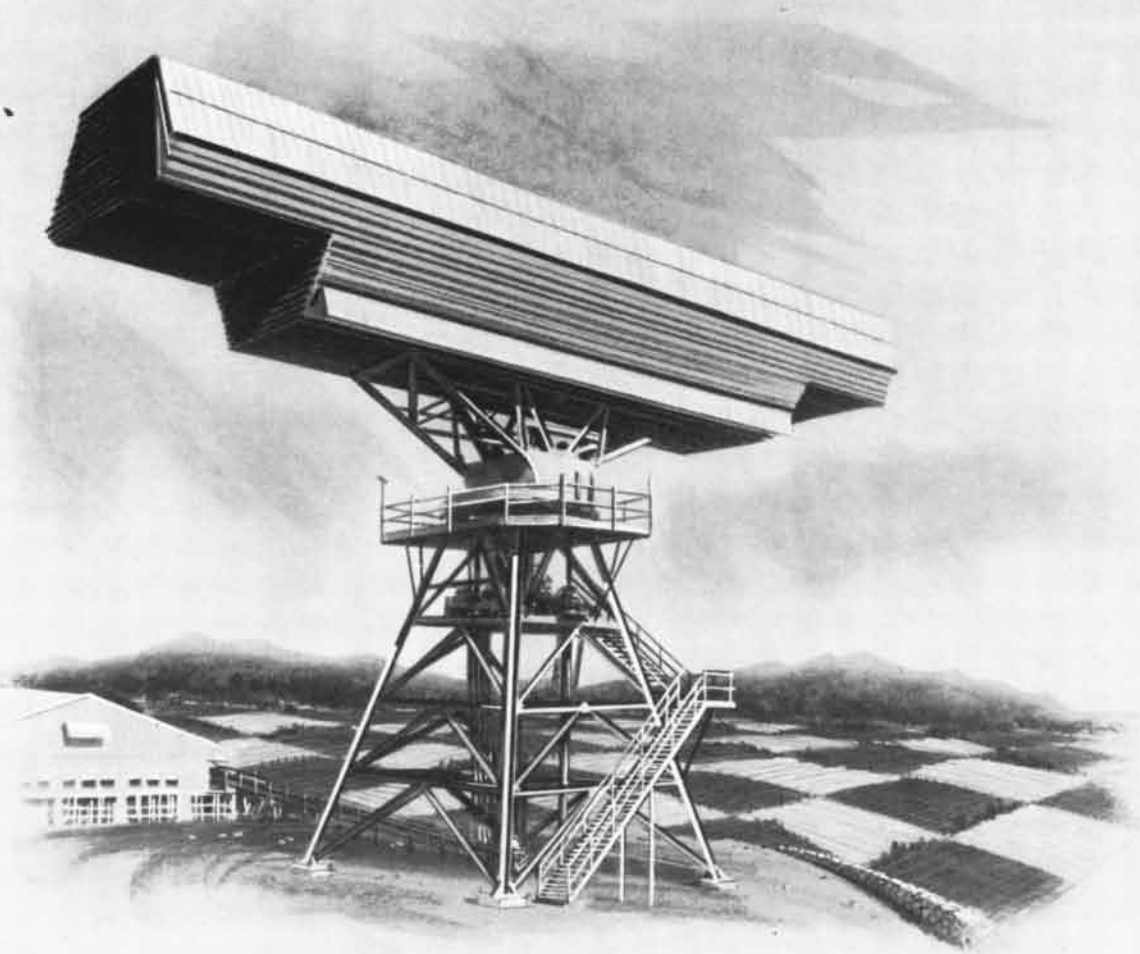
This was a remarkable and highly controversial conclusion because it contradicted what Aristotle, the Scholastics and Descartes had said about the impossibility of a vacuum. When the mercury that had originally filled it sank in the tube, what remained in the vacant space? Nothing, said Torricelli; but, said Descartes, nothing can be filled with Nothing. If any portion of the tube were truly empty, it would instantaneously collapse. Pascal, excited by Torricelli's discovery, decided to make his own experiments to extend it. Rouen had the best glassworks in Europe; Etienne had money to pay for the research; Petit had the engineering experience; Blaise had the enthusiasm. With glass tubes of different lengths, breadths and shapes (two were 46 feet long and were bound to ship's masts to strengthen them) he was able to show that the space vacated by the falling liquid was indeed a void. Neither rarefied air nor mercury vapor, as the "plenists" desperately asserted, was to be found in the vacant space. He varied the apparatus; he invented the plunger-type syringe to serve as a vacuum pump; he gave sensational public demonstrations with five-story-high siphons before 500 of the city's Eminences. All his ingenious experiments gave a consistent result: For a given liquid the height of the column in the tube was always the same; it was unaffected by the space at the top; it was not being sucked up from above but must be pressed up from below and from outside.

He now had in mind the writing of a treatise on the vacuum, and for this purpose other experiments were needed. Momentarily, however, he was diverted by a religious crisis.

It was occasioned, as Mortimer tells us, by an accident to Pascal's father. On a night in January, 1646, Etienne hastened out of doors to prevent a duel, slipped on ice and dislocated his hip. First aid was given by two "reformed characters," brothers named Deschamps who had been converted by a pious curé of a Rouen suburb and were devoting their lives to good works, "especially the good work of bone-setting, at which they were adept." The example of their charity and fervor awakened religious feelings in the whole Pascal family. Each was deeply stirred, and each responded in character. Etienne decided the time had come to look to his spiritual progress; Gilberte and her husband became "consistently devout"; Jacqueline moved closer to the decision of giving herself entirely to the religious life. Blaise's response was "more enigmatic." He immersed himself in theological tracts and began serious study of the Bible. His letters begin to show that he was "aflame with religious zeal." "Corporeal things," he wrote Gilberte, "are nothing but an image of the spiritual, and God has represented the invisible in the visible." Undoubtedly he was in conflict with himself over his scientific interests. They were "morally dangerous" in the eyes of the Deschamps brothers, "as leading to intellectual pride and distracting the attention from the quest of salvation" and of dubious value. But the realist and the lover of natural philosophy could not bring himself to renounce his experiments. He had undergone a crisis, and had turned in a direction that he would never abandon, yet the years 1648 to 1654 were to be his most fruitful and triumphant period of scientific discovery.

In 1647 he fell seriously ill, the diagnosis being "overwork." He was medically advised to avoid all intellectual exertion and to seek relaxation in society. (His physician was obviously a realist.) He retired to Paris with Jacqueline as his housekeeper and secretary. Soon he was back at his experiments and working on his *New Experiments Touching on Vacuum*. Descartes visited him in Paris and they discussed Torricelli's work. A couple of months later Pascal arranged to have his brother-in-law conduct an experiment on the Puy-de-Dôme, a mountain near Clermont, to determine whether a column of mercury would stand higher at the base of the mountain than at the summit. The results were conclusive, and the way was open for hydrostatics and hydrodynamics.

He sketched two treatises: *The Great Experiment on the Equilibrium of Liquids* and *On the Weight and Mass of Air*, neither of which was published till after his death. The pressure of the air was, he saw, a clue to a more general law of the behavior of "liquids" (including gases). His experiments led him to a startling principle. Pressure, it appeared, exerted at any place on a fluid in a closed vessel is transmitted undiminished throughout the fluid and acts at right angles to all surfaces. Suppose two tanks of equal size are filled with water and joined by a pipe at the base; obviously the water in the tanks will be in equilibrium, like equal weights in the pans of a scale. But suppose one tank is



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100 times larger than the other? The water will still be in equilibrium. As Pascal explained, by putting into each tank a piston that fits it exactly, "a man pushing on the small piston will exert a force equal to that of one hundred men who are pushing on the piston which is one hundred times as large. . . . It may be added, for greater clearness, that the water is under equal pressure beneath the two pistons; for if one of them has one hundred times more weight than the other, it also touches one hundred times as many parts of the liquid." From this principle, which leads to anomalies and paradoxes that have puzzled students for years, came the hydraulic press.

"Nothing that has to do with faith can be the concern of the reason." This was the principle Blaise had learned in his boyhood. Some might regard it as even more anomalous than the principle of the behavior of fluids, but he lived by it and worked it into greater fullness. He held his religious beliefs with a growing fervor, but he refused to be "stampeded into a flight from reason." In one of the most famous of his *Pensées* he says: "It is the way of God, who does all things gently, to put religion into the mind by reason, and into the heart by grace."

The period from 1648 to 1653 was one of uncertainty and inner struggle in Pascal's life. His father died, his beloved sister Jacqueline, who had been his closest companion, finally renounced the outer world and entered a convent at Port-Royal. He contemplated marriage, but not very seriously. Bleak and lonely though his life had suddenly become, he was better off single; like Charles Lamb he was one of "nature's bachelors." He did not, however, cut himself off from the salons of Paris society. He was a man of science, but he was also a man of fashion and ambition, besides which he enjoyed "savoring human types." He formed an important friendship with a great nobleman who liked science better than women, the young Duc de Roannez; he lectured to a brilliant assembly in the drawing room of the Duchesse d'Aiguillon, Richelieu's niece, demonstrating his calculating machine and speaking on recent advances in hydrostatics; he sent Queen Christina of Sweden—who had recently finished off poor Descartes by requiring him to expound science and philosophy to her on cold mornings before breakfast—a gift of one of his calculating machines. This was accompanied by a celebrated letter which, though suitably gracious in tone, said in effect: "Your Majesty is a very great person by virtue of your sovereign rank. As we may agree, I am a still greater person by virtue of my sovereign intellect."

His social relaxations did not prevent him from reading and writing. At the very height of this period it is likely that he produced, in addition to scientific essays, a large part of the marvelous *Pensées*, which was not published until after his death. He was also immersed in Montaigne's *Essays*, which filled him with contradictory emotions. He cherished Montaigne's honesty, his hatred of cruelty, his scorn of dogmatism and love of intellectual freedom, his benevolent interest in human nature, "the stoical tranquility he practised and preached in an evil time"; and he admired the incomparable vitality of his style. But the *Essays* also shocked and horrified him. Montaigne had an ironical and detached view of religion. If religion was sublime, it was also celestial; it was heaven's affair rather than man's. Why should one imagine that municipal laws are the laws of the universe? Man is miserably weak, supremely foolish, moved by base passions and vanity. Wisdom and justice are unknown to him. His sages and philosophers are chatterers. He can rely neither upon his senses nor upon his sense. There was no vast difference, says Mortimer, between Montaigne's outlook and Hobbes's view that "the life of man is solitary, poor, nasty, brutish and short." Man, Montaigne said, is the prey of trivial chances. He wrote (in a translation of the time): "A gust of contrarie winds, the croking of a flight of Ravens, the false pase of a Horse, the casual flight of an Eagle, a dreame, a sodaine voyce, a false signe, a mornings mist, an evening fogge, are enough to overthrow, sufficient to overwhelme and pull him to the ground." And if it be urged in mitigation that, despite man's wretched condition and contemptible character, he has religion, the reply is yes, he has the religion that chance flung in his way: "Man cannot make a worm, but he makes Gods by the dozen."

In Sainte-Beuve's phrase, Montaigne became anchored in the soul of Pascal. He would not follow where Montaigne beckoned, but he could not turn away from him. This dilemma, centered on one man, was the epitome of the crisis of Pascal's entire outlook, of his doubting faith, his troubled convictions, his fluctuating commitments.

In 1653 Pascal made a trip to Poitou with the Duc de Roannez. One of the party was the Chevalier de Méré, a member of the great house of Condé, a soldier, scholar, skeptic and "cultivated libertine." To this man the world owes a debt made up of strangely incongruous parts. Méré was an elegant and skillful writer; Pascal's style, says Mortimer, attained "its complete freedom from affectation and verbiage" from Méré's teaching. The other part of the debt is more intriguing and important. Méré was a gambler, and the occasion arose, shortly after the journey to Poitou, for him to ask Pascal to solve two problems of practical use to gamblers. Pascal had for some months been disaffected and weary, preoccupied with his soul. On his return to Paris, however, he began to settle his estate, to buy property, to renew his efforts to sell his arithmetical machine, and before long his scientific interests, touched off by Méré, "awoke from a long sleep." The first problem was: "When one plays with two dice, what is the minimum number of throws on which one can advantageously bet that a double six will turn up?" This was easy for Pascal; 24 throws would be a bad bet; 25, a good one. The other question was harder.

Two players have agreed that the stakes will go to the one who first wins three games. Before this happens their play is interrupted. How, under different circumstances, are the stakes to be divided? Pascal found an ingenious and simple answer. Suppose A has won two games and B one, and the stake is 16 pistoles. In that case A should receive 12 pistoles and B four. Pascal reasoned as follows: Assume that one more game could be played. If A won it, he would be entitled to the full 16 pistoles; if B won it, at that point he could claim half the stakes. So when only three games have been played, A can say to B: "Win or lose the next game, I have at least eight pistoles due me. That leaves the other eight for the next game, in which the chances are equal, so if we cannot play the next game, we divide equally, and I get four." Pascal worked out the other cases. He sent his solution to Pierre de Fermat in Toulouse, who had got the same results by algebraic methods. Pascal was very pleased. "I see," he wrote, "that the truth is the same in Toulouse and in Paris." The independent work of both men laid the basis of the mathematical theory of probability. (Girolamo Cardano had anticipated some of their results in the preceding century, but his book on the subject lay unnoticed.)

Pascal's success in solving Méré's problems stimulated him to further study of the mathematical theory of chance. One of his brilliant ideas was the arithmetical triangle, a capsule of the calculus of probabilities. Pascal flung himself into this work with immense energy;

it was his way when his interest had been roused to tackle a subject—physics, theology, mathematics, even business—in a frenzy, as if nothing else mattered, as if time were running out. His program was unbelievably ambitious. He proposed to write treatises on the theory of numbers, on the equilibrium of liquids, on the arithmetical triangle; to write papers on magic squares, on circles, on conic sections, on perspective; and "to reduce to an exact art, with the rigour of mathematical demonstration, the incertitude of chance, thus creating a new science which could justly claim the stupefying title: the geometry of hazard."

Of this fantastic plan only a small part came to fruition. Its grandiosity marked his desperation. He had to keep going, to drive himself, whether in high society or high science, so as not to be alone with his dark thoughts. He was "a made man and a celebrity," yet he was a tormented man. He doubted his God; he felt empty and lost.

On November 23, 1654, he experienced another intense religious episode, "a timeless eternal moment." Immediately after his vision he wrote at headlong speed an account which, together with a parchment copy, was found after his death, sewn into his doublet. His life from then on was changed. Prayer and sacred study were his main concerns. He never again attached his name to any of his writings ("an evident discipline against vanity"); he withdrew more and more from society. His health began to deteriorate. For a brief period he entered a retreat of the Port-Royalists. Doctrinal questions fevered him. We are "tied and bound with the chain of our sins," but does this mean there is no hope, that the truth is beyond us? He thought not; there is a function for the human will, a way to salvation; it is not as prideful as the way of Epictetus, nor as limited as the way of Montaigne. Out of the quarrel between the assignment of moral power and moral weakness Pascal drew a synthesis: "Faith teaches us to assign these two inclinations to different things: infirmity to human nature, but power to grace."

I shall not follow him in his career as a pamphleteer. His famous anti-Jesuit *Provincial Letters* are a mixture of tedious theological claptrap, moral grandeur, humor and irony. They are masterpieces of polemical literature; even Voltaire, who despised everything about Pascal, found the wit of the letters a match for Molière's finest comedies. The *Provincial Letters*, the background of the dispute that occasioned them, the history of Port-Royal, and Pascal's relation to

Jansenism are all well described in Mortimer's excellent book.

In the years that remained, Pascal neither entirely abandoned science nor renounced fashionable society, though religious questions were uppermost in his thoughts. He wrote his *Spirit of Geometry*, a philosophical essay that, in Mortimer's view, is Pascal's equivalent of Descartes' *Discourse on Method*. He greatly advanced knowledge of the mathematics of the cycloid. One night, awakened by a violent toothache, there came, as his sister Gilberte tells it, "uninvited into his mind some thought on the problem of the roulette [*i.e.*, cycloid]." A whole crowd of thoughts followed. He determined the area of a section produced by any line parallel to the base, the volume generated by it revolving around its base, and the centers of gravity of these volumes. Anonymously he sent out a challenge to all mathematicians to solve these problems; entries came from Christiaan Huygens, Christopher Wren, John Wallis and others. No one matched Pascal's solutions which, when published, caused a sensation, not only as an intellectual feat but also because he stirred up old and bitter scientific quarrels. He did not attach his name to the publications, but there was no doubt who was the author.

Now at last—this was 1659—he "bade a final farewell to the glories and quarrels of science." This may be the moment "at which he began to wear next his skin an iron belt with small spikes which he pressed at any temptation to pride." As his health deteriorated he became a solitary and an ascetic. He gave up his carriage and horses, his tapestries, even his books—"except the Bible . . . and (surely) Montaigne." He found it difficult to eat and could take only liquids.

He wished once more to meet with his friend Fermat, but he was not strong enough to make the journey even to a midway point. His letter to Fermat explaining why he could not come gives a moving self-portrait. "I find geometry the noblest exercise of the mind, yet I know it to be so useless that I see no difference between a geometer and a clever artisan. I call it the loveliest occupation in the world, but only an occupation. . . . A singular chance about a year or two ago did set me at mathematics, but having settled the matter I am not likely ever to touch the subject again."

He was dying. He had resigned himself and was waiting upon God, filling a page of the *Pensées* when he could. Yet in the midst of his departure came an almost comic interlude. Suddenly he immersed himself in the formation of the first omnibus company, which soon ran its first line from the Porte Saint-Antoine to the Luxembourg Palace. It was a far more profitable venture than his calculating machine. He gave the money to charity and bequeathed half his interest in the company to the hospitals of Clermont and Paris.

In June, 1663, he was attacked by terrible headaches. Convulsions followed. On August 18 he died, aged 39.

Mortimer has made Pascal understandable. But perhaps, after all, "realist" is not the best word for him. He had many gifts; he was many things. He was divided as experience itself is divided; he was uncertain in an uncertain world. His scientific achievements were extraordinary, yet it is in the *Pensées* that he achieved supremely. He had a profound sense of man's loneliness, of his terror of nothingness and longing to find his place in a vast, indifferent universe; and an exquisite way of transfixing truth, of making anguish stand still, of speaking the questions that men have asked since the beginning. No one, neither scientist nor philosopher, neither rationalist nor mystic, has transcended his insight into man's condition:

"For after all what is man in nature? A nothing in relation to infinity, all in relation to nothing, a central point between nothing and all, and infinitely from understanding either. The end of things and their beginnings are impregnably concealed from him in an impenetrable secret. He is equally incapable of seeing the nothingness out of which he was drawn and the infinite in which he is engulfed."

Children's Books

MAN-MADE SUN, by J. D. Jukes. Abelard-Schuman ($2.75). At last, a thoroughly good popular book on physical science, so knowledgeable, so well written and so free of condescension that adults will get as much out of it as teen-agers. Primarily this is the story of Zeta, the British machine for achieving very high temperatures as a first step toward fusion power; but the author, a research engineer at the British Atomic Energy Research Establishment, prepares the ground by giving an admirable account of the fundamentals of electricity and electric power, of the structure of atoms and nuclei, of nuclear physics, of fission and fusion. He has a remarkable facility for straight talk and lucid, metaphorless exposition; he takes apart a very complex problem and never for a moment forgets that his readers are not specialists, cannot be driven too hard and must be gently led. The result is fascinating. We should have more books by John Jukes.

ISAAC NEWTON: PIONEER OF SPACE MATHEMATICS, by Beulah Tannenbaum and Myra Stillman. McGraw-Hill Book Company, Inc. ($3). The subtitle is absurd and vulgar, as if Madison Avenue had been retained to put the man over, but this is a capable young people's biography of Newton that makes an honest if not very deep-probing attempt to describe his discoveries in mathematics and physics. For readers of 12 and older.

THE WONDERFUL WORLD OF THE AIR, by James Fisher. THE WONDERFUL WORLD OF LIFE, by Julian Huxley. Garden City Books ($2.95 each). These recent additions to an attractive, colorful, large-format series are better than average but suffer by comparison with the best of the earlier volumes, in particular, Lord Boyd-Orr's *The Wonderful World of Food,* reviewed here last December. Fisher uses air as an excuse for soaring through a variety of topics. In 60 pages of pictures and brief text he covers bacteria, airports, the chemistry of gases, music, Benjamin Franklin, bird navigation, volcanoes, algae, anticyclones, flying fish, photosynthesis, squids, insects, paleontology, fungi, bats, sailing, the flight of an arrow, Torricelli, rockets and missiles, von Guericke's experiments, thunderclouds, mine explosions, ballooning, the history of aviation, Lindbergh, commercial air travel, radar, Pascal, comets, da Vinci, Mach number, the anatomy of the lungs, troposphere, Galileo and a hundred other topics. The effect is confusion and mild exhilaration. Huxley's book is more disciplined because it sticks to the story of evolution. It considers how the different forms of life are related, how life changes with time, how it produces its amazing variety, how it advances. Many of the pages are too busy, with arrows darting in all directions, crowded sequences and insets, and the illustrations lean to the lurid, but there is plenty of good stuff for mind and eye. Both books are addressed to teenagers.

THE STORY OF FLIGHT, by John Lewellen and Irwin Shapiro. Golden Press, Inc. ($3.95). From ancient legends to the age of space, illustrated with old prints, photographs, original paintings and drawings. The emphasis on the military aspect of aviation is heavy, but there is no doubt that the appetite for murder has played a large part in turning man's eyes to the sky and propelling him toward heaven. For readers of 12 and older.

THE DISCOVERER OF INSULIN, DR. FREDERICK G. BANTING, by I. E. Levine. Julian Messner, Inc. ($2.95). A well-paced biography for teenagers which describes in considerable detail the scientific researches that brought Banting a Nobel prize and the gratitude of millions of sufferers from diabetes.

HOW PAPER IS MADE, by David C. Cooke. Dodd, Mead & Company ($2.75). From tree to this page. Photographs, straightforward captions. For readers of 10 and older.

THE UNKNOWN OCEAN, by Amabel Williams-Ellis. G. P. Putnam's Sons ($2). Chapters on the adventures and researches of Alain Bombard (across the Atlantic in a rubber raft), Thor Heyerdahl (*Kon-Tiki*), Jacques-Yves Cousteau (aqualung inventor and explorer of old sunken ships), William Beebe and the Piccards (bathysphere and bathyscaph), and others who have helped make the ocean less unknown. For readers from 8 to 11.

THE MOON, by George Gamow. Abelard-Schuman ($2.75). Revised edition of an excellent popularization, bringing matters up to date—but who can keep up with the Russians? For teenagers and older readers.

THEY WANTED THE REAL ANSWERS, by Amabel Williams-Ellis. G. P. Putnam's Sons ($2). The stories of four men who got the answers. "They" are Aristotle, Pasteur, Darwin, Edison. For 9- to 11-year-olds.

PLANTS THAT HEAL, by Millicent E. Selsam. William Morrow and Company, Inc. ($2.50). A short sketch about plants that have medicinal properties. Among the healers are Rauwolfia, ipecac, castor beans, cascara, aloes, psyllium, senna, foxglove, ephedra, Jimson weed, Eucalyptus, Cinchona, opium poppy, coca leaves, Strychnos, henbane, belladonna, ergot, curare—and of course the molds. Miss Selsam tells when and how they were first used, and their status in the pharmacopoeia today. For readers of 12 to 14.

HOW BOATS GO UPHILL, by Roger Pilkington. Abelard-Schuman ($2.50). The story of canal locks, elevators and other lifts to help boats climb. The illustrations are more decorative than elucidative.

WATER, RICHES OR RUIN, by Helen Bauer. Doubleday & Company, Inc. ($3). There are many books on water conservation. This one has nothing to say that has not been said much better, but the photographs, drawings and diagrams, of which there are many, tell the story well for 8- to 10-year-olds.

MATHEMATICS, by Irving Adler. Golden Press (50 cents). Fifty colorfully and imaginatively illustrated pages containing a remarkable amount of mathematical information. Snapshots of the origins of mathematics; the history of written numbers; the meaning of rectangular, triangular, square and cubic numbers, and of primes; Fibonacci series; the anatomy of triangles; the Pythagorean theorem; *pi*; polygons; mathematics in nature; equations; navigation; coordinate axes; probability; Pascal's triangle; slide rules; computers; mathematics and music; mathematics and art; card tricks; magic squares. Adler does not give more than a couple of pages to each of these, yet he manages to explain fundamentals and to whet the reader's appetite for more. A tour de force. For readers of 12 and older.

MEN, MOSS AND REINDEER, by Erick Berry. Coward-McCann, Inc. ($2.50). An introduction to Lapland: the life of the people, the character of the country and climate, the story of the reindeer herds. Modest and informative. For ages 10 to 14.

THE QUEST OF GALILEO, by Patricia Lauber. Garden City Books ($2.50). The merit of this short biography of Galileo is its clear exposition of the fundamentals of his studies in motion and mechanics, and his work in astronomy. Good diagrams. A nice entry into the subject for a thoughtful 12- to 14-year-old.

WORDS OF SCIENCE, AND THE HISTORY BEHIND THEM, by Isaac Asimov. Houghton Mifflin Company ($5). The purpose of this portmanteau of words, from absolute zero to zodiac, is to entertain. It contains an assortment of historical, etymological, biographical, anecdotal and scientific tidbits. Information about the word zero (from the Arabic word *sifr*, meaning empty), oxygen (meaning "that of which a sharp taste is born"), cobalt (from the German *kobold*, an underground spirit), ion ("going" in Greek), influenza ("influence" in Italian), gas (from the Greek "chaos"), ellipse ("defect" in Greek, *i.e.*, a defective circle), bowels (from the Latin for "little sausage"), cortisone (short for 11-dehydro-17-hydroxycorticosterone), and so on. Dinner-table conversation for teenagers and adults.

DISCOVERING CHEMISTRY, by Elizabeth K. Cooper. Harcourt, Brace and Company ($3). Miss Cooper tells how to set up your own home laboratory, lists the simple, inexpensive apparatus you will need, describes 30 common chemical elements to be found in household items and ordinary, easy-to-get things, introduces the structure of atoms and molecules, discusses the principles of chemical reactions and gives precise instructions for performing a wide variety of non-dangerous experiments. She writes clearly and has a sure feeling for a youngster's curiosity as well as the limits of his patience. (There is nothing more dismaying to the parents of young chemists than half-finished, overambitious experiments whose remains are apt to tincture the stew.) An excellent, helpfully illustrated primer for 12's and older.

THE NEW MATERIALS, by Gerald Leach. Roy Publishers ($2.50). A brief, illustrated account of new metals, plastics and other materials introduced by modern technology. Good for readers of 12 and up.

THE FIRST BOOK OF MAPS AND GLOBES, by Sam and Beryl Epstein. Franklin Watts, Inc. ($1.95). For 10- to 12-year-olds, the different kinds of maps, how to read them, their uses, the meaning of various symbols and scales, how maps are made, the concepts of latitude, longitude, great circle, meridian and so on.

ALL ABOUT THE ICE AGE, by Patricia Lauber; ALL ABOUT PREHISTORIC CAVE MEN, by Sam and Beryl Epstein; ALL ABOUT ARCHAEOLOGY, by Anne Terry White. Random House ($1.95 each). New members of a series designed for 10- to 14-year-olds and well received by them. Miss Lauber sometimes finds it hard to nail down her point but she succeeds in giving a sound account of the causes, history and effects of the most recent ice age. Her chapters deal with the pioneer glacier-studies of Louis Agassiz, life in the ice age, paleontological research, modern exploration of glaciers, the "greenhouse" effect, continental drift and polar wandering, the Ewing-Donn theory of the meteorological cause of ice ages. The Epsteins spin off the well-worn stories about Peking man, the tooth found in the Chinese druggist's shop, ancient stone tools, Neanderthalers, Cro-Magnons, the caves of Altamira and Lascaux. The information is accurate, but other books accessible to this age group cover the field better. Miss White does the able job one expects of her in this sort of sketch, which has to cover a broad subject quickly without making the reader feel rushed. She explains the evidence archaeologists look for, the work they do, how they interpret what they find and piece together their results. Her examples include the discoveries of Boucher de Perthes, the exploration of Neanderthal burial caves, the uncovering of Etruscan tombs, Heinrich Schliemann's digs in Troy, Arthur Evans's labors at Minos, the tomb of Tut-ankh-amen, and Sumerian, Aztec, Mayan and Inca remains.

PEOPLE AND PLACES, by Margaret Mead. The World Publishing Company ($4.95). Though she is a highly competent anthropologist and can write well, Miss Mead has never learned how to be brief and direct. In this book, however, which touches on a rich variety of ideas and topics, and which is properly discursive, her weakness as an expositor is her strength. She ambles hither and yon, drawing effectively on her wide experience and knowledge, and succeeds in imparting a better general notion of the community of man than a teen-ager is likely to find in any other single book. Her survey is in three parts. The first deals with man's discovery of man: his curiosity about those different from himself, his coming together with others by travel and trade, the work of the anthropologist. The second describes how some peoples live: the Eskimos, the Plains Indians, the Ashanti of West Africa, the Balinese, the Minoans of Crete. The third considers what men have contributed to each other: their essential interdependence; the steps that must be taken to improve the conditions of great numbers of people, to make better use of the world's resources, to guard against the possibility of suicidal wars. An admirable, exceptionally interesting and elevating book. For teen-agers.

PUSH AND PULL, by Paul E. Blackwood. Whittlesey House ($3). About solar energy, mechanics, chemical energy, electricity, radiant and nuclear energy. The facts are correct; the presentation is pedestrian; the illustrations are insipid and inadequate.

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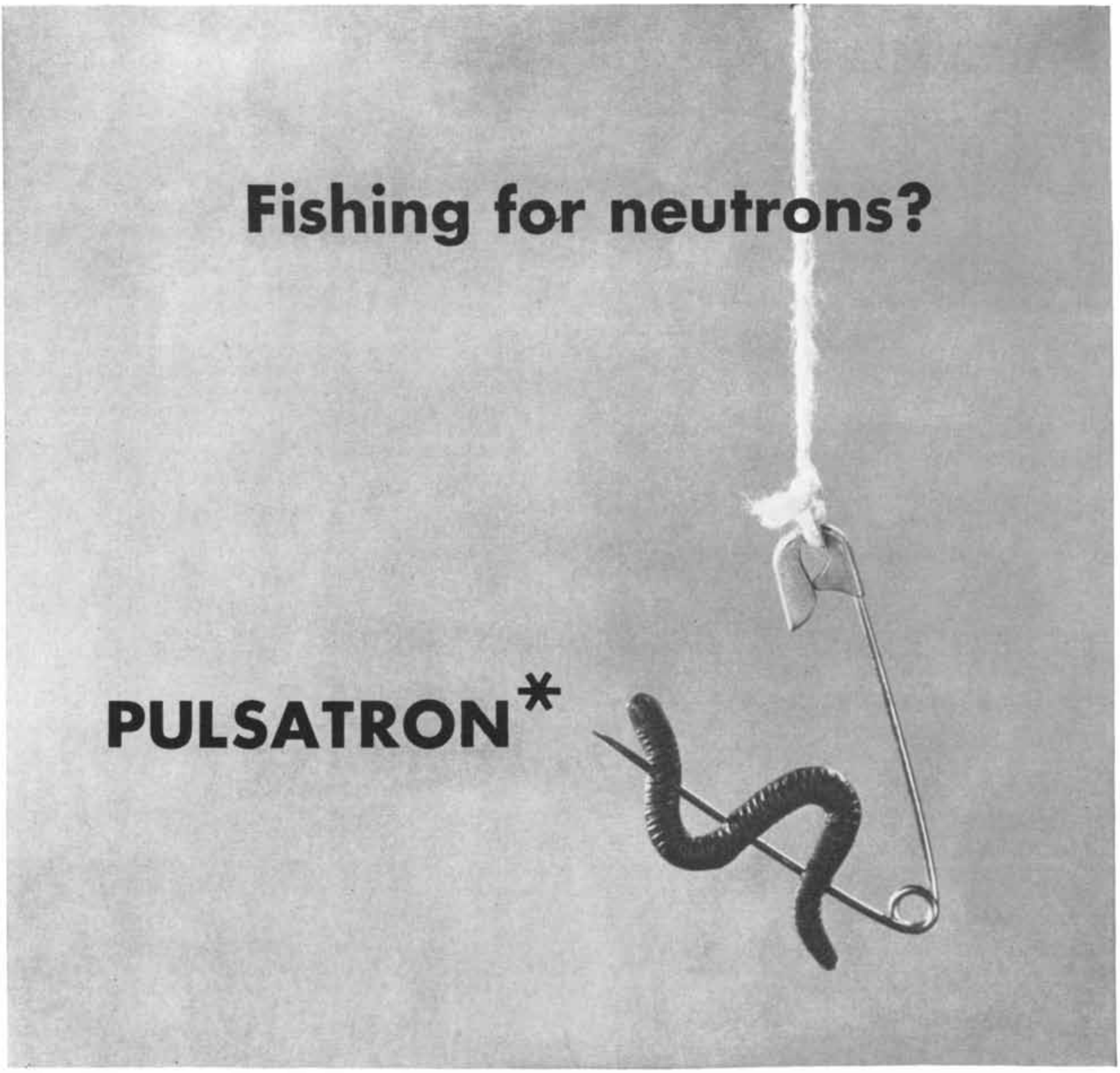
Fishing for neutrons?
PULSATRON*

ANNUAL INDEX

The following index lists all the articles and authors that appeared in Scientific American *during 1959. The index also lists the principal book review in each issue.*

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