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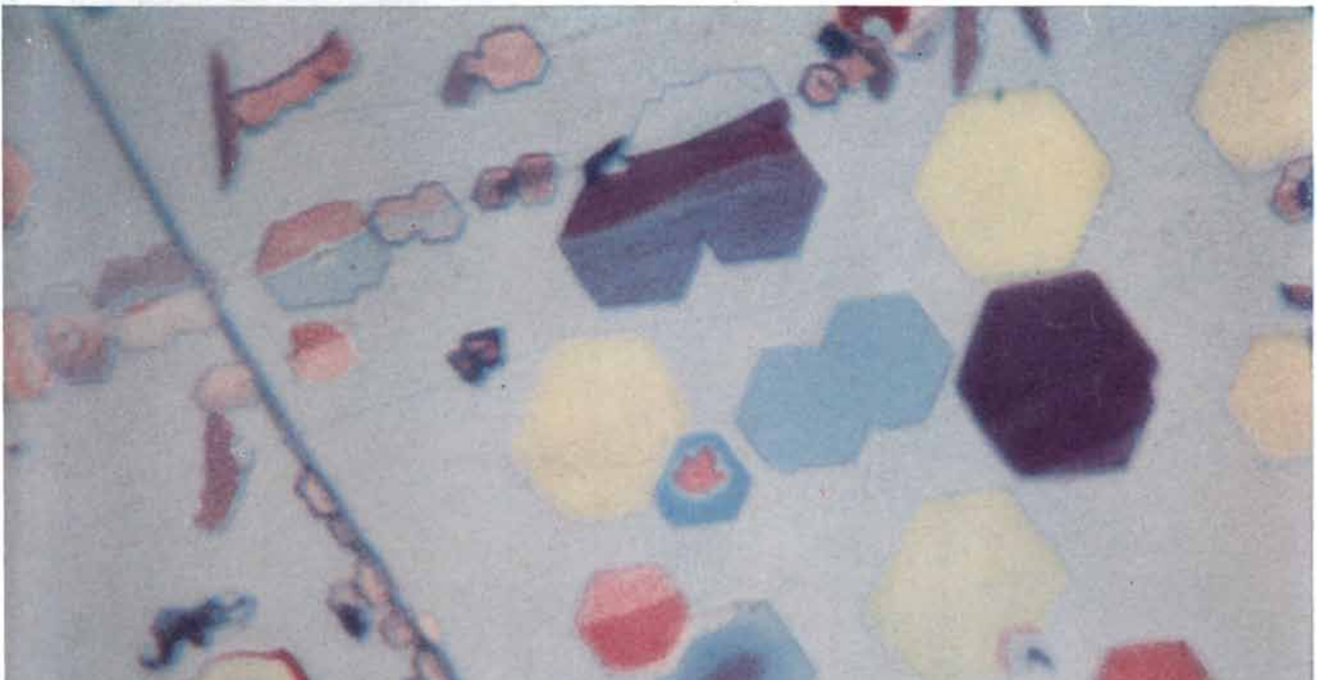

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Established 1845 **SCIENTIFIC AMERICAN** January, 1961 Volume 204 Number 1

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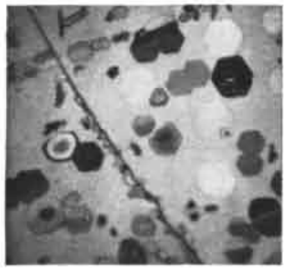

THE COVER

The photomicrograph on the cover shows crystals of ice growing in the laboratory of B. J. Mason at the Imperial College of Science and Technology in London (*see page 120*). The crystals are illuminated by reflected light; their various colors are due to the interference of light reflected from their rear surfaces and light reflected from their front surfaces. Crystals of the same color have the same thickness. Growth rate can be determined by the rate at which colors change. The ice crystals are all growing on the surface of a large single crystal of natural cupric sulfide, or covellite.

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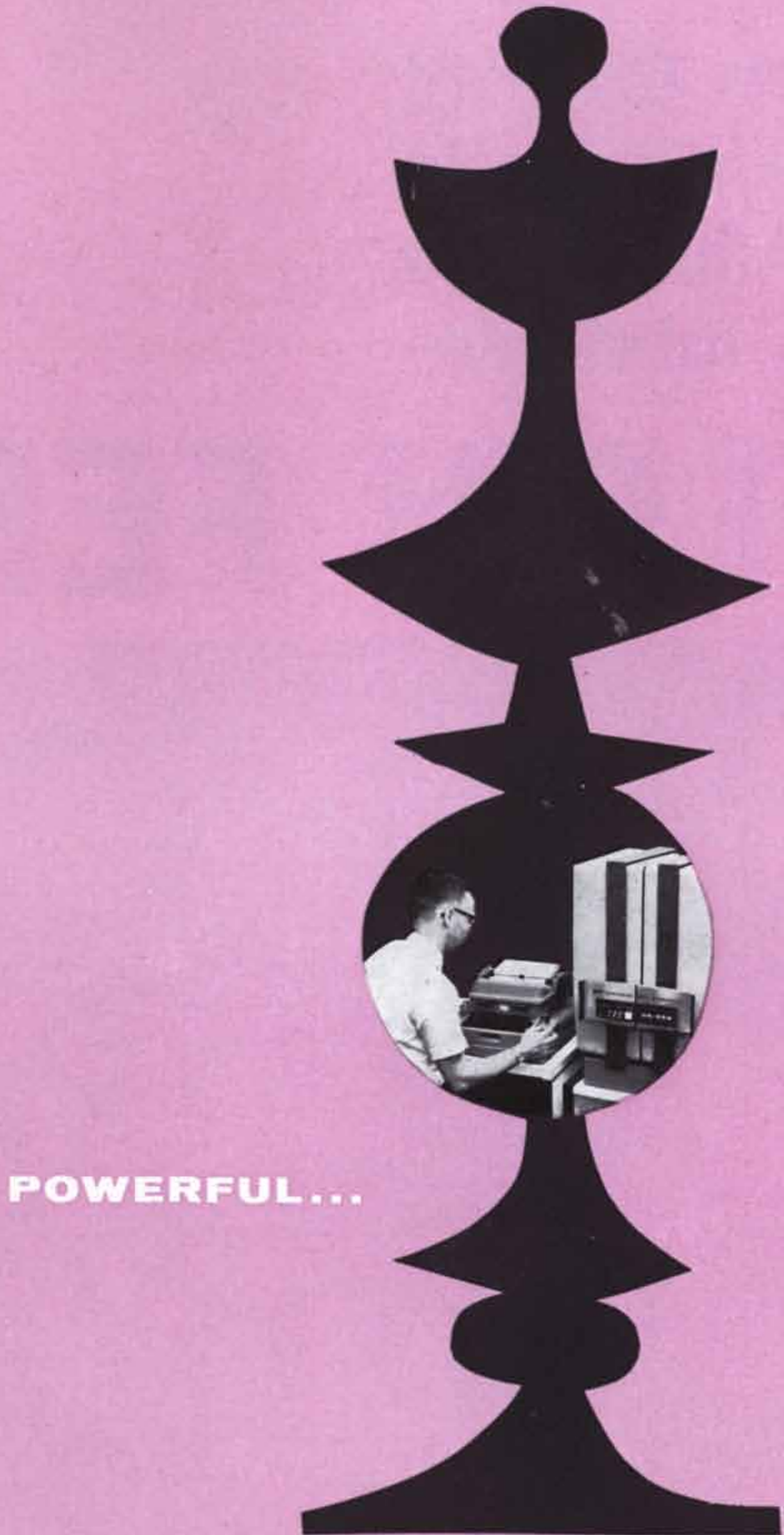

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Ultimate Elongation	300%
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Coefficient of Friction	0.09

ELECTRICAL PROPERTIES

Dielectric Constant	
23°C., 100 cps. to 100 Mc.	2.1±0.1
1000 cps., -40°C. to 225°C.	2.13–2.04
Dissipation Factor	
23°C. 100 cps. to 100 Mc.	.0002—.0007
1000 cps., -40°C. to 240°C.	.0002
100,000 cps., < -40°C. to 240°C.	.0005
Volume Resistivity	
-40°C. to 240°C.	> 10^{17} ohm/cm
Surface Resistivity	
-40°C. to 240°C.	> 10^{16} ohm/sq. unit
Dielectric Strength	
23°C., 60 cps.	
1 mil film	4000 volts/mil
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Surface Arc Resistance (sample melted in arc . . . did not track)	>165 sec.

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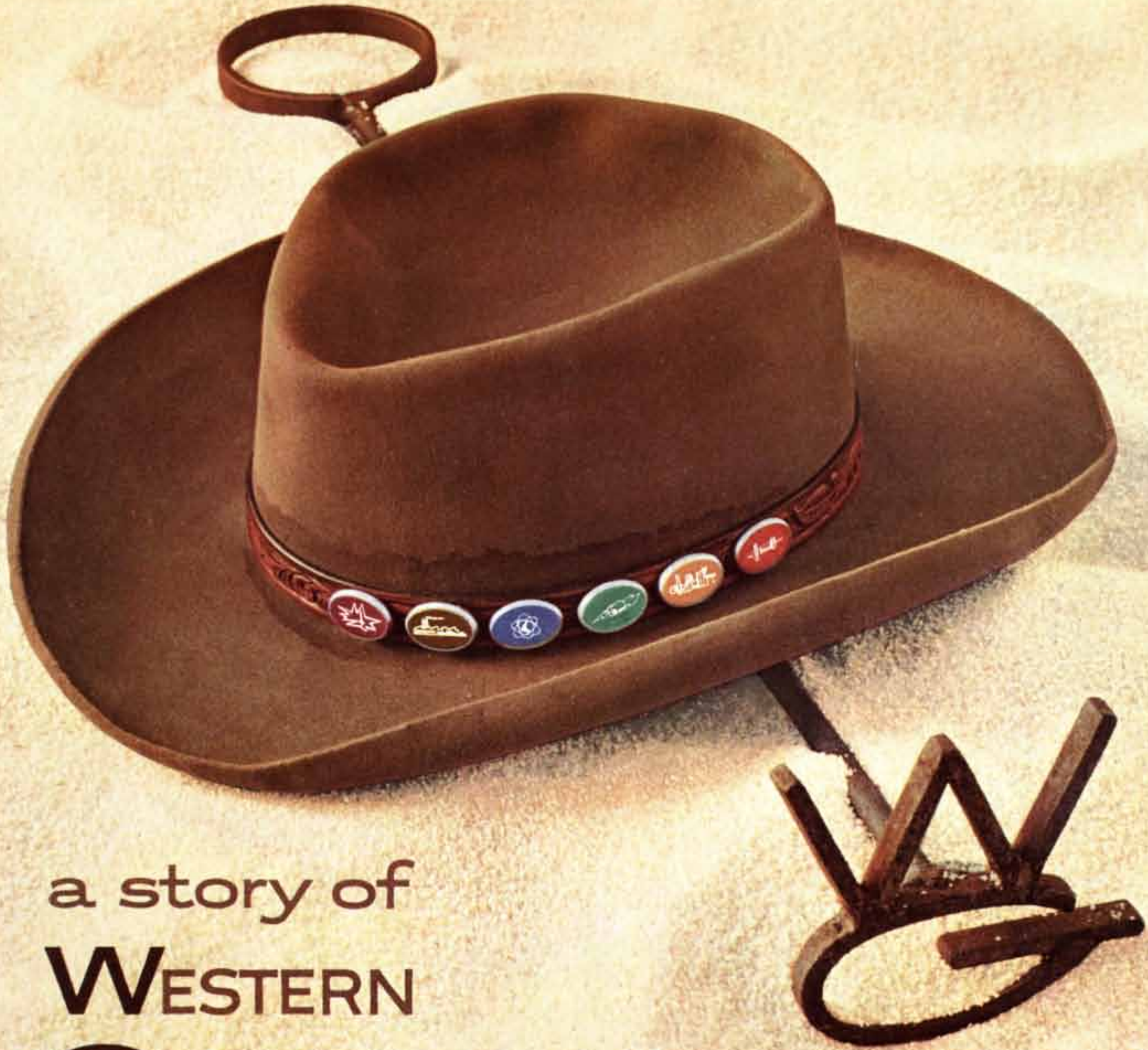

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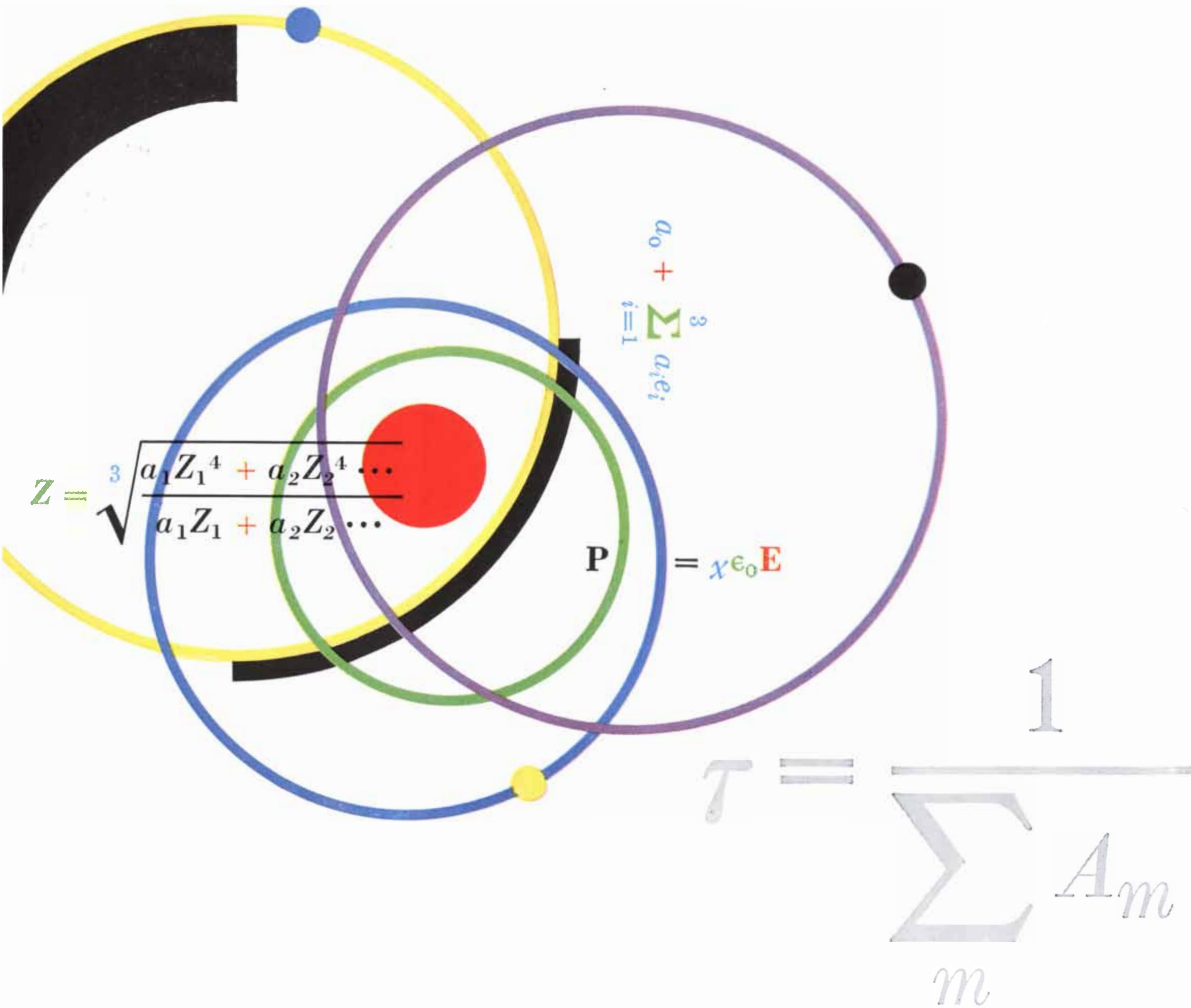

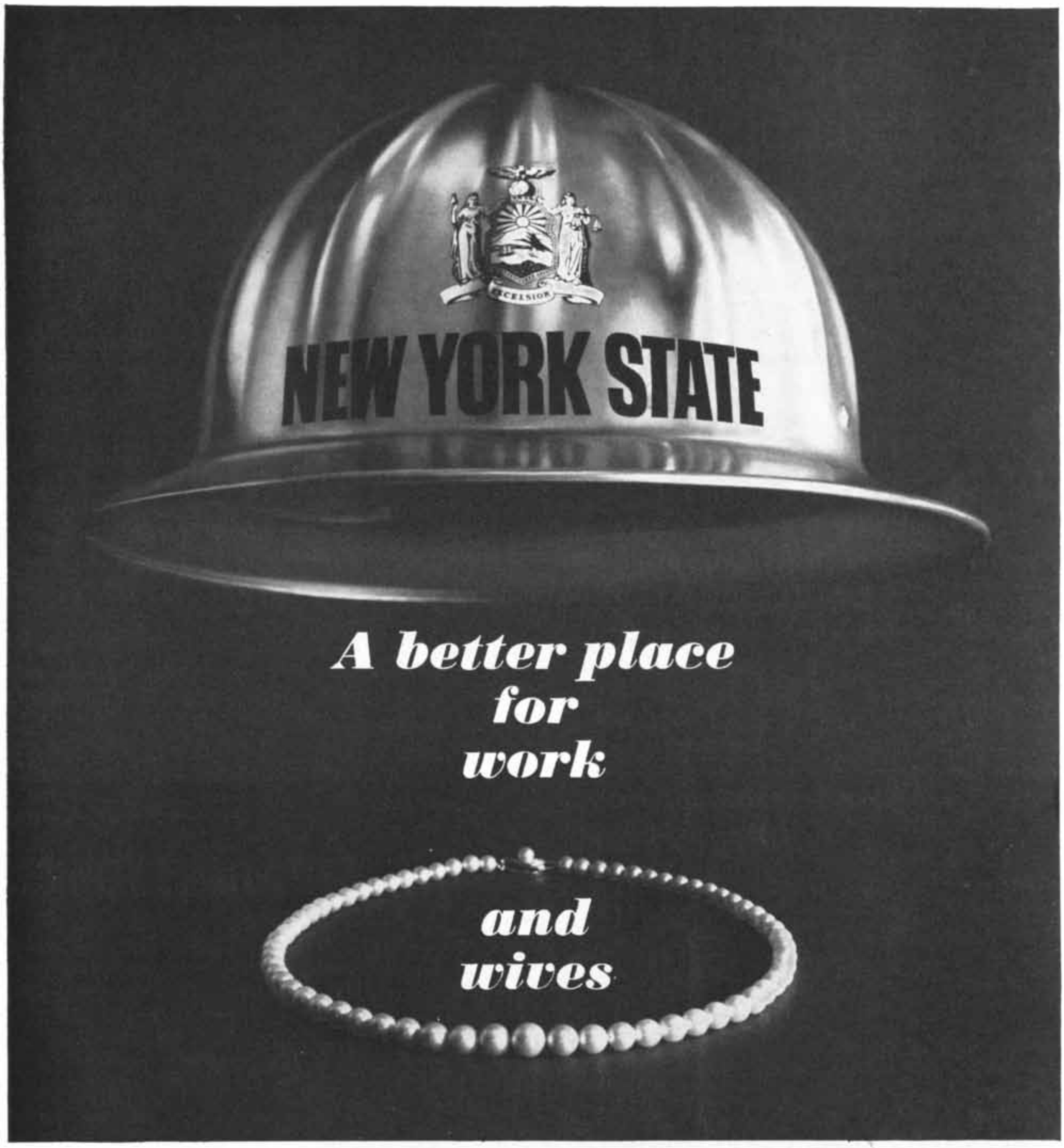
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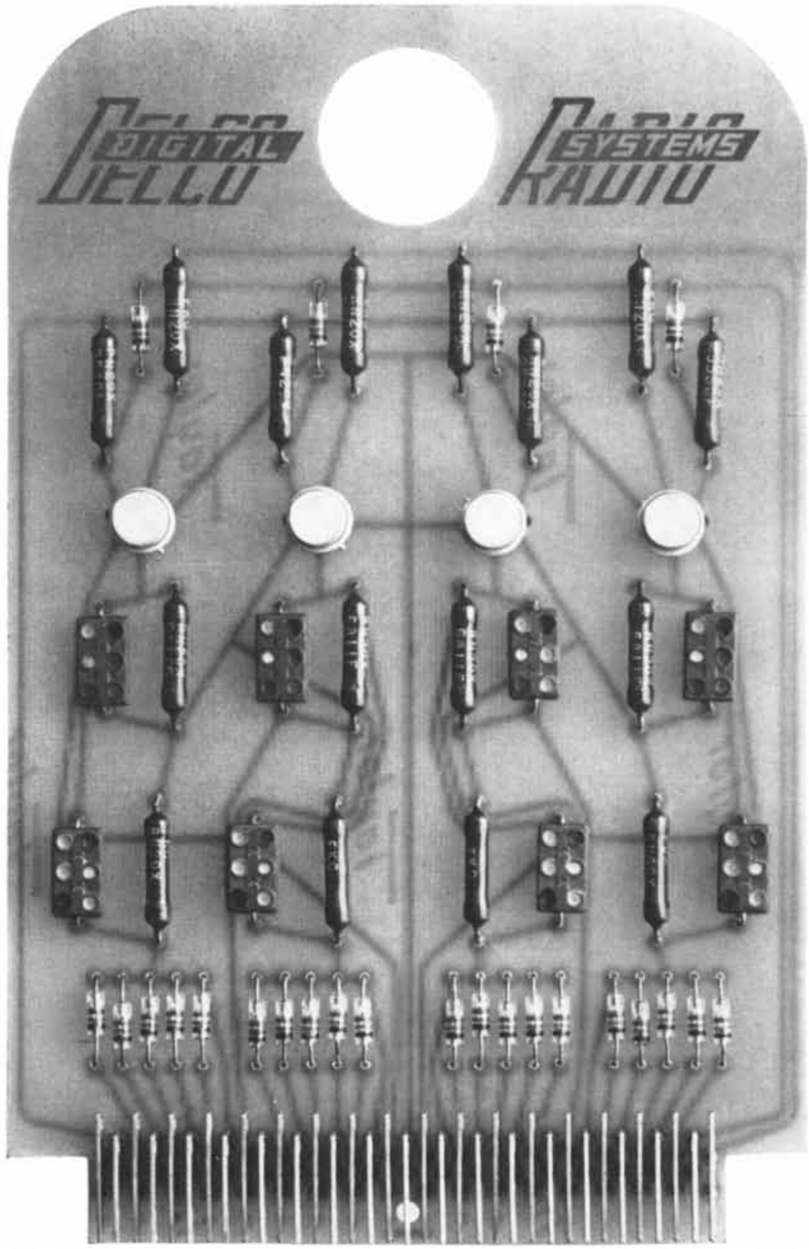

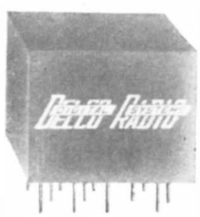

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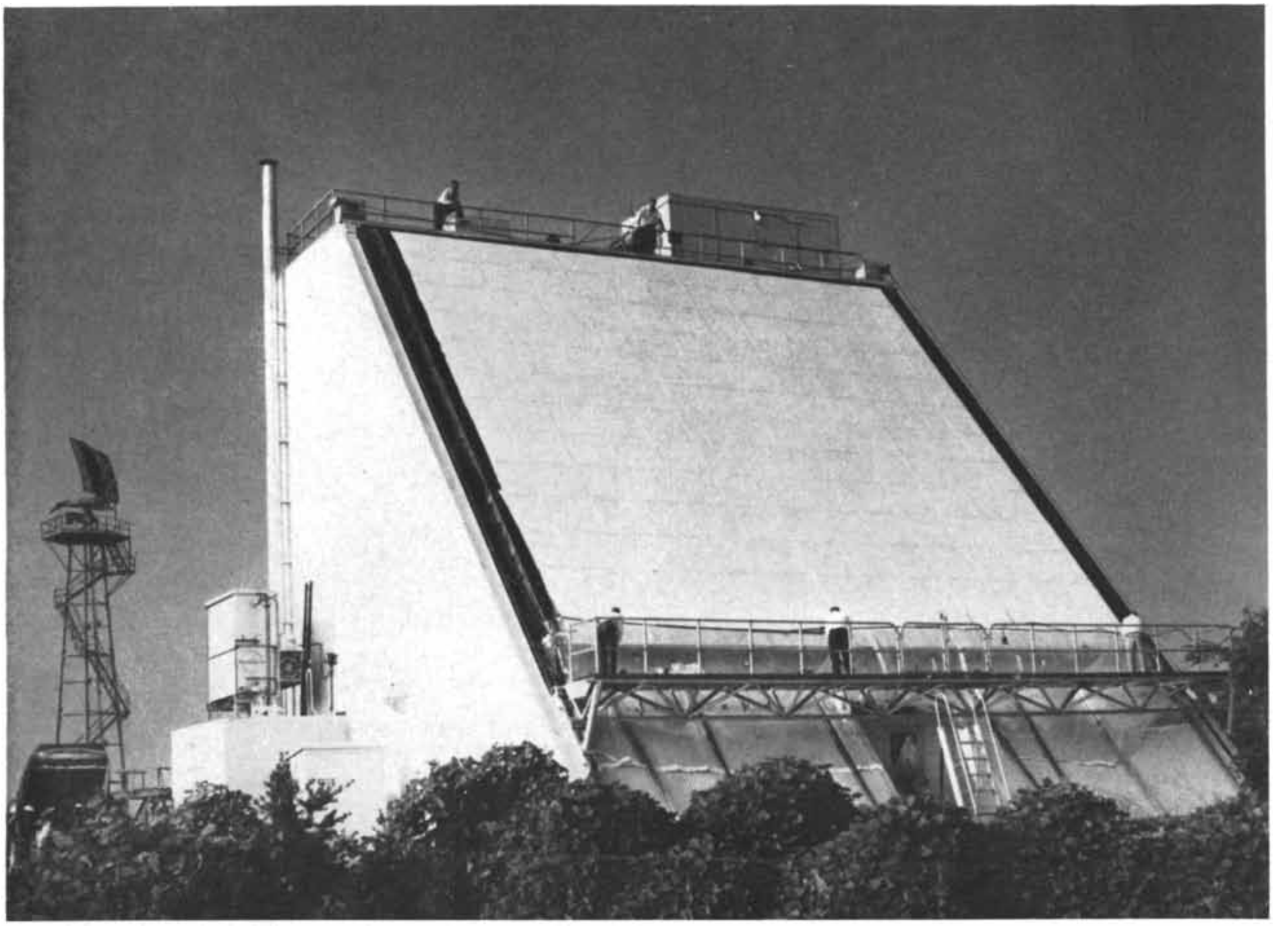


This new type Bendix radar, initiated by the United States Air Force, Rome Air Development Center, and now sponsored by the Advanced Research Projects Agency, Dept. of Defense, is the forerunner of radars promising unprecedented protection. Note how much it differs from conventional radar in background.

THIS ENTIRELY DIFFERENT RADAR PROMISES NEW PROTECTION

You are looking at an entirely different type of radar. One that we believe will, for the first time, be able to spot and track thousands of enemy ballistic missiles simultaneously.

It is known as ESAR (electronically steerable array radar). It contains no moving parts and it differs radically in performance and appearance from conventional radar which has rotating antennas.

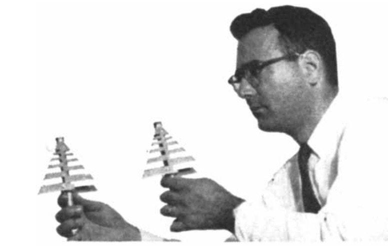
The demonstration model, shown above, is located at our Radio Division, Baltimore, Maryland. Its great five-story face houses nearly 9,000 tiny, individual antennas whose "computer-steered" beams can be electronically shifted from target to target quicker than a wink. It will track rockets fired from the National Aeronautics and Space Administration launching site at Wallops Island, Va., and keep an alert watch on air traffic in the Baltimore-Washington area.

When development is successfully completed, larger ESAR type radars may also be used to keep tabs on thousands of earth-circling satellites, and to track and communicate with space vehicles launched on deep probes to the moon and other planets.

Bendix is a leading producer of all kinds of radar for civilian and military uses. Surveillance stations equipped with our radar include northern early warning installations, others throughout this country, as well as towers at sea and in distant lands—all in all watching over 25,000,000 square miles.

Because Bendix airborne weather radar provides an accurate picture of weather conditions 150 miles ahead, pilots of thirty-three domestic and foreign airlines are able to minimize the effects of storms and thus give their passengers smoother, safer rides. Bendix® Doppler Radar is an airborne navigation system that is adding greater safety to United Airlines overseas flights.

Other Bendix radar devices include: airport surveillance equipment, Ground Controlled Approach radar, radar systems for military helicopters, marine radar, proximity fuses, and TV weather-reporting radar.



ESAR contains nearly 9,000 of these Christmas tree type antennas. "Electronically steerable," they can watch thousands of missiles, aircraft, and satellites simultaneously.

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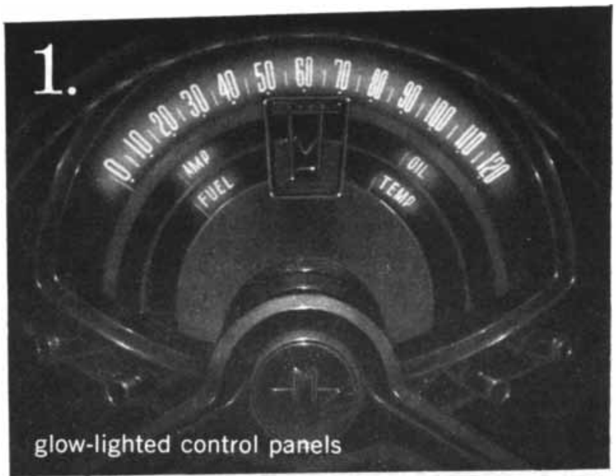

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LETTERS

Sirs:

Many of us here at the Buescher Band Instrument Company read with great interest the article by Arthur H. Benade, "The Physics of Wood Winds," that appeared in the October issue of your magazine.

It has occurred to me that you and your readers might be interested to know that one of the features that Dr. Benade mentioned as being hypothetically possible is incorporated in some of the instruments that we manufacture. In the next to the last paragraph of the article Dr. Benade stated that an instrument maker might provide "a few extra open holes at the bottom of the bore which would be used only as emitters of sound."

We have provided an extra hole in the side of the bell of an alto, a tenor and a baritone saxophone that we manufacture, whose sole function is as an emitter. This hole on these saxophones is not fitted with a key or pad and so remains open at all times, as Dr. Benade suggested might be done.

LYNN L. SAMS

President
Buescher Band Instrument Company
Elkhart, Ind.

Sirs:

Near the close of his review in your September issue of "The Western Intellectual Tradition," by J. Bronowski and Bruce Mazlish, C. P. Snow comments on the nearly simultaneous discoveries of non-Euclidean geometries by Gauss, Lobachevski and Bolyai, as "quite obviously more than a chance."

One need not look far for a cause. In the work of Immanuel Kant, particularly in the *Critique of Pure Reason*, great emphasis is laid on the existence of only one geometry. Kant interprets this uniqueness as due to the fundamental nature of human intellect; in his view it constitutes one of the eternal limitations subject to which we perceive the universe.

Absolute assertions such as this in philosophy have always constituted challenges to scientific investigation. Kant's mathematical contemporaries naturally responded with the appropriate inquiry and investigation. Whether the stimulus came directly from Kant's own work, or from the general philosophical climate of the time in which Kant flourished, is another question.

CHARLES F. RICHTER

California Institute of Technology
Pasadena, Calif.

Sirs:

In "Mathematical Games" for July, Martin Gardner has some speculation about the current length of *pi* which caused me to recall the latest information to come to my attention.

In the February, 1959, issue of *Mathematical Reviews* (Vol. 20, No. 2) J. C. P. Miller of Cambridge, England, reviews a paper by François Genuys which gives *pi* to 10,000 decimals, computed from Machin's formula on an IBM 704 computer.

Miller checked this value against that of G. E. Felton, who had previously worked it out to 10,017 decimals using two methods. (It was Felton's preliminary unchecked results, published in 1957 in *Oxford Mathematical Conference: Abbreviated Proceedings*, which went wrong after 7,480 decimals.) Miller found Genuys in agreement with Felton to 10,000 places.

Since Felton's two values agree with each other and with Genuys', I think we can be reasonably satisfied that *pi* is known to over 10,000 places.

BEN E. DYER

New York, N. Y.

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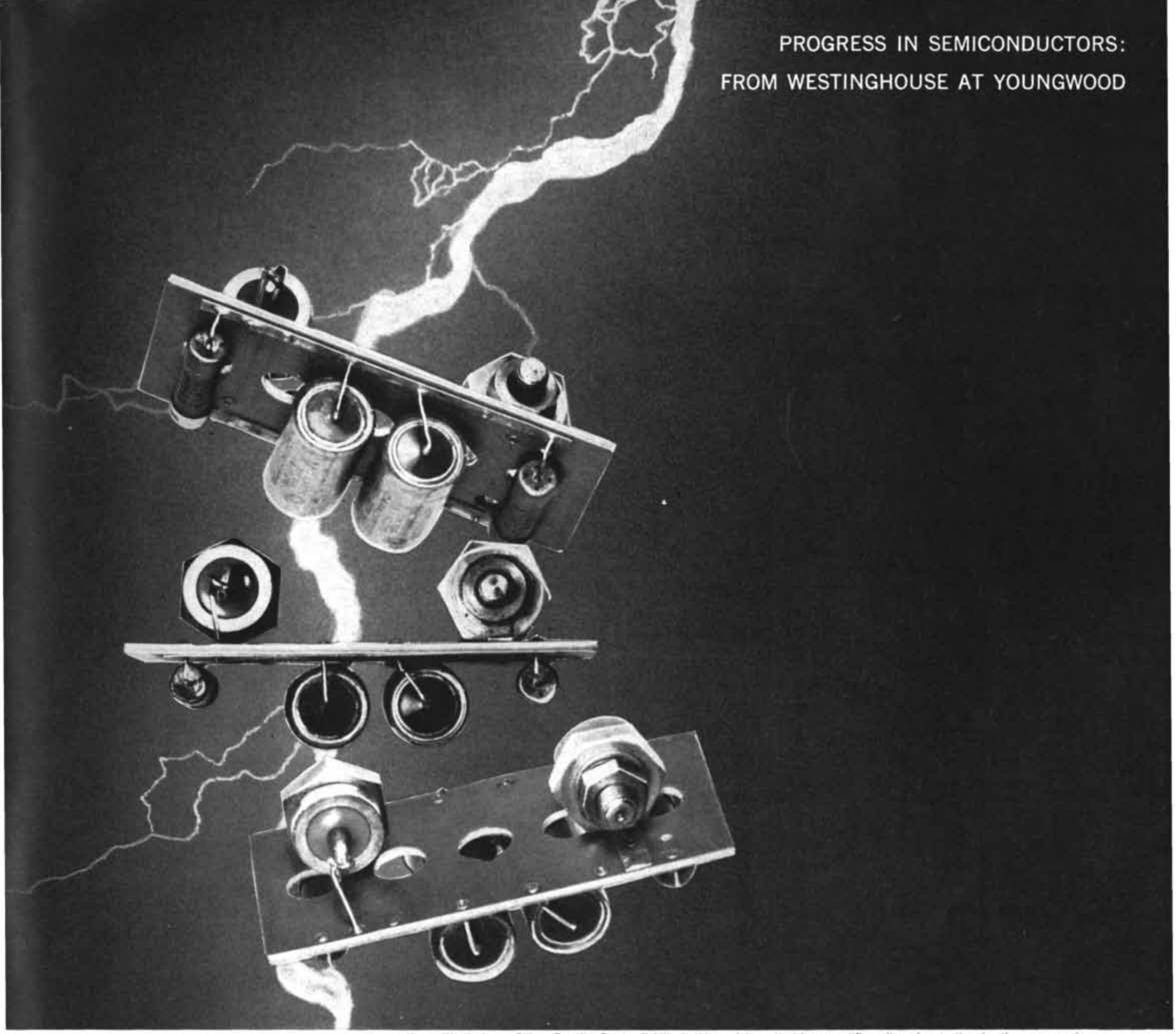

Key to Westinghouse Silicon Rectifier Stack reliability is this modular unit with two rectifier cells and protective shunting components.

The first high-voltage silicon rectifiers with a perfect reliability record

Westinghouse High Voltage Silicon Rectifier Stacks provide high direct-current potentials utilizing the cumulative effect of silicon rectifier cells connected in series. Since these stacks first became available, there has been no record of a single stack failure. Over 20,000,000 failure-free stack-hours have been achieved in a wide variety of industrial applications.

Silicon Rectifier Stacks were introduced to industry a few years ago and began to replace mechanical rectifiers, vacuum tubes, and selenium assemblies. Because of silicon's inherently higher efficiency and unlimited life, this method of rectification seemed to offer great promise. Early applications, however, suffered from mysterious failures. Before entering this field, Westinghouse Semiconductor Engineers initiated a broad investigation which ultimately defined the basic problem—to maintain equal division of both transient and steady state reverse voltages among the series elements. Once the problem was determined, they were able to design modular circuits which successfully provided equal division of reverse voltages under all conditions.

The solution of this problem has resulted in Westinghouse High Voltage Silicon Rectifier Stacks which offer industry the advantages of high efficiency, unlimited life and operation in high ambient temperatures.

These Westinghouse Stacks are presently available in a wide range of current ratings: from 1.2 to 18 amperes; from 9.6 to 35 kilovolts. Their reliability record has been proved in such applications as: electrostatic precipitators; radio broadcasting transmitters; radar transmitters; pulse modulators. For more information, you are invited to call or write: Westinghouse Electric Corporation, Semiconductor Dept., Youngwood, Penna. SC-1018

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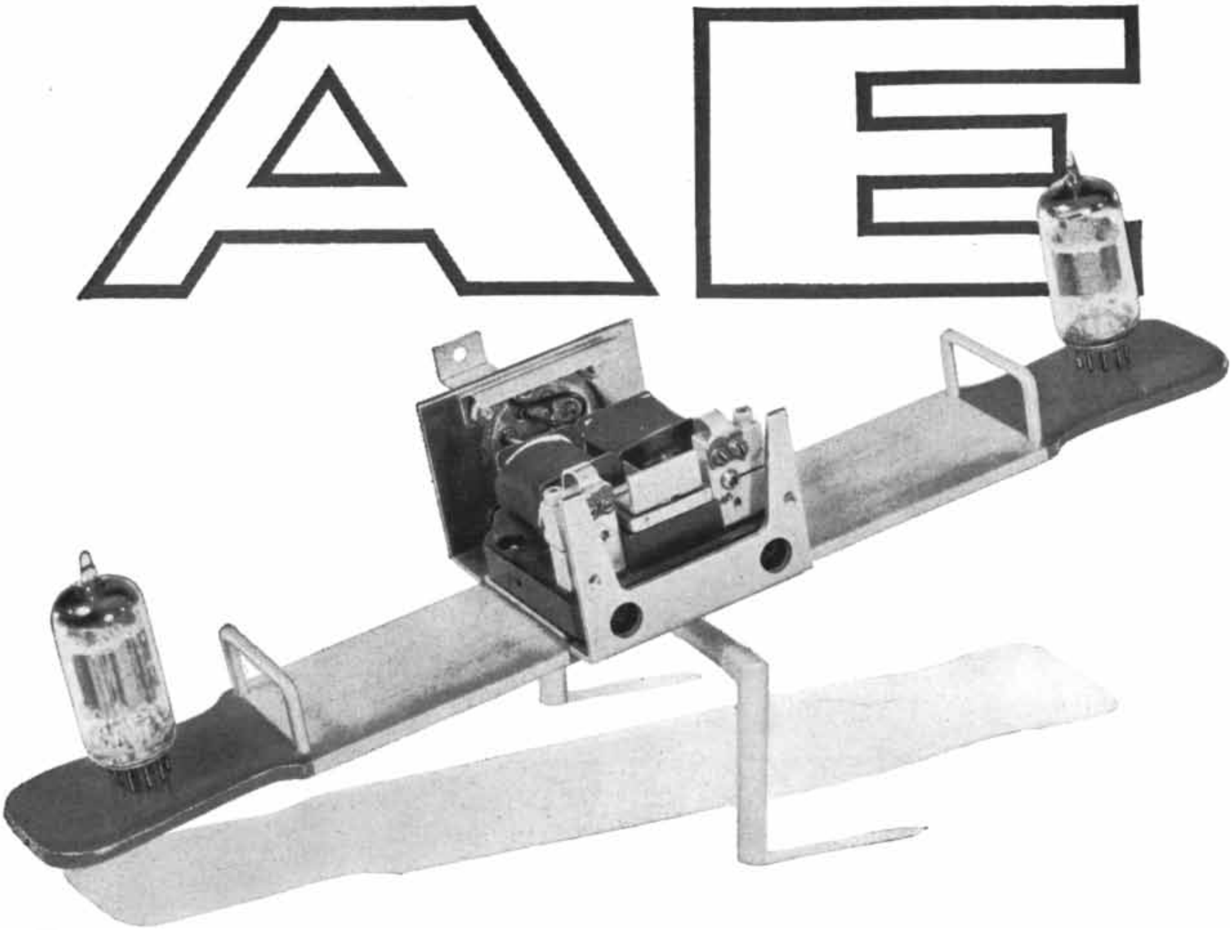

To the Engineer

looking for a fast circuit seesaw

If you're in need of something better than a flip-flop that only *partially* transfers a circuit —something with a transit time of less than a millisecond—then you'll be delighted with AE's Series PTW Polar Relay. This magnetically biased relay will transfer a circuit with the beautiful regularity of an observatory clock, and trigger on only a few mils from your available energy source.

Substantially smaller than other polar relays, the PTW's unique design virtually guarantees the high-speed switching of a single circuit *billions of times without readjustment!* Its service records to date in telegraph and teleprinter circuits and differential controls suggest that its life is practically limitless. Terminals to meet your specs.

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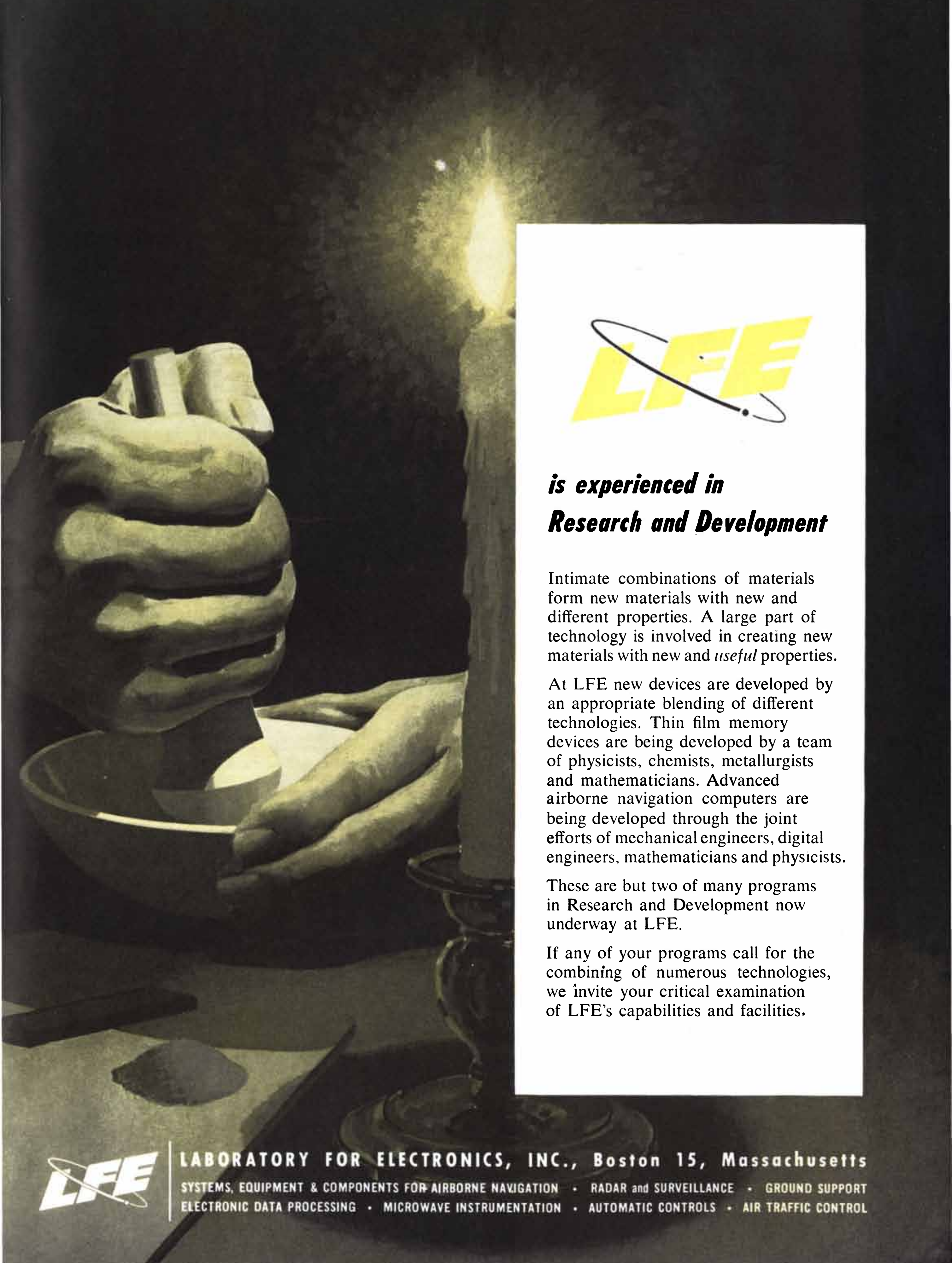
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These are but two of many programs in Research and Development now underway at LFE.
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50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

JANUARY, 1911: "It is with positive consternation that we learn of the determination of the Navy Department to place reciprocating engines in the new battleship *Texas*. Presumably the object of the Navy Department in going back to a type of engine which has been discarded by all the navies of the world is to economize on fuel, the reciprocating engine in our scouts and battleships having shown itself to be at cruising speeds more economical than the turbine. The turbine is more reliable, particularly when the engines are being driven at maximum speed, under which condition the engineers in charge of reciprocating engines are in constant dread lest the failure of some minor part will put the engines entirely out of commission. The fatuity of the action of the Department in this matter was very aptly put by one of the leading naval architects of the world when he said: 'I had supposed that the advantage of the turbine for sustaining high speed was an important battle consideration; but it seems to me that the navy of the United States should now prepare a signal, for hoisting when meeting an enemy at sea, which will read: Please don't disturb us; we are proceeding at our most economical speed.' "

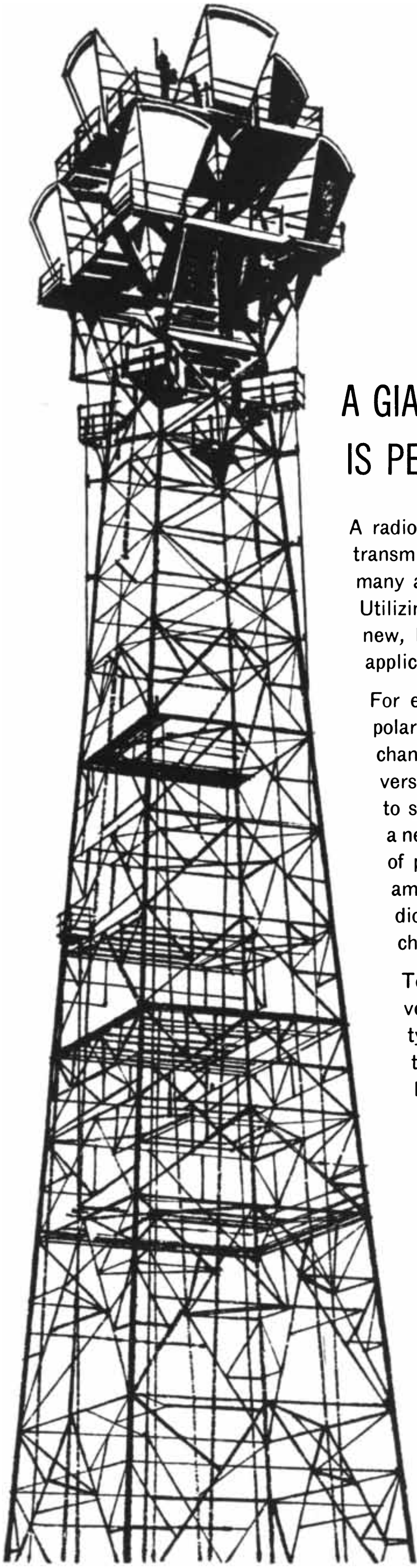
"During the hearing of the case of Marconi v. the British Radio Telegraph and Telephone Company, in the King's Bench Division, London, the judge and lawyers will have practical demonstrations, permission having been granted for the conversion of the court into a 'wireless' operator's office. Messages will be sent and received. The arrangements will be carried out under the superintendence of Professor Boys."

"Heavy is the toll taken annually by the sea of British shipping and the foreign vessels sailing near the English coast. Casualties were received by 10,650 vessels during the year, and 4,738 lives were lost. Of vessels belonging to the United Kingdom, 5,276 suffered casualty, and 322 of these were totally lost. The number of seamen and passengers saved from British wrecks, and wrecks of foreign vessels near the British coast, was 7,820."

"Had the incident occurred a quarter of a century ago we could have understood better the discussion which has been provoked in that august body, the Academy of Sciences, Paris, by the candidature of Madame Curie for membership. Respect for custom and tradition is an admirable attitude if it be judiciously tempered by due considerations of time, place and personality; but we cannot help feeling that in this advanced age, in such a center of enlightenment as Paris, and where a scientist of such brilliant performance as Madame Curie is concerned, this discussion as to whether she is eligible for admission to the Academy of Sciences is altogether deplorable. When science comes to the matter of bestowing its rewards it should be blind to the mere accident of sex; one does not have to be an enthusiast on the subject of the extension of the rights and privileges of her sex to feel that here is a woman who, by her brilliant achievement, has won the right to take her place with her compeers in the Academy, or any similar institution devoted to the furthering of science."

"Why is it that the Diesel motor, which must be considered as one of the triumphs of German mechanical genius, has been so greatly neglected in this country that there is today no American firm engaged in its manufacture? Here is a new type of motor, sound in principle, economical and durable in operation, guaranteed both in laboratory tests and under various conditions of commercial operation, which for some reason or other has been totally neglected in the U. S. We are at the dawn of a motor-driven ocean steamship era, and it is the Diesel motor which is being installed in the fine vessels now building for ocean service. Is the U. S. to have no part in this development?"

"Neon appears to give remarkable results when used in vacuum tubes for lighting purposes. The rarefied gas produces a strong light as is brought out by M. Georges Claude. However, it is very difficult to prepare such tubes, as neon loses its effect when in the presence of a small amount of other gas. To overcome this he uses Dr. Dewar's principle of absorbing by carbon at a very low temperature. Carbon is placed in bulbs connected to the tubes and kept very cold so that all the gases are absorbed but the neon and a little hydrogen. The



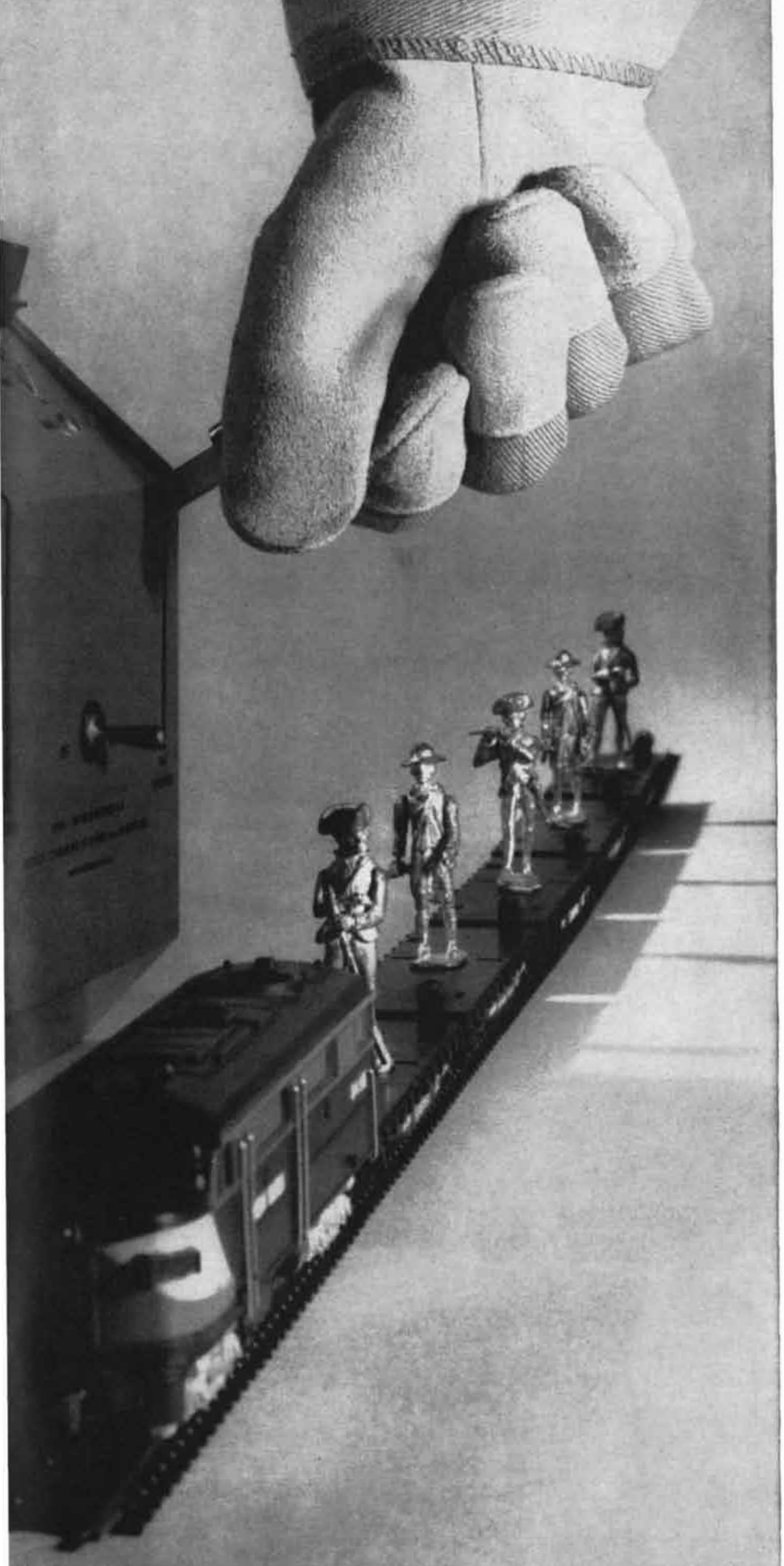
carbon bulbs can then be removed. He uses a tube with a 20-foot distance between electrodes and two inches diameter. Only 1,000 volts is needed, compared with 3,000 volts for a nitrogen tube. It gives 1,320 total candle power, consuming 850 watts, or .64 watts per candle power. No doubt this value will fall much lower after experiments."

Scientific American.

JANUARY, 1861: "The metal aluminum is coming more and more into use. A firm at Newcastle-on-Tyne, England, has begun the manufacture of it on a large scale, in the pure state and as bronze. Unexpected results have been obtained in experimenting with it as an alloy; 20 parts of aluminum with 80 of copper produce a metal which, to the eye, has all the appearance of gold. Alter the proportions, and mix 10 of aluminum with 90 of copper, and the result is a metal singularly hard."

"Our present issue shows that we have brought out the big gun, and that we have got upon the stocks iron-plated frigates of war, soon to be in readiness for sanguinary conflict upon the high seas. We have not yet reached those 'last days' spoken of by the prophet Isaiah, when 'nation shall not lift up sword against nation, neither shall they learn war any more.' For 15 years past we have had extensive correspondence with mechanics and manufacturers throughout all the states, and we have yet to learn that the predictions of the inspired prophet have even an incipient realization on this or any other continent. We know not of an instance where a single sword has been beaten into a plowshare, but we have heard it announced that even the weather-beaten muskets of our distinguished fellow citizen, George Law, have at last found a ready sale. Amidst the general dullness of trade and finance, the forges of Mars are blazing away with unwonted fury, and even 'strange fire' is issuing forth from their smoky embers. Dragon's teeth have suddenly sprung up as armed men, and we can almost hear 'the shout, the shock, the groan of war.' "

"The convention of the State of Florida, assembled at Tallahassee, passed an ordinance of secession on the 11th inst. Mississippi, in convention on the 9th, declared herself out of the Union; and Alabama will, in all probability, have voted herself out before we go to press."



He's got Minutemen "working on the railroad"

Hard basing is one way to protect America's force of retaliatory ICBM's. The problem was to find an alternate means of accomplishing the same mission. The Air Force solution was a new ICBM mobility concept—railroad car-mounted Minuteman, utilizing the nation's vast track mileage for numerical and geographical dispersion, creating a difficult target for enemy attack.

To put the Minuteman, its support systems and associated equipment on rails was a completely new problem in missile handling. The first requirement assigned by Boeing to American Machine & Foundry Company and ACF Industries, Inc., was a feasibility study of the existing limitations of roadbeds, rails, railroad operations and right-of-way. Unique tactical cars are being designed within these limitations to carry the Minuteman—cars that can handle the missile and its operating equipment, safely isolated from roadbed shock and ready for immediate retaliatory launching.

Single Command Concept

Whether for conceptual problems such as this one, or for challenges in design or manufacturing, AMF has ingenuity you can use. AMF people are organized in a single operational unit offering a wide range of engineering and production capability. Its purpose—to accept assignments at any stage from concept through development, to production, and service training...and to complete them faster in

- *Ground Support Equipment*
- *Weapon Systems*
- *Undersea Warfare*
- *Radar*
- *Automatic Handling & Processing*
- *Range Instrumentation*
- *Space Environment Equipment*
- *Nuclear Research & Development*

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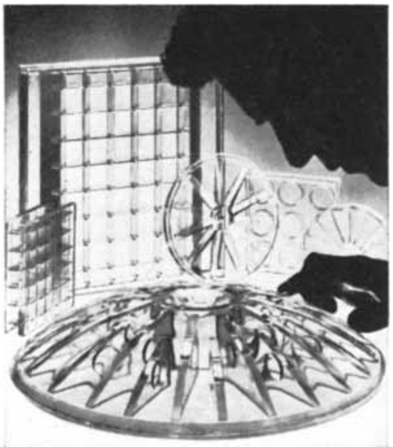
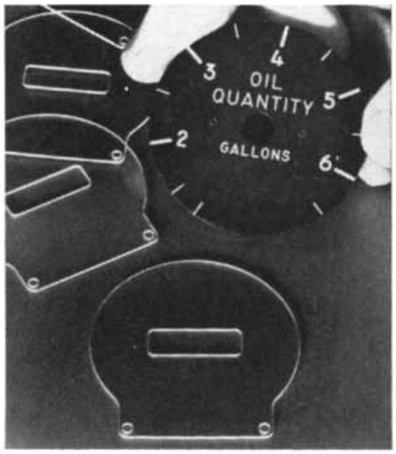
THIS IS GLASS

A BULLETIN OF PRACTICAL NEW IDEAS FROM CORNING





99.999+% PURE FUSED SILICA

Astronomers are notoriously strict about materials. Well they might be, since a minor deviation in an optical material makes for catastrophic miscalculations when extrapolated through the infinity of space.

A new fused silica which we developed is eliciting quiet approval, the most anyone expects, from the meticulous astronomer. Drop to the molecular level and you will find only several parts of impurity per million of silica.

Such purity is naturally beneficial to the optical properties of the material. It has an extremely high degree of optical homogeneity. When you talk visible or ultraviolet light, it is the most transparent glass we have ever made. On the physical side, it has a coefficient of expansion of $5.6 \times 10^{-7}/°C$. Its refractive index is n_D-1.4584. Birefringence constant: 3.40 m mu/cm/kg/cm^2. Neither gamma nor X-rays darken it.

Among some of the various products that we have made or are presently working on are telescope mirrors up to 80 inches, ultrasonic delay lines; windows for wind tunnels, high temperature viewing and star guidance systems.

We can play a few tricks with this fused silica in designing. Witness the unique sandwich construction of the mirror blanks above. This simple design innovation cuts as much as 50% off the weight of the mirror blanks without sacrificing rigidity one whit.

The coupon is your invitation to get more information on this new Corning material.

WILL THE MACHINE GIVE WAY TO CHEMICALS?

The dial faces below were made without the assistance of a single die or jig, without grinding or cutting or drilling or milling or stamping or any other mechanical operation.

We made them by exposing photosensitive glass to a precisely drawn pattern and a series of chemical etchants.

This is more than a parlor trick.

It is a method of making parts precisely which would be impossible or far too costly to make mechanically. It is the FOTOFORM® process.

We make brush holders for digital computers which call for rectangular holes measuring 0.0075″ x 0.015″.

We can take a square inch and riddle it with as many as 250,000 holes, each precisely like all its neighbors. Or, with a simple inexpensive change in art work, we could make just one of those 250,000 holes a triangle.

The material itself is nonporous and dimensionally stable glass, utterly free of flaws and voids and able to operate continuously at 500°C.

We can use the same process on FOTOCERAM,® one of our glass-ceramics which has a coefficient of expansion nudging zero.

If you would like to know more about chemical machining and the photosensitive glasses, please send the coupon.

FOR 10^{-6}mm Hg GREASELESSLY

With all due apologies to the people who make grease, it *is* usually a nuisance in vacuum lines.

It's also a likely source of contamination.

So, we say, get rid of grease.

There are recesses in the sockets of this joint which match to perfection the configuration and dimensions of a Buna-N O-ring.

Even without grease, this seal will hold a vacuum down as far as 10^{-6} without leaking.

The assembly accepts a standard socket and clamp.

The glass is PYREX® brand No. 7740, so it will not serve as a source of contamination either. It's easily worked to fit into any setup, so it should be in demand for more than the usual bench-top vacuum line. There should be considerable demand among people everywhere who want a tight, greaseless joint.

The November 1959 issue of *The Review of Scientific Instruments* has something to say about this useful new tool. So do we. For our message, call your local lab supply dealer, or send us the coupon direct.

LG-2 IS HERE

If you work with lab glassware, you know that LG is the code name for the catalog of PYREX labware. The latest edition is now out and you are welcome to a copy, if you have occasion to order such ware.

CORNING MEANS RESEARCH IN GLASS

CORNING GLASS WORKS, 4901 Crystal St., Corning, N. Y.

Please send information on:

☐ Fused silica ☐ FOTOFORM ☐ O-ring vacuum joint

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

Daydreams won't pay for books. Many people want college educations for their children but can't shoulder the burden. Starting a U. S. Savings Bond program now makes sure the money will be ready for the college education your youngster deserves.

How to give him 4 years of college for the price of 3

If your money and your youngster grew up together, it would certainly help meet college costs, wouldn't it? That's exactly how it works when you save for his education with U. S. Savings Bonds. For example, if you start putting $6.25 a week into U. S. Savings Bonds when he's 2 or 3, you'll have put in $4900 by the time he reaches college age. Then cash the Bonds as you need them, and you'll get back about $6900—enough for a fair share of 4 years at State.

Give him his chance at America's opportunities. He needs a peaceful world to grow in. Every U.S. Savings Bond you buy helps assure peace by keeping our country strong.

WHY U. S. SAVINGS BONDS ARE SUCH A GOOD WAY TO SAVE

You can save automatically on the Payroll Savings Plan, or buy Bonds at any bank • You now earn 3¾% to maturity, ½% more than ever before • You invest without risk under a U. S. Government guarantee • Your Bonds are replaced free if lost or stolen • You can get your money with interest anytime you want it • You save more than money—you buy shares in a stronger America

U.S. Savings Bonds are theft-proof! Fire-proof and loss-proof, too. Since 1941 the Treasury Department has replaced 1,300,000 Bonds at no cost to the owners.

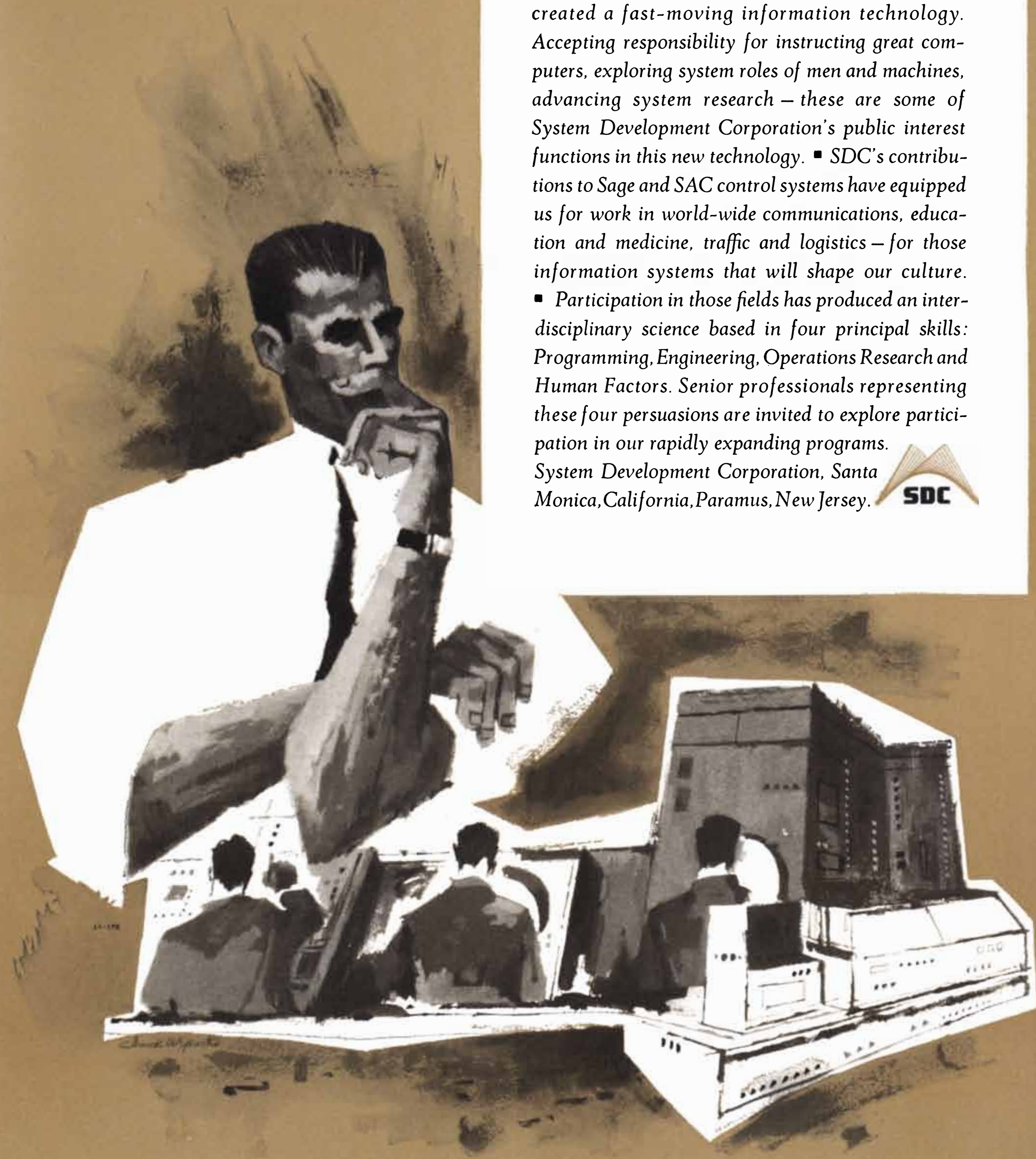
You save more than money with U.S. Savings Bonds

20th ANNIVERSARY 1941 1961

To help men make decisions and exert control

The need for systems to help men make decisions and exert control over vast networks of rapid actions has created a fast-moving information technology. Accepting responsibility for instructing great computers, exploring system roles of men and machines, advancing system research – these are some of System Development Corporation's public interest functions in this new technology. ▪ SDC's contributions to Sage and SAC control systems have equipped us for work in world-wide communications, education and medicine, traffic and logistics – for those information systems that will shape our culture. ▪ Participation in those fields has produced an interdisciplinary science based in four principal skills: Programming, Engineering, Operations Research and Human Factors. Senior professionals representing these four persuasions are invited to explore participation in our rapidly expanding programs. System Development Corporation, Santa Monica, California, Paramus, New Jersey.

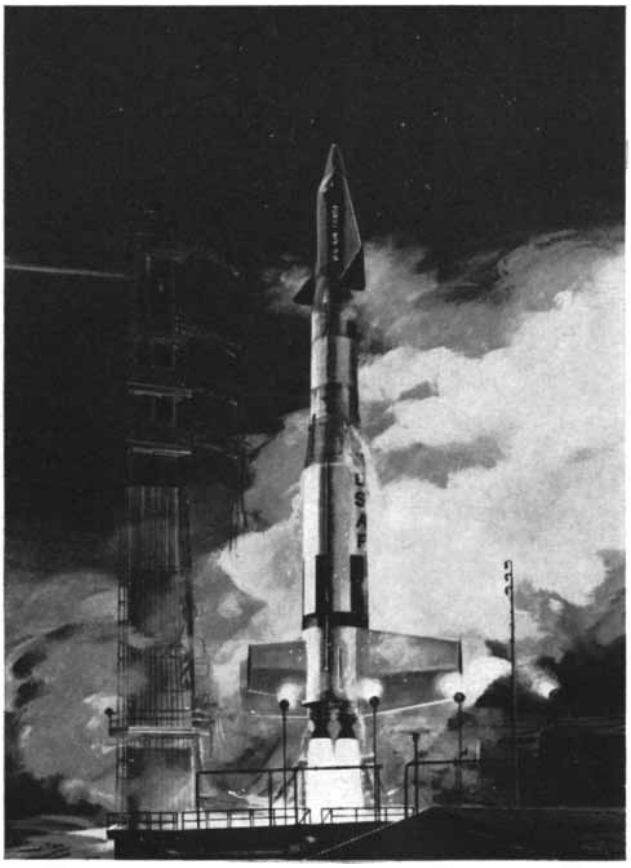
SDC



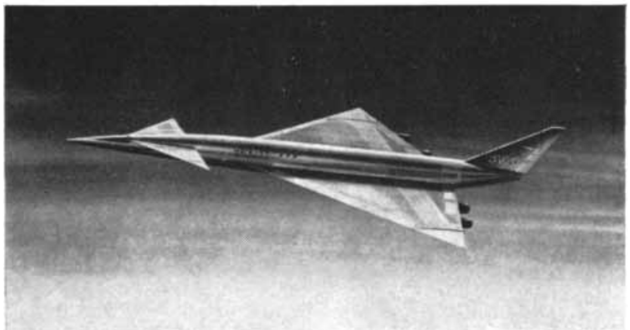
BULLETIN FROM BOEING ...

...WHERE CAPABILITY HAS MANY FACES

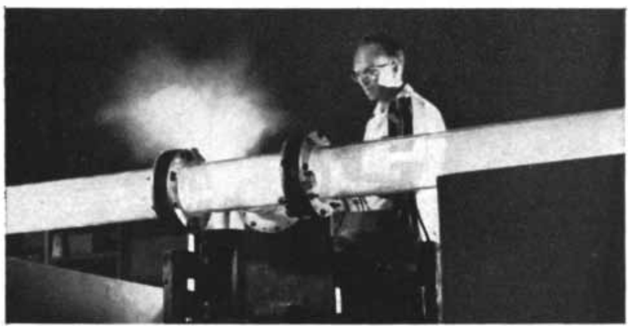
Expanding the frontiers of knowledge through basic research is the business of the Boeing Scientific Research Laboratories, left. Here Boeing scientists are at work in the fields of solid state physics, flight sciences, advanced mathematics, plasma physics and geo-astrophysics.



SPACE GLIDER. Artist's concept shows Dyna Soar manned space glider perched atop modified Titan ICBM for launching. In space, the glider and booster would separate, leaving Dyna Soar vehicle in piloted, near-orbital flight. Pilot could later glide to conventional landing at a selected base. Dyna Soar is being developed by the U. S. Air Force in cooperation with NASA, with Boeing as prime contractor for both the system and the glider.



FUTURE SKYLINER. Boeing, builder of famous 707, America's first jet airliner, has long been at work on next generation of aerial transports, which could look like the Boeing design pictured above. Supersonic jetliners, probably a decade away, could have speed in neighborhood of 2,000 miles an hour. Flight time, from Paris to New York, would be about two and a half hours!

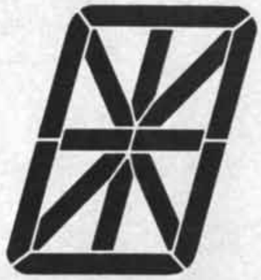


SHOCK TUBE. Industry's most powerful shock tube, designed and built by Boeing Scientific Research Laboratories scientists, creates shock waves which begin at 300 times speed of sound, then collide in tube at "slowed" rate of 80 times speed of sound. Gas temperature within the tube reaches approximately one million degrees. Studies could be important in developing effective ion and plasma-propulsion systems for use in space.

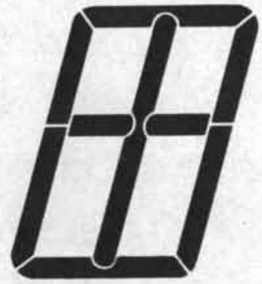
BOEING

JET AIRCRAFT, MISSILES, HELICOPTERS, GAS-TURBINE ENGINES, WEAPON-SYSTEM MANAGEMENT, SPACE-FLIGHT VEHICLES AND SYSTEMS.

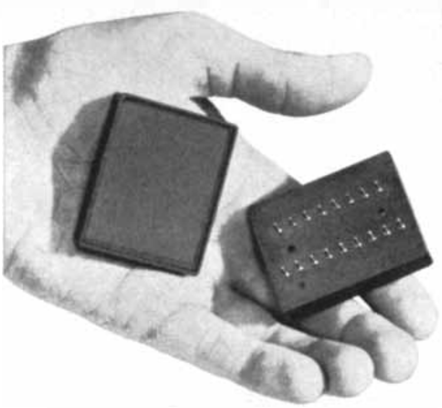
NEW HIGH-RELIABILITY READOUT DEVICES NOW AVAILABLE



SYLVANIA TYPE AN-150 . . . 1½" ALPHA-NUMERIC . . . is diagramed above in actual size to show the 14 segments that produce the complete English alphabet, 0-to-9 numerics, and selected mathematical symbols.



SYLVANIA TYPE NU-150 . . . 1½" NUMERIC . . . is diagramed above in actual size to show the 9 segments that produce a display of 0-to-9 numerics.



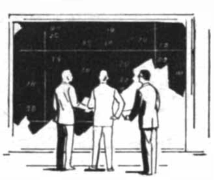
Sylvania Electroluminescent Panels provide new techniques for display of numeric and alpha-numeric information

Sylvania EL Readout Devices are composed of segments of electroluminescent lamps, insulated from each other and separately terminated. By selective excitation of the segments, symbols are produced for visual display.

The basic design and structural simplicity of *Sylvania EL Display Devices* offer the important benefits of minimal catastrophic failure, exceptional reliability, long life, simplified circuitry, negligible power requirements, compactness, flat construction for wide-angle viewing, high readability despite ambient light conditions, and plug-in design for instant interchangeability.

Want more details? Send today for the descriptive brochure "Sylvania Electroluminescent Display Devices." Write Electronic Tubes Division, Sylvania Electric Products Inc., Dept. EL, 1100 Main Street, Buffalo 9, N. Y. Want to discuss your specific requirements for readout devices? Contact your nearest Sylvania Sales Engineering office.

If you are designing . . . Digital Voltmeters, Cash Registers, Call Boards . . . investigate new SYLVANIA EL "READOUTS"!



If you are designing . . . Systems Displays, Tote Boards, Arrival Boards . . . investigate new SYLVANIA EL "READOUTS"!

If you are designing . . . Dispatch Boards for Police, Fire, Utilities, Commercial Carriers . . . investigate new SYLVANIA EL "READOUTS"!

SYLVANIA

Subsidiary of **GENERAL TELEPHONE & ELECTRONICS**

Oil-well drilling operations offer many new and unusual uses for calcium chloride from Allied's Solvay Process Division.

News from Allied Chemical:

Uncommon uses for a common compound... Calcium Chloride

Paradoxical stuff, calcium chloride: Sort of like the man who warms his hands and cools his soup with the same breath. It's a dandy ice melter—far better than salt; yet as refrigerating brine it's the ideal ice maker. It will keep your basement nice and dry; yet it's used to keep unpaved roads moist to hold down dust.

Despite (or perhaps because of) calcium chloride's well-known uses as highway dust-layer and sidewalk de-icer, few people recognize its potential as an *industrial chemical.* But first, a few of its new uses, some of which may spark an idea for its application in *your* field of interest.

Oil driller's friend. There are at least seven important uses for calcium chloride in drilling an oil well. Those who bore for black gold can use it as: (1) An ingredient in a drilling mud to prevent clay hydration. (2) A "work-over" fluid when reworking a well. (3) A "completion" fluid before cementing a well. (4) A carrier for gravel packing. (5) A cement curing accelerator. (6) An additive in acidizing solution. (7) A bit lubricant along with potassium stearate. Oil men, who know what these terms mean, also know how a few tons of calcium chloride can save them time and money.

Papermaker's pal. Kraft papermakers are putting calcium chloride to an ingenious new use. When paper is made, it goes through a stage where it is neither solid nor fluid. It's a mushy slush, called a "web." It's fragile—ready to break and stop production. Now, papermakers add a small percentage of calcium chloride to the web. This makes it stronger, easier to handle—and expedites production.

Industrial chemical—new role for $CaCl_2$. We are always surprised to find that so many people fail to see calcium chloride as a processing chemical. Yet it is being used today in the manufacture of many products like calcium arsenate, nemesis of the boll weevil. And in the manufacture of such diverse products as portland cement, metallic sodium, petroleum, synthetic detergents, herbicides, and in rubber reclaiming, too. In addition to its familiar properties, $CaCl_2$ is low in turbidity, boron, strontium and other metal impurities.

Moral of this message: If you think a low-cost, hygroscopic, exothermic compound, in flake or liquid form, might help *your* product or process, our Solvay Process Division has the answer in SOLVAY® calcium chloride. We also have technical literature to enlighten you more fully on the points so briefly touched on here.

For information, just write to Allied Chemical Corporation, Dept. 11-T, 61 Broadway, New York 6, N. Y., or phone HAnover 2-7300, stating field of interest.

Allied Chemical

Basic to America's Progress

THE AUTHORS

JOHN V. BECKER ("Re-entry from Space"), chief of the Aero-Physics Division at the Langley Research Center of the National Aeronautics and Space Administration, has been associated with NASA (and its predecessor, the National Advisory Committee on Aeronautics) for the past 25 years. A graduate of New York University, where he acquired his M.S. in 1936, Becker has specialized in high-speed aerodynamics research. He was a member of the group that in 1945 developed the first successful hypersonic wind tunnel. In 1954 he headed the group of researchers at Langley who proposed the construction of a manned hypersonic airplane capable of leaving the atmosphere for brief periods of weightless flight. The proposal later became the specification for the X-15 research project. For the past three years much of Becker's time has been devoted to the joint Air Force-NASA Dyna-Soar project.

SIR MACFARLANE BURNET ("The Mechanism of Immunity") is director of the Walter & Eliza Hall Institute of Medical Research at The Royal Melbourne Hospital in Australia. He received his M.D. degree from the University of Melbourne in 1923 and later took a Ph.D. at the University of London. A Fellow and Royal Medalist of the Royal Society, Burnet has long been recognized as a leading authority on viruses and virus diseases, a field in which he has made a number of fundamental contributions. More than a decade ago he became interested in the processes by which an organism protects itself against the intrusion of foreign proteins and other substances. For the theory of the immunological mechanism that he proposed in 1949, Burnet shared (with P. B. Medawar of University College London) the 1960 Nobel prize in medicine and physiology.

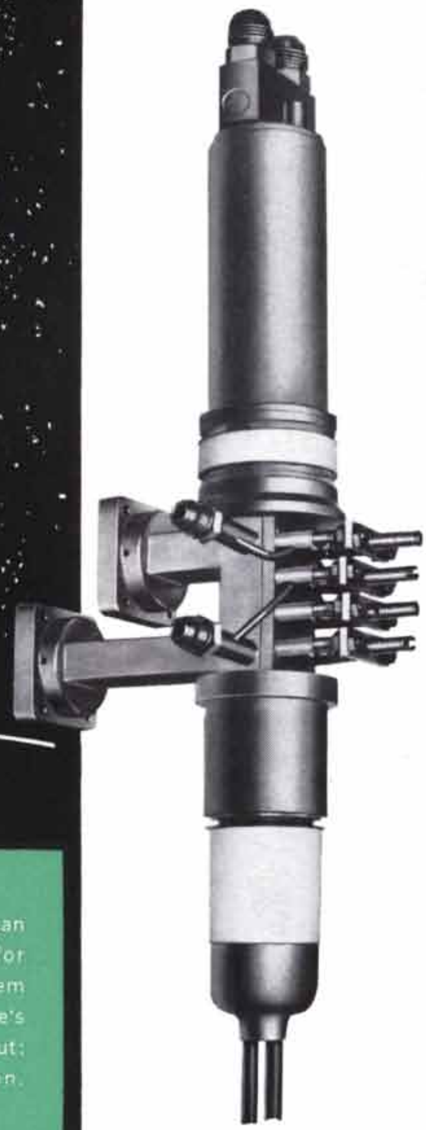
ROMAN GHIRSHMAN ("The Ziggurat of Tchoga-Zanbil") is a member of the French Archeological Mission to Iran that has been excavating the ziggurat since the end of World War II. Ghirshman is presently engaged in archeological research on Kharg Island in the Persian Gulf.

CHARLES H. GREENE ("Glass") is professor of glass technology and chairman of the Glass Technology Department at the State University of New York College of Ceramics at Alfred University. Born in Troy, Pa., in 1904, he received a B.A. from Haverford College in 1926. He went on to do graduate work at Harvard University, where he acquired his M.A. in 1927 and his Ph.D. in physical chemistry in 1931. During his last year of study he also worked for the Corning Glass Works in Corning, N.Y., as a research chemist. From 1931 to 1937 he was an instructor in analytical chemistry at Harvard and did research on the atomic weights of lithium and sodium and on the isotopic abundances of hydrogen and oxygen. For the next three years he again worked for Corning as a research chemist. From 1940 to 1953 he was a glass technologist and manager of melting development for the same company, doing research on a wide variety of glass problems, particularly the strength of glass and the behavior of bubbles in glass. He took up his present position at Alfred University in 1953.

O. C. WILSON ("A New Scale of Stellar Distances"), a staff member of the Mount Wilson and Palomar Observatories, is an astronomer who accounts for his interest in the field by "an accident that occurred to someone I never met." After enrolling in a general science course in high school, he writes, "it developed that the regular teacher had broken his leg. He was replaced by a young and innocent substitute who spoke knowingly of various astronomical matters in such a manner that I was led to wonder if she really knew what she was talking about. In order to settle this point, I began reading books on the subject . . . and have been completely sold on it ever since. Unfortunately, the time interval is too great for me to remember now whether the substitute teacher was vindicated." Wilson acquired his B.A. at the University of California in 1929 and his Ph.D. in astrophysics at the California Institute of Technology in 1934. He joined the Mount Wilson Observatory as a computer in 1931 and has been there since that time (except for four years during World War II, when he did research on rockets and aircraft torpedoes at Cal Tech). At present all of Wilson's research involves some form of astronomical spectroscopy; in particular the study of the H and K spectral lines discussed in his article.

B. J. MASON ("The Growth of Snow Crystals") is Warren Research Fellow of the Royal Society of London and head of the cloud physics laboratory at the for space systems

20kW CW at X-band



Varian's new VA-849 amplifier klystrons are rated to deliver higher CW power at X-band than any existing tube in the world . . . 20kW!

Varian's new VA-849 power klystron opens up a variety of new design approaches to space systems. Possible applications exist in communication concepts such as repeater satellites, moon-bounce signalling, or in reflections from clouds of tiny orbiting needles. Radio astronomers, too, will welcome the VA-849.

Immediate applications include CW radar and illuminator service. Low incidental noise. Water cooling. Electromagnet focusing. Another significant advance in microwave components from Varian's broad experience and research in super-power tubes.

FEATURES

- **7.125 to 8.5 kMc**
- **20 kW CW**
- **50 db Gain.**
- **30 Mc Minimum Bandwidth**
- **Tunable 60 Mc.**

It's likely that Varian can provide a solution for your particular system design problem. There's a good way to find out: write Tube Division.

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Imperial College of Science and Technology in London. His research work has centered for the most part on cloud and rain formation, thunderstorm electricity, aerosol physics and the physical properties of water and ice. Mason is the author of *The Physics of Clouds*, which was published in 1957 by the Oxford University Press.

T. H. BENZINGER ("The Human Thermostat") is head of the Calorimetry Branch and the Bio-Energetics Division of the Naval Medical Research Institute in Bethesda, Md. He was born in Germany in 1905, and studied at the universities of Tübingen and Munich and at the Stuttgart Institute of Technology. From 1927 to 1933 he studied medicine at Tübingen and the universities of Berlin and Freiburg, receiving his M.D. degree from the latter institution. During World War II Benzinger was head of both the Medical Division of the German Air Force Testing Center and the Medical Branch of the Research Division in the Air Ministry. After two years at the U. S. Air Force Aero-Medical Center in Heidelberg, he went to the Naval Medical Research Institute in 1947.

N. J. BERRILL ("Salpa") is Strathcona Professor of Zoology at McGill University in Montreal, where he has taught since 1927. He was educated in England and is a graduate of the universities of Bristol and London and a Fellow of the Royal Society. Having spent his school and college vacations along the coasts of Cornwall and Devonshire, Berrill feels that his interest in Salpa and other marine organisms reflects a desire to be near the sea "rather than a special concern with marine biology as a science." The seaside vacations he takes now are "busman's holidays" at his house at Boothbay Harbor, Me. Berrill is the author of several books for the general reader; his "magnum opus," *Growth, Development and Pattern,* will be published this spring.

O. G. SUTTON, who in this issue reviews Lewis F. Richardson's *Arms and Insecurity* and *Statistics of Deadly Quarrels,* is head of the British official weather service. A mathematical physicist by training, Sutton has done research in meteorology, rocket development, tank armaments and radar. From 1947 to 1953 he was Bashforth Professor of Mathematical Physics and Dean of the Royal Military College of Science. He is a Fellow of the Royal Society and has written books on micrometeorology, aerodynamics and applied mathematics.

Photo by Frank Cowan

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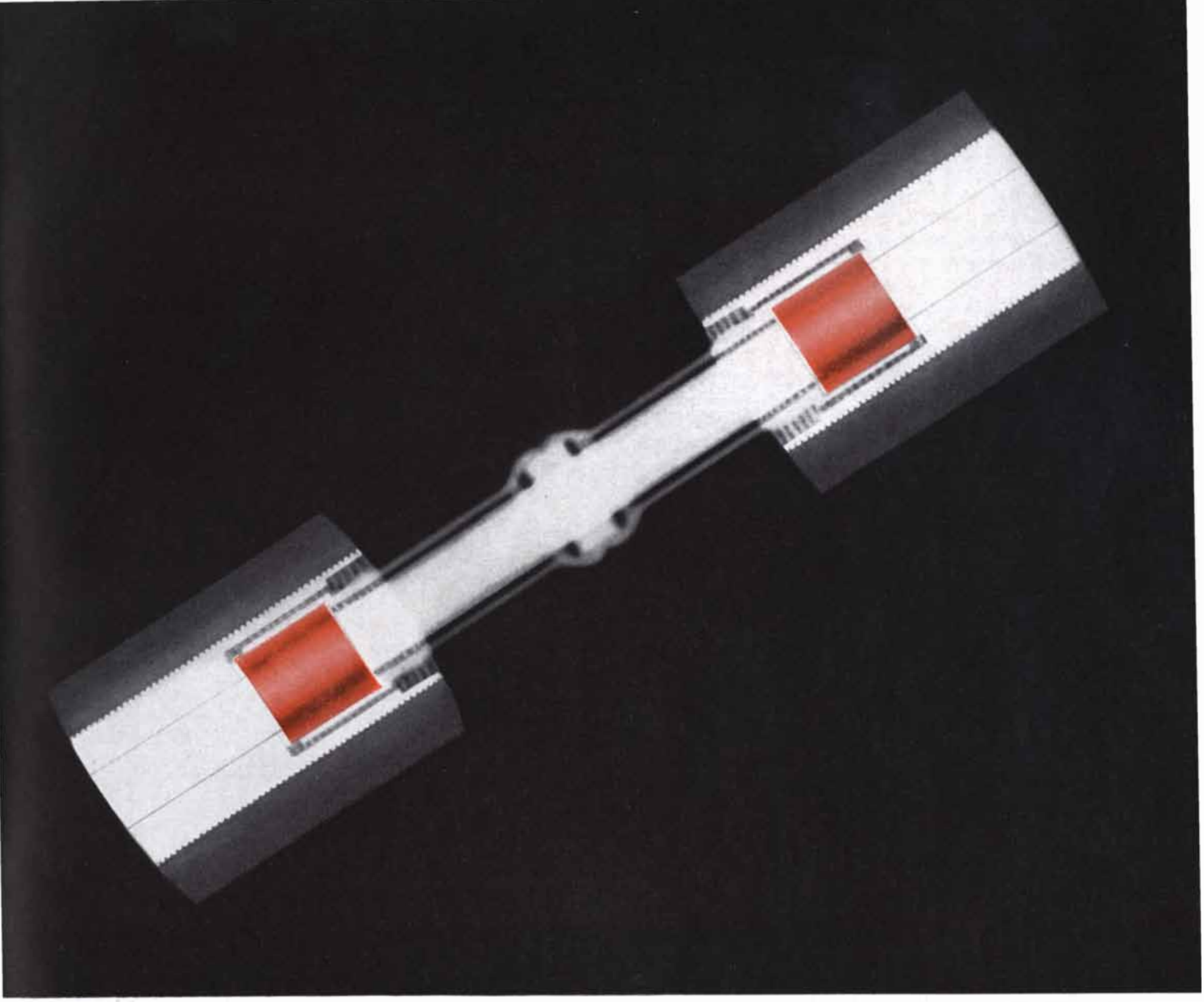

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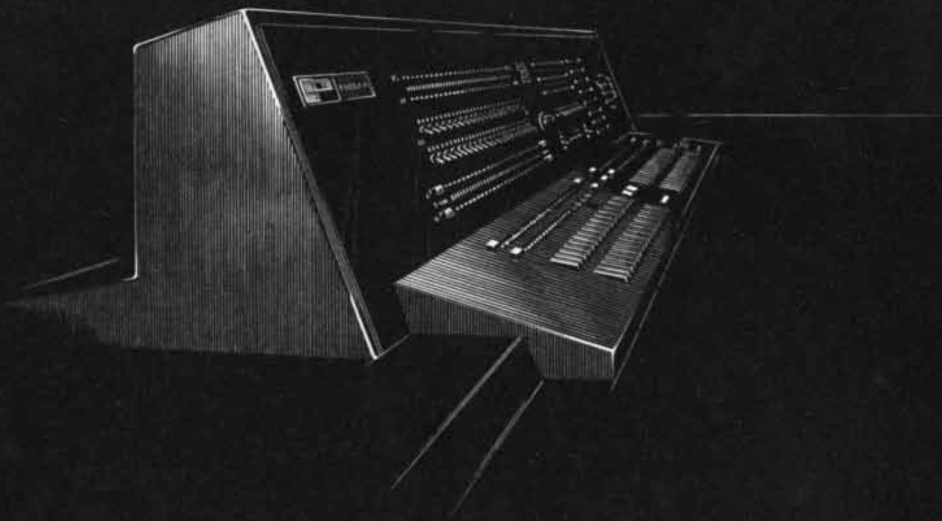

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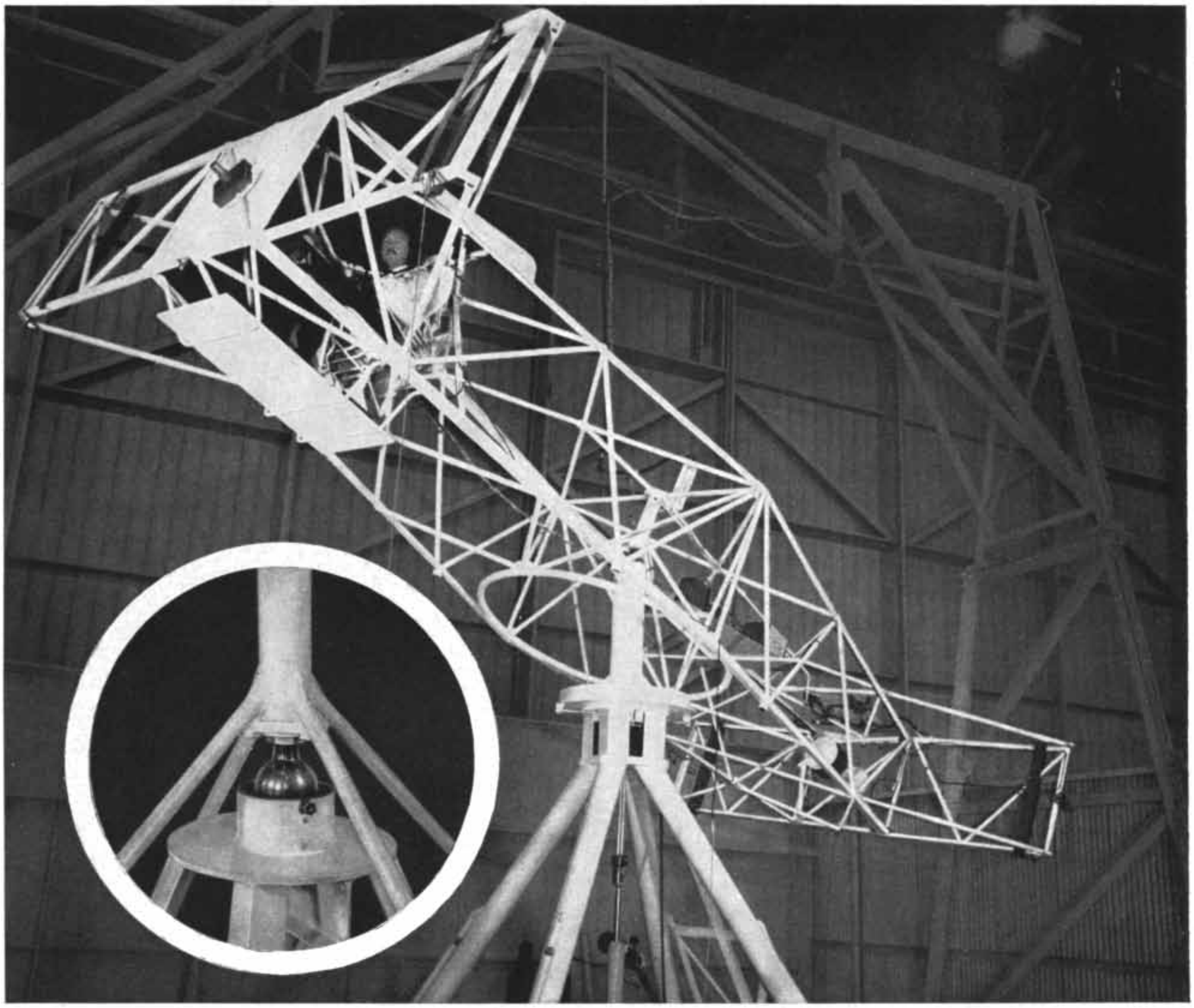

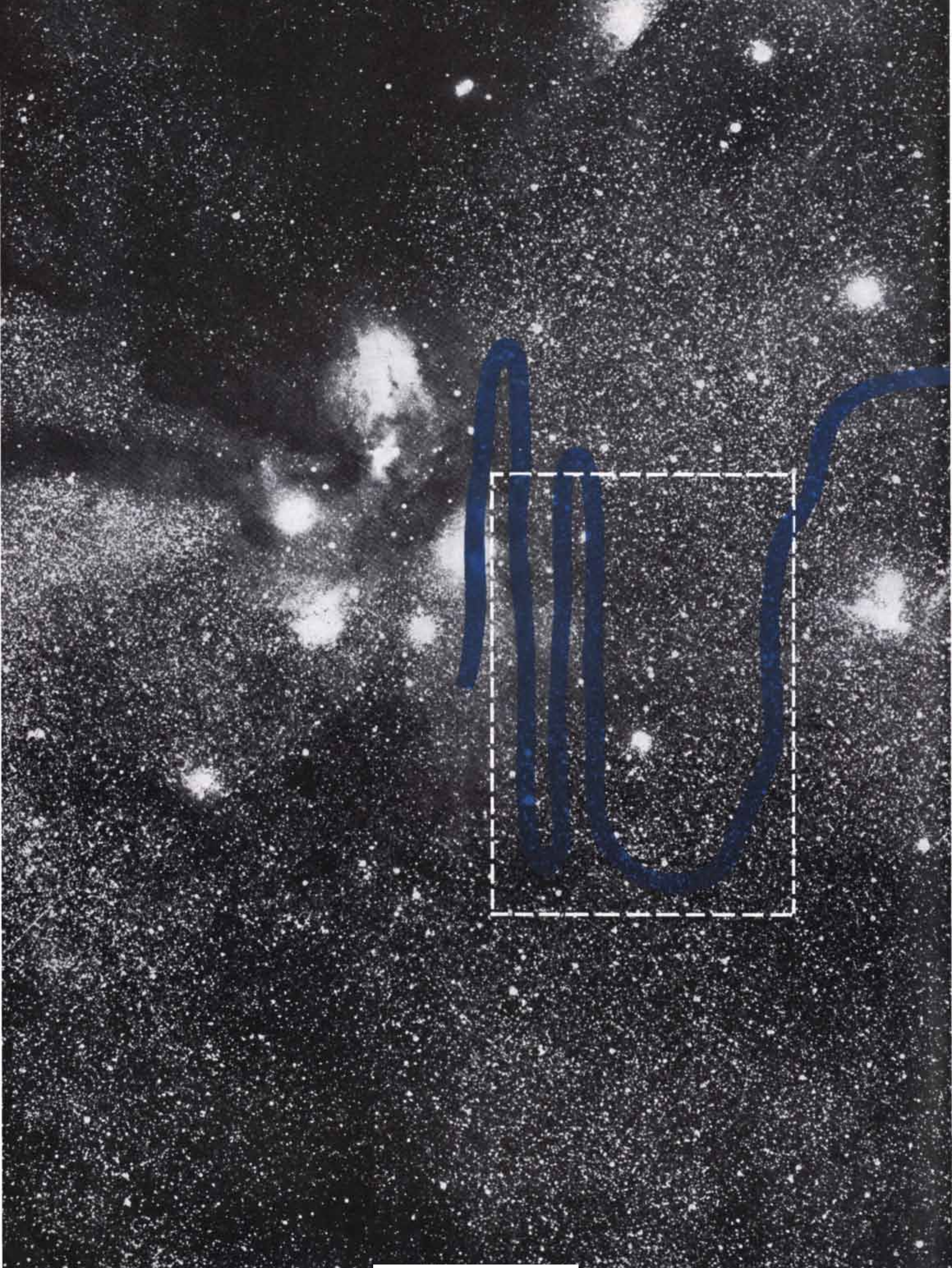

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Today, most millimeter and sub-millimeter electromagnetic waves get through the atmosphere with ease, yet those shorter wavelengths which have been measured are attenuated to the point of uselessness. — ▪ — Yesterday, the same problem existed

with infrared. It, too, faced an attenuation barrier until science discovered "windows" in the atmosphere through which IR waves could travel. If it is true for IR, why not for millimeter waves? Or, if the atmosphere remains a barrier, what about the sea? Today, we think it attenuates all but sonar waves. Yet there could be millimeter windows in the sea which do not exist in the air. — ▪ — These are the kinds of problems we explore at Loral where specific research delves into such areas as cryogenics, molecular electronics, and parametric amplifiers, in order to produce the operational equipments of tomorrow. If you enjoy this type of exploration . . . if you would rather not think in terms which are delimiting, but in terms of the limitless . . . and if you are a senior scientist or engineer, write LORAL Electronics Corporation, New York 72, New York.

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Sir Archibald Geikie...on geological evolution

"What art effects upon the marble block, nature accomplishes upon the surface of the land. Her tools are many and varied — air, frost, rain, springs, torrents, rivers, avalanches, glaciers, and the sea — each producing its own characteristic traces in the sculpture. With these implements, out of the huge bulk of the land she cuts the valleys and ravines, scoops the lake-basins, hews with bold hand the colossal outlines of the mountains, carves out peak and crag, crest and cliff, chisels the courses of the torrents, splinters the sides of the precipices, spreads out the alluvium of the rivers, and piles up the moraines of the glaciers. Patiently and unceasingly has this great earth-sculptor sat at her task since the land first rose above the sea, washing down into the ocean the debris of her labour, to form the materials for the framework of future countries; and there will she remain at work so long as mountains stand, and rain falls, and rivers flow."

—Geological Sketches at Home and Abroad, 1882

Established 1845 SCIENTIFIC AMERICAN January, 1961 Volume 204 Number 1

Re-entry from Space

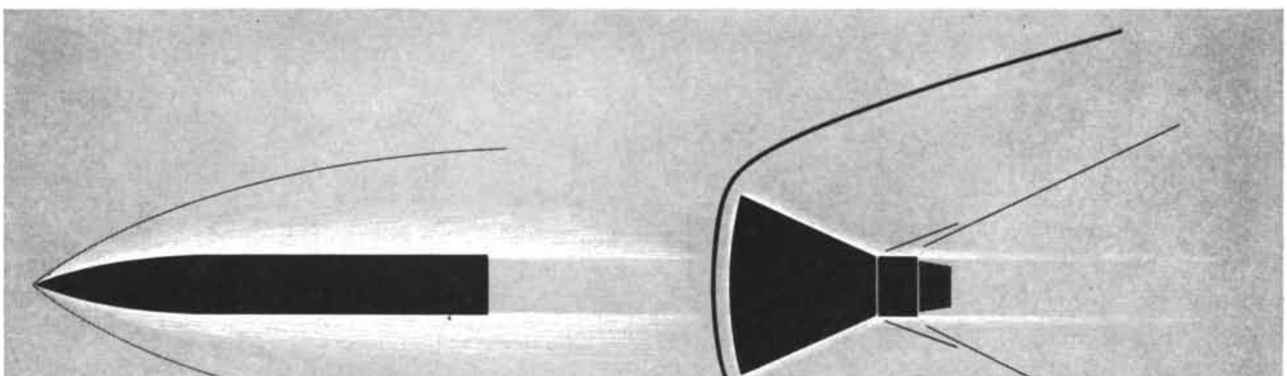
Before it lands, a vehicle returning from space must convert its enormous energy into heat. The problem of protecting the vehicle from this heat can be solved in a variety of ways

by John V. Becker

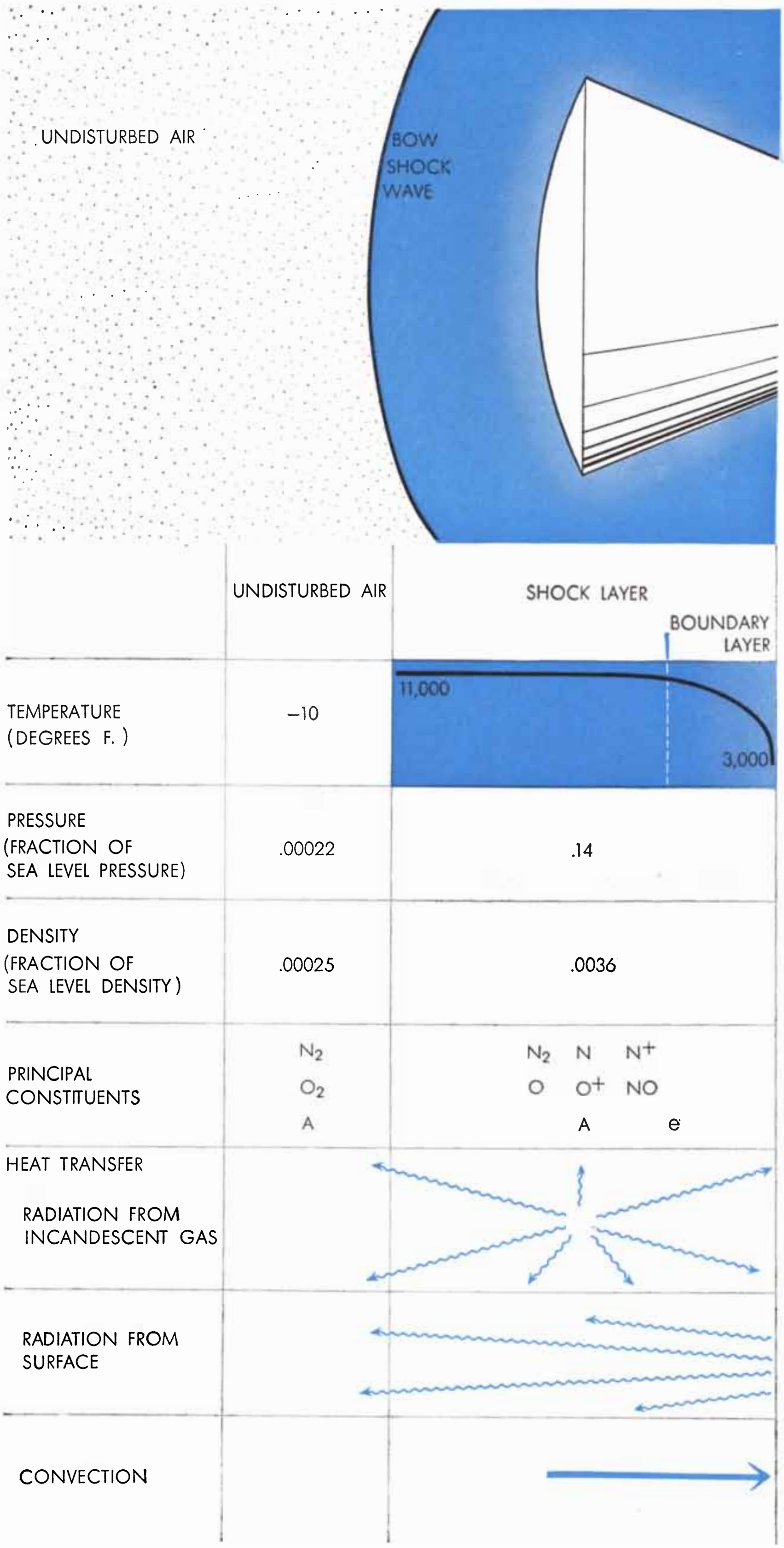
The return trip from the moon or from another planet will be essentially a long fall toward the earth. Near the end of the fall the space craft will have accelerated to an enormous speed: 25,000 miles per hour or more. How to slow it down and bring ship and passengers safely through the atmosphere to the ground is one of the most challenging and difficult problems of space flight.

An obvious approach would be the use of reverse-thrust rockets to slow down the vehicle in space, before it encountered the atmosphere—a reversal of the launching process. But this brute-force technique requires rockets many times heavier than the vehicle proper. Payloads consisting largely of braking-rocket fuel offer an unattractive prospect, even if we had boosters capable of launching them. The alternative is to let the air itself provide the decelerating force.

Considering that returning space vehicles will be entering the air almost as fast as meteors do, the feasibility of atmospheric deceleration is by no means obvious at first glance. Meteors are slowed by the atmosphere, but at rates far beyond the tolerance of any human occupant of a space vehicle. In fact, nearly all meteors completely melt and vaporize in the intense heat produced by compression and friction. When serious study of re-entry began some dozen years ago, no one knew whether atmospheric deceleration could provide a workable answer at all. Today there



STRENGTH OF SHOCK WAVE (*black curves*) determines the heat and drag applied directly to vehicle by air friction. Slender shape creates weak shock wave and therefore a heavy frictional layer (*white area*). Blunt shape has strong shock and little friction.

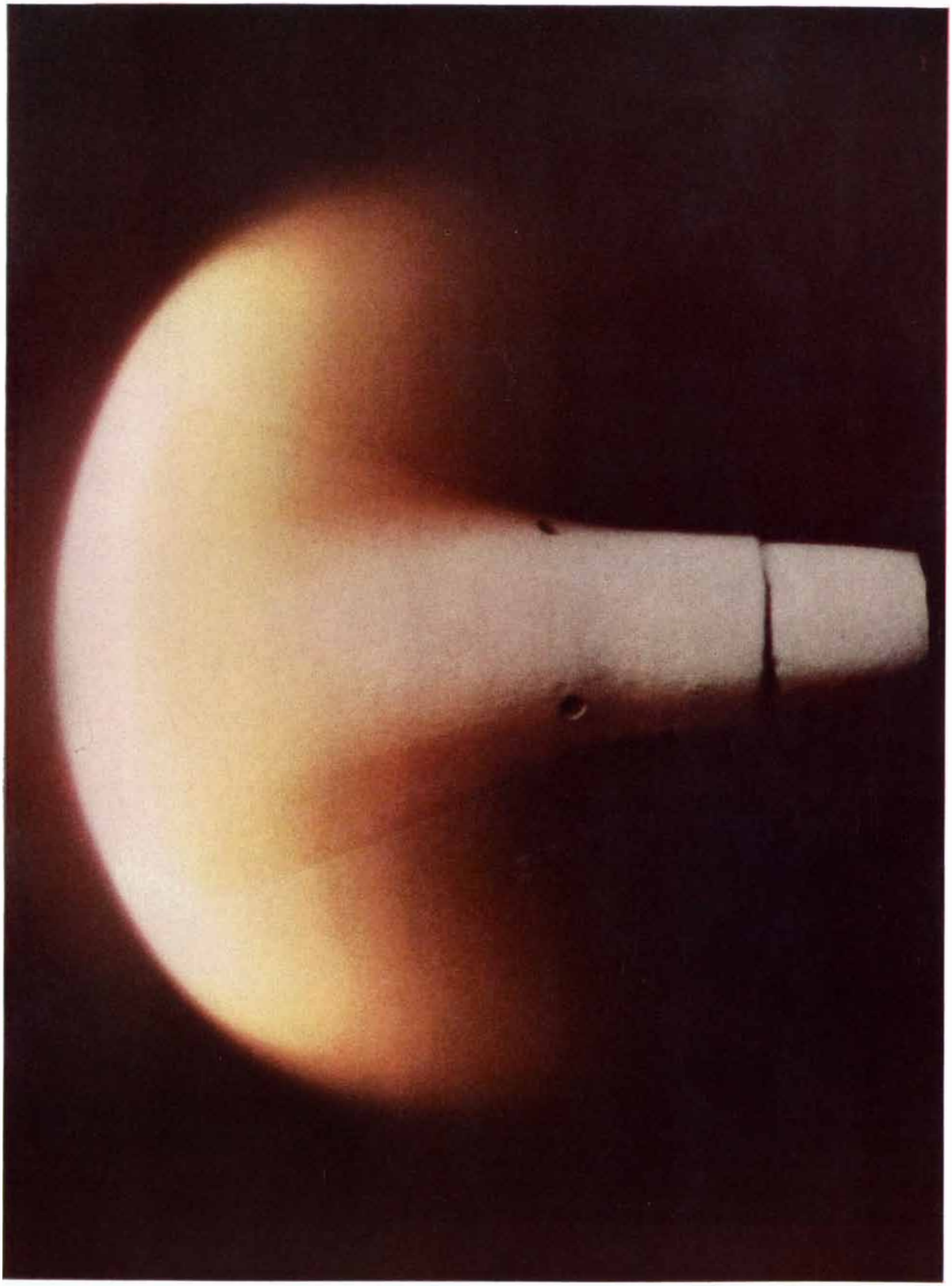


CONDITIONS IN SHOCK LAYER (*colored area*) **created by re-entering Mercury capsule are summarized in table. Boundary layer is shown in lighter color. In list of constituents N stands for nitrogen atoms; O, for oxygen atoms; A, for argon atoms; *e*, for free electrons. Principal means of heat transport to surface is by convection from hot shock layer.**

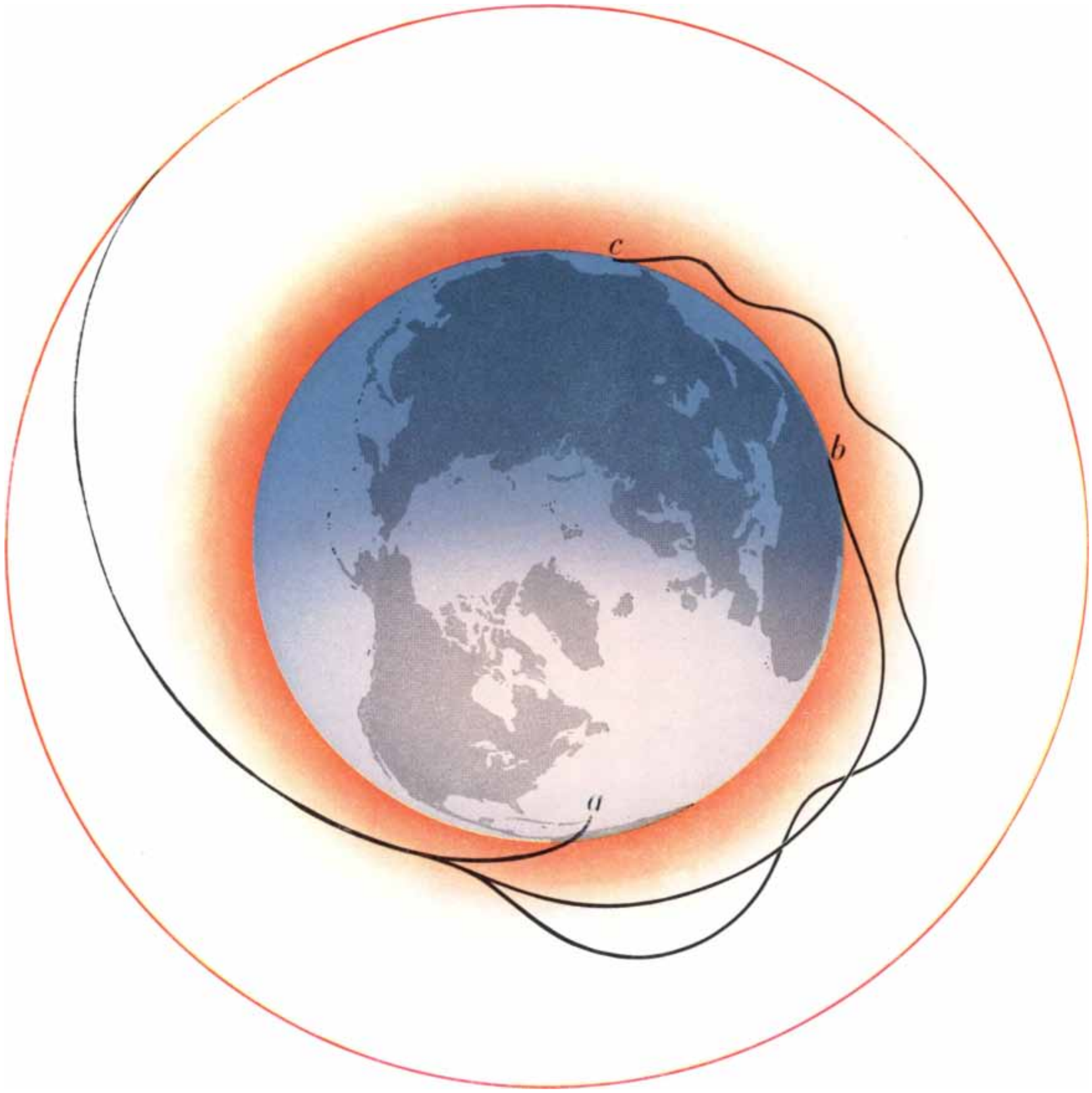
is no doubt that it can, but the technological difficulties are formidable.

The first manned craft to re-enter the atmosphere from space will come not from the moon or more distant points, but from satellite orbits a few hundred miles above the surface of the earth. Since they will be starting down at a speed of about 17,500 miles per hour, the problem of deceleration will be somewhat less severe. To get some idea of what is involved, consider the course that has been calculated for the vehicle to be used in Project Mercury—the operation of putting the first U. S. traveler into space and bringing him back again. To start the descent from orbit, a small retarding rocket will be fired, reducing the speed by only 1 or 2 per cent, but enough to deflect the path slightly downward toward the atmosphere. The vehicle will cover a horizontal distance of some 3,000 miles while dropping to an altitude of 60 miles, where it will encounter the first significant atmospheric effects. Now a shock wave will form just ahead of the blunt nose, heating the air in this region to about 11,000 degrees Fahrenheit. As the vehicle plunges into denser air, it will be increasingly heated by this enveloping layer of incandescent air. The surface of the heat shield on the nose will start to char, some of the material melting and vaporizing, and the metal afterbody will glow cherry-red at about 1,600 degrees. Climactic heating will come approximately four minutes after the first atmospheric forces are encountered. About 30 seconds later the decelerating force will reach its maximum of nine g (*i.e.*, nine times the force of gravity at the surface of the earth). Now falling almost vertically, the vehicle will descend to a height of two miles, where its parachutes will open and lower it to an uncomfortable but nevertheless tolerable impact.

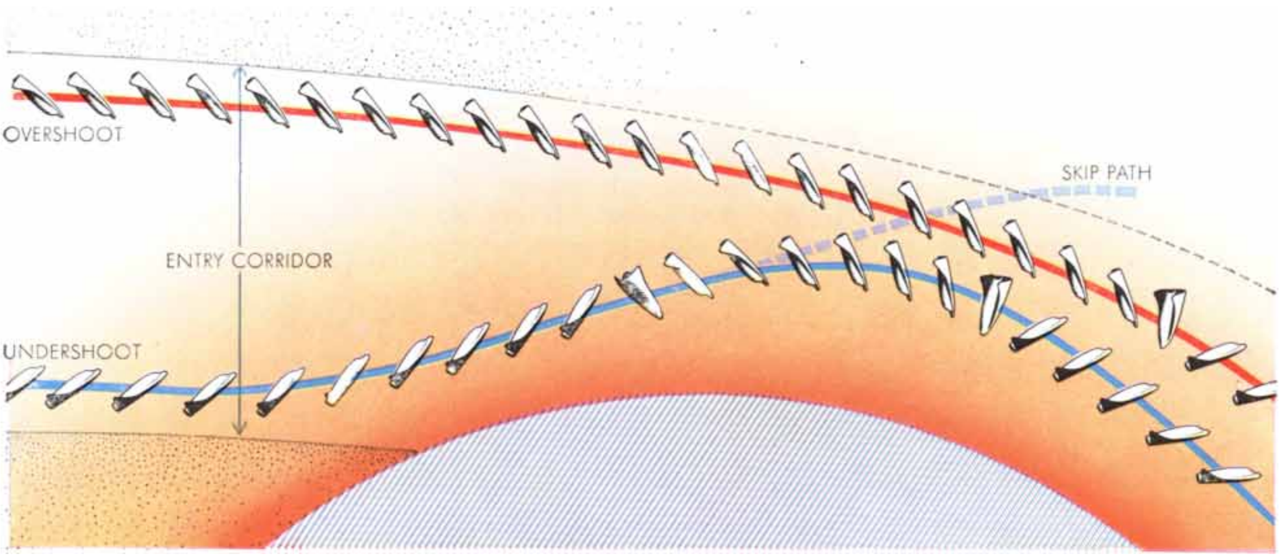
In this sequence, as in every case where braking force is provided by the atmosphere, all of the vehicle's enormous kinetic energy is converted into heat. At 17,500 miles per hour, the energy of a satellite is equivalent to about 13,500 B.T.U. (British thermal units) of heat for every pound of the vehicle's weight. Since kinetic energy depends on the square of velocity, the heat equivalent in a re-entry from the moon at 25,000 miles per hour is approximately twice as great. In absorbing one B.T.U. a pound of steel, for example, would heat up by about 10 degrees F. Thus a heat load of 13,500 B.T.U. per pound is several times more



SHOCK WAVE encloses the bright layer of incandescent air around the nose of a model of the Mercury capsule in a high-temperature shock tunnel. The maximum temperature in the shock layer is 10,000 degrees Fahrenheit. The pink glow to the left of the shock wave is reflected from the tunnel wall. The photograph was made by J. J. Jones of the Langley Research Center at Langley Field, Va.



RE-ENTRY PATHS (*black curves*) from a near-earth satellite orbit vary with characteristics of the vehicle. All paths start at the point where a retarding rocket is fired. Route ending at *a* is the "ballistic" path of a vehicle without lift. Those ending at *b* and *c* are, respectively, samples of paths that could be followed by vehicles with variable and with constant lifting power.



ENTRY CORRIDOR defines vertical limits for approach to atmosphere. Limits are widened by maneuvers to vary lift. By directing lift temporarily downward, vehicle can land from initial paths that would otherwise result in an overshoot or undershoot.

than enough to vaporize the space craft, its contents and any cooling system it could carry. Obviously a large part of the total heat of re-entry must somehow be diverted from the vehicle.

There are substantially only two ways to do this. The first is the one that applies in the re-entry we have just been describing: unloading a major part of the heat on the atmosphere by the action of strong shock waves. The second possibility is to radiate heat away from the hot surfaces of the craft. This technique fails when the rate of heating is too high, as it is in a comparatively dense, freely falling vehicle such as the Mercury capsule. Other types of manned space craft, that will be discussed later, will be able to cool themselves largely by radiation.

The diversion of heat by a strong bow shock wave is the result of molecular interactions in the air around the vehicle. When molecules strike the forward surface, they bounce back at high speed. Many of the rebounding particles collide with oncoming molecules, diverting them from the surface and preventing them from heating it by direct impact. The high-pressure, high-temperature buffer layer in which this happens is bounded on its forward surface by the shock wave. The wave extends a considerable distance into the atmosphere on either side of the body, leaving a broad wake of heated air that contains a major fraction of the total heat load. The heat that does reach the vehicle comes from the shock layer, mainly by conduction, diffusion and friction.

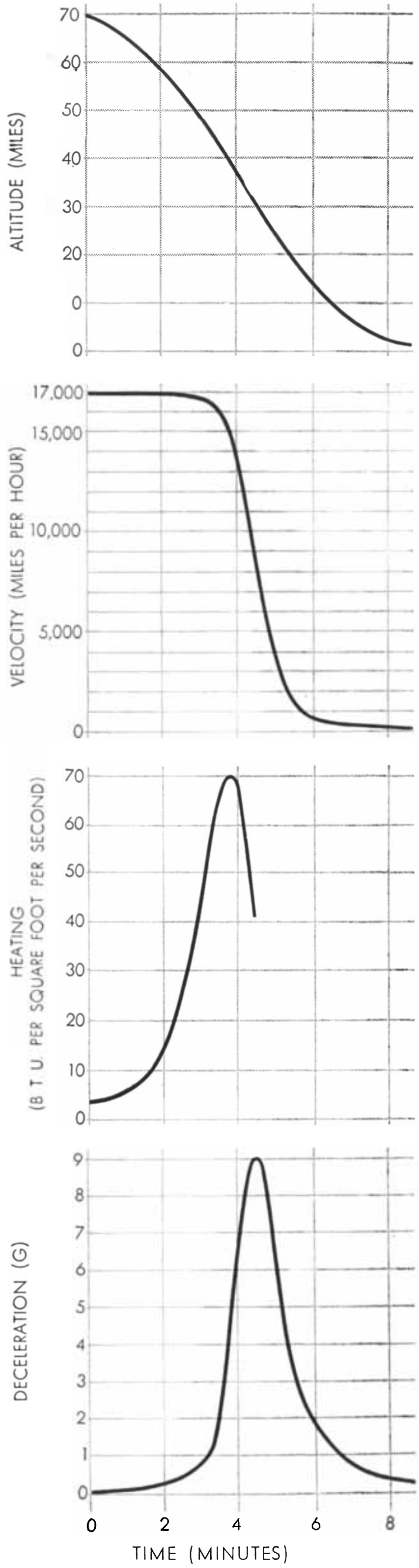
The stronger the shock wave, the larger the fraction of the total heat load that is transferred to the atmosphere, and the smaller the frictional component. For this reason a re-entry vehicle is given a blunt shape rather than the slender, streamlined configuration that has been the classic solution to aerodynamic problems at lower speeds. A broad nose area, advancing almost perpendicular to the direction of travel, produces maximum shock strength. In the case of the Mercury capsule the shock action diverts about 99 per cent of the heat energy, and furnishes 98 per cent of the decelerating force.

When the problem of re-entry from space was first studied seriously in the late 1940's, the unprecedentedly high gas temperatures that would be reached in the shock layer caused much concern. The temperatures are high enough to dissociate most of the oxygen molecules and a substantial fraction of the nitrogen molecules into separate atoms, and to ionize many of them. The chemical reactions that would take place among the fragments further complicated matters, and added to the uncertainty. Moreover, it was feared that the incandescent plasma would seriously heat the vehicle by direct radiation. In the past decade the problem has been thoroughly studied, both theoretically and by actual re-entry tests of missile nose-cones and models of the Mercury vehicle. It has been found that, for re-entry from satellite orbits, these processes do not affect heating significantly. At the higher speeds and higher temperatures of a return from the moon, however, radiation from the shock layer will constitute a substantial portion of the heat load.

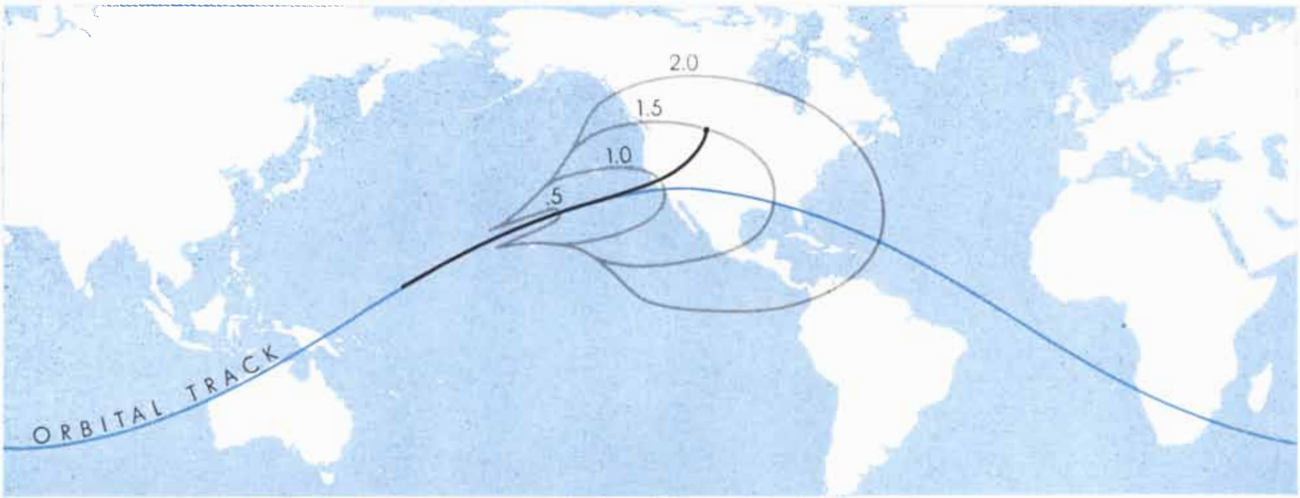
What happens to the heat that does reach the vehicle? In a blunt-shaped satellite it can be handled simply by making the metal skin thick enough to absorb the entire amount without exceeding the allowable temperature. But metals have low heat capacity, and so a considerable weight is required. For a lunar vehicle this simple approach will not work.

A far more effective technique is now available, which was discovered more or less by accident. Attempting to reduce the flow of heat into the metal, designers applied insulating layers of fiber glass and similar materials. They found that the heat-blocking action was much greater than expected; so great, in fact, that a heat shield constructed entirely of fiber glass, properly applied and bonded, turned out to be much lighter than the best metal heat-sink. Under intense heat the outer layer of this material chars, melts and vaporizes—a combination of processes collectively known as ablation. In itself ablation absorbs a good deal of heat, and in addition the vaporized material tends to block the flow of heat from the hot shock-layer into the body. The combined effects result in a heat capacity of 5,000 B.T.U. per pound or more. With ablation materials the heat shield of a ballistic satellite vehicle takes up no more than about 15 per cent of its total re-entry weight. Practical solutions for a lunar return also appear definitely within reach through the use of this technique.

The ballistic, blunt-nosed vehicle with an ablation heat shield is one of the lightest, and certainly the simplest solution of the re-entry problem that can be achieved. Nevertheless, we find ourselves less than satisfied with it, especially for manned vehicles. It has several undesirable features: a decelerating force



ENTRY OF MERCURY capsule is summarized in these graphs. The time scale on the horizontal axes begins when the capsule has descended to an altitude of 70 miles, shortly before it is exposed to substantial atmospheric forces. B.T.U. stands for British thermal unit, and g for a decelerating force equal to gravity at the earth's surface.



VARIATION IN LANDING POINT that can be achieved by vehicles with lift, starting their maneuvers at a given position in the orbit, is indicated by gray curves. Numbers refer to the ratio of lift to drag (*L/D*). Each curve traces possible landing points for constant *L/D*. Varying the ratio allows landings within the contours. Black line traces a typical maneuver using an *L/D* of 1.5.

near the limit of human tolerance; the requirement of a very flat entry path; a sizable uncertainty in the point of impact, perhaps as much as 100 miles; and finally all the hazards and discomforts of a parachute landing.

In attempting to find better solutions it is natural for the designer to turn to lift—the source of many desirable properties in low-level flight. Lift is the component of aerodynamic force that acts at right angles to the flight path. It is what holds an ordinary airplane up. Applied to a vehicle re-entering the atmosphere from space, lift can reduce the rate of descent, thus lengthening the path to the ground and decreasing the maximum deceleration and the rate of heating. Alternatively, if high deceleration is accepted, the use of lift allows the vehicle to enter the atmosphere at a much steeper angle.

The performance of any lifting body depends on its "*L* over *D*": the ratio of its lift to its drag, or the retarding force acting along the flight path. The slenderer the shape, the higher the value attainable of *L/D*. For a given shape the ratio can be altered by changing the "attitude," that is, by tilting the body up or down with respect to its flight path.

As the illustration at the top of this page shows, vehicles with an *L/D* of no more than 2 can be landed anywhere in an area extending thousands of miles, both forward and laterally, from a given entry point. (The pattern has come to be known as "Dyna-Soar footprints," after Project Dyna-Soar. The name is short for "dynamic soaring"; that is, gliding at very high speeds, where the centrifugal force in the curved path around the earth supports a major part of the glider's weight.) By banking the vehicle and varying its attitude, it can be brought down at any spot within the extremes of the range. Such variable-lift maneuvers also can reduce the peak deceleration below that attainable with a constant *L/D*.

What penalties must be paid for these advantages? The first is a greater heat load. As we have mentioned, slender, low-drag shapes produce weak shock waves and therefore themselves take up a large fraction of the heat produced in deceleration. At an *L/D* of 2, for example, a vehicle must accept 10 to 15 times more heat per pound than the Mercury vehicle. The second penalty for the use of lift is increased weight. This arises in part from the structural requirements of a long, thin shape and in part from the larger quantity of heat involved.

Even the best ablation materials are

	1	2	3
			
LIFT/DRAG RATIO	0	1/4	1/2
RELATIVE WEIGHT (FOR EQUAL PAYLOADS)	1	1.2	1.3
WEIGHT/AREA (POUNDS PER SQUARE FOOT)	50	60	60
ALTITUDE FOR MAXIMUM HEAT-RATE (MILES)	38	40	42
MAXIMUM NOSE-TEMPERATURES (DEGREES F.)	3,200	3,200	3,200
MATERIALS	CERAMIC; NICKEL-CHROMIUM ALLOY		CERAMIC; COBALT-BASE ALLOY

POSSIBLE DESIGNS of re-entry vehicles vary from blunt-nosed Mercury type with no lift (1) to slender, high-lift shape resembling present hypersonic airplanes (7). The greater inadequate to protect against the total heat load of a lifting vehicle. Fortunately the rate of heat production can be made low enough to allow radiation cooling. Instead of a heavy, thick shield, a radiation-cooled design has a thin metal skin with negligible heat capacity. The temperature of the skin adjusts itself instantaneously to the rate at which heat is applied, keeping the outflow equal to the inflow. The only proviso is that the temperature in this equilibrium situation must not exceed the capability of the metal.

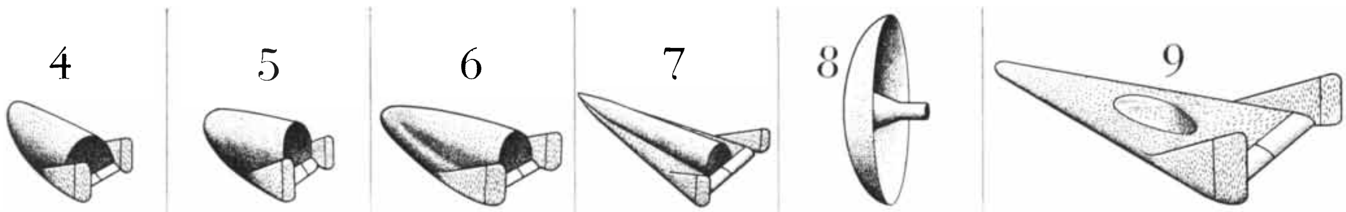
Once he has settled on a particular shape, the designer can control the rate of heat production, and thus the maximum skin temperature, by varying the area loading, that is, the weight per square foot of wing area (or frontal area in the case of a ballistic vehicle). Decreasing the loading means that the vehicle will begin to decelerate at higher altitude, in thinner air. This in turn reduces the rate of heating due to atmospheric friction.

With conventional rigid metal structures the lowest maximum surface temperatures attainable range from about 2,400 to 3,200 degrees F. These values are too high for even the best of the usual high-temperature metal alloys, and thus skins made of refractory metals such as molybdenum, or of ceramics, are required in critical areas such as the nose and leading edges of re-entry gliders. In order to get down to 1,400 degrees, where common materials can be used, the loading must be reduced to three or four pounds per square foot. This will require radical innovations in design, perhaps incorporating thin metal membranes of inflatable metal mesh [*see last two columns of illustration below*]. Such structures would be so large and fragile, however, that they would have to be collapsed for launching, and could be erected only in orbit.

There is thus a wide spectrum of possibilities for satellite re-entry vehicles. They range from the ballistic type with an L/D of zero to gliders with a ratio of perhaps 1.5. The latter are capable of a conventional low-speed landing at a large airport—a "dead-stick" landing from space! Beyond 1.5 the increase in maneuverability is probably not worth the additional weight and heat load. Although the high-lift re-entry designs will be evolutionary descendants of the graceful, sharp-nosed, thin-winged supersonic aircraft of today, they will not look much like their ancestors. An L/D ratio of 1.5 can be achieved with a short, stubby design—much smaller over-all for a given passenger capacity. Its thick, rounded "wings" will be much better adapted to extreme heating conditions than the knifelike structures of present airplanes.

At present we cannot predict with any confidence what the standard re-entry vehicle of the distant future will look like. As to the short-term line of development, there are two schools of thought. One favors the ballistic vehicle (or at most a very low-lift vehicle) because of the advantage in weight. The crude features of ballistic re-entry are considered acceptable to the trained explorers who, for years to come, will be the only human beings venturing into space. The other school considers ballistic hardships unnecessary, and holds that the added weight of lifting vehicles is more than compensated by their low deceleration and maneuverability. Furthermore, the argument goes, more powerful rocket boosters, to be expected in a few years, will relax the current limitations on weight.

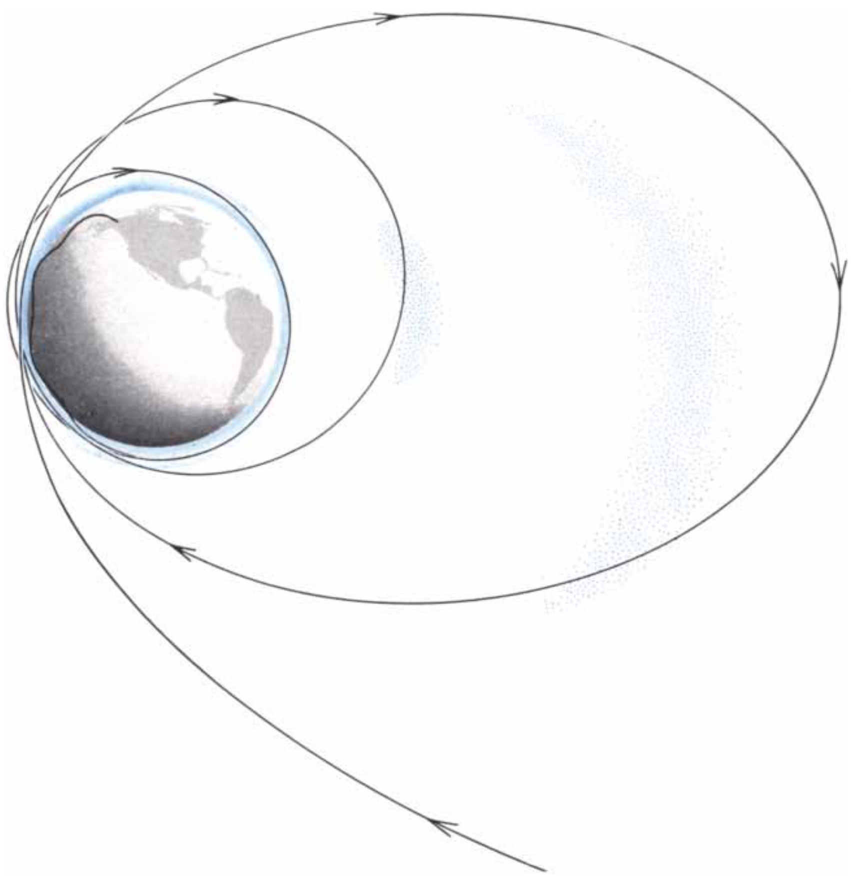
The designers of the Mercury vehicle were obviously not concerned with these arguments. Limited by the capabilities of present rockets, they had no choice but to minimize weight; hence they adopted a ballistic vehicle. Interestingly enough, however, the disk-shaped



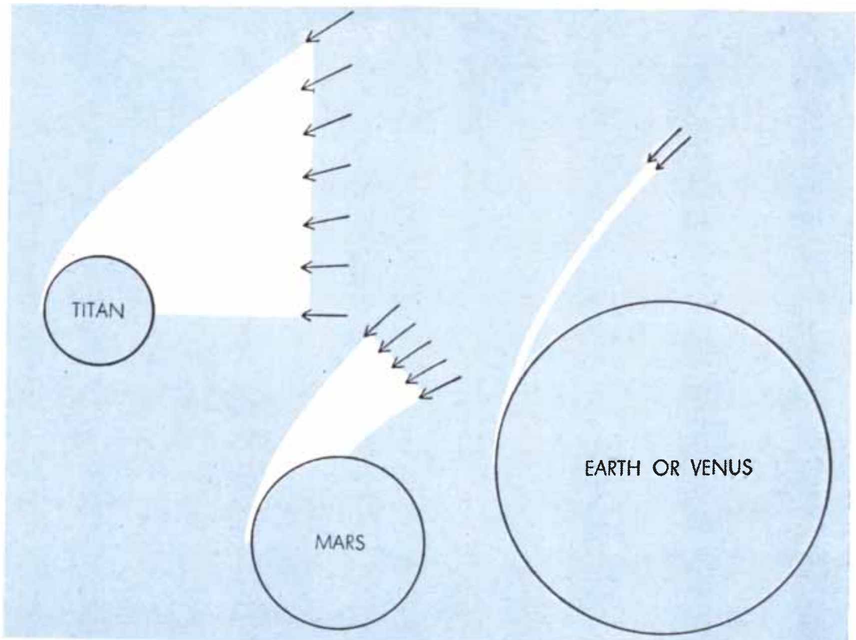
	4	5	6	7	8	9
	½	1	1½	2	0	1
	1.3	1.5	1.6	1.7	1	2
	60	60	60	30	3	3
	42	43	44	46	50	60
	3,200	3,400	3,400	3,600	1,400	2,000
		CERAMIC; COATED GRAPHITE; COATED MOLYBDENUM; NICKEL-CHROMIUM ALLOY			NICKEL-CHROMIUM ALLOY WIRE MESH (ERECTED IN ORBIT)	

the lift, the greater the penalty in weight and in heating. The designs numbered 8 and 9 represent a radical approach to heating problem.

Thin and fragile surface materials reduce ratio of weight to area so that deceleration occurs in thinner air and friction is reduced.



MULTIPLE PASSES through the atmosphere represent a possible mode of re-entry from the moon or more distant points. Heat developed on each approach is radiated away on next loop. Method involves repeated passage through high-radiation belts (*stippled areas*).



POSSIBLE APPROACH PATHS, for a vehicle with lift, to Venus, Mars and Titan (a moon of Saturn) lie within white areas. The scale is approximately one inch to 4,000 miles.

forebody of the Mercury capsule can itself be made to generate lift. Simply by tilting the capsule forward an L/D of one-fourth is obtained. And if the afterbody is shortened so as to keep it out of the direct airstream at high angles of tilt, an L/D of one half or more can be attained. Lens-shaped objects of this kind, quite similar to the legendary "flying saucer," are being considered for round-trip lunar journeys.

It has already been pointed out that the conditions for re-entry from the moon are more rigorous than for satellite orbits. Consequently the choice of techniques is more limited. Let us consider first the "simple" case of a ballistic re-entry. Approaching at a speed of 25,000 miles per hour, the vehicle should ideally enter along a path inclined downward about five degrees to the horizontal at the "top" of the atmosphere. Because it is traveling faster than the Mercury vehicle, and along a steeper path, its deceleration will reach a sizable value sooner. Although a large decelerating force persists for a longer time (about three minutes), the peak value is lower (only six times the force of gravity). The total interval between entry and landing is less than for a satellite.

So much for the ideal path. But suppose the approach path of our craft fails to intersect the atmosphere at exactly the right point. If it comes in as little as four miles too high, it will fail to slow down enough and will pass out into space again. If it is four miles too low, the deceleration will exceed the tolerance of the passengers, if not of the space craft. Thus at the end of the 250,000-mile trip from the moon, the ballistic vehicle must hit an atmospheric target or corridor only eight miles high. This requires a launching accuracy from the moon many times better than the best that can now be achieved with ballistic missiles.

Parenthetically it may be noted that until recently an overshoot path was considered a good way to come back from the moon or more distant points. Each pass through the atmosphere would slow down the vehicle a little, so that it would return again and again in a series of successively shorter ellipses [*see top illustration at left*]. In this way the heat problem would be solved piecemeal, heat taken aboard on each approach being radiated away during the next outward journey. The scheme lost its attractiveness for manned flight with the discovery of the Van Allen belts, and the realization that repeated crossings of these zones would result in exposure to heavy radiation.

To widen the entry corridor appreciably we must have recourse to lift [*see bottom illustration on page 52*]. In extending the upper limit by the greatest possible amount, the lifting force is reversed: The vehicle approaches the atmosphere upside down, so that it is pulled downward. As its speed decreases the downward force is decreased, until finally, at about 17,000 miles per hour, the vehicle rolls over into the normal position. On the underside of the corridor the approach is made with maximum upward lift, which is reduced when the maximum allowable deceleration has been reached. At this point the vehicle is headed upward again, and it will skip out into space unless it rolls over to direct the lift downward. After slowing down to satellite velocity, the vehicle flips over again and enters its final glide right side up. By means of such sophisticated maneuvers the entry corridor can be widened to about 130 miles, with a maximum L/D of 1.5.

Landing on other planets of the solar system presents an analogous problem to a return to earth from deep space. The entry characteristics are different for each of the bodies, however, because of the wide variations in their diameter and gravitational force, which determine the entry velocity, and because of the great dissimilarity of their atmospheres. Enough is now known about the atmospheres of Venus, Mars and Jupiter [*see table on this page*] to allow some predictions on their entry problems.

Aside from our moon, the nearest and most important objectives for manned exploration are Venus and Mars. Looking first at Venus, with its atmosphere of carbon dioxide and nitrogen, we are impressed with the close similarity of the escape velocity and other factors affecting entry to those of the earth. (For purposes of comparison we assume that entry will be made at the escape velocity.) A major difference, however, is the dense layer of cloud that perpetually covers the surface. It will not be possible to select a favorable landing site beforehand, and the payload will have to include instruments and equipment for a blind landing. Fortunately the high density of the Venusian atmosphere will reduce the actual landing speed to a fourth of that for the earth.

Mars is generally considered the most attractive and hopeful planet for initial manned exploration. Its atmosphere is by far the easiest of any planet to enter because the small mass of the planet results in the low escape velocity of only 11,400 miles per hour. In addition, the density of the atmosphere increases slowly with decreasing altitude, providing a softer cushion that stretches out the period of deceleration and reduces the peak deceleration. At the surface, however, the atmosphere is only about one-twelfth as dense as that of the earth; therefore the landing speed would be about twice as high as on earth. The atmosphere is mostly clear, so that the terrain can be reconnoitered and the landing made visually. From the heating standpoint a Martian entry at escape speed will be less difficult than a low-orbit satellite entry into the earth's atmosphere. An extremely wide corridor is achievable—about eight times wider than the corridors of the earth or Venus.

The giant planet Jupiter presents so many forbidding obstacles to exploration, and so little potential reward, that any attempt to send a manned vehicle there seems quite unlikely. Jupiter's surface is thought to be entirely covered with chemical ices, and its stormy atmosphere is largely beclouded by ammonia crystals. So far as decelerating force is concerned, a lifting vehicle would have an entry corridor about as wide as that of the earth. But it would approach the Jovian atmosphere at the fantastic speed of 135,000 miles per hour, with 60 times the kinetic energy of an earth satellite. No presently conceivable design could possibly dispose of this much heat energy.

Some of the distant moons of the outer planets furnish more attractive targets for manned vehicles than these planets themselves. Titan, one of the moons of Saturn, is of special interest. About the same size and weight as our moon, it has the added advantage of an atmosphere. With an escape velocity of only 6,700 miles per hour, all conceivable approach paths appear to be feasible, even one heading straight in at 90 degrees to the horizontal.

The details of these predictions are still speculative because they rest on crude and incomplete information about the planetary atmospheres. Before manned landings are attempted much more data will have been collected, by telescopes in satellites and by instrumented space probes. Even now, however, we can confidently say that the atmospheres of Mars and Venus, like that of the earth, will be extremely helpful to explorers of space.

	VENUS	EARTH	MARS	JUPITER	TITAN
RADIUS (PER CENT OF EARTH'S RADIUS)	97	100	53	1,100	33
FORCE OF GRAVITY (PER CENT OF EARTH'S GRAVITY)	87	100	38	263	22
ESCAPE VELOCITY (MILES PER HOUR)	23,000	25,000	11,400	135,000	6,700
PRINCIPAL GASES OF ATMOSPHERE	CO_2, N_2	N_2, O_2	N_2, CO_2	CH_4, NH_3, H_2, He	CH_4, NH_3
AVERAGE TEMPERATURE OF ATMOSPHERE (DEGREES FAHRENHEIT)	10	–20	–30	–235	–230
SURFACE DENSITY OF ATMOSPHERE (PER CENT OF DENSITY OF EARTH'S ATMOSPHERE)	1,300	100	8	?	?
ALTITUDE WHERE ATMOSPHERE HAS 10 PER CENT OF ITS SURFACE DENSITY (MILES)	9	10	26	26	43

DIFFICULTY OF LANDING on various bodies of the solar system is chiefly determined by the characteristics listed in this table. The principal gases are carbon dioxide (CO_2), nitrogen (N_2), oxygen (O_2), methane (CH_4), ammonia (NH_3), hydrogen (H_2) and helium (He).

THE MECHANISM OF IMMUNITY

How does an animal make an antibody that neutralizes a single foreign substance, or antigen? The evidence favors the theory that cells able to make the antibody are "selected" by the antigen and then multiply

by Sir Macfarlane Burnet

Deliberate defense against infectious disease started in the late 18th century with Edward Jenner's discovery of the principle of immunity, so triumphantly demonstrated by the success of Jenner's vaccine against smallpox. Today the technique of immunization provides protection against all the significant diseases that have not been eliminated by public-health measures or that do not yield readily to chemotherapy. Much public-health work remains to be done, particularly in the underdeveloped areas of the tropics, but without important exception man can now control all the infectious diseases that seriously threaten human life.

Although the practical problems of immunization have been solved, immunology remains an important branch of medicine. The immunologist of today, however, is not so much interested in finding out how to immunize people more effectively against diphtheria or poliomyelitis as he is concerned with understanding what happens when people become immune. He asks more sophisticated questions than in the past. For example: Why can a surgeon successfully graft skin or other tissue from one part of the body to another but not from one individual to another, except in the case of grafts between identical twins? How is it that occasionally a pair of fraternal (nonidentical) twins share two blood groups and accept skin grafts from each other? How can an individual who had suffered a single attack of a virus disease 20, 30 or even 60 years ago continue to produce antibody against the virus? And why are there "autoimmune" diseases, such as rheumatoid arthritis, acquired hemolytic anemia and Hashimoto's disease of the thyroid, in which an abnormal immune reaction is directed against the body's own cells and tissues? Any modern formulation of immunological theory must supply at least provisional answers to these and other equally complex questions.

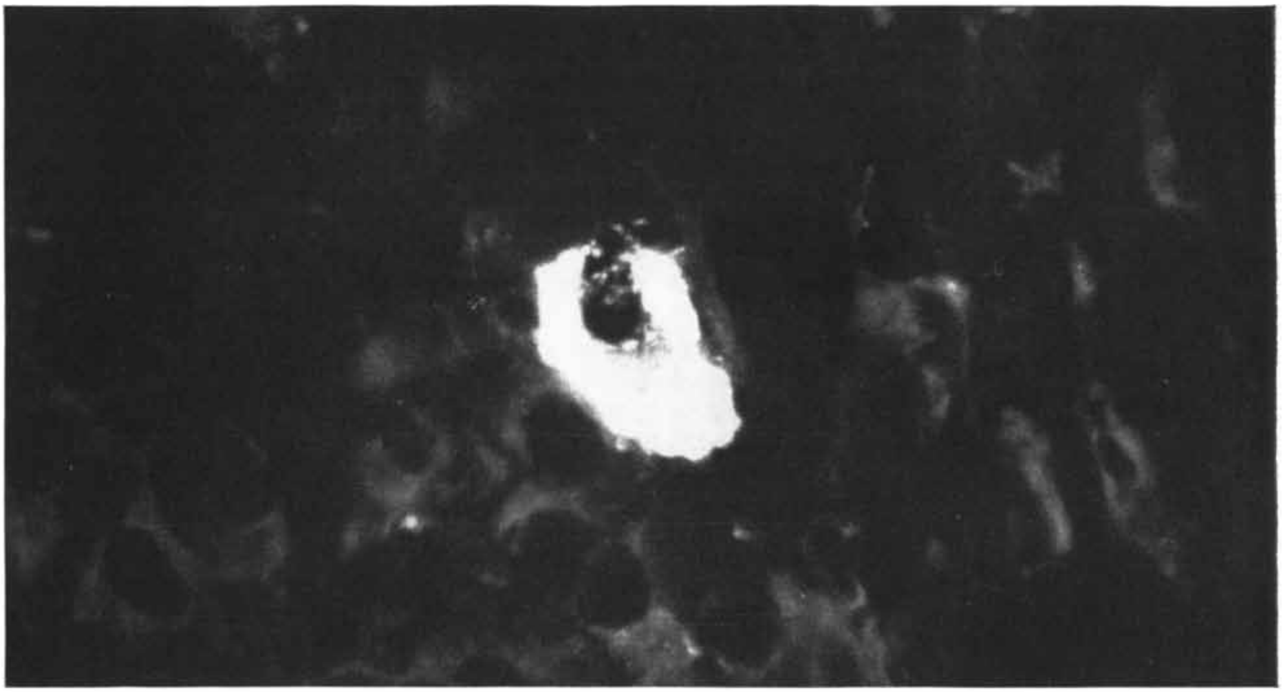
But immunology is not simply a branch of medicine. It is a discipline in its own right, potentially able to make a rich contribution to the understanding of the central problems of biology, notably the nature of genetic information and the mechanism of protein synthesis. Both of these problems are intimately tied to any theory of immunity.

In its modern form orthodox immunological theory holds that the central feature of immunity is the production of antibody by a specialized group of tissue cells known as plasma cells. Antibody is a globular protein of blood plasma which can be identified by its physical behavior as a "gamma globulin." Each antibody has a highly specific affinity with the particular antigen which stimulates its production. An antigen may be part of a virus, bacterium or foreign tissue cell, or a fragment of some such structure, a protein or a polysaccharide (a large molecule made of many simple sugar units). Antibody protects the organism against a foreign substance by combining with it and thereby rendering it inactive.

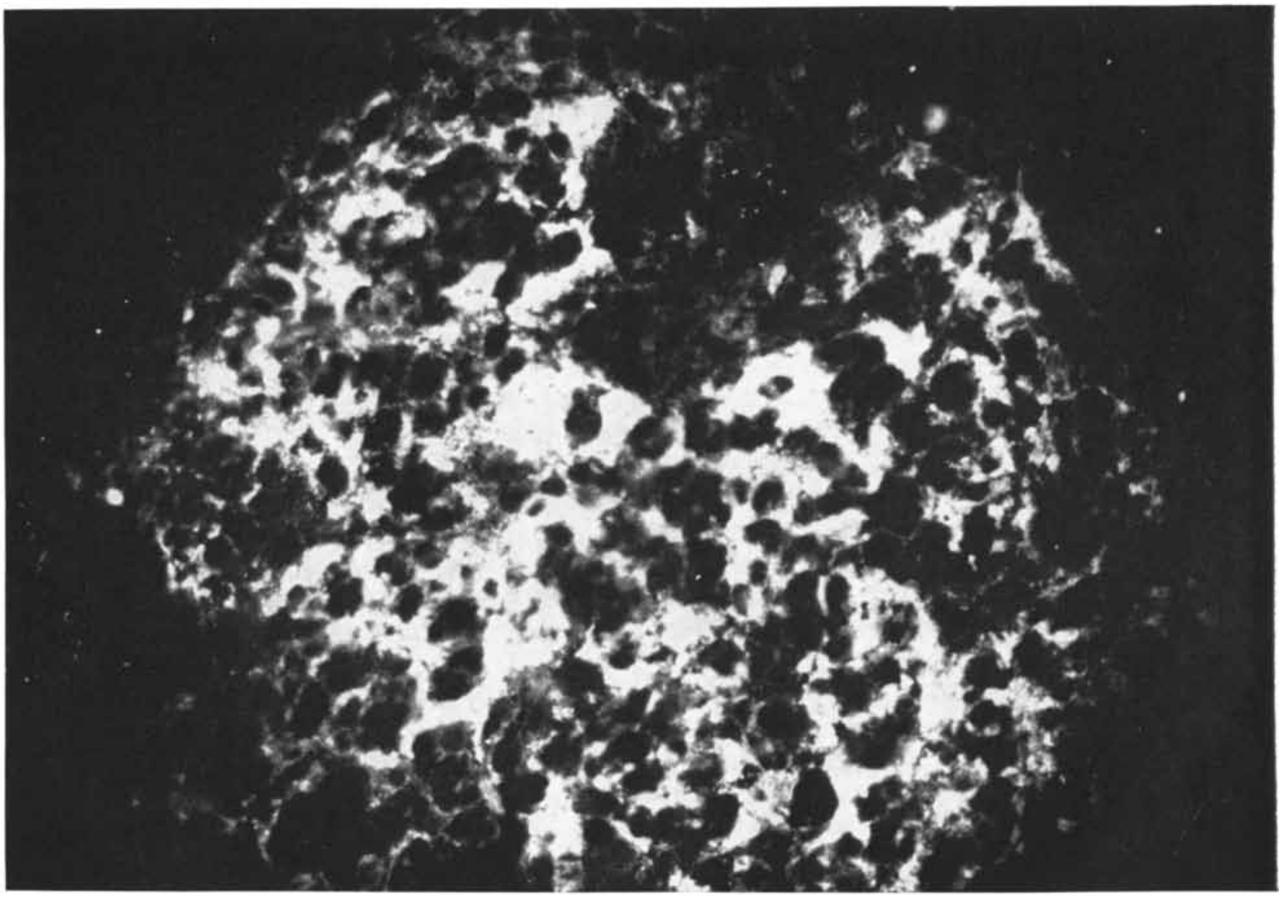
Antigen and antibody are both large in the chemical sense, that is, the molecules of both consist of a great many atoms. Antibody globulin has a molecular weight of about 160,000 (10,000 times the weight of the oxygen atom). Typical antigens are of the same order of size. The sites of chemical activity which bring antibody and antigen together into combination, however, represent relatively small portions of these complex molecules. A single site may be thought of as equivalent to the region occupied by three to five of the several hundred amino-acid units in an average protein (a protein being composed of combinations of any of 20-odd different amino acids), or an equally small number of the monosaccharide units in a polysaccharide. These small regions of active union are called antigenic determinants on the antigen and specific patches on the antibody. According to the classical theory, the two combine because the geometrical configuration of the specific patch is complementary to the pattern of the antigenic determinant. They fit each other just as a particular key matches its lock. In this scheme, which bears the strong imprint of such figures as Paul Ehrlich, Karl Landsteiner and Linus Pauling, the specific patch on the antibody acquires its pattern by being synthesized in contact with the antigenic determinant. The antigen itself is presumably taken into the cell and comes into action after the amino-acid units of the globulin molecule have been assembled by the cell's machinery of synthesis and are in process of being folded into globular form. At the folding stage the globulin is brought into contact with the antigen and is molded into the required complementary pattern.

This is the simplest form of what Joshua Lederberg of Stanford University has called the "instructive" theory of antibody formation: the antigenic determinant itself supplies the information from which each highly specific antibody is constructed. The instructive theory does not, however, account satisfactorily for several significant processes associated with immunity, such as the persistence of immunity and the origin of the autoimmune diseases. A fundamentally different view has accordingly been advanced by the proponents of the so-called selection theory.

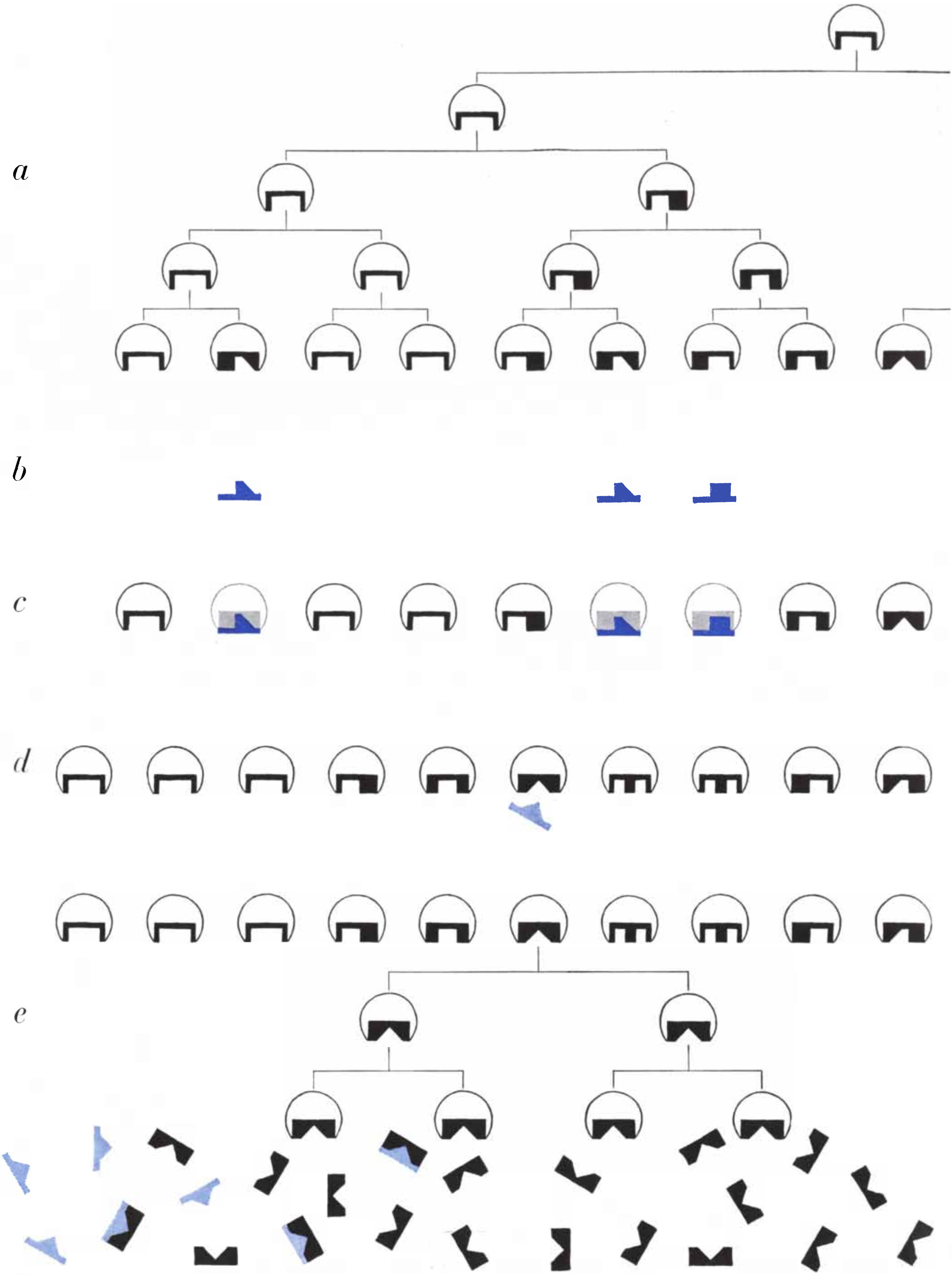
This theory holds that antibody molecules are made in essentially the same way that other proteins are synthesized,



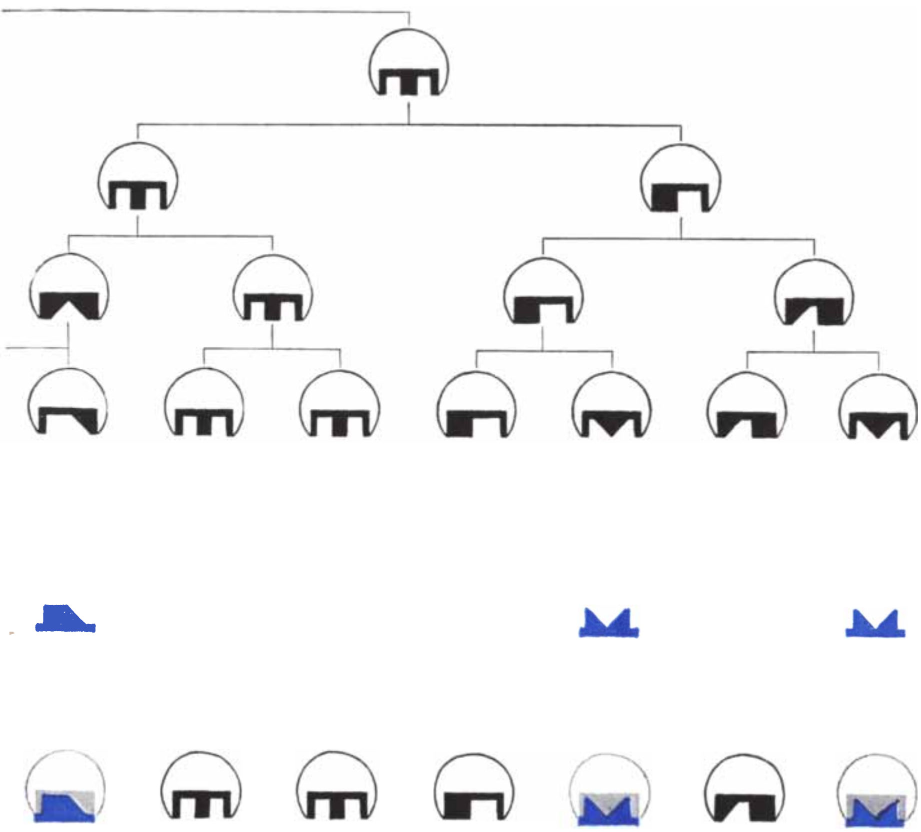
MATURE PLASMA CELL containing rheumatoid factor is made visible by reaction with a fluorescing compound. Neighboring cells have no rheumatoid factor, hence do not combine with fluorescing compound and are barely visible. Interpretation according to selection theory would be that fluorescing cell "inherited" a particular antibody pattern which is carried in its genetic material.



NODULAR AGGREGATION of cells in lymph node fluoresces because cells contain rheumatoid factor, a giant molecule with antibody-like characteristics found in blood of majority of patients with rheumatoid arthritis. It may indicate an autoimmune response. The photomicrographs were made by Robert C. Mellors, Hospital for Special Surgery, New York Hospital-Cornell Medical Center.



a
b
c
d
e



SELECTION THEORY OF IMMUNITY proposes that early in embryonic life immunological cells mutate frequently (*a*), producing all possible antibody patterns, represented here by only 11 different symbols. Some will match antigens native to the body (*b*). These antigens will kill immunological cells having the complementary pattern (*c*), leaving only the cells with antibody patterns which correspond to foreign antigens (*d*). When these cells have matured, a foreign antigen reaching one of them (*d*) stimulates it to proliferate rapidly (*e*). Its descendants produce antibody which combines with and inactivates foreign antigen.

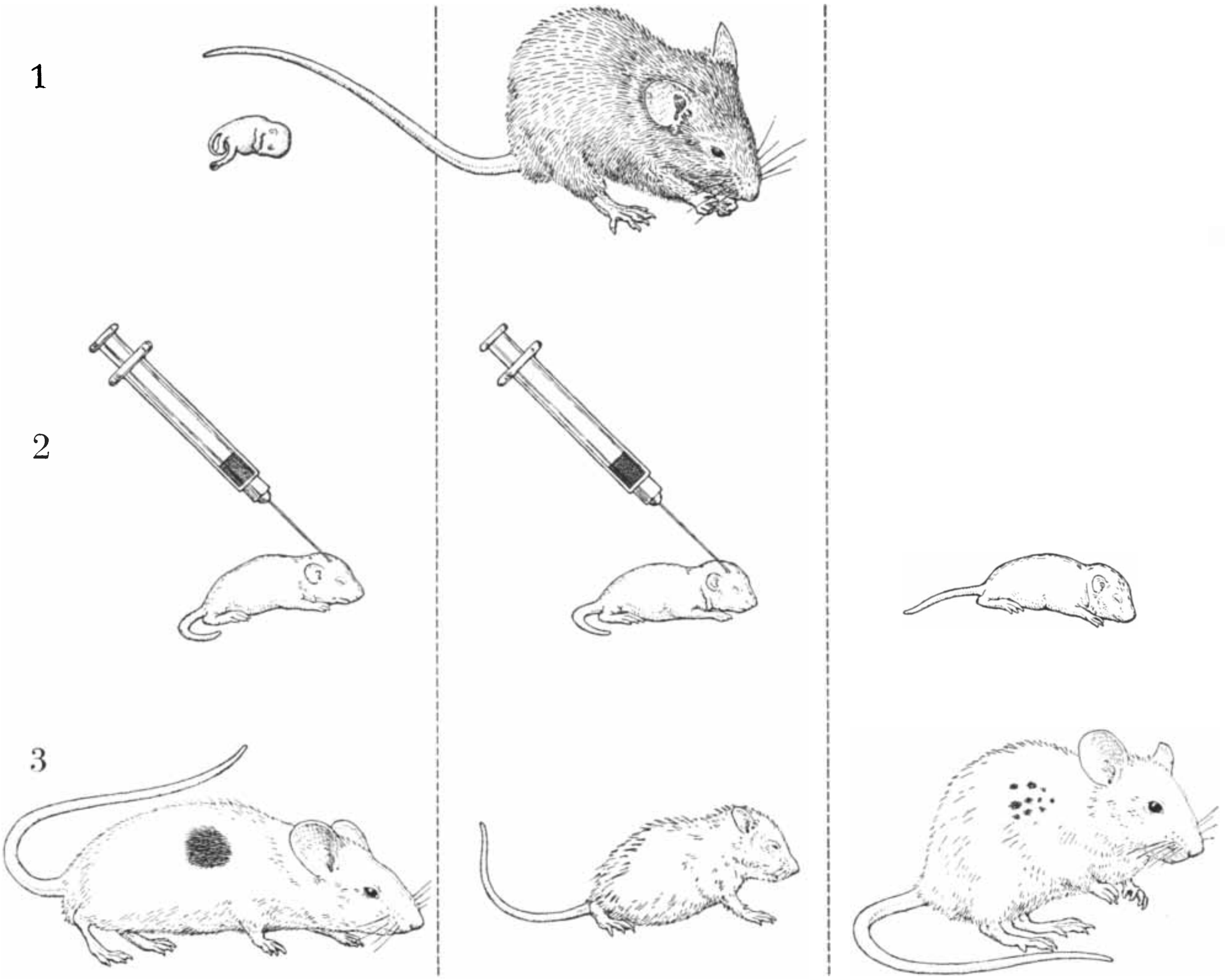
that is, according to genetic instructions contained in the nucleus of the manufacturing cell. At no time does information enter the cell from outside. Instead, for each one of the thousands of possible foreign antigens, the body already contains a cell or group of cells genetically capable of synthesizing the appropriate antibody. Each of these cells or groups of cells "knows" how to make the specific antibody even if the complementary antigen never enters the body. The function of the antigen is simply to select and stimulate the proliferation of the appropriate group of cells, thus increasing production of the required antibody.

The idea of selection has been central to biology ever since the publication of the *Origin of Species*: The environment selects among organisms for the differential survival attributes or potentialities which are conferred upon them by genetic processes. The sun does not breed maggots in a dead dog unless the fertilized fly deposits the necessary genetic information in the carrion. No one now seriously argues that evolution produced the whale and the giraffe by the Lamarckian formula according to which function in the environment molds form—first physically and then inheritably—in the right direction. Recently, however, some investigators have held that bacteria show a wide capacity to produce "adaptive" enzymes on demand. It was indeed observed that bacterial cultures can start producing new enzymes when presented with unusual substances in their nutrient. But it soon became clear that adaptive-enzyme formation is a much subtler phenomenon. Current interpretation tends toward the view that a bacterium can produce a given enzyme only if the necessary information is incorporated in its genetic mechanism; the experimental change in the environment allows the emergence into activity of what was formerly only a latent capacity.

It is likely that views of antibody formation will change in the same direction, toward a wider acceptance of selection theories. Certainly this approach leads more directly to the central process in immunology, which I defined a long time ago as the differentiation between the self and the not-self. The body does not normally produce antibodies against its own tissues, although it is at least potentially capable of producing antibodies against any protein or any other substance of appropriate molecular character that is not present in the body. The implications of this fact are the most important reasons for favoring a selection theory of immunity.

Most proteins are antigenic to an organism that has not been concerned in producing them. At the present time only one protein is known well enough to permit a comparison of its chemical structure with its immunological activity. This is insulin, one of the smallest proteins; the full sequence of amino-acid units has been worked out for the insulins of several animal species. Of course insulin is not antigenic in the animal that produces it, and it also happens that it is a rather mild antigen. Most diabetics can receive beef or sheep insulin for years without any trouble. Some, however, become resistant to insulin because they are making antibodies against it. This difficulty can usually be circumvented by using pig insulin. The difference between beef insulin and pig insulin is known [*see illustration on pages 64 and 65*]. Of the 51 amino-acid units in the insulin molecule, 48 have the same arrangement in the insulins of different species; the sequence of units in one segment of three units varies. If an insulin is antigenic for a mammal, it is because this sequence differs from the corresponding sequence of the animal's own insulin.

In these days when genetics has come so close to biochemistry it is worth pointing out that an antigen, like a gene, is a purely relative concept. A gene is an entity devised to explain an observable hereditary difference between two interbreeding stocks or individuals. Long stretches of a chromosome must remain genetically silent if there are no regions of observable difference between available stocks. An antigen, or more strictly



GRAFT AND HOST INTERACT in mice. At left spleen cells from embryo mouse of strain B (1) are injected into newborn mouse of strain A (2). Later skin graft from B takes on A (3), showing mutual tolerance of host and graft. In center spleen cells from adult mouse A are injected into second newborn B mouse, which develops runt disease (3) because injected cells set up immune response to it. Third newborn B mouse (*right*) receives no injection at birth to establish tolerance, later (3) rejects skin graft from strain A.

an antigenic determinant, is also an expression of difference. It contains certain patterns which differ from any pattern present in the animal in which it is tested for antigenicity. In one kind of animal one part of a foreign protein molecule may be antigenic; in another species an entirely different segment of the same molecule may stimulate the antibody reaction.

Even though insulin is a poor antigen, it still presents rather clearly the central question: How does the insulin-resistant diabetic "recognize" the tiny difference between beef insulin and his own insulin and so make antibody against the former? Basically this is a problem of information. How does the body acquire or generate the information needed to distinguish foreign chemical configurations from its own?

The most important clue is provided by experimental manipulations that trick an organism into accepting as its own a substance or a cell that genetically speaking has no right to be there. Probably the most impressive example comes from the rare experiments of nature by which genetically dissimilar human twins share a common placental circulation in their mother's uterus. This will ensure that each twin receives a variety of cells from the other, including cells that can settle down in the bone marrow and multiply to produce the red blood cells. Three pairs of such twins have been recognized in adult life. When their blood was typed prior to their acting as blood donors, they were found to have two blood groups: their own and that which was genetically appropriate to their twin. Such fraternal twins have a second striking difference from an ordinary pair of dissimilar twins. Fraternal twins who have developed in the usual fashion from two separate placentas will not accept skin transplants from each other. An immune reaction kills the grafts. But fraternal twins with double blood groups (at least the only pair of twins so far tested) have been found to accept cross skin-grafting as happily as if they were genetically identical twins. This indicates that self-recognition in the antibody-producing system is not due simply to hereditary traits. Rather, self-recognition seems to develop as a secondary process sometime during embryonic life.

Much work has been done in recent years on the experimental demonstration of immunological tolerance, most often in mice and rats. Laboratories now possess many lines of mice so inbred and so similar genetically that each individual will accept grafts of skin or other tissue from any other member of its strain. Two very illuminating experiments can be carried out with two suitable strains: A and B. In both experiments an emulsion of living cells from a mouse of strain B is inoculated into a vein on the face of a newborn mouse of strain A. This requires steady hands and a good eye, but it is done routinely.

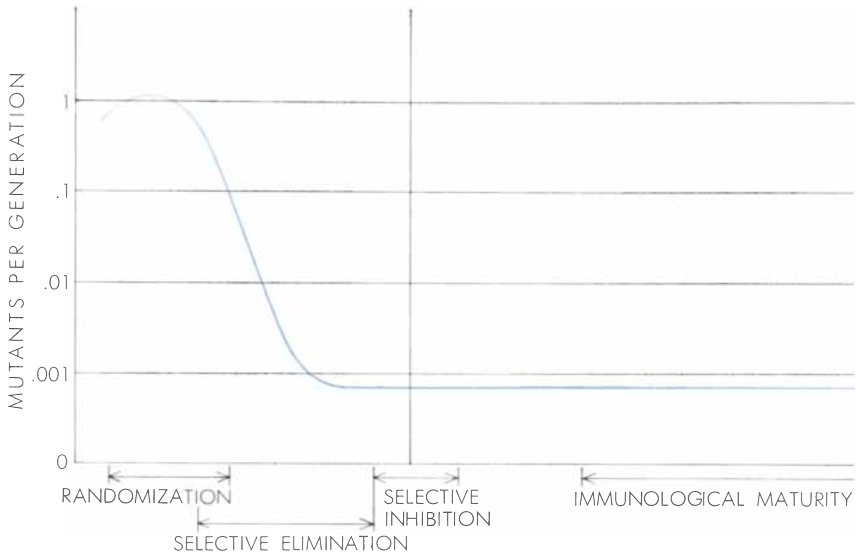
In the first experiment cells from the spleen and kidney of an embryo of mouse B are inoculated into a newborn mouse of strain A. The mouse develops normally. If a piece of B skin is grafted to the mouse when it is sufficiently grown, the graft "takes" and persists in a healthy condition. If the A mice are white and the B mice are black, the A mouse presents the unprecedented anomaly of a patch of healthy black hair.

In the second experiment another mouseling of strain A is inoculated with cells from the spleen of an adult B mouse, not an embryo. The result is disastrous. Depending upon the number of cells and the particular pair of mouse strains being used, the mouseling either dies within two or three weeks or develops slowly into an undersized, scruffy-looking individual suffering from what has been called runt disease [*see illustration on opposite page*].

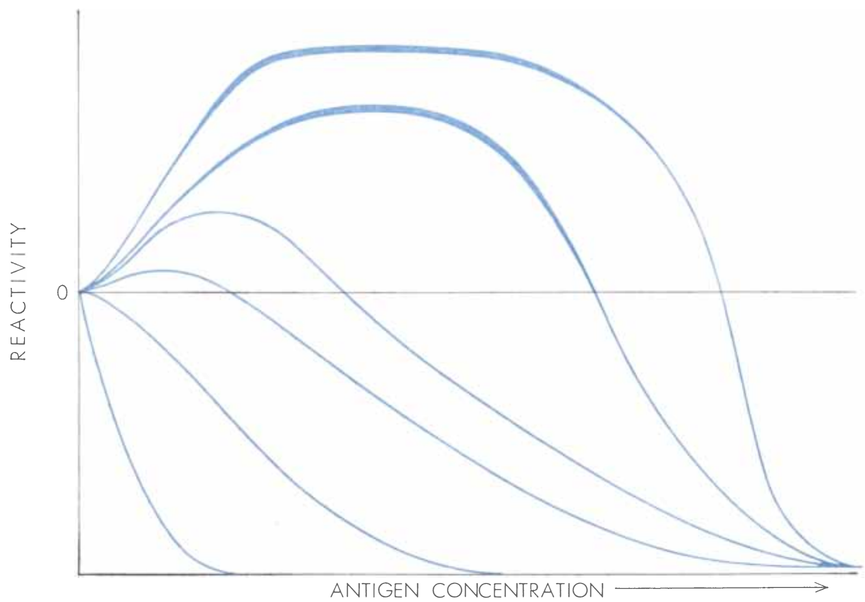
A slightly oversimplified explanation is that in the first experiment host A becomes tolerant of the B cells implanted in its tissues just after birth. As a result A subsequently tolerates a graft of B skin. But it is important to note that the cells that are implanted have qualities just as definite as those of the host. If an equilibrium is to be reached, the implanted B cells must become tolerant of their foreign host as well as vice versa. The embryonic B cells do become tolerant. But in the second experiment the adult B cells set up their own immune reaction against their host and produce runt disease or death.

A detailed consideration of many phenomena of the same general quality permits the formulation of the key question in the self and not-self problem: What is the process by which the body learns during development to differentiate its own substance from that of others? As Niels K. Jerne of the World Health Organization has put it, where or what is the dictionary that the body must consult to decide whether such and such a word (chemical configuration) is foreign or belongs to its own language? Along with Lederberg and other investigators, he believes that the dictionary lists only foreign words and that it has in it a list of all the foreign words without ever having heard them!

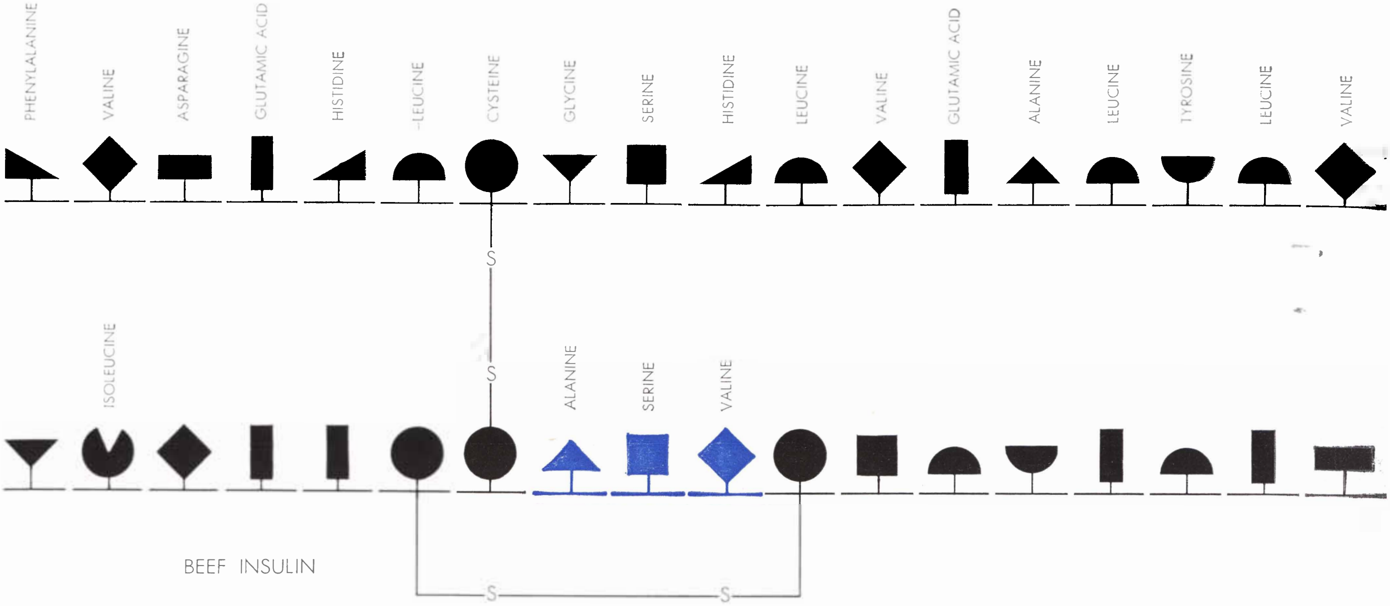
Such a dictionary can be pictured in several possible ways, but basically it must contain a large, though not infinite, number of patterns (words) which among them can offer a complementary specific antibody patch to correspond with every possible antigenic determinant. The proposal is not as outrageously unlikely as it sounds, because the number of antigenic determinants is not impossibly large. Both the antigenic determinants and the specific patches are small configurations. The number of different three- and four-letter combinations for the 20-letter alphabet of amino-acid units in proteins is respectively 8,000 and 160,000; these are very few compared with the number of cells in

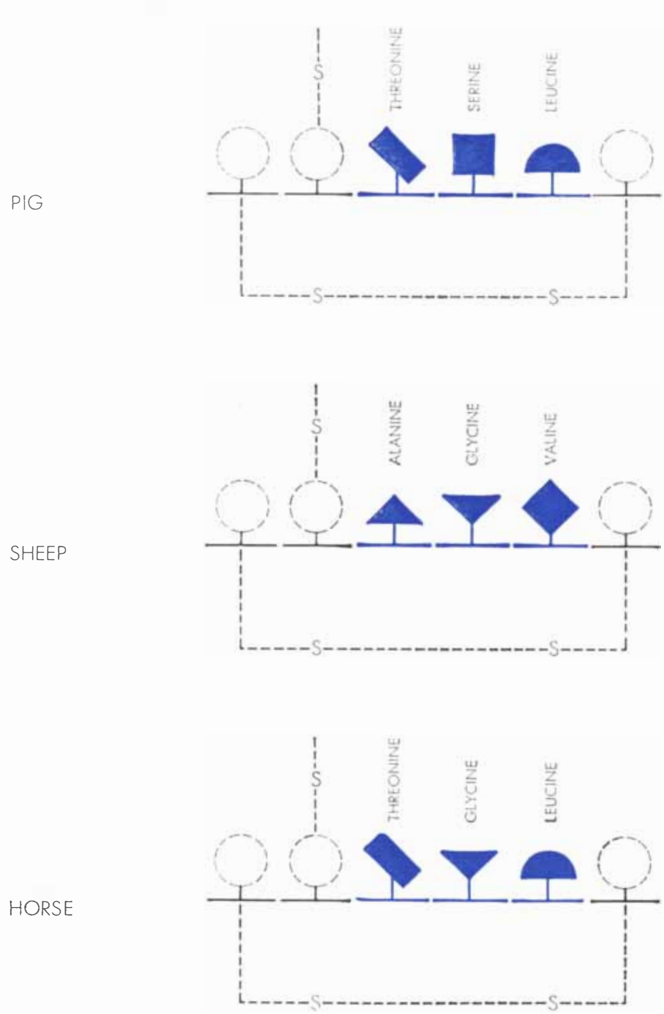


MUTATION RATE per cell-generation of genes carrying antibody patterns is high in early embryonic life (*vertical line down chart indicates birth*). Then mutation rate slows and most cells carrying "self"-antibody patterns are eliminated; later others are selectively inhibited. Immunological maturity occurs some time after birth. Mutations continue to appear throughout life, but at a much lower rate than in an individual's early embryonic life.



MATURITY CHANGES REACTION of immunological cells to increasing concentration of antigen. The most immature cells are represented by bottom curve; the most mature cells, by top curve. Zero line indicates no reaction to antigen. Above it, cells proliferate, and the thickened curves indicate development of plasma cells and production of antibody. Below the zero line immune cells are first inhibited and then, as the curves indicate, further concentration of antigen can drive them to dormancy and can even destroy the very immature cells.



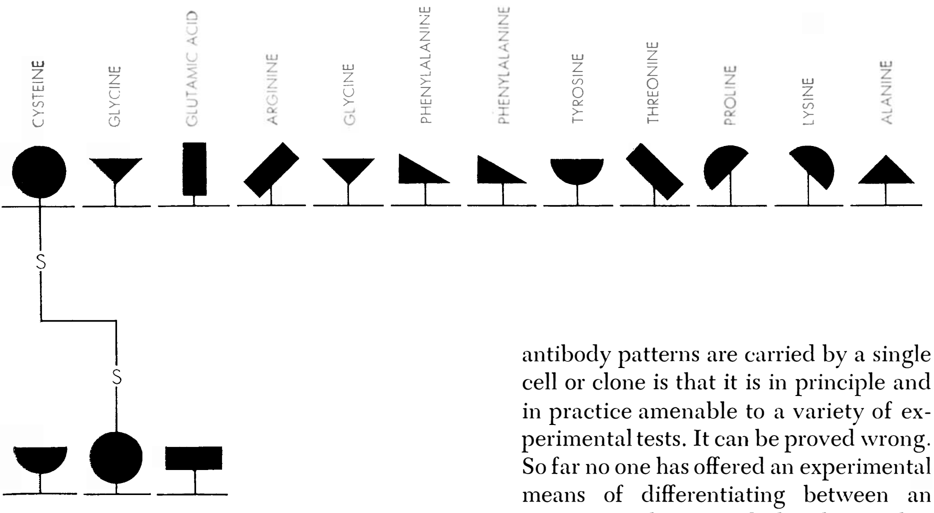


even a mouse. David W. Talmage of the University of Colorado School of Medicine has estimated that only some 10,000 different patterns are needed.

It is not difficult to imagine how the body might create its foreign-word dictionary. The lymphocytes (one important group of the mobile white blood cells) are the most likely carriers of the words, or antibody patterns. In the early stages of embryonic life the ancestors of these cells are assumed to be highly mutable in this particular quality. Their genetic material would change spontaneously and in a random fashion, creating all the possible antibody patterns. Each mutated cell, through simple division, would become the ancestor of a small group of cells, called a clone, all identical and all carrying the pattern for one or at most a few specific antibodies. Since the mutation process would be random, antibody patterns against antigens within the body would arise. It is therefore necessary to postulate that such cells are destroyed by contact with their corresponding antigen. (It is well known that a high concentration of antigen in an adult will inhibit antibody formation.) Thus during an early phase of embryonic development, "forbidden" clones that match "self"-antigens would be eliminated as they arose. Foreign antigens normally cannot reach an embryo, but when they do (as in the case of the nonidentical twins sharing one placenta), they come to be accepted as self. If no foreign antigens reach the embryo, it presumably retains all the foreign patterns.

Later in embryonic life the rate of mutations in immunological cells would decrease drastically to the mutation rate

DIFFERENCES IN INSULIN MOLECULES produced by various mammals are slight. Sequence of amino-acid units in entire beef-insulin molecule appears at top. Only three units (*color*) differ from those found in pig, sheep and horse, as indicated below.



found everywhere in the body throughout life. (It has been estimated that as many as a million body cells undergo mutation each day.) Forbidden clones would continue to arise, though infrequently, and would normally be killed off, or at least inhibited, while still immature. Mature immunological cells, instead of being destroyed by the appropriate antigen, would be stimulated by it to proliferate [*see illustration on pages 60 and 61*], producing among their offspring a great many of the plasma cells that probably manufacture the actual antibody molecules to combine with and deactivate foreign antigens.

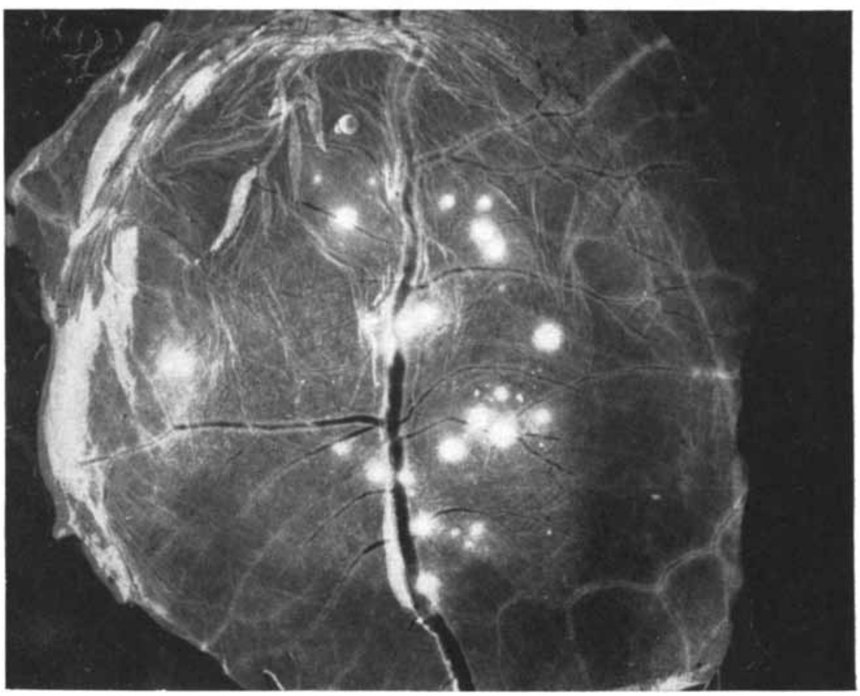
The theory is called the clonal-selection theory because the action of the antigen is simply to select for proliferation that particular clone of cells which can react with it. In the original form of the hypothesis each clone was believed to carry only one pattern, but two patterns per clone now seems to accord better with evidence from observations.

Many immunologists are highly sympathetic to the general idea of a clonal-selection theory, but are skeptical of the necessity of limiting the capacity of a given cell or clone to one, two or at most three patterns. They would prefer a substantial number, perhaps 10 to 20 related patterns per clone. Some even press the idea to its logical conclusion and assume that every cell which is a potential antibody producer carries its own complete foreign-word dictionary and can therefore recognize any antigenic determinant and through its descendants produce antibody against it.

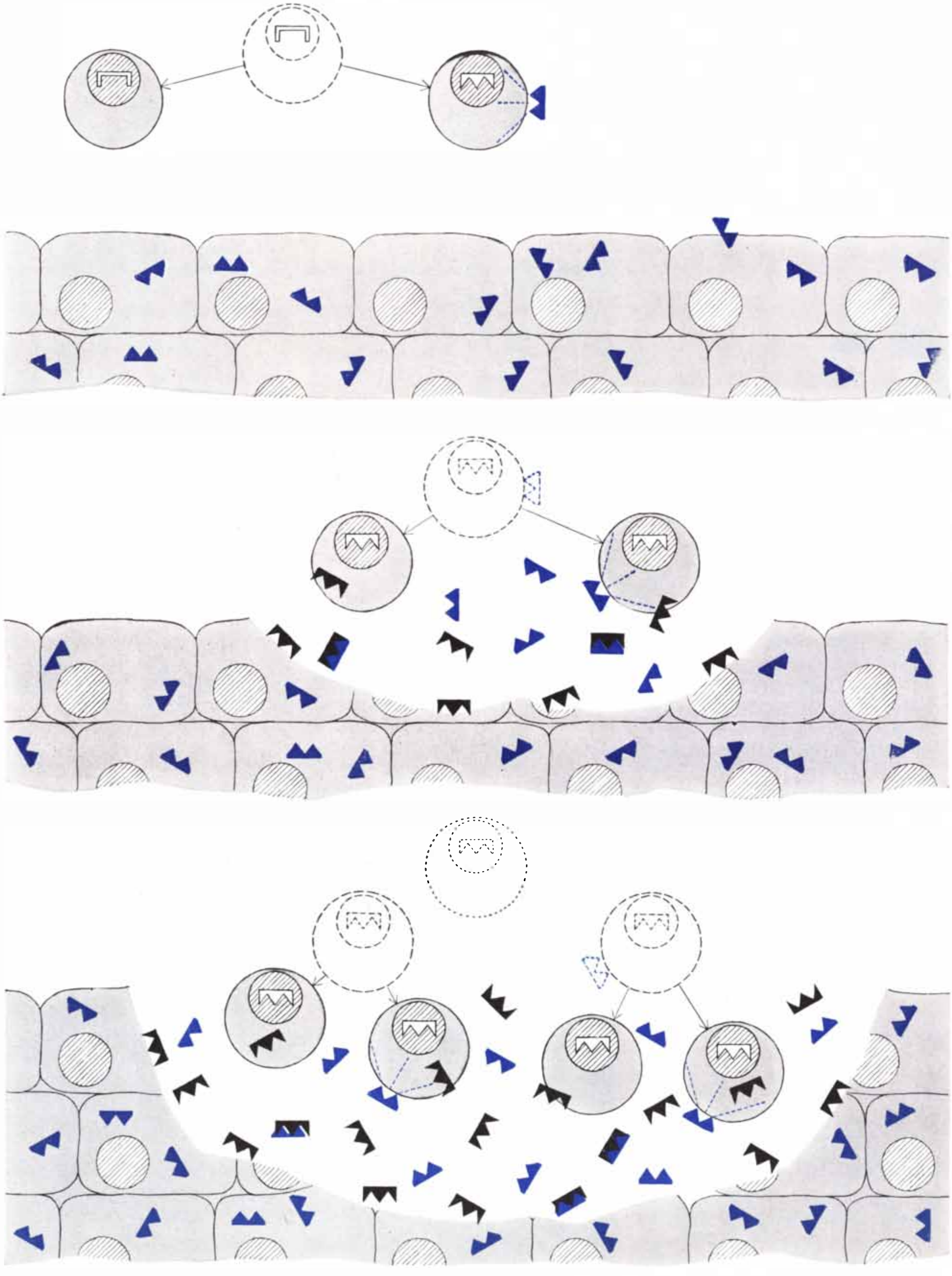
The main virtue of the clonal-selection theory in which not more than three antibody patterns are carried by a single cell or clone is that it is in principle and in practice amenable to a variety of experimental tests. It can be proved wrong. So far no one has offered an experimental means of differentiating between an instructive theory and the theory that every immunological cell carries all possible antibody patterns. Furthermore, it is extremely difficult to picture how every one of these cells could contain all the information needed for the recognition of every foreign antigenic determinant.

In biology the only function of a generalization is to present clearly a statement in such a form that any interested worker can grasp the type of experimental or observational information that will be needed to disprove it or to compel its modification. No theory can ever be proved to be correct. The only major virtue of the clonal-selection hypothesis is that it draws attention to the essential role of cells, rather than of antigens, in antibody production and immunity. Hence it must stimulate attempts to define the potentialities of single cells and to analyze the population dynamics of the immunological cells in the body.

Several experimental approaches are possible. One is the study of the ability of single cells to produce antibody and of the number of types of antibody that a single cell can produce. It is now established that in an animal immunized with more than one antigen most cells produce only one type of antibody, but that an occasional cell can undoubtedly produce two. Another type of experiment is based on finding a situation in which a small proportion of cells with some special antibody pattern can be sorted out from a large population of immunological cells. At our laboratory in Melbourne we have recently been engaged in producing immunological "pocks" on the chorioallantois of the chick embryo, the membrane in the egg which supplies the chick with oxygen [*see illustration below*]. We do this by inoculating the membrane with white blood cells from a mature chicken. The inoculation produces one focus, or pock, for roughly every 20,000 white cells. One focus, we believe, represents one cell; our provi-



MEMBRANE OF CHICK EMBRYO shows white spots due to attack by adult-chicken lymphocytes implanted in egg. Technique isolates the 1 in 20,000 lymphocytes which apparently carries antibody pattern matching membrane antigen. Photograph was made by author.



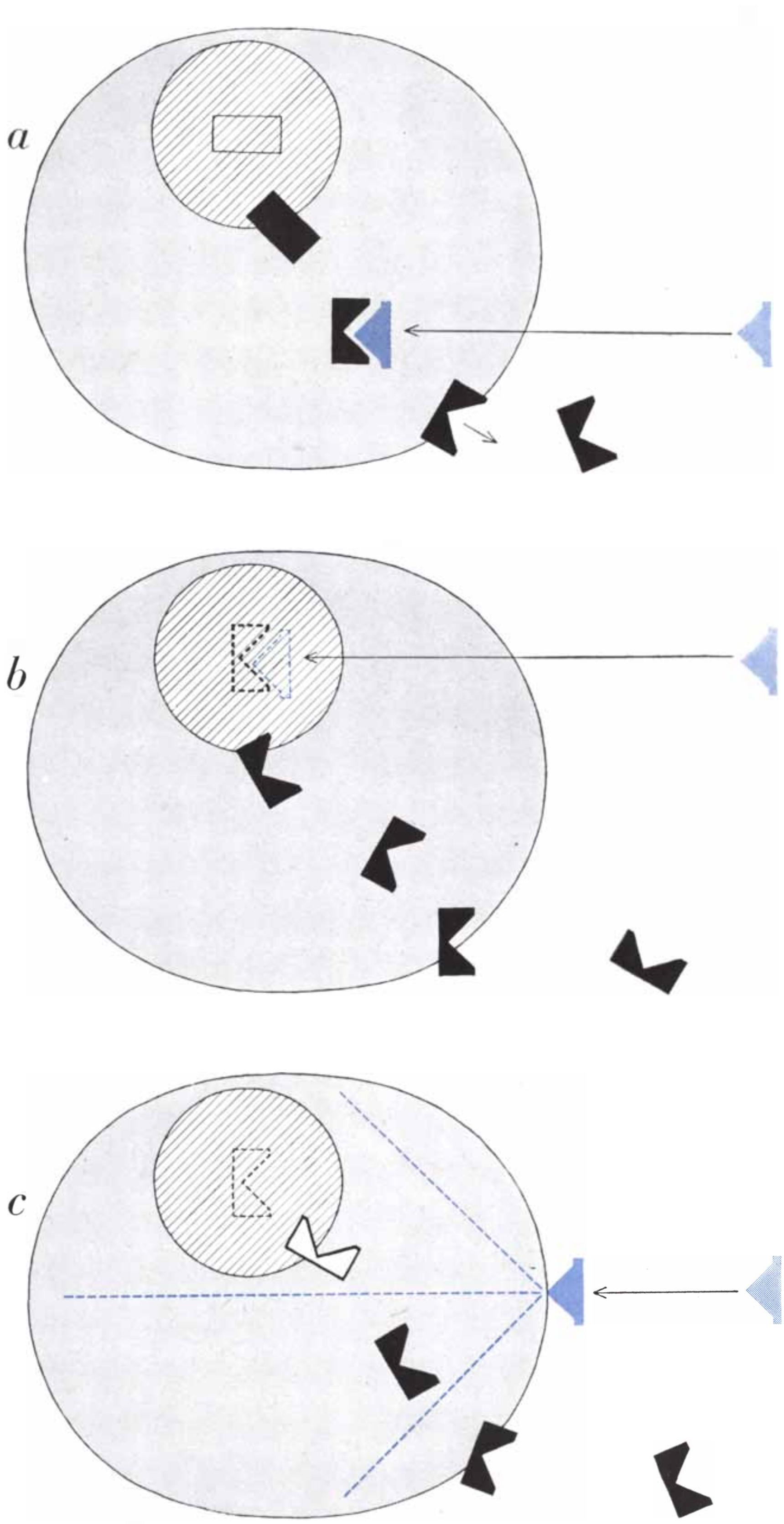
"VICIOUS CIRCLE" of autoimmune disease might start when immunological cell produces offspring (*top*) which by mutation has acquired a "forbidden" antibody pattern, matching a self-antigen. The antigen (*color*) stimulates proliferation of cell (*center*). Antibodies attack tissue which contains this antigen. More antigen is released, causing stepped-up attack (*bottom*).

sional interpretation is that this ratio of 1 to 20,000 reflects the proportion of the white cells with the preformed patterns that correspond to and react with antigens in the chick embryo not present in the chicken that provided the white cells.

The clonal-selection theory could be decisively disproved if it were possible to grow antibody-producing cells in tissue culture and show that from a very small initial population of cells any desired type of antibody could be produced by stimulation from a variety of antigens. So far no one has produced such a demonstration.

To me the most gratifying feature of the clonal-selection theory has been the way in which it can fit all the pieces into a reasonably self-consistent pattern. The explanation of the important autoimmune diseases was particularly obscure when the instructive theories of immunity were the only ones available. The selection theory allows these phenomena to fall easily into place. It postulates that a forbidden clone, through mutation or otherwise, enjoys an abnormal protection from destruction or inhibition by its corresponding antigen. There are difficult problems to be faced in some of the more severe autoimmune diseases, but in one group the process is more readily understood because the antigens concerned are normally of very limited accessibility in the body. They arise in such well-"insulated" tissues as those of the nervous system or the interior of the thyroid gland; they do not normally circulate in quantity in the blood and hence fail to eliminate the complementary clone during the embryonic selection period. Once the antibody-forming cells start to attack, they break down the cells and tissues containing the antigen, releasing more antigen. The antigen stimulates proliferation of the forbidden clone, which steps up the attack, and the vicious circle of autoimmune disease sets in [*see illustration on opposite page*].

At the other, theoretical, end of the conventional range of medicine is the central problem of biology—the way in which genetic information in the chromosomes of the cell nucleus is expressed in the specific geometric configuration of proteins such as enzymes. At this level, too, the idea of a preadapted pattern determined by the genetic material, which is the essence of the clonal-selection theory, seems to fit better with modern conceptions of protein synthesis than the rather crudely mechanical concept of the orthodox instructive theory.



THREE THEORIES OF IMMUNITY are classical "instructive" hypothesis (*a*), the author's earlier indirect-template theory (*b*) and clonal selection (*c*). In the instructive theory antigen enters antibody-producing cell and becomes a direct template from which antibody takes its final, complementary form. In *b* the antigen somehow incorporates an image of itself in genetic mechanism of cell. Author's recent clonal-selection theory holds that the cell is "born" with pattern complementary to specific antigen, and that antigen does not enter the cell but simply selects and encourages proliferation of cell having right pattern.

VERTICAL AERIAL PHOTOGRAPH shows the ziggurat of Tchoga-Zanbil as a small square (*center*). The faint rectangle around the square is the remains of a wall 1,300 feet on a side. Irregular outline near the edges of the photograph is the remains of another wall.

The Ziggurat of Tchoga-Zanbil

In the desert of southwestern Iran stand the remains of a temple that was originally 165 feet high. Built by the Elamites of 3,000 years ago, it is the same kind of structure as the Tower of Babel

by Roman Ghirshman

Each city of the "cradle of civilization" (the region of the Middle East now embraced by Iran and Iraq) was dominated by a "ziggurat": a lofty, stepped, pyramidal tower with stairways leading to a shrine at the top. The Tower of Babel—"whose top may reach high heaven"—was a ziggurat. In Mesopotamia (modern Iraq) the ruins of more than a score of such structures are known. But none of them was so imposing as the ziggurat that is presently being uncovered and partially restored at Tchoga-Zanbil in the gazelle- and jackal-haunted wilderness of southwestern Iran.

Tchoga-Zanbil means "hill (in the shape of a) basket," and the great mound that concealed the ruin indeed looked like a basket upside down. In the 1930's the search for oil brought a geologist who was also an amateur archeologist into that part of Iran. He guessed at once that the mound might contain the remains of a lost civilization. By good fortune he found a brick that bore an inscription, and he took this to the head of the French Archeological Mission that was digging some 20 miles away at Susa, the capital of ancient Elam. The inscription was in the Elamite tongue. It told of a sacred city that had recently been built by Untash-Gal, a king who reigned in Elam around 1250 B.C.

French archeologists have been digging at Tchoga-Zanbil since the end of World War II. Gradually the remains of temples, palaces and tombs have been emerging from beneath the ground. In place of the "hill" there stands the immense bulk of the mutilated but now clearly recognizable sacred tower.

The Elamites are not nearly so well known to history as the Sumerians, Assyrians and Babylonians who were their predecessors, contemporaries and successors in the ziggurat architectural tradition. Apparently the Elamites were neither Semites nor Indo-Europeans, but were related to the indigenous peoples who inhabited the mountains between the Persian Gulf and the Caspian Sea. In the third millennium B.C. they had already evolved a kingdom. By the time of Untash-Gal, in the second half of the second millennium, expansion and conquest had extended the power of the Elamite kingdom far beyond its heartland on the eastern side of the Persian Gulf (modern Khuzistan) to include parts of Mesopotamia to the west and the Iranian plateau to the north. The Elamite capital Susa is "Shushan the palace" mentioned in the Book of Esther. The sacred city built by Untash-Gal—called Dur-Untashi—is also known from the account of campaigns of the Assyrian king Assurbanipal. Around 640 B.C. Assurbanipal conquered Elam, devastated Susa and pillaged and destroyed Dur-Untashi.

It took six seasons of excavation—a total of 21 months of work—to clear away the Tchoga-Zanbil and reveal the massive monument within. Close to 100,000 cubic yards of debris were carted off and dumped in ravines beyond the margins of the ancient city. The techniques of

OBLIQUE AERIAL PHOTOGRAPH shows the northeast face of the ziggurat after its excavation by the French Archeological Mission in Iran. Each side of the base is 345 feet long.

AT BEGINNING OF EXCAVATION the remains of the ziggurat were an almost formless mound. (Tchoga-Zanbil is roughly translated as "hill in the shape of a basket.") In the foreground workmen dump material from the excavation at the end of a ramp of debris.

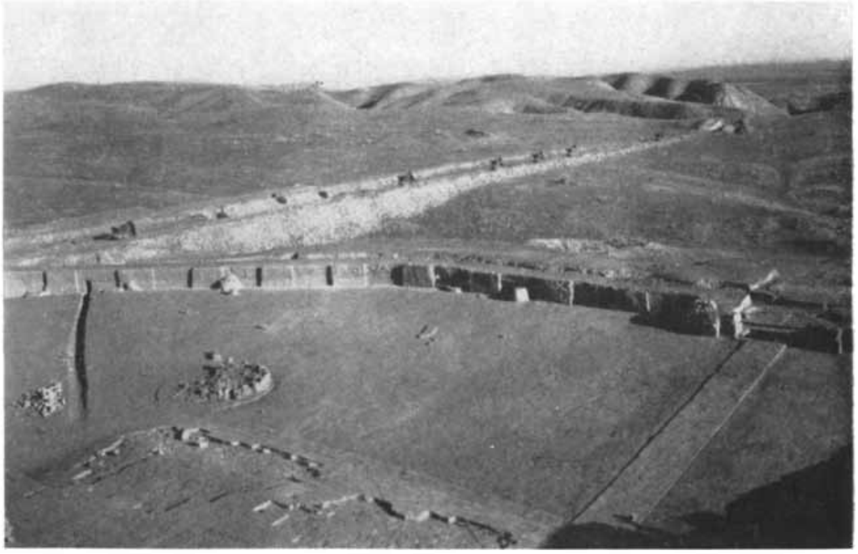
AFTER EXCAVATION the massive construction of the northeast side of the ziggurat is revealed. In the center is one of the structure's four gates. This gate has been restored. Its scale may be judged from the figure of the man standing inside the entrance.

mechanization are not yet of much help in archeology: man does the digging, exchanging his pickax at times for a smaller pick or even a trowel and a brush; another man stands by and shovels the earth on the cart, taking care to examine each shovelful for interesting objects or fragments. The French Mission employed 100 to 125 laborers each season.

By now the plan of the holy precinct—the *temenos*—of the city is clear. It was a quadrangle 1,300 feet square, enclosed by a wall, containing a cluster of temples and open courtyards for processions of the faithful. At the center stood the ziggurat, 345 feet square at its base and rising in five stepped stages to a height of 165 feet. Crowning the tower was a temple which was the home of Inshushinak (Lord of Susa), chief god in the Elamite pantheon. That temple vanished, however, as the upper 80 feet of the structure crumbled and fell outward upon the lower stages.

Although it has been thought that ziggurats were built by piling successively receding layers one upon the other, this structure has proved to consist of five concentric towers, each of which rises to its full height from ground level. The fifth stage, which was innermost and highest, was 115 feet square. Sun-dried brick was the principal building material, but an outer facing of kiln-fired brick protected the vulnerable raw brick from the infrequent but often violent winter rains. The bricks in each 11th course of the outer facing were inscribed in the cuneiform writing of the Elamite language; they record the names of the builder-king, his father and the god to whom the tower was dedicated. In addition these inscriptions pronounce a curse upon anyone who would destroy the work of the king. The bricks that faced the upper temple have been found scattered on the lower slopes of the ruin and in the interior courts of the tower. They were glazed in blue or green, with a shimmer of gold or silver. This explains those Babylonian inscriptions in which the kings boast of building temples covered with gold and silver.

Four monumental gates were cut into the four sides of the ziggurat. Three gates led to stairs, which ascended only as far as the surface of the second stage. The southwest gate (the corners of the structure were oriented to the cardinal points of the compass) led to stairs in the inner towers which rose ultimately to the temple of the fifth stage. These inner stairs still reach up to the surface of the third stage, and one arch is intact after 3,000 years. From the remains that have been identified it has been possible



COURTYARD of the ziggurat is seen from the northeast face. At right and lower left courtyard was paved. In background workmen trundle material from the excavation along a ramp.

SACRIFICIAL TABLES are arrayed in two rows outside the southwest gate. Just beyond the meter rule at right center is a drain for removing the blood of the sacrificial animals.

FOUR SMALL TEMPLES have been excavated in a corner of the quadrangular wall that surrounds the ziggurat. Within the wall are numerous temples dedicated to Elamite deities.

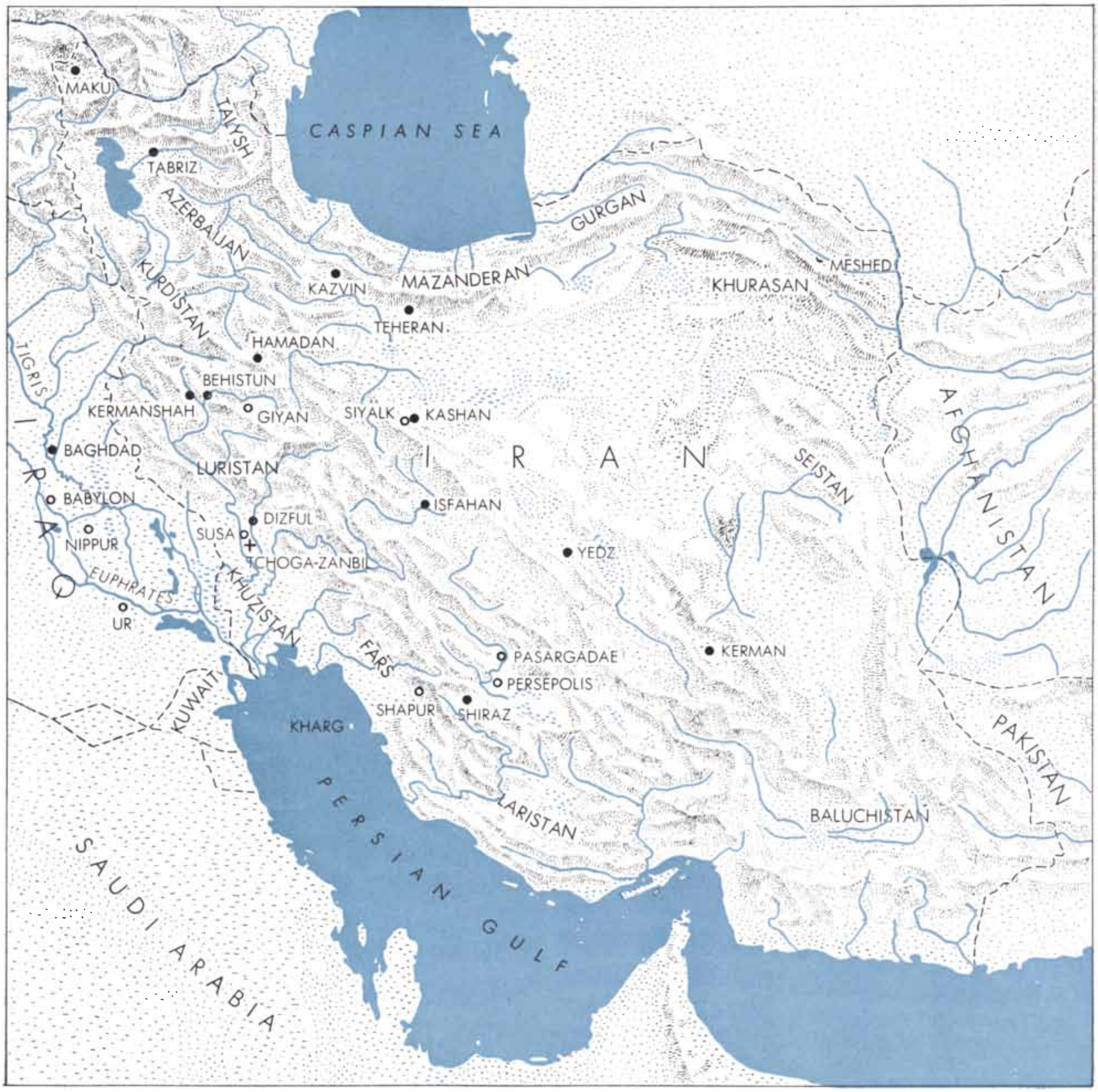
for the first time to reconstruct the entire plan of the stairway system leading to the temple at the top of a ziggurat.

A century of archeological excavation in Mesopotamia has brought to light several thousand tablets containing cuneiform writing. Among them are political, economic and religious texts; but they tell nothing of the religious ceremonies that must have taken place outside and on top of the ziggurat. Nonetheless, by questioning the "stones" (in this case the remains of the monument), one may try to reconstruct the function of the sacred edifice.

Excavation has revealed the existence of two temples within the heavy masonry of the wall of the second stage. One temple had a monumental gate, 25 feet high, which faced toward the interior of the ziggurat; this gate had been entirely blocked up with brick. It thus became clear that the ziggurat was not built at a single time, but that its construction proceeded in at least two phases. In the first phase only the first two stages were built, leaving a space at ground level in the center. The upper stages which occupy this center space were erected only after the closing and bricking off of the temple.

On the other hand, the second temple in the wall of the second stage opened, through an arched gateway, toward the exterior of the ziggurat, onto the court between the second and the first stage. This temple was thus in use throughout the lifetime of the ziggurat. The door in this gate, as in all the other gates of the ziggurat and the temples of the sacred city, was made of wood decorated with a mosaic of opaque black and white glass tiles. The discovery of this door, *in situ* and largely intact, revealed a hitherto unknown fact: There was already a flourishing glass industry in Elam in the 13th century B.C.

Together with the upper temple that



TCHOGA-ZANBIL is located by the small cross at the left in this map of Iran and adjoining states. The small open circles indicate the sites of ancient cities; the black dots, modern cities. Just northwest of Tchoga-Zanbil is Susa, which was the capital of Elam.

crowned the ziggurat, this sanctuary must have served in the ceremonial manifestations of the deity to which the ziggurat was consecrated. The god's effigy was probably kept in the upper temple and brought down by the priests for presentation to the king in the chapel of the lower temple.

Exploration of the three other walls of the second stage has revealed a number of rooms which were reached from above, by stairs coming down from the surface of the second stage. It is not yet possible to assign a function to these rooms. All of them were empty, except two that were filled with what are apparently architectural ornaments in glazed terra cotta, designed to adorn the upper part of the outside wall.

The court before the stairway in the southwest gate of the ziggurat must have been the site for major rituals. Small brick tables, 14 in all, arranged in two rows of seven each, with a drain nearby, were uncovered in this court. The tables were used for sacrificing animals, whose blood must have run down the drain. Probably the sacrifice was made in the presence of the king and queen, whose thrones were placed on two small daises at either end of the row of sacrificial tables. In trying to reconstruct the sequence of the ritual, one may guess that after the sacrifice the gathering, led by the royal couple, proceeded to the nearby lower temple. There the high priest would present the king and his immediate entourage with the effigy of the god, brought down from its abode in the upper temple.

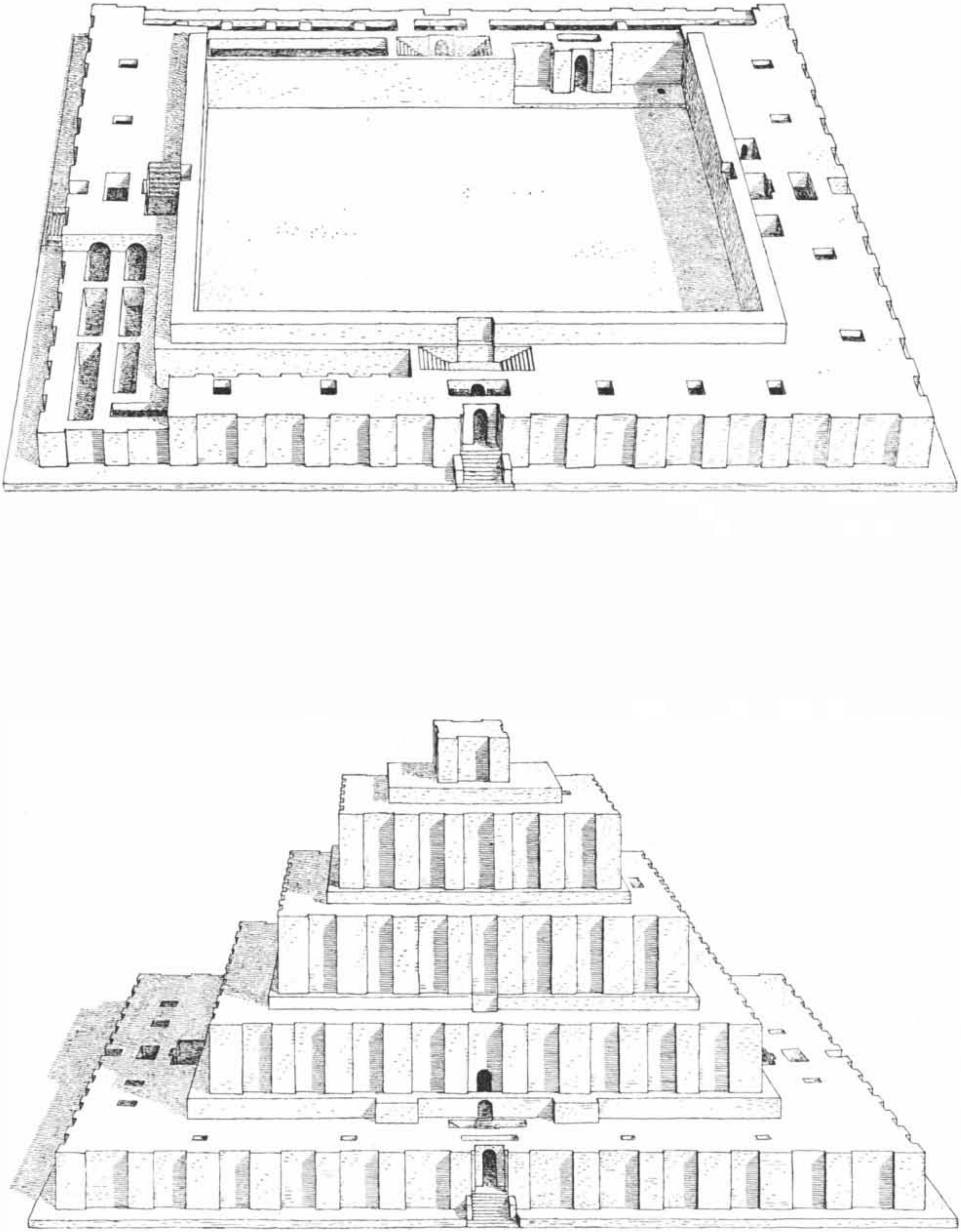
The design and location of the stairs which made it possible to go up to the first stage and on upward to the second stage suggest that the terraces of these two stages were reserved to the clergy, who must have taken their places there according to their rank in the priestly hierarchy. The laity were probably excluded from the ziggurat entirely and restricted to the vast paved courts that surround the structure. These courts are enclosed within a wall with seven gates; the area could hold a procession of several thousand worshippers.

These speculations are supported by the plan of the ziggurat and its surroundings. But one can only guess at the theological significance vested in the ziggurat. Herodotus, the Greek historian who visited Babylon in the fifth century B.C., hardly a century after the fall of the last Babylonian dynasty, wrote that the Tower of Babylon contained the tomb of the Babylonian Jupiter. This passage raises the question: Was the ziggurat a temple, or was it, like an Egyptian pyramid, a tomb? Without claiming to offer a definitive solution to this problem, to which scholars over the past century have dedicated a sizable number of monographs, I believe it may be suggested, in the light of available information, that the ziggurat was both temple and tomb.

VASE in the form of a woman's head was found outside the ziggurat in the temple of the Elamite deity Ishniqarab-Kiririsha. The priests of the temples sold such objects to pilgrims.

All the peoples of the region of Asia that concerns us here—the Sumerians, Babylonians, Assyrians, Elamites—buried their dead under the floors of their homes. The spirits of the departed were to go on taking part in family life. Now it happens that the inscriptions on the facing of the upper temple state that the sanctuary was the home of the god Inshushinak. Therefore, by analogy with the custom of ordinary mortals, if the home of the god was on top of the tower, his symbolic tomb might well have been built in the lower stages of the ziggurat. Not all the gods were immortal. Some of them, especially those worshipped in relation to the fertility of the land, would die when the merciless summer sun scorched the land; they would then be resurrected when the bountiful rains brought life back to nature. The ziggurat may thus have had the function of a tomb. We are planning, in the course of future excavations, to drive a tunnel to the heart of the ziggurat. This may at least shed some light on the rituals that took place during the first phase of the ziggurat's construction.

Whether temple, tomb or both, the ziggurat answers the desire of human beings to build a material bridge between the world here below and the celestial world. The term ziggurat, of



ZIGGURAT IS RECONSTRUCTED in these drawings based on models made by the wife of the author. The drawing at top shows the first phase of construction, with interior chambers partly cut away. Drawing at bottom shows the completed five-stage structure.

Sumerian origin, is related to the idea of "rising toward the sky." The god, descending from heaven, makes his home in the upper temple of the ziggurat before he makes himself manifest to man. If this hypothesis is correct, the ideal which inspired the builders of the ziggurat is not foreign to the ideal of the builders of the medieval cathedrals. Jacob's Ladder ("A ladder set up on the earth, and the top of it reached to heaven") has always haunted men's minds. One can see reflections of this ideal, in materialistic, scientific terms, in 20th-century man's efforts to penetrate the mysteries of interstellar space.

Numerous temples, dedicated to the various deities of the Elamite pantheon, surrounded the ziggurat at Dur-Untashi. Our excavations have revealed 11 temples so far, and several more must be concealed in the holy precinct within which the ziggurat lies. A complex of four juxtaposed temples has recently been uncovered in a corner of the great quadrangle. Those temples which were dedicated to a divine couple had two tables for offerings; those to a single god, a single table. The names of the gods were found on inscribed bricks in each of the temples.

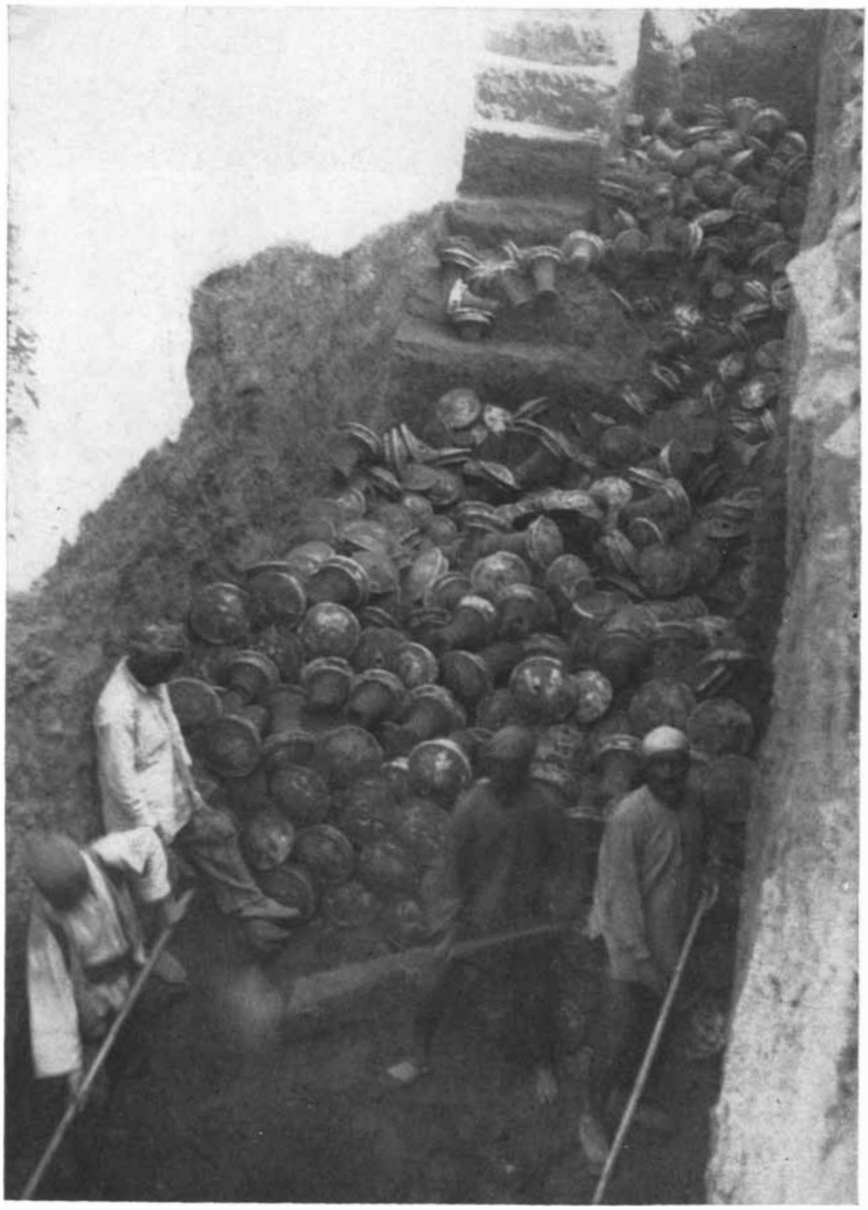
Most of the names were already known from discoveries at Susa, but the nature of the deities was still a mystery. Then the excavation of the temples at Dur-Untashi brought to light a number of votive objects in gold, silver, bronze, terra cotta and glazed earthenware. Their nature or appearance revealed the "function" of the deity to whom they were dedicated. It has become clear that the Elamite religion was one of nature worship, and that its principal deities symbolized concern with the fertility of the land and of the people. Take for example the goddess Pinikir, whose name figures prominently in a major treaty concluded between Elam and a king of Babylon. Nothing was known of her but her name. Then figurines of the goddess nursing a baby were found in her temple. These showed her to be the great goddess of procreation. Thus by joining architecture and the study of *objets d'art* to the standard techniques of epigraphy (the interpretation of inscriptions) it has become possible to reconstruct significant aspects of the Elamite religion.

In close association with the temples we found the workshops which produced the votive objects, especially the more common glazed terra cotta figurines. These objects were sold by the priests to pilgrims, who left them as offerings in the temples or chapels of this great pilgrim center. In this the world has changed little: the so-called art of Saint Sulpice, with its mixture of piety and profit, was already thriving several millennia ago.

The invasion by the Assyrians under Assurbanipal in 640 B.C. virtually put an end to the Elamite kingdom. Susa was captured and destroyed. The Elamite king retreated toward the mountains, and the pursuing Assyrians sacked a number of other cities, among them sacred Dur-Untashi.

The temples of the city were pillaged by the Assyrian soldiery. In the antechamber of one temple the Assyrians left close to 200 objects, most of them coats of arms in marble, bronze or iron. Almost all bore the name of King Untash-Gal. Nearby lay other objects in bronze, precious metals and glazed pottery.

The great gates of the ziggurat were guarded by statues representing real or composite animals half life-size. Before the northeast gate stood a statue of a bull, the animal symbol of the god Inshushinak. It was made of blue-glazed terra cotta; a long dedication in cuneiform writing appeared on its back. The Assyrians smashed the bull with a blow on the back. From the fragments found on the steps of the gateway my wife succeeded in reconstructing the body of the animal. But the head and feet were missing. Five years later, while the walls of



ROOM WITH STAIRWAY inside the northeast wall of the ziggurat was found to be piled with studs made of glazed terra cotta. These were apparently set in the walls of the ziggurat.

CYLINDER SEAL is among the many votive objects found in the great quadrangle surrounding the ziggurat proper. At right is the cylinder seal itself. At left is a flat impression that was made recently by rolling the seal across a strip of wet plaster of paris.

the gateway were being restored, the head and feet of the bull were found in a deep corner, to the great surprise of all of us. Doubtless a pious hand collected and hid those relatively intact parts of the smashed statue. The statue has now been completely restored.

The sacred city did not rise again after its terrible destruction. The temple priests who escaped massacre seem to have abandoned it. The sanctuaries, built of raw brick that was vulnerable to the elements, disintegrated; the ziggurat, sapped by the rains, slowly fell into ruin. Under the spade and pick of the archeologist, however, the ruin has now begun to yield more information about the plan and function of the ziggurat than any other structure of its kind, and to provide new insight into a significant period of religious history.

PANEL OF A MOSAIC was reconstructed after its fragments had been found in the excavation. The inlaid parts of the mosaic, here merely resting on paper, are made of ivory. At top is the head of an Elamite deity; at bottom is a frieze of dancing animals.

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Deplete an animal of vitamin E and creatine shows up in urine. Creatine is $NH_2\text{-}\underset{\|}{C}(NH)\text{-}\underset{|}{N}(CH_3)\text{-}CH_2\text{-}\underset{\|}{C}(O)OH$. Normally creatine is used by combining with adenosine triphosphate to make phosphocreatine. After phosphocreatine yields up its energy, creatinine is left. Creatinine is anhydride of creatine. Vitamin E somehow mixed up in this. Creatine-to-creatinine ratio in urine is therefore good index of vitamin E status. OK.

Alacreatine is $NH_2\text{-}\underset{\|}{C}(NH)\text{-}\underset{|}{N}(H)\text{-}\underset{|}{CH}(CH_3)\text{-}\underset{\|}{C}(O)OH$. Note that difference from creatine is position of methyl group. Feed alacreatine to rats and what happens in 6 weeks? They become very weak, as in nutritional muscular dystrophy from lack of vitamin E (*Nature*, *187*, 421). (Different etiology from human muscular dystrophy.)

Does alacreatine take place of genuine creatine in combining with ATP? Good question. Good answer could come from someone who buys our alacreatine for further studies. Might beat us in learning new fact about behavior of vitamin E. Would be consolation to know he at least used our alacreatine.

We make alacreatine by reacting thiourea with ethyl bromide to yield ethyl isothiourea hydrobromide, then add this with alkali to alanine. Product splits out with ethyl mercaptan. Ethyl mercaptan stench pretty well worn out as subject for levity.

Nature makes creatine by two-step method also. In kidney an amidine group from arginine transfers to glycine to make glycocyamine. In liver the glycocyamine takes on methyl group from methionine, becomes creatine. It's all done with enzymes. Nature neater, cheaper, makes more useful product.

If inconvenient to get from nature, get Creatine *from us also as Eastman 951. Also offer* Creatinine *as Eastman 918.* Creatinine Hydrochloride *as Eastman 7642,* Creatinine Zinc Chloride *as Eastman 1272, and some 3800 other Eastman Organic Chemicals. Complete catalog from Distillation Products Industries, Rochester 3, N. Y. (Division of Eastman Kodak Company.)*

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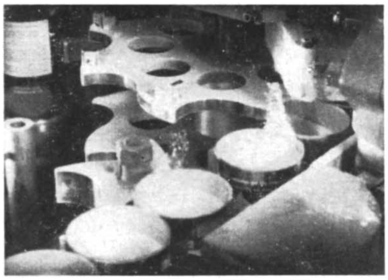
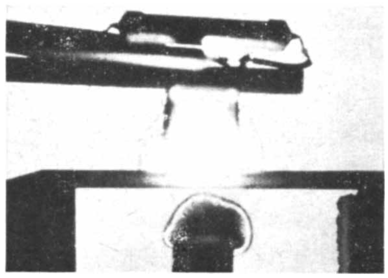
Samples of Tenite Polypropylene *are available from Eastman Chemical Products, Inc., Kingsport, Tenn. (Subsidiary of Eastman Kodak Company.)*

Favor for the high-speed congress



Dust Performs for Plant's Pollution-Control Movies, *Chem. Week*, 84:84, 86, May 2, 1959. (Procter & Gamble uses high-speed motion-picture sequences for the qualitative control of in-plant dust.)



The Ignition of Explosives by Radiation, J. Eggert, *J. Phys. Chem.*, 63:11-15, Jan., 1959: also in *Photochemistry in the Liquid and Solid States*, edited by F. Daniels, J. Wiley, N. Y., 1960, pp. 147-53. (High-speed photography proves that the detonation of nitrogen iodide starts before the light flash ends, showing that only a fraction of the energy is used for the detonation.)

Lathe Check Formation in Douglas-fir Veneer, *Forest Products J.*, 10:139-40, March, 1960. (High-speed motion pictures were used to analyze production variables.)

Time after time we have visited a customer proud of some accomplishment with high-speed movies. He is willing to show us—eager, delighted to show us. The projector is started and we watch. We see a collection of strange objects. We don't know for sure what they are. Little seems to be happening. After quite a while, a new object enters the scene from the left. Shortly another new object comes up from the bottom. The two dance around each other, touch, and exit from the top of the frame. All is again static on the screen. After another while the reel comes to its end and we jump to our feet exclaiming hearty congratulations.

He deserves congratulations, probably. If we had lived with the problem as he has, the objects in the picture might have seemed no stranger than the face in the bathroom mirror; the dance might have been the triumphant, forceful, sudden, undisputed clincher to a vexatious problem; the all-purpose enthusiasm of the born salesman might have meant more.

Nevertheless, we need not be ashamed. We help scientists and engineers use high-speed photography by manufacturing a group of films to the stringent mechanical requirements of high-speed cameras. *Kodak Plus-X Reversal Film* we make for reversal processing to a fine-grain positive. *Kodak Tri-X Reversal Film* is four times as fast. *Kodak Double-X Panchromatic Negative Film*, which is a bit faster yet and very sharp, is picked when a quick negative will suffice or when several prints may be wanted later. *Kodak Royal-X Pan Recording Film* is picked only when light is very limited indeed; *Kodak Linagraph Ortho Film*, for accentuated sensitivity to green light; *Kodak High Speed Infrared Film*, for sensitivity to 9000A, with a maximum from 7700A to 8400A; *Kodachrome Film*, for color, with low-cost commercial processing widely available; *Ektachrome ER Film*, for color at exposure index of 160 or higher.

Another thing. A bibliography on high-speed photography. Every item our library knows. Forty-six pages of items like the specimens at the immediate left. No pictures, though. No charge either. Coverage extends into 1960. Got it ready to distribute to the Fifth International Congress on High-Speed Photography in Washington in October. Doomed to a short life, since the Congress promptly generated so many *new* papers on high-speed photography that the abstracts alone run from p. 609 to p. 682 of the September, 1960, issue of the *Journal of the Society of Motion Picture and Television Engineers*.

Eastman Kodak Company, Photorecording Methods Division, Rochester 4, N. Y., would be glad to send the bibliography or answer questions about the above-named films.

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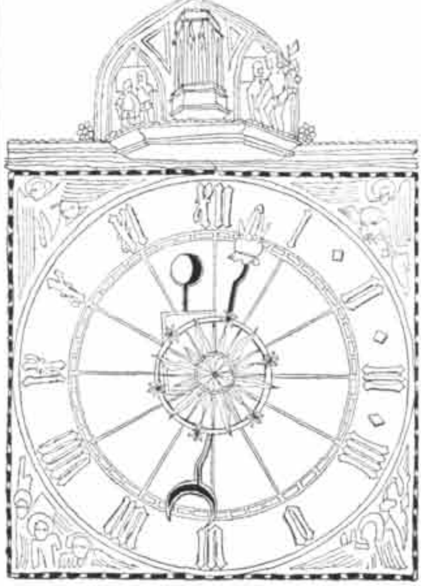

Universities and Government

"Whether the quantity and quality of basic research and graduate education in the U. S. will be adequate or inadequate depends primarily on the Government. . . . From this responsibility the Federal Government has no escape. Either it will find the policies—and the resources—which will permit our universities to flourish and their duties to be adequately discharged—or no one will." So concluded the President's Science Advisory Committee in a recently published report.

Federal support of science in universities, which has consisted largely of separate grants for individual research projects, must be greatly widened, the Committee urged. Funds are required to raise "the shockingly low level" of faculty salaries, to help defray the cost of educating graduate students and to provide "badly needed new buildings and equipment." There is no occasion for a "timid mistrust" that such extensive aid would be "necessarily subversive of university freedom." Each party can be expected to respect "the rights and responsibilities of the other."

Current practices, both in Government and universities, foster an "artificial and fundamentally wrong" division between research and teaching. By letting contracts that call for answers to specific problems, the Government helps exclude the graduate student from the research program. But research and teaching are "essentially inseparable," the report pointed out. "The apprentice scientist learns best when he learns in an atmosphere of active research work." Besides, the pattern of piecemeal contracts has "undermined" universities by saddling them with overhead costs on the projects.

Some Federal agencies are already including overhead allowances in research contracts, and the National Science Foundation as well as the National Institutes of Health have begun to make long-term, less restrictive grants. The Committee asked that the policies be extended throughout the Government.

The report, entitled "Scientific Progress, the Universities and the Federal Government" was prepared by a group under the chairmanship of chemist Glenn T. Seaborg, now chancellor of the University of California. Among its other recommendations are: The Government should seek to identify new fields of research and education that need encouragement. Steps should be taken to double the present number of 15 to 20 "first-rate academic centers of science" in the U. S. over the next 15 years.

Status for Social Science

By establishing a new Division of the Social Sciences, the National Science Foundation has placed this branch of inquiry on a formal par with the physical and biological sciences. Alan T. Waterman, director of the Foundation, explained that the creation of the new division "recognizes the insistent need for supporting more fundamental studies in the social sciences, particularly in the face of diminishing support from other sources." He said that several large private foundations have recently reduced their grants for social science or have shifted them from basic to applied research.

In the past two years, Waterman added, social-science allotments by the National Science Foundation have amounted to only a fifth of the funds requested. In 1959 the Foundation gave $853,000; in 1960, $1,925,000. For 1961 the new division will have $3,400,000 to divide among approximately 130 grants. This is 5 per cent of the 1961 research budget of the Foundation, which includes $26,500,000 for the biological and medical sciences, and $35,200,000 for the mathematical, physical and engineering sciences.

The Foundation made its first grants

in the social sciences six years ago and in 1958 set up an Office of Social Sciences. The head of that office, Henry W. Riecken, a social psychologist, will direct the new division.

Cavities Win

Proposals to fluoridate public water-supplies in order to prevent dental caries were rejected by voters in 29 out of 35 communities in the recent elections, according to the latest count of the American Dental Association. The population of the 29 communities totals more than a million, compared to the 43,000 total population of the six communities where the proposal carried. Among the communities rejecting fluoridation were 14 high-income San Francisco suburbs in Marin County, Calif., the industrial city of Cincinnati, Ohio, and the village of Maple Shade, N. J. The outcome of the 1960 referendums on the issue follows the pattern of recent years.

Despite the unpopularity of the measure on the ballot, the records of the U. S. Public Health Service show that 1,956 communities, with a population of 37 million, now fluoridate their water supplies, as against an estimated 1,000 communities, with a population of 17 million, in 1955. In most cases, however, the local government has acted without submitting the question to the electorate. This year's defeat in Cincinnati was the second one for the proponents of the measure in that city; the first was in 1953, when a referendum reversed the city government's decision to proceed with fluoridation.

Virus Protein

Investigators at the University of California's Virus Laboratory have determined the complete chemical structure of the protein molecule of the tobacco mosaic virus (TMV). Some 2,200 of these molecules form the protein cylinder around the nucleic-acid core of the virus. The TMV molecule has now been shown to be made up of 158 amino acid units, and is the third and largest protein to be so elucidated. Frederick Sanger and his co-workers at the University of Cambridge described the 51-unit sequence of insulin in 1954, and in 1959 William H. Stein and Stanford Moore at the Rockefeller Institute determined the 124-unit sequence of the enzyme ribonuclease.

In *Proceedings of the National Academy of Sciences* the California group—which includes Heinz Fraenkel-Conrat, C. A. Knight and Wendell M. Stanley—observes that simple viruses such as TMV "represent particularly suitable objects for the study of the genetic control of protein structure, since they appear to consist exclusively of the genetic material (nucleic acid) and the characteristic protein presumably produced as a result of the information carried by the nucleic acid." The authors have already demonstrated a specific structural change in TMV protein resulting from a genetic mutation. "The next step," they say, "will be to relate the structure of viral nucleic acid to its specific protein in a point-to-point manner."

The Comet Did It

Investigators in the U.S.S.R. have come up with a new solution to an old geophysical mystery: What happened in the Tungus forest in Siberia on the night of June 30, 1908? The facts are that something exploded there, leveling many square miles of trees and knocking down people more than 30 miles away. At the same time the night sky glowed brightly over a large part of the Northern Hemisphere.

For years the explosion has been attributed to a great "Tungus meteorite." Yet no one has found a crater in the area, or any meteoritic material. Last year the Soviet press published speculations, based on the supposed discovery of high radioactivity in the area by an expedition of amateurs, that the meteorite was an atomic-powered space ship. This publicity precipitated a new inquiry into the matter by the Committee on Meteorites of the Academy of Sciences of the U.S.S.R. The Committee now reports that there is no unusual radioactivity in the area and no meteoritic fragments.

According to Vasily G. Fesenkov, chairman of the Committee, the evidence indicates that the body which felled the trees was almost certainly a comet. In a summary prepared for *The New York Times,* Fesenkov said that the object approached from a direction opposite that of the earth's motion around the sun. Comets sometimes move in such a direction, but meteorites always travel in the direction of the planetary orbits. Moreover, the pattern of damage indicates an explosion hundreds of feet

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TURN PAGE ➡

above the ground—a likely outcome for a body composed of dust and frozen gases, as comets are, but not for a meteorite of stone or iron. Finally, the extensive nightglow could have been caused by the dispersion of cometary material in the atmosphere. Taken altogether, the facts suggest the explosion of a comet several miles in diameter and weighing about a million tons.

Man-Made ACTH

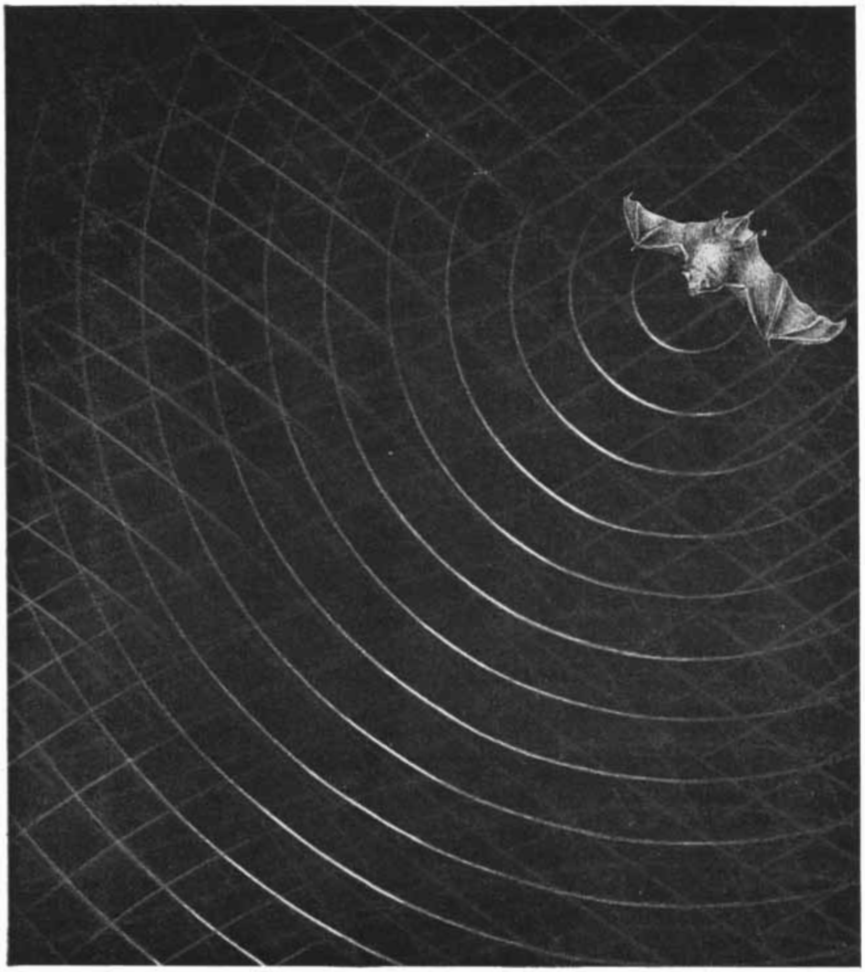
A compound with the full biological activity of ACTH, the hormone that is excreted by the pituitary gland and controls the production of cortisone in the adrenal glands, has been synthesized by a team of University of Pittsburgh chemists headed by Klaus H. Hofmann. The new substance is a chain of 23 amino acid units, and is the largest protein-like molecule yet synthesized. Previous studies had indicated that 24 of the 39 amino acid units in the pituitary hormone are essential to its biological activity; this is the first time the full effects of ACTH have been obtained with fewer amino acid units. Hofmann—a German-born, Swiss-trained organic chemist who came to the U. S. before World War II —and his colleagues have worked on the synthesis of ACTH for seven years.

About a week before the announcement by Hofmann's group, Choh Hao Li and his co-workers at the University of California reported that they had prepared a compound containing 19 of the amino acid units in ACTH. In tests on animals it exhibited only one third the activity of the natural hormone.

Tolerant Cheek

A group of investigators at the Wistar Institute of Anatomy and Biology in Philadelphia has found an explanation for a strange immunological puzzle: the ability of foreign tissue to survive when grafted into the cheek pouch of the Syrian hamster. Ordinarily tissue cannot be transplanted from one animal or individual to another. Yet the culture of human cancers and numerous other tissues by transplantation into the hamster cheek-pouch is an established laboratory procedure. The rest of the hamster's body does not show this unique tolerance to grafts.

At the annual meeting of the National Academy of Sciences, held in Philadelphia, R. E. Billingham reported that he and his associates have found an unusual layer of mucilaginous connective tissue under the skin of the pouch. If



the layer, or pouch skin containing the layer, is transplanted to another part of the animal's body, skin or other tissues grafted over it will survive. Grafts survive even in a hole cut down to, but not through, the mucilaginous layer. Thus the layer suppresses the immunological reactions that normally result in the rejection of a graft. Other experiments indicate that it does so by preventing antigens from leaking into the host animal and precipitating the formation of antibodies against the graft.

Billingham does not know whether the unusual properties of the pouch, which the animal uses for storing food, have a special adaptive value for the hamster or are merely an evolutionary quirk. However, study of the pouch may shed light not only on transplantation but also on such problems as why a mother does not ordinarily form antibodies against her unborn child—an immunological "stranger" to her. Perhaps the fetus is protected, Billingham suggests, by some mechanism that prevents fetal antigens from escaping into the mother's system and provoking antibodies that would destroy the child.

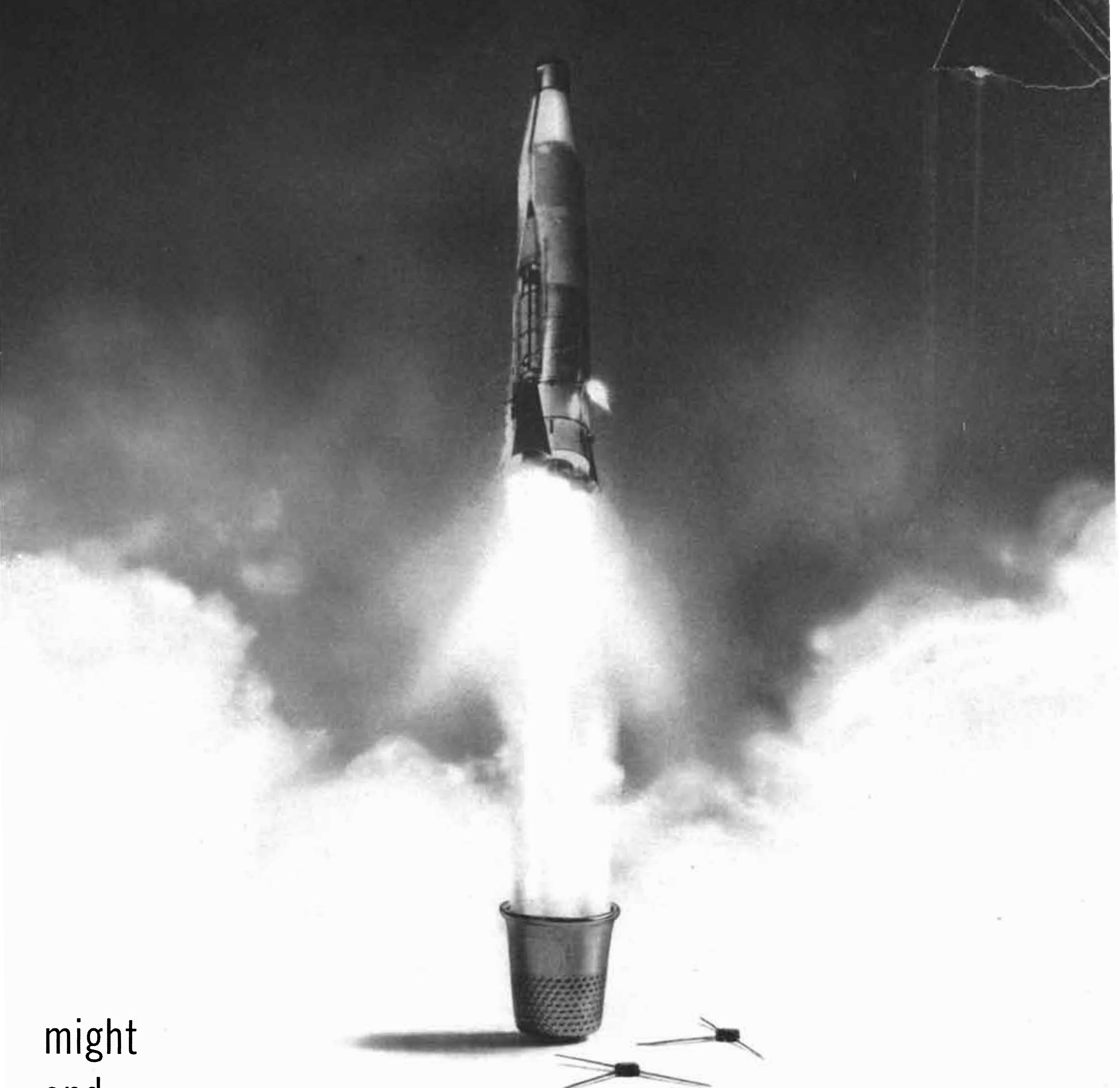
Electroshaping

A new process that uses electric current as a "cutting tool" has been developed at the Battelle Memorial Institute for forming complex shapes of metals that are hard to machine.

The process is carried out in an electrolytic cell in which the die or template serves as the negative electrode and the piece to be shaped as the positive electrode. The two are placed very close together and the electrolyte between them is pumped through the cell at a rapid rate. Any lump or projection on the negative electrode produces a corresponding hollow in the part of the positive electrode opposite it. The metal that is removed is not deposited on the negative die, but is carried away in the flowing electrolyte.

The method is well suited to processing hard metals and metals easily damaged by the heat generated in conventional machining. Parts only a few thousandths of an inch thick are easily electroshaped to very close tolerances. Operating at currents up to 1,500 amperes per square inch, electroshaping is a quick process. Since there is no wear on the negative-electrode dies and no deposit of metal, they can be re-used indefinitely.

The Steel Improvement and Forge Company of Cleveland, the firm for which Battelle developed the method,



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Tree Medicine

The first chemical treatment for a disease of trees that is cheap and effective enough to use on entire timber forests was announced last month at a meeting of the Society of American Foresters in Washington, D.C. Homer J. Hartman of the U. S. Forest Service told the meeting that cycloheximide, an antibiotic originally discovered in 1946, can control blister rust, a fungus infection of the western white pine. In recent years a cycloheximide spray eradicated the disease in large stands of white pine, at a cost of a few cents a tree. Many infected trees were saved, and the spread of the blight was arrested. By 1970, Hartman estimated, it should be possible to protect all commercial stands in the tree's principal growing area—northern Idaho and neighboring parts of Washington and Montana—exclusively through the use of the antibiotic. Other reports indicate that cycloheximide is also effective against blister rust of the sugar pine and against related fungus diseases of the Douglas fir and such valuable southern species as the jack pine.

Graphic Stutter

A decade ago investigators of speech hit upon the device of recording speech on tape and playing it back in such a way that the speaker heard his voice a fraction of a second after he had actually uttered each sound. The results were a striking demonstration of the extent to which a person depends on hearing his voice in order to monitor his speech; individuals subjected to the arrangement stuttered badly, and often showed more extreme signs of stress.

Tape recorders designed to register the video signals of television have now made it possible to do the same with sight. With the aid of a video recorder and associated television gear, William M. Smith and his colleagues at Dartmouth College and the University of Wisconsin set up an experiment in which two volunteers were called upon to perform a variety of tasks without being able to see what they were doing except as shown, after a delay of just over half a second, on the television screen.

The subjects were set such tasks as tracing a maze or drawing simple geometric figures. When they could see what they were doing on the screen without any delay, both did quite well.

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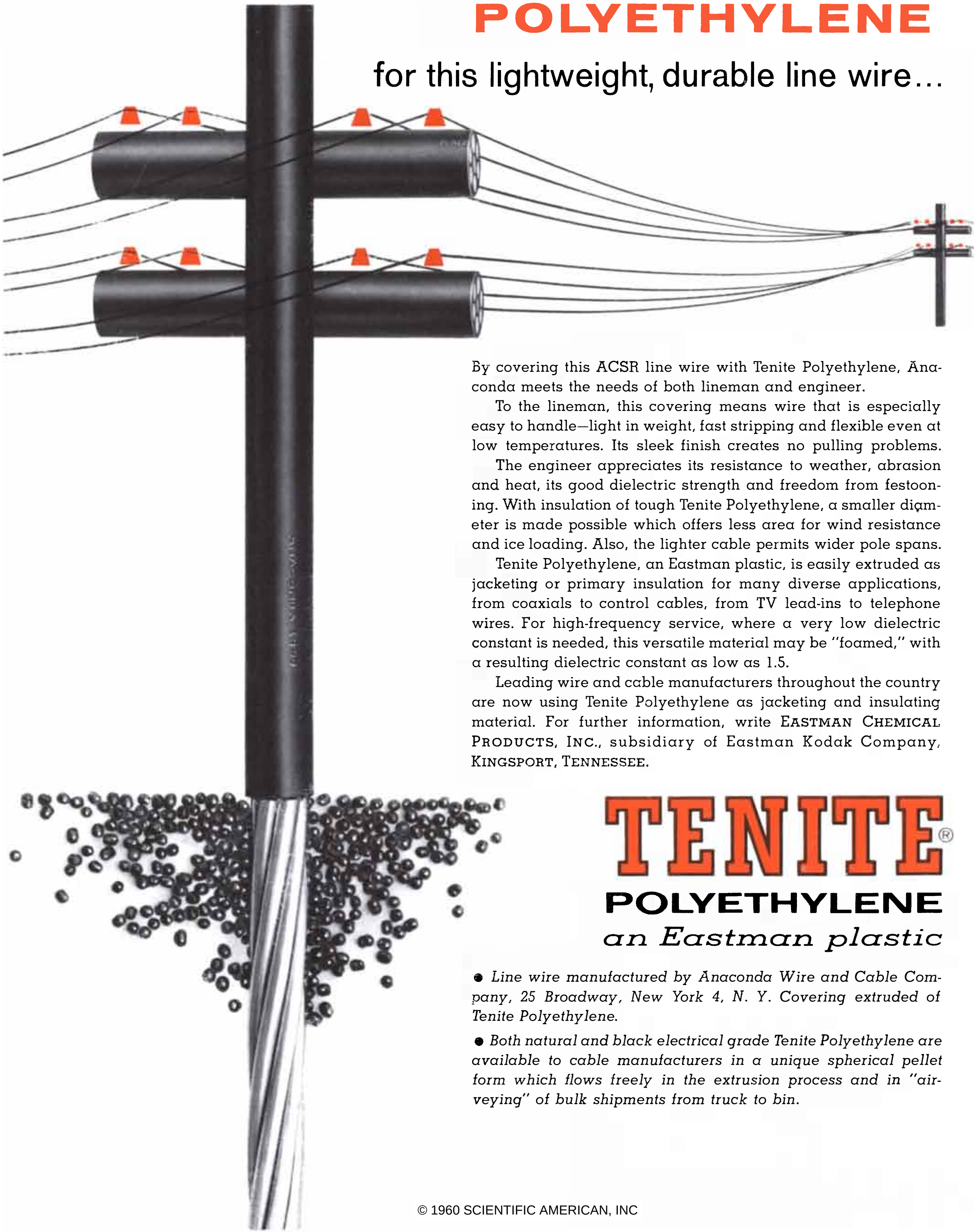

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When the time delay was introduced, they required two to seven times as long to complete the task. The quality of the drawings fell off drastically; several were unrecognizable. Other tests called for writing three- and four-letter words and nonsense syllables. The time delay brought about not only a marked slowing down and deterioration in handwriting, but also numerous errors in spelling. By far the most frequent errors were the duplication and insertion of extra letters. Without prompt visual feedback to guide them, as Smith and his colleagues observed in *Science,* the subjects fell victim to "graphic stammering and stuttering."

Shuttling Ghosts

Artificial earth satellites leave a wake of ionized clouds that appear to shuttle back and forth between the Northern and Southern hemispheres. After *Sputnik I* was launched observers in the U. S. noticed an increase in the strength of radio signals from distant ground-transmitters as the satellite passed through the northern auroral zone. The effect was attributed to the reflecting properties of clouds of ions formed when the satellite crashed through curtains of electrified particles in the auroral zone and the fringes of the inner Van Allen belt.

The expected effect on ground-station radio signals was also noted when *Sputnik III*—launched in May, 1958—penetrated the northern auroral zone on orbits near the Ohio State University Radio Observatory. On passes during January and February, 1959, however, John D. Kraus and his associates detected a similar but smaller effect on signals from WWV, the National Bureau of Standards station near Washington, D.C., when the satellite was over the Southern Hemisphere. The effect was observed again on later passes.

In *Proceedings of the Institute of Radio Engineers* Kraus advanced two possible explanations for the signal reinforcement while *Sputnik III* was in the Southern Hemisphere. One is that the radio signals traveled to the Southern Hemisphere and were reflected back from the ion cloud around the satellite. The other postulates that the cloud itself was detached from the satellite and shuttled back and forth between hemispheres along lines of force of the earth's magnetic field. Careful calculation of *Sputnik III*'s position during Southern Hemisphere passes, Kraus reports, makes the "ghosts" a more likely source of the signal reflections.

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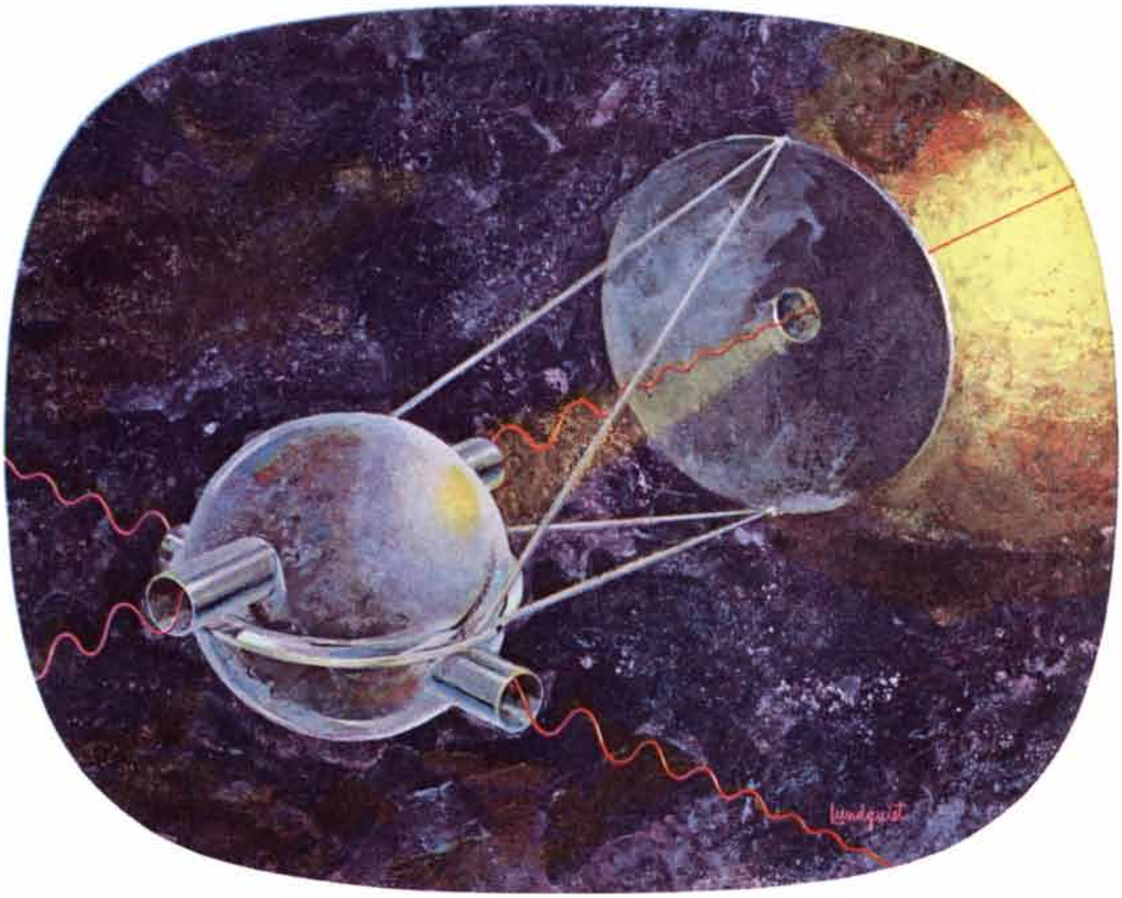

Satellite model showing telescopes and solar shield.

Aberrascope Test of General Theory of Relativity

Albert Einstein proposed three methods of testing his general theory of relativity: measurement of the advancement of the perihelion of Mercury, the gravitational shift of spectral lines [1], and the deflection of starlight passing close to the sun. Measurement of starlight deflection has previously been conducted during a solar eclipse . . . with many attendant difficulties. A recent proposal would utilize a satellite-borne Stellar Aberrascope [2] to measure this deflection. Accuracy of 0.01 seconds of arc appears feasible.

The General Mills Stellar Aberrascope measures the change in the relative positions of two nearly diametrically opposite stars, one of which is close to the sun. Accuracy of this system can be achieved in a satellite environment by virtually eliminating instrument alignment errors and through independent determination of the "scale" of the effect.

[1] "The Mössbauer Effect," Sergio De Benedetti, *Scientific American*, April, 1960.

[2] "Test of Theory of Relativity by Measurement of Gravitational Light Deflection," R. L. Lillestrand, General Mills, presented at the American Astronautical Society, New York, January 18, 1960.

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GLASS

An ancient substance of steadily widening utility, it is still poorly understood. It may be regarded as both an undercooled liquid and as an inorganic polymer with a highly cross-linked structure

by Charles H. Greene

It does no harm to be reminded occasionally that modern technologies still contain large elements of empiricism. It can be stated almost as a rule that the more ancient the art the greater the empirical content. Two of the oldest manufacturing arts are probably metallurgy and glassmaking, both dating back to at least 3000 B.C. Of the two there can be little question that glassmaking still contains the higher ratio of art to science.

That this should be so presents something of a paradox, for glass has been the versatile handmaiden of scientific inquiry ever since the time of Galileo. Until very recently glass, in microscopes and in telescopes, offered man his only access to objects too small or too distant to be seen with the unaided eye. Shaped into laboratory apparatus, glass has been indispensable to generations of chemists, physicists and biologists. Even the modern laboratory or the modern radio observatory, filled with electronic equipment, would be crippled without glass. (Vacuum tubes are still with us and many transistors are sealed in glass.) Yet the atomic structure of glass itself is known only in a general way, and there is still much controversy over details.

It is easy to excuse our ignorance by saying that glass, being a supercooled liquid, shares with liquids a random and irregular, though coherent, structure that is extraordinarily difficult to analyze. But the excuse is not very convincing. If as much research had been focused on the glassy state as on the solid state in the past dozen years, we would probably now have most of the answers we seek. Glass has not received corresponding attention, it seems reasonable to guess, because neither government nor industry (with the exception of a very few companies) can imagine that intensive study of glass will repay the cost of the effort. The art of glassmaking has been so successful with so little scientific underpinning that it is not obvious how greater understanding would dramatically improve the technology. Almost certainly the future will show this complacency to be mistaken.

Crystals and Glasses

The present-day understanding of glass rests heavily on a single lucid paper, only 12 pages long, written in 1932 by William H. Zachariasen, then a 26-year-old associate professor of physics at the University of Chicago. Zachariasen's "model" of glass structure ranks with the model of organic polymer structures proposed by Hermann Staudinger of Germany only a few years earlier. And, as we shall see, glasses and organic polymers—which include all the products of the plastics industry—have a great deal in common, even though glassmakers view plastics disdainfully.

Before describing Zachariasen's model, we should define the word glass. This is not quite so easy as it may seem. (For example, the Terminology Commission of the Soviet Academy of Sciences, which is greatly concerned with glass theory, reported recently that it was not able to agree on a definition.) Broadly speaking, however, all solids can be classified into two groups: crystalline and amorphous. In crystals the constituent atoms are locked into symmetrical and repeating patterns. Crystals have a sharp melting point and tend to cleave in preferred directions. Amorphous solids show none of these properties. The glassy state is a subcategory of the amorphous state; not all amorphous solids are glasses. The term glass refers to amorphous solids that may be melted to viscous liquids by heating and then converted again to the solid state by cooling without crystallization. (In actual glassmaking, crystallization sometimes occurs and ruins the melt.) While many substances, both inorganic and organic (*e.g.*, sugars and certain alcohols), will pass into the glassy state, the term glass itself is commonly applied only to inorganic solids, typically those that remain solid even at relatively high temperatures.

Thus George W. Morey of the Geophysical Laboratory of the Carnegie Institution of Washington defines glass as "an inorganic substance in a condition which is continuous with, and analogous to, the liquid state of that substance, but which, as a result of a reversible change in viscosity during cooling, has attained so high a degree of viscosity as to be for all practical purposes rigid."

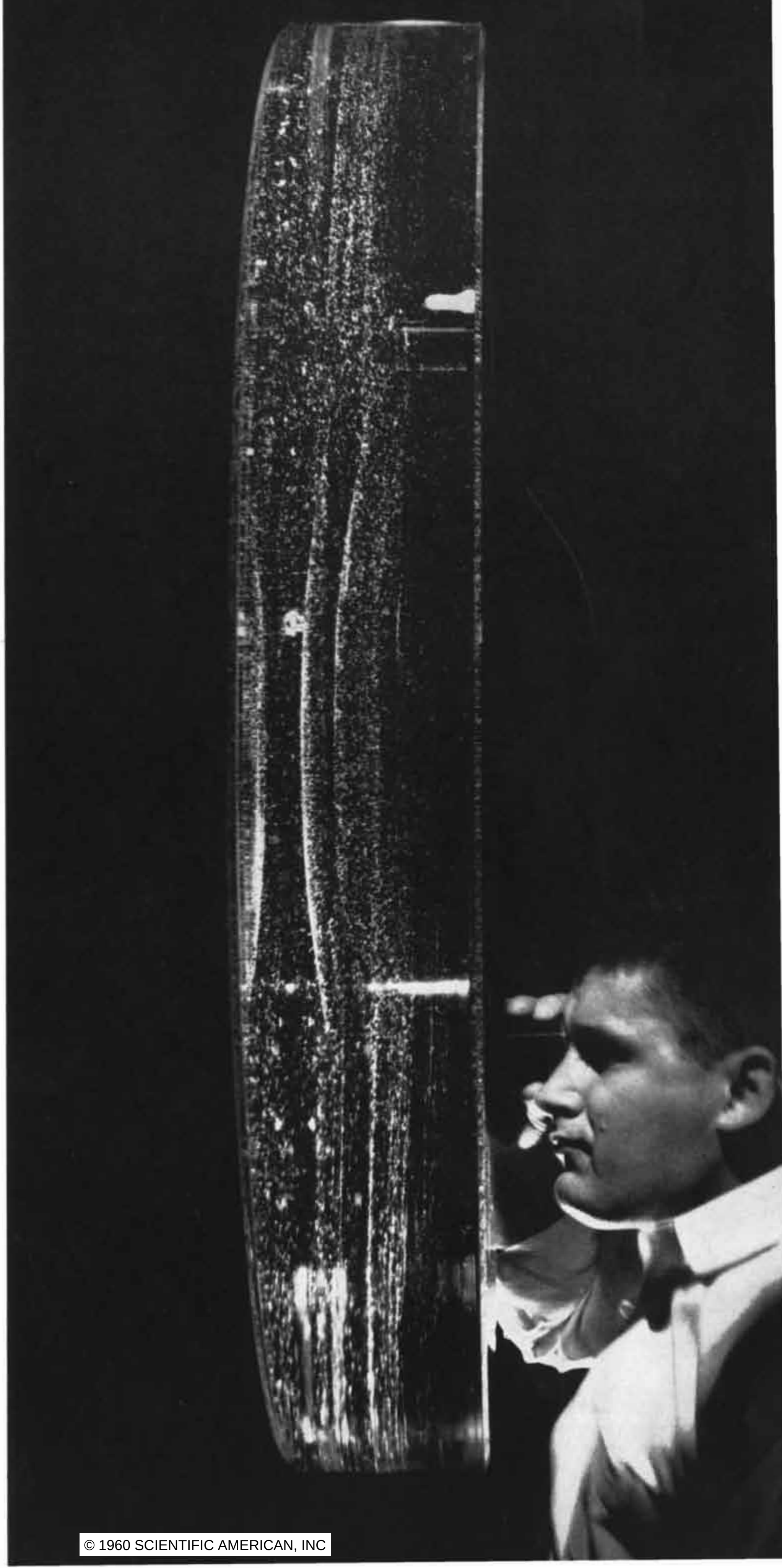
The differences in atomic structure between glasses and crystals can be readily demonstrated by X-ray diffraction. Monochromatic X-rays are reflected from the regular atomic arrays in crystals only at definite sharply defined angles. Thus, a sample consisting of a powdered crystalline substance will produce a diffraction pattern consisting of sharp concentric rings when struck by a beam of X-rays. Crystallographers can calculate back from the X-ray patterns to the spacings of atoms that produce them.

When X-rays are diffracted by glass, however, the pattern consists of a few concentric rings, which are fuzzy and diffuse much like those made by a liquid. This pattern gives only a little information on the average distance between close neighbors among the atoms in the glass and shows that there is no order or symmetry beyond a few atomic diameters.

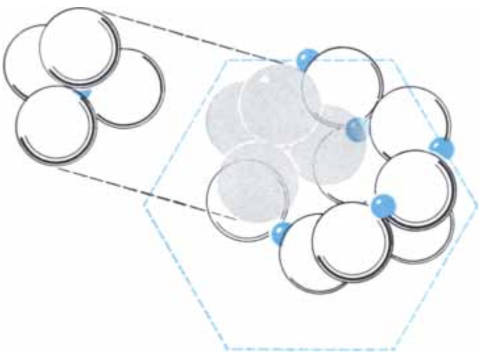
Before Zachariasen's work glass experts generally regarded glass as a supercooled solution of various silicate molecules in silica. In 1921 A. A. Lebedev, now a Soviet Academician, proposed the theory that glass might consist of a mass of very tiny crystals called crystallites. In silicate glasses these were supposed to be quartz, and they presumably accounted for changes in the behavior of glass in the region between 500 and 600 degrees centigrade where quartz undergoes a change of habit from low or alpha quartz to beta quartz. This crystallite theory of glass structure has been strongly supported by Russian investigators who believe that the crystallites may include other forms of silica such as tridymite and cristobalite [*see illustrations at top of next two pages*].

There was one major defect in the crystallite hypothesis: it did not account for the properties of glass. One of the most striking properties of glass, especially of pure silica glass, is its low coefficient of expansion. Whereas crystalline silica will expand along one of its crystal axes almost as much as steel when heated, silica glass will expand only about a twentieth as much. Moreover the crystallite hypothesis fails to explain why the density of silica glass is about 10 per cent less than that of cristobalite.

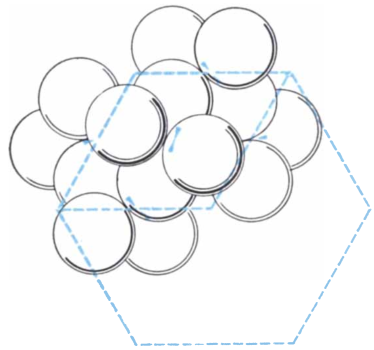
In his 1932 paper Zachariasen proposed a radically different hypothesis of glass structure. He suggested that glass is composed of three-dimensional random networks of alternate atoms of silicon and oxygen joined in long and cross-linked chains. He proposed, in short, that glass is an inorganic polymer. As in crystalline silica, the basic structural unit is a tetrahedron of one silicon atom surrounded by four oxygen atoms. Zachariasen visualized that the glass polymer is formed by having the tetrahedrons share corners, or oxygen atoms, just as they do when they form crystalline silica. The difference is that in glass the resulting network is a random one. "If we make use of crystal structure terminology," he wrote, "we may say that the network in glass is char-



PURE SILICA MIRROR for balloon-borne telescope is the largest optical piece ever made of this intractable material. The mirror blank was formed by Corning Glass Works and optically ground by Perkin-Elmer. Carried to an altitude of 80,000 feet in Project Stratoscope II, the mirror will be utilized to make photographs of the sun.



LOW QUARTZ of ordinary sand used in glassmaking has a spiral crystal structure. Large balls represent oxygen atoms; small ones, silicon atoms. The basic building block is a tetrahedron of one silicon and four oxygens. The crystal has hexagonal symmetry.

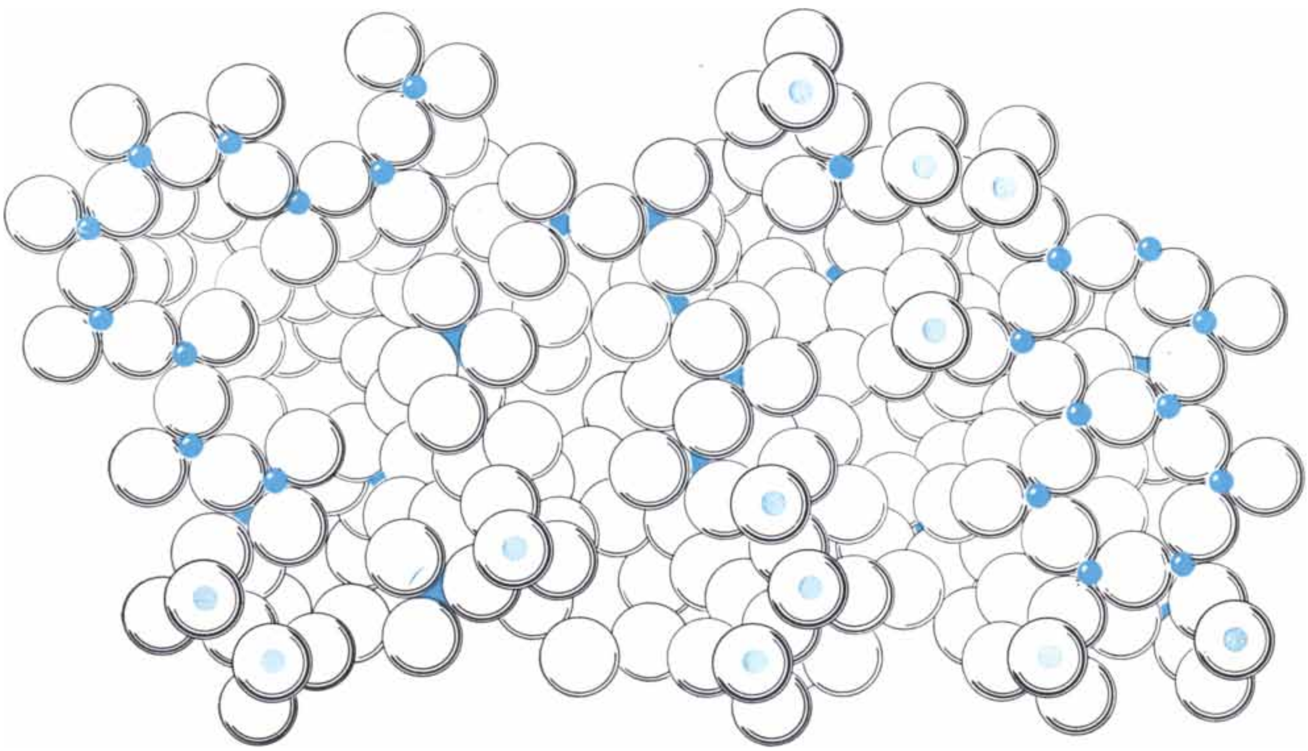


BETA QUARTZ arises from low quartz at 573 degrees centigrade as spirals are shaken out of the structure. A unit cell of quartz is either a whole hexagon or the third enclosed by a rhombus. Either atomic grouping, if repeated, will form a crystal.

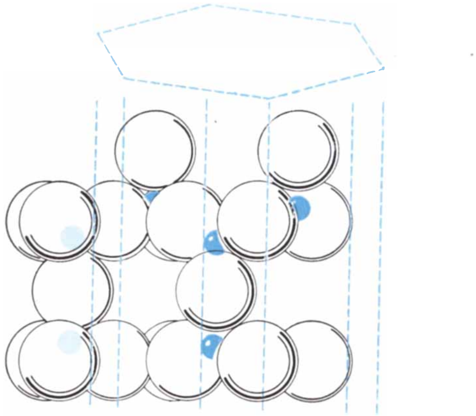
acterized by an infinitely large unit cell containing an infinite number of atoms. Because of the lack of periodicity no two atoms are structurally equivalent, while in a crystal lattice like that of sodium chloride all the sodium atoms are equivalent and all the chlorine atoms."

This asymmetry, Zachariasen believed, would explain why glasses soften gradually rather than melt abruptly. Each atom in a glass will have bonds slightly different in strength from those of every other atom; each will therefore absorb a different amount of energy before becoming detached. On heating, the atoms become detached over a rather broad range of temperatures; the breakdown of the glass network is therefore continuous rather than abrupt.

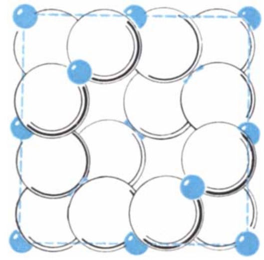
While Zachariasen did not offer an explanation for the low expansion coefficient of silica glass, the explanation was implicit in his concept of a random network (as others later pointed out). One can assume that when crystalline silica is heated, expansion may arise from two processes: a change in interatomic distances, or a change in the angle of the bonds linking silicon to oxygen. Because the silicon-oxygen bond is very strong, it is likely that bond-angle changes are the chief source of expansion. In a crystal, which has a symmetrical structure, the bonds can all change or rotate more or less in unison, in what B. E. Warren



SILICA GLASS, according to theory of W. H. Zachariasen, consists of a random network of silica tetrahedra that share oxygen atoms at their corners. Silicon atoms (*colored balls*) of a chain of tetrahedra 10 units long appear at upper left. For clarity the fourth oxygen atom of each tetrahedron is removed. A chain forming two interlocking hexagons appears at far right.



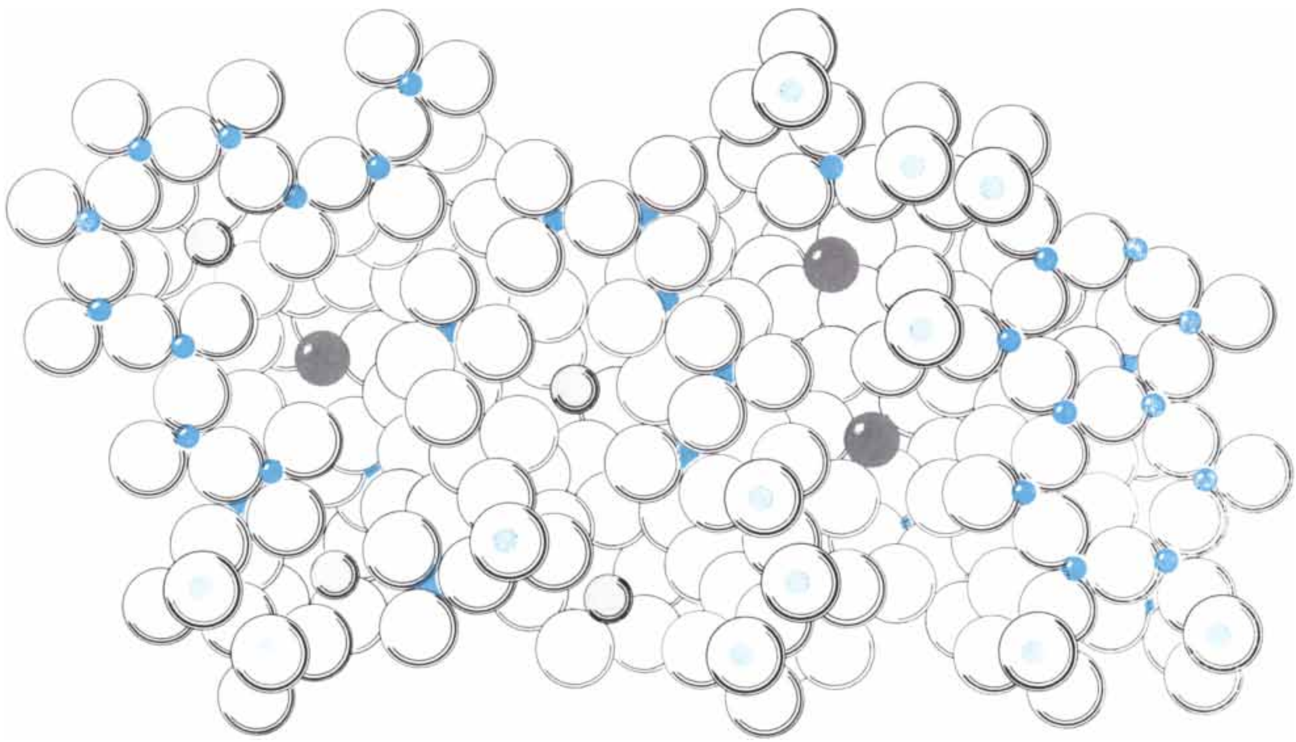
BETA TRIDYMITE is a still higher temperature form of silica, crystallizing above 870 degrees C. It is shown here from the side rather than in the basal projection of preceding drawings. Broken-line hexagon is foreshortened; crystal is actually symmetrical.



HIGH BETA CRISTOBALITE occurs above 1,470 degrees C. Like two preceding forms it is not stable at ordinary temperatures. Its "habit" is cubic. The crystallite hypothesis for glass structure states that glass is permeated with tiny crystals of cristobalite.

of the Massachusetts Institute of Technology has called a "co-operative maneuver." This could account for considerable changes in the external dimensions of silica on heating. In the random network of silica glass, on the other hand, such a maneuver is ruled out, so that in the aggregate, bond-rotations tend to cancel out internally and thus produce relatively little change in external dimensions.

Zachariasen adduced from his model a number of successful rules for predicting whether or not a given substance would form a glass. One rule is that glass-forming oxides must form tetrahedrons or triangles of oxygen atoms around the central atom. This rule predicts, for example, a triangular arrangement of oxygen atoms around boron in a glass made from boron oxide. This has recently been confirmed in nuclear magnetic-resonance studies made by Philip J. Bray at Brown University [*see illustrations on next two pages*]. Zachariasen also predicted that random networks of the sort he proposed would have holes in them "excellently suited" for holding elements of just the type that glassmakers commonly add to silica glass to make the glass more workable [*see illustration below*]. These elements include sodium, calcium, potassium, magnesium and lead. The oxygen atoms that are introduced with them break the strong network of silicon-

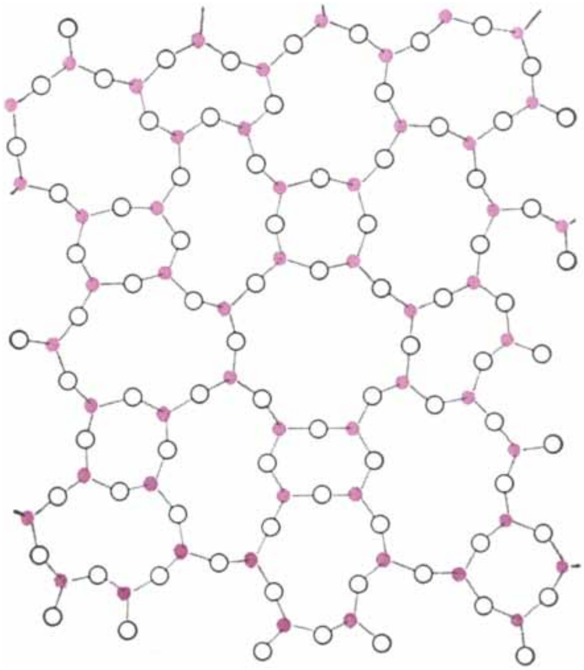


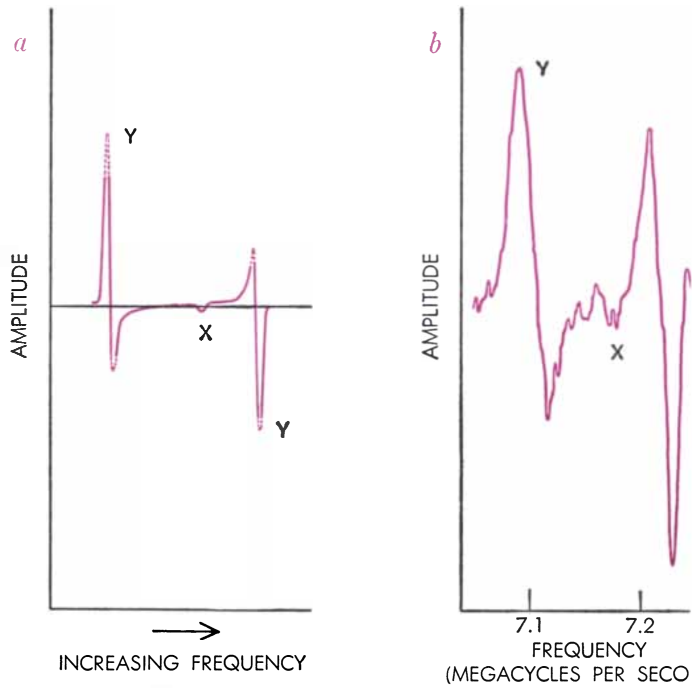
SODA-LIME GLASS, the most common commercial type, contains sodium atoms (*light gray*) and calcium atoms (*dark gray*) randomly dispersed in holes in the silica network. Soda and lime also provide extra oxygens that break tetrahedra chains and make glass easier to work. These two glass diagrams are based on drawings made by Willis G. Lawrence of College of Ceramics at Alfred University.

oxygen bonds and lower the softening point of the glass.

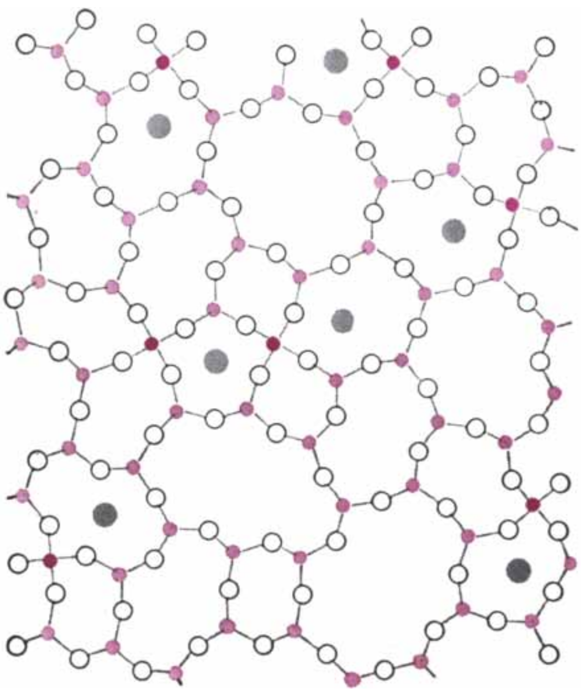
While Zachariasen's model has been extremely useful, and has been extended by a number of workers, it has not yet led to quantitative predictions of glass properties. It is for lack of a quantitative theory that glassmaking still remains an empirical art.

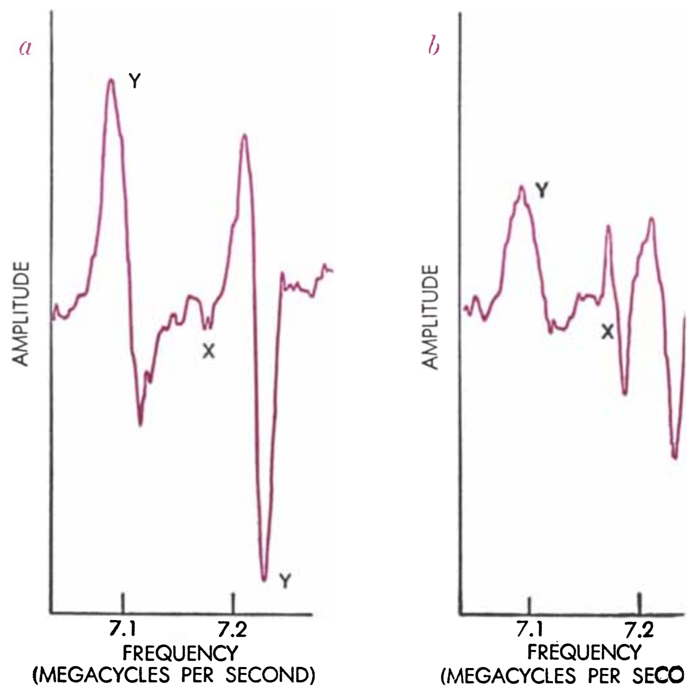
Judging by recent publications, Russian investigators are devoting much more attention to the structure of glass than are workers elsewhere. All-Union conferences held in Leningrad in 1953 and 1959 have yielded two large volumes of proceedings, describing glass studies made with a wide variety of optical, spectroscopic and electrical techniques. The two conferences were enlivened by sharp debates over structure. Quite a few Russian workers still favor Lebe-





IN BORON OXIDE GLASS, according to Zachariasen, the boron atoms (*color*) are each bonded to three oxygen atoms, creating random networks. In this planar triangular arrangement, boron 11 (the most common isotope of boron) should respond to radio-frequency energy in a characteristic way, measurable by nuclear-magnetic-resonance methods. In predicted curve of response v. frequency (*a*) Y-Y are distinctive peaks arising from the triply bonded boron atoms. A response at X would indicate boron bonded to four oxygens in a tetrahedral configuration with boron at the center. The actual spectrometer tracing (*b*) confirms Zachariasen's concept.





IN SODA BORON OXIDE GLASS, according to B. E. Warren, the added sodium (from sodium oxide) enters the glass network as ions (*large circles*), while the added oxygen bonds to boron atoms (*dark color*) to form tetrahedra. The actual structure was investigated by nuclear-magnetic-resonance methods. Tracing for glass of zero sodium oxide content (*a*) shows as before no response at X dev's crystallite hypothesis. In an opening statement at the 1959 conference Lebedev cited a number of recent findings which, he said, "are very inconsistent with the concept of glass structure as a dreary, uniform, atomic framework or as a continuous random network." However, E. A. Porai-Koshits, editor of the conference volumes, took the view that "further continuation of this almost purely terminological argument [over structure] is useless." He proposed as a compromise that glass be regarded as having a "polymer-crystallite" structure.

My own view is that there is no fundamental difference between the crystallite theory and the random-network theory of glass structure. The fact is that the random network in some parts has a structure identical with cristobalite; in other parts it has the arrangement of quartz or tridymite; and in still other parts it is composed of five-membered rings and other less symmetrical structures. The results of X-ray-diffraction experiments indicate that these regions of ordered structure are small, with only a few unit cells in each crystallite. Possibly the work that J. D. Bernal is doing on the structure of liquids will contain important ideas for glass theorists [see "The Structure of Liquids," by J. D. Bernal; SCIENTIFIC AMERICAN, August, 1960]. Eventually such a theory should enable us to calculate the properties of a glass from its composition and temperature history.

The Glasses of Commerce

The number of possible glass formulas is infinite. The Corning Glass Works has made up and tested more than 65,000 in the last 110 years and develops new ones at the rate of 30 a day. Glasses in regular production incorporate almost half the elements in the periodic table. But the principal ingredient in the eight million tons of glass produced annually in the U. S. is silica in the form of sand. (The annual glass output, by weight, exceeds by 60 per cent that of all synthetic polymers, including synthetic rubber; it is more than four times that of aluminum, and is exceeded among metals only by iron and steel.)

Pure silica glass, as noted earlier, is impractical for general use. Not only is a very high temperature needed to melt silica, but the resulting liquid is too viscous to permit bubbles of air trapped between grains of sand to escape. Raising the temperature high enough to lower the viscosity causes the silica to evaporate.

Glassmakers learned centuries ago how to solve this problem. They put more oxygen atoms into their melts—long before they knew anything about oxygen or atoms. The oxygen was usually added, as it is today, in the form of metal oxides. These were obtained from sodium carbonate (soda ash), calcium carbonate (usually limestone) or sometimes as the double carbonate of calcium and magnesium known as dolomite. Regardless of the source, each of the extra oxygen atoms breaks a bond between silicon and oxygen in the silica network. As a result the structure of the silica glass is weakened so that it flows more readily. Small amounts of other ingredients serve other purposes. Alumina helps to prevent crystallization or devitrification. Borax and barium oxide help in melting the sand. Sodium sulfate and arsenic oxide help to remove bubbles from the viscous glass.

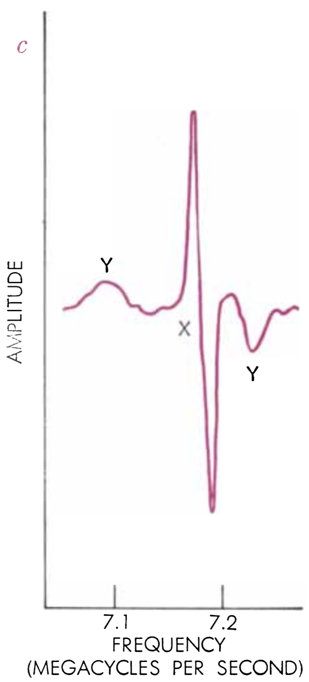
Glasses to Withstand Heat

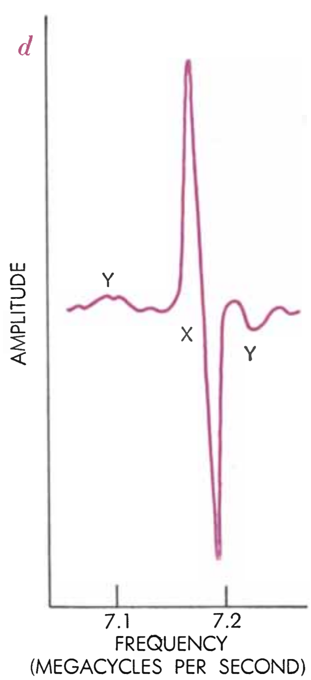
The soda-lime glasses made in huge tonnage for bottles and window glass have a well-known drawback. They are sensitive to thermal shock: they break when they are suddenly heated or chilled. This is because they have a coefficient of expansion of about 90×10^{-7} per degree C., compared to only 5×10^{-7} for pure silica glass. (A silica-glass rod a mile long would lengthen barely a millimeter if heated one degree C.)

About 1910 Corning investigators developed the general family of glasses sold under the trademark Pyrex. Some of the family have a coefficient of expansion as low as 32×10^{-7}, about a third that of ordinary soda-lime glass. The important additive is boron oxide, making up about 13 per cent of the formula, and the glass is therefore called a borosilicate. Its resistance to heat shock makes it highly useful for chemical apparatus and industrial glassware. It is also unusually resistant to attack by acids.

Some of the household top-of-stove ware bearing the label Pyrex (*e.g.*, glass coffeemakers), are not made from the borosilicate formula, but are endowed with strength and shock resistance by a tempering process. The process is also used to toughen some of the window glass used in cars and the all-glass doors now so common in buildings. To temper glass it is heated until it begins to soften, and then cooled quickly and uniformly by blowing air on the whole surface or by plunging it into a bath of oil or molten salt.

The sudden cooling produces a temperature gradient in the plastic glass, the whole surface being relatively cold and the interior hot. Because the glass is somewhat soft and plastic, little or no strain is caused by the initial thermal contraction of the surface. Eventually





from tetrahedrally bonded boron atoms. But tetrahedral bonding shows up increasingly in subsequent tracings (*b, c and d*) for glasses containing 5, 16 and 33.3 per cent sodium oxide. Work depicted here was done by Philip J. Bray and Arnold H. Silver at Brown University.

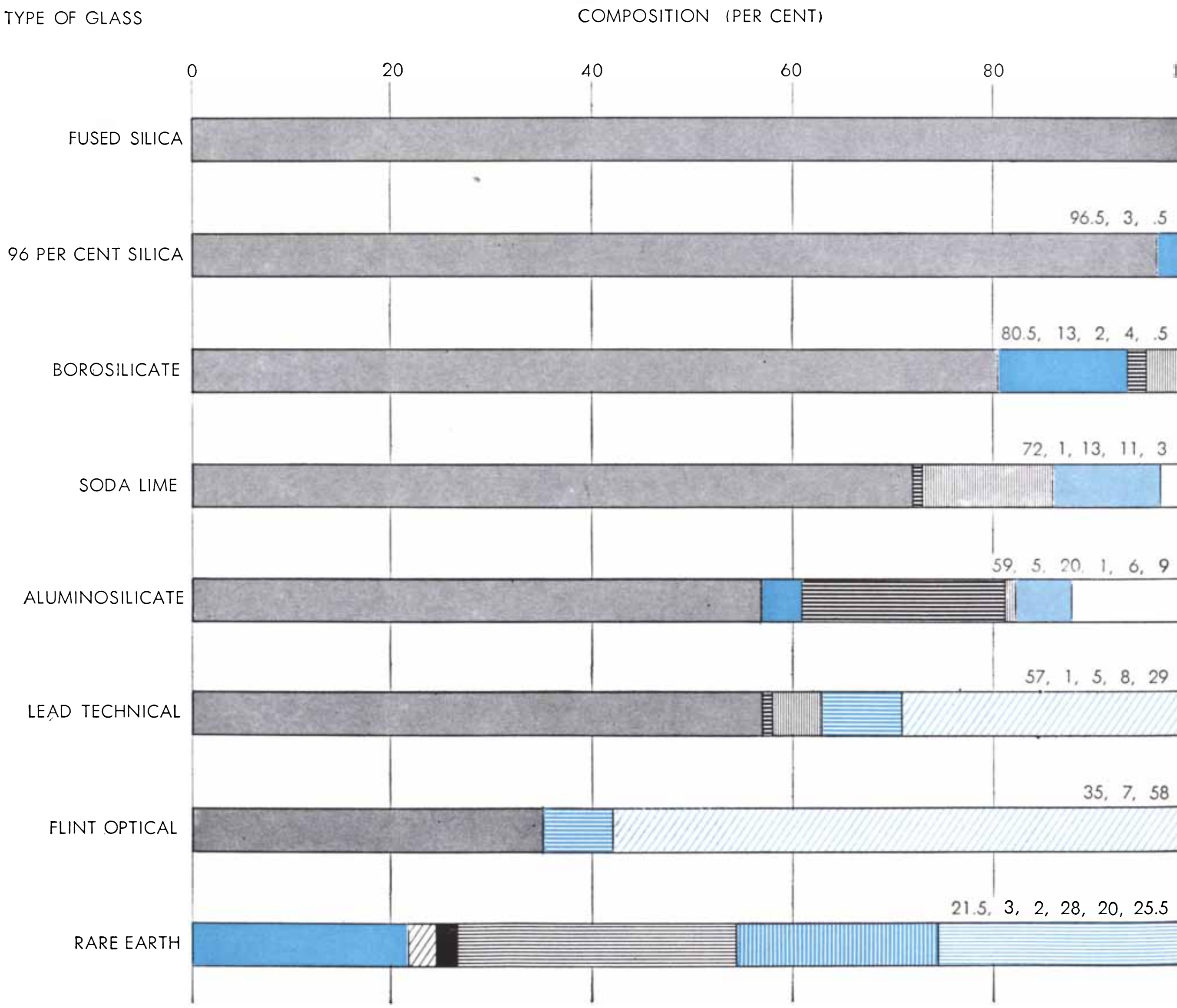
the surface of the glass cools to the air or bath temperature, forming a rigid skin around the still plastic and expanded interior mass. Upon further cooling, the interior of the glass tries to contract but, being bound tightly to the outer skin, it cannot shrink as much as it would normally. The final result is a glass with an interior stretched or in tension, and a surface squeezed together or in compression.

When a piece of glass tempered in this way is loaded in service, the tensile strain in the surface caused by the load, which might cause the piece to break, is diminished by the compressive strain introduced in tempering, so that the net strain is insufficient to cause breakage. In the interior of the glass, where the tensile strain is increased by the tempering, the glass has practically unlimited strength because no flaws are present. The series of photographs on page 102 shows the stress patterns inside a tempered and an untempered glass rod when a load is applied.

The Search for a Pure Silica Glass

Over the years, in the quest for a heat-stable glass, many laboratories tried to find practical ways to produce a pure silica glass. As early as 1930 pure fused silica was used in special and costly technical apparatus. But a major step toward practical silica-ware was achieved about 1940 by two Corning scientists, H. P. Hood and M. E. Nordberg. They observed that borosilicate glasses containing unusually large amounts of boron oxide were attacked quite badly by dilute acid. They also noted that the more carefully the glasses were annealed, the more rapidly the acid attacked. The glasses, however, did not dissolve completely. The acid dissolved the boron oxide and soda but not the silica.

After lengthy development Hood and Nordberg perfected a process in which soda and boron oxide are leached from a piece of glassware and molded in any desired shape, leaving a "skeleton" of glassy silica intact. If the piece is then heated to about 1,200 degrees C., the pores close, making a clear transparent glass structure about 14 per cent smaller than the original and consisting of more than 96 per cent silica. The new glass, which Corning calls Vycor, has a ther-



EIGHT TYPES OF GLASS embrace main commercial varieties. Except for first two, each type comes in numerous formulations. One firm has 65,000 formulas on file. The glassmaker's term "flint" connotes a very clear glass and was originally applied to fine English

mal expansion only a little greater than pure fused silica and about the same electrical properties, resistance to chemicals, and transparency to ultraviolet light.

Within the past few years Corning has developed a process for making large boules, or circular slabs, of essentially 100 per cent silica. The boules are built up of silica condensed from the vapor state in a furnace held above 1,000 degrees C. The photograph on page 93 shows a 36-inch telescope mirror made from the new material. Its extremely low thermal expansion makes it admirably suited to its job. It will be used to photograph the sun from an altitude above 80,000 feet, in a telescope carried aloft by the balloon of Project Stratoscope II. Stratoscope I, which used a 12-inch mirror of fused silica, produced solar photographs with a sharpness never before approached, and the new instrument is expected to improve greatly on them.

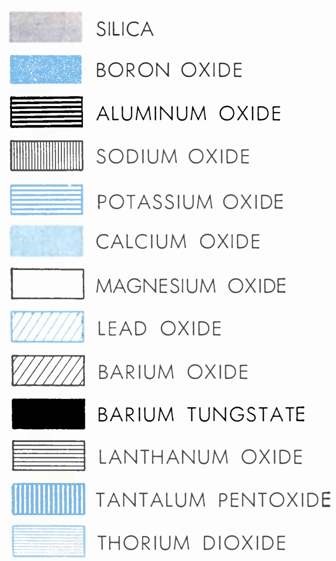
When glass is used as a telescope mirror we are apt to forget that it is functioning purely and simply as a structural material. None of its properties of transparency or refractivity are being exploited at all. The glass is being used solely as a rigid substance, of great heat stability, which can be ground and polished to extremely close tolerances. It is therefore something of an accident that glass retains in reflection optics the indispensability it achieved in refraction—or transmission—optics.

The Glasses of Optics

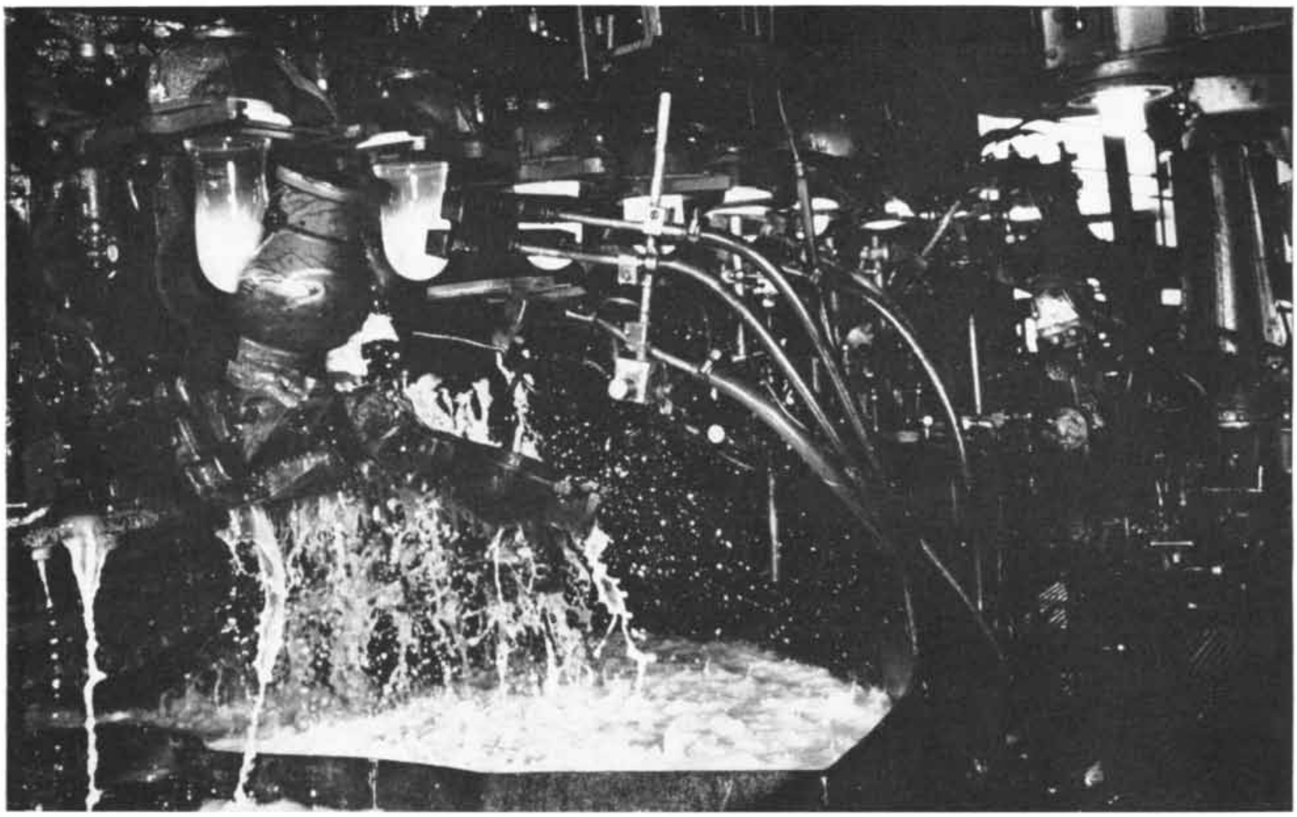
No aspect of glass technology has called forth greater ingenuity than the development of optical glass, dating back more than two centuries. Early instrument makers found that whenever they tried to increase the power of their telescopes or microscopes by making the lenses stronger beyond a certain point, the resolution became worse rather than better because of colored fringes that surrounded the images. Believing this chromatic aberration to be insurmountable, Newton invented the reflecting telescope. Almost simultaneously, however, English glassmakers made a discovery that was to solve the color-fringe problem. They discovered the art of making lead glass, using litharge (lead oxide) and potash (potassium oxide). This sparkling heavy glass, which became known as English crystal, gave new brilliance to tableware and vases. Its brilliance came from two properties. It could bend light more than ordinary soda-lime glass, that is, it had a higher refractive index. And it also had a higher dispersion or ability to separate different wavelengths of light.

Some 50 years later, in 1757, Chester M. Hall and John Dollond combined a strong converging lens of soda lime or "crown" glass with a weaker diverging lens of lead glass in such a way that the lead glass lens just overcomes the separation of colors caused by the crown glass without entirely neutralizing its power to bring light to a focus. This

SOFTENING POINT (DEGREES C.)	COEFFICIENT OF EXPANSION PER DEGREE C.	REFRACTIVE INDEX	USES
1,640	5.5×10^{-7}	1.46	
1,520	8×10^{-7}	1.46	SCIENTIFIC AND TECHNICAL APPARATUS
820	32×10^{-7}	1.47	
700	92×10^{-7}	1.51	WINDOW GLASS, CONTAINERS, LAMP BULBS
915	42×10^{-7}	1.53	HIGH-TEMPERATURE ARTICLES
630	89×10^{-7}	1.56	STEMS OF VACUUM TUBES, ELECTRICAL SEALS
580	91×10^{-7}	1.69	LENSES, PRISMS
		1.85	



glassware whose formula included powdered flint, a microcrystalline form of quartz. U. S. production of glass last year amounted to about eight million tons, of which nearly six million tons (of the soda-lime variety) went into the making of containers.



GLASS COFFEEPOTS are produced at high speed by a machine that blows soft glass into hinged molds. This Corning machine is typical of many that have mechanized the ancient art of hand-blowing. Large pieces, such as carboys, are still made by hand.

combination, which brings all the colored constituents of white light to almost the same focus and produces clear, sharp images without the troublesome color fringes, is known as an achromatic lens.

Before satisfactory optical instruments could be made, however, it was necessary to have really homogeneous glass. In ordinary glass-melting the batch materials tend to separate because of differences in density, and even the best of refractory pots dissolve to a certain extent in the molten glass. The resulting differences in composition produce differences in refractive index in various parts of the glass, bending light rays in erratic paths and making it quite impossible to focus them to a sharp image. Molten glass is so viscous that such differences in composition are evened out only very slowly by diffusion and convection. It was not until Pierre Louis Guinand, a Swiss watchmaker, developed a method of stirring glass with a

GLASS FIBERS are produced when thin streams of molten glass are fed into a blast of hot gas. The high-speed jet forms the glass into tangled wisps, floating off to right.

FIBER SPOOLING operation places glass fibers on beams, or spools. The

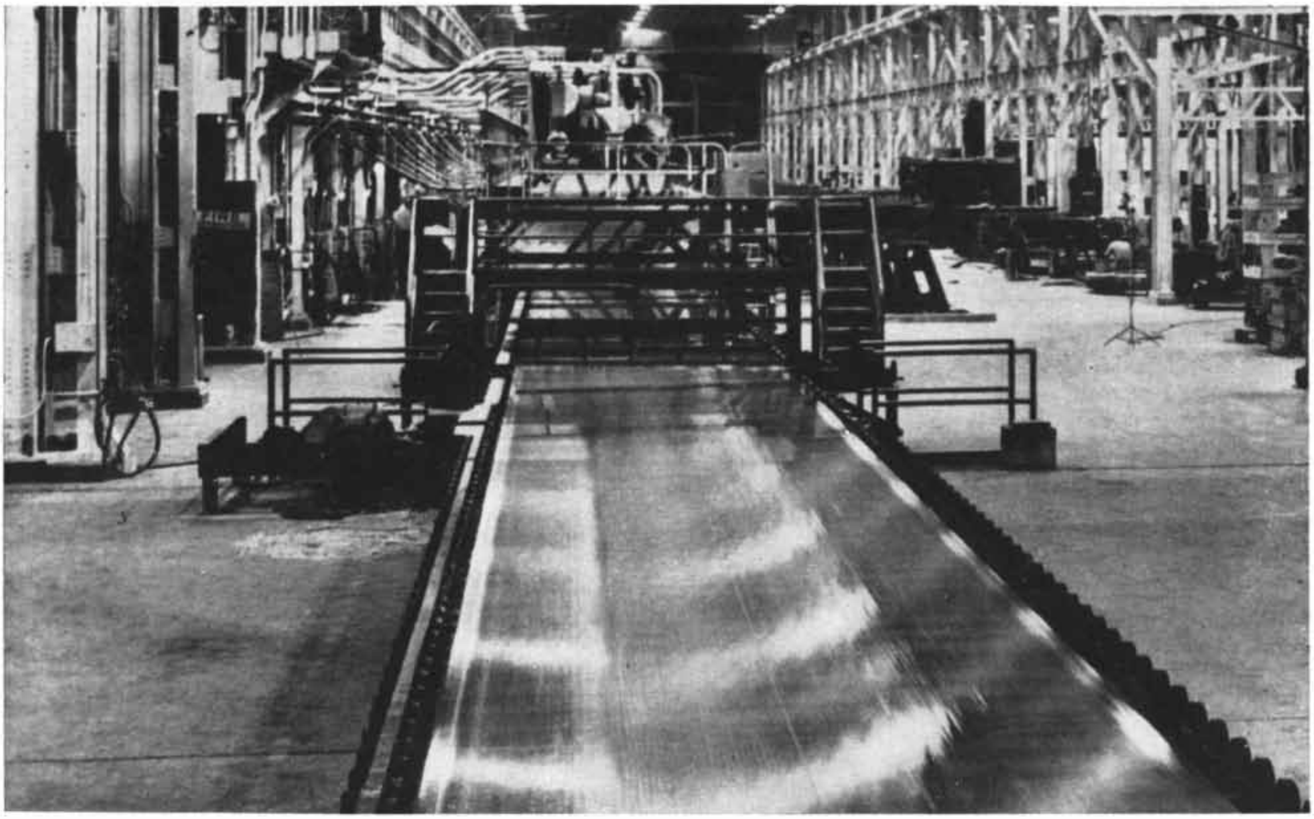
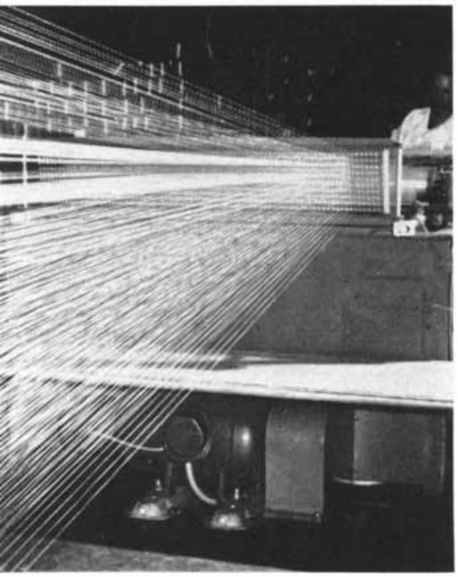


PLATE GLASS, still in rough unfinished state as it leaves the annealing lehr, an oven, passes into a twin-grinding machine at the plant of Libbey-Owens-Ford. The machine has 22 heads that grind the glass at top and bottom simultaneously. Glass is 100 inches wide.

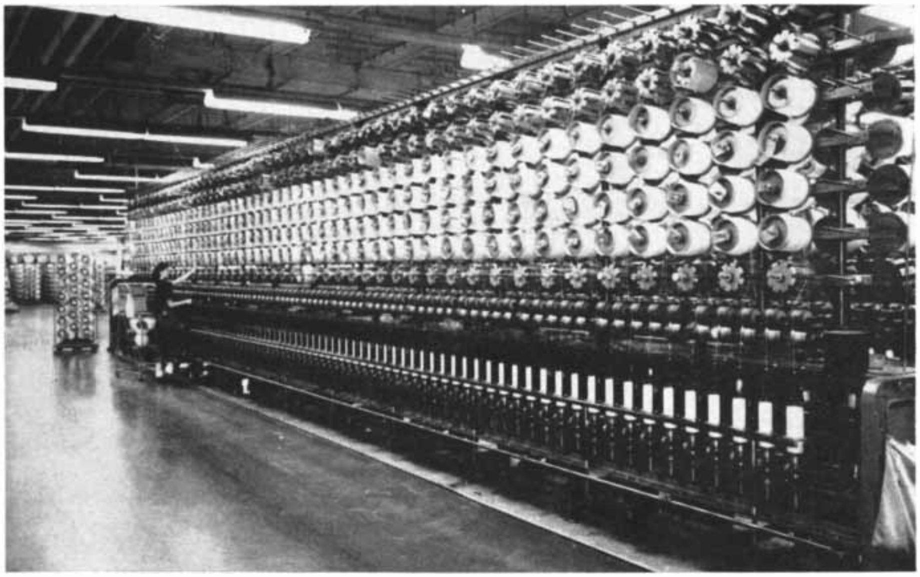
refractory rod that satisfactory optical glass could be made, particularly for large lenses and prisms.

The next step in the development of modern optical glass was a systematic study of the effect of new elements in glass on its refractive index and dispersion. About 1880 the German physicist Ernst Abbe and the glass chemist Otto Schott started a program of research which produced scores of new types of glass and permitted optical designers to make great improvements in the speed and sharpness of lenses for all sorts of instruments.

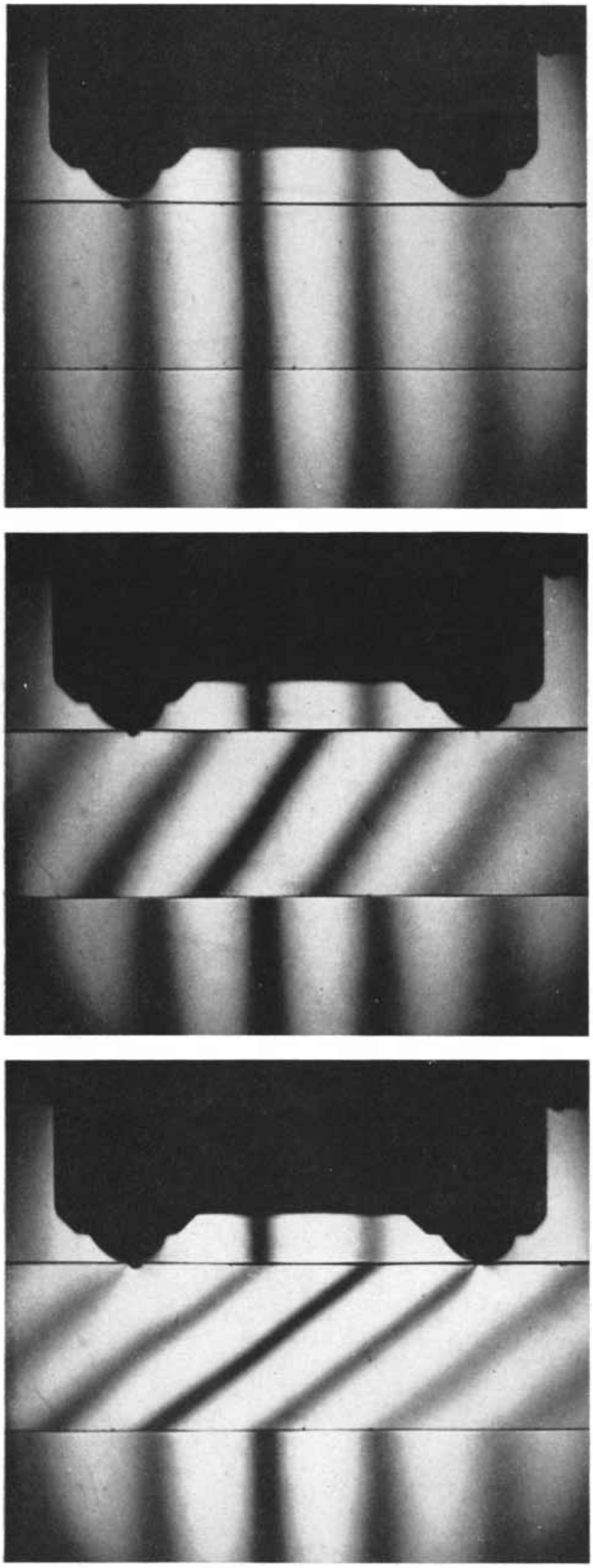
The latest major advance in optical glass was made during the 1930's by George W. Morey, who invented a series of glasses based on oxides of rare-earth elements, chiefly lanthanum and thorium. These glasses, containing little or no silica, combine a very high refractive index with relatively low dispersion. In the past dozen years these glasses, manu-

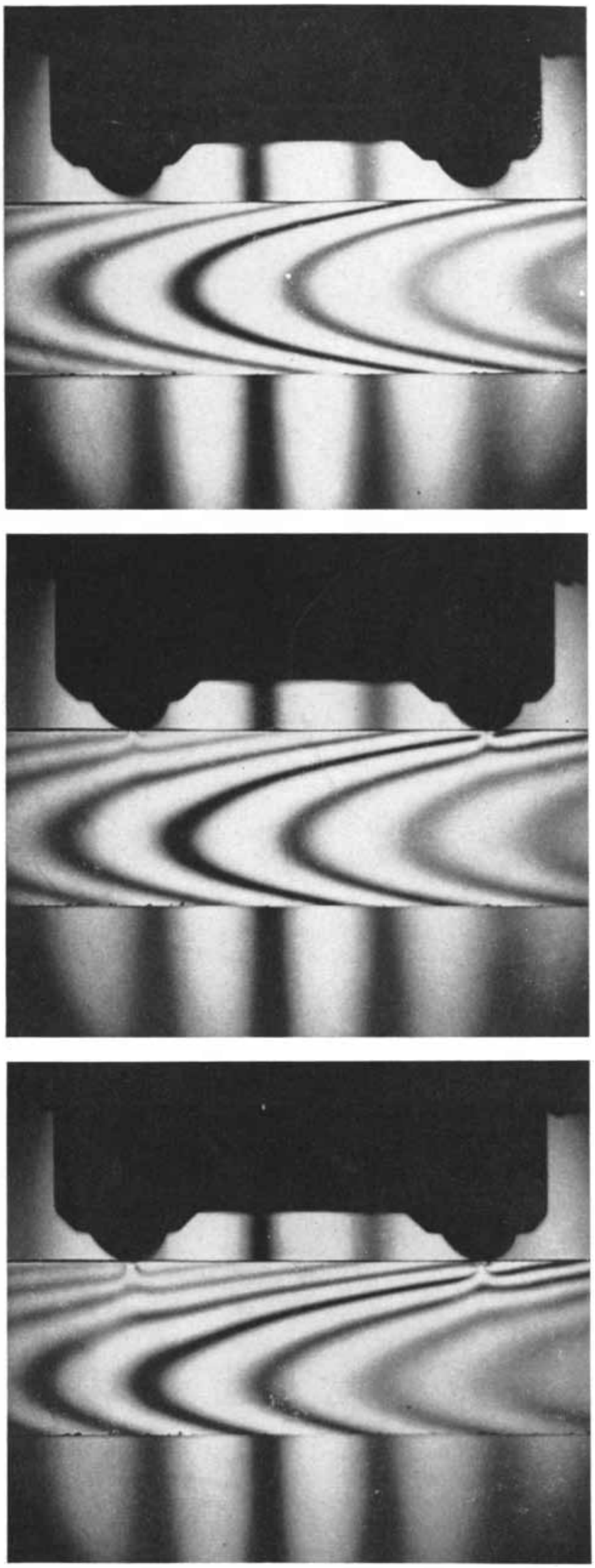


fibers will be used as a reinforcing material in making wrapping tapes.



TWIST-AND-PLY equipment for continuous filament glass yarns is of the same type as that used in conventional textile plants. This is the Owens-Corning Fiberglas plant at Anderson, S.C.





UNTEMPERED GLASS BAR, placed in polarimeter, does not distort lines or fringes of polarized light when unloaded (*top*). When lines slant a distance of half a fringe (*center*), the lower surface of the glass is under tensile stress of about 2,500 pounds per square inch. At full fringe displacement (*bottom*), tension is 5,100 p.s.i. The bar will break at about 6,600 p.s.i. tension.

TEMPERED GLASS BAR, unloaded (*top*), shows curved strain patterns indicating that the surfaces of the bar are under a compression of about 5,000 p.s.i. A small load (*center*) offsets about 3,300 p.s.i. of this compression. Heavier load (*bottom*) fully offsets compression and creates about 300 p.s.i. of tension. Increasing the tension to about 6,600 p.s.i. will cause bar to break.

factured in the U. S. by the Eastman Kodak Co., have permitted the design of camera lenses of unusually high performance.

Light-Sensitive Glass

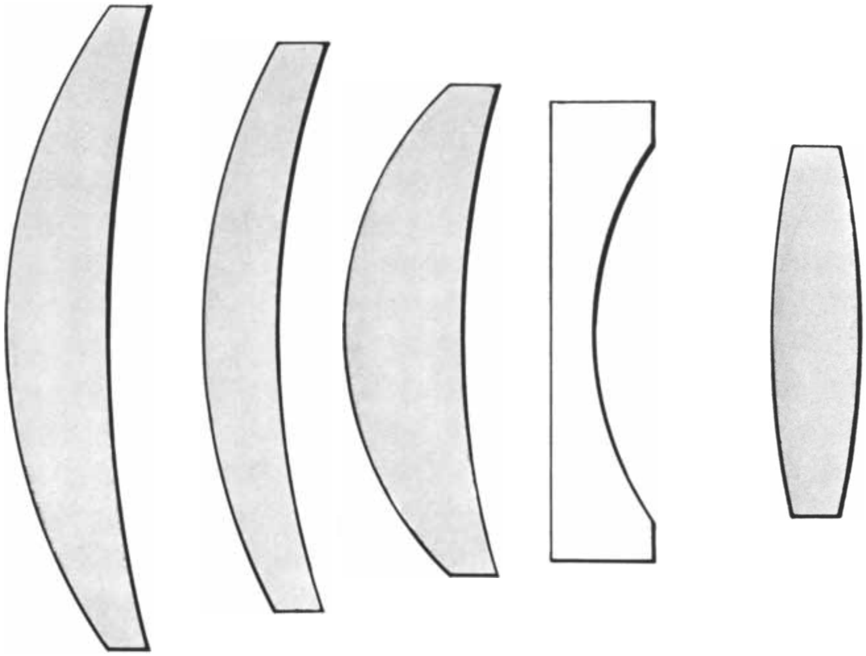
It has been known for years that glass will sometimes discolor, frequently taking on delicate violet hues, on long exposure to light. Only recently, however, has light sensitivity been deliberately engineered into glass. The process starts with a little cerium oxide, which is added to the glass batch with just the right amounts of silver or gold. The cerium ions in the glass absorb ultraviolet light and apparently transfer electrons to the gold or silver ions, converting them to gold or silver atoms. After the exposure to light, these atoms remain invisible in the glass as a sort of latent image.

Next the glass is heated until it begins to soften. This permits the metal atoms to collect into colloidal particles of silver or gold. The silver particles make a weak yellow image of whatever pattern was thrown on the glass with the ultraviolet light. The gold develops as the glass is heated to a beautiful blue or purple picture corresponding to whatever negative was used during the ultraviolet exposure. Since the sensitivity extends through the full thickness of the glass, the developed images produce the illusion of depth, which makes the picture extraordinarily lifelike. They are as permanent as the glass itself.

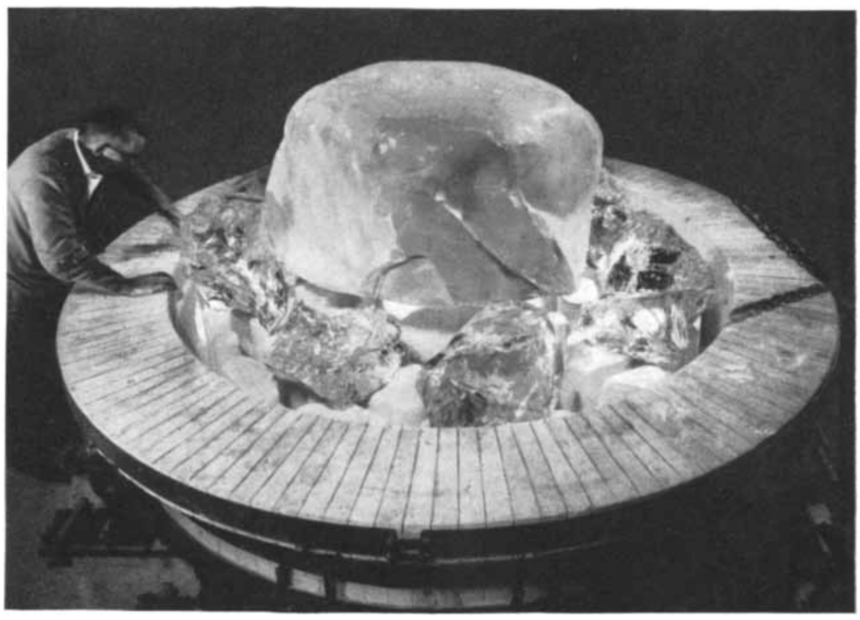
The weak yellow silver-images are of little use as such, but the tiny silver particles formed by the photosensitive process may serve as nuclei for further developments. One of these consists in precipitating fluoride particles, which convert the glass to a dense white opal. By careful adjustment of the composition the white pattern in the glass is made to follow the lines exposed to ultraviolet light. One use of this process is to make built-in louvers for directing the passage of light through illuminating fixtures.

Even more startling results are produced by developing the silver particles in a glass of special composition, which crystallizes or devitrifies where they are present. After heating such glass, a white crystalline image appears where the ultraviolet light struck the glass. If the piece is now immersed in hydrofluoric acid, the crystallized glass dissolves so much faster than the clear glass, which was shielded from the light, that a pattern of almost any desired form may be chemically machined from the glass. In one instance 200,000 holes, each .009 inch in diameter, were etched in an area 12 inches in diameter. This process, known as photoforming, is used to make a wide variety of intricately patterned glass elements for use in electronics [*see top illustration on next page*].

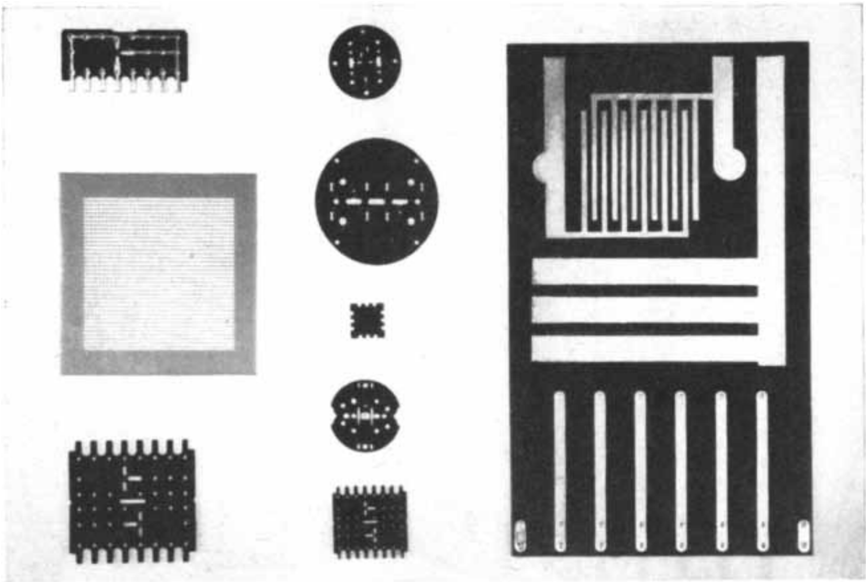
One day in the Corning laboratory a piece of photoformed glass was placed in an oven prior to the acid-etching steps. By accident the glass was left overnight, at a much higher temperature than customary. When removed from the oven next morning, the glass, which had been clear, looked like porcelain. A laboratory worker accidentally dropped the piece on the floor and was amazed to see that it did not break. This was the start of a development, guided by S. D. Stookey, that led to a new class of tough ceramics. The new material, obtained by controlled devitrification of glass, contains smaller, more uniform crystals than do conventional ceramics; it is also completely nonporous. It may be made with a coefficient of expansion rivaling that of pure silica glass, and it has several



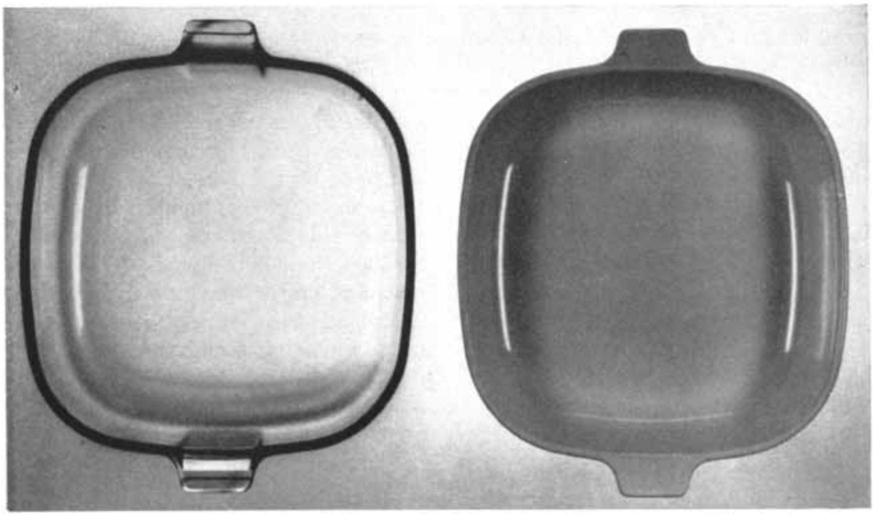
CAMERA LENS by Bausch & Lomb uses four rare-earth elements (*gray*) to achieve exceptional speed of *f*/1.1. Not yet on market, it is for eight-millimeter movie cameras.



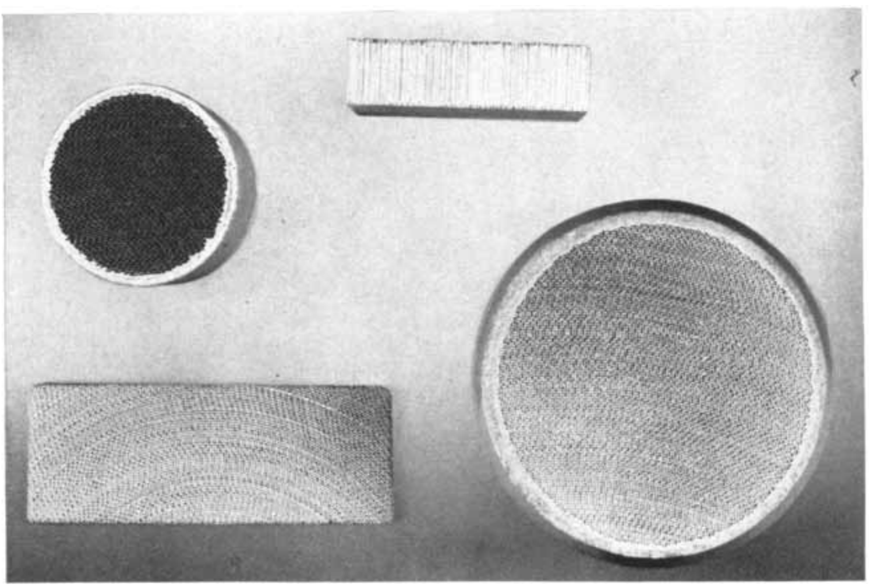
MIRROR FOR KITT PEAK TELESCOPE was formed by Corning using a sagging process. The large chunks of borosilicate glass sagged smoothly into shape when heated to 1,275 degrees C. The 84-inch mirror is largest made in the U. S. since Palomar 200-inch.



PRECISE GLASS SHAPES, used in electronics, are made of glass that becomes acid-soluble where struck by utraviolet light. Glass can thus be shaped in response to a photoimage.



ULTRASTRONG CERAMIC, called Pyroceram, makes a tough heat-resistant dish (*right*). Before the ceramic crystals are formed by heat treatment, the dish is in the glassy state (*left*).



CERAMIC HONEYCOMB, made in part from Pyroceram, is corrosion-resistant, strong and light (density is half that of water). But no one has yet found a commercial use for it.

times the strength of ordinary glass. The new material, which Corning calls Pyroceram, recommends itself for scientific and industrial apparatus as well as for cooking utensils. Being transparent to radar waves and highly resistant to thermal shock, it is employed for missile nose cones.

Glass in Fiber Form

Scarcely more than 25 years ago glass fibers were a curiosity, sometimes produced to the amazement of onlookers by itinerant glassblowers. Today whole industries have been built on glass in fiber form. Glass fibers make excellent insulation; they may be woven into colorful fabrics, or bonded with plastics to form chairs, fishing rods, boats and even automobile bodies.

Fiber glass comes in two general forms: as "staple," which consists of short lengths of fiber loosely packed together, and as continuous filament. In the manufacture of staple fiber the molten glass flows through many small orifices in the bottom of an electrically heated platinum trough, or "bushing," and is pulled into fine filaments by a blast of high-pressure air or steam. These filaments may be used loose as insulating wool or they may be bonded into insulating board by the application of an organic resin and heat.

The glass for continuous filaments is usually made first into marbles that can be readily inspected for defects which would interfere with the spinning operation. These marbles, being of uniform size, can be easily fed into small electric furnaces, where they are melted. The glass flows through 102 small holes in a platinum bushing and forms a bundle of filaments that are pulled mechanically by a rotating spindle at a rate of more than 60 miles per hour. The resulting strand of 102 filaments, each about .0003 inch in diameter, is twisted with other strands to form glass yarn which may be woven into various fabrics with standard textile machines. Tape made from this fiber glass is particularly useful for insulating motors and other electrical equipment.

In a variation of these processes the glass is first drawn mechanically into rather coarse fibers about .03 inch in diameter. These fibers are then remelted in high velocity flames which stretch them into ultrafine filaments. The product, which has a diameter between .00003 and .0002 inch, is used for sound- and heat-insulation in aircraft. Still finer fiber, less than .00003 inch in diameter, is made into a glass paper which is most useful for filtering acids and other corrosive substances.

Ordinary soda-lime glass is slowly attacked by moisture in the air, but the consequences are rarely visible or damaging. Glass fibers, however, are so fine and expose such a large surface area to the air that deterioration from moisture is very rapid. Special glass formulas have therefore had to be developed for use in fibers. High durability is achieved by reducing the amount of soda in the glass to less than 2 per cent and adding boron oxide and alumina.

The strength-to-weight ratio for fiber glass is unequalled by any other material, provided the surface of the fibers has not been abraded. Strengths up to almost a million pounds per square inch have been measured. However, the slightest contact, particularly contact with the surface of another fiber, greatly weakens the glass. For this reason lubricants are usually sprayed on the fibers as they are formed. The strength may also be preserved by bonding the glass fibers in plastics. The glass bears the load while the plastic separates the fibers and protects them from abrasion.

This article has not tried to recount the enormous ingenuity that has gone into automatic glassmaking machinery of all sorts—the machines that make bottles, lamp bulbs, window glass and a host of other items. But one process announced just about a year ago by Pilkington Brothers Limited in Britain must be mentioned, for it handles glass in a way that glass has never been handled before. In an art as old as glassmaking this is quite an achievement. The process is for making plate glass.

In the conventional process a ribbon of glass flows out of a furnace through a pair of water-cooled rollers that produce a continuous sheet up to 10 feet wide. The sheet passes through an annealing oven and then between twin grinding heads that grind both sides of the sheet simultaneously. The ground sheet is then cut into large panes for final polishing.

In the new Pilkington process the glass, after passing between the rollers, is floated onto a bath of molten metal. This provides an absolutely smooth undersurface. The upper surface is fire-polished to equivalent smoothness. The crucial step, which Pilkington has not described in detail, is to solidify the glass ribbon and move it off the molten metal without damage. Pilkington calls its technique the "float-glass" process. It shows that the glassmaker's ancient artistry is still very much alive.

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A New Scale of Stellar Distances

The distance of a star can be determined by comparing its apparent with its intrinsic brightness. A new index to intrinsic brightness has been found in the calcium absorption spectra of many cool stars

by O. C. Wilson

The measurement of distance is still a fundamental problem at every level of astronomy. Outside the solar system only about 170 celestial objects—the stars lying within some 30 light-years of the earth—have been located with an error of less than 10 per cent. Estimates for perhaps another 600 are half as good, but the great majority of them are stars of a particular type—intrinsically faint objects still in an early phase of their evolution. As to the remaining millions of observable members of our galaxy, only their average distribution is known with fair accuracy. We probably have a better idea of the distances to some galaxies a million or more light-years away than to most individual stars in the Milky Way.

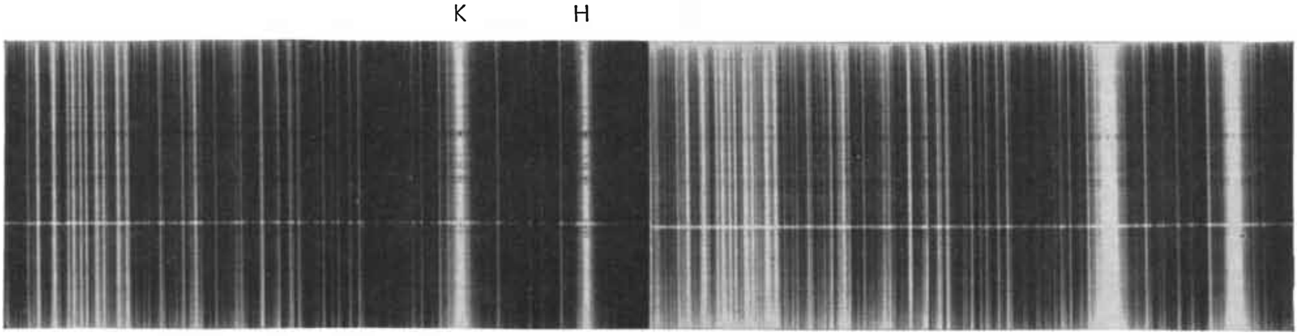
Yet many questions about the structure and history of the galaxy can be answered only through the accurate placement of individual stars. Thus it is not surprising that astronomers are always on an eager lookout for improved methods of measuring stellar distances. Recently a new one has turned up. It applies to a substantial fraction of stars out to about 2,000 light-years, and it can fix their distance within about 15 per cent. At the same time it has provided astrophysicists with the entertaining problem, still unsolved, of explaining why it works.

Every new astronomical yardstick must of course overlap an older one; eventually all are tied to the scale of distance for the closest stars. This is established by trigonometric parallax: the measurement of the apparent angular displacement of a nearby star, against the background of more distant ones, when it is observed from opposite sides of the earth's orbit around the sun. The method is direct and unambiguous, but it is limited by the small size of the angles that must be determined. At a distance of about 30 light-years the shift is only 1/36,000 of a degree—the apparent angular size of a penny seen at a distance of 24 miles! Even such an angle is measurable within an error of 10 per cent. At greater distances the attainable accuracy rapidly drops off, and at 60 light-years the apparent shift is essentially too small to measure.

Beyond the effective range of trigonometric parallax it is no longer possible to get at the distance of individual stars directly. The only way to place them is through a knowledge of their intrinsic brightness, or "absolute magnitude." The observed brightness of a star is proportional to its intrinsic brightness divided by the square of its distance. Thus determining the intrinsic brightness is equivalent to determining the distance.

Two ways of finding the absolute magnitude of certain types of stars have been known for half a century. One applies only to a class of pulsating stars: the cepheid variables [see "Pulsating Stars and Cosmic Distances," by Robert P. Kraft; SCIENTIFIC AMERICAN, July, 1959]. Although no one yet knows why, the rate at which the cepheids wax and wane is connected with their absolute magnitudes. The exact relationship is still in some doubt, but these stars have provided the best mileposts for the outer reaches of the Milky Way and for nearby galaxies. (The nearest cepheid is the Pole Star, 300 light-years distant.)

The second long-established index to intrinsic brightness bears the figurative name "spectroscopic parallax." The term refers to a correlation between brightness and the relative intensity of certain pairs of absorption lines in stellar spectra [*see illustration on page 116*]. Although the

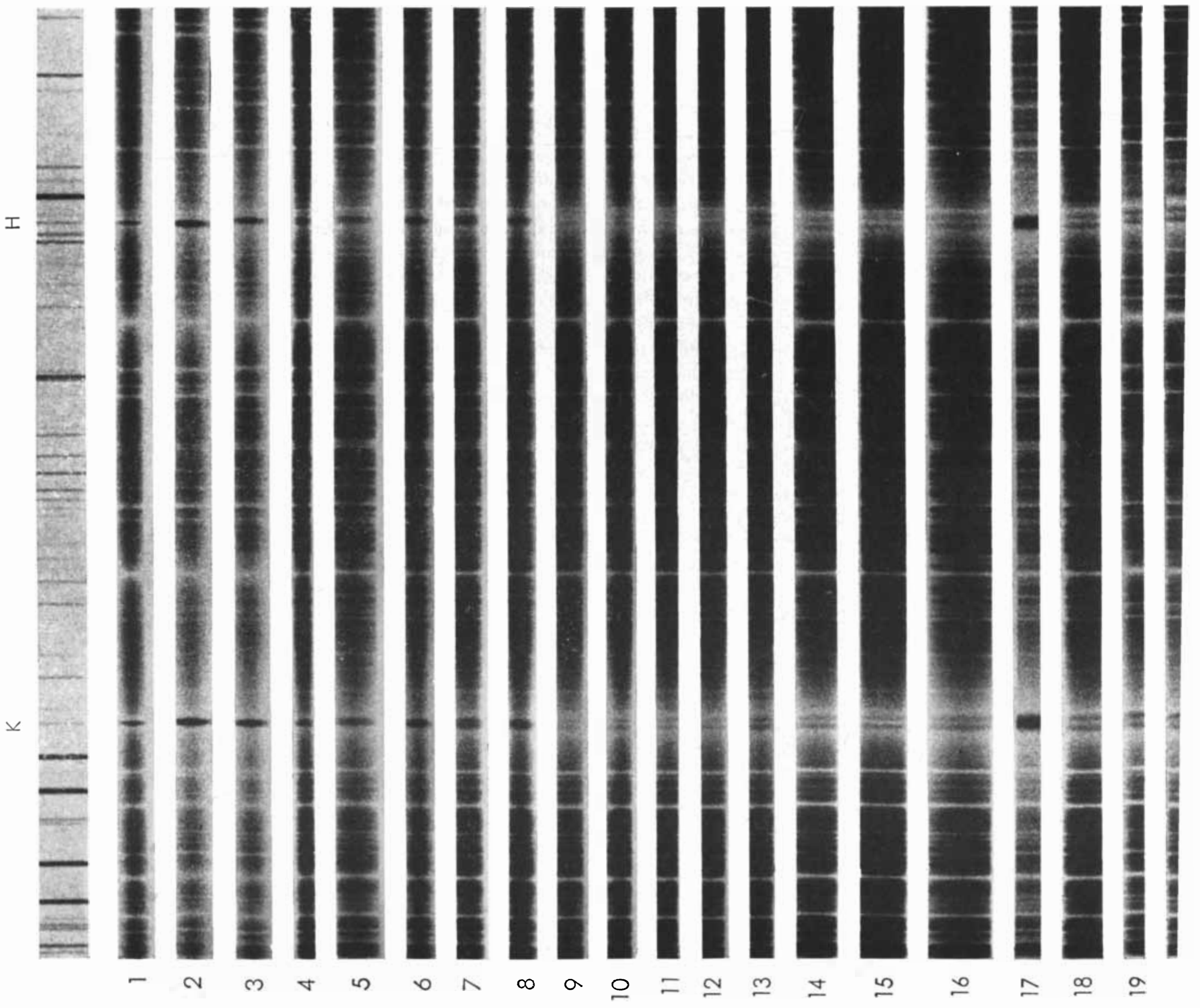


K AND H LINES of ionized calcium in stellar spectra form basis of a new method for measuring the intrinsic luminosity of stars. In this solar spectrum light and dark areas are reversed, and K and H absorption lines appear as bright bands. Black lines in their centers are "emission features," the widths of which are correlated with luminosity. Horizontal streak is caused by a sunspot.

details need not concern us here, this phenomenon does have an explanation. Briefly, spectroscopic parallax depends on the fact that larger, more luminous stars have relatively less mass, and therefore less surface gravity, than smaller ones. The resulting pressure differences in the atmospheres of the stars lead to differences in their spectra. When checked against stars whose distance (or absolute magnitude) is known from trigonometric measurements, spectroscopic parallax is found to be quite accurate for certain types of star. First devised at the Mount Wilson Observatory 50 years ago, and recently refined by W. W. Morgan and his associates at the Yerkes Observatory, the method has been very helpful in tracing out the major features of our galaxy within a few thousand light-years of the earth.

The new method is also spectroscopic, and it supplements rather than replaces spectroscopic parallax. It applies to stars of the spectral types designated G, K and M: the last three letters in the sequence—O, B, A, F, G, K, M—used to classify stars according to their surface temperature. The list runs from hotter to cooler: A typical O star might have a temperature of 30,000 degrees centigrade; an M star, 3,000 degrees. The stars of the last three groups represent a substantial fraction of the stellar population. Our sun is a member; its surface temperature of nearly 6,000 degrees classifies it as G2, meaning that its spectrum fits into the sequence 2/10 of the way from G0 to K0.

Spectra of these cooler stars always contain many dark lines, chiefly the absorption lines of neutral atoms and singly ionized atoms (atoms lacking one electron) of the common metals. They are formed in the following way. When we look at a star, we see into its atmosphere down to a considerable depth. The light we observe is a sort of average made up of the contributions from the hotter and brighter lower layers and the cooler and fainter upper ones. At most wavelengths the depth to which we can see into a cool star is limited by the negative hydrogen ions (hydrogen atoms with an extra electron) that are always present in its outer gases. They produce a general haziness or opacity. At the wavelengths of the absorption lines, however, the emerging light encounters an additional obstacle in the scattering produced by the metal atoms and ions. Thus within the section of the spectrum covered by an absorption line we cannot see as far



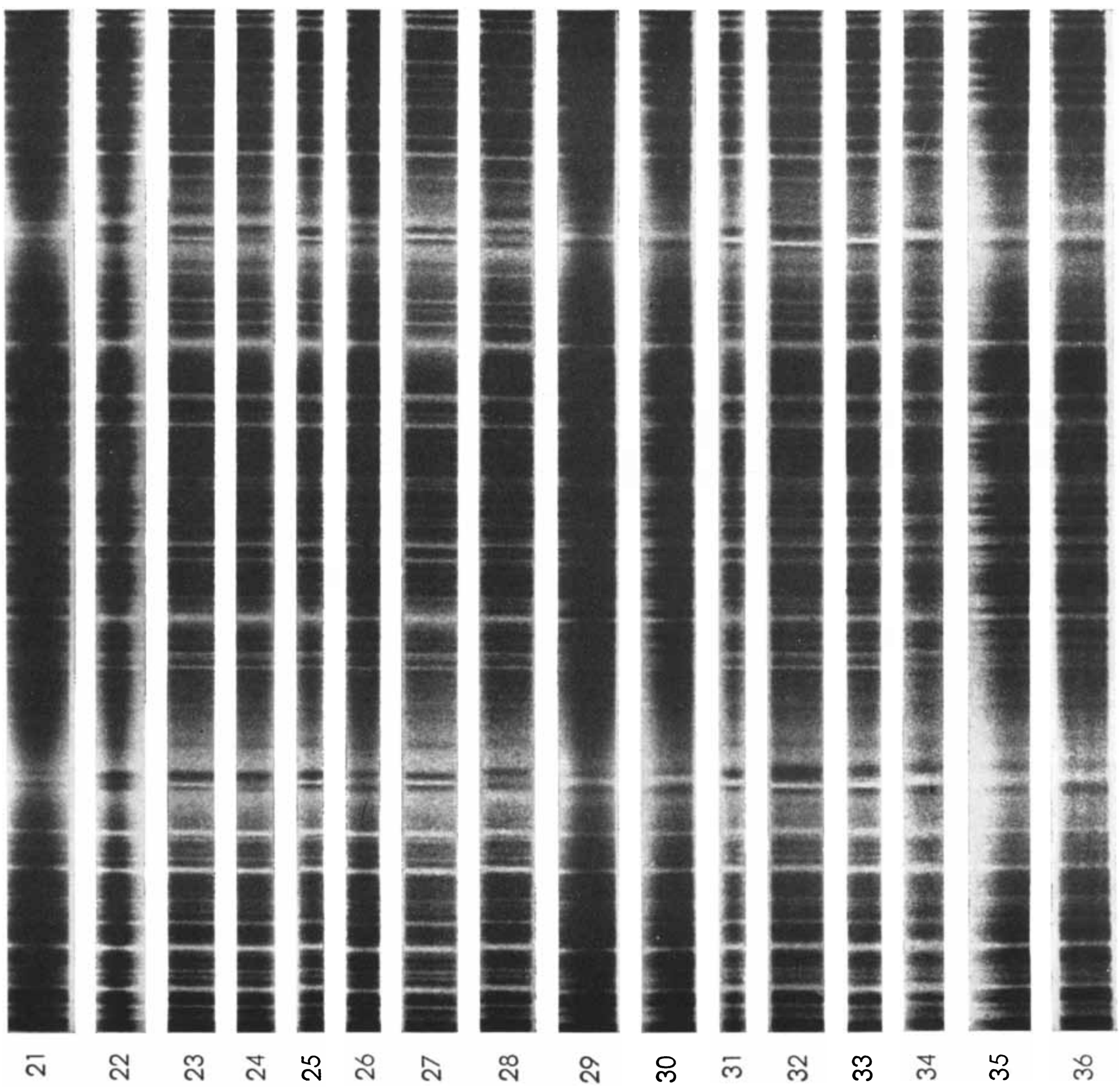
down as we can at other wavelengths. The higher layers that we do see are cooler, on the average, than those producing the radiation in adjacent parts of the spectrum. Therefore the lines appear dark across their entire width.

This is the pattern of all the spectral lines of cool stars, with two exceptions. It is in the exceptions that we have found our new distance scale.

In the spectra of cool stars as seen at the surface of the earth the strongest absorption lines are a pair in the violet, designated H and K. (The system for naming spectral lines has no connection with the one mentioned earlier for distinguishing types of stars, although it uses some of the same symbols.) Produced by singly ionized calcium, the lines owe their strength to the fact that calcium is a fairly abundant metal which occurs mostly in the singly ionized state in cool stars, and which has a high probability of making the atomic quantum-jumps associated with the H and K wavelengths.

What is remarkable about the lines, however, is not their strength but their internal structure. In the great majority of spectra of cool stars the H and K lines contain near their centers an emission component, or bright line, called a reversal. Almost always it is divided into two parts by a darker strip running down the middle [*see illustration at bottom of these two pages*]. The reversals in the solar spectrum, which are rather weak, have been known since about 1870, and were studied extensively at Mount Wilson in the early days of the Observatory. In fact the notation still used to describe them was originated by George Ellery Hale, the first director of Mount Wilson. The broad absorption lines are denoted H_1 and K_1; the emissions, H_2 and K_2; the central dark band, H_3 and K_3. In 1913 two German astronomers found the first H and K reversals in a stellar spectrum. Then observers began to discover the feature in one star after another, and eventually published extensive lists of the bodies in which they occur.

Even on spectrograms of quite modest dispersion, where the wavelengths are not spread widely, it is possible to see a systematic difference between the H and K reversals in intrinsically bright and intrinsically faint stars. In the latter each emission line is sharp and narrow, while in the bright stars it is noticeably wider, and the central dark strip is clearly ap-

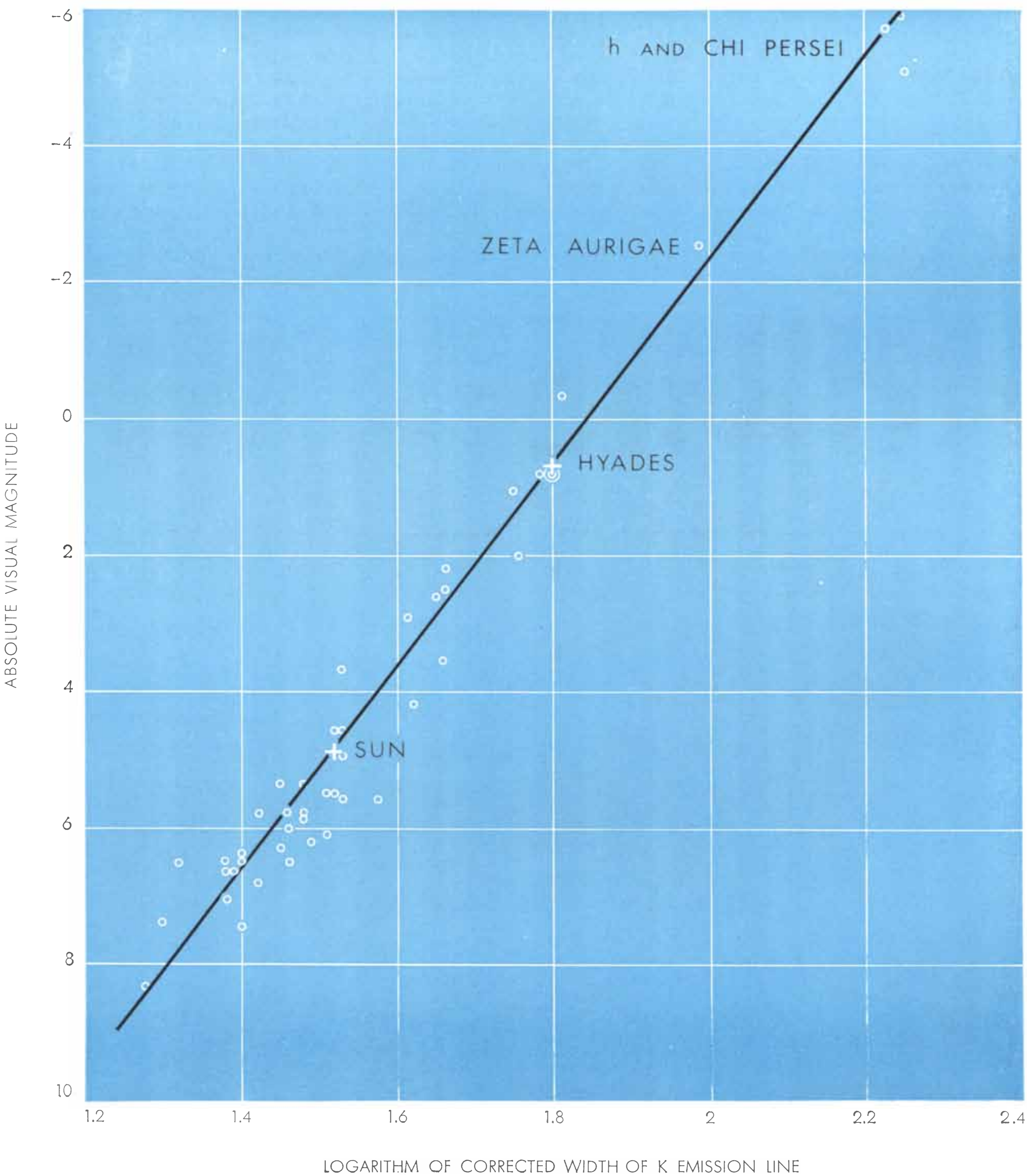


LINES OF IONIZED CALCIUM are compared in the spectra of 36 cool stars. Intrinsic brightnesses increase from top to bottom, with a total spread of more than a million times. The central, light emission feature in the lines grows wider as luminosity increases. The correlation thus provides a measure of intrinsic brightness or distance.

parent. Many astronomers must have noticed this fact, but curiously until a few years ago no one had followed it up.

At that time a young Indian astrophysicist, M. K. V. Bappu, and I decided to investigate the matter systematically. As test objects we chose a number of G, K and M stars whose absolute magnitudes had been determined by the Yerkes group with spectroscopic parallax. With the 100-inch telescope on Mount Wilson and the 200-inch on Palomar Mountain we prepared spectrograms of these stars at a uniform dispersion. At first it was not clear what aspect of the spectra we should concentrate on. After some preliminary trials the significant feature turned out to be simply the outside width of the bright components: H_2 and K_2.

When the logarithms of the widths



CORRELATION between logarithms of width of K emission line and absolute magnitude is shown in this graph. (Negative values of the magnitude represent brighter stars than positive values.) The straight line was drawn through points (*crosses*) representing the sun and stars in the Hyades cluster, whose absolute magnitudes are accurately known. Circles show other stars of known magnitude.

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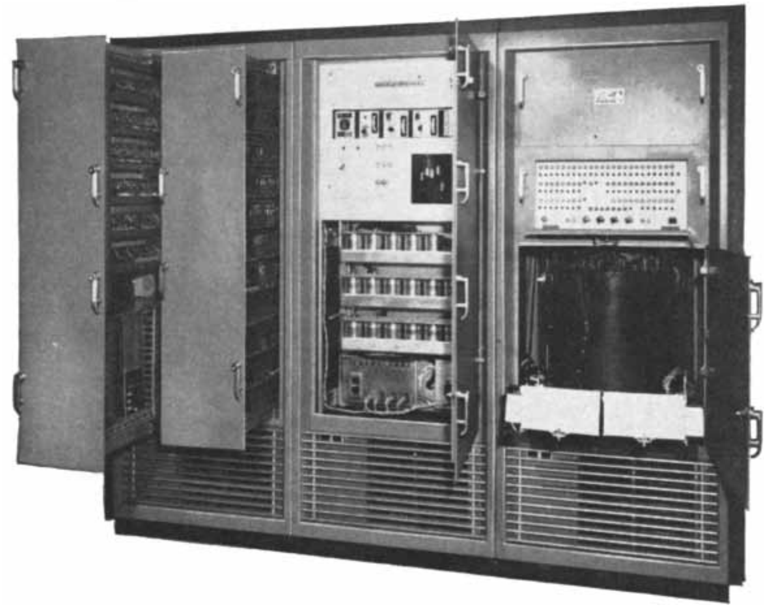

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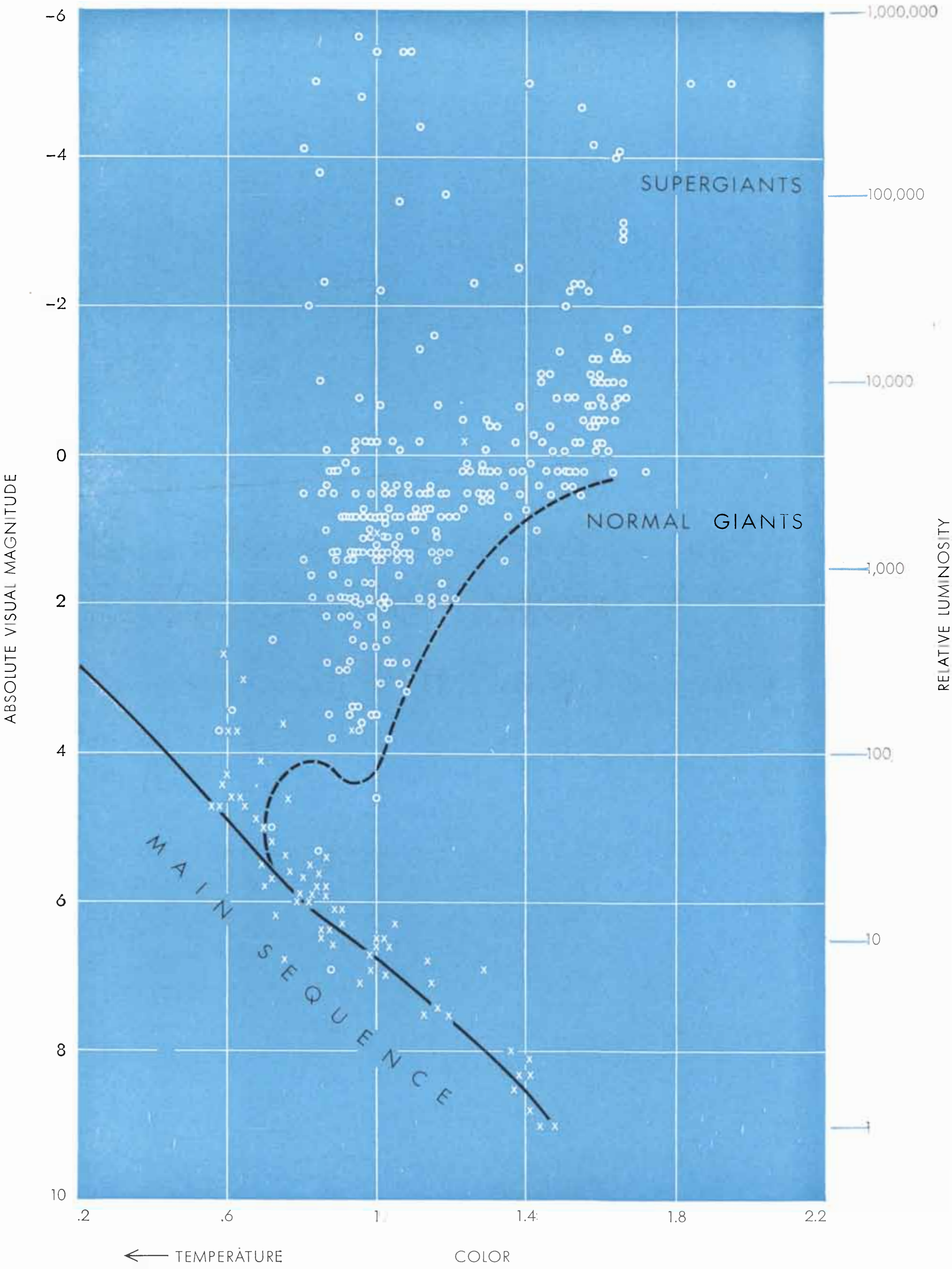


COLOR-MAGNITUDE DIAGRAM for stars in the neighborhood of the sun shows main-sequence stars clustering about solid line; giant and supergiant stars lying entirely above broken line. Magnitudes found by K-line method appear as circles; those found by trigonometric parallax, as crosses. Temperatures increase from right to left, in the direction opposite to horizontal color scale.

were plotted against absolute magnitudes (which are also measured on a logarithmic scale), a dramatically simple relationship emerged. The points obviously clustered around a straight line running diagonally across the graph. The correlation extended over a range of 14 magnitudes (corresponding to a ratio of nearly a million between the luminosities of the faintest and brightest stars in this range). It apparently depended neither on the strength of the H and K emissions nor on the spectral type of the stars. Moreover, the nature of the scatter in the diagram suggested that much of it was due to a tendency of spectroscopic parallax to lump together stars that actually differ appreciably in brightness.

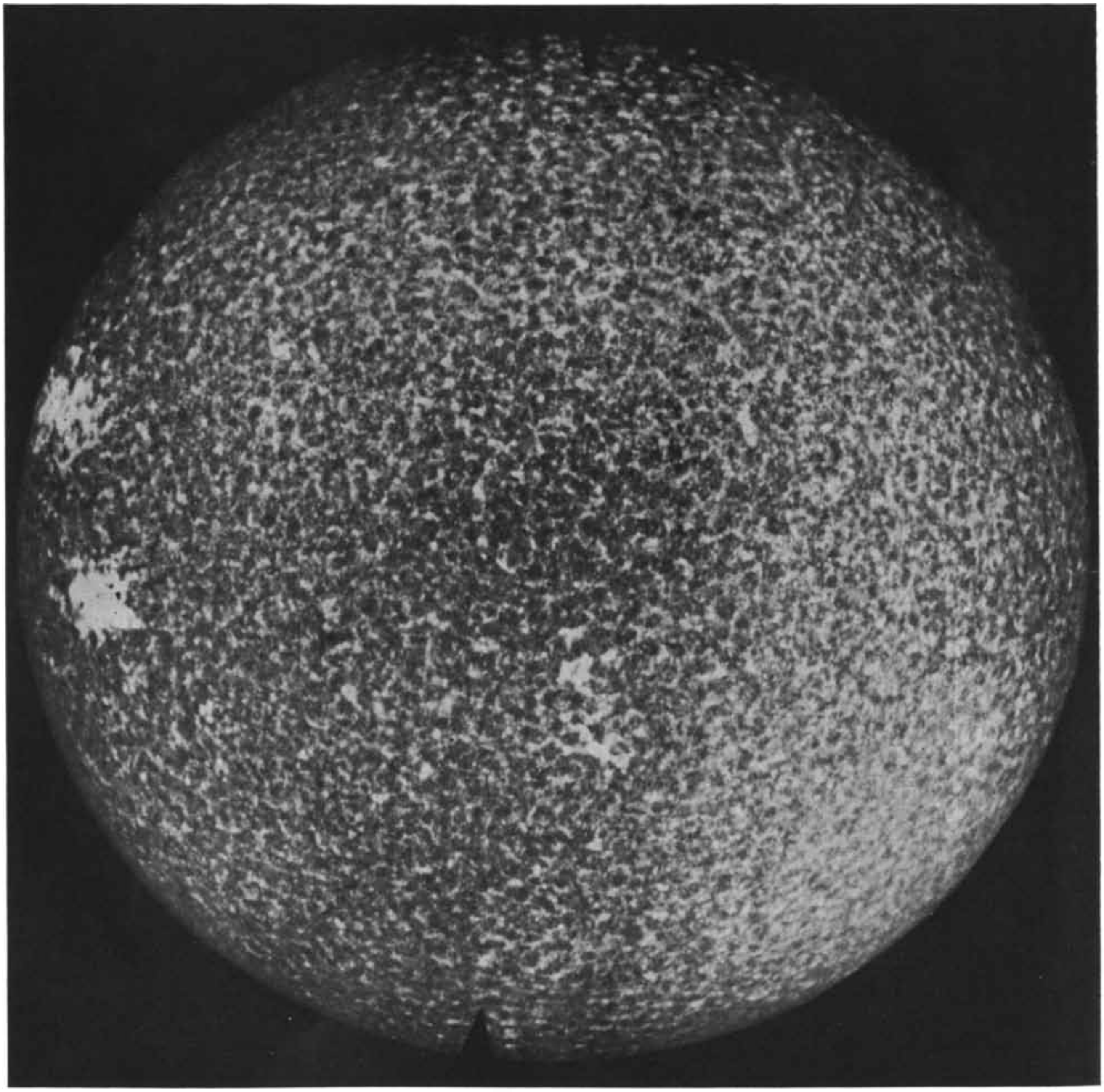
Once the general shape of the relationship had been established, it was necessary to calibrate it more closely. Rather than fit a line to all the points, with their widely varying errors in the magnitude figures, we wished to place it by using only the most accurate available data. Since the relationship was linear, two points were in fact all we needed.

One of them was furnished by the sun. Its distance, and therefore its intrinsic luminosity, is known hundreds of times more accurately than that of any other star. As has been mentioned, the H and K reversals in the solar spectrum are weak. On a high-dispersion spectrogram, however, their width can be precisely determined.

For the second calibration point we chose four K-type stars in the Hyades cluster. This is a physical grouping of stars, containing about 140 known members, which are close together and moving on parallel paths through space. (The brighter members of the cluster can be seen in the winter sky as a "V" in the constellation of Taurus.) Because it is the nearest such cluster in the heavens, 130 light-years away, the "proper motion" of its stars (their apparent motion at right angles to the line of sight) has been measured with exceptional accuracy. As with other fairly bright stars, their motion along the line of sight can be found from the Doppler shift in their spectra. Combining the proper and line-of-sight motions, and knowing that the stars are in fact moving along parallel lines, the distances to the individual members of the group can be calculated. The result is unusually precise for objects beyond the range of trigonometric parallax. When the distances are translated into intrinsic brightness, four of the K-type stars in the Hyades cluster are found to have nearly the same luminosity. Measuring the width of the H and K emissions in their spectra thus furnished the second calibration point. Now that the line was fixed, the absolute magnitude of any star could presumably be read off once the width of its H and K emission components had been measured.

To check the accuracy of the method, we applied it to a number of nearby stars whose absolute magnitudes were known from trigonometric parallax [*see illustration on page 110*]. A statistical comparison of the results showed that for so-called normal giant stars one good width measurement of the H or K reversal gives the intrinsic brightness with an uncertainty of about .3 magnitude (corresponding to an error of 15 per cent in distance). By using an average of several width measurements the uncertainty can be reduced to .2 magnitude. For dwarf stars the accuracy of the new method proved to be somewhat lower. This is not too serious because, as will appear in a moment, we are primarily interested in the distance of the giants. Among supergiants, the intrinsically very brilliant stars, good test objects are almost nonexistent. The binary star Zeta Aurigae provides one point, based essentially on spectroscopic evidence. Moreover, in the cluster known as h and Chi Persei, the distance of which can be determined on the theory of galactic rotation, there are several M-type supergiants. Both Zeta Aurigae and the Persei cluster stars fit our line remarkably well.

Although there is no longer much doubt as to its accuracy, the H-and-K-line method has a serious drawback. It works only on stars with an apparent brightness sufficient to produce the necessary spectra in a reasonable time and with adequate dispersion. As a practical matter, this at present restricts observation to stars brighter than about the seventh magnitude. Soon the technique will undoubtedly be extended to fainter



SURFACE OF THE SUN is photographed in the light of the central emission of the calcium K line. Variations in brightness are probably associated with fluctuations in the strength of the magnetic field at the surface. The bright patches at left surround sunspots.

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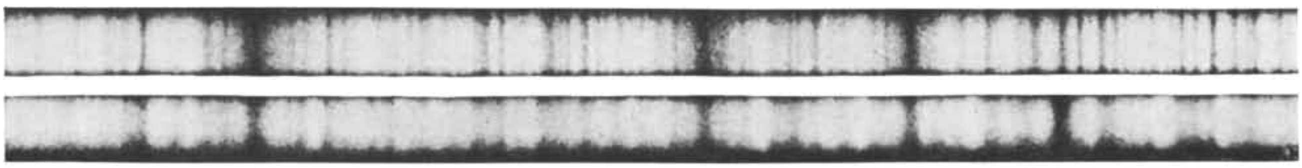

SPECTROSCOPIC PARALLAX measures intrinsic brightness of stars by comparison of the strengths of certain lines in their spectra. Upper spectrum is from an intrinsically faint star; lower one from a star almost a million times as bright. Features marked *a*, *b* and *c* are absorption lines of neutral iron; *d* is an absorption line of ionized strontium. It is stronger, compared to iron lines, in brighter star.

stars with the help of image-converter tubes or similar intensifying devices.

Even now, however, the technique can accomplish more than merely proving itself. In particular, it has already provided one of the best estimates of the age of our galaxy. Such estimates flow out of the modern theory of stellar evolution, which will be reviewed briefly here. The basic tool for analyzing the stages in the development of stars is the color-magnitude diagram: a graph in which individual stars are located horizontally according to their color and vertically according to their absolute magnitude [*see illustration on page 112*]. When the diagram is drawn up, it is seen that one class of bodies—smaller stars such as the sun—fall along a line known as the main sequence, running from top left to bottom right. To the right of the line in the upper part of the diagram are scattered the normal giants and supergiants.

The distribution is thought to come about as follows. Shortly after a star is born, it moves onto the main sequence, and remains there until a certain fraction of its hydrogen is consumed in nuclear reactions. Then it undergoes an internal rearrangement that converts it into a giant, moving it away from the main sequence upward and to the right. If a group of stars is formed at the same time, all its members will lie for a while on the main sequence. As the assemblage ages, the intrinsically bright stars, the spendthrifts at the top of the main sequence that burn their hydrogen most rapidly, are the first to move off. They are followed by successively fainter stars as time goes on. At any given epoch the absolute magnitude of the faintest stars that have moved off the main sequence measures the age of the assemblage.

In the case of the stars of our galaxy we are doubtless dealing with objects of all ages, from the aboriginal inhabitants to some formed quite recently. Nevertheless, the faintest stars that have just left the main sequence furnish an index to the age of the oldest members of the collection. Hence by determining the absolute magnitudes of large numbers of the stars we can establish this lower border of the normal giants, which leads to the age of the galaxy. From the H and K measurements made thus far the age appears to be at least 10 billion years. As the boundary is sharpened by observations of more stars, and as the theory itself is refined, the estimate can be expected to improve.

A second important application of distance information is in finding the dynamic structure of the galaxy. As was mentioned in connection with the Hyades cluster, when the true motion of a star (or group of stars) is known, then the distance can be found from the line-of-sight velocity and apparent motion across the sky. Conversely, if we know the distance to a star, we can deduce its true motion from its line-of-sight velocity and apparent or proper motion across the sky. Thus the new technique for measuring distance will allow us to compute the galactic orbits of many more stars and to discover whether certain distant groups that appear to be moving together are actually doing so.

Finally we may ask how it is that a simple linear measure of a feature in the spectrum of a star can accurately tell us its brightness. Thus far there are only some glimmerings of the answer. Early studies of the H and K lines in the sun showed that the emission comes from a rather thin layer located above the region responsible for the ordinary absorption lines. Moreover, it was found that the atoms responsible for both the H_2 and K_2 emission are moving upward at about two kilometers per second, while those producing the central absorptions, H_3 and K_3, are falling at a speed of about one kilometer per second. The reversals appear, at least weakly, virtually everywhere on the solar disk, but with many fluctuations of brightness and width over the surface. For instance, when the spectrograph slit crosses a sunspot, the emission lines over the dark central part of the spot are always much narrower than those over the normal surface.

In recent years observers on Mount Wilson have discovered a very strong correlation between the local magnetic-field strength and the intensity of the calcium emission over the solar surface. Evidently the H and K reversals depend somehow on the presence of a magnetic field. Perhaps hydromagnetic waves propel calcium ions, causing them to collide violently enough with surrounding neutral atoms to excite the emission of the H and K lines.

The most likely source of energy for the hydromagnetic waves is the so-called hydrogen convection zone, a transition region lying not far below the visible surface in the cooler stars where the ionization of hydrogen changes from almost 100 per cent at the bottom to nearly zero at the top. As a consequence of the large difference in energy between ionized and un-ionized hydrogen, vertical convection currents are set up. They carry a large part of the outflowing stellar energy flux. Perhaps the velocities of the material in the convection zone are somehow transferred from the visible surface into the chromosphere, the layer immediately above the visible surface. Here their effects can be seen in the width of the H and K emission components. Some theoretical work along these lines looks promising, but no really complete theory has been constructed, nor is there yet any general agreement among those who have thought about the problem.

Perhaps it is best to close by observing simply that, whatever the explanation of the correlation between emission-line width and luminosity, the fact that it holds over such a large range of stellar brightness implies a fundamental connection between the interior of a star, where its energy is generated, and the activity of the chromosphere. To find the nature of this connection is a problem of great general interest. In the meantime the correlation serves as a tool for attacking still other problems. It is one of those gifts that nature sometimes provides, as though in partial compensation for her obscurity elsewhere.

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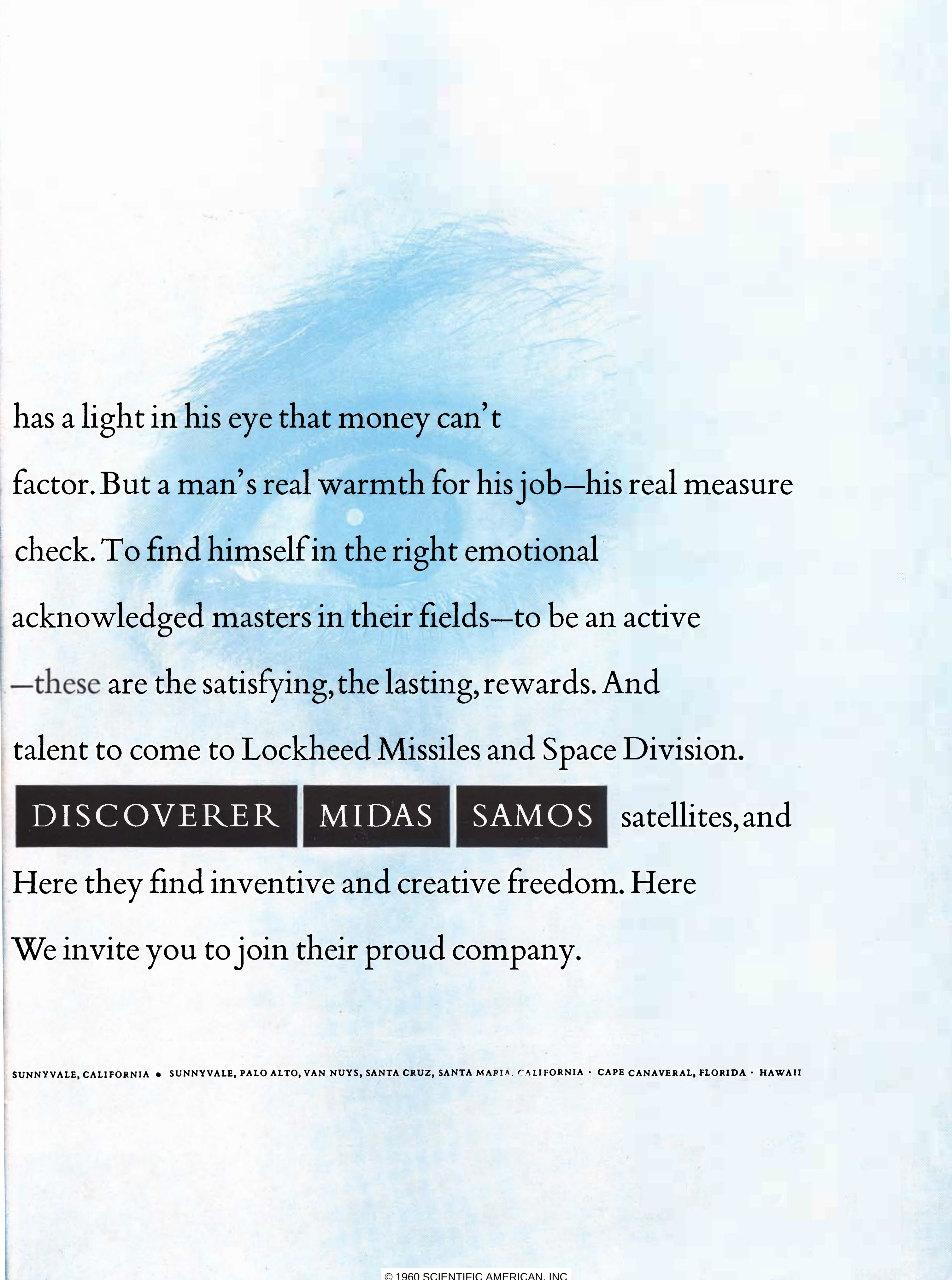
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The Growth of Snow Crystals

Much of the world's precipitation is triggered by natural dusts that act as nuclei in causing water droplets in clouds to freeze. Some artificial nuclei work more effectively than natural ones

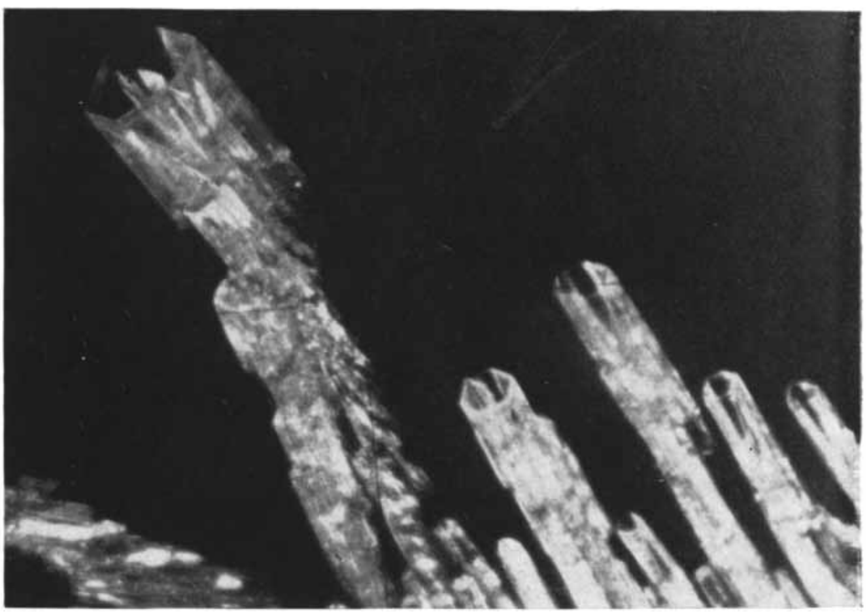
by B. J. Mason

The remarkable beauty of snow crystals, revealed in the classic elegance of their simple geometrical shapes and the delicate tracery of their more intricate forms, has long been recognized and recorded by the scientist, the artist and the industrial designer. It is only in recent years that a serious scientific study has been made of their structure, germination and growth. These studies have been largely motivated by the increasing interest in the physics of clouds and the formation of rain, and in the possibility of modifying these processes artificially. It appears that over large portions of the earth raindrops first begin their lives as snow crystals; then they melt before they reach the ground.

My colleagues and I at the Imperial College of Science and Technology in London have spent a number of years studying the birth and growth of snow crystals in the laboratory, hoping to learn something about the way the crystals develop in clouds. Except for the very cold, high-altitude cirrus types, which are thin veils of small ice crystals, clouds consist mainly of water droplets so tiny and so dispersed that they stay suspended in the air like smoke particles. For years meteorologists puzzled over this stability of clouds, and were hard pressed to explain how the tiny water droplets ever grow large enough to fall as rain. It was equally puzzling that the water droplets often refuse to freeze even though the cloud may be many degrees below the nominal freezing point of water: zero degrees centigrade, or 32 degrees Fahrenheit. Even on a hot summer day the temperature of the air above 15,000 feet is usually below freezing.

During the 1930's Tor Bergeron of Sweden and Walter Findeisen of Germany provided a theory of cloud behavior that seems to account satisfactorily for much of the world's precipitation. They proposed that clouds remain stable until a small percentage of the cloud droplets finally freeze, spontaneously or otherwise. When water molecules are locked into place in an ice crystal, they evaporate much less readily than they do from a drop of water. Thus if a cloud contains both water droplets and ice crystals, the water molecules that diffuse from the vapor state onto the ice crystals tend to be bound fast, and those that condense on the water droplets are relatively free to evaporate again. As a result the crystals grow more rapidly than the droplets; finally, as the air is denuded of moisture by the ice crystals, the water droplets evaporate and disappear. The ice crystals meanwhile grow large enough to fall toward the earth. After growing for about an hour in a deep layer of cloud, a snow crystal will reach the size of a drop in a drizzle, or perhaps the size of a small raindrop. Such crystals fall at the rate of about one foot per second. Several of them may become joined together, as they settle through the air in a fluttering or tumbling motion, to form a snowflake which, in falling into the warmer regions of the cloud, may melt and reach the ground as a raindrop.

Bergeron and Findeisen originally believed that virtually all the world's precipitation—snow or rain—originated with this ice-crystal mechanism, but it is now known that, especially in the tropics, rain sometimes falls from clouds so warm that ice could never have formed



THREE BASIC FORMS OF SNOW CRYSTALS provide the basis for an infinite variety of shapes. Hollow prismatic columns (*left*) populate cirrus clouds, which are usually colder

in them. Findeisen proposed as early as 1938 that for ice crystals to appear in supercooled clouds a nucleating or seeding agent might be required. He suggested that the agent might be dust particles of the proper configuration to start the nucleation of snow crystals, but he was never able to demonstrate its existence.

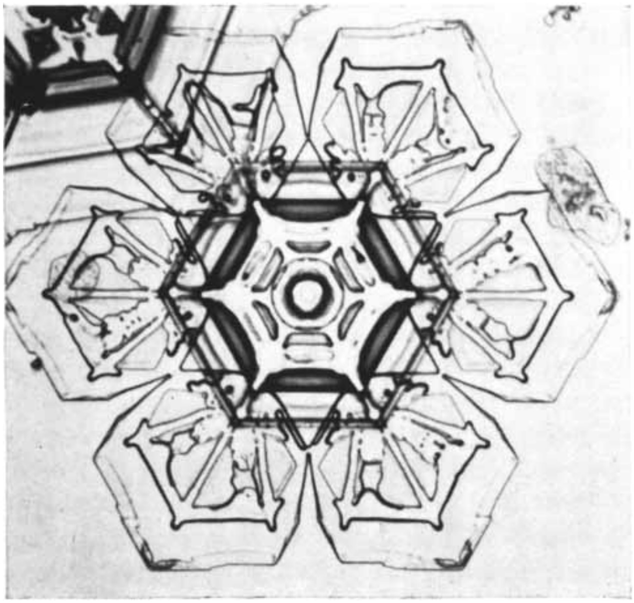
The subsequent history of cloud-seeding is well known. In 1946 Vincent J. Schaefer, then working at the General Electric Research Laboratory, discovered that ice crystals could be nucleated in a supercooled cloud by dropping dry ice into it. He discerned correctly that dry ice, at 78.5 degrees below zero C., causes water droplets to freeze spontaneously. Within months Bernard Vonnegut, then also with General Electric, conceived the use of silver iodide as an ice-nucleating, or seeding, agent. These two discoveries provided the impetus for rain-making experiments that have been conducted in many parts of the world. After a dozen years the success of these experiments is still debated. Although it has been convincingly demonstrated that the behavior of individual clouds may be modified by seeding them from aircraft, the outcome of operations aimed at producing economically significant increases in rain over large areas is much less conclusive. Evidence is accumulating, however, that modest increases of 10 to 15 per cent may be produced in favorable circumstances.

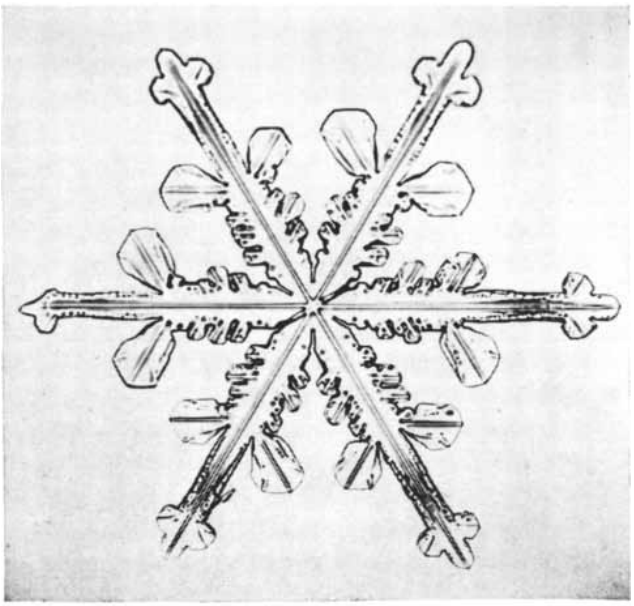
In our laboratory we have been studying the precise conditions under which supercooled water freezes and how the freezing point may be influenced by nucleating agents of various sorts. We have found that the freezing point of water varies over a range of more than 40 degrees C., depending upon the volume of the sample, the rate of cooling and the presence of impurities that may function as nucleating agents. We have frozen many thousands of water droplets, varying in diameter from one centimeter down to a thousandth of a centimeter and all containing small foreign nuclei. The water droplets are held between layers of two liquids that are practically immiscible with water and with each other. The system is cooled at a constant rate in a refrigerator, and we record the temperature at which each drop freezes. We have found that there is a linear relationship between the freezing temperature and the logarithm of the drop diameter. Thus if one-centimeter drops of a certain sample of water freeze at 18 degrees below zero C., one-millimeter drops will freeze at 24 degrees below zero, and one-tenth-millimeter drops at 31 degrees below zero [*see illustration on page 125*]. This relationship characterizes the nucleation of water droplets by foreign particles and indicates that a decrease in temperature makes a logarithmically increasing number of atmospheric particles capable of acting as nuclei.

We have recently been successful in purifying water to such an extent that we can produce large numbers of drops entirely free of foreign particles. We accomplish this by repeatedly filtering and distilling water in a closed apparatus from which atmospheric air is rigidly excluded. One-millimeter droplets of such very pure water may be supercooled to 33 degrees below zero C. before freezing, and droplets one-thousandth of a millimeter in diameter may be cooled to 41 degrees below zero. These droplets of pure water freeze spontaneously.

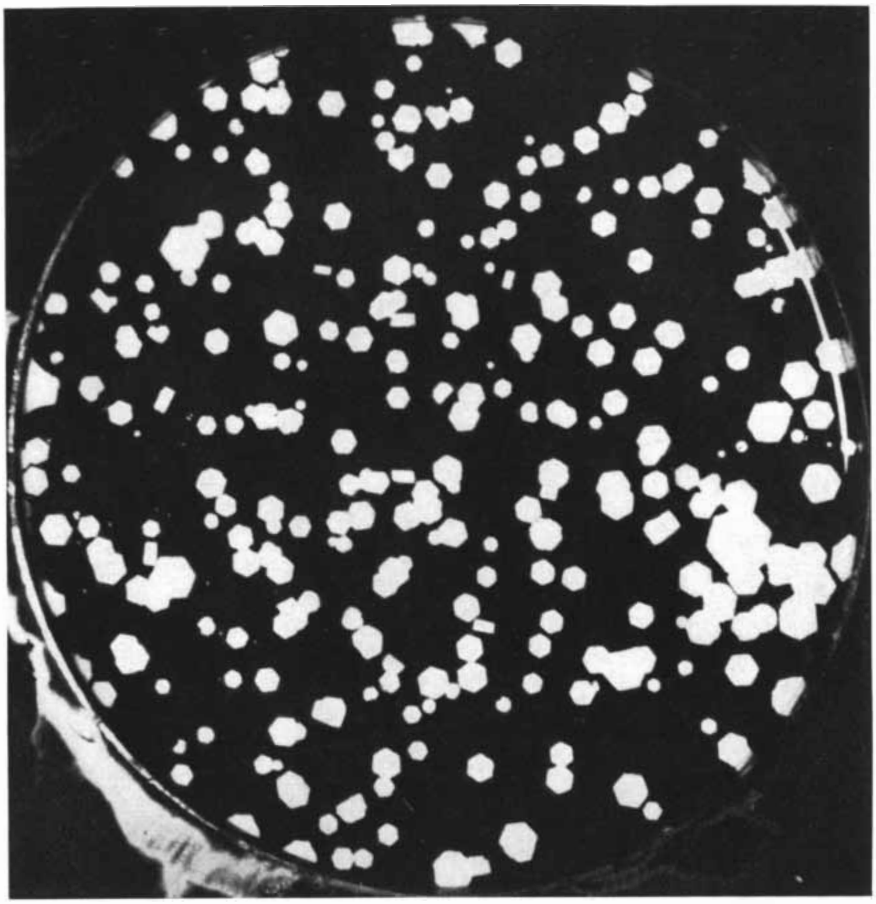
Presumably small groups of water molecules, undergoing random fluctuations in position and velocity, become locked by chance into an icelike arrangement and thereby serve as nuclei to initiate the freezing process. One can calculate the rate at which such aggregates form and hence the probability that a drop of a given size will freeze. The lower curve in the illustration on page 125 indicates the computed temperatures at which droplets of various sizes should freeze within one second. The curve coincides rather well with experimental observations, and is distinctly different from the freezing curve where foreign particles play a nucleating role.

Except at very low temperatures—lower than 40 degrees below zero C.—the ice-nucleus content of the air is of fundamental importance for snow formation. It is not easily measured. A favorite method requires a cloud chamber in which a sample of atmospheric air is saturated with water vapor and rapidly

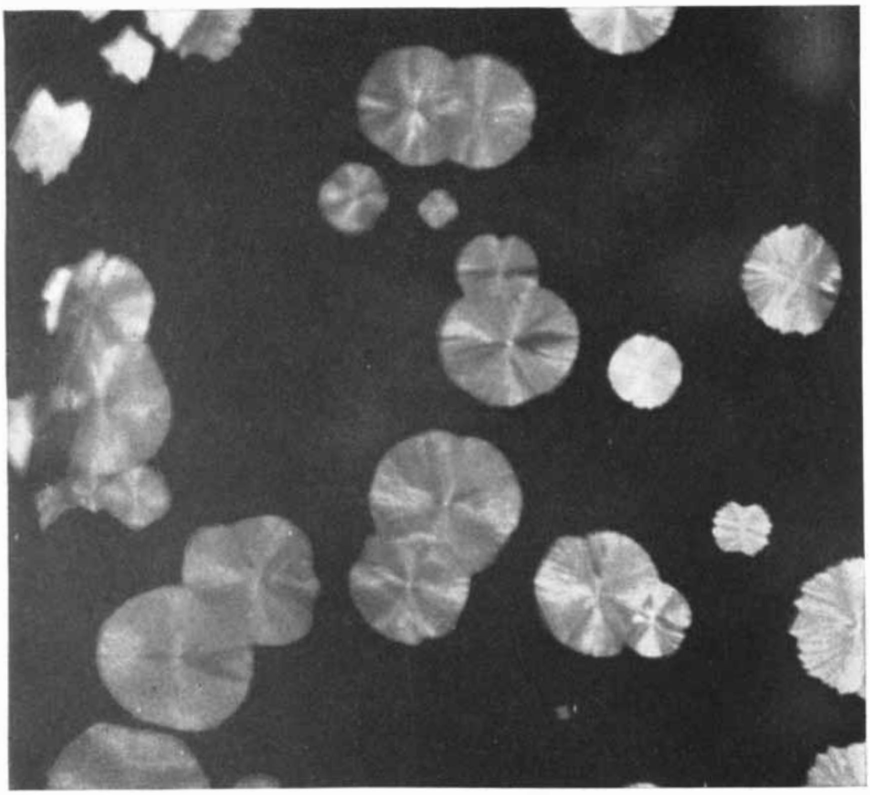




than 30 degrees below zero centigrade. (These columns happen to be formed from heavy water.) The thin hexagonal plate (*center*) is one millimeter in diameter and has petal-like extensions. Star-shaped crystal (*right*) forms the basis of the typical snowflake.



SUPERCOOLED SUGAR SOLUTION provides a way to count tiny ice crystals created in a cloud chamber. After falling on the sugar solution, crystals grow to appreciable size.



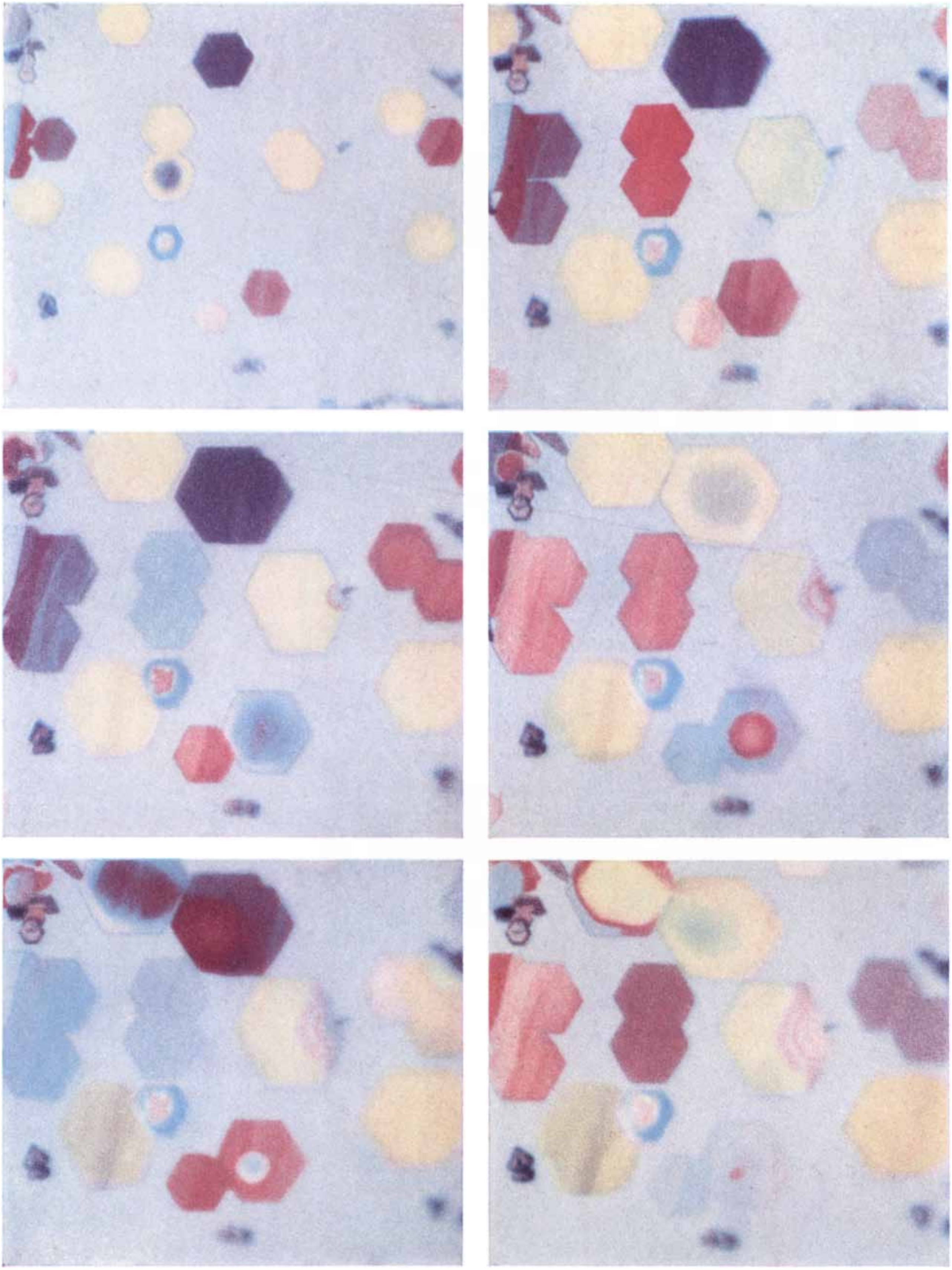
SUPERCOOLED SOAP FILM is a simple detector for determining nuclei-content of the atmosphere. Tiny ice crystals enclosing nuclei are counted after they land on film and grow.

cooled by sudden expansion. During the rapid cooling, water vapor condenses on some of the airborne particles to produce a cloud of tiny supercooled droplets. Some of these contain ice nuclei; they freeze and grow into ice crystals. The technique is then to count the number of crystals glittering in an illuminated volume of the cloud, successive measurements being made at lower and lower temperatures achieved by larger and larger expansions. Because it is not easy to discern small numbers of crystals swirling about in a thick fog, direct visual counts are not very accurate. This led my former colleague Keith Bigg to devise an ingenious technique in which the ice crystals fall into a tray of sugar solution placed at the bottom of the cloud chamber. The water in the solution supercools, and when the tiny ice crystals fall into it, they quickly grow to visible size and may be easily counted [*see illustration at left*].

Measurements made from aircraft over both land and sea show that the ice-nucleus population of the atmosphere varies considerably from day to day and from place to place. On some occasions it appears to fall below the minimum value required for the efficient release of precipitation from clouds. This is the justification for rain-making experiments.

The nature and origin of the nuclei necessary to initiate the formation of ice crystals are subjects of considerable interest and controversy. While I believe that they originate mainly from the earth's surface as dust particles carried aloft by the wind, E. G. Bowen of Australia's Commonwealth Scientific and Industrial Research Organization has suggested that the debris of meteorites may be an important source. He has made analyses of world rainfall patterns which seem to show some correlation with the annual meteor showers. In an attempt to test these rival hypotheses John Maybank and I have recently examined, in the laboratory, the ice-nucleating ability of various types of soil particles and mineral dust and also of meteoritic dust.

Of the 30 terrestrial dusts we have tested, 16 (mainly silicate minerals of the clay and mica variety) produced ice crystals in supercooled clouds at temperatures between 10 and 15 degrees below zero C. [*see illustration on pages 130 and 131*]. These substances are all minor constituents of the earth's crust. It is significant that common materials such as sea sand were not active. (Since the quartz of ordinary sand has a hexagonal



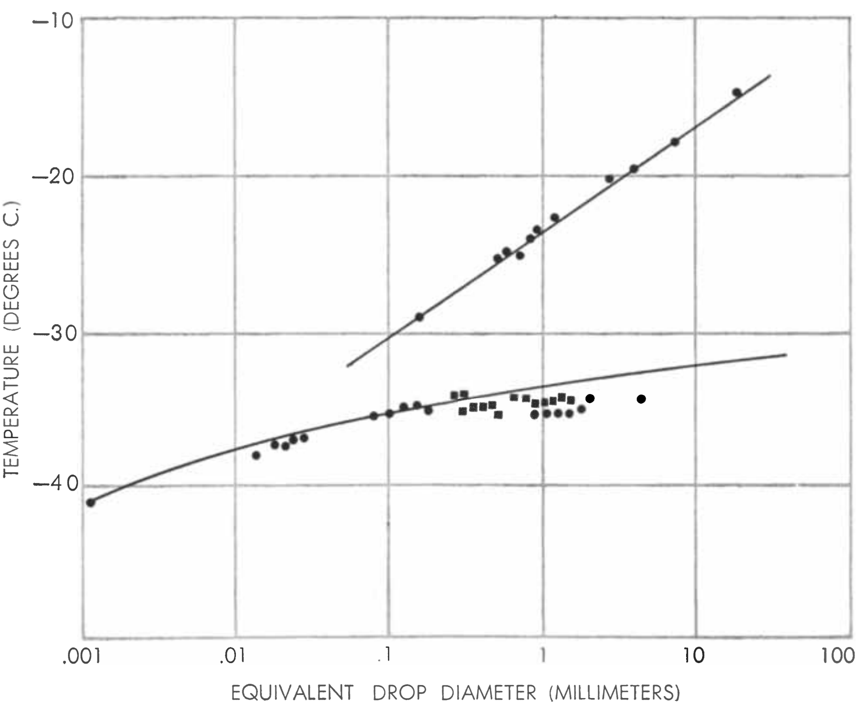
GROWTH OF SNOW CRYSTALS is revealed in this series of photomicrographs made with reflected light. The hexagonal ice crystals, growing on a single crystal of natural cupric sulfide, appear to change color (due to canceling of certain wavelengths by interference) as they become thicker. Time interval between first picture (*top left*) and second (*top right*) was 45 seconds. The rest of the series followed at 15-second intervals. Ice crystals tend to grow in diameter until they meet another crystal, then they thicken. Crystals that are of differing thickness when separate tend to acquire the same thickness after coming in contact.

crystal-structure resembling that of ice, Findeisen had thought that quartz might be an effective nucleating agent. But a superficial resemblance in structure is not enough.)

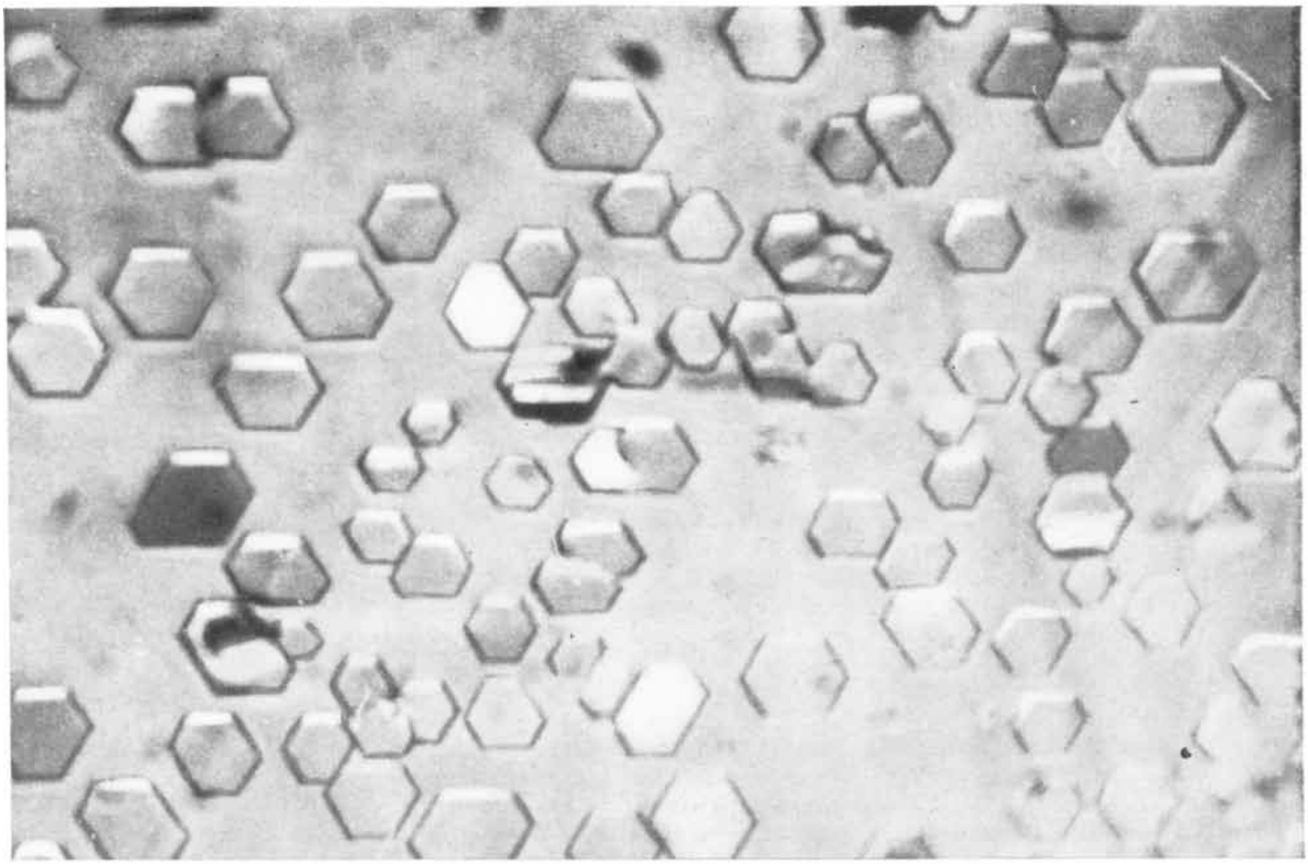
The most abundant of the active substances we have tested is kaolinite, which initiates ice formation at nine degrees below zero C. This mineral is common enough to provide an important source of ice nuclei, but not so common that the atmosphere always contains high concentrations of its particles.

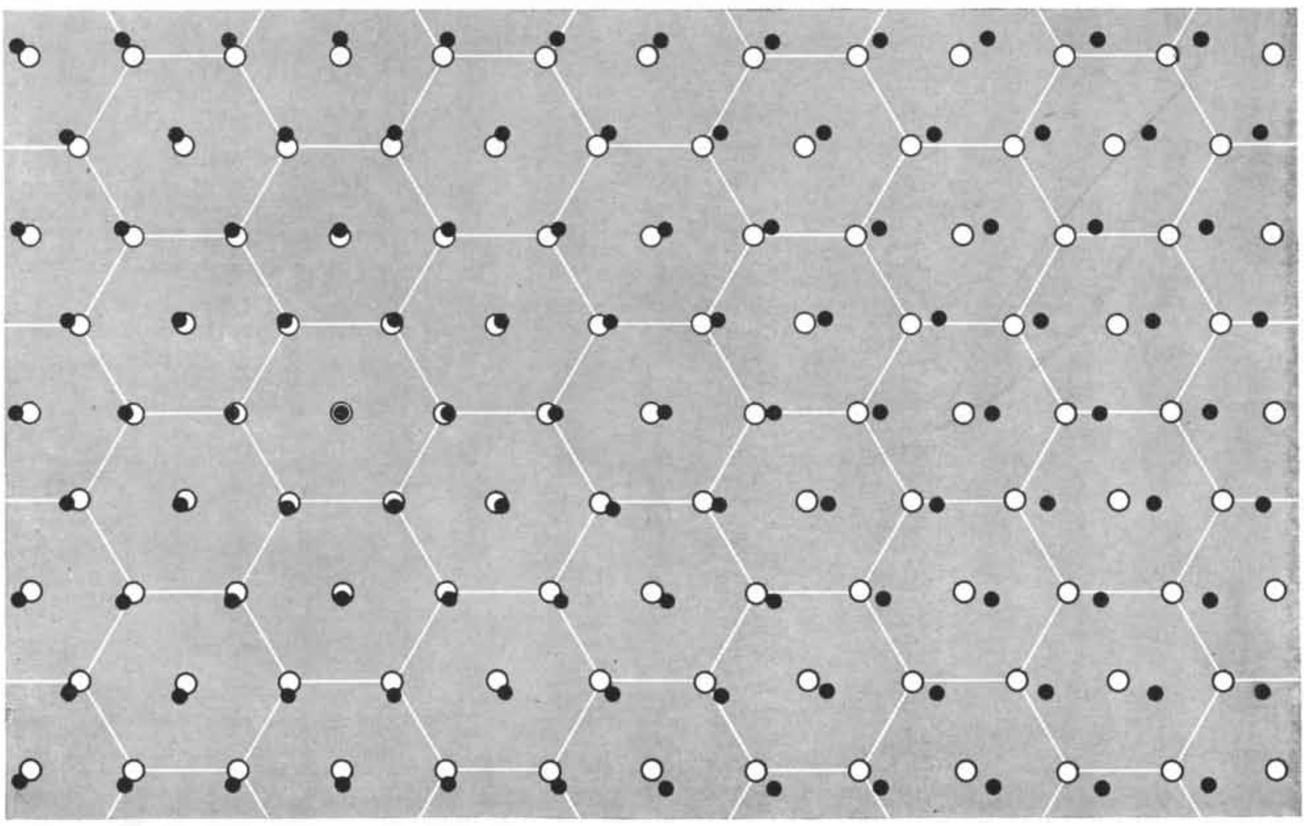
These particular experiments were greatly facilitated by the use of a simple, convenient and readily renewable nucleus detector. It consists of a very stable soap film (obtained from a half-and-half mixture of water and a liquid detergent) stretched across a metal ring. When tiny ice crystals, enclosing submicroscopic nuclei, land on the supercooled soap film, they grow rapidly into crystals large enough to be easily detected and counted [*see bottom illustration on page 122*].

In the course of our nucleation experiments we made a surprising discovery: Ten of the terrestrial dusts were found to become more effective ice nuclei if they had previously been involved in ice-crystal formation. In other words, they could be preactivated, or "trained." Thus when ice crystals grown on kaolinite nuclei, which are initially active at nine degrees below zero, are evaporated in a dry atmosphere, they leave behind nuclei which are thereafter effective at temperatures as much as five degrees higher. Particles of montmorillonite (another important constituent of some clays), which initially become active nuclei only at temperatures some 25 degrees below zero, may be preactivated to work at 10 degrees below zero. It seems that, although the bulk of ice surrounding the nucleus is removed during the drying process, small germs of ice, retained in pores and crevices, survive and serve as effective nuclei when the particle is again exposed to a supercooled cloud. We now have an interesting possibility. Some soil particles, such as those of montmorillonite, which are initially rather poor as ice nuclei may be carried aloft to form ice crystals at the very low temperatures associated with the high cirrus clouds. Later, if the crystals should evaporate without reaching the earth, they may leave behind trained nuclei capable of nucleating lower clouds at temperatures only a few degrees below freezing. If we accept this possibility of training initially unpromising material in the upper atmosphere, we need not interpret the



FREEZING POINT OF WATER varies with drop size. Upper curve shows freezing point of water containing impurities. Curve falls linearly with logarithmic decrease in drop size. Lower curve is theoretical freezing point for pure water and agrees well with author's values (*circles*) and those (*squares*) of Stanley Mossop of the University of Oxford.





ICE GROWING ON SILVER IODIDE (*top*) shows how underlying symmetry of a large single crystal forces ice crystals to assume a parallel orientation. The relationship between the lattices of the two crystals is diagrammed below. Oxygen ions (*open circles*) define the corners of the hexagonal ice lattice; silver ions (*black dots*) lie at the corners of the silver iodide lattice. Assuming the two crystals are in perfect superposition at left of center, the match between them becomes progressively poorer in all directions, here exaggerated about threefold. Silver iodide provides best lattice fit in three dimensions of all artificial nuclei.

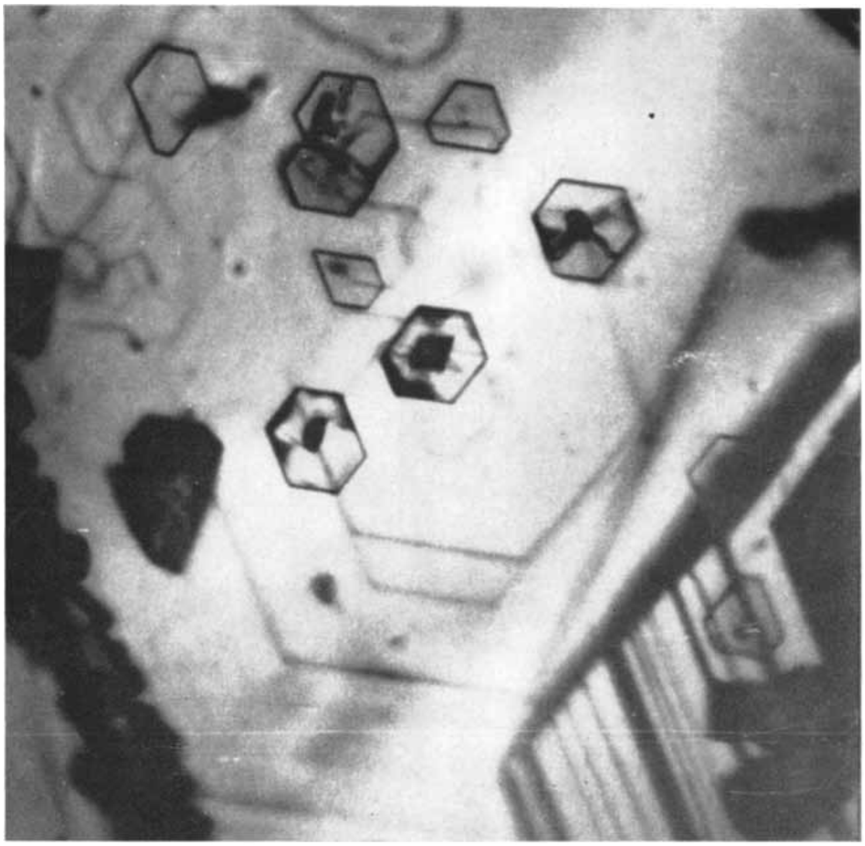
fact that efficient nuclei are occasionally more abundant at higher levels as implying that they must have entered the atmosphere from outer space.

In an attempt to provide a direct test of Bowen's meteoritic-dust hypothesis, we have tested the ice-nucleating ability of the fine dust resulting from the grinding and vaporization of several different types of stony meteorite. None has proved effective at temperatures higher than 17 degrees below zero C.

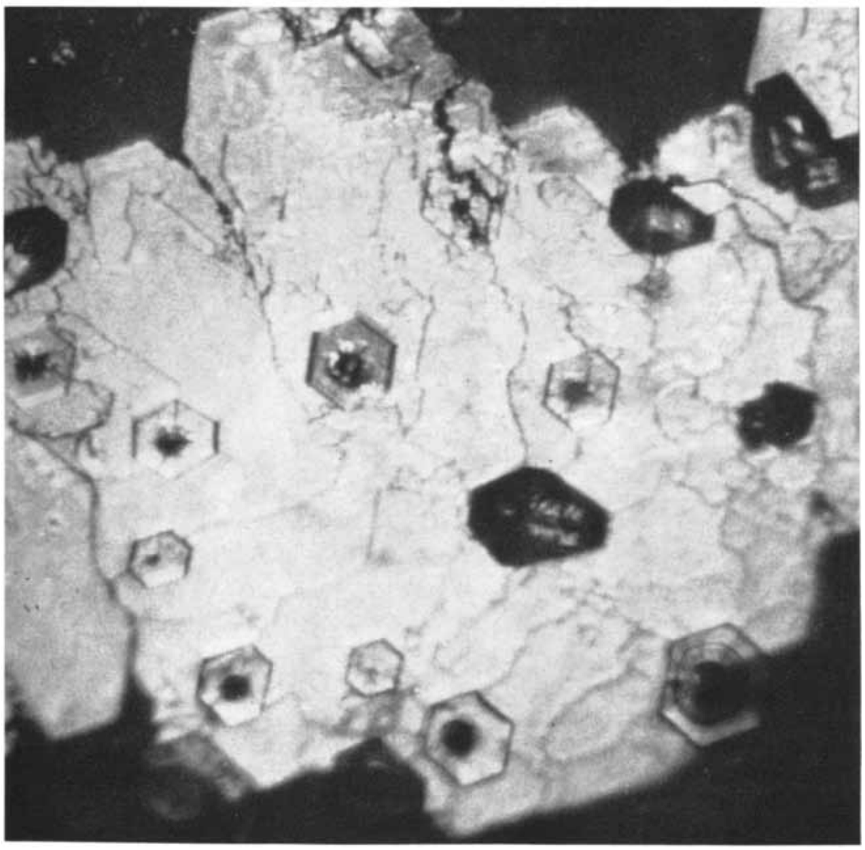
The evidence therefore appears to favor the theory that atmospheric ice-nuclei are predominantly of terrestrial origin, with the clay minerals, especially kaolinite, being a major source. Additional confirmation is provided by Japanese workers who have used the electron microscope and electron-diffraction techniques to examine the nuclei at the centers of natural snow crystals. More than three quarters of the particles were identified as soil particles, with kaolinite and montmorillonite as the most likely constituents.

Since the discovery by Vonnegut that tiny particles of silver iodide, introduced as a smoke into a supercooled cloud, cause ice crystals to appear at temperatures as high as four degrees below zero C., an intensive search has been made for other substances that might be even more effective and cheaper for cloud-seeding purposes. The table on pages 130 and 131 lists those artificial nuclei that have proved active at temperatures between four and 14 degrees below zero. The temperature shown is that at which at least one particle in 10,000 will produce an ice crystal in a supercooled cloud in the laboratory. Greater numbers of effective nuclei are obtained as the temperature is lowered below the threshold value. The first seven substances in the table are active at temperatures between four and 11 degrees, where only a very small proportion of natural ice nuclei are effective; hence the seven are all potential seeding agents. But silver iodide, being more potent and more easily dispersed than its rivals, retains first place. Nuclei of ammonium fluoride, cadmium iodide and iodine, being soluble substances, would dissolve within a minute or two of entering a water cloud, but they can be made to act as ice nuclei under special laboratory conditions.

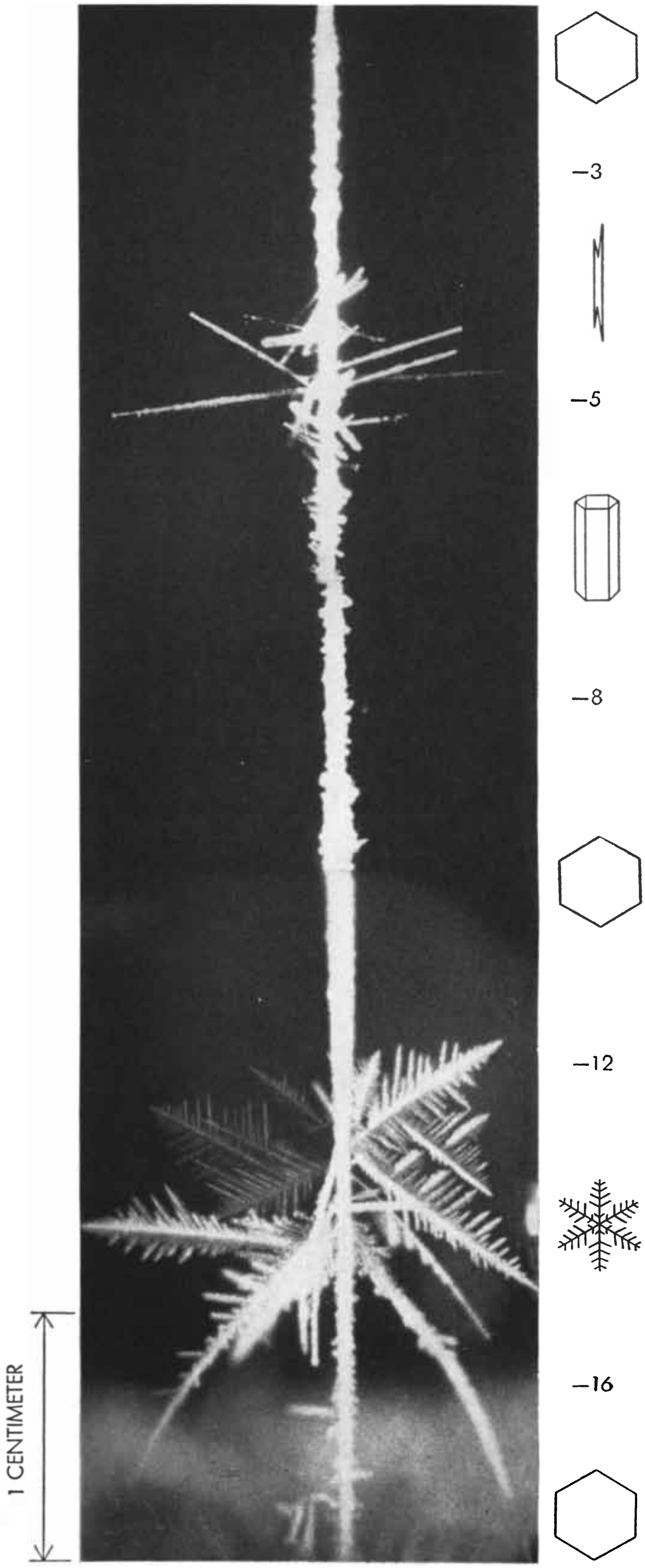
There is a tendency for the more effective nucleators to be hexagonal crystals in which the atomic arrangement is reasonably similar to that of ice, but there are exceptions. Nevertheless for all those substances that are active above



ON CADMIUM IODIDE CRYSTAL with spiral growth steps, ice crystals form preferentially at the edges of the steps. Hexagonal sides of ice crystals maintain parallelism.



ON LEAD IODIDE CRYSTAL with a variety of growth steps resembling a contour map, ice crystals nucleate at edges of the higher steps. The most effective are about .1 micron high.



GAMUT OF ICE CRYSTAL SHAPES grows on a filament suspended in a diffusion chamber with controlled temperature gradient. Crystals take characteristic forms at various temperatures as indicated along the right edge of the photograph. Reading from the top, the symbols represent: thin hexagonal plates, needles (which are defective prisms), hollow prismatic columns, hexagonal plates, branched star-shaped crystals (or dendrites), and hexagonal plates. At temperatures lower than 25 degrees below zero C., prisms appear again.

15 degrees below zero C. it is possible to find a crystal face on which the atomic spacings differ from those of ice by only a few per cent. On the other hand, we now know that the nucleating ability of a particle is not determined solely by the degree to which its atomic structure matches that of ice, and that other factors, not yet fully understood, play a role.

To investigate such factors in more detail my colleagues and I have studied, under carefully controlled conditions of temperature and humidity, the growth of ice on individual faces of single crystals of various nucleating agents. We have observed that ice crystals always assume a parallel orientation when they are grown on the hexagonal crystals of silver iodide, lead iodide, cupric sulfide, cadmium iodide and brucite, and also on crystals of calcite, mercuric iodide, iodine, vanadium pentoxide and freshly cleaved mica.

We also find that ice crystals start growing preferentially around local imperfections on the crystal surface, which show up as small dark spots in our photomicrographs. Often the ice crystals appear at the edges of steps formed during the growth or cleavage of the nucleating crystal. They also show a definite preference for the deeper steps. On lead iodide, for example, steps which are about a tenth of a micron (one ten-thousandth of a millimeter) in height provide effective nucleation sites if the air is supersaturated by about 10 per cent, but much higher supersaturations, exceeding 100 per cent, are required for nucleation on the very flat areas of the host crystal.

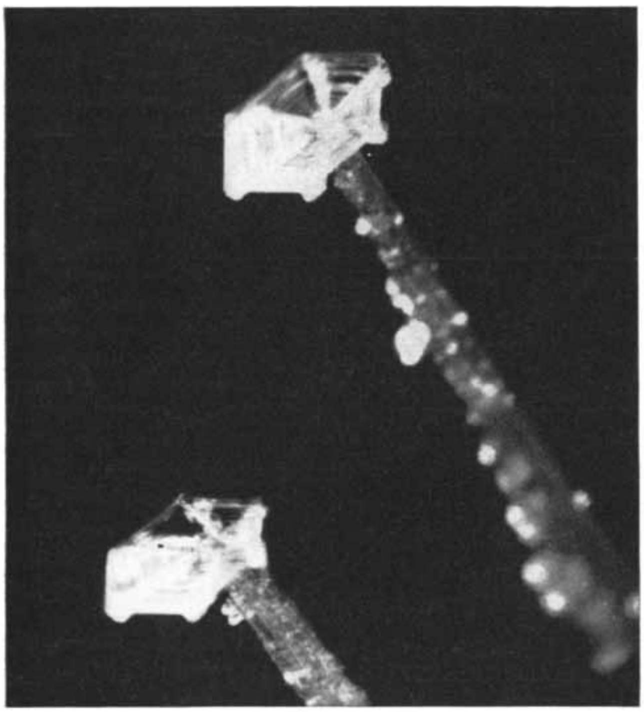
A number of striking color effects that appear during the growth of ice crystals on a blue crystal of natural cupric sulfide (covellite) reveal much about the growth mechanism. Being only a few hundred millimicrons high, and thus comparable to the wavelength of visible light, the growing hexagonal ice plates produce interference colors that give a very accurate measure of plate thickness. The series of six photographs on page 123 are typical of many we have made. They show that in the first stages some crystals grow in diameter with no change in color, indicating no appreciable change in thickness. Evidently the water molecules arriving at the upper surface of the crystal are not captured but migrate over the surface to be built in at the crystal edges. When two crystals touch, however, they begin to thicken as colored growth-layers spread, with a speed of a few microns per second, from the point of contact across the crystal surface. Crystals that are of differing thickness when separate tend to acquire the same thickness after coming into contact. We now know that perfect crystals grow only very slowly under normal supersaturations. It seems that to allow a crystal to grow at an observable rate, imperfections must be set up, as when a crystal accidentally hits a step or another crystal. Thus crystals sitting astride a step are often of different thickness on either side, as indicated by their two-toned appearance.

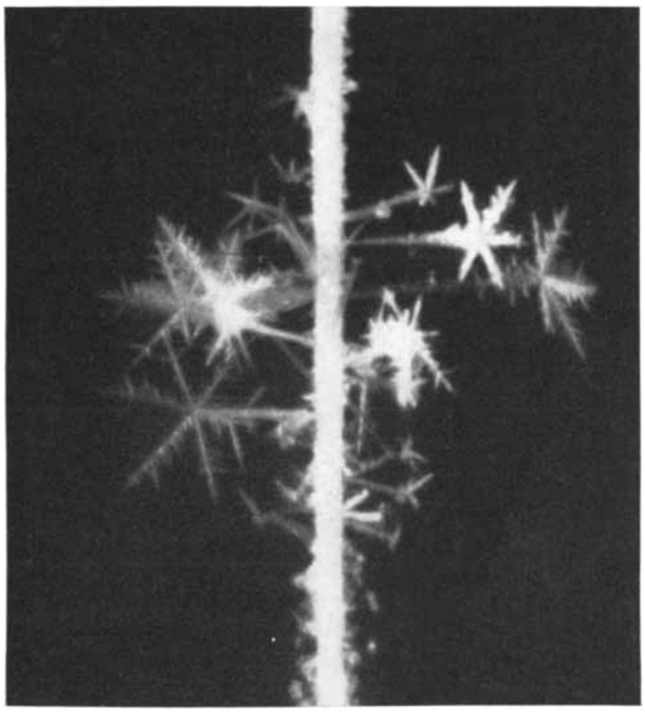
Although snow crystals occur in almost infinite variety, they can all be classified into three basic forms: the hexagonal prismatic column, the thin hexagonal plate and the branching star-shaped form, sometimes called dendritic [*see illustrations on pages 120 and 121*]. Until recently experts disagreed on the reasons for the differences in form. Some argued that the form depended less on temperature of formation than on the degree of supersaturation of the surrounding air.

It is almost impossible to assign reasons for the different crystal forms by collecting snowflakes on the ground. Accordingly much effort has gone into collecting ice crystals from aircraft and noting the temperature of the surrounding air. Such studies have revealed that at a given temperature a particular crystal type tends to be dominant. The high cirrus clouds, which are usually colder than 30 degrees below zero, consist of prismatic columns, typically half a millimeter long and containing pronounced funnel-shaped cavities at each end. The medium-altitude clouds, whose temperatures range between 15 and 30 degrees below zero, contain both plates and prisms. The greatest variety of crystals are found in the lower portions of supercooled clouds, where temperatures run from about five degrees below zero up to zero. Here occur hexagonal plates, short prisms, long thin needles and, most striking of all, beautiful, intricate stars up to several millimeters in diameter. Snowflakes, which are composed of from two to several hundred individual crystals, form at temperatures only a few degrees below zero.

The observation of clouds thus suggests that the shape of a snow crystal is largely controlled by the temperature of the air in which it grows. This has been confirmed in a striking manner by growing crystals under carefully controlled conditions in the laboratory. We grow crystals on a thin fiber running vertically through the center of a diffusion cloud chamber in which the vertical gradients of temperature and vapor density can be accurately controlled and measured. The results of many experiments, covering a temperature range from zero down to 50 degrees below zero and vapor supersaturations varying from a few per cent to 300 per cent, consistently show that the crystal shape varies with temperature along the length of the fiber. The cycle of shapes —from the hexagonal plates at zero degrees through needles at three degrees below zero—is always precisely reproducible. The boundaries between one form and another are very sharp [*see illustration on opposite page*]. For example, the transitions between plates and needles at three degrees below zero and those between hollow prisms and plates at eight degrees below zero occur within temperature intervals of less than one degree. Crystals grown from heavy water are almost identical with ordinary ice crystals except that the transition temperature between forms is shifted upward by about four degrees. This conforms with the melting point of heavy ice, 3.8 degrees above zero.

Our experiments have shown conclusively that it is temperature alone, and not supersaturation of the surrounding vapor, that governs the crystal form. The effect of supersaturation is simply to alter the growth rate: the greater the supersaturation, the faster the growth. The dependence of crystal growth upon temperature may be demonstrated in dramatic fashion merely by raising or lowering the fiber in the chamber. Whenever a crystal is thus transferred to a new environment, its further growth takes the form characteristic of the new temperature regime. By



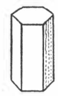
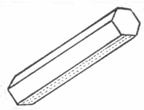
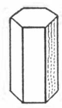
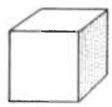
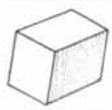
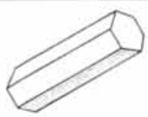
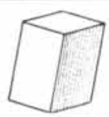
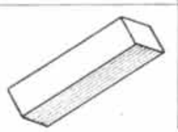


CRYSTAL HYBRIDS show how form is dictated by temperature. Needles grown at five degrees below zero C. developed plates on their ends when shifted to a temperature of 10 degrees below zero (*left*); stars when shifted to 14 degrees below zero (*right*).

thus altering the temperature we have been able to produce hybrid combinations of all the basic crystal types [*see illustrations on preceding page*].

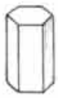
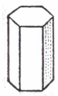
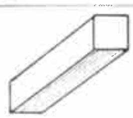
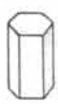
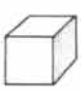
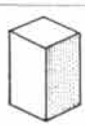
The exact nature of the growth mechanism that can completely change the crystal shape in the space of a degree or two, and that produces five complete changes of habit in the space of only 25 degrees, is still something of a mystery. Our studies indicate, however, that the rate of migration of molecules from one crystal face to another, which appears to be very sensitive to the temperature, will be an important ingredient of the final explanation.

The work I have described does not tell us whether we can hope eventually to modify the weather, but it is aimed at establishing some of the basic physical processes that are involved in the natural formation of rain. We know that water droplets of the size found in clouds will rarely freeze spontaneously except at temperatures of 30 degrees or more below zero. We also know that there are terrestrial dusts capable of acting as nucleating agents at temperatures as high as five degrees below zero. Some

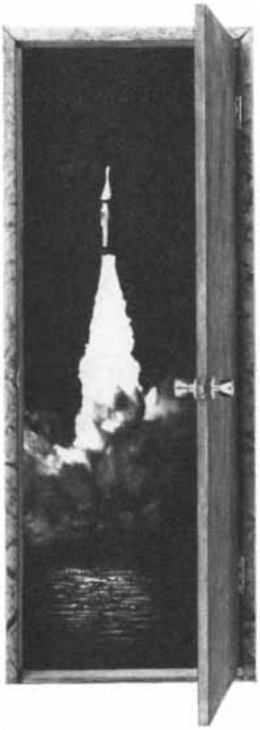
NATURAL NUCLEI					ARTIFICIAL	
SUBSTANCE	CRYSTAL SYMMETRY	CRYSTAL FORM	LATTICE MISFIT WITH ICE (PER CENT)	THRESHOLD TEMPERATURE (DEGREES C.)	SUBSTANCE	CRYSTAL SYMMETRY
ICE CRYSTAL	HEXAGONAL		0	0	SILVER IODIDE	HEXAGONAL
COVELLITE	HEXAGONAL		–2.8	–5	LEAD IODIDE	HEXAGONAL
BETA TRIDYMITE	HEXAGONAL		–3.5	–7	CUPRIC SULFIDE	HEXAGONAL
MAGNETITE	CUBIC		–7.1	–8	MERCURIC IODIDE	TETRAGONAL
KAOLINITE	TRICLINIC		–1.1	–9	SILVER SULFIDE	MONOCLINIC
GLACIAL DEBRIS				–10	AMMONIUM FLUORIDE	HEXAGONAL
HEMATITE	HEXAGONAL		–3.5	–10	SILVER OXIDE	CUBIC
GIBBSITE	MONOCLINIC		+12	–11	CADMIUM IODIDE	HEXAGONAL
VOLCANIC ASH				–13	VANADIUM PENTOXIDE	ORTHORHOMBIC
VERMICULITE	MONOCLINIC			–15	IODINE	ORTHORHOMBIC

NATURAL AND ARTIFICIAL ICE-NUCLEATING AGENTS tend to have hexagonal crystal habits, though there are notable exceptions. At left are nine of the 16 atmospheric dusts found to be effective nuclei at temperatures of 15 degrees below zero C. or higher. At right are 10 of the most effective artificial nuclei. The dimensional agreement between the crystal lattices of effective nuclei and the lattice of ice is usually a good one, but it does not necessarily correlate with threshold temperatures. The best fit may of the dusts can even be trained to be more effective than they are normally. But every stable, supercooled cloud is visible evidence that effective nucleating agents are frequently lacking. Whether providing them artificially, under favorable conditions, will significantly increase snowfall or rainfall is a matter still to be resolved to the general satisfaction of meteorologists.

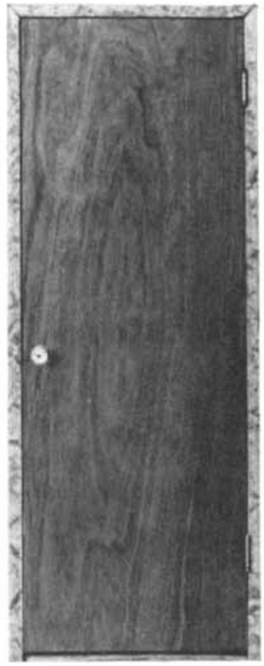
N U C L E I

CRYSTAL FORM	LATTICE MISFIT WITH ICE (PER CENT)	THRESHOLD TEMPERATURE (DEGREES C.)
	+1.3	–4
	+0.4	–6
	–2.8	–6
	–3.5	–8
	–0.3	–8
	–2.9	–9
	–3.8	–11
	–6.2	–12
	–2.1	–14
	–1.5	–14

occur between uneven multiples of the lattice constants of the crystal and of ice. The best fit for any one dimension of the lattices is shown in the fourth and ninth columns.



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



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

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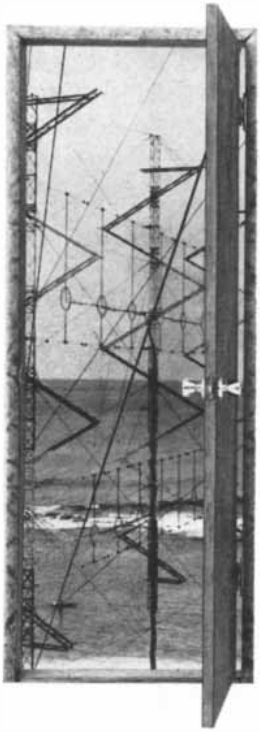
X-15: Northrop produces Q-Ball, the flight angle sensor for safe re-entry of X-15 and other aerospace vehicles.

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

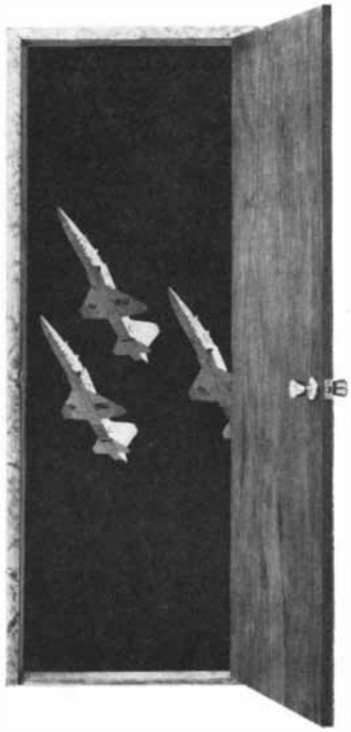
TITAN: Northrop supplies complete technical and industrial management to activate the T-2 Titan missile base.

Northrop Corporation, Beverly Hills, California • Divisions: Norair, Nortronics, Radioplane, Northrop International

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



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



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

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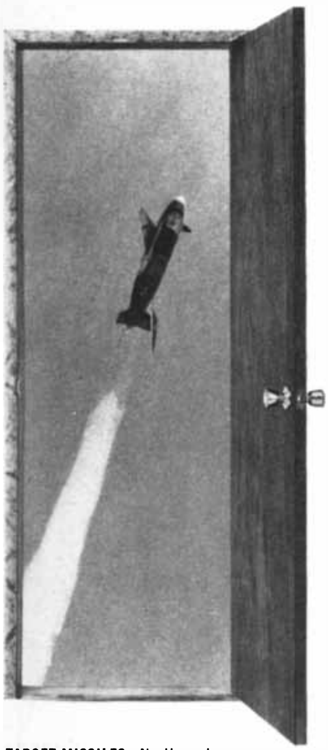

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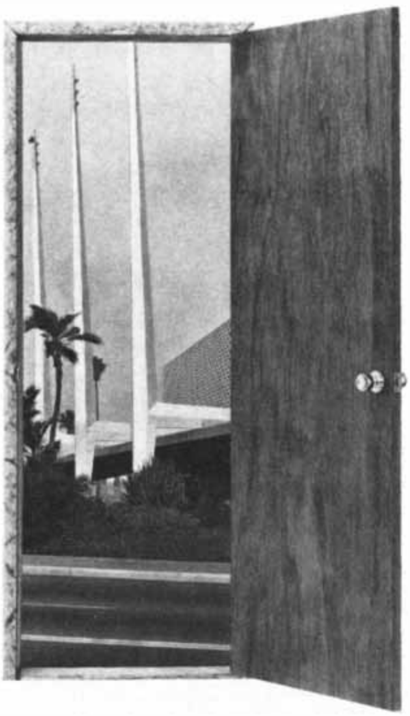

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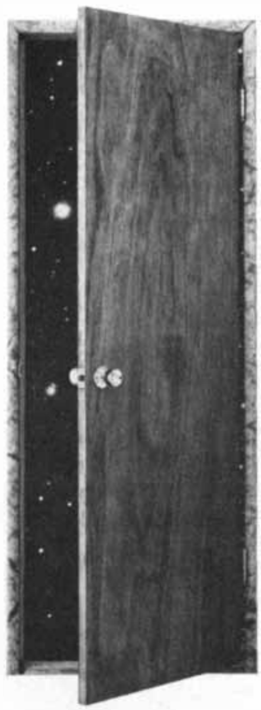

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THE HUMAN THERMOSTAT

A newly discovered sensory organ in the brain precisely measures the body temperature and trips the heat-dissipating mechanisms that maintain the temperature within a fraction of one degree

by T. H. Benzinger

Fever is usually the first symptom to arouse concern in illness. The rise in body temperature is not great in the absolute sense. On the contrary, the attention it attracts is a measure of the constancy with which the body temperature is normally maintained. Compared to the daily and seasonal variation in the temperature of "cold-blooded" animals, whose internal temperature depends upon that of the environment, a fever represents a tiny variation in temperature. Yet it is many times greater than the normal variation in the regulated temperature of the healthy body. In spite of large differences in environmental temperature—from the arctic tundra and windswept highlands to fiery deserts and steaming jungles, from season to season and from day to night—the body temperature departs little from the norm of 37 degrees centigrade (98.6 degrees Fahrenheit). Life in the cells continues undisturbed, although the metabolic processes are irrevocably linked to temperature by the laws of thermodynamics and the kinetics of chemical reactions.

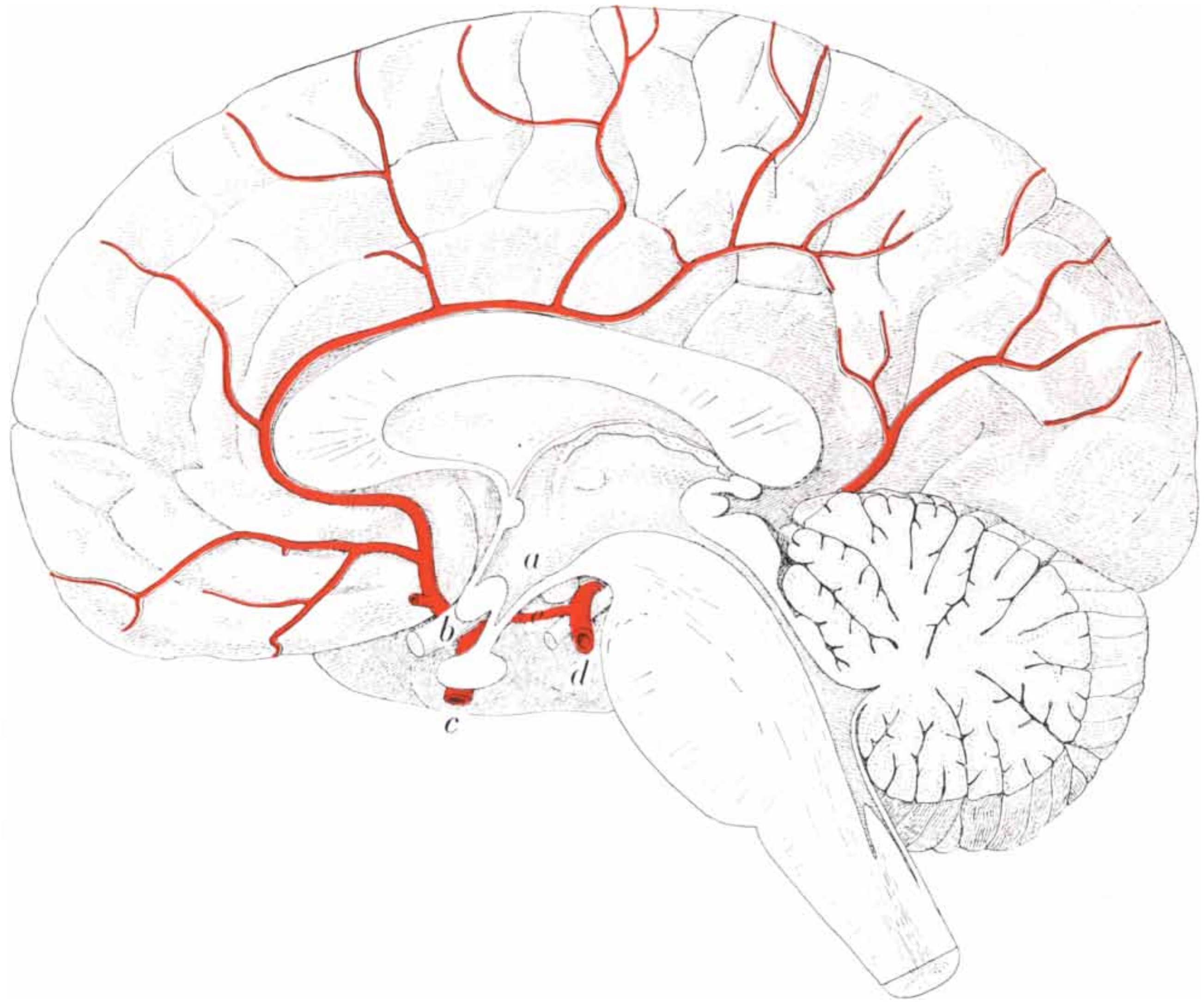
Heat is a by-product of these processes. With the body at rest, the heat of basal metabolism easily supplies the necessary interior warmth when external conditions are comfortably cool. Only under extreme conditions does the system fail; as when, in a hot environment, physical effort fans the flame of the metabolic furnace beyond control by the regulatory system; or when, in a very cold environment, the loss of heat by radiation, conduction and convection overbalances the metabolic production of heat and reduces body temperature to a fatal degree. Man of course shares this vital capacity with other mammals and with birds. Favored in consequence with nervous systems maintained at optimal working temperatures under all environmental conditions, the "warm-blooded" animals have become masters of the living world on our planet.

The question of how the body keeps its temperature constant within such narrow limits has engaged the efforts of an astonishing number of investigators. It is only recently, however, that one of the two parts of the regulating mechanism—defense against overheating—has been clarified. Max Rubner of Berlin had recognized in 1900 that sweating and the dilation of the peripheral blood vessels constitute the effector mechanisms for the dissipation of excess heat from the body. E. Aronsohn and J. Sachs, two medical students at the University of Berlin, came upon the center of control in the brain as long ago as 1884, when they damaged in animals an area "adjacent to the corpus striatum toward the midline." A few months earlier Charles Richet of Paris had also produced excessive body temperature by puncturing the forebrain. It now seems certain that in both cases the investigators damaged the hypothalamus, an area at the base of the brain stem just above the crossing of the optic nerves.

But how does the body sense and measure its temperature and bring the control center into action? The investigation of this question was confused for a long time by the conspicuous part that the temperature-sensitive nerve endings in the skin play in the feeling of warmth and cold. In recent years, however, a new approach to the problem has been made possible by the development of a new principle of measurement called gradient calorimetry and of the instrumentation to go with it. Experiments employing this instrumentation have now located the sensory end-organ at which the body "takes" its own temperature when it becomes too warm. The discovery is an unusual one at this late date in the history of physiology. The body's "thermostat" must now be included in the short list of major sensory organs adapted to the primary reception and measurement of physical or chemical quantities. Moreover, it now becomes possible to measure the characteristic responses of the thermostat and perhaps to produce or to suppress those responses artificially. Such investigation will lead to a better understanding not only of the aberration of fever but also of the precise regulation of internal temperature that is so important to the vital function of the body, particularly to the function of the delicate nervous system. With the thermostat identified, it has also become possible to explain

TEMPERATURE AT THERMOSTAT in the brain is measured by thermocouples

placed at forward wall of ethmoid sinus ("*a*" *in diagram at left*), deep in rear wall of nasopharyngeal cavity (*c*) and at eardrum (*d*). Thermostat itself is in hypothalamus behind sphenoid sinus (*b*), at which temperature has also been measured by thermocouple.



HEAT CONTROL CENTER is located in forward part of hypothalamus (*a*), shown in cross section (*left*) and from below (*right*). Hypothalamus, centrally located under great hemispheres of brain, rests on the Circle of Willis (*e*), an arterial ring through which

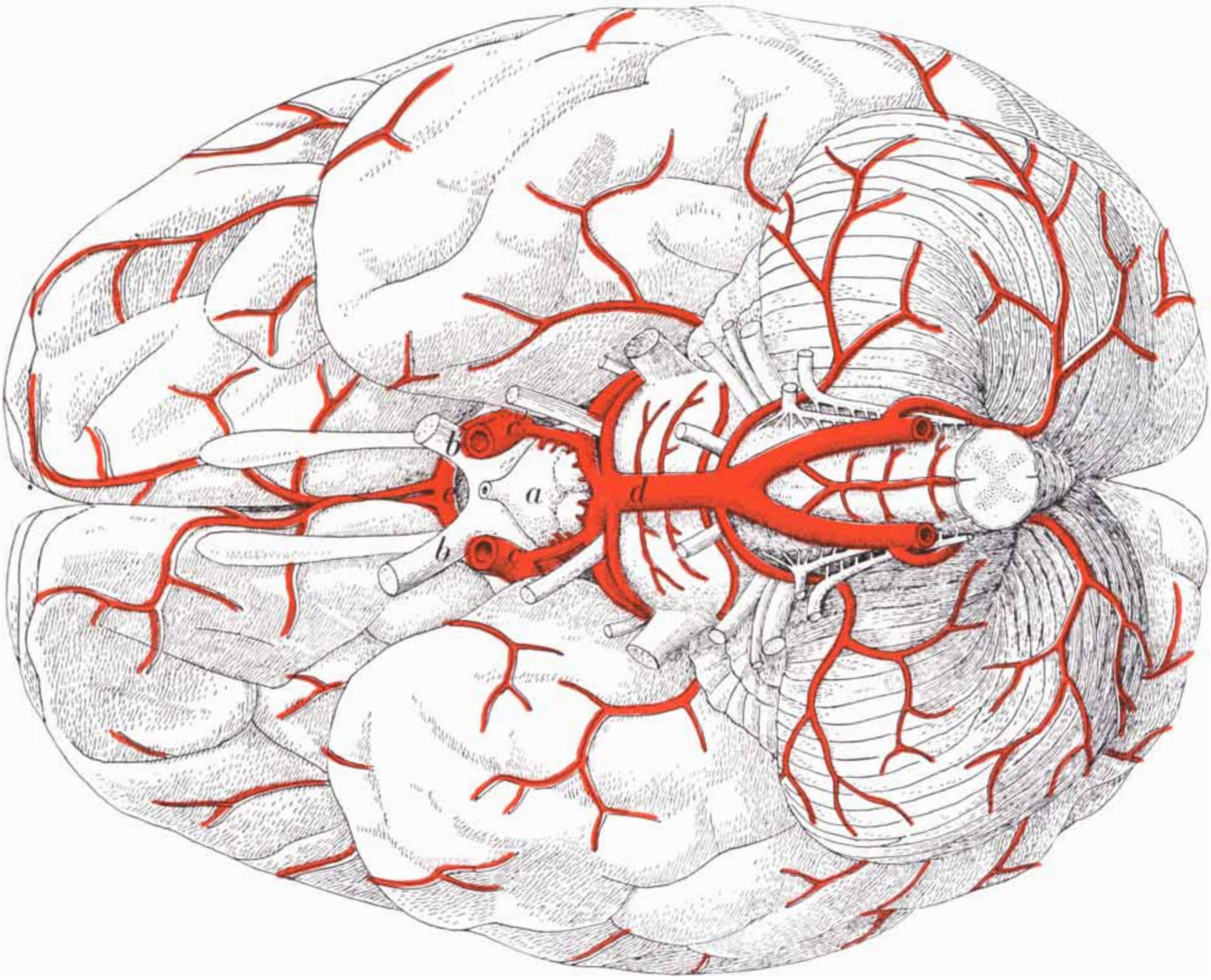
the effects of such mundane factors as a hot meal, a cold drink, a hot bath and a cold shower.

When one encounters a physical or chemical quantity in technology or in a living organism that is maintained at a constant level against disturbances from outside, one looks for a "servomechanism." Pressure, rate of flow, chemical composition or temperature are automatically controlled by such mechanisms in the realm of engineering. The servomechanisms of the body control the same kinds of variable. In man-made devices the chain of control begins with a "sensory" instrument, perhaps a thermometer, which measures the variable in question. The measurement is relayed to a "controller" which compares it with a set point to which the variable is to be held. Whenever the need arises, the controller sends instruction to an "effector" mechanism, perhaps to the heating system, which brings the temperature into accord with the set point in the controller [see "Feedback," by Arnold Tustin; SCIENTIFIC AMERICAN, September, 1952].

The corresponding elements in biological servomechanisms and the nervous and chemical pathways that interconnect the sites of stimulus and response constitute systems of far greater complexity. They are nonetheless put together in a similar way. A servomechanism in the human body may be considered to be clarified when the sensory organ, the controller and the effector mechanism are known, and when a reproducible, inseparable and quantitative relation has been established between the magnitudes of the stimuli and of the responses they induce. The net effect of the response must be the restoration of "homeostatic" equilibrium; that is, the variable in question must return to the optimum, stable level essential to the life of the cells.

In the control circuit that prevents overheating of the body, classical physiology had identified the effector and the controller mechanism, but not the sensory organ. In a hot environment, as Rubner showed, the effector is the dilation of the blood vessels in the skin, which increases the transport of heat from the interior of the body to the surface; and sweating, which increases the rate of total heat loss from the surface to the environment as energy is absorbed in evaporation. In a cold environment the corresponding mechanism is increased metabolic heat-production.

The location of the controller in the hypothalamus by Aronsohn and Sachs



blood supply to the brain flows from carotid arteries (*c and c′*) and basilar artery (*d*). Hypothalamus, optic nerves (*b and b′*) and retina derive from same tissue matrix. Bulb of pituitary gland attached to hypothalamus appears at left, but is cut away at right.

was confirmed by later investigators. Some of them applied the stimulus of temperature directly to the site. In 1904 Richard Hans Kahn of the German University in Prague found that heating the head arteries of a dog lowered its body temperature. In 1912 Henry Gray Barbour, a young American physician working in Vienna, carrying out an experiment designed by the pharmacologist H. Meyer, applied warm and cold probes to the general area of the hypothalamus. He observed the expected thermoregulatory responses. In 1938 Horace W. Magoun, now at the University of California at Los Angeles, discovered that this function is mediated by a circumscribed area in the forward part of the hypothalamus. Bengt Andersson of the Royal Swedish Veterinary Institute in 1956 delineated the organ with unprecedented precision in goats. In 1950 Curt von Euler of the Nobel Neurophysiological Institute in Stockholm even succeeded in recording, in parallel with temperature changes, slow electrical "action potentials" from this area of the hypothalamus of cats.

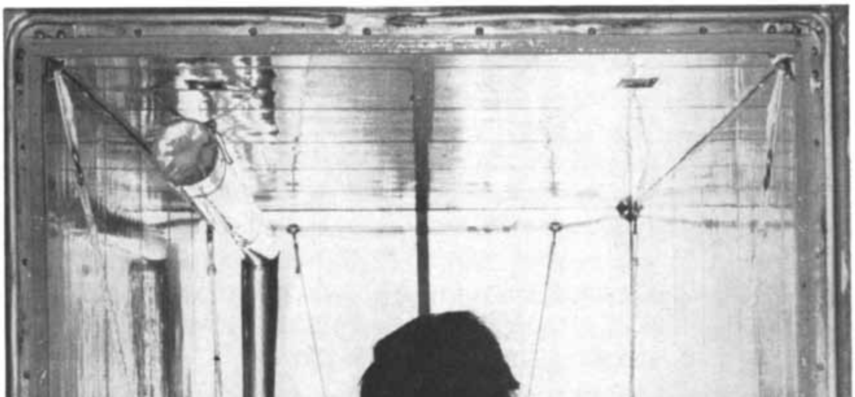
But the body is also equipped with an elaborate system of millions of tiny sensitive nerve endings, distributed throughout the skin, which produce conscious sensations of warmth. The scientific literature tended to support the view that the skin and not the hypothalamus furnishes the primary temperature measurements to the control center for sweating and the dilation of the arteries. Some investigators held that both systems were involved; a rise in the temperature of the "heat center" in the hypothalamus supposedly made it more responsive to incoming impulses from the temperature-sensing organs of the skin. The question, in this view, was one of determining the relative importance of the two sites. It was also possible, as some believed, that the body possessed a third area sensitive to temperature or heat flow, and that neither the skin nor the brain was involved.

It was not easy to design a conclusive experiment. In experimental animals one might destroy the nervous pathways from the thermoreceptors in the skin to the heat center. But the results of such an experiment would not exclude the possibility that the temperature of these centers played a role in heat regulation under normal conditions. It would still be necessary to carry out the reverse experiment and destroy the heat-sensitive part of the hypothalamus. Since this structure is intimately involved with the temperature-control center itself, it seems impossible to secure the final evidence by surgical procedures alone.

To observe the operation of sensory receptors in the skin and in the brain independently of each other in the intact organism presented comparable difficulties. No one, apparently, had succeeded in keeping one of the two sites at a constant temperature while observing the effects brought about by a temperature change in the other. This approach called for techniques to measure temperature in the human body at the two sites of presumed temperature-reception—the skin and the hypothalamus—and some way to record, rapidly and continuously, the effector responses of vasodilation and sweating.

The gradient calorimeter has satisfied the second of these two requirements. This rapidly responding and continuously recording successor to the classical calorimeter makes it possible to record for the first time the total output of the effector mechanisms. It measures separately the heat that is carried from the body by radiation and convection and the heat that is dissipated by the evaporation of sweat. From working models made and tested by Charlotte Kitzinger at the Naval Medical Research Institute in Bethesda, Md., the first full-scale human gradient calorimeter was constructed under the direction of Richard G. Huebscher at the laboratory of the American Society of Heating and Ventilating Engineers in Cleveland. Similar units have now been constructed at other laboratories. The gradient calorimeter now operated at Bethesda is a chamber large enough to hold a man stretched out at full length [*see illustration below*]. The subject is suspended in an open-weave sling, out of contact with the floor or walls of the chamber, and is free to go through the motions of prescribed exercise when the experiment calls for such exertion.

The new and essential feature of gradient calorimetry is the "gradient layer," a thin foil of material with a uniform resistance to heat flow which lines the entire inner surface of the chamber. Some thousands of thermoelectric junctions interlace the foil in a regular pattern and measure the local difference in temperature (and hence the local heat flow) at as many points across the foil. The junctions are wired in series; their readings are thus recorded in a single potential at the terminals of the circuit. That potential measures the total energetic output from the subject's skin, independent of his position with respect to the surfaces of the gradient layer lining the chamber. The rate of blood flow through the skin

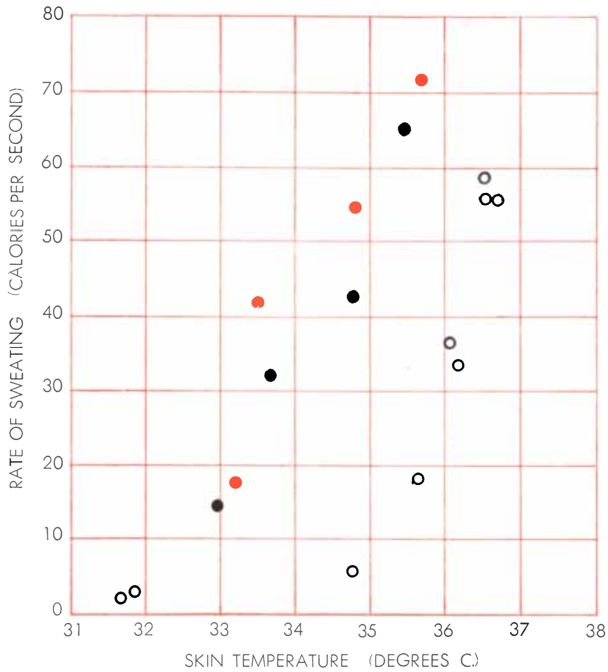


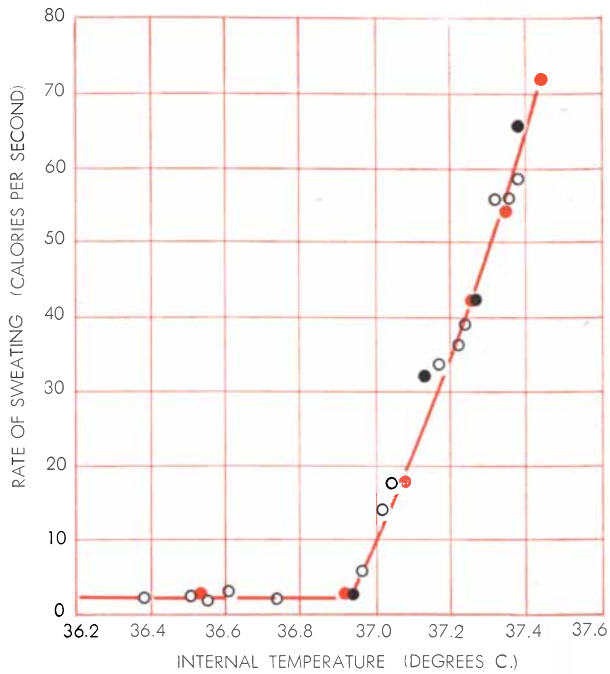
HUMAN GRADIENT CALORIMETER makes it possible to correlate body temperature with dissipation of heat by radiation and convection from skin and by evaporation of sweat. Lining of chamber is interlaced with thermoelectric junctions which measure heat loss from skin; loss by sweating is measured by temperature and humidity control system of calorimeter.

can be derived by computing this measurement against the temperature of the outgoing blood (measured internally) and the temperature of the returning blood (measured on the skin), since the observed transfer of heat per unit time at any given difference between internal and external temperature can be effected by only one calculable rate of blood flow. The energy dissipated by evaporation from the subject's skin is also measured by gradient layers which line heat-exchange meters at the inlet and outlet of the air circuit of the calorimeter. Measurements taken for control make it possible to maintain the same temperature and humidity in the air at these two points, so that the air neither gains nor loses energy as it passes through the system. The unbalanced output from the additional gradient layers thus precisely measures the heat loss by evaporation and hence the sweat-gland activity. Heat loss through the lungs is measured separately and subtracted from the total.

With the help of the gradient calorimeter our group at Bethesda set out to establish the correlations obtaining, on the one hand, between the performance of the effector mechanisms and the temperature of the skin and, on the other hand, between the performance of the effector mechanisms and the internal temperature of the body. In these first experiments it was assumed that rectal temperature provided an adequate index of internal temperature as measured at the internal temperature-sensing organ, wherever that might be located. But no correlation could be found, in either resting or "working" subjects, between rectal temperature and the observed rates of sweating. Measurement of skin temperature against the same heat-dissipation variable yielded equally meaningless plots. For a time it seemed that all the effort that had gone into the design of the gradient calorimeter had been wasted. The results made sense only in terms of the classical notion that the thermostat in the interior of the body and the temperature-sensing nerve endings in the skin have indissolubly interlaced effects upon the vasodilation and sweating responses.

Then we found a way to measure the internal temperature of the body at a site near the center of temperature regulation in the brain. We introduced a thermocouple through the outer ear canal and held it against the eardrum membrane under slight pressure. The eardrum is near the hypothalamus and shares a common blood supply with it from the internal carotid artery. At the





HEAT DISSIPATION by sweating plotted against skin temperature yields senseless graph (*left*) when natural correlation between skin and internal temperature is broken by internal heating through exercise. When the same measurements of sweating are plotted instead against internal head temperature (*right*), an inseparable and always reproducible relation appears between the stimulus of temperature and the response of the sweat glands, whether the subject is sweating or not.

very first attempt we observed temperature changes associated with the eating of ice or the drinking of hot fluids, and we soon found we could detect variations caused by immersion of the limbs in warm water. Parallel rectal measurement did not show these variations at all. To make sure that the entire region of the head supplied by the carotid arteries can be expected to show the same temperature variations as the eardrum, we tried other sites. With the help of local anesthesia H. W. Taylor, a surgeon at the Naval Hospital in Bethesda, placed thermocouples in our heads: at the main trunk of the internal carotid in the rear of the nasopharyngeal cavity, in the nasal cavity below the forebrain and at the forward wall of the sphenoid sinus only one inch away from the hypothalamus [*see illustration on pages 134 and 135*]. Continuous measurements of temperature at these points showed large discrepancies with internal temperature as measured at the rectum.

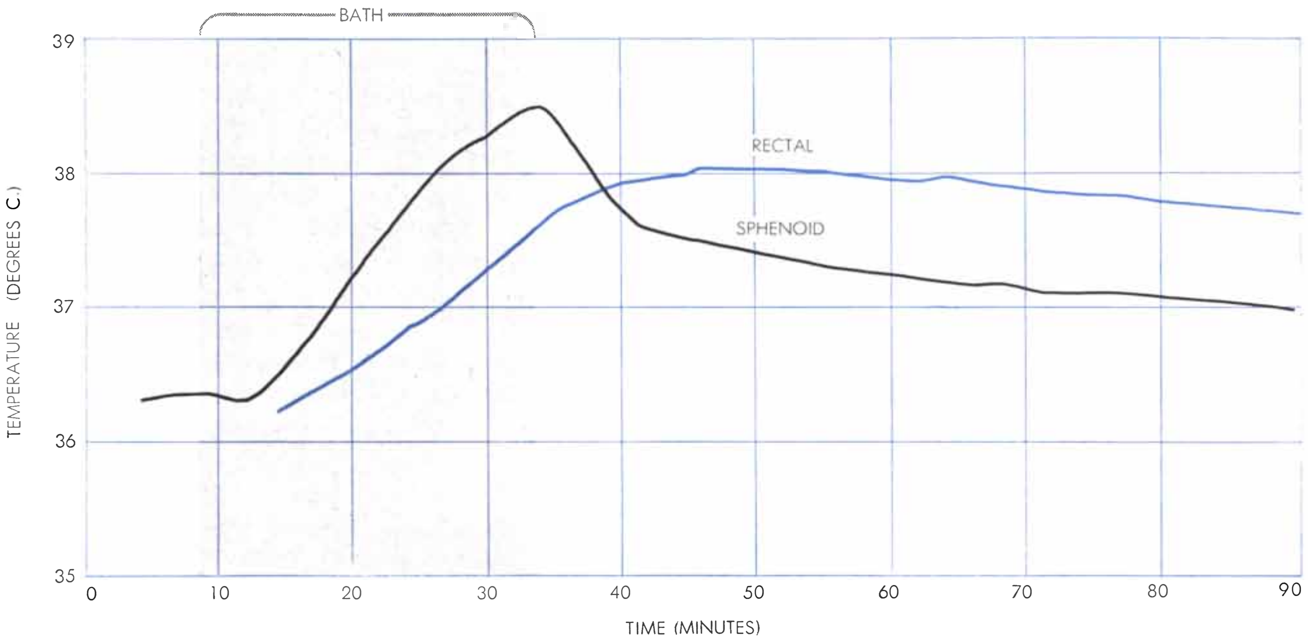
The discrepancies appeared before and after the subject exerted himself by physical exercise, after internal cooling by the eating of ice, after warming the arms or legs in warm water and cooling them in cold water and after immersing the whole body in warm or cold water. These were precisely the situations in which earlier experimenters had found the same absence of correlation between rectal temperature and the heat-dissipating responses of vasodilation and sweating. It was clear that the temperature at the rectum could under no circumstances be trusted as reflecting the temperature at the internal temperature-sensing organ. The hypothalamus was plainly the place to look for correlation between changes of internal temperature and the responses that regulate it. Since the eardrum is by all odds the most accessible of the four sites thus measured in the head, it was adopted in the experiments that followed. Readings could be taken here with an error of .01 degree centigrade against a standard of temperature maintained with an error of .002 degree C.

The subjects now spent time in the calorimeter on many different days at different environmental temperatures ranging from almost intolerably cold for the nude body at rest to almost intolerably hot for the subject undergoing exertion. Between these two extremes, measurements were made for all the intermediate levels at five-degree temperature intervals and with the subject at rest and at work. Under each set of circumstances the instruments kept a continuous record as the state of homeostasis was reached and maintained for one hour. This arduous series of experiments, extended over two months, made it possible to plot for the first time the heat-dissipating responses of vasodilation and sweating independently against skin temperature and against internal head temperature. The volunteer subject for this series, Lawrence R. Neff, was observed with a cool skin and cool interior (resting in a cold environment), with a cool skin and warm interior (working in a cold environment), with a hot skin and a relatively cool interior (resting in a hot environment) and with a hot skin and warm interior (working in a hot environment).

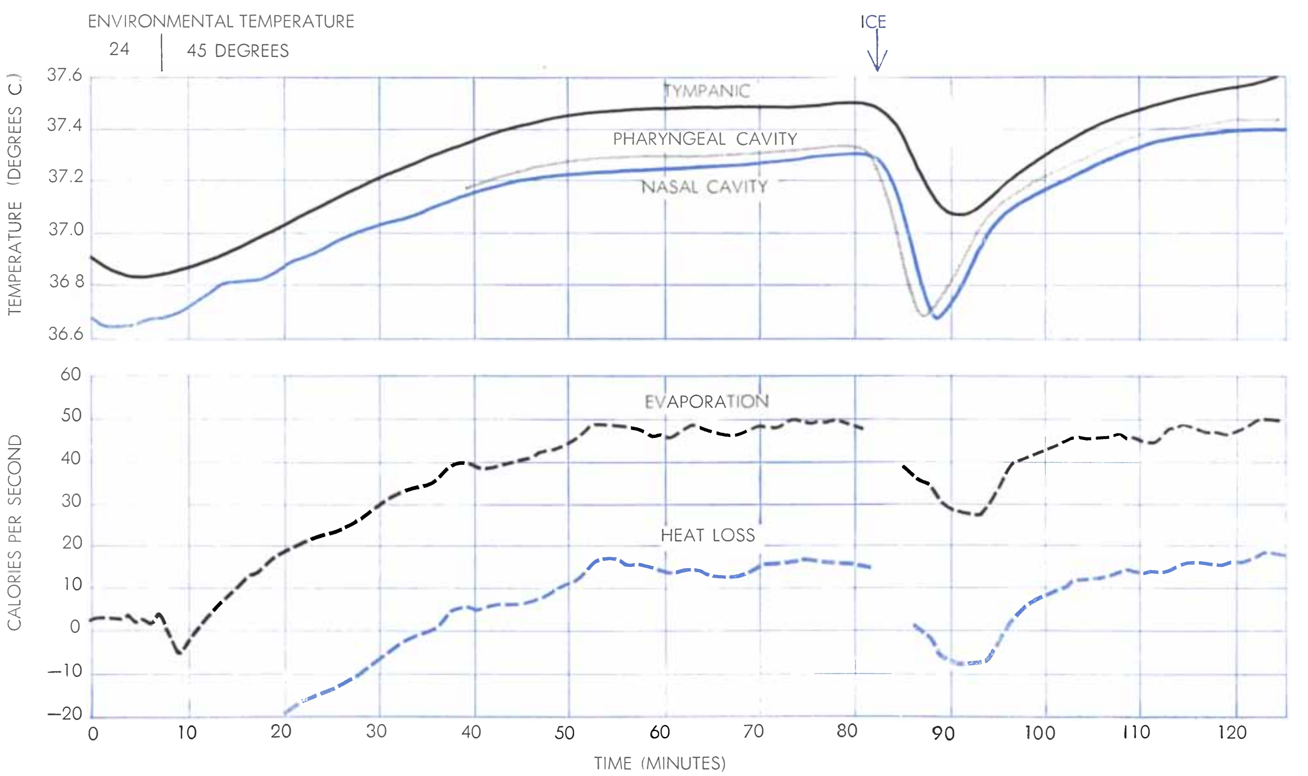
The records showed the familiar disordered relationship between the heat-dissipating responses and skin temperature. But the plot of the responses against eardrum temperature showed an almost perfect undisturbed relation. Whatever the temperature of the skin, one certain specific rate of sweating and no other invariably showed up in association with a given internal temperature measured at the eardrum. A reproducible, inseparable and quantitative relation between the stimulus of temperature and one of the heat-dissipating responses had at last been observed. It exhibited a sharply defined breakoff at 36.9 degrees C. (98.4 degrees F.). This was no doubt the set point of the human thermostat in this subject at the time of the experiment. The response proved to be so forceful that a mere .01-degree-C.

rise in temperature was sufficient to increase the dissipation of heat through sweating by one calorie per second and to raise the blood flow through the skin by 15 milliliters per minute.

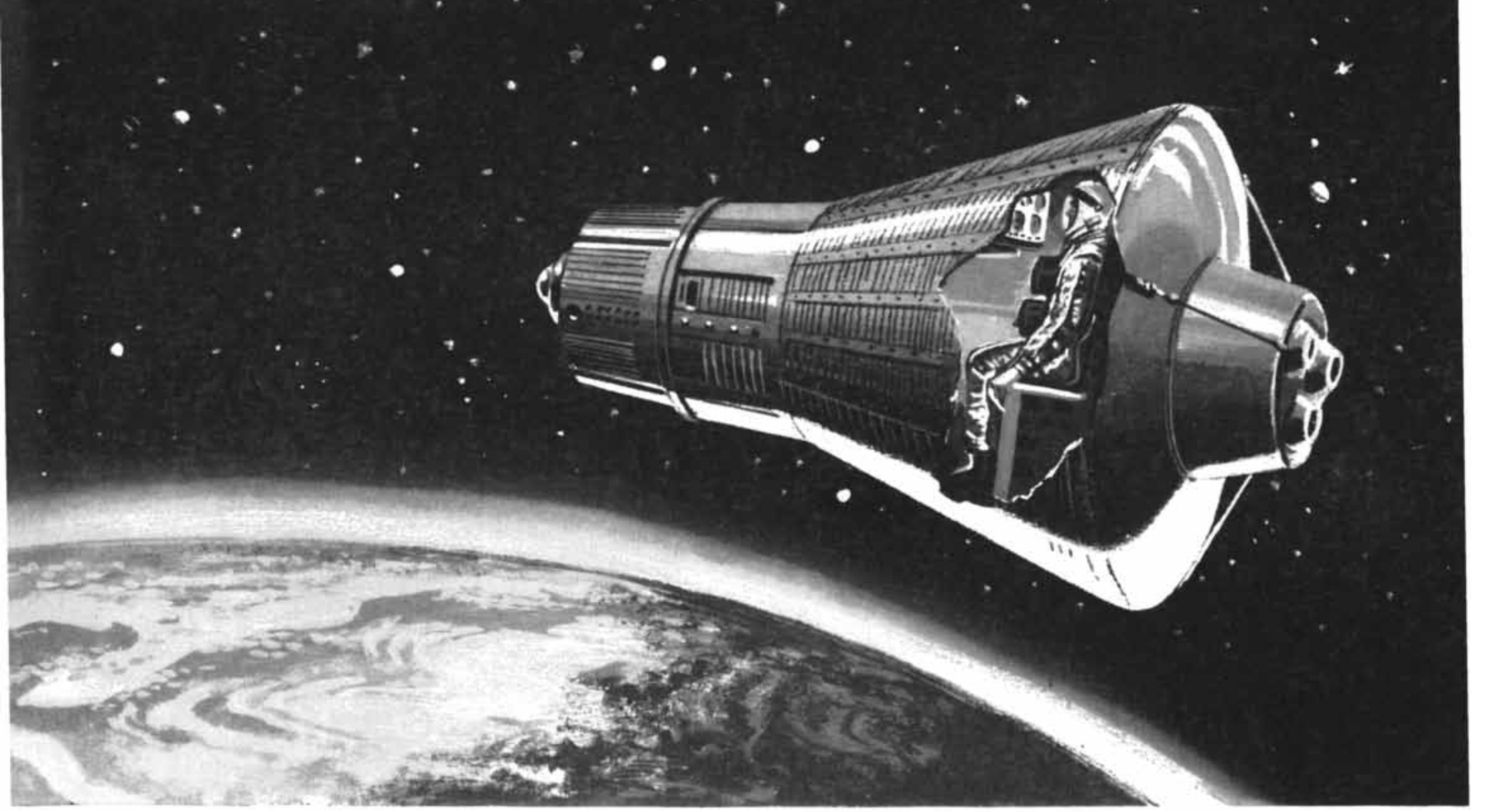
The success of this series of experiments in distinguishing between the variations in skin and brain temperature was confirmed in many other experiments that subjected the body to quite different sets of extremes. In one of them the skin and the interior of the body were warmed as the subject accommodated himself in the calorimeter to an environmental temperature of 45 degrees C. (113 degrees F.). With homeostasis attained, the subject gulped down large measured helpings of sherbet three times at suitable intervals. On each occasion, as the melting ice withdrew heat from the internal organs and the circulating blood, the brain temperature declined. No less impressively, the skin temperature was observed to rise. The curve



RECTAL TEMPERATURE is shown in this graph to have an uncertain relationship to the hypothalamic temperature measured at the forward wall of the sphenoid sinus. The sphenoid temperature rises sharply as an experimental subject enters a warm bath and falls off sharply when the subject leaves the bath. The rectal temperature reaches a peak only after the subject has left the bath.



MEASUREMENTS OF HEAD TEMPERATURE at three points near the hypothalamus—at eardrum (*tympanic*), at ethmoid sinus (*nasal cavity*) and in rear wall of pharyngeal cavity—show close correspondence with one another and with the heat dissipation by evaporation of sweat and heat loss by vasodilation. Location of these points is shown in the illustration on pages 134 and 135.



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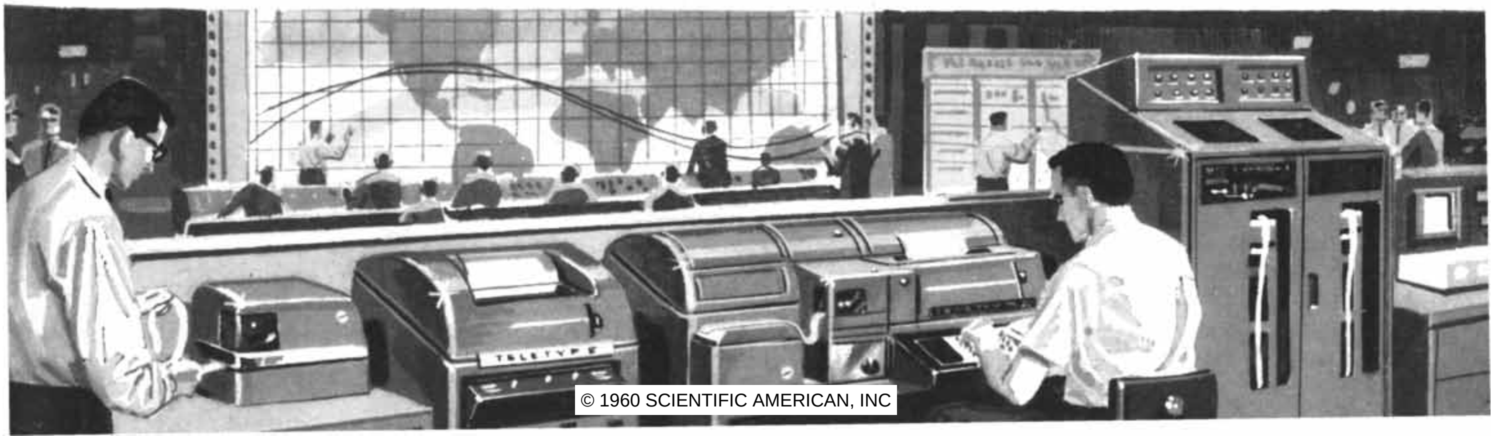
Teletype page printer, tape punch and reader units will be used throughout Project Mercury's global communications network to gather and relay flight data.

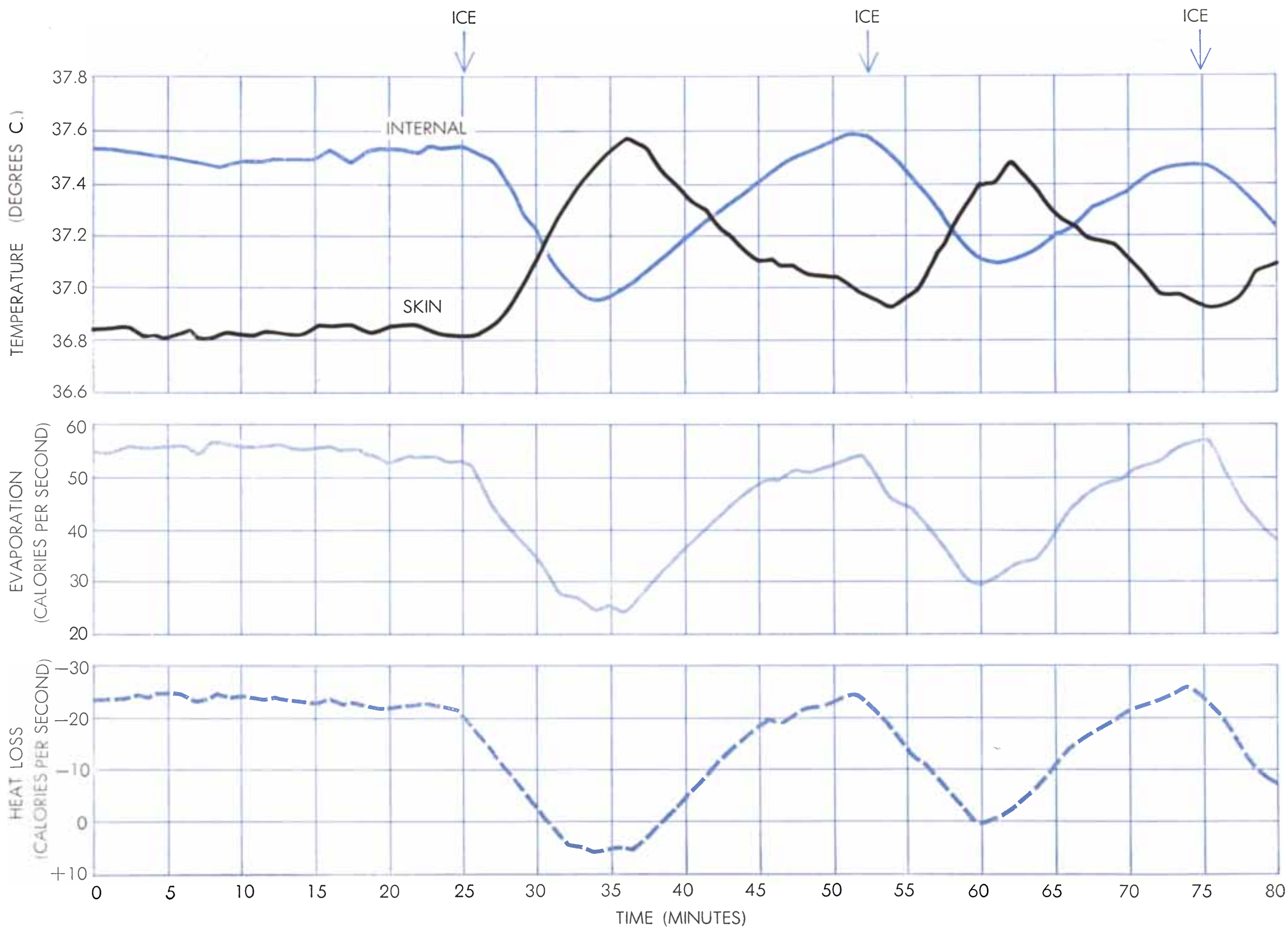


drawn by sweat-gland activity now showed unequivocally which temperature-sensing system controls the heat-dissipating responses: the rate of sweating fell off and rose in perfect parallel with the decline and rise in internal head temperature. It was the consequent drying of the skin that caused the skin to be heated by radiation and conduction in the hot environment. But the sensory reception of heat in the skin brought no response from the heat-dissipating mechanism.

These observations accord well with the familiar constancy of the body temperature. It is difficult to see how it could be maintained within the same narrow range, year in and year out, if the heat-controlling responses were not always triggered at the same set point. As these experiments show, moreover, the responses always closely match the magnitude of the stimulus. Such precise regulation of temperature could not be achieved by measurement of skin temperature. As in all feedback systems, the quantity which is controlled must itself be measured. An architect who wants to control the temperature of a house does not distribute thousands of thermometers over the outside walls. One thermostat in the living room suffices. It responds not only to warming and chilling from out-of-doors but to overheating from within. The thermostat in the hypothalamus similarly monitors the internal temperature of the body from the inside and thereby maintains its constancy.

This is not to say that the warm-sensitive nerve endings of the skin have no function in the regulation of body temperature. They are the sensory organs for another system which operates via the centers of consciousness in the cortex, bypassing the unconscious control center in the hypothalamus. To sensations of heat or cold reported by the skin the body reacts by using the muscles as effector organs. Under the stimulus of discomfort from the extremes of both heat and cold, man seeks a cooler or a warmer environment or takes the measures necessary to make his environment comfortably cool or warm. But for all the mastery of external circumstances that follows from this linkage in the body's temperature-sensing equipment, the skin thermoreceptors cannot regulate internal temperature with any degree of precision. They can contribute directly to the regulation of skin temperature alone. The automatic system of hypothalamic temperature regulation takes over from there and achieves the final adjustment with almost unbelievable sensitivity and precision.

In the regulation of internal temperature, therefore, the hypothalamus can



CONCLUSIVE EXPERIMENT establishing hypothalamic temperature as key to control of body temperature is charted. At left in top chart the subject's hypothalamic (internal) temperature is stabilized at the "normal" 37 degrees C. in an environment of 45 degrees C. (113 degrees F.). Upon ingestion of ice at half-hour intervals, internal temperature drops sharply and skin temperature ascends. In middle chart rate of sweating falls and rises in close correlation with hypothalamic temperature; shutdown of sweating accounts for rise in skin temperature. In bottom chart heat loss from skin shows same correlation with hypothalamic temperature.

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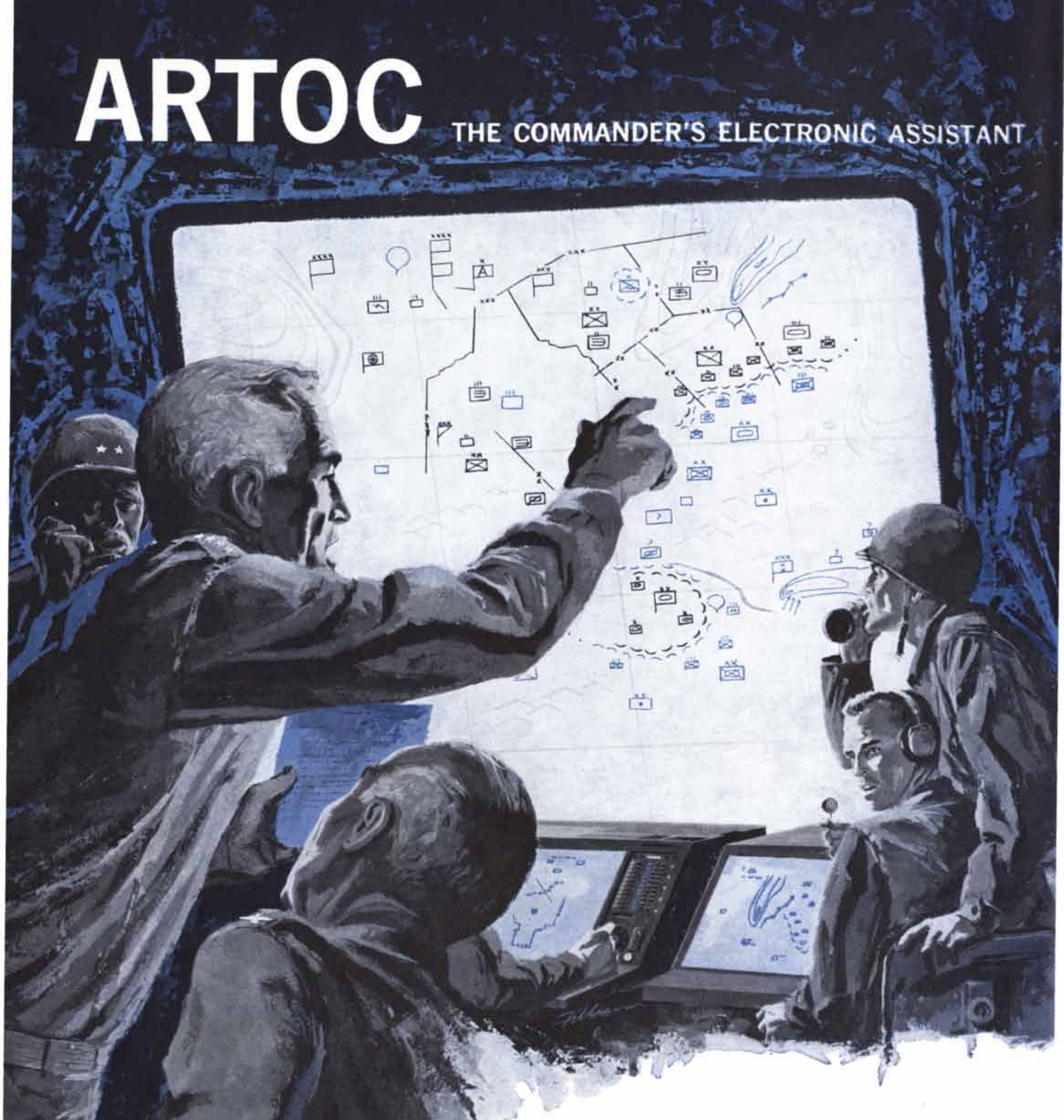

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no longer be regarded simply as a controller which converts incoming sensory stimuli into outgoing impulses to the effector system. It is itself the site of a receptor end-organ, an "eye" for temperature comparable to the retina—the receptor organ for light. This analogy between the temperature eye and the optical eye has, in fact, a sound anatomical basis. Both are derived from the same matrix: the bottom of the third ventricle of the brain. These are two parts of the brain that have a proved sensory receptor function. In the course of evolution the optical eye moved outward to connect with a dioptric apparatus partly derived from the skin, and thereby gained a view of the external world. The temperature eye in the hypothalamus is located in the interior of the head, where it properly belongs. It measures as well as regulates the temperature of the blood which bathes its cells and the rest of the brain, the vital function of which requires a closely maintained optimal temperature.

The feedback system that dissipates heat and thus keeps the body from overheating under normal conditions has thus been elucidated. The same cannot be said, however, of the regulatory system that steps up metabolic heat production and keeps the body temperature from falling below the optimum level. It appears that the two systems operate quite differently and that in the metabolic warming-up of the body the temperature-eye performs its task by inhibition of sensory impulses originating elsewhere.

On the other hand, the sure location of the thermostat in experiments on the "warm side" now makes it possible to renew the study of many interesting questions. Temperature measurements at sites that reliably reflect hypothalamic temperature should replace rectal observations of temperature in all these studies and even in some clinical situations. How bacterial toxins produce fever and how drugs act to reduce it can now be redefined in terms of shifts in the set point of the thermostat and may be made the subject of quantitative investigation. The same direct attack may also be made upon individual or group tolerances and the adaptability of human temperature regulation. These are important objectives in connection with hypothermia (the reduction of the body temperature to low levels) in surgical operations, and with the conquest of new spaces for the life of the human species.

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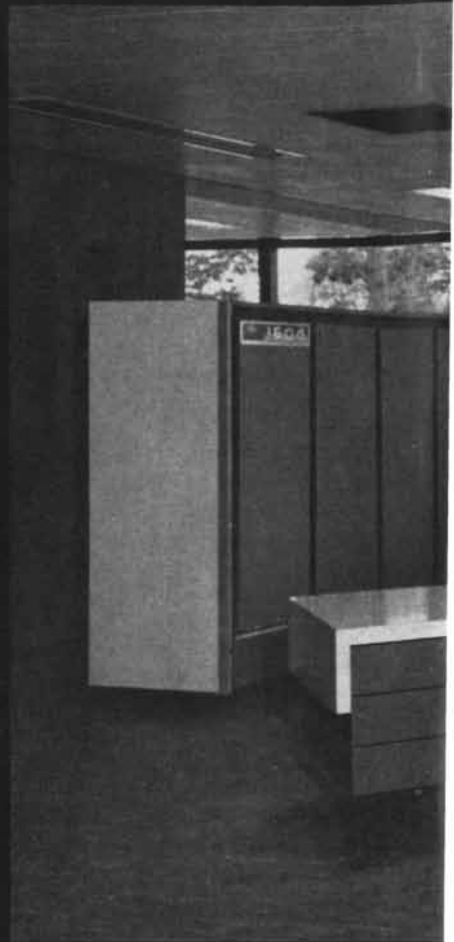
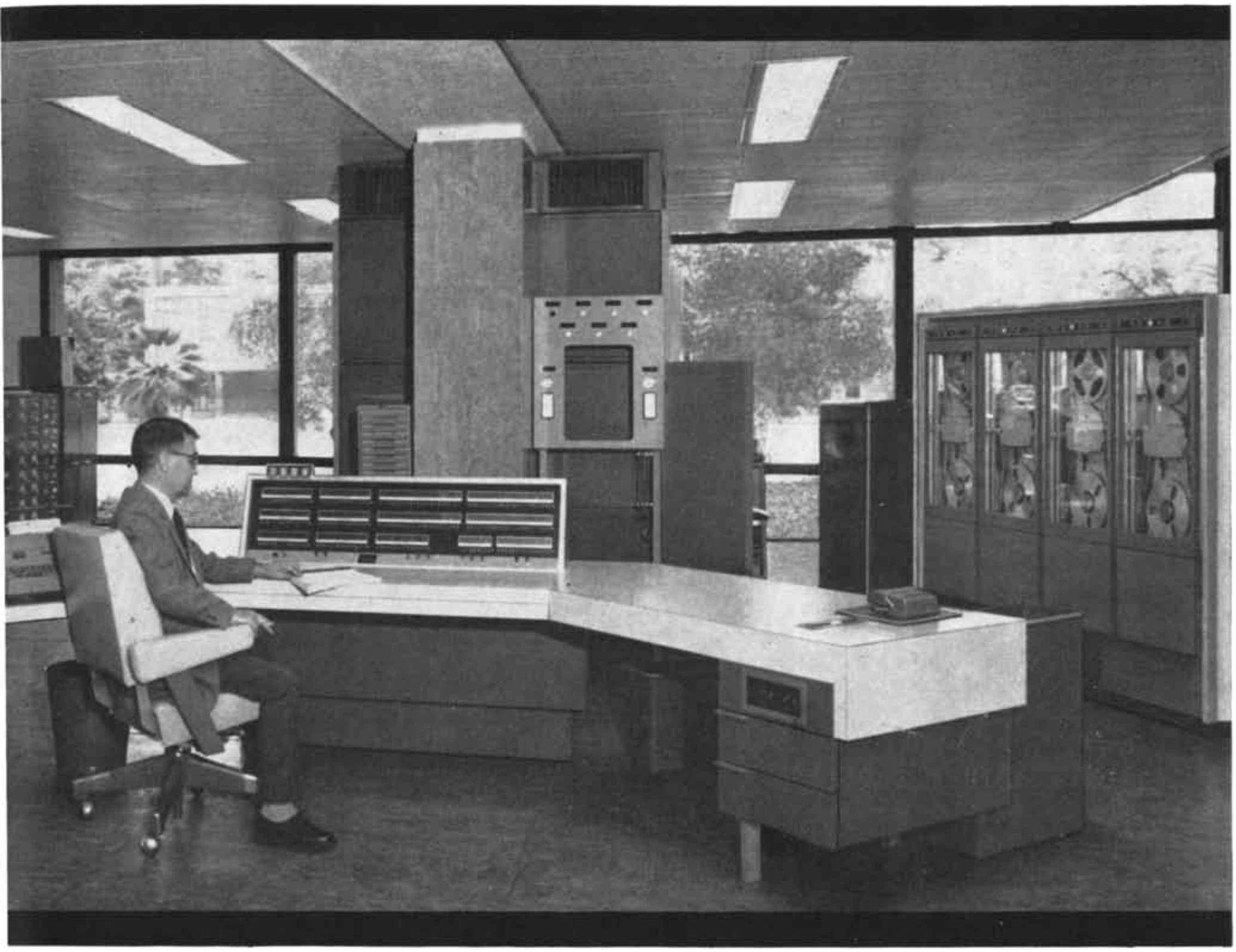


January 12, 1960	The first production model 1604 arrived at the U. S. Naval Postgraduate School, Monterey, California.
January 17, 1960	The large-scale 1604 Computer was put into full operation.
January 21, 1960	The complete system was formally accepted by the U. S. Navy.

Since acceptance *the Control Data 1604 has been used in a variety of applications. The Navy project NANWEP (Navy Numerical Weather Prediction) makes use of the 1604 for meteorological problems, both in research and in practical applications such as weather predictions for the Pacific Missile Range and for hemisphere-wide Fleet support. In addition, students in nearly all curricula of the School receive course and laboratory work in the application and operation of the 1604 Computer and peripheral equipment.*



Professor Elmo J. Stewart, Director of the U. S. Naval Postgraduate School Computing Center, at the console of the 1604 which has been proving its reliability in round-the-clock performance for a full year.

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SALPA

With the vast spaces of most of the oceans for a habitat this delicate creature has developed a curious life cycle that stretches the reproductive processes to their limits

by N. J. Berrill

The open seas, far from the edges of contaminating continents, contain a great number of certain delicate and beautiful forms of animal life. They are rarely seen, now that large, high-speed vessels and airplanes have superseded the precarious but often enlightening custom of crossing the oceans in small sailing ships. These organisms must be seen close at hand to be seen at all; as watery and transparent as the sea itself, they cannot be dragged up in nets without suffering damage. Among the most abundant and successful are the salps, or species of the genus Salpa, for which there is no other name. Members of the chordate phylum to which we ourselves belong, they and their closest relatives constitute the subphylum Tunicata—the tunicates, most of which go by the expressive name of seasquirts and spend their adult life attached like plants to the sea floor.

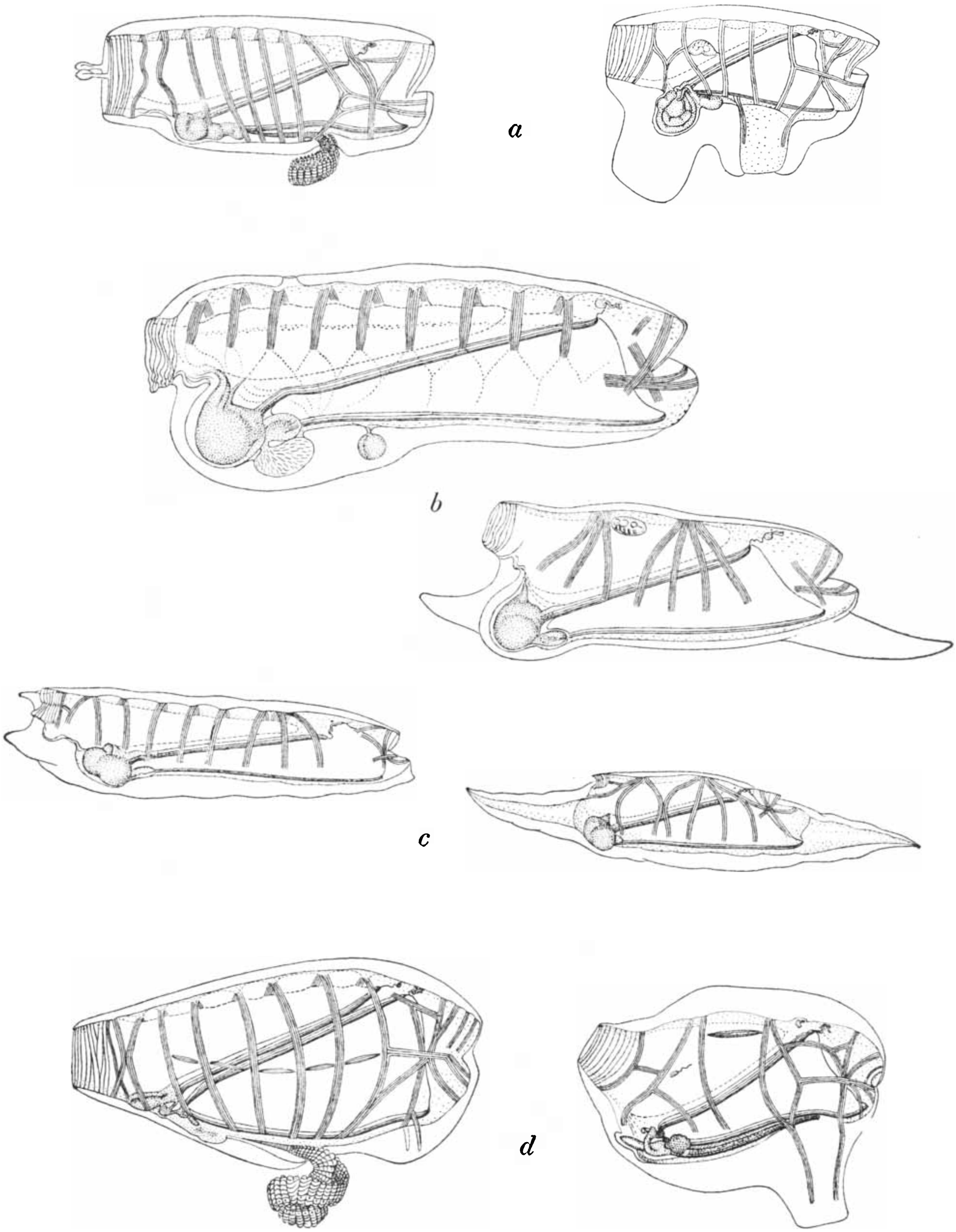
The salps, however, swim freely. Feeding directly upon the microscopic algae that constitute the pasturage of the sea, they live almost throughout the oceans. Their range extends from 60 degrees north latitude to 60 degrees south, from the surface down to depths of 500 and even 1,000 feet. With little competition among themselves or with other creatures for the unlimited food supply in this almost unlimited space, the salps have compounded propagation and stretched reproductive processes to their limits. Their strange life cycle confused the taxonomists of the 19th century. Every species of Salpa has two kinds of reproduction, sexual and asexual, culminating in two distinctly different types. Each type was originally discovered and named independently as a species in its own right. If Salpa can be said to have found a niche, it is a niche of world-wide proportions. The main problem of the species would seem to be that of contending with its own innate fragility, a problem that its unusual reproductive processes seem to have met.

Salpa presents a model subject for the study of some of the most challenging problems in the whole of biology. The difficulty lies in bringing healthy salps and alert biologists together. The organism has attracted the attention of some outstanding personalities. Peter Forskal, who was a protege of Carl von Linné (Linnaeus) and was exiled from Sweden for defending civil liberties, found and named Salpa late in the 18th century. In 1815 the fantastic life cycle of Salpa was observed and described for the first time by the German poet and naturalist Adelbert von Chamisso, who was on a Russian scientific voyage around the world. Chamisso had written the story of *Peter Schlemihl*, about a man who sold his shadow (the forerunner of Peter Pan), and his report on Salpa was regarded as another of his tall tales. Truth eventually prevailed, and in 1893 W. K. Brooks, founder of the graduate school of zoology at Johns Hopkins University, devoted to Salpa one of the largest volumes ever produced on a single genus.

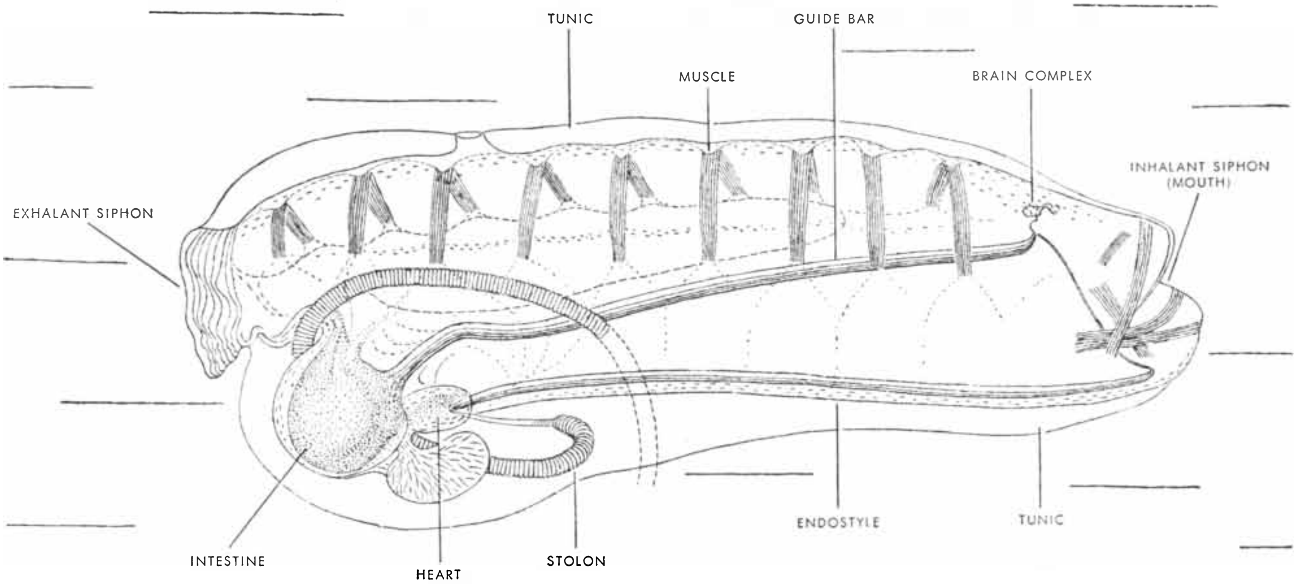
Salpa has a barrel-shaped body which is open at both ends and ranges in length from half an inch to six inches when fully grown, depending upon the species. Up to nine broad muscle bands reach almost around the transparent body like barrel hoops. Contraction of the muscles closes the forward opening—the mouth or inhalant siphon—and the water in the internal cavity is forced in a jet through the rear opening or exhalant siphon. On relaxation the body regains its shape, the mouth opens and water rushes in. Rhythmic contractions and relaxations accordingly propel the animal forward at considerable speed. This single activity provides the means of both locomotion and feeding. A small brain, or neural ganglion, on the back of the animal maintains and controls its muscular activity. A single light-sensitive (but not image-forming) "eye" is attached to the ganglion. The ability to detect light is very helpful to Salpa, for its food grows where there is light. As salps gulp and push through the water they strain out the small organisms which supply them with nourishment.

When studied in terms of its function, however, the simple barrel displays important elaborations and refinements, both internally and externally. As the name tunicate implies, Salpa possesses an outer tunic that envelops its whole body, from one opening to the other. The tunic consists primarily of native cellulose, a most unusual substance for an animal to produce, but a feature that Salpa shares with other tunicates. Cells and chemicals exuding through the epidermis from within reinforce the tunic material to form a gelatinous external layer unique in the animal kingdom. It is this plastic, amorphous substance that is molded to give precise shape to the organism, including such nautical requirements as fore and aft streamlining and, in many species, a central and lateral keel.

Efficient locomotion and feeding depend upon an unrestricted flow of water through the inner cavity. Thus the interior of the body suggests a deck cleared for action. The vital organs lie well out of the way; the heart and intestine in particular are virtually confined to a bulb at the stern below the level of the jet stream. The valveless

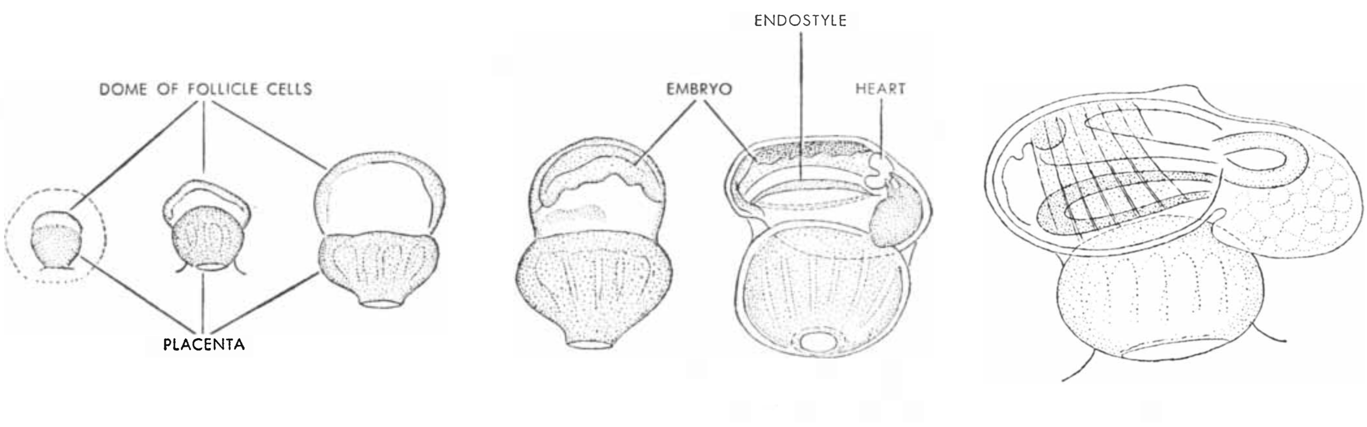


FOUR SPECIES OF SALPA appear to be eight because each has two forms. Solitary or asexual types are at left; aggregate or sexual types are at right. Species are *affinis* (*a*), *maxima* (*b*), *fusiformis* (*c*) and *pinnata* (*d*). Aggregate *maxima* contains an embryo, visible as an oval structure in its back, between the muscle groups. The scale is the same for each pair but different for the four species.



MAJOR ORGANS OF SALPA appear in this diagram of solitary form of *Salpa maxima*, shown approximately natural size. The guide bar directs mucus, and nutrient organisms trapped in it, back to intestine. Brain complex includes brain, eye and subneural gland. Contractions of muscles squeeze the hollow body, forcing a jet of water out of exhalant siphon to propel the animal forward.

heart, like that of all tunicates, regularly reverses its direction of pumping after every 40 or 50 beats. In front of this "engine room" a long glandular groove, the endostyle, extends to the forward end of the large inner chamber. Endostyle tissue secretes strands and sheets of mucus that pass up the sides of the chamber and are directed largely by the flow of water backward and downward to the intake of the alimentary system at the rear. As the water flows through the chamber, the mucus traps the food organisms and carries them into the intestine. The feeding process comes to some extent under the control of the subneural gland that touches the underside of the brain and has a duct opening into a feeding chamber. Both the endostyle and the subneural gland are of great evolutionary significance. The endostyle is un-



a *b* *c* *d* *e* *f*

GROWTH OF EMBRYO from egg in *Salpa democratica* starts (*a*) with a placenta and a dome made of follicle cells furnished by parent. Dividing cells of egg "plaster" dome (*b and c*), using it as a scaffolding. Tissue differentiation begins (*d and e*), and an embryo becomes recognizable (*f*). These drawings and those on opposite page are all to same scale and greatly enlarge the embryo.

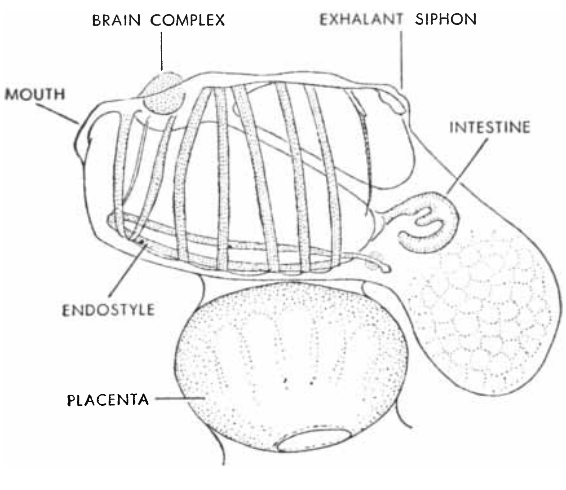
doubtedly homologous with the thyroid gland of vertebrates. The subneural gland represents the pituitary, complete with pituitary hormones, although the function of the gland and its hormones in Salpa and other tunicates is still obscure.

Such is the basic organism. It is the reproductive processes of Salpa, however, that really set the genus apart. The alternating sexual and asexual life cycle was first deciphered by Chamisso. In all of the species the sexually produced salp is known as the solitary type; the alternate generation, produced by a process of budding, is called the aggregate type. The solitary type is always the larger and better formed, although it never develops sexual reproductive tissue of its own. Instead, it produces a long, ropelike, budding "stolon" from the lower side of the interior cavern of the body, between the heart and the endostyle. As this tube grows, it subdivides into segments that remain joined together but develop into individual salps, smaller than the parent. Each length of chain gives rise to 50 to several hundred individuals, so that many thousands may be produced by a single solitary form. Each of the aggregate forms resulting from this process produces one embryo within itself by union of egg and sperm from its hermaphroditic sexual organs. The embryo is sexless but is equipped with an already budding stolon when it approaches full size and bursts the body of its nurse. Consequently each one of these embryos produced by the sexual process, and launched as an independent solitary form, has a good chance of producing its budding chain of hundreds or thousands of sexual nurses. The process of budding, which is like knocking chips off the same block, gives rise to an enormous population of individuals all exactly alike. The sexual process, on the other hand, not only multiplies that population but introduces some degree of variability, and therefore adaptability, to changes in the oceanic environment. So it goes, the chain or aggregate salps producing eggs that develop into the sexless solitary forms, and the solitary salps producing sexual chain forms.

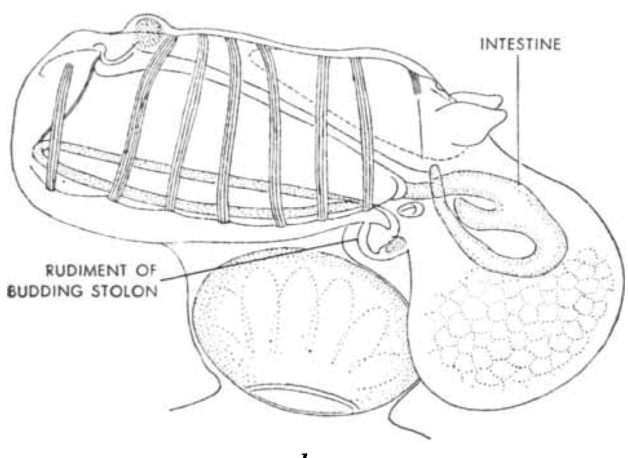
Many problems concerning the physiology of Salpa and the ways in which the alternating types behave in relation to ocean currents at various depths remain for investigation. The most challenging questions, however, concern the dynamics and developmental mechanics of both asexual and sexual reproduction, for these relate to the very nature of life itself, especially to the nature of the organization of living matter.

All familiar objects, including living things, exist in three spatial dimensions. A building, a crystal and an organism can be described with reference to these three dimensions, always with assurance in the case of the building and crystal, and usually without qualms in the case of an organism. Every organism, however, is a dynamic, open system that changes with time, and the time dimension cannot be tacitly ignored, as it is in the consideration of an inanimate object. This is one reason why an organism is so difficult to define, for the thing itself includes all that exists and happens from the beginning to the end of its developmental cycle, from conception and the cradle to old age and death. Salpa is no exception, but it is more than usually elusive. Salpa the egg becomes the fully grown solitary salp with its rapidly growing and subdividing stolon which is still part of itself. Or is it? Here the individual becomes truly confused between the one and the many. In fact the events that take place during the outgrowth of the Salpa stolon show that nature's way with geometry, solid and dynamic though it may be, is more mystifying than enlightening.

The outgrowth itself first emerges as a hemispherical bulge and then as a string on the belly side of the early embryo of the solitary type, while it is still developing within its nurse. The stolon grows rapidly to form a long slender tube. The outer envelope of the tube is an extension of the parental epidermis. Within this envelope lies an inner tube that grows from the lining of the inner chamber of Salpa just behind the endostyle. The only other tissue participating in the initiation of the stolon is a strand of connective tissue derived from that of the parent and extending along one side of the stolon in the space between the two tubes. The stolon as a whole not only grows in length; it is continually added to by new stolon tissue rapidly



g



h

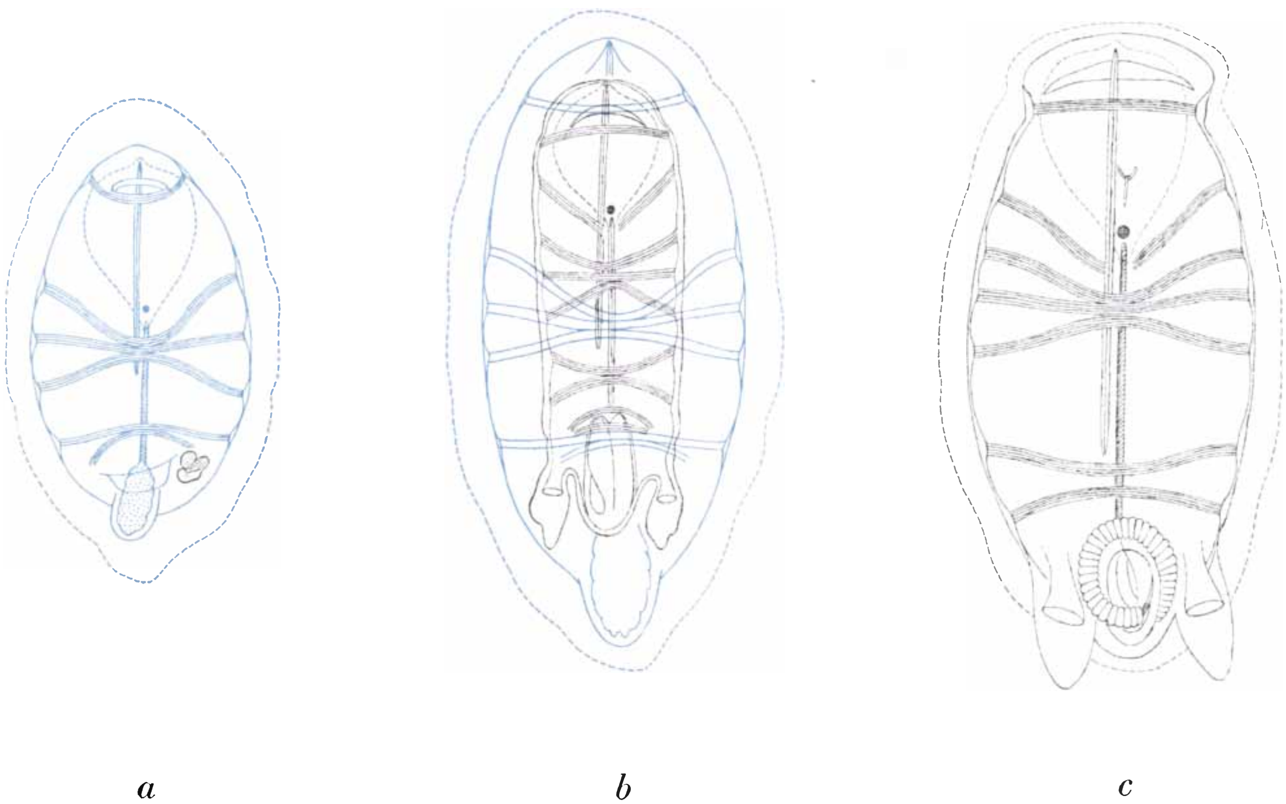
DEVELOPMENT CONTINUES with the appearance of muscle bands, the mouth, the exhalant siphon and other features (*g*). Even the rudiments of the stolon appear (*h*), long before the embryo is large enough to be recognized by the naked eye as a tiny salp. All the growth takes place within the parent or nurse salp (not shown here). Later development is illustrated on next page.

forming at the junction of stolon and body. Stolon tissue already formed is consequently shunted progressively farther and farther from the point of origin. It is this comparatively simple tubular structure that produces thousands of sexually mature salps.

The process of production, both qualitatively and quantitatively, is a significant one. To begin with, the stolon, as a tube within a tube, represents the primary organization of most animals; that is, a digestive tube within an epidermal envelope and additional tissue in between. Two other components appear early in the development of the stolon. A groove sinks in along the outer wall, on the side opposite the strand of connective tissue, and quickly deepens to form a slender tube below the outer surface, finally separating completely to lie in the space between the original outer and inner tubes of the stolon. This process of groove and tube formation is virtually the same as the process by which the neural tube, leading to the formation of the spinal cord and brain, develops in the embryos of all vertebrate animals. In Salpa the tube thus formed similarly gives rise to the brain, eye and subneural gland of the sexual salps-to-be. In a somewhat comparable manner the lateral wall of the original inner tube of the stolon everts at two points on opposite sides of the central cavity to form two more tubelike structures in the annular space between the two original tubes. These are the rudiments of the future feeding and digestive apparatus. Lastly the connective-tissue strand between the outer and inner walls begins to differentiate as ovary and testis.

This procedure of forming the primary tissues one from another is customary and is of general interest to embryologists. The truly paradoxical situation here is that the embryonic process of tissue differentiation is already well under way, yet the individuals destined to develop from it have not been defined. The stolonic tube is a straight, undivided column growing mainly from its base, like toothpaste squeezed from a tube. A cross section a short distance from the base looks like a cross section of an early-stage vertebrate embryo. But there is as yet no definable individual salp to be seen. In other words, organization is well established in two of the three spatial dimensions but not in the third dimension, corresponding to the longitudinal axis of the stolon. It is as though the stolon material continued to flow out from the base or point of origin without developing pattern or organization in the direction of flow, but progressively developing pattern in the two transverse planes. This phenomenon is characteristic of that state of matter known as liquid crystal, which is typical of substances that combine a degree of crystalline pattern with the capacity to flow. The suggestion has often been made that living matter is essentially a liquid crystal, and here perhaps is one of the most striking examples in the living kingdom. Admittedly this explains very little. On the other hand it emphasizes the challenging nature of salp reproduction and the need to understand it.

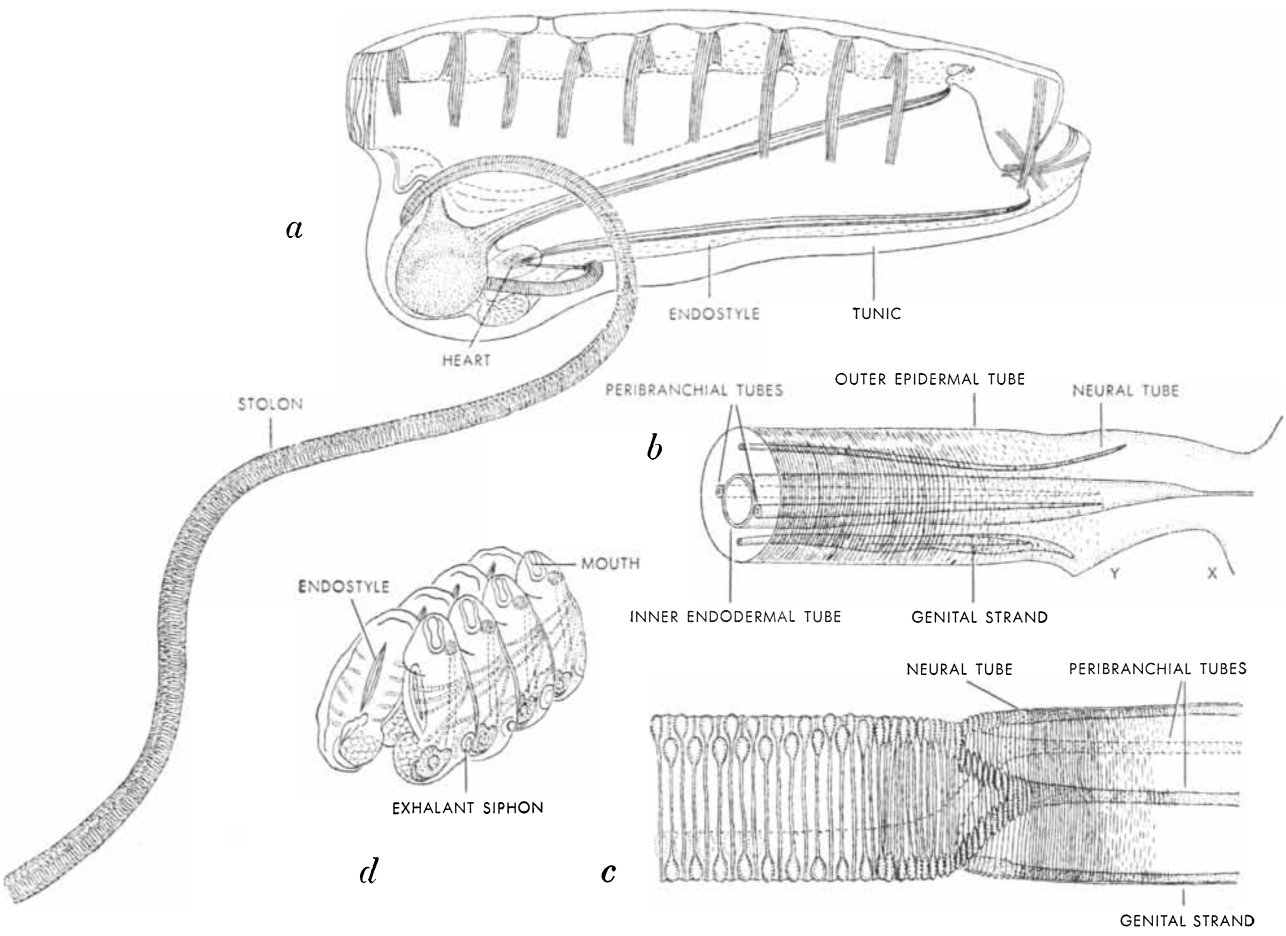
Commencing with this mysteriously flowing and incompletely organizing stolonic tube, how do the separate individuals of the salp chain arise? The way this end is accomplished is almost as remarkable as the fact that it needs



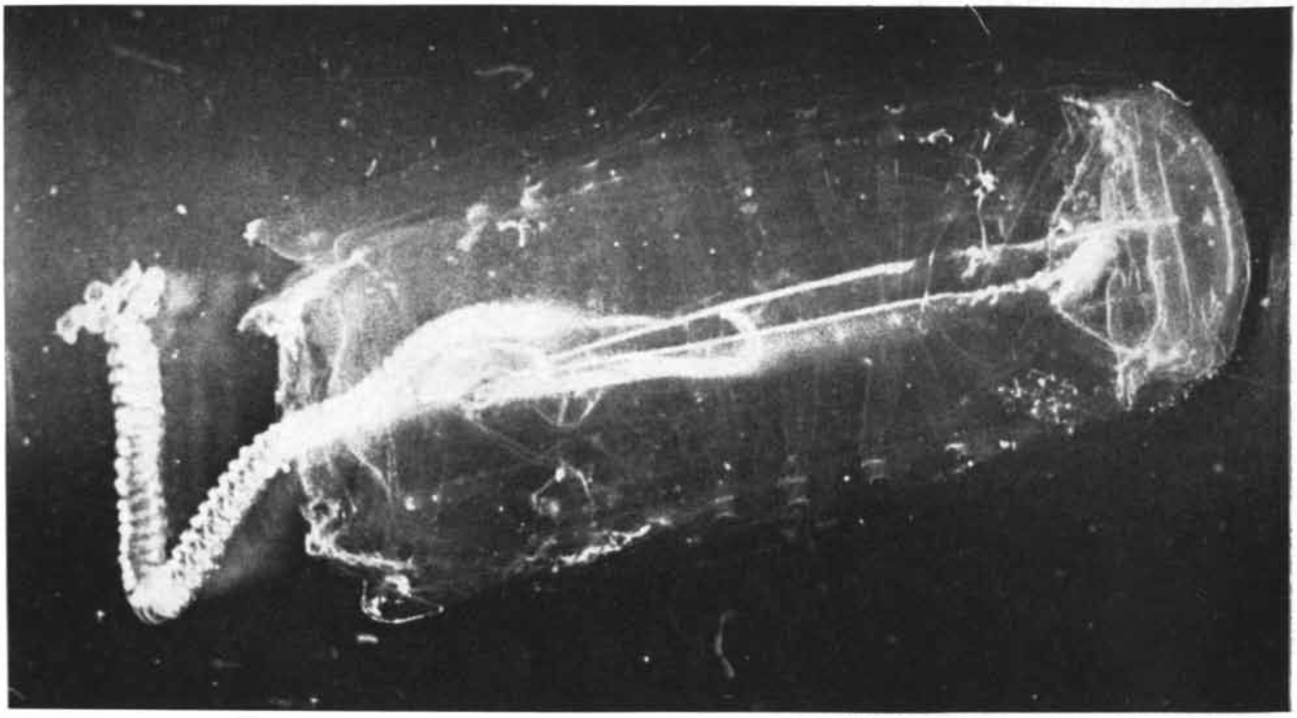
PARENT OR NURSE SALP (*color*) is still immature (*a*), but contains embryo (*black*) at stage of development seen in last drawing on preceding page. View here is from top. Nurse matures (*b*) as embryo grows large. Finally embryo bursts parental body and goes free (*c*), bearing a well-developed stolon which will produce thousands of sexual salps. Broken line indicates outer edge of tunic.

to be accomplished at all. It is as though a sausage were sliced very thin and held together while each slice grew thicker and thicker until it became a complete sausage itself. In actuality the outer wall of the lengthening stolon, although persisting as a single layer, thickens in the region just beyond the point where the neural tube has formed. The cells in this thickened zone arrange themselves in parallel rows running completely round the stolon, as though lined up on parade. Then each front row steps out, so to speak, and its cells stretch and divide, forming a ring or band around the stolon that is first two cells wide, then four cells wide, and so on. By this process each band steadily expands in the direction of the long axis of the stolon and begins to curve inward at its front and hind borders. A groove thereupon appears between each encircling band and the next, pinching inward deeper and deeper as growth continues. The tubular stolon is thus virtually cut into a series of rings, each more or less separate from its neighbors. Each ring, including a section of the internal components of the stolon, develops into a complete individual salp of the sexual type. Epidermal foldings thus effectively slice the stolon into prospective individuals. But what actually occurs in the epidermal outer wall of the stolon to cause the cells to line up in rows, each row representing a whole sexual individual-to-be, is a complete mystery.

If this were all, the outcome would be a chain of salps linked together head to tail. But such is not the case. Two kinds of structural shift now intervene. The first of these is the "assembly"; it consists of a relative shifting or migrating of tissues in the transverse plane of the stolon, a process as difficult to follow as to describe. In the second shift, the "deployment," the developing single chain transforms itself into a double chain of salps placed back to back. W. K. Brooks described this process in an analogy: "Let us represent the series of salpae by a file of soldiers, all facing the same way. Now imagine that each alternate soldier moves to the right, and the others to the left, to form two files still facing the same way. Now let them face about so that the backs of these in one row are turned towards the backs of those in the other row. They will now represent the two rows of salpae." This is essentially what happens. In the genus Cyclosalpa the proc-



STOLON OF SALPA, holding thousands of tiny nurse salps, may stretch for six feet behind solitary form (*a*). Developing and segmenting zones (*b*) lie within parent, close to heart and endostyle. Stolonic growth takes place between X and Y, in direction of Y. Every pair of vertical lines in segmenting region represents a future salp. The peribranchial tubes will become digestive systems. The assembly and deployment zones (*c*), with new salps forming in the third dimension, are at point where stolon comes out through tunic (*as seen in "a"*). Further along the stolon consists of small, well-formed sexual salps (*d*), which will break off.

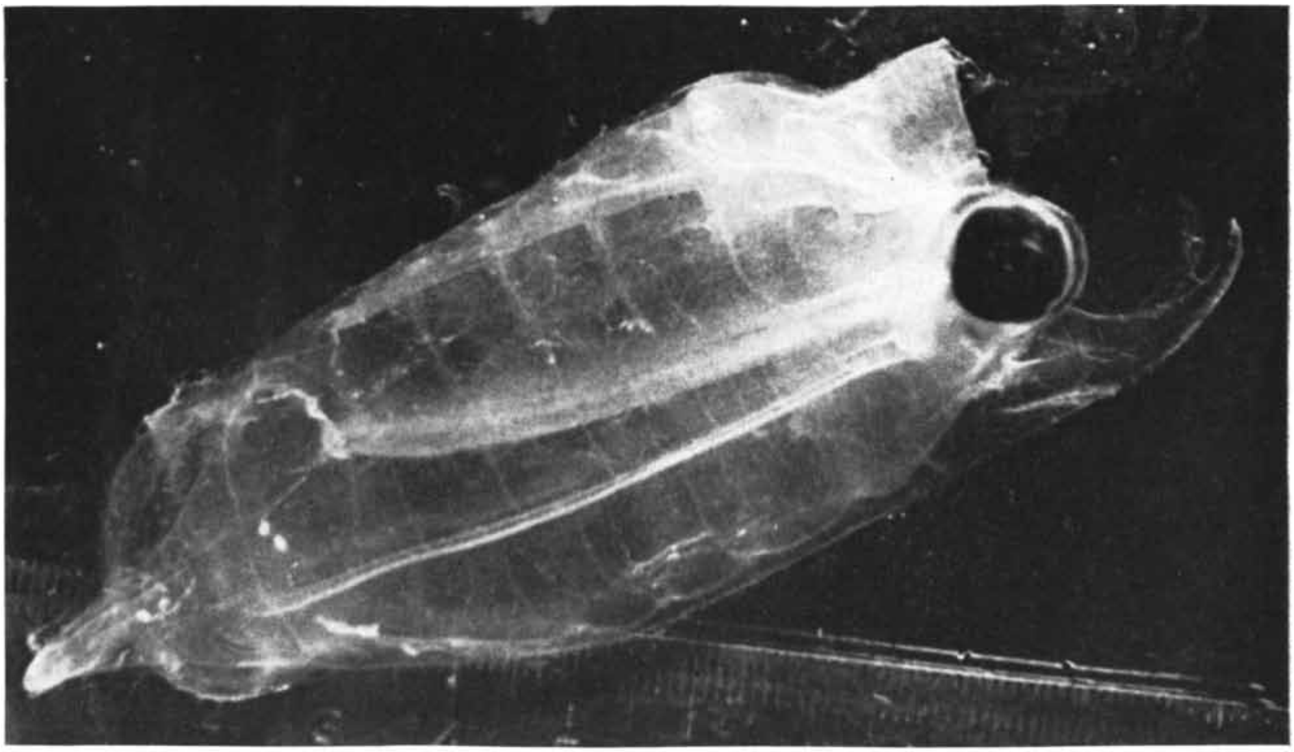


LIVING SALPA FUSIFORMIS of the solitary type, taken from the Bay of Naples, trails its stolon. In actuality the animal is only 1½ inches long. This photograph and the one below were both taken by Anita Brinckmann at the Naples Zoological Station.

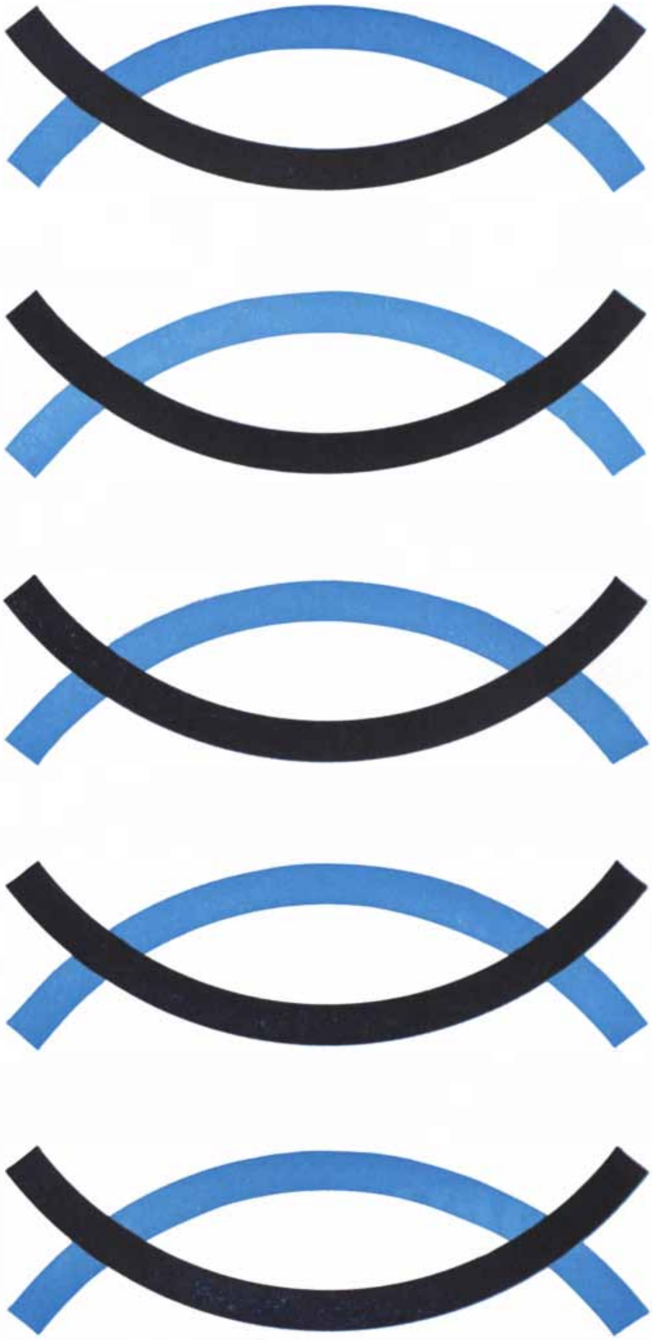
ess is even more complicated and produces a chain of salps arranged in wheels.

As if this were not challenge enough, Salpa complicates the picture further. To the primary rhythmical process by which it figuratively slices the stolon up into prospective sexual or nurse salps, the salp adds another by generating the stolon from its point of origin not in a steady, continuous outgrowth but in a succession of growths and pauses. The solitary salp thus produces a long chain that is divided into blocks, each block consisting of individuals of much the same size but separate from the block before and behind it. What starts and stops each surge of growth of the stolon remains a mystery.

In view of the bizarre nature of its



SALPA MAXIMA of the aggregate type, derived from a stolon, was also alive when photographed. Aggregate salps produce an egg and one offspring. This particular specimen is about 4½ inches long, as can be calculated from centimeter rule in the picture.



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MIL-SPEC ELECTRON TUBES AND SEMICONDUCTORS—INDUSTRIAL AND AUTOMOTIVE LAMPS asexual reproduction, it is perhaps not surprising that the egg of a salp develops in a manner exclusively its own. The eggs of most animals develop more or less straightforwardly into organized structures simply as the result of successive cell divisions, mutual cohesion among the cells and progressive chemical differentiation of their substance.

Salpa approaches the problem of making a salp out of an egg rather differently. Cells of maternal origin, known as follicle cells, form an envelope enclosing the fertilized egg, and the egg remains protected and nourished by the maternal organism. This alone is not too unusual a means of ensuring successful development of animal eggs. What is unique is that the protective tissues, of parental origin, lay out the scale, the axes and the relative dimensions of the future embryo long before an embryo exists, like a scaffolding erected around a house about to be built. Within this structure the egg undergoes a succession of cleavages in the usual way, except that its cells fail to remain together as a developing embryo; on the contrary, they form isolated clusters with the follicular tissue. These clusters slowly expand into sheets of embryonic tissue which stick to the walls of the enveloping protective tissue. When they finally join up with one another, the enveloping structure disappears, and only then can a true embryo be said to exist. It is as though the inner walls of an enclosing scaffolding were plastered with rapidly growing egg material. The scaffolding, which sets the initial scale of organization and the primary axes of the future salp, finally disappears when the need for it is past.

Taken together, the processes of sexual and asexual reproduction and development in Salpa show a striking opposition. In sexual development the cells derived from cleavage of the egg form isolated clusters that belatedly unite to make the individual whole, whereas in asexual reproduction the original single individual becomes many, though remaining organically and genetically one. Many questions arise, two above all: the philosophical question concerning the nature of individuality, and the fundamental problem of the nature of biological organization. When salps, biologists and technical facilities eventually come together under suitable circumstances, Salpa may become one of the great contributors to the understanding of the nature of living matter.

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In which the author chats again with Dr. Matrix, numerologist extraordinary

by Martin Gardner

Readers of this department may recall that a year ago ["Mathematical Games"; January, 1960] I wrote of my visit to Dr. Matrix, a remarkable numerologist then living in New York. Dr. Matrix had pointed out that Nelson A. Rockefeller would be a much stronger Republican candidate than Richard M. Nixon because of a curious numerological law which makes it imperative that every U. S. president of the 20th century have a double letter in his name. (Dwight D. Eisenhower is the sole exception, but in both his elections his opponent, Adlai E. Stevenson, lacked the double letter. Ike's double initials were therefore sufficient to tip the scales.) Dr. Matrix's law was so dramatically confirmed by the subsequent election of John F. Kennedy (the only serious contender for the Democratic nomination, by the way, whose name contained a double letter) that I was eager to see him once more, hoping to extract from him similar insights into the events of the coming year.

Telephone inquiries revealed that Dr. Matrix had moved to Los Angeles. Late in December I had occasion to fly to L. A. for other reasons, so I made a special point of wiring him and arranging for an appointment. His office was on the 14th floor of a large apartment building not far from the University of California at Los Angeles. When I entered his spacious reception room I was pleased to see that Miss Toshiyori, his attractive Eurasian secretary, was still with him. She gave me a charming smile of recognition, and immediately ushered me into the numerologist's office.

"Please sit down," she said. "Dr. Matrix will be with you in a moment."

Soft strains of unfamiliar music, Oriental in flavor, came from a concealed overhead source. Large gold numerals, in a square array, gleamed against a backdrop of black velvet on the wall behind a glass-topped desk. I was adding the rows to see if they formed a magic square, when Dr. Matrix parted the curtains of a side door and entered the room. He was a tall, lean man with a large, hawklike nose.

"On my last visit," I said as we shook hands, "those numerals formed the holy triangle of the Pythagoreans."

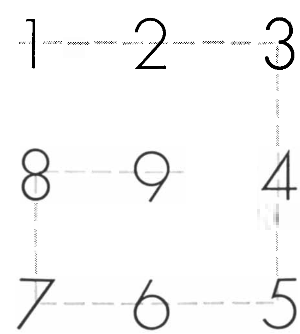
"Ah, yes," he said. "I like to change their arrangement every month. What you see here is an antimagic square. Each row, column and main diagonal sums to a *different* total."

"Most interesting," I commented as I jotted the square on my note pad [*see illustration below*].

"Not really," he replied. "There are several hundred ways to construct such a square. Much stronger antimagic three-by-three squares are possible, with additional sets of three cells participating in the antimagic property, but I'm rather fond of this one because of the spiral way the digits are arranged."

"By the way," I said, "coming up in the elevator I noticed that the building has no 13th floor. Doesn't that make your floor—the 14th—really the 13th?"

His green eyes twinkled with amusement. "Of course. I hope you don't think me superstitious. By the way, are you aware that in this country 13 is something of a national symbol? Why, you Americans are surrounded with reminders of your 13 original states, from the number of stripes on your flag to the number of buttons on the flap of a sail-



Spiral of digits forms antimagic square

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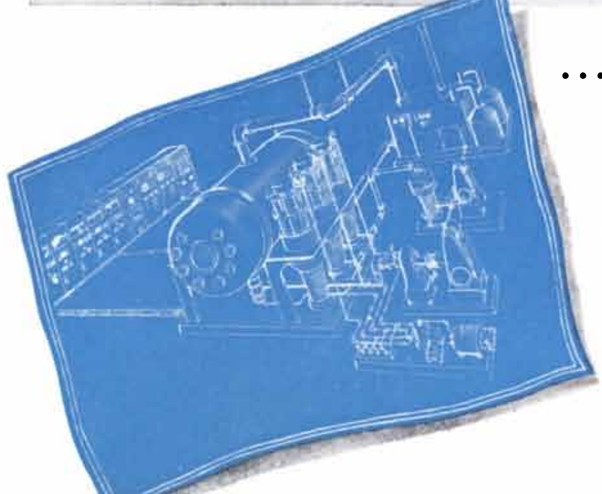

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U	V	W	X	Y	Z				

An old Celtic key for analyzing the names of Kennedy and Nixon

or's dress blues. Do you have a dollar bill?"

I took a bill from my wallet; Dr. Matrix pointed to the green side, on which are reproduced the two faces of the Great Seal of the United States. "If you count the steps of the pyramid," he said, "you'll find there are exactly 13. The motto above the pyramid, *Annuit coeptis,* has 13 letters. The bald eagle on the right has a ribbon in its beak that bears the motto *E pluribus unum*—also 13 letters. Over the eagle's head are 13 stars. There are 13 stripes on the shield. The eagle's left talon holds 13 war arrows and its right talon holds an olive branch of peace with 13 leaves. At the base of the pyramid you'll see the date 1776 in Roman numerals. Seven and six add up to 13. Of course all this doesn't prevent me from trying to collect as many dollar bills as I can."

"Nor me," I agreed. "And I could have collected quite a few of them last January if I had followed your hints and bet on Kennedy's election."

"Yes," he said. "Kennedy's double N gave him enormous odds against all the candidates except Rockefeller. In addition, if we use the ancient Celtic numerological key, appropriate to Kennedy's Irish ancestry, the results are also propitious." Dr. Matrix pressed a button on his desk, and a panel on the wall slid back to reveal a large blackboard. He walked to the blackboard and chalked on it the digits from 0 to 9. Beneath these digits he printed the alphabet [*see illustration above*].

"If we add the numerical values of J. F. KENNEDY," he explained, "we obtain 35, and of course the winner of the election is the 35th president."

"Have you tried this with R. M. NIXON?", I asked.

"Yes. It adds up to 30, the newspaper reporter's traditional symbol for the end of a story. Incidentally, I would like to emphasize that the double N in Kennedy's name marks an important break in the double-letter law. As C. C. Basore of Mountain Center, Calif., has pointed out, there have been nine other presidents in this century with double letters; in every case the letter is L, O or R. These letters form an arithmetic progression, each being three letters ahead—in alphabetical order—of the previous one. Kennedy's N is not part of this series. It's a lucky break for him, because it provides an escape from another—and rather ominous—law."

"I think I know what you mean," I said. "Every president since 1840, elected in a year ending in 0, has died in office."

"Precisely. Harrison was elected in 1840. He died one month later. There was, of course, no election in 1850. Lincoln, elected in 1860, was assassinated. Garfield, elected in 1880, and McKinley, elected in 1900, were also assassinated. Harding—1920—and Roosevelt—1940—both died in office. The only presidents elected before 1840, in years ending with 0, were Jefferson in 1800 and Monroe in 1820. Neither man died in office, but both died on Independence Day."

After jotting all this down, I said, "Do you have any explanation of Rockefeller's famous slip of the tongue at the Republican convention, where he introduced Nixon as Richard *E.* Nixon?"

"Yes, indeed. Slips of the tongue are seldom accidental. Freud was right in attributing them to unconscious hopes and fears, but he underestimated the important role also played by numerical and verbal structure."

"Are you referring to the fact that Thomas Dewey's middle initial is E.?"

"Partly that, but also much more." Dr. Matrix returned to the blackboard and chalked on it the initials R.E.N.

"It is true," he continued, "that Rockefeller's subconscious was linking Nixon with Thomas E. Dewey, the last Republican candidate to be defeated. But

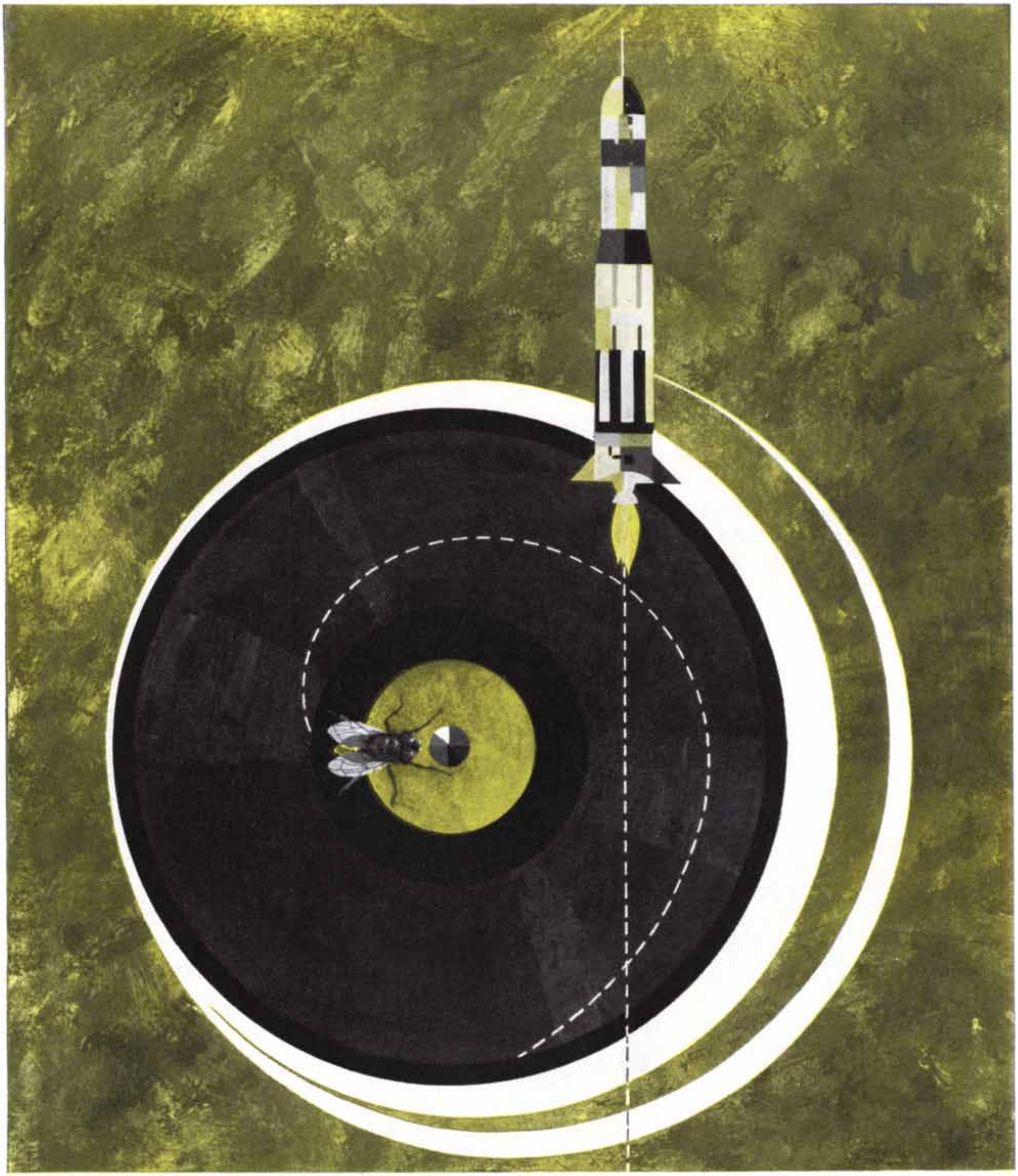
note what happens when we add Dewey's first and last initials." He printed a T in front of the three letters on the blackboard, and a D at the end, forming the word T.R.E.N.D.

"It was Rockefeller's subconscious," said Dr. Matrix, "expressing its hope that the national trend for Nixon would follow the same trend as it did for Dewey. But I think an even more important hidden attitude turns up if we take the first four letters of Milhous, Nixon's middle name, and see what happens when the M becomes an E."

Dr. Matrix printed EILH on the blackboard. "The election year was 1960, so six is our key number here. The sixth letter ahead of E in the alphabet is K, the sixth letter ahead of I is O, the sixth letter ahead of L is R, and the sixth letter ahead of H is N." As he spoke he chalked above EILH the word KORN. "This has a double meaning," he went on. "First, it expressed Rockefeller's private opinion of the speech he had just made; second, it expressed his secret conviction that Kennedy would 'K.O.' R.N."

"And you seriously believe all this is more than coincidence?" I asked.

"Yes, I do," answered Dr. Matrix, unsmiling. "It is naive to suppose that there is such a thing as a randomly arranged group of symbols. Random means without order or pattern. The term obviously is self-contradictory. You can no more find a patternless arrangement of digits or letters than you can find a cloud without a shape or a culture without folkways. In my opinion every pattern of symbols conceals a secret meaning, though it may require great skill to discover it. Death dates, in particular, are often correlated with earlier patterns. 'In today,' as Schiller so aptly phrased it, 'already walks tomorrow.' I could give you thousands of examples. Dickens, in the last paragraph of his last completed novel, *Our Mutual Friend*, tells how he narrowly escaped being killed in a railway accident on June 9. Five years later, on June 9, Dickens died. Have you ever noticed the tendency of great political events to occur on strongly patterned dates? The bugles sounded cease fire at the close of the First World War at the 11th hour of the 11th day of the 11th month, 1918. The invasion of France by the Allies in the Second World War began at the sixth hour of the sixth day of the sixth month, 1944. Roosevelt, Churchill and Stalin opened their famous Yalta meeting on February 3, 1945, a date that has four digits in serial order when it is written 2-3-45. West Germany became a sovereign state on 5-5-



55. Stalin died on March 5, 1953, a date with the interesting mirror reflection of 3-5-53."

"Are there any patterned dates in 1961?"

"How could it be otherwise? The two most striking date patterns are 1-6-61 and 6-1-61, or January 6 and June 1. Events of world-wide import have a high probability of taking place on both occasions. February 8 is another date that bears close watching; if this is written out in full it is 2-8-1961, and 281,961 is the square of 531, or May 31. I anticipate important, closely linked events on both these days."

Dr. Matrix waited until I finished scribbling, then he continued. "It is in the physical world, however, that we find the most remarkable numerical patterns. A numerologist knows it is not a coincidence that the sun's disk, viewed from the earth, is almost identical in size to the moon's disk, or that the sun's period of rotation is almost exactly the same as the moon's period of revolution around the earth. Has it ever occurred to you how strange it is that the earth makes 365 spins in each revolution around the sun?"

I shook my head.

"It's a truly amazing instance of Divine harmony—the harmony that Kepler so clearly perceived, but which later astronomers have regrettably ignored. Three hundred and sixty-five is not only the sum of 10 squared plus 11 squared plus 12 squared; it is also the sum of 13 squared and 14 squared. We can write it this way."

He printed on the blackboard: $10^2 + 11^2 + 12^2 = 13^2 + 14^2 = 365$.

"Are you familiar," he asked, "with Arthur Stanley Eddington's work on the so-called fine-structure constant?"

"Vaguely. The number is 137, isn't it? As I recall, Eddington had a clever way of deducing it, apart from experimental observation. Didn't he first arrive at 136?"

Dr. Matrix nodded. "He gave a complicated mathematical explanation of why he revised it to 137, but the truth is that Stanley was one of my most distinguished pupils. We worked it out one day over a bottle of Greek wine. We took Eddington's birth year, 1882, multiplied the digits to obtain 128, then added nine, the number of letters in Eddington's name."

"I can believe it," I said, chuckling. "Tell me, do you have any interesting numerological puzzles that my readers might enjoy?"

Dr. Matrix scratched his nose. "Yes, I had an unusual problem called to my

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"In other words," I said, "the longest chain that can be formed with two symbols, without having two adjacent patterns that are duplicates, is a chain of three symbols."

"Correct. Now the problem is this. What is the longest chain that can be written with *three* symbols? For example, we can't write 132132 because it repeats the pattern 132. But we can write 1323132, because now the two patterns of 132 are separated. Is there a limit to the size of a chain that can be constructed on this basis?"

Dr. Matrix proceeded to show me exactly how the problem could be solved, but the procedure is a bit lengthy and I shall keep the details until next month.

On my way out I stopped to chat with Miss Toshiyori. "I expect to be in L. A. for a few more days," I said. "Is there any chance that you could have dinner with me tomorrow night?"

She stopped typing and smiled. "Why don't you phone me at home this evening? My number is. . . ."

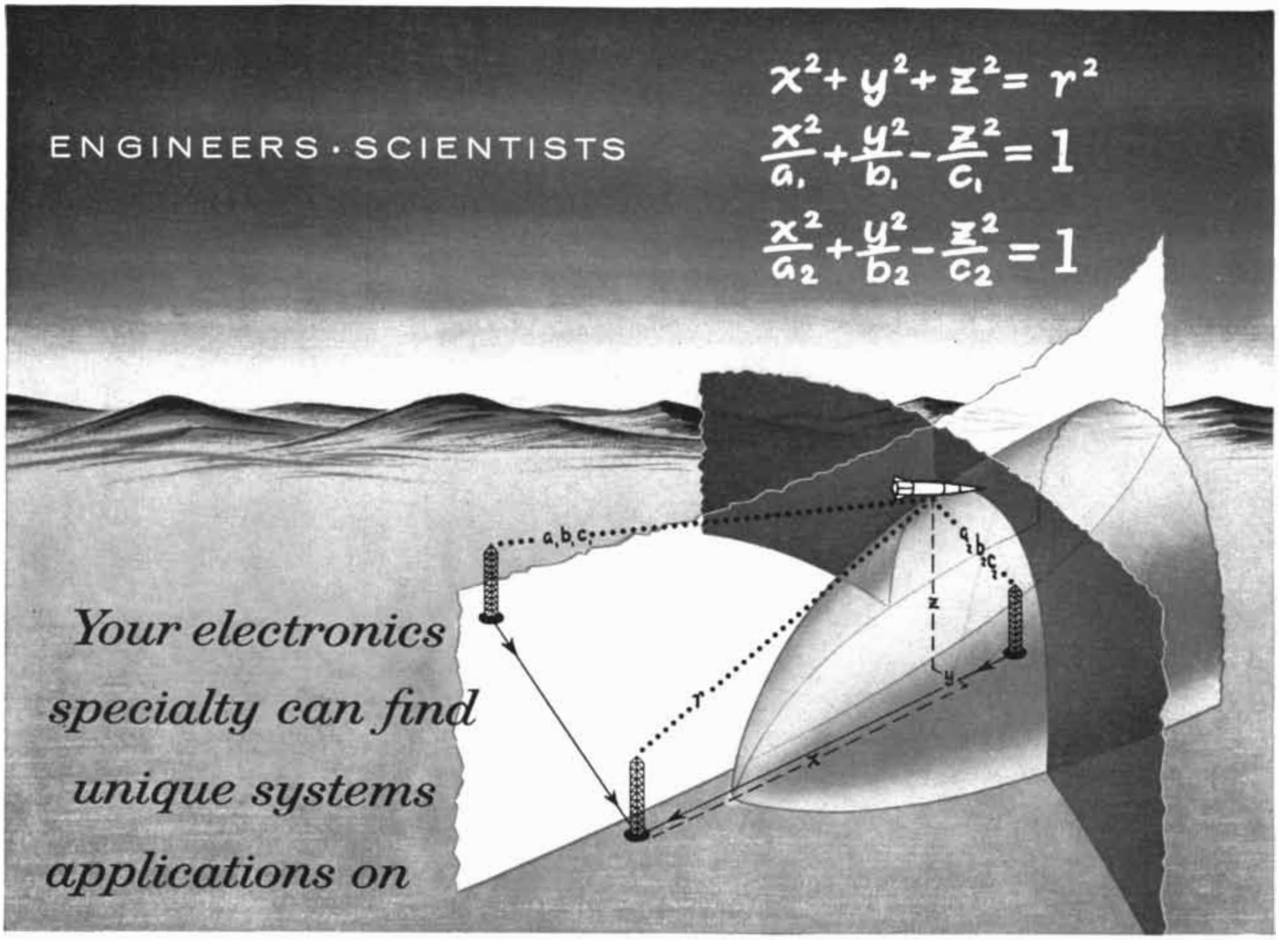
I whipped out my pad and pencil, wrote down the exchange and waited.

"The number," she said, "has a 4 at the end of it. If you move the 4 to the front to make it the first digit instead of the last, the new number is exactly four times larger than the old one."

I looked blank. "You mean I have to figure this out before I can call you?"

She nodded and started typing again. I figured it out all right. Perhaps it will be less difficult for the reader.

Last month's logic problem can be solved with the punch-cards as follows: Let A, B, C, D and E stand for Abner, Beryl, Cleo, Dale and Ellsworth. A term is true if the person is watching television; otherwise it is false. Premise 1 eliminates all cards bearing $A\bar{B}$; premise 2 eliminates $\bar{D}\bar{E}$; premise 3 eliminates BC and $\bar{B}\bar{C}$; premise 4 eliminates $\bar{C}D$ and $C\bar{D}$; premise 5 eliminates $\bar{A}E$ and $\bar{D}E$. Only one card remains, bearing the combination $\bar{A}\bar{B}CD\bar{E}$. We conclude that Cleo and Dale are watching television, and that the others are not.



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THE AMATEUR SCIENTIST

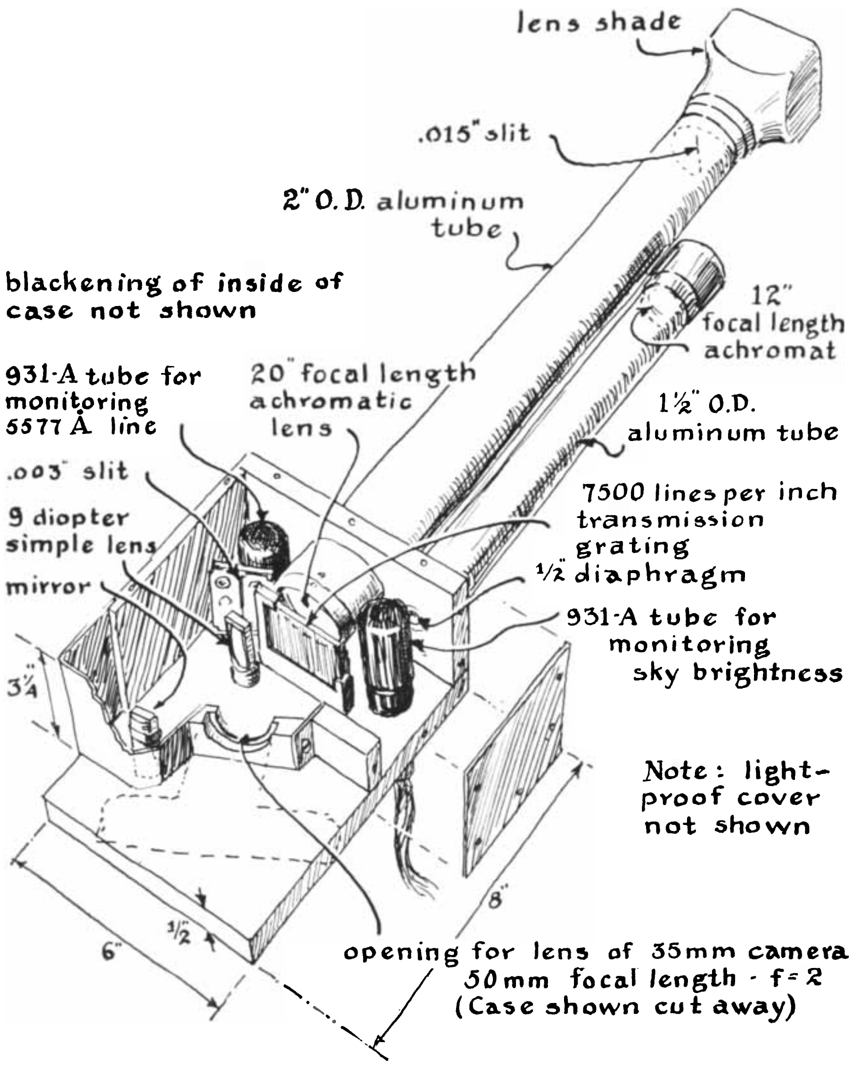
An amateur makes spectra of the aurora and photographs the sun's "green flash"

Conducted by C. L. Stong

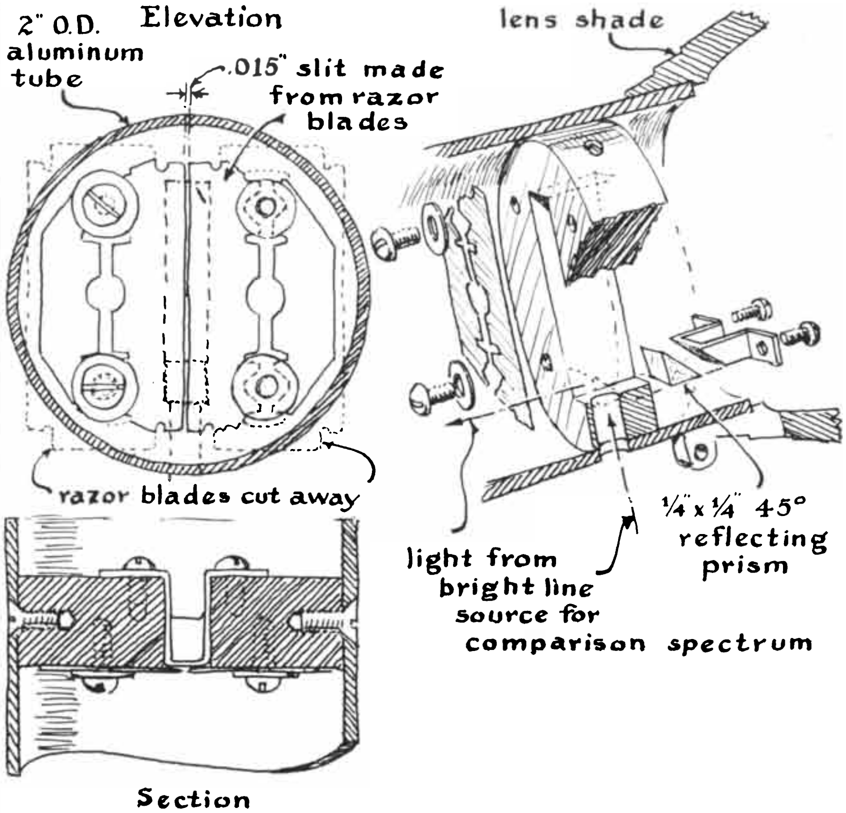
Studies undertaken during the International Geophysical Year appear to have opened a new era in amateur astronomy. Before 1957 followers of this classic avocation occupied themselves largely with such time-honored activities as looking for new comets and observing changes in the brightness of variable stars. Today amateurs also track artificial satellites, patrol solar flares, electronically time the occultation of stars by the moon and participate in other investigations that were unknown a decade ago. The number of amateur astronomers has grown in proportion. Part of this burgeoning popularity can doubtless be explained by the novelty of the IGY projects. After all, artificial satellites are objects of uncommon fascination. But part can be ascribed to a new ease of acquiring instruments. Ten years ago most beginners could afford to own a telescope of reasonable power only by mastering the exacting art of shaping optical glass. Many of the current activities can be undertaken without any telescope at all. The required instruments can often be assembled with parts recovered from surplus apparatus or with those that fail to meet rigid specifications. For example, Walter A. Feibelman, a physicist of Pittsburgh, Pa., has used such parts to build a spectrograph for analyzing the light emitted by the aurora borealis. His design calls for little more than a pair of razor blades, an inexpensive replica diffraction grating, a conventional camera and a small achromatic lens. With a similar lens he has also made a telescopic camera to photograph the "green flash" and other curious optical effects that are associated with the setting sun.

"Like many amateurs," writes Feibelman, "I wanted to have a part in the IGY and volunteered to participate in the observation of auroras [see "The Amateur Scientist"; January, 1957]. The prospects for success did not seem too bright because one would not expect to see many auroras at the latitude of Pittsburgh. Moreover, industrial areas do not provide the most favorable seeing conditions. The project nonetheless turned out to be highly rewarding. Beginning with the very large and bright display on the official opening night of the IGY, I observed and photographed a total of 45 auroras by November, 1960. Others were doubtless missed because of clouds, smog or bright moonlight. No two displays were ever exactly alike, and the changing patterns and colors were always fascinating to watch.

"In all I made over 700 black-and-white photographs of auroras, plus 20 or so in color. Most were taken with an old camera using 120-millimeter film. The exposures were 15 seconds or less at $f/2.9$. I used Royal-X Pan film de-



An auroral spectrograph designed for amateur construction



Details of the slit for the auroral spectrograph

veloped in DK 60A. The pictures were so easy to make that the novelty soon wore off, and I began to cast about for something additional to do. Eventually I hit on the idea of building an aurora spectrograph. This instrument helps to distinguish among the several kinds of aurora and reveals the presence of displays that are invisible to the eye. It is a simple apparatus, but the literature disclosed scant information about its construction. With a few hints from astronomers I wound up designing my own.

"Aurora spectrographs include four basic parts: (1) a mechanical slit for admitting a thin ribbon of light to the instrument, (2) a lens for bending the diverging ribbon into a parallel beam, (3) either a diffracting or a refracting element for dispersing the collimated beam into its constituent colors and (4) a camera for recording the spectral pattern on photographic film. No telescope or other light-gathering device is used. None is needed to make auroral spectrograms. (No illumination would be gained by bringing a small patch of the glowing area to focus on the slit.) If desired, a telescope can be added. The instrument can then be used for photographing stellar spectra by focusing the image of a selected star on the slit.

"The structural arrangement is as follows. All of the optical parts are supported by aluminum tubing and an associated housing made of aluminum plates and sheet stock as depicted in the accompanying drawing [*preceding page*]. When in use, the instrument is mounted on a conventional camera tripod. A second camera, for making wide-field pictures, is mounted on an accessory bracket. The slit assembly consists of a cylindrical base that can be made of any convenient material such as aluminum, plastic or even hardwood. Two safety-razor blades are fastened to the base with screws as shown in the second drawing [*above*]. The cutting edges of the blades must be parallel and separated .015 inch. A rectangular hole, somewhat larger than the slit, is made in the base for admitting light to the lens. The slit assembly is mounted in one end of an aluminum tube. An achromatic lens 1¾ inches in diameter fits into the other end of the tube at the distance of its focal length from the slit—20 inches in the case of my instrument. Neither the diameter of the lens nor its focal length are critical. The diffraction grating is placed immediately behind the lens and at an approximate right angle to the beam, as depicted in the third drawing [*page 180*]. The grating and the back face of

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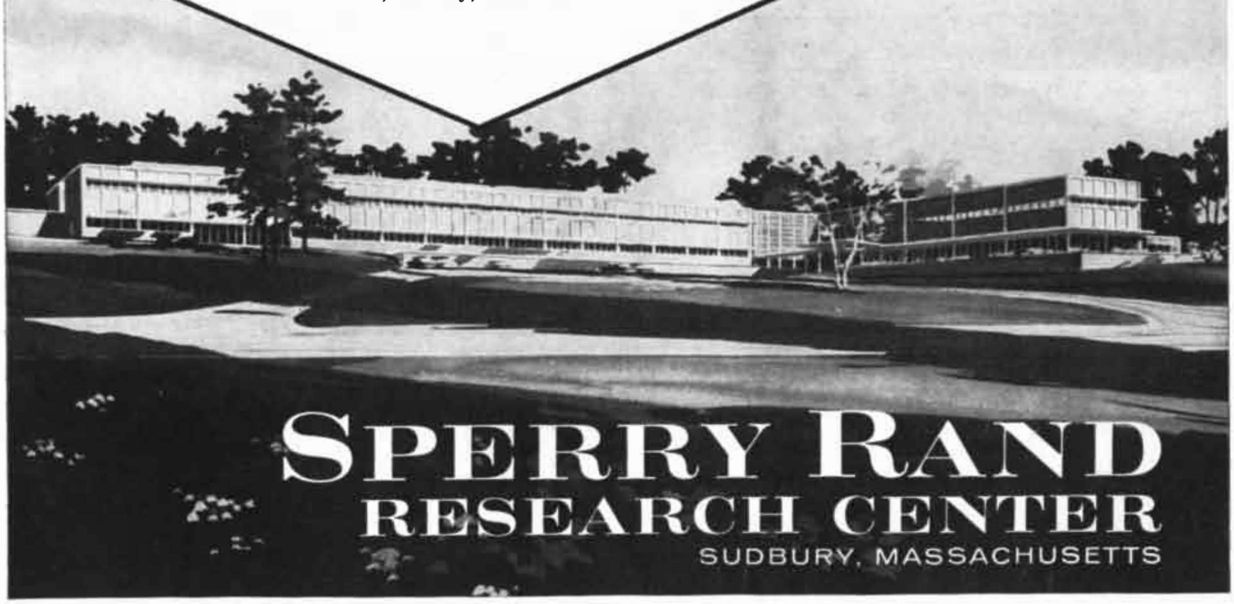
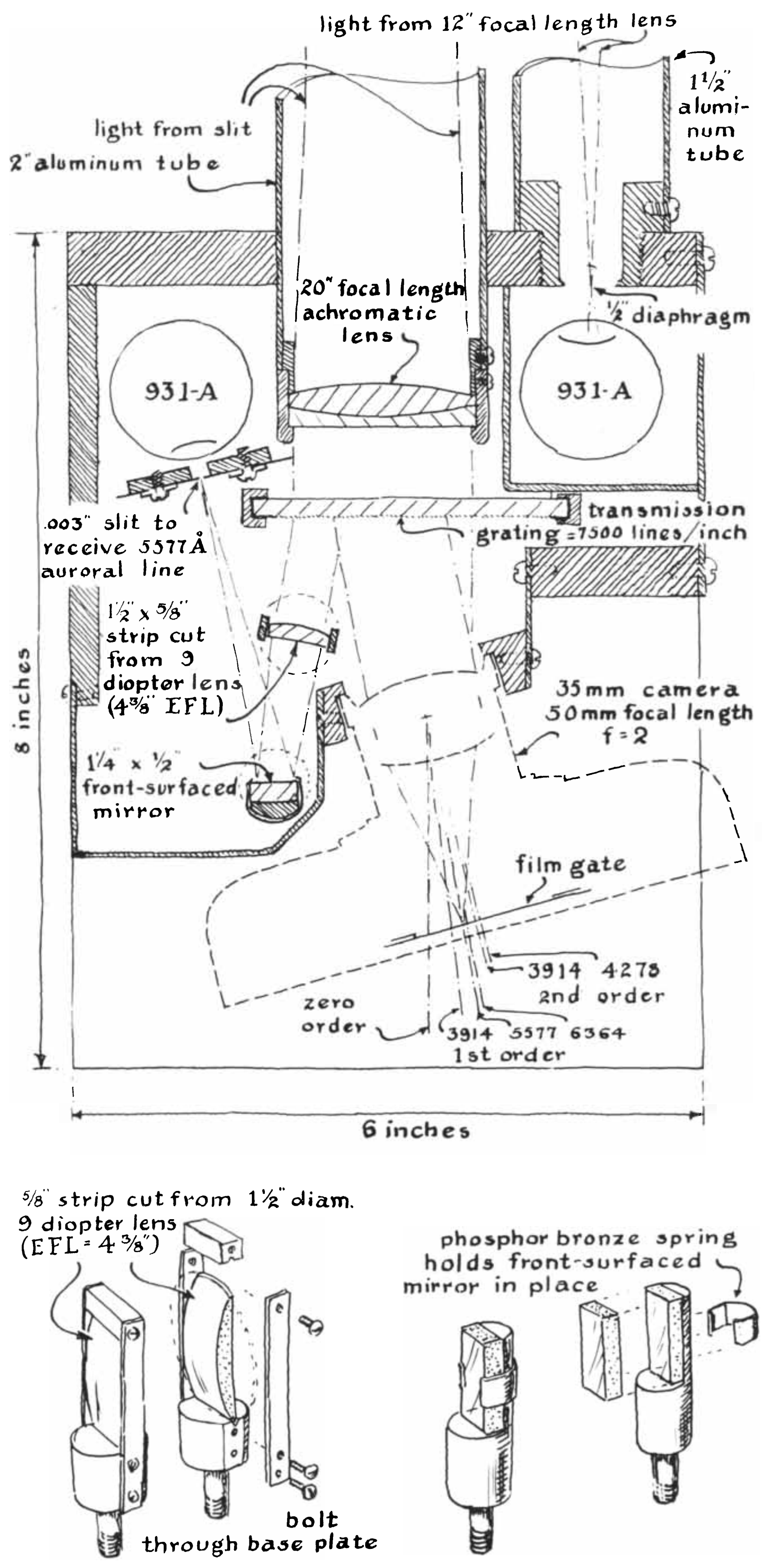




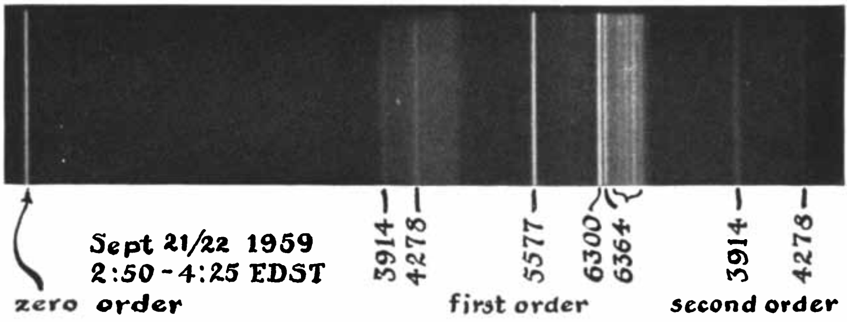
Plan view of the spectrograph (top) *and details of the front-surfaced mirror* (bottom)

the lens are enclosed by a housing. A hole in the rear of the housing, which makes a light-tight fit with the lens barrel of the camera, admits the dispersed rays to the camera lens. The focusing adjustment of the camera is set at infinity. I use a 35-millimeter Retina camera equipped with an $f/2$ lens. The time required for exposures depends in part on the light-gathering power of the camera lens. In general, focal ratios substantially larger than $f/2$ are not satisfactory.

"For the dispersing element I prefer a transmission (*i.e.*, transparent) replica grating to a glass prism. A grating spreads the colors more than a prism does, and the dispersion is uniform throughout the spectrum. A spectrum made by a prism becomes increasingly crowded toward its red end. Spectral colors appear as parallel bands or lines that cross the ribbon-shaped pattern like the rungs of a ladder. Crowding obviously increases the difficulty of identifying interesting lines.

"Gratings are not without disadvantages, however. Whereas prisms disperse light into a single spectral pattern, gratings produce multiple spectra that overlap at the ends, somewhat like the 'ghost' images that appear on television screens. To minimize this effect, gratings are commonly 'blazed,' that is, ruled with V-shaped grooves that are tilted at a slight angle to deflect most of the light into one preferred image, or spectral 'order.' My grating is blazed to favor the first spectral order. The lines of this order accordingly show up more prominently in my photographs than those of higher orders. The lines of the higher orders are also more widely spaced than those of the first order, a further aid in distinguishing the first-order lines [see "The Amateur Scientist;" June, 1955, and April, 1958]. My grating was manufactured by the Bausch & Lomb Optical Co. and can be purchased through a dealer in scientific supplies.

"With this combination of grating and camera the exposure time required to photograph the brightest aurora averages about 10 minutes. Good photographs have been made with Ansco Super Hypan film. The best results are obtained, however, with spectroscopic emulsions such as Kodak 103a-F, which is specially sensitized for the far-red region of the spectrum. Spectrograms have been made of several auroras that were not visible, in some cases by extending exposures to four hours. The outcome of such attempts is a matter of pure chance. You have no way of knowing if an aurora is up there. So you just point the instrument toward the northern



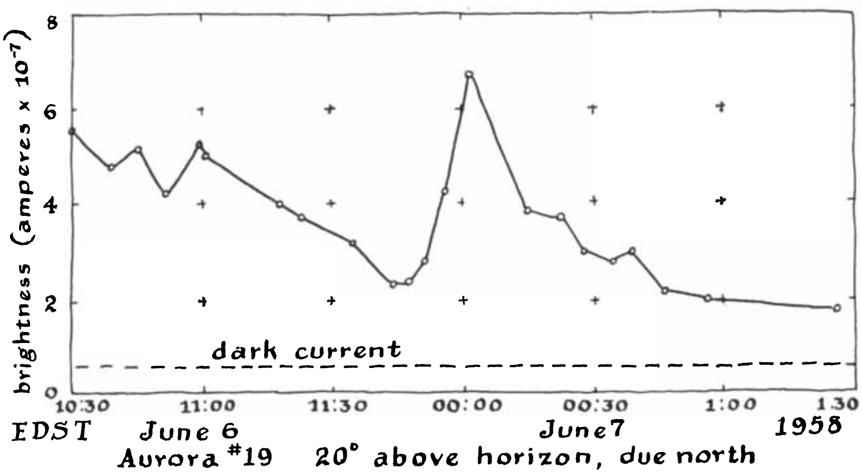
Spectrum made with the auroral spectrograph

sky at night, open the shutter and go away. With luck, spectral lines characteristic of the aurora will appear when you develop the film.

"For many years auroral spectra presented investigators with something of a mystery. Certain of the lines could not be reproduced by light sources then available in the laboratory, and came to be known as 'forbidden' lines. The brightest of the forbidden lines appears in the green portion of the spectrum; it is formed by light waves that measure 5,577 angstrom units in length. This line is emitted when highly ionized atoms of oxygen in the upper atmosphere release a finite part of the energy acquired by collision with particles hurled into space by the sun. The 5,577-angstrom line is observed to some extent in all auroras. When intense, it accounts for the characteristic green color of most displays; when weak, the auroras look pale white or gray. Also characteristic are two lines at 6,300 and 6,364 angstroms in the red part of the spectrum; these also are emitted by ionized oxygen. Still another relatively prominent line is found at 3,914 angstroms in the extreme violet. It is emitted by ionized nitrogen. Weaker lines also appear throughout auroral spectra. Most are associated with the emission of energy from oxygen and nitrogen, although occasional spectrograms show a well-defined line at 6,563 angstroms that has been identified with hydrogen.

"The relative intensity of the spectral pattern varies with the intensity, height and type of the display; the temperature of the upper air; the state of the earth's magnetic field, and related environmental factors. Quite often spectral lines also show variation in brightness along their length. Auroras in the early evening or morning, when part of the display is in the earth's shadow and part in the sunlit upper atmosphere, are of particular interest because not all of the accompanying effects are understood in detail. They are investigated by pointing the spectrograph toward the area in question. The techniques of analyzing spectrograms to determine the height of a display or the temperature of the air in a selected region are described in the literature [*see page 211 of 'Bibliography'*].

"Several optional features were built into the basic instrument to facilitate its operation. A small right-angle prism was



Graph showing the changing brightness of an aurora

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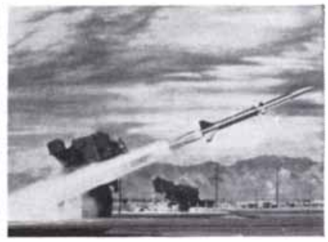

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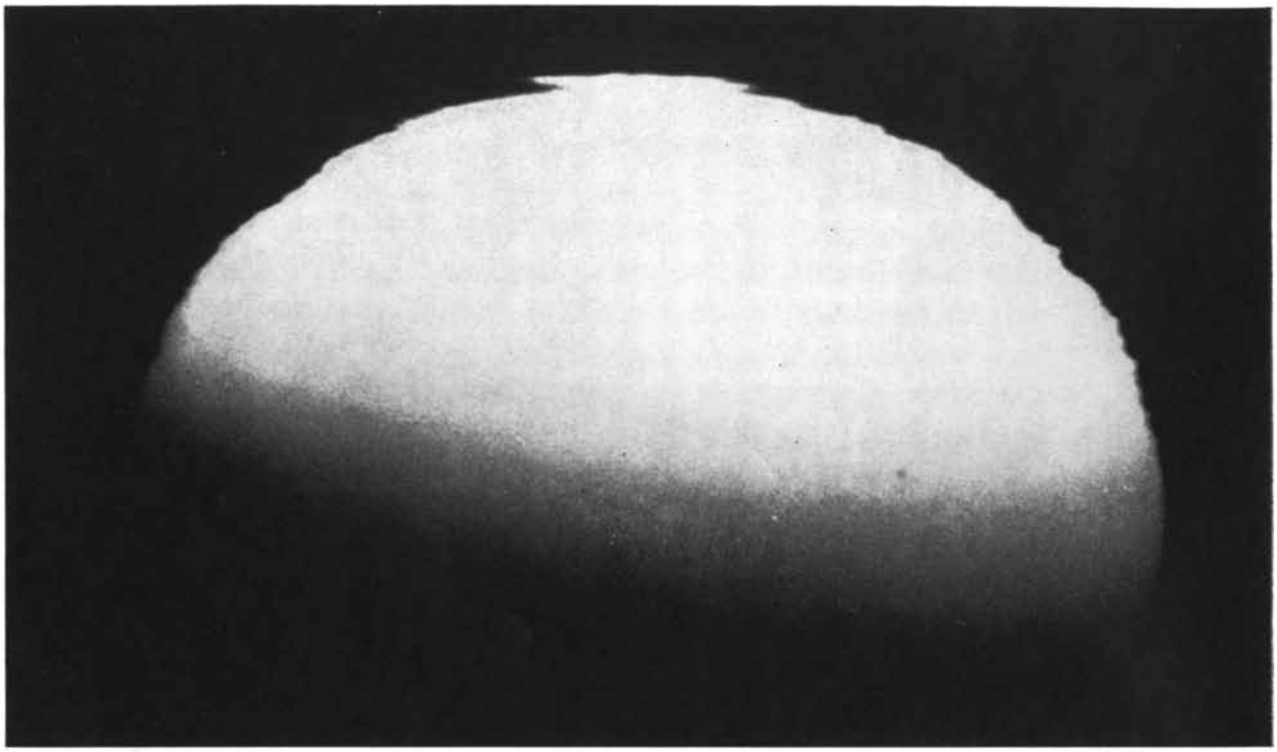
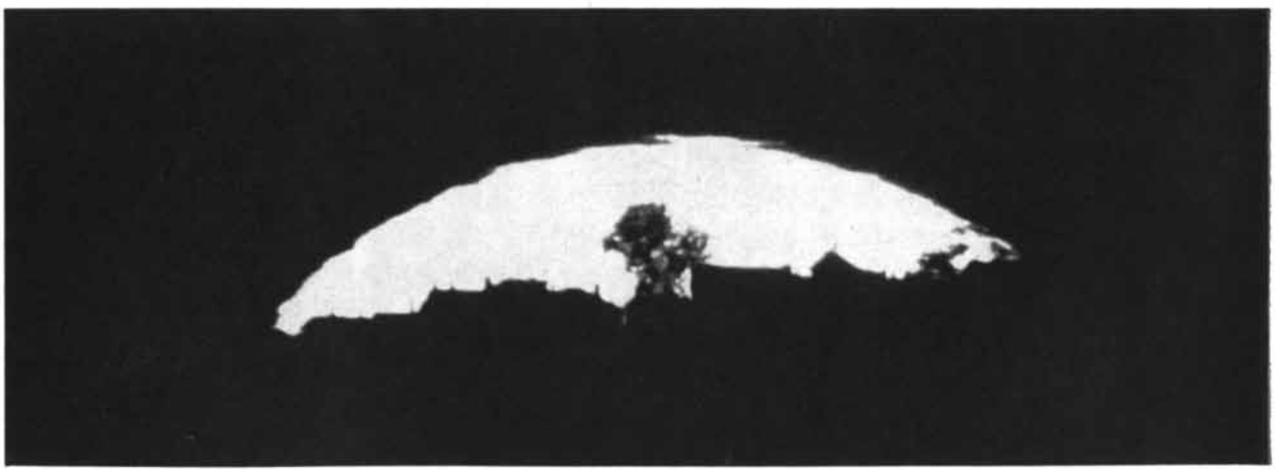


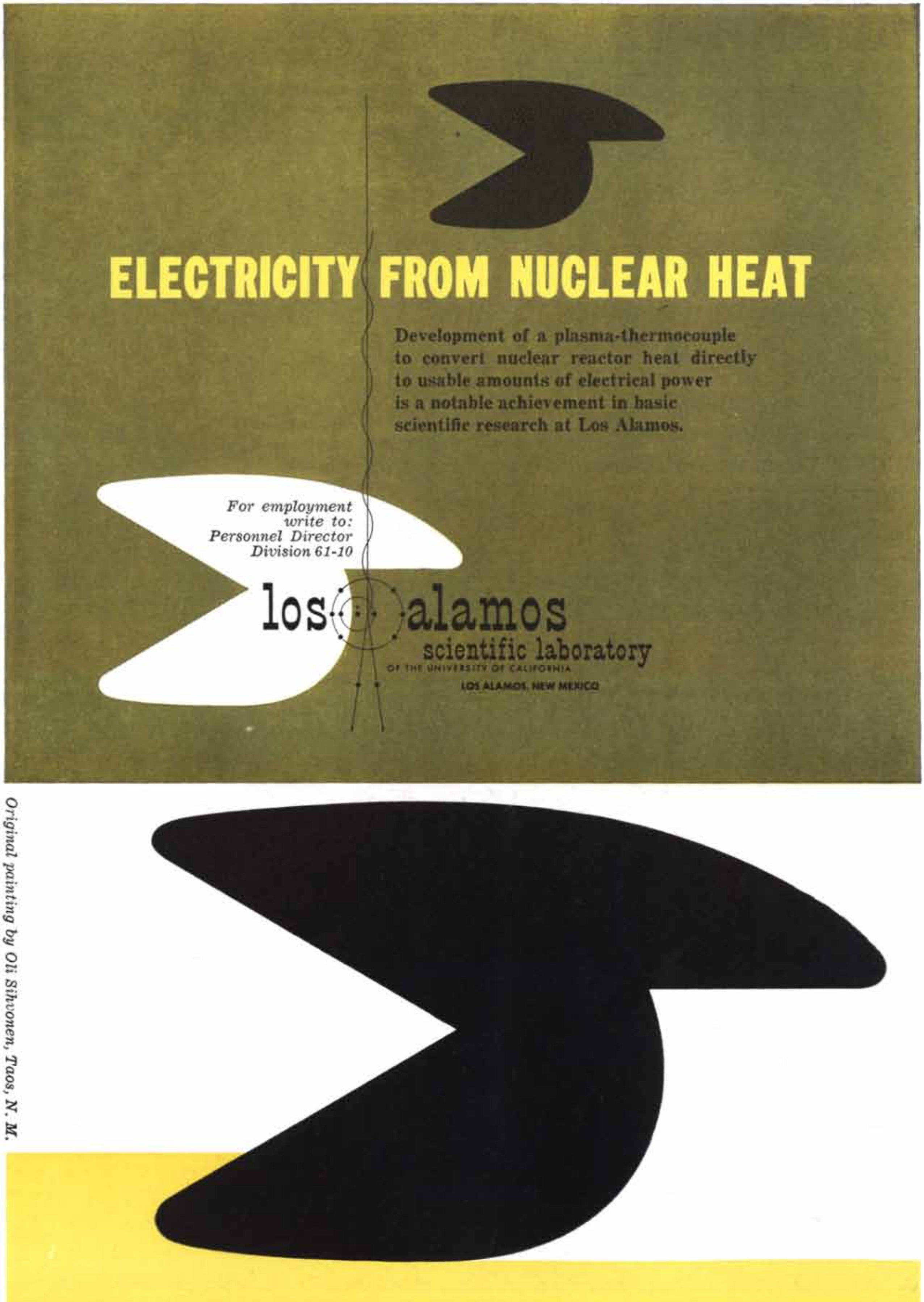
Green flash appears in black-and-white photograph as a horizontal wisp at top of solar disk. Here sun sets in smog

added at the lower edge of the slit so that a comparison spectrum can be photographed simultaneously as an aid in the identification of unknown lines. Light from a small neon bulb is directed against the lower face of the prism for about 10 seconds. Any miniature neon bulb can be used. Neon emits particularly strong lines at 5,400, 5,852 and 6,402 angstroms. This accessory is not too important, because the 5,577 lines can always be recognized, as is apparent in the accompanying spectrogram [*top of page 182*]. Incidentally, the lines may be sharpened by making the slit narrower than .015 inch. Sharpness is gained at the cost of longer exposure, however, because the light admitted to the film varies inversely with the width of the slit. Moreover, a narrow slit emphasizes the higher-order images.

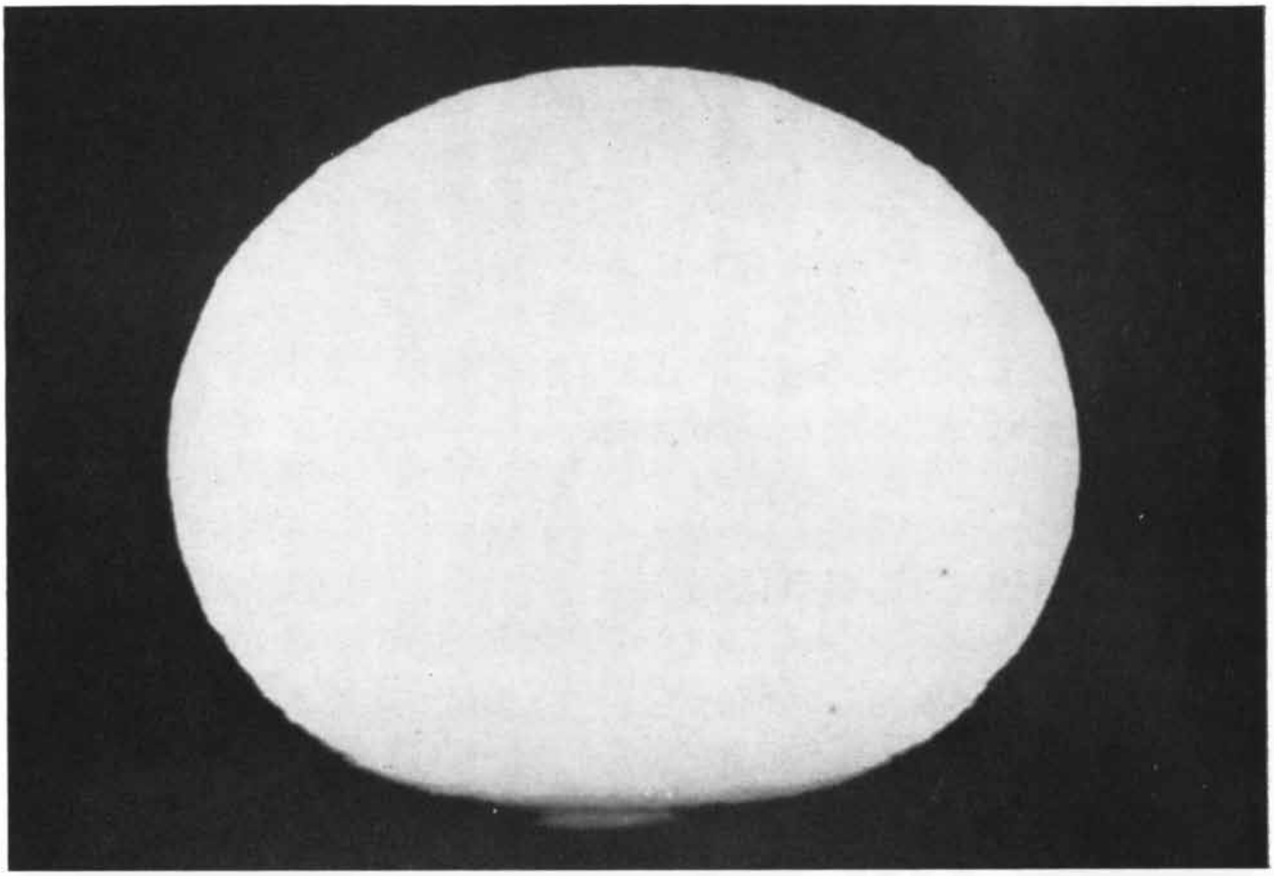
"To aid in estimating exposures and plotting variations of auroral brightness a 931-A photomultiplier tube was incorporated in the instrument. The photocathode is illuminated by a small telescope equipped with an objective lens of 1½ inches diameter and 12 inches focal length. The incoming light is focused on the photocathode through a diaphragm 1/2 inch in diameter that limits the illumination to a patch of aurora about five degrees in diameter. The output of the phototube actuates a microammeter. Brightness is indicated simply by the movement of the pointer. If an ultrasensitive meter is used, so that a current of 10 microamperes drives the pointer to full scale, no amplifier is necessary. If not, the circuit must include a direct-current amplifier. Warning: The 900-volt supply for the photomultiplier can be lethal if handled carelessly. The tube and all parts of the circuit must be well insulated from the metal housing;



Green flash is photographed with most of the sun's disk below the horizon



Original painting by Oli Sihvonen, Taos, N. M.



Red flash appears in black-and-white photograph as horizontal wisp below sun's disk

Large sunspot is visible at lower right on the sun's disk no bare wires or terminals can be exposed. The instrument is used in darkness, a condition that invites accidents.

"A meter of the pen-recording type would be preferable because it would plot a continuous graph of brightness against time automatically. I have not, however, invested in one. The accompanying graph [*bottom of page 182*] of a typical aurora was plotted by hand from periodic meter readings. The display was of medium intensity and showed a strong peak at midnight. The spectrograph was pointed due north and about 20 degrees above the horizon. The early portion of the record doubtless includes some twilight. The photomultiplier tube draws a small amount of current even when no light falls on the photocathode, an effort that establishes the minimum illumination to which the tube is sensitive. It is called the 'dark current,' and is indicated on the graph by the horizontal broken line near the bottom.

"A second 931-A photomultiplier is being added to operate an alarm system during sleeping hours. It will be actuated by light dispersed to the side of the axis opposite the camera location. The characteristic green line at 5,577 angstroms is focused by a small lens on a second slit that excludes all other light from the photomultiplier. For mechanical compactness the beam is folded by a small front-surfaced mirror [*see bottom illustration on page 180*] that can be rotated during initial adjustment to center the 5,577 line on the slit. The output of the photomultiplier is amplified for operating a relay that in turn triggers an alarm when the 5,577-angstrom line reaches a predetermined intensity.

"As a consequence of working with the auroral spectrograph I became interested in other optical phenomena of the atmosphere, in particular the 'green flash' that is occasionally observed at the upper edge of the setting sun [see "The Green Flash," by D. J. K. O'Connell, S. J.; SCIENTIFIC AMERICAN, January, 1960]. Somehow I had gained the impression that observation of the green flash requires a large telescope, exceptionally good seeing and the smooth horizon of a large body of water or a desert. This proved not to be the case. The accompanying photographs [*pages 184, 186 and 188*] were made with modest equipment through an industrial atmosphere in a hilly region.

"During the past 18 months scores of such photographs have been made from the eastern side of Pittsburgh, overlooking the downtown area about eight miles away. Green and red flashes have been observed on numerous occasions, and al-

most every evening the sun has a green rim at the top and a red rim at the bottom. Green flashes have been seen as long as half an hour before sunset, as well as when the sun was partly below the horizon. In several cases green flashes have been seen and photographed even when the bottom edge of the sun was immersed in thick haze. Smoke and haze cause a pronounced reddening of the solar disk, however, and dilute the green flash with yellow. On exceptionally clear days the green flash appears bluish; on one occasion it was a deep violet. The phenomena are most pronounced when an abrupt drop in temperature follows several days of uniform weather. Incidentally, distortions of the solar disk at sunset can be used for predicting astronomical seeing for the night: the better the green flash, the worse the seeing will be.

"All the photographs have been made with an achromatic lens of two inches diameter and 50 inches focal length. The lens is mounted in one end of an aluminum tube; a 35-millimeter camera (with the lens removed) occupies the other end. Originally I used a small homemade camera box equipped with a Compur shutter of 1/500 second maximum speed. Pictures made with this equipment showed a five-cornered star pattern that was traced to nonuniform motion of the five leaves of the shutter. This difficulty was solved by replacing the homemade camera with a Leica equipped with a focal-plane shutter. The complete assembly is mounted on a conventional tripod that rests against a window sill for added support.

"A reflex attachment is useful both as a view finder and when making the initial adjustment, but it is not essential. Once the focus is established at infinity, you are in business. I made a provision for inserting filters ahead of the lens, but this feature has never been used. An iris diaphragm was mounted ahead of the lens. It is useful for reducing brightness when looking at the sun through the reflex attachment. Warning: Care must be exercised when looking through the instrument at the sun, particularly when the sun is at an appreciable elevation. Serious eye injury can result. The illumination must be reduced either by means of an iris diaphragm, a dark filter or some optical arrangement that diverts most of the rays from the eyepiece.

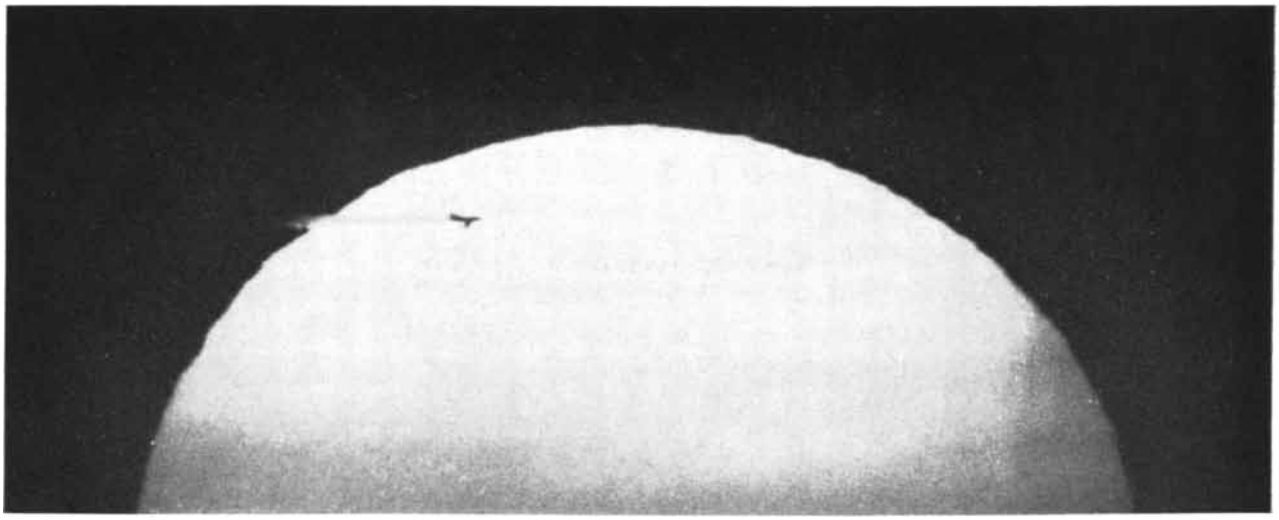
"Most green flashes are observed when the sun is near the horizon. The accompanying photographs show that extremely low elevation is not a critical condition for the phenomenon. One of the pictures [*top of page 184*] shows a green flash (the narrow sliver of light at the top of the disk) just coming off the limb. Note that the bottom of the disk is immersed in smog. This picture was made on November 15, 1959. The second photograph [*bottom of page 184*] shows a green flash at the moment of detachment from the disk and after a substantial portion of the sun has disappeared below the horizon. The silhouetted buildings in the photograph are about eight miles away.

"The third photograph [*top of page 186*] shows a red flash that was detached from the bottom edge of the sun after the disk had been grossly flattened by atmospheric refraction. Such flashes separate from the disk abruptly, float free for an instant and then merge with the disk. Sometimes they resemble a suspended bubble.

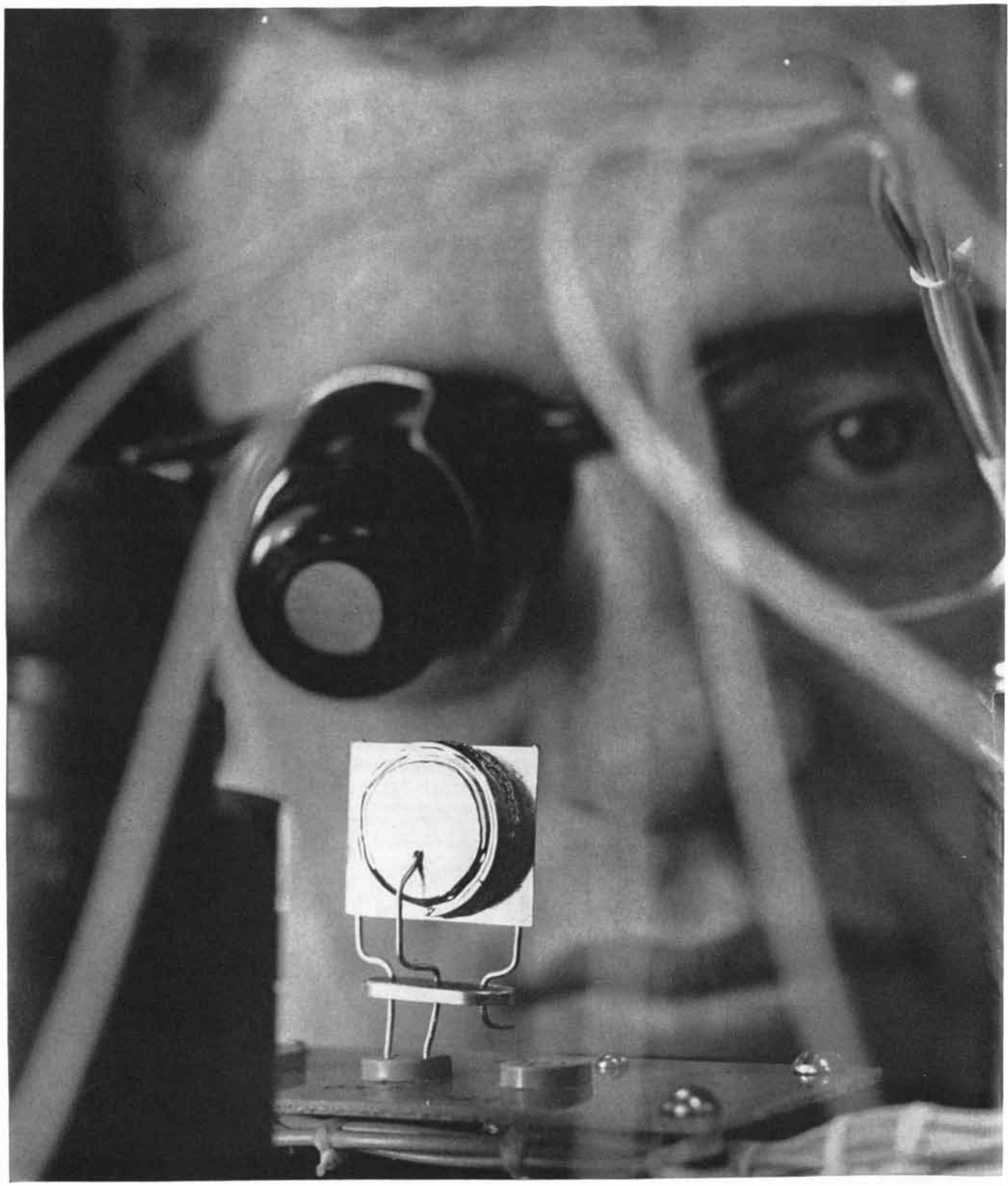
"Occasionally the camera records large sunspots. One is seen in the fourth photograph [*bottom of page 186*] above the rear of the cathedral at the right. The buildings are about 10 miles away.

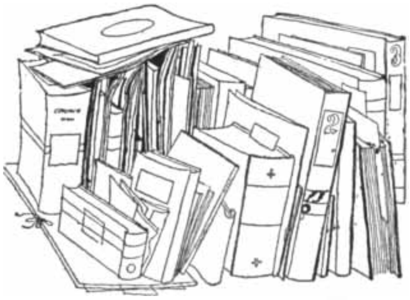
"By good fortune the Greater Pittsburgh Airport happens to be situated on the west side of town, about 20 miles distant, and planes coming in for landings or taking off frequently cross the sun's disk. The exhaust gases always appear to be illuminated for a couple of seconds when the plane comes out of the sun, creating the impression that the plane has sliced out part of the disk and is dragging it away. The illusion is particularly pronounced in the case of jets. When the camera is replaced by an eyepiece, the hot exhaust gases are seen to be responsible for optical effects that are altogether comparable to the green, red and violet flashes.

"The last photograph [*below*] shows the phenomenon in black and white. These effects can originate quite close to the observer. One evening I watched a Constellation that was flying directly into the sun. Knowing that the wingspread of the plane is 126 feet and that the solar disk subtends an angle of about half a degree, it was easy to calculate that the plane was some 2¾ miles away. Suddenly, at about this distance, the plane banked and turned from the disk. As each engine crossed, the limb portions of the disk appeared to be dragged behind. Each of the turbulences flashed red and green. Obviously these colors were of local origin."



Green flash caused by turbulence in wake of airplane appears here as a small wisp jutting out to left of sun's disk





BOOKS

A mathematician's attempt to define the causes of war

by O. G. Sutton

ARMS AND INSECURITY, by Lewis F. Richardson; edited by Nicolas Rashevsky and Ernesto Trucco. The Boxwood Press and Quadrangle Books, Inc. ($10).

STATISTICS OF DEADLY QUARRELS, by Lewis F. Richardson; edited by Quincy Wright and C. C. Lienau. The Boxwood Press and Quadrangle Books, Inc. ($12.50).

These two books are unlike any others in the literature of mathematics. They were written rather late in life by a man who was unusual even among mathematicians, but who is assured of a permanent place in the history of the development of physical science. To appreciate these works, now generally available for the first time, one must know something of the man who wrote them, and of the motives which led to their composition.

Lewis Fry Richardson (1881-1953) was a British mathematical physicist who made contributions to the application of the calculus of finite differences to the solution of physical problems, did outstanding work in both macrometeorology and micrometeorology, wrote some papers on psychology and at various times, especially in his later years, attempted to apply mathematics to elucidate the causes of wars. That is the bare outline of the career of a very remarkable scientist. To understand his approach to almost every aspect of life, including much of his professional work, one must add that he was an active member of the Society of Friends, to which his family had belonged for generations. Quakerism was for him more than religious devotion, and in its gentle and compassionate creed lay the inspiration for many of his activities.

His early days were very much like those of any child of reasonably well-off middle-class English parents (his family were tanners in the industrial north of England) toward the end of the 19th century. His education began at a famous Yorkshire boarding school run by Quakers, and he afterwards took a good degree (first-class honors) in physics at Cambridge. On leaving the university he first did some work at the National Physical Laboratory (the British counterpart of the U. S. National Bureau of Standards) and then taught at a small Welsh college, which he left to become "chemist" to a firm called National Peat Industries. He was then 25 years of age. His stay with this firm came to an end after one year (apparently the managing director absconded with a large sum of money), but it was notable in that it saw the beginning of Richardson's researches in mathematics.

Mathematical physics nearly always involves the solution of differential equations. Some of the equations can be solved exactly by formulas; others cannot, and approximate methods have to be used. Richardson, who like Lord Kelvin had "no satisfaction in formulas" until they were transformed into numbers, was led to apply arithmetical methods to differential equations by his work on the flow of water in peat. It is characteristic of his life-long attitude to mathematics that he gave imaginative but illuminating names to the processes he devised. To make such problems determinate it is necessary to include appropriate "boundary conditions" which select the unique solution of the physical problem from the infinity of solutions of the mathematical equation. The "boundary" may be a curve or surface in space or in a space-time continuum, and Richardson distinguished two main kinds of question which he called "jury" and "marching" problems according to the nature of the boundary conditions. If we know what happens at two extreme values of the independent variable, the solution must be determined with reference to the whole of the boundary lying between these termini. This is a jury problem. On the other hand, we may know what happens at one terminus only (as in the problem of weather prediction) and the solution has to be found by "stepping out" in small increments. This is a marching problem. The methods invented by Richardson gave mathematics a powerful tool and in many ways anticipated the work of others at a much later date.

In 1913 Richardson, who had come under the influence of an enthusiastic amateur meteorologist when at school, joined the Meteorological Office and became superintendent of a meteorological observatory at Eskdalemuir, a lonely village in the border country of Scotland. Here, in tranquillity, he began to formulate his ideas for the work by which he is best known. Characteristically he selected a problem, the forecasting of weather by the use of mathematics, which was then regarded as completely intractable.

From the middle of the 19th century the various meteorological services had published daily forecasts, but the results were often not very impressive. In 1913, before the Norwegians had developed the frontal theory of cyclonic disturbances, forecasting was almost entirely empirical. The forecaster made little or no use of mathematical theory and based his predictions upon his memory of past weather coupled with an uncertain understanding of the physical processes at work. The amount of information available was pitifully small and almost entirely restricted to the lower levels of the atmosphere.

Richardson had been impressed by the successes of astronomy. Predictions of eclipses do not depend upon the memory of the astronomer, and he asked why weather forecasts should not ultimately be equally precise and objective. He understood as well as anyone the formidable nature of the obstacles—the intractability of the physical equations, the lack of data and the limited time available for calculation—but he must also have realized that he knew as much as any living man about handling formally insoluble problems by numerical methods. He set to work to draw up an ambitious scheme for the forecasting of weather by the solution of differential equations.

The work was interrupted by the outbreak of war in 1914. Richardson's Quaker conscience gave him no rest until he managed, despite official frowns, to get to France as a member of a Friends' ambulance unit. The first calculations for what is now called "numerical forecasting" were done in uncomfortable rest billets behind the lines. On one occasion his precious manuscript was lost, to be discovered later underneath a heap of coal.

This immense single-handed effort finally resulted in one of the most extraordinary books in meteorology, *Weather Prediction by Numerical Process*, published at Cambridge in 1922. For the mathematical notation he used not only the entire Roman and Greek alphabets but also part of the Coptic alphabet and some unusual symbols which he invented, such as a leaf to represent evaporation from vegetation. He also discussed the cost of the service and suggested a fantastic plan for the meteorological office of the future, which he thought should be housed in a vast dome-like building with the chief mathematician in the center "conducting," with beams of colored lights and a concourse of 64,000 mathematicians—the number he estimated would be needed to keep pace with the weather of the world. He did not forget to include playing fields, "for it was thought that those who compute the weather should breathe of it freely."

Despite these eccentricities, Richardson's book has an honored place as "the first text-book of dynamical meteorology." The exposition makes considerable demands on the mathematical knowledge of the reader, but the central idea is relatively simple. It depends on the fact that from the equations of physics the time-rates of change of the main meteorological elements (velocity, pressure and density) at a *point* can, in theory, be found by numerical methods from a knowledge of the spatial distributions of the same elements at a given *time*. Now the distribution of wind, pressure and temperature (and therefore density) in space at any given time can be found, at least approximately, from the observations of the meteorological stations, and when the instantaneous time-rates of change have been computed with the aid of the equations from these data, a new spatial distribution can be found for a brief time ahead, say one hour. This process, when it is repeated many times, "marches" to give a forecast of the physical state of the atmosphere at any future time from which the coming weather can be deduced. The forecasting problem can in theory be solved in this manner.

The scheme involves an enormous number of individual calculations, which Richardson, using only a desk computer, carried out for one occasion on which the data were, for that time, unusually complete. The final result was a grotesque failure. During the six hours in question the barometer remained almost stationary in the selected area, whereas the calculations predicted a rise of 145 millibars (about 3.7 inches). This is 10 to 100 times greater than any rate of rise of pressure that has ever been observed (except perhaps for brief periods in the center of a tornado) and it must have required considerable moral courage to publish such a prediction as the culmination of the long and tedious calculations.

The reasons for this spectacular failure are now known. The initial data were inadequate and Richardson had not overcome all the mathematical and computing difficulties of the work. But time has justified his faith in the concept. A better understanding of the dynamics of the atmosphere and of the difficulties of the approximations, together with the invention of the high-speed computer, have now brought numerical forecasting to the stage when it can compete successfully with "conventional" methods. The sequence of operations is basically that used by Richardson. History cannot be written on the basis of "if," and it would be going too far to claim that without Richardson's pioneer effort numerical forecasting would not be in operation today. But those who have developed the present techniques from 1946 onward have always been ready to acknowledge their debt to the original attempt.

The remainder of his contributions to physics must be summarized very briefly. He did remarkable work, far ahead of its time, in the problem of turbulent diffusion. In the dynamics of nonhomogeneous fluids his researches are remembered by the "Richardson number," now universally recognized as the basic parameter in this difficult study.

His Quaker conscience compelled him to resign from the Meteorological Office when it became part of the Air Ministry in 1920, and he returned to teaching. In 1926 his standing in science was recognized by election to the Royal Society. After his retirement from academic life in 1940 he continued his studies of the causes of war, which he had begun in

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1919. He died in Scotland in 1953, at the age of 72.

The books reviewed here are the result of Richardson's life-long "concern" with the prominence of violence in both national and international life. As early as 1919 he had written a pamphlet entitled *Mathematical Psychology of War*, of which only a few copies now exist, mainly in the British copyright libraries. Later he expanded these ideas in a monograph called *Generalized Foreign Politics. Arms and Insecurity*, produced in 1947 as a manuscript on microfilm, is an enlargement of *Generalized Foreign Politics. Statistics of Deadly Quarrels* was produced in microfilm form in 1950. Neither work was generally accessible until the present editions appeared; they were probably known only to a small circle before the appearance in 1956 of James R. Newman's anthology *The World of Mathematics*, Volume II of which contains summaries of them.

Arms and Insecurity is the shorter and, to me, the more attractive of the two books. It is absorbing but not always easy reading, not because of the difficulties of the mathematics (the technical demands made of the reader are far below those required for *Weather Prediction by Numerical Process*), but because of Richardson's peculiar manner of writing, which is best described as distracting. His pages are littered with quotations and proper names. All mathematicians, I suspect, invent an *alter ego* to act as a devil's advocate when they are formulating an argument. Usually they keep their musing private, but Richardson had no inhibitions about revealing his misgivings in print. His *alter ego* is "Critic," who every few pages interjects caustic remarks to which the author replies, sometimes not very convincingly.

The main argument of *Arms and Insecurity* is a denial of the ancient Roman philosophy of *Qui desiderat pacem, praeparet bellum* (Let him who desires peace, prepare for war). But it is more than a rhetorical appeal to history. Richardson's method is to study the conditions of equilibrium between nations that have massive armaments by an examination of the solutions of certain differential equations which, in his view, give a tolerably faithful representation of the main features of this complex situation. His concept is perhaps best summed up in his own words, in one of his imaginary conversations:

CRITIC: How can anyone possibly make scientific statements about foreign politics? These are questions of right, of loyalty, of power, of the dignity of free choice. . . .

AUTHOR: . . . Nowadays science does usefully treat many phenomena that are only in part deterministic. . . .

CRITIC: Can you predict the date at which the next war will break out?

AUTHOR: No, of course not. The equations are merely a description of what people would do if they did not stop to think. . . . The process described by the ensuing equations is not to be thought of as inevitable. It is what *would occur if instinct and tradition were allowed to act uncontrolled*. . . .

The equations to which Richardson refers are intended to describe conditions during an arms race. They are simple in form and have a physical analogy in linked oscillating systems such as a double pendulum. Their derivation can be understood without calling in advanced mathematics, as follows: if x represents the "defenses" of a country and y that of its rival, Richardson first assumes that each country endeavors to keep pace with its potential enemy. In mathematical terms, the rate of growth of x (dx/dt, where t is time) is made proportional to y and equally, the rate of increase of y is made proportional to x. A simple system of this kind is inherently unstable, that is, the solutions for x and y contain terms that increase indefinitely with time. The appearance of infinities in the analysis of a physical problem often indicates to the mathematician that the original model no longer represents the phenomenon being studied. To Richardson instability meant war, not bankruptcy, but he recognized that in practice certain restraints operate, something like friction in the pendulum. To allow for the stabilizing influence of the "fatigue and expense" of keeping up armaments he brings into each of the equations negative terms proportional to x and y, respectively. Finally, to take account of the widely held view that armaments are merely the outward symptom of national ambitions and grievances, two "constants" are added. Thus finally he arrives at two simultaneous differential equations which say that in both countries the rate of increase of defenses is determined by what the other side does plus a factor attributable to ambitions and grievances but constrained by the manpower claims and financial burdens of the defenses.

There are certain simple consequences

of the equations which Richardson regards as evidence of their internal consistency and applicability to real situations. Bilateral disarmament is permanent if and only if all defenses are abolished and all ambitions and grievances are satisfied simultaneously. Unilateral disarmament cannot produce a steady state. This may not seem very convincing, but Richardson gives a striking example of the validity of his analysis in a real historical situation. He considers the period of the European arms race from 1909 to 1914, when France was allied with Russia, and Germany with Austria-Hungary. His mathematical analysis shows that the rate of increase of the combined annual defense budgets of the two alliances should be proportional to the combined defense budgets; and he demonstrates from the published figures that this is what actually happened, the agreement being so close that, in the words of one critic, "if the question [of the validity of the theory] were one of physics, it would be regarded as settled." Further, the equation, when fitted to the data, indicates that equilibrium would have been reached if the combined total costs had been agreed at a certain figure which is close to the value of the sum of the imports of the two groups from each other. Richardson suggests that if the defense budgets of the year 1907 had been adjusted to satisfy his criterion of "no tendency to increase":

"World War I would not have occurred. . . . The changes required to reach the point of balance [which] we must imagine . . . to have been voted or approved in the usual manner as an expression of mutual good will . . . are of the order of the expenditures of the same nations in a couple of days of the subsequent war.

"Appeasement, as attempted by Mr. Neville Chamberlain in 1937 to 1938, was quite different. It was a rather vague offer to negotiate, accompanied by a marked increase in armaments on both sides."

Later in the book Richardson develops, on the same basis, a theory of the interactions of any number of nations with, naturally, a more complicated mathematical treatment. He deduces, among other things, that a world composed of a large number of small nations of equal "size" is more inclined to instability than one made up of a few large powers. His examination of the arms race that ended in the Second World War indicates that the world was unstable in the 1930's and that pacification during this period would have required not only the cessation of all defense expenditures by the nations involved but also "further active obligements among them," such as the alleviation of grievances. For the present period his tentative conclusions are best given in his own words:

"So it may come to pass that the world will for most of the time be content with just enough stability. . . . We are led to the tentative hypothesis that: *on the average over the peaceful part of a long period such as a century, during which aviation is increasing, the world may be expected to be just stable.*"

These words, it should be remembered, were written when the potentialities of large rockets armed with atomic war-heads were hardly realized.

The second volume, *Statistics of Deadly Quarrels*, is of a different type, although the style is *sui generis* and the Socratic dialogues still appear. It is an attempt to examine statistically how far conditions between nations, groups and individuals which have led to wars and murders are measurable. It is both a source book and an analysis of the causes of violence. Richardson's list of more than 300 wars from 1820 to 1949 is likely, as the editors say, to be "a mine of information for social scientists and historians as well as for statistical analysts." From this mass of facts he makes some interesting deductions, many of which run counter to commonly held beliefs. For example, he concludes that between 1820 and 1949 no one nation could be singled out as the chief troublemaker—aggression was widespread. Karl Marx's dogma that the class struggle was the most important element in the causes of war in this period is not supported by the analysis, nor are there grounds for the belief of Zamenhof, the inventor of Esperanto, that a common language, by promoting mutual understanding, would have had a pacificatory effect. As regards the effects of the diversity of religious beliefs (including communism, which Richardson finally considered to be a religion, "for it permeates the whole life and is somewhat resistant to evidence"), the calculations give verdicts of "not proved" against both the Christian and Moslem religions on the charges of having notably instigated or prevented wars between their adherents. An interesting result is that the number of outbreaks of war in a year follows quite closely the statistical law known as Poisson's distribution, but more of this later.

One could fill many pages with examples of fascinating and often challenging deductions made by Richardson from his mathematical scrutiny of history. But the truth or otherwise of any single deduction is, I feel, of less importance than the question of the significance and validity of the methods used. Can we now judge if he had evolved a new technique in historical and social research by the free, though undoubtedly skillful, use of mathematics?

In work of this kind one must guard continually against importing an emotional significance into purely mathematical results. Take, for example, Richardson's demonstration that the number of outbreaks of war in any year from 1820 to 1949 conforms to the Poisson distribution. This distribution is sometimes called "the law of improbable events." It relates to circumstances in which a given mean number of occurrences of a single type is the result of many opportunities for events which individually have only a small chance of happening. There are many instances of this distribution, ranging from deaths in cavalry regiments by the kick of a horse, to the density of traffic on a highway and the number of alpha particles emitted by a radioactive substance in a given time. In the latter instance we know that in any short interval of time a relatively small number of the many millions of atoms in a piece of radium will change, but we cannot say when or why this will happen for any particular atom. The Poisson law here provides a simple mathematical model for the study of fluctuations in the number of alpha particles emitted in various time-intervals.

Is it justifiable to conclude (as the editors do) that wars are distributed in time "by chance"? This seems incredible. One may, perhaps, consider death by lightning stroke as a matter of "chance," for there is no conceivable method of predicting where and when the next stroke will occur and no means of averting the danger short of spending one's life in a deep cave or in the polar regions. But it is widely held that the danger of war can be foreseen and its outbreak averted by statesmanship. Otherwise much of the study of history and politics is vain.

Statistical theory rarely provides a means of discovering radically new truths, and its chief use is to examine the internal consistency of the data and to assess objectively the weight of evidence for an assertion. In the problem of wars, the chance of an outbreak occurring on any day is small, but the number of days in a year is, statistically, large. One would therefore expect *a priori* a tolerably close agreement between the historical facts and the theoretical law. The numerical analysis, in my view, simply verifies this statement, just as agreement between the results of a coin-tossing trial and the binomial distribution shows no more than that the tosses were fair and the coin true, and does not provide evidence for a hidden "law of averages," as is widely believed. So many factors influence international relations that the problem of predicting the number of wars that will start in a given year is insoluble. But this is not to say that the timing of wars is a matter of chance in the sense of death by lightning stroke.

Arms and Insecurity is a very different kind of book, for it is not primarily based upon statistical theory. In it Richardson, by constructing a definite model of a physical kind to simulate the interactions of nations, attempts much more than a weighing of evidence. Such a procedure is fraught with far greater danger than a statistical inquiry, but, on the other hand, if the model is valid, the gain in precision is immense.

Throughout the work he considers only linear relations, that is, the magnitudes of the effects are in simple proportion to the causes, and the various factors are additive. Linearization is recognized as a proper first step in the approach to a physical problem, for it avoids the difficulties of dealing with the complete nonlinear equations and often is sufficient to reveal the main features of a phenomenon. But mathematics is a sharp-edged tool which has to be used with care, and even completely rigorous arguments can lead to false conclusions in real phenomena. Classical hydrodynamics, for example, proves by impeccable reasoning that a totally submerged body of any shape moving steadily through a fluid experiences no drag. This result, known as d'Alembert's principle, is completely at variance with experience. The explanation is that classical hydrodynamics ignores viscosity, which even in a fluid such as air must be taken into account to produce a realistic answer.

Richardson was quite clear about this limitation. In reply to a question in one of his dialogues—whether he seriously believed that it is possible to prove by mathematics anything about the behavior of nations—he says:

"All that can be proved by mathematics is that certain consequences follow from certain abstract hypotheses. But, after such proofs are established, we shall compare the observed behavior of nations with some of the deduced consequences and so form an opinion as to whether the hypotheses are a true description of nations. . . . It all depends upon hypotheses."

In his first quantitative examination of the arms race that preceded the First World War, Richardson made out a good ease for his "hypotheses." We may doubt, however, his implied conclusion that if both sides had been aware of the approaching instability, they would have called a halt. The lust of individuals for power is an irrational factor that can upset all calculations based on economics.

There is a rather sad postscript to the book which seems to indicate that Richardson had come to a somewhat similar conclusion after the end of the Second World War. With the innate honesty that compelled him to publish the ludicrous weather forecast in 1922, he wrote in 1946:

CRITIC: In view of the evidence at the Nürnberg Trial I suppose that you will now admit that Hitler and his associates planned the war deliberately.

AUTHOR: Yes, the evidence of formerly secret documents convinces me of what I was formerly loath to believe.

CRITIC: And with that admission all your fine theories about defense coefficients and what-not blow away in smoke!

AUTHOR: Not a bit. For it is firmly founded on numerical fact.

CRITIC: But you cannot say both that the war was caused by mutual interactions between populations and that a small clique planned it deliberately.

AUTHOR: I think that these two statements are compatible, because leaders lead peoples where they are willing to be led.

What, then, are we to conclude about these remarkable studies? An intellectual exercise that leads nowhere, or the beginning of a new approach to the understanding of the most important problem of our day? The question is perhaps more appropriately addressed to a historian than to a mathematician, but for me the reading of these books has been more than a stimulating intellectual experience. Time has proved the worth of many of Richardson's contributions to physical science, eccentric though they must have appeared to his contemporaries. Will history be repeated?

Short Reviews

SCIENCE AND CIVILIZATION IN CHINA: VOLUME III, by Joseph Needham. Cambridge University Press ($27.50). It is a rare experience to witness the growth of a great work. The appearance of the third volume of Needham's magnificent survey cannot fail to excite one's admiration—almost to the point of incredulity—of his energy, his scholarship and his ability to handle with such authority and assurance the vast array of material he has gathered about the science and technology of China and its relation to the growth of knowledge elsewhere in the world. "With this volume we reach the ore of the work as a whole, and leave behind all tunnels and adits." Its purpose is to describe and explain the Chinese contributions to mathematics and to the sciences of the heavens and of the earth: astronomy, meteorology, geography, geology. The sheer bulk of the material and the detail may seem bewildering (the section on astronomy alone runs to almost 300 pages), yet, as Needham reminds us, we are concerned with the culture of more than a fifth of the human race, inhabiting for 3,000 years a land area at least as large as Europe. Needham characterizes Chinese science as "fundamentally empirical and observational." The Chinese were not concerned primarily with logic or abstractions, with elegant demonstrations or beautiful systems. Their science had work to do; it was practical, a tool for understanding nature and mastering the environment. What Needham makes abundantly clear is not only the magnitude and variety of their accomplishments, but in how many instances they gave of knowledge to the outside world more than they received. In mathematics they invented a numeral notation of nine figures with a place-value component equivalent to zero (by 1400 B.C.), the concept of negative numbers, the triangle of binomial coefficients (some 400 years before Pascal), the idea of determinants (before Leibniz independently discovered it). Like the Greeks they were interested in numbers, number mysticism and numerology. Their geometry was much inferior to that of the Greeks; on the other hand, by the fifth century they had worked out *pi* to 3.1415929, an accuracy not equaled elsewhere until the 16th century. Chinese algebra was as strong as their geometry was weak. Already in the first century they used quadratic equations and numerical higher equations of special kinds as far as the third degree. What is most remarkable is that despite their proficiency in this department their algebra was rhetorical. They solved problems such as $x^3 = 1,860,867$ and $x^2 + 34x = 71,000$ by setting them up on counting rods on a board. So far as another major branch of mathematics—analysis—is concerned, neither the Chinese nor the Japanese attained the dynamic conception of the calculus until after the arrival at the beginning of the 17th century of the Jesuits, and the "consequent unification of world science." Needham elucidates the Chinese achievement in astronomy. They invented a polar-and-equatorial system different from that of the Hellenistic peoples, "though equally logical"; they early imagined an infinite universe, with the stars as bodies floating in infinite space; they developed huge star catalogues, elaborated an amazing assortment of astronomical instruments, invented a clock drive for the forerunner of the telescope, and maintained for longer continuous periods than any other civilization accurate records of celestial phenomena such as eclipses, novae, comets and sunspots. The Chinese invented the seismograph in the second century A.D. Their best maps, of which an extraordinary example (with wonderfully firm coastal outlines and precise river networks) carved on stone in A.D. 1137 is reproduced in this volume, far surpassed those of Western medieval cartographers. Here, as in the earlier installments, Needham is less convincing in his examination of the evidence as to "influences and transmissions" than in his account of the scientific work itself. And while his conjectures as to the reason for the failure of Chinese science and mathematics to make the jump forward that Europe made after the Renaissance are always thoughtful, knowledgeable and even fascinating, they are less than compelling. In his view socioeconomic circumstances explain both Europe's spurt in science and China's stagnation: the rise of a mercantile culture in the first case, the stultifying effects of an agrarian bureaucracy in the second. This is a judgment which many will find unacceptable, preferring to believe that it was the revival of the Greek tradition that stimulated Europe and the very lack of the Greek passion for abstraction that hobbled the Chinese. A reviewer can do no better than urge the reader to acquaint himself at first hand with Needham's own brief as presented in this superb history. It has been said before, but it deserves to be said again, that the books are as beautiful as only the Cambridge University Press can make them.

MATHEMATICAL METHODS IN THE SOCIAL SCIENCES, 1959, edited by Kenneth J. Arrow, Samuel Karlin and Patrick Suppes. Stanford University Press ($8.50). Proceedings of the first Stanford Symposium, held at the University in 1959, containing papers on the use of mathematics in economics, management science and psychology. One of the contributions, by Eugene Galanter and George A. Miller, raises an interesting, important and too-little-recognized question. They point out that the stochastic models of human behavior that are currently available rely heavily—and in ways seldom made explicit—upon a particular kind of psychological theory. Yet, they remind us, if that theory is incorrect, models based on it will have limitations that cannot be overcome by using more sophisticated mathematics, and nothing less would serve than fundamental changes in psychological theory "and even, perhaps, in our underlying conception of the nature of man." The question deserves the attention not only of those who apply mathematics to psychology, but also of those who in other branches of social science, following the modish trend, are erecting increasingly formidable mathematical structures which rest upon accepted, but not necessarily acknowledged or carefully examined, hypotheses. Mathematical seasoning may make the flavor more exotic without adding any nourishment to the stew.

AN ESSAY ON THE APPLICATION OF MATHEMATICAL ANALYSIS TO THE THEORIES OF ELECTRICITY AND MAGNETISM, by George Green. Chalmers University of Technology ($5). A facsimile edition, printed for Professor Stig Ekelöf of the Chalmers University of Technology in Sweden, of George Green's famous 1828 essay—a landmark of the mathematical theory of electrostatics and magnetostatics which contains, among other well-known results, Green's theorems connecting surface and volume integrals, and Green's function, the concept widely used in the solution of partial differential equations. This lucid work, by a 34-year-old, self-taught miller's son from Nottingham, has been described as "the beginning of mathematical physics in England." A most attractively made little book, which historians of science and students of physics and mathematics will be happy to have in their libraries.

THE CONCISE ENCYCLOPEDIA OF WESTERN PHILOSOPHY & PHILOSOPHERS, edited by J. O. Urmson. Hawthorn Books, Inc. ($12.95). Of philosophy Descartes said in his *Discourse on Method* that "there is not a single matter within in its sphere which is not still in dispute." His statement, as Urmson observes in introducing this work, is as true in the 20th century as it was in the 17th. We cannot expect, therefore, to find in the 400-odd pages of this book pat answers to the great questions with which philosophers have wrestled for centuries, such as the meaning of the universe, the nature of reality, the essence of matter, the relativity of moral standards, the relation of mind and body; or even the solutions to lesser problems: the views of Hegel or Heraclitus, the disagreement between empiricists and rationalists, the systems of Leibniz or Wittgenstein. There remains much that an encyclopedia of philosophy can accomplish, especially when it is as well thought out as this volume is, and when its contributors include many of the ablest practitioners of the art, among them A. J. Ayer, Marvin Farber, Ernest Nagel, Gilbert Ryle, Stephan Körner, Alasdair Macintyre, H. B. Acton, G. J. Warnock, Philip Merlan and others equally well known in their fields. One's general impression when leafing the pages, reading here and there as the treatment of one topic prompts one's curiosity as to the treatment of another, is that this is a well-executed task covering a wide ground. The writing is at a remarkably high level of clarity and succinctness, surprisingly free of professional double-talk. Technical terms are intelligently defined, a matter of the first importance, since these are the counters of the game. Long articles cover standard subjects: analysis, ethics, epistemology, metaphysics, logical positivism, empiricism, idealism, utilitarianism, logic and so on. Several of these are excellent, and manage, despite the dimensions of the subject and the limitations of space, to give the reader the warm feeling of piercing difficult matters which he had hitherto despaired of understanding. The great philosophers get their due in balanced and informative summaries, which are of course, as the editor points out, no substitute for the original writings but serve both as sources of background information and as preliminary guides to further study. As is to be expected in a work of this kind, treatment and emphasis are uneven and curious omissions occur in almost every department, which will dismay different readers in different degree, but all readers to some degree. If, for example, you hope to find in this book, especially because you can find it in no other, a plain explanation of the principle of indeterminacy, you will not only be disappointed but affronted, for the topic is not treated at all except in a single sentence forming the tail of an inadequate article on determinism. Neither cause nor causality appears as an entry; nor Kurt Gödel, nor his proof (which cannot be because he is primarily a mathematician and logician,

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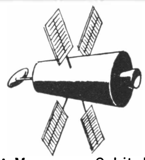

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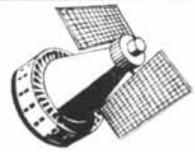

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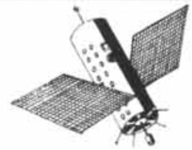

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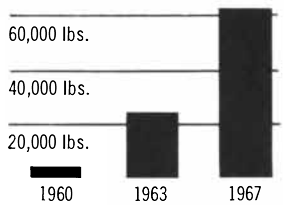

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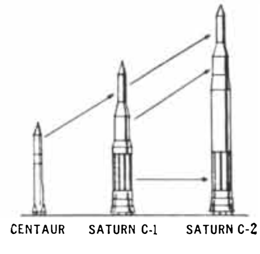

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National Aeronautics and Space Administration since any number of philosophers whose sole concern is with logic and mathematics are included); nor logical paradoxes—except for what Bertrand Russell or Gottlob Frege had to say about certain of them. There are many such cases, most of them the result, no doubt, of the editor's deliberate choice, for a quart bottle will hold no more than a quart, and to have included something which was finally excluded would have meant the exclusion of something which is included. Editors, like anthologists, have a hard life. Still, things got by that were not mere matters of choice and that should never have got by. For example, the article on existentialism succeeds in making a marvelously fuzzy concept even fuzzier. But altogether this is an illuminating and enriching book, dependable for quick reference and a pleasure to read at leisure. Two additional features are a helpful guide for further reading and a splendid set of 104 plates (eight in color), giving fine portraits, especially of contemporary philosophers.

PHYSICS OF THE UPPER ATMOSPHERE, edited by J. A. Ratcliffe. Academic Press, Inc. ($14.50). A collection of monographs on the atmosphere above 60 kilometers: the thermosphere (Sydney Chapman); properties and constitution of the upper atmosphere (Marcel Nicolet); study of the upper atmosphere by rockets and satellites (Homer E. Newell, Jr.); the sun's ionizing radiations (Herbert Friedman); the airglow (D. R. Bates); the general character of auroras (D. R. Bates); the auroral spectrum (D. R. Bates); radar studies of the aurora (Henry G. Booker); the ionosphere (J. A. Ratcliffe and K. Weekes); the upper atmosphere and geomagnetism (E. H. Vestine); the upper atmosphere and meteors (J. S. Greenhow and A. C. B. Lovell).

INGENIOUS MATHEMATICAL PROBLEMS AND METHODS, by L. A. Graham. Dover Publications, Inc. ($1.45). A paperback collection of 100 of the best problems which have appeared during the past 18 years in the puzzle column of the Graham *Dial*. Examples: What is the shortest line in which the multiplication 4,109,589,041,096 × 83 can be accomplished? It can be done in one second, by putting the 3 of 83 in front of the multiplicand and the 8 at the end, because the answer is 341,095,890,410,968. What is the explanation and are there any more such cases? A stone falls the last half of the height of a wall in half a second. How high is the wall? What is the earliest point in a regulation major-league baseball schedule that a team can be assured at least a tie for first place in the final standings?

OPERATIONS RESEARCH AND SYSTEMS ENGINEERING, edited by Charles D. Flagle, William H. Huggins and Robert H. Roy. The Johns Hopkins Press ($14.50). A co-operative volume containing a set of lectures delivered by the authors in the Johns Hopkins University annual two-week course for management. The range of topics is as sprawling as the curious and diffuse subject of operations research: statistical quality control, digital computers, linear programming, queuing theory, simulation techniques, theory of games, symbolic logic, human engineering, operations research in a hospital, a case study in a telephone company, simulation of tactical war games, operations research "in the world crisis in science and technology," and so on and on.

A BIBLIOGRAPHY OF INTERNAL MEDICINE, by Arthur L. Bloomfield, M.D. University of Chicago Press ($6). In this volume the author continues the excellent bibliographical survey begun in his earlier work on communicable diseases. Here he has selected 21 diseases "of old and honorable lineage" (including auricular fibrillation, coronary occlusion, pernicious anemia, leukemia, diabetes, Hodgkin's disease, Graves' disease, gout, Bright's disease, bronchial asthma, scurvy, trichinosis), listed the fundamentally important references to each from 1800 to the present, and given abstracts or partial translations of each item. Bloomfield's labors are distinguished by his skillful summaries and quotations, which invariably get to the heart of each paper, and which when followed in sequence present an absorbing history of the searching and the progress of medical science.

HANDBOOK OF SOCIAL GERONTOLOGY, edited by Clark Tibbitts. University of Chicago Press ($10). This second of three handbooks covering all that is currently known about human aging consists of 19 papers concerned with various aspects of the relation of older adults to the "total environment" and sociocultural framework. Some of the topics covered are the changing demographic profile, aging in preindustrial societies, the technological and societal basis of aging, the impact of aging on the social structure, the health of aging people, income security, work patterns, retirement, the uses of leisure, the older person in the family, health programs, governmental responsibility and functions.

APULIA, by C. A. Willemsen and D. Odenthal. Frederick A. Praeger, Inc. ($12.50). The southeastern part of Italy was known in earlier times as Apulia. Many nations have ruled this land, but the main architectural and artistic imprint upon it was made in about two centuries: from 1043, when the Norman, William the Iron Arm, became count of Apulia, to 1250, which marked the death and end of the reign of Frederick II, the Hohenstauffen. This volume presents 230 photographs, supported by a brief text, of the landscape, and of the castles, palaces, chateaux, churches and cathedrals which remain of the many magnificent structures reared during this creative era.

Notes

ECOLOGY AND DISTRIBUTION OF RECENT FORAMINIFERA, by Fred B. Phleger. Johns Hopkins Press ($7.50). A summary and evaluation of research on these small calcareous protozoa, whose empty shells have for millions of years sunk to the bottom of the sea, and whose distribution provides valuable information about sea floors, the temperature of ancient seas, the location of oil, the movement of glaciers and other natural phenomena.

ESSAYS IN THE SCIENCE OF CULTURE IN HONOR OF LESLIE A. WHITE, edited by Gertrude E. Dole and Robert L. Carneiro. Thomas Y. Crowell Company ($6.25). A *festschrift* on the occasion of the sixtieth birthday of the founder of culturology, a major defender of evolutionary theory in anthropology.

DISPOSAL OF RADIOACTIVE WASTES, VOL. I: International Atomic Energy Agency. International Publications, Inc. ($6). Proceedings of the 1959 Scientific Conference on the Disposal of Radioactive Wastes, held in Monaco, sponsored by the International Atomic Energy Agency and UNESCO. The papers in this volume deal with the nature of radioactive wastes, treatment and processing, present methods of waste disposal.

A PRIMER OF REAL FUNCTIONS, by Ralph P. Boas, Jr. John Wiley & Sons, Inc. ($4). A course of informal lectures on some of the concepts and methods of real variables. One of the Carus mathematical monographs.

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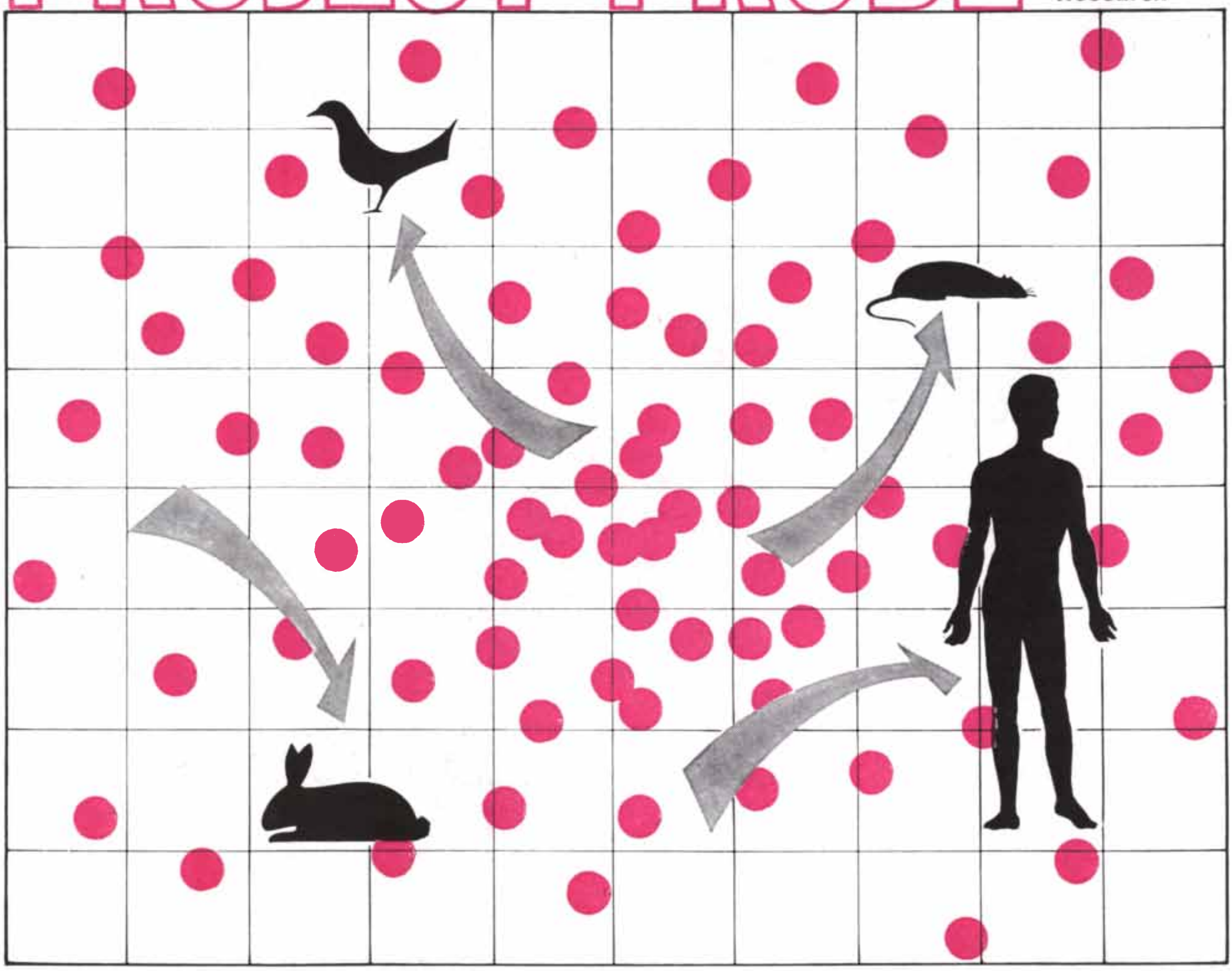

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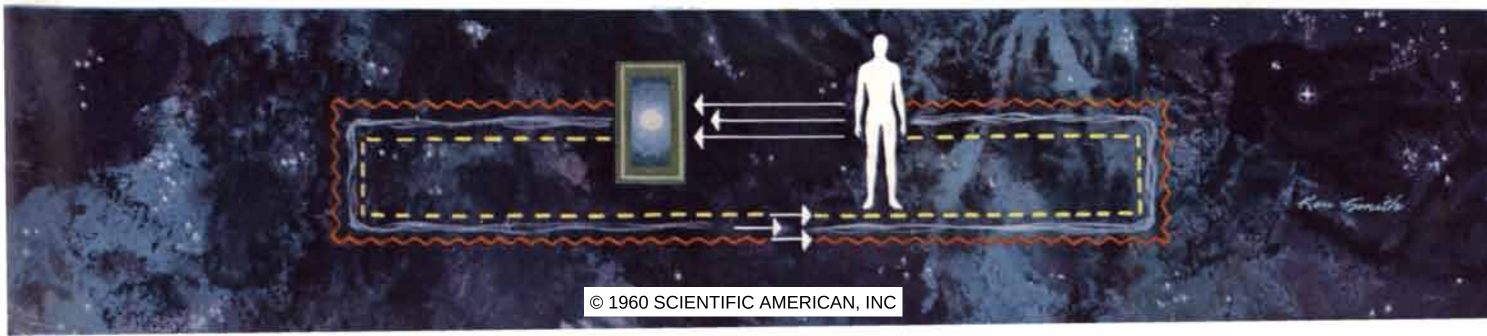

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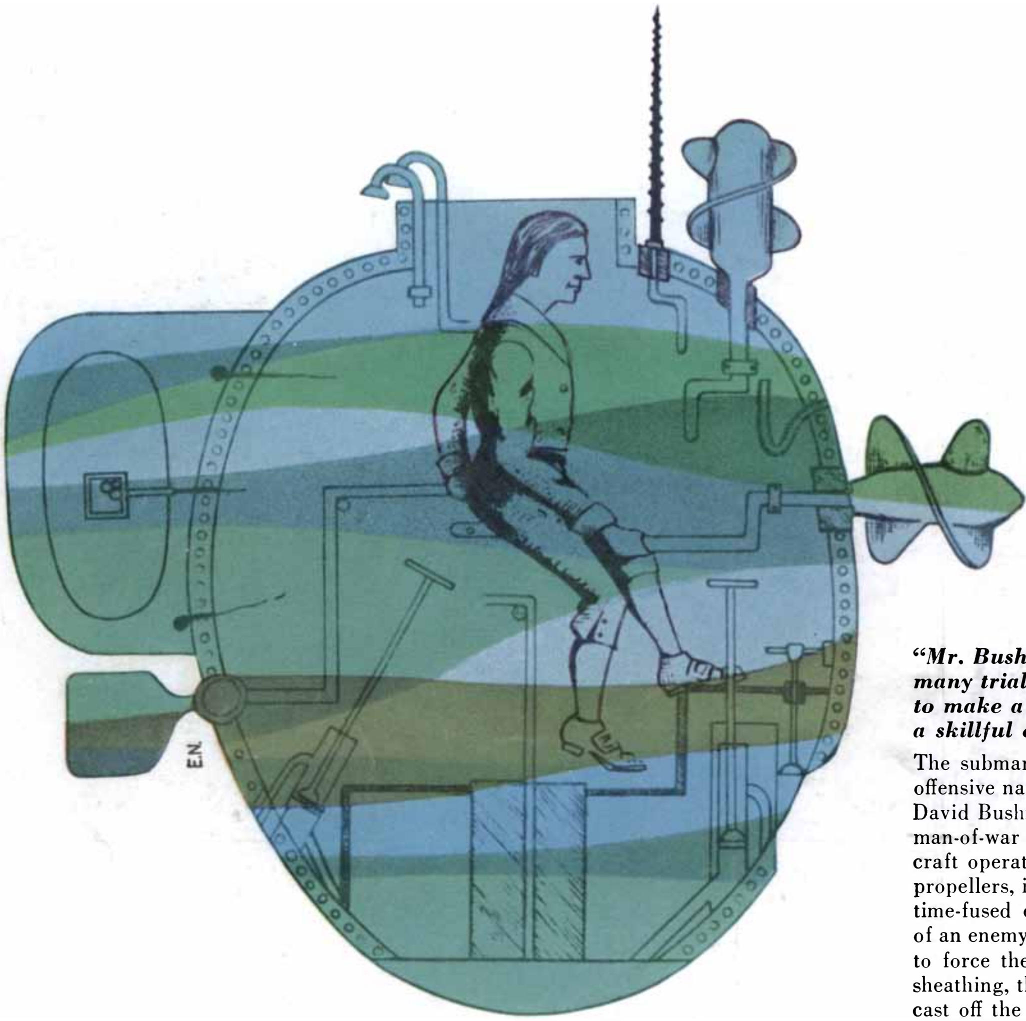

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