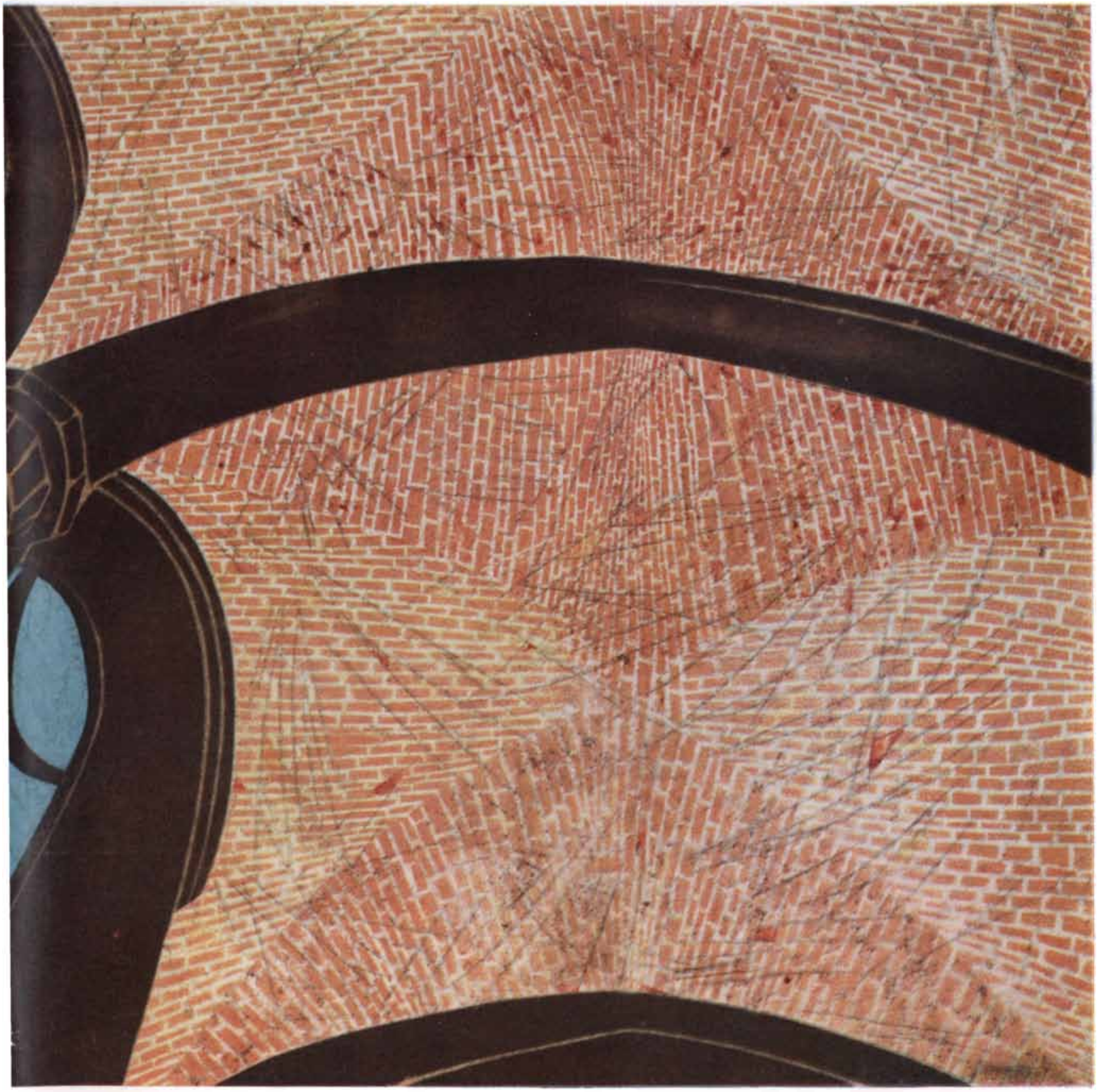
SCIENTIFIC AMERICAN



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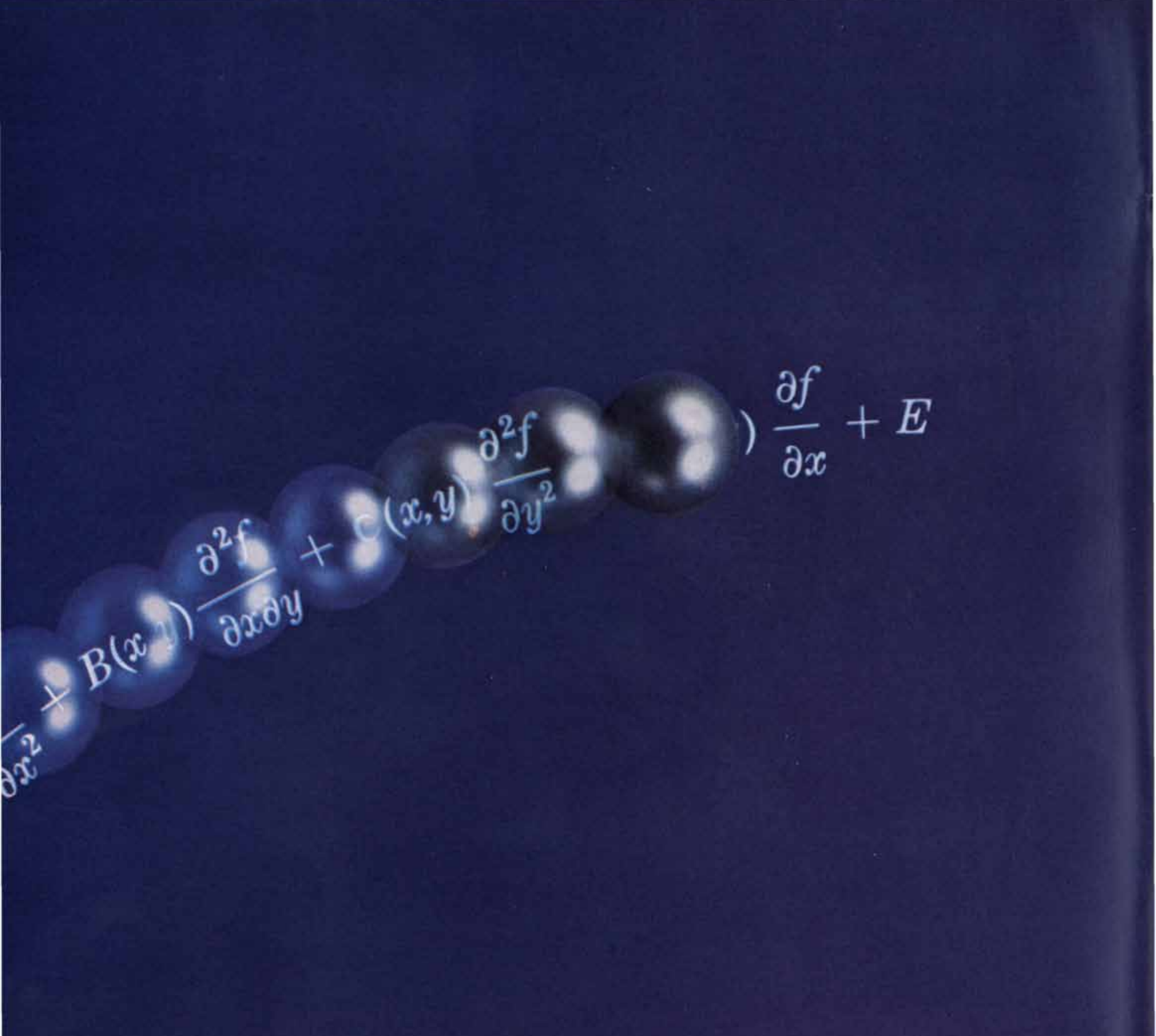
November 1961



At 18,000 mph, only computers can keep up

Satellites travel so fast that an IBM computer system is being used to give U.S. scientists continuous, up-to-the-second information about them.

There's only one way to know exactly what a satellite is doing in space. Follow it mathematically, making calculations as fast as information comes in from the satellite. This means using high-speed computers linked to ground tracking stations. Working with the National Aeronautics and Space Administration, IBM has developed such a system for the U.S. space program. It includes large-scale IBM computers at Bermuda, Cape Canaveral, and the Goddard Space Flight Center just outside Washington, D.C.

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This system is one of the most powerful computer-communications networks in the world. IBM is helping to develop information systems like this to handle the increasingly complex data requirements of government, business and science in the space age.

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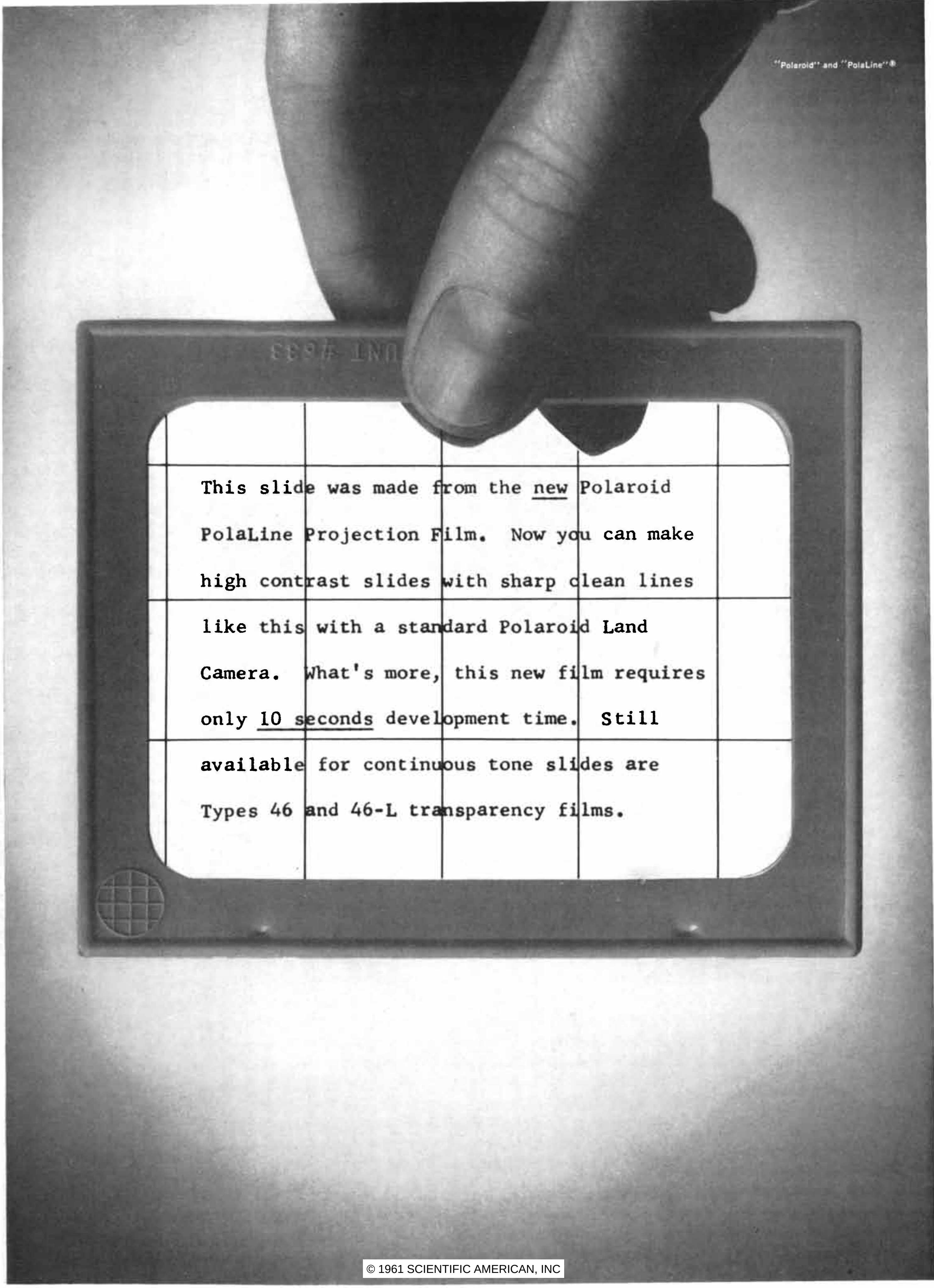
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Types 46 and 46-L transparency films.

Established 1845 SCIENTIFIC AMERICAN November 1961 Volume 205 Number 5

ARTICLES

DEPARTMENTS

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THE COVER

The woodcut on the cover symbolizes the vault, the architectural form that was for centuries the primary means of roofing large areas and now plays a central role in contemporary construction. Its evolution is a major thread in the history of architecture (*see page 144*). The roof depicted by the artist is that of the Church of St. Sauveur at Figeac in France. The 12th-century church was modified in the 14th century and the roof was reconstructed in the 17th. As a result St. Sauveur has Romanesque pillars, Gothic window detail and a folded-shell vault without diagonal ribs, a feature characteristic of the later period.

THE ILLUSTRATIONS

Cover by Antonio Frasconi

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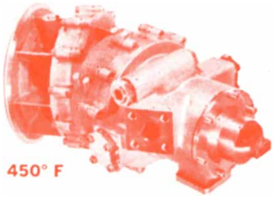
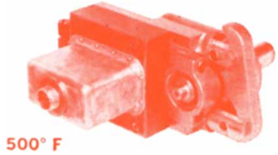
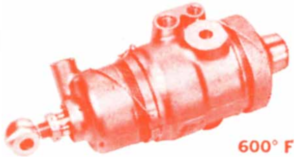


Mach 3 starter motor/pump

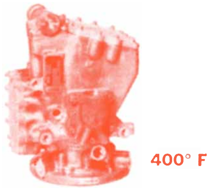


Hot gas servo valve



Titanium rudder actuator

Hi-temp servo valve



Dual pump for X-15

CAPABILITY is spelled M-a-c-h 3 s-y-s-t-e-m-s

Flight speeds of Mach 3 and higher introduce new problems in auxiliary power system design and operation. A well defined program* in existence for more than six years at Vickers has been devoted to high temperatures—in the 350° to 1400° F range—and their effects on materials, fluids and tolerances.

Exotic Fluids—Systems have been designed and tested for a broad range of hard-to-handle fluids including: deodorized kerosene at 350° F . . . synthetic base fluids (MLO 8200) at 450° F . . . super refined mineral oil (MLO 7243) at 700° F . . . mixed isomers of bis (phenoxyphenyl) ether at 700° F . . . liquid metal (NaK 77) at temperatures to 1400° F.

Hi-temp Components—Specialized high temperature applications require parallel activity in servo systems and related components (see examples at left). A typical development program includes servo valves for the –65° to 500° F range with extremely low thermal drift.

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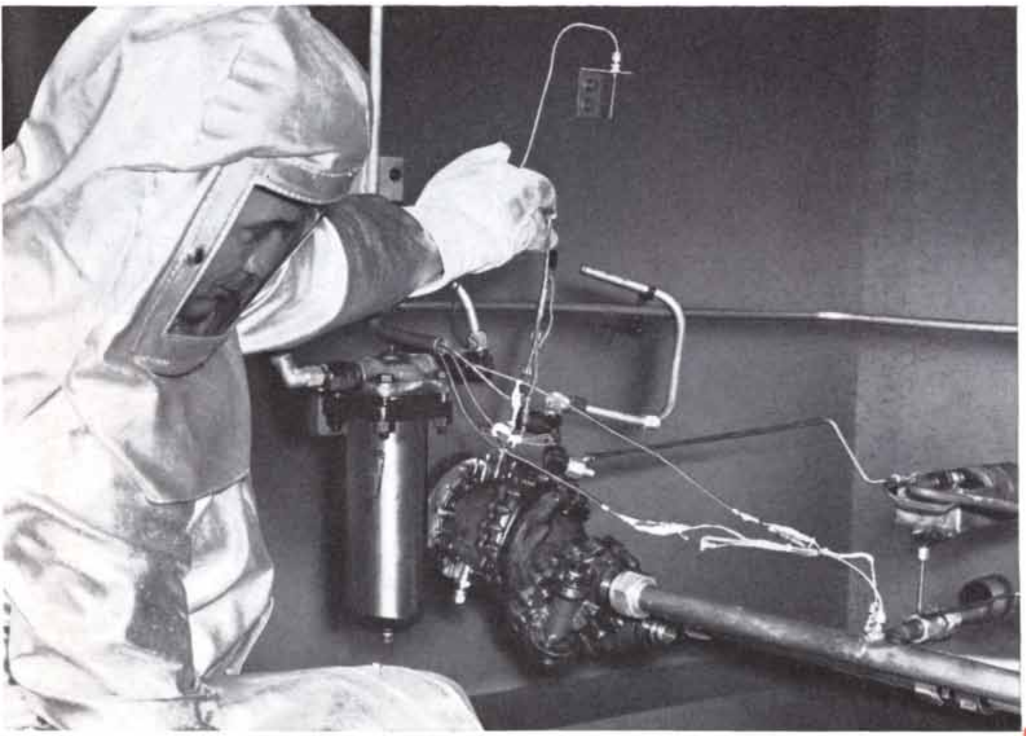

At completion of high temperature test, technician removes prototype pump that is heart of system being developed for Mach 3 flight. Systems are often hermetically sealed and pressurized with inert gas, necessitating special test facilities to simulate operating conditions.

Hot hardness tester is used to predict behavior of special alloys during extended operations at elevated temperatures.

Maximum safety building located at some distance from main research facilities has test cells used extensively in high temperature tests. ▶

Looking for a solution to your

BRPE Tape Punch

Perforates 5, 6, 7 or 8 level tape at 100 char/sec. Synchronous unit, with parallel-wire input. For business machine readout, or, with de-serializer, for data reception over DATA-PHONE or other high speed communication channels.

CX Tape Reader

Reads fully perforated or chadless tape—5, 6, 7 or 8 level codes—at 100 char/sec. For use as computer input device, or, with serializer, for transmission over DATA-PHONE or other high speed communication

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Produces 5, 6, 7 or 8 level tape at 20 char/sec. Parallel input. May be used for cross-office relaying, data collection, or providing by-product tapes from business machines. Companion input tape reader available (LX).

data communication problems?

LBXD Tape Reader

Dual-purpose model: permits, (1) tape transmission on-line and/or to business machines, or (2) direct read-out (without tape) from business machines for on-line transmission. Speed, 10 char/sec; 5, 6, 7 or 8 level codes.

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Produces 5-level "common language tape," prints data right on tape for handling ease. Speed, 10 char/sec. Non-typing version of this unit also available (LRPE).

LXD Tape Reader

For on-line transmission of 5, 6, 7 or 8 level tape at 10 char/sec. Transmission may be pulsed.

Teletype Corporation offers an extensive line of paper tape punching and reading equipment, with capabilities for meeting a wide variety of needs. In addition to the individual units illustrated, numerous combination sets are available—such as gang-mounted punches and readers, punch-reader relay sets, high-low and low-high speed converters, and page-tape consoles.

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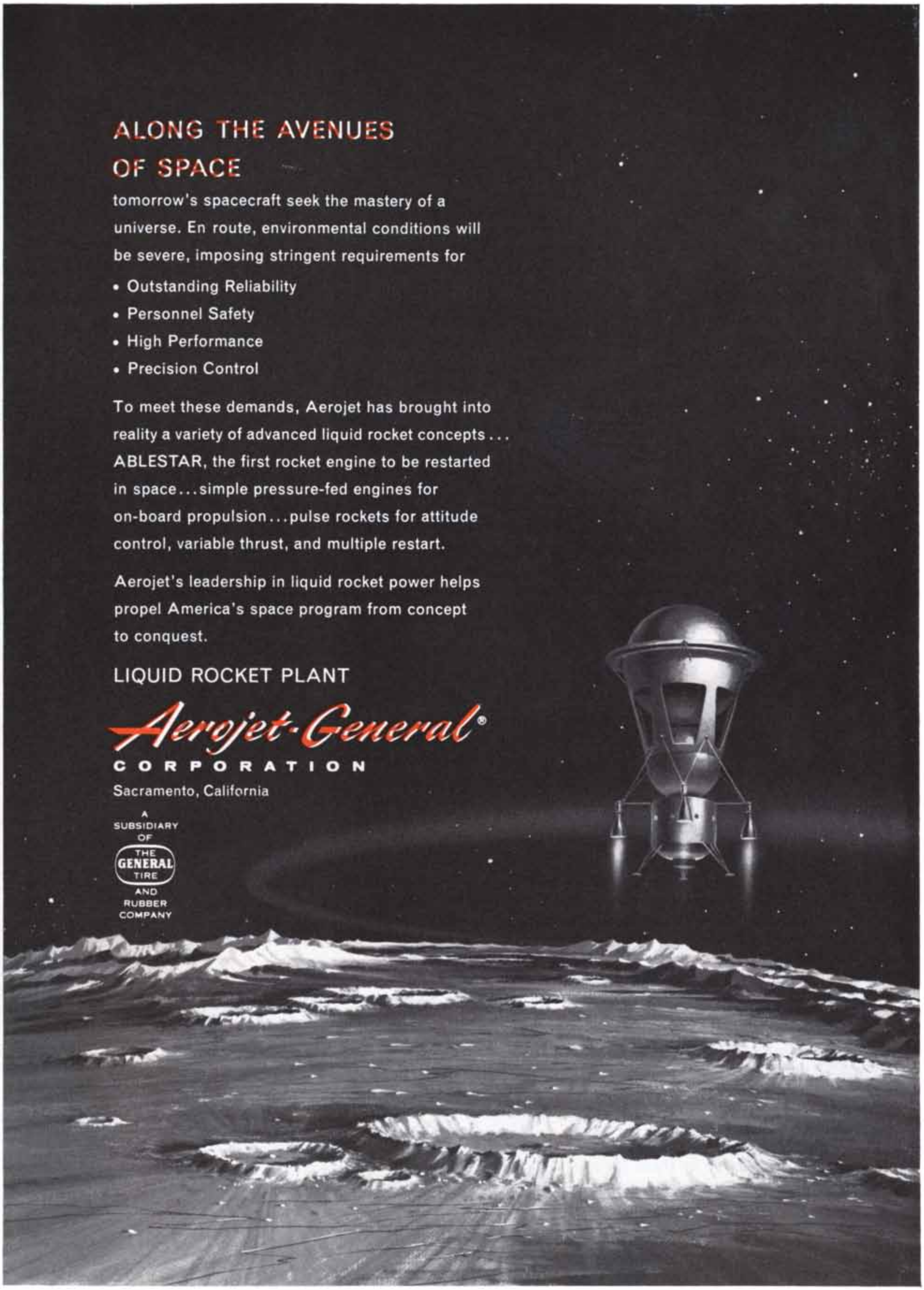
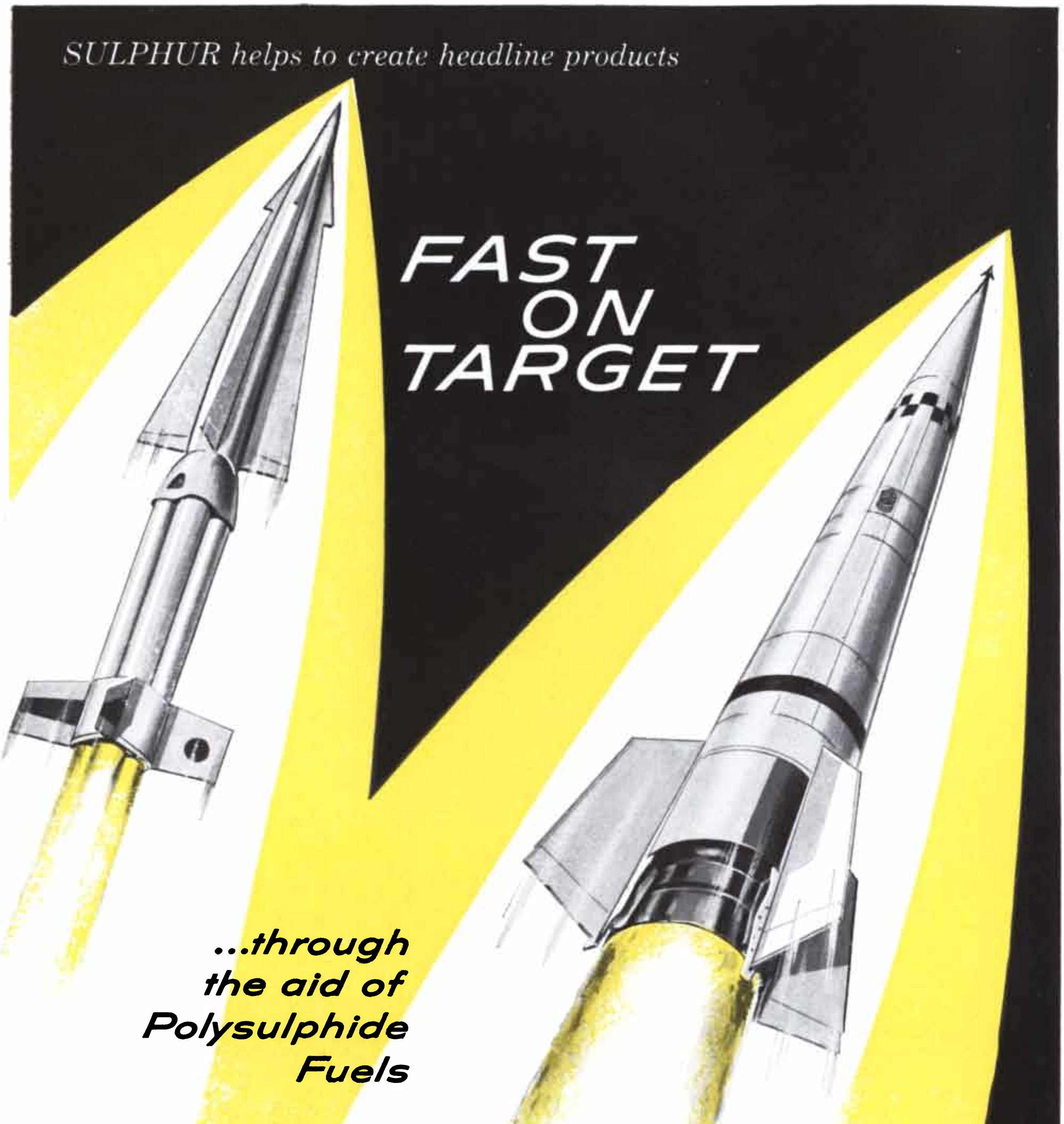


Engineers, scientists: investigate outstanding opportunities at Aerojet.



From the earliest days of our missile program solid fuels have been very much in the picture—with the polysulphides playing a leading role all the way. Today's successful NIKE HERCULES Defense Missile and SERGEANT Attack Missile are excellent examples of the types using polysulphide solid propellants. Motors for these missiles are produced by Thiokol Chemical Corporation. The need for sulphur in these fuels is important—a need that cannot be satisfied as well by any other element or by any compound.

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LETTERS

Sirs:

"The Census of 1960" [Scientific American, July], by Philip M. Hauser, contains some minor flaws of factual omission and commission.

The assertion that "states that have gained population are entitled to an increase in the number of their representatives [in Congress] at the expense of the others" is not quite correct. What is meant, of course, is that states receive additional representation when they record gains at a more rapid rate than the nation as a whole. The sizable increase of over 800,000 in Pennsylvania was exceeded in quantity in only eight states. Yet, with a rate of growth less than half that of the nation and with its large base population, Pennsylvania loses more congressmen than any other state.

The listing of the 12 largest cities in the nation, with the accompanying statement that only one (Los Angeles) gained during the decade, ranks the cities by their size in 1950 rather than currently. This was not so stated, and the context would lead the casual reader to assume otherwise. Of the 12 largest municipalities in 1960, two others (Houston and Milwaukee) joined Los Angeles in recording gains during the 1950's. To be sure, both annexed new territory during the decade; the description of the plight of most large cities remains valid.

The assertion that metropolitan growth accounts for 97 per cent of the national increase, while technically correct, exaggerates a metropolitan growth that in any event is quite large enough to be impressive. As noted in the article, the number of SMSA's (Standard Metropolitan Statistical Areas) was increased by 44 during the decade. In addition, a number of counties were added to the territory of the previously existing 168 areas. The inclusion of these new territories in the total 1960 metropolitan population, the comparison of this population with that of the fewer counties so designated in 1950, and the use of the word "increase" to denote the difference between the two figures are somewhat deceptive.

One point should, I think, be added to the discussion of marriage and family trends in America during the 1950's. The increase of youthful marriages, or, put another way, the decline in the median age of first marriage on the part of both sexes, is one of the most important demographic trends of recent years.

Joseph S. Vandiver

Oklahoma State University
Stillwater, Okla.

Sirs:

In general, the points made by my sociologist colleague are well taken, and his observations serve to clarify some of the nuances of the statistics and interpretations in my article. But some comments are in order:

1. Vandiver's observation about the relation of population changes to representation in Congress is quite correct and the phrase "states that have gained population are entitled . . ." should have read "states that have achieved relative gains in population. . . ."

2. In my statement about "population losses of the nation's largest cities . . ." I followed the convention of considering change from the beginning of the decade—that is, 1950. It would certainly have been clearer had I been explicit in the manner that he suggests but it would also have been more cumbersome.

3. My statement indicating that metropolitan growth accounted for 97 per cent of the national population increase is, as Professor Vandiver acknowledges, technically correct. I disagree with his observation that it "exaggerated" metropolitan growth or that it is in any way "deceptive." There are at least two ways to compare metropolitan population changes. One is to make the comparison by adjusting the universe of metropolitan

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He's solving a real estate problem

This AMF engineer's job is determining how best to move big missiles off shore for launching. Should they be floated out horizontally, flooded to an upright position, and then launched? Or, would it be more feasible to barge them out? Might they be moved to or assembled on "Texas Towers," or would a causeway or simply land-fill be the answer?

Behind the project is our shrinking real estate at launching sites, plus the hazards inherent in launching Saturn-sized missiles (and the coming, nuclear-powered missiles) near other installations. Off-shore launching may be the answer.

Feasibility studies of all types are an AMF specialty. What kind of remotely controlled machinery is required to service nuclear-powered aircraft? What kind of habitation could be built on (or under) the surface of the moon? What sort of machines (manned and unmanned) could survey the moon's surface without, for example, falling into a fissure? What is the best way to assemble a space station? All these are problems AMF engineers are presently investigating.

If your problem is the first of its kind, AMF will not, of course, have met it before. But AMF's long experience in accepting totally unique challenges gives it an advantage enjoyed by few other organizations concerned with ground support, launchability and space environment. To get further information write American Machine & Foundry Company, 261 Madison Avenue, New York 16, N. Y.

In engineering and manufacturing AMF has ingenuity you can use... AMERICAN MACHINE & FOUNDRY COMPANY areas as defined in prior censuses to the boundaries of metropolitan areas reported in the most recent census. By this procedure the population increase that has occurred in the constant geographical areas defined as "metropolitan" in the most recent census is given. But the question that I was answering at this point was a different question. I was answering the question "What change occurred in the population of the United States classified as 'metropolitan' between 1950 and 1960?" This also is a legitimate question and the correct answer to it is the answer I gave.

4. Vandiver violates his own standard of precision in his reference to the median age at first marriage. It is true that the decline in the median age at first marriage contributed in an important way to the boom in both marriage and babies during the 1940's. This decline in the 1940's, however, did not continue during the 1950's. . . .

PHILIP M. HAUSER

University of Chicago
Chicago, Ill.

Sirs:

In the very interesting article "Enzymes in Medical Diagnosis" [SCIENTIFIC AMERICAN, August] Felix Wróblewski spoke of the remarkable correlation between mouse tumor growth and the increased appearance of lactic dehydrogenase (LDH) in the peripheral blood serum of the host.

More recent work from this laboratory shows that this LDH elevation is largely due to the presence of a transmissible virus-like agent that engages in a synergistic reaction with the tumor to produce the substantial enzyme increase in the plasma. Most tumor-bearing mice have normal plasma LDH values in the absence of these agents. An account of this tumor-virus effect has appeared in *Science* for September 8.

The role of viruses in altering the enzymic *milieu intérieur* further increases the interest of biochemical biopsy and its promise of improving our understanding of benign and malignant processes, as well as assistance in early diagnosis and in following the course of the patient's struggle with his disease.

VERNON RILEY

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Automatic information retrieval system

Kalvar —*the uncommon denominator*

Mathematicians may quarrel with our use of "the uncommon denominator". Not, however, the creative men of IBM, Litton Industries, Thompson Ramo Wooldridge Inc. and other break-through companies who are using Kalvar's heat-developable photographic materials as basic components in a wide range of systems and projects.

Kalvar produces photographic films and paper that are developed by heat alone, in a completely dry state, and in normal room lighting.

Of all available photosystems, only Kalvar is based on the principle of light-scattering, rather than the light-absorption principle common to conventional films. Kalvar has developed this unique principle into practical films that, in addition to the above advantages, are completely processed in seconds, project beautifully, and are tough and untearable. The same basic characteristics of Kalvar's films hold true for the heat-developed photographic paper recently introduced.

The wide versatility of the Kalvar photosystem is rather dramatically illustrated in these examples:

Random Access Information Retrieval. IBM is developing for the Central Intelligence Agency a new information retrieval system, "Walnut", that will retrieve and exhibit within 10 seconds any one of millions of documents filed at random. The original documents are reproduced on Kalvar film at 1/1000th of their original size. The film is stored in small "cells" within a bin that can hold 990,000 document-images. When an inquiry is made for a document, its image is automatically reproduced in seconds, by ultraviolet light and heat alone, on Kalvar film contained in an IBM aperture card. This allows the document to be viewed on a screen or printed on paper without removing the original image from storage.

Computer Display System. Thompson Ramo Wooldridge Inc. is using Kalvar film in a highly advanced computer display system being produced for the Department of Defense. The purpose of the system is to generate and update photographs, charts, maps and other situation displays for individual or group viewing by top level military commanders. The requirement of an extremely rapid response time (one minute or less from the time the information is requested until it is projected on viewing screens) led to the selection of Kalvar film, on which updating information can be exposed and processed in a few seconds under normal room illumination.

Direct Print and Readout. Litton Industries is designing and manufacturing cathode ray tube transducers to direct print and read Kalvar film electronically. Adaptations of several Litton cathode ray tubes are now being used, and will extend the use of Kalvar in computers, data processing equipment, and large-picture display.

A new booklet, "Kalvar's Partners in Progress", outlines additional current research or uses for the Kalvar photosystem in a wide range of fields . . . microfilm reproduction . . . electronics . . . automatic source recording . . . the graphic arts . . . radiology . . . office-copying.

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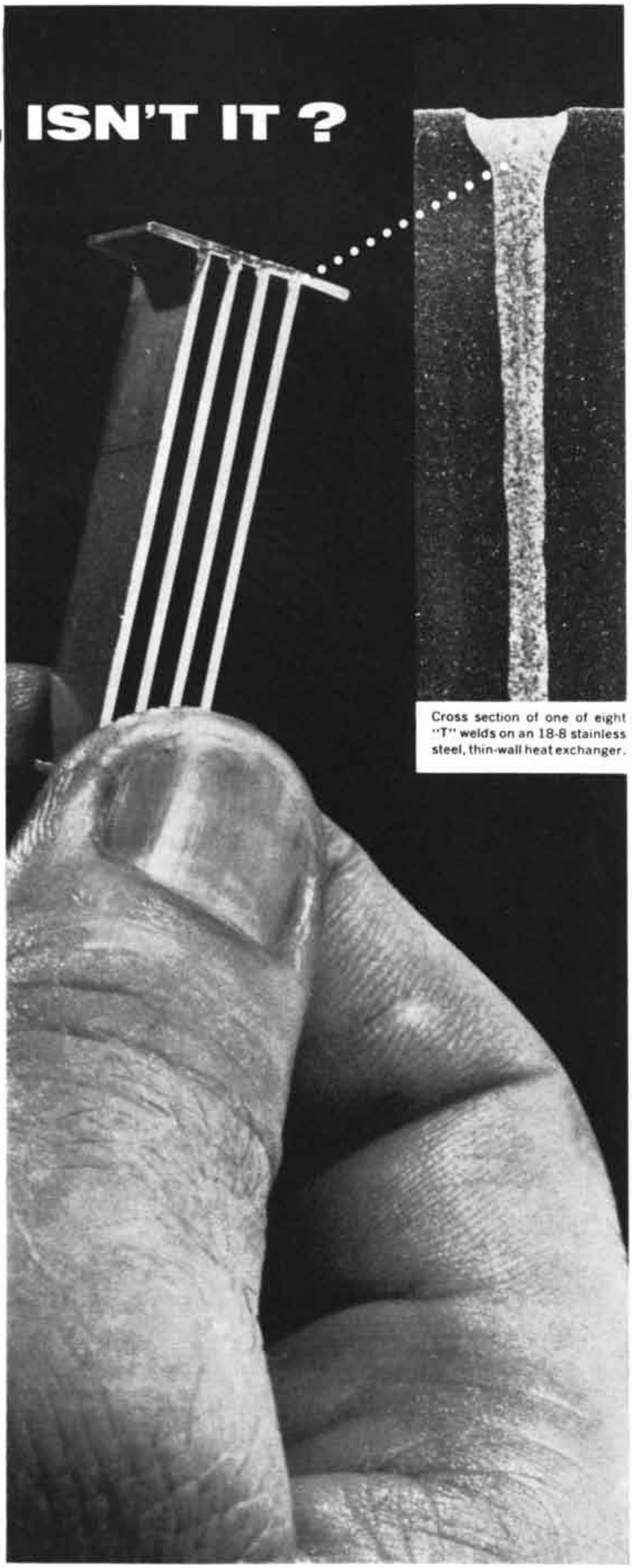

Cross section of one of eight "T" welds on an 18-8 stainless steel, thin-wall heat exchanger.

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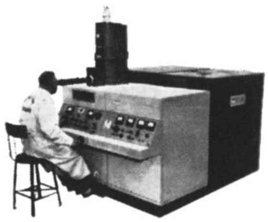

Complete information on Hamilton-Zeiss machines is available from Hamilton-Electrona, Inc., Time-Life Building, New York, New York.

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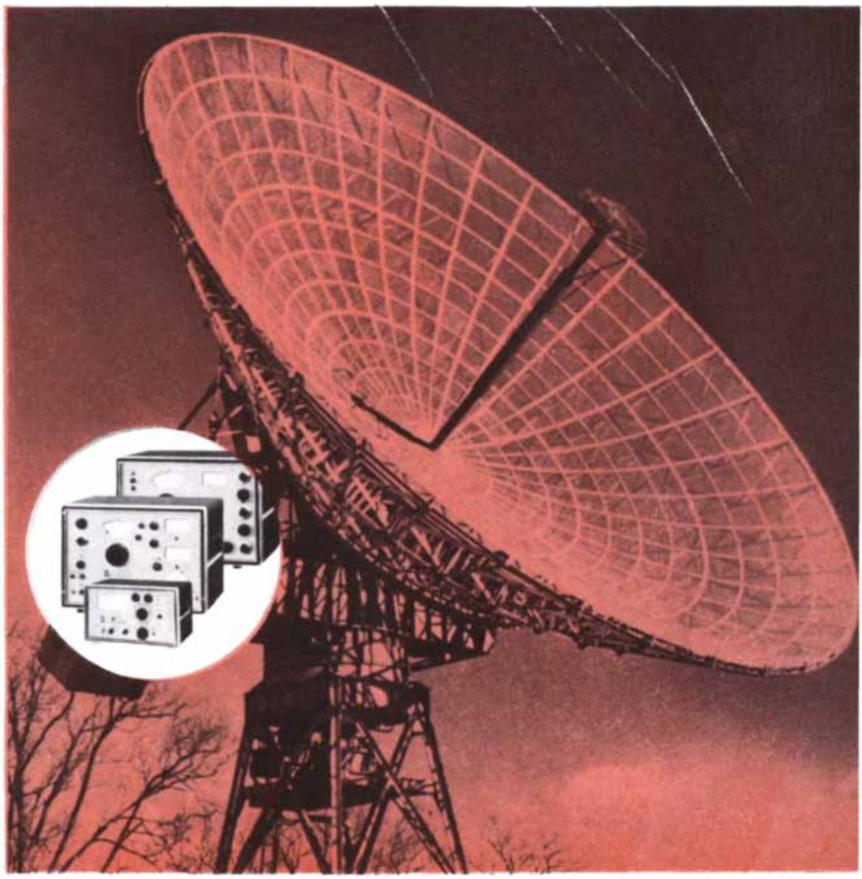

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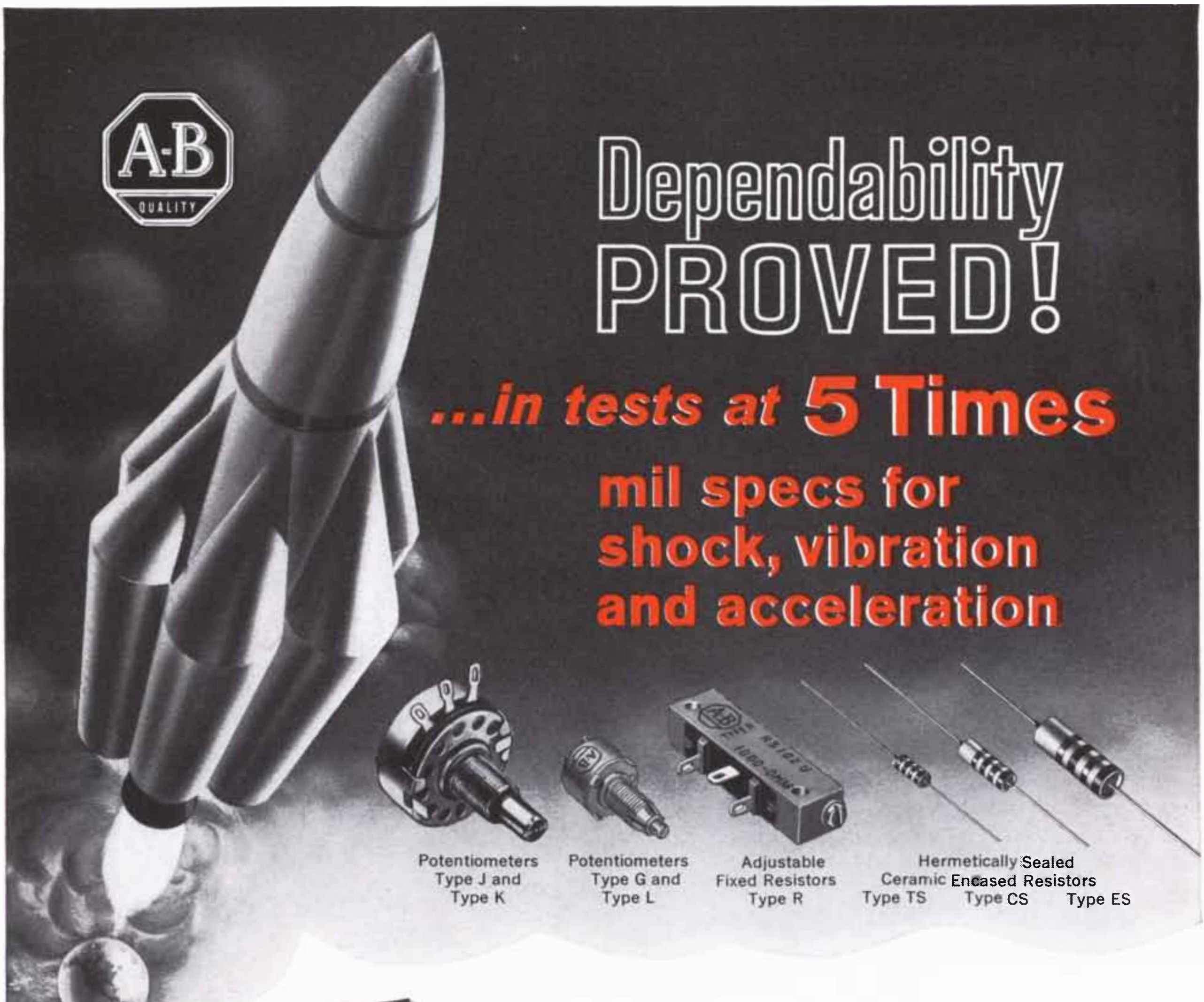

About the test

At the United States Testing Co., Inc.* the above Allen-Bradley resistors and potentiometers were subjected to a constant acceleration of 300g, impact shock of 150g and vibration of 50g from 55 to 2,000 cps. All tests were conducted in accordance with procedures outlined in the latest Mil Specs.

*Test Report #71801, Sept. 1960

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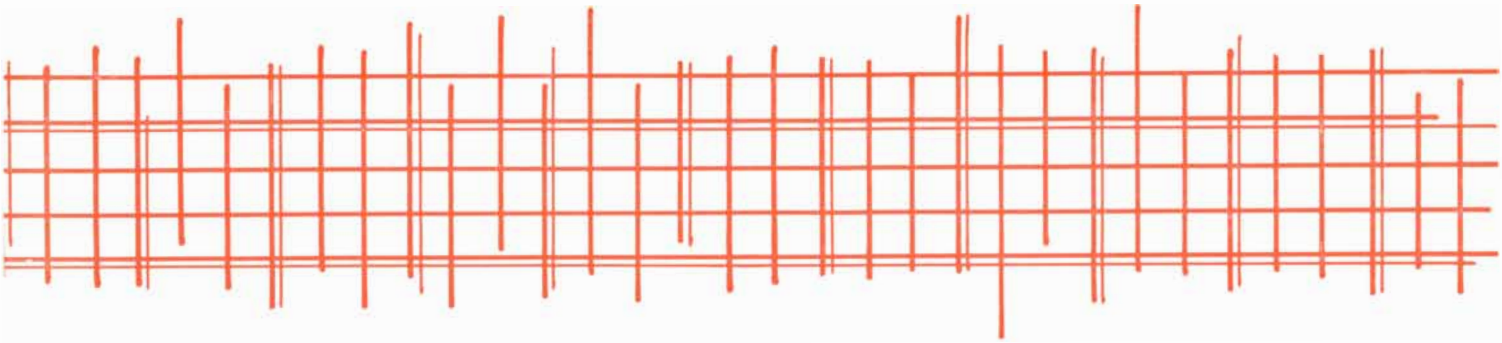

genus: homo · species: sapiens
discipline: factors engineering

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SCIENTIFIC AMERICAN

NOVEMBER, 1911: "The news has just been published of the award to Madame Curie of the Nobel prize for chemistry. This great woman scientist thus enjoys the extraordinary distinction of having twice been honored with this prize, for in 1903 one-half of the award in the section of physics went to Pierre Curie and Madame Curie jointly, the other half being bestowed upon Prof. Becquerel. The material benefits conferred with the prize amount to the sum of $40,000, a gift which is not to be despised, although perhaps the principal value to the recipient lies in the great honor which attaches to this award, the list of the Nobel prize winners comprising, as it stands today, a perfect galaxy of the greatest genii in the scientific world of our time."

"The most notable fact in the development of submarines is their increase in size and in steaming radius. This means that the submarine is approaching the day when it will accompany the fleet on the high seas and play a most important part in the general action of the future. The British are building two new classes of submarines, one of 600 tons, and the other of 800 to 1,000 tons displacement. Sixty-six of their latest submarines have a surface radius of 2,000 miles, which is being raised to 4,000 and 5,000 miles in what is known as the new 'B' and 'E' classes."

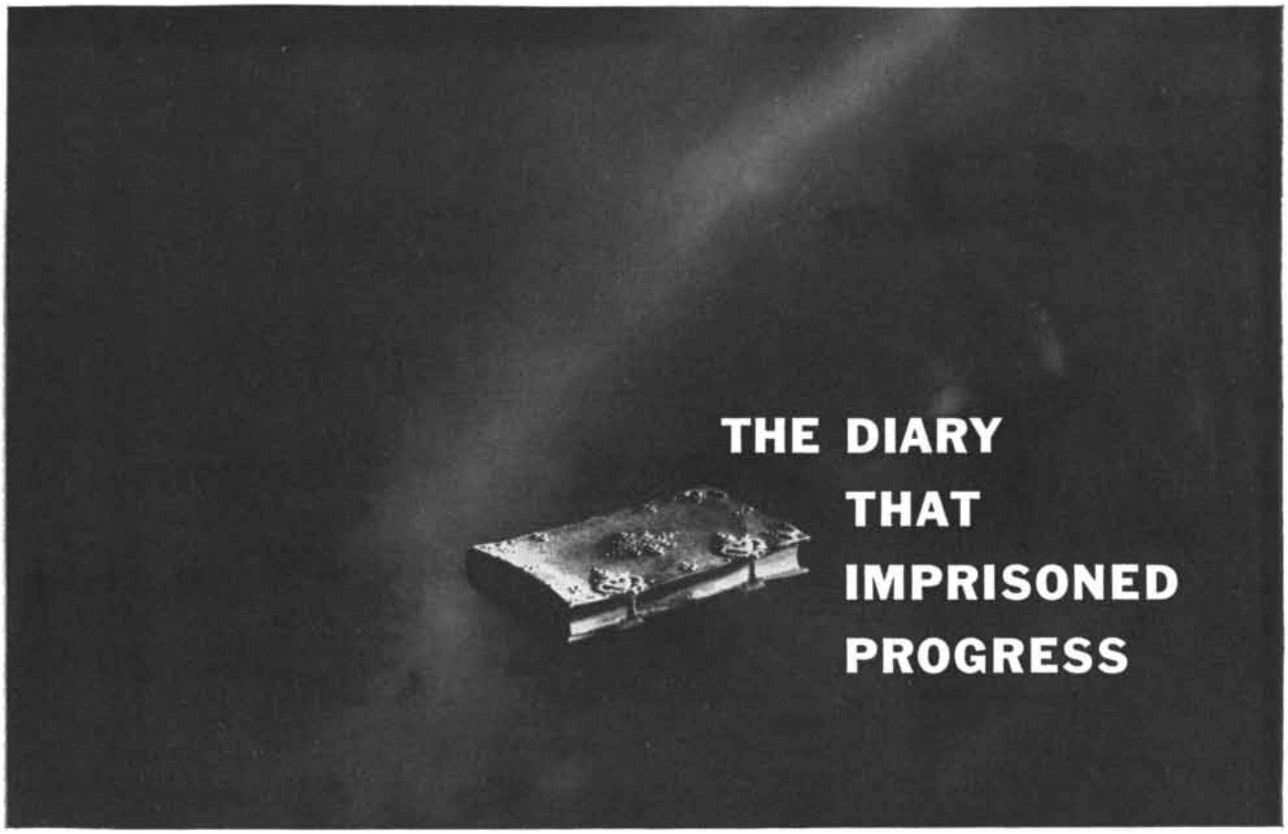
"According to the report of the post office inspectors to the Postmaster-General, no less than 43,247 pieces of mail matter were despatched by aeroplane from the Nassau Boulevard Aerodrome between September 23 and October 1. So enthusiastic has the Postmaster-General become as to the possibility of saving time and money in delivering mail in certain districts by aeroplanes that he has asked for an appropriation of $50,000 to enable the Post Office Department to experiment thoroughly along these lines. Just as the automobile is at the present day rapidly replacing the horse in city mail delivery, so the aeroplane will no doubt displace the fast express before many years have passed."

"Many of the most serious automobile accidents are due to a misunderstanding or ignorance of the driver's intentions, and so a system of hand signaling has come into vogue, which, although crude, answers many purposes so long as the driver of one car is enabled to see that of another. At night such communication between the car operators is impossible. A rear signal has been devised for the purpose. It is electrically operated and consists of three lamps and a horn. A red lamp is lighted permanently, while above is a green lamp, which, being flashed, signifies that the driver is about to stop. To the right and left are white lamps, signifying his intention to turn to the right or left. These signals are all electric and are operated by buttons, conveniently placed for operation by the chauffeur. As any one of these signals is made, the horn is sounded to attract the attention of whoever may be following."

Scientific American.

NOVEMBER, 1861: "A great work is accomplished. The Pacific shore of the country is in instantaneous telegraphic communication with the Atlantic. Though amid the excitement of war no noisy demonstrations have marked the successful termination of this enterprise, it is recognized as an event of the very highest importance. Above its inestimable value in transmitting public intelligence and facilitating the operations of commerce, above even its higher uses in communicating the knowledge of deaths and other social events to widely separated families, must be its influence on the destinies of the nation. It is an intellectual nerve stretching across the continent and constituting the strongest of all bands to bind the extreme East to the farthest West."

"Steel, even that of the most expensive kind, is rapidly taking the place of wrought iron in various parts of railway and other machinery. On the Continental railways steel tyres and axles are in extensive, indeed general, use. Steel tyres, at nearly £5 ($25) per hundredweight, have been largely adopted also on various English lines, and cast-steel crank axles, of both Prussian and Sheffield make, are coming into favor, notwithstanding the very high price at which



Nearly two centuries ago, Karl Gauss, "Prince of Mathematicians," kept a diary which was destined to become one of the most significant documents in the history of mathematics.

In his diary Gauss jotted down the results of elaborate calculations that had led him to fundamental discoveries in mathematics. But he never published these discoveries, and many of them remained undisclosed during his lifetime.

It wasn't until almost 50 years after Gauss's death that his diary was found and published. Much time and talent, meanwhile, had been spent in duplicating Gauss's efforts. Mathematical progress had been needlessly slowed.

In contrast, today's scientists and engineers are alert to the importance of sharing their findings through publication. In fact, the number of definitive papers published in a scientific or technological field has become a sure sign of the creative effort in that field.

Bell Laboratories scientists and engineers publish more than 800 papers a year, reporting new observations and new thinking in the arts and sciences that serve communications. They have also authored more than 50 technical books, many of which have become standard works of reference. The steady stream of new information that comes out of Bell Laboratories again reflects the scope and depth of the creativity that works to improve Bell System communications.

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they are sold. Heretofore the general notion of steel has been that it was too brittle for use in any kind of work exposed to concussion, but if we regard as steel any combination of iron and carbon that may be hardened by immersion, while heated, into a liquid, then we may have steel that has not only greater cohesive strength but also greater absolute tenacity under all circumstances than the best wrought iron."

"The *Army and Navy Gazette* (British) states that while England is busily engaged in converting some of the timber war steamers of the navy into armor-plated vessels, after the pattern of the French frigate *La Gloire*, the French have actually abandoned the plan and are building all their vessels solely of iron. It is said that this step is the result of experience gained by trials with *La Gloire*. Her timbers have been found unable to bear the weight of the armor and the strain of broadsides."

"From a report of a lecture delivered at the Melbourne Mechanics' Institute by Mr. Edward Wilson, of the *Argus* newspaper, it appears that the work of acclimatizing European birds and fishes to Australia is being pursued vigorously and with considerable success. The skylark and the thrush were breeding freely in a wild state. A number of fallow deer had been turned out and had taken readily to bush life. Several kinds of English pond fish had been safely brought over and transferred to the native waters. A collection of birds, among others the Indian curassow, gold, silver and common pheasants, Ceylon peafowl, American and other waterfowl, were being prepared in the Botanic Gardens for transfer to wild land, and it was thought that all would eventually thrive. The llama has been acclimatized and its wool has become one of the products of Australia."

"Up to the time of the arrival of the Arctic explorers two weeks ago at Halifax, N.S., they had received news only once in twelve months about American affairs. This was at Uppernavic, in an English newspaper containing President Lincoln's call for the extra session of Congress. The *United States*, the vessel in which Dr. Hayes and his companions went upon their expedition, sailed from Boston in July, 1860, and proceeded to Uppernavic and Smith Sound. In the latter place she remained until July last, when she started on her return. Dr. Hayes and three men, with dog sleds and boats, went as far north as 81°35′."

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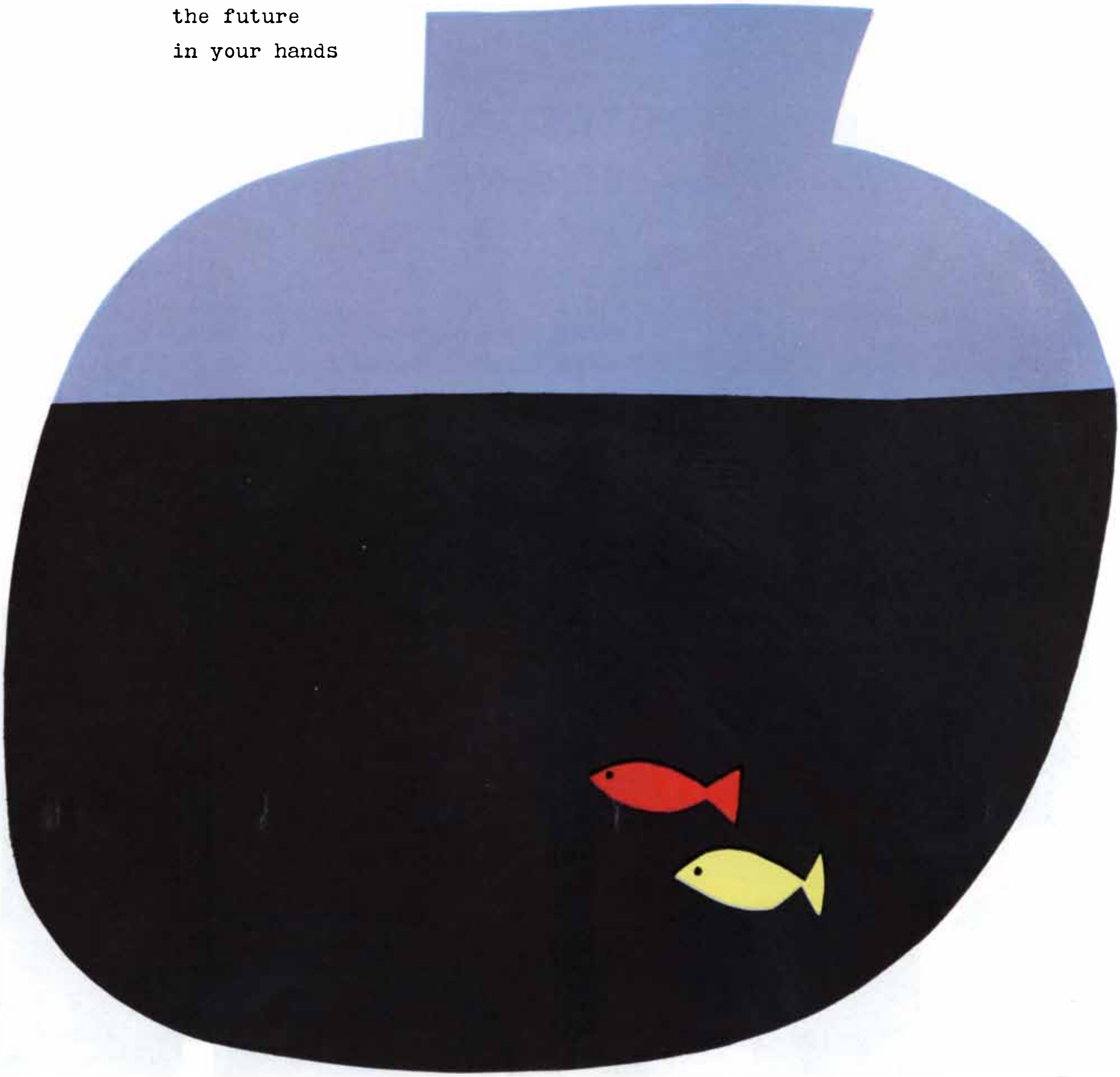


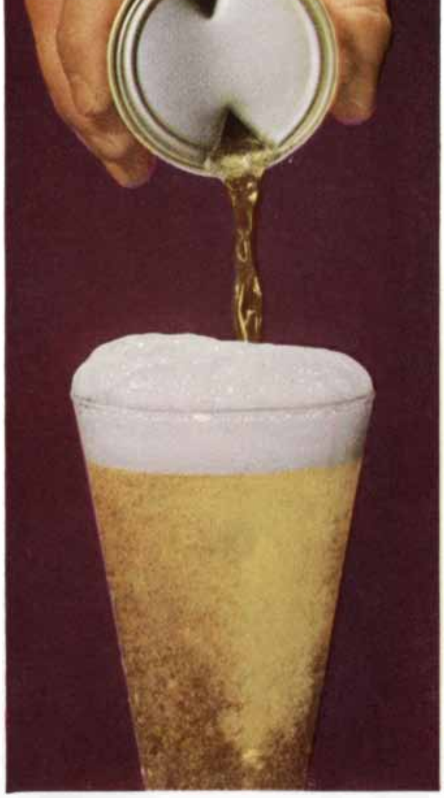
Man is like a Goldfish in a Bowl of Ink...His view of the "ultraviolet universe" is shut off by the blanket of air which surrounds him.

The earth's atmosphere is like the ink in a goldfish bowl. It absorbs so much of the ultraviolet light from outer space that little gets through to show us what lies out there.

But now, an electronic imaging tube, sensitive to this ultraviolet light, has been developed by Westinghouse Research scientists. Westinghouse is working with the Smithsonian Institution and the National Aeronautics and Space Administration to mount these tubes in satellites so that they can "see" in outer space and radio their findings back to earth.

Every time mankind removes the limitations on human sight... with the telescope, the microscope, the fluoroscope and electronic imaging tubes...we find things which have a profound effect upon our lives.

You can be sure...if it's **Westinghouse**

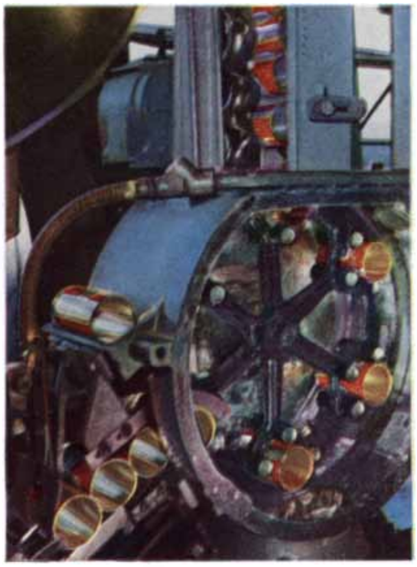


TWELVE MICRONS SEPARATE "AH-H-H!" FROM "PFUI!"

Between a flavorful beverage and its metal container, Glidden can coatings only .0005" thick make the difference between a tasty treat and an unappetizing disappointment.

Concentrated research by Glidden chemists on petroleum monomers provided the basis for a new can coating system that gives full protection and meets FDA and consumer requirements.

Butoxy base coats provide highly impervious can linings that are applied by existing coating equipment, yet cost up to one-third less. New Glidden vinyl top coats are readily applied over the base coat for complete protection of beverage from taste and appearance failures.



1 Copper sulfate test shows up any eyeholes or breaks in the coating as black spots. Glidden-developed coating completely protects test can end (at top) even after fabrication, processing and extended storage.

2 In the Glidden can coatings laboratory, this 15-inch roll-coater, one of only six in the nation, enables Glidden chemists to duplicate coating methods to be used on customers' production lines.

3 Retractable spray-gun deposits continuous coatings of Glidden taste-inert vinyl top coat over entire inner surface of the can body. Glidden technical service personnel work closely with customers' technical and production men to assure that coating is perfectly suited to application equipment.

4 At six Glidden Industrial Finishes plants, formulations of special can coatings to highest quality-control standards are produced in batches from a few drums to tank-wagon lots.

If your product requires a finish, a coating, or a resin, Glidden is ready to work with you. To obtain the formulation best suited to your product and application methods, write or phone:

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e Glidden Company, Ltd., Toronto, Ontario

A look at what's ahead in the realities of space exploration

Some predictions from Douglas —the company that has helped launch 70% of all U.S. satellites & space probes

Our mastery of space has advanced so rapidly that only diehard pessimists doubt the moon and planets will know our footsteps within a few decades.

Already a vehicle capable of orbiting a 19,000-pound payload, or driving 5,000 pounds to escape velocity, or lofting 2,500 pounds to Mars or Venus is being built in the U.S. This is Saturn, taller than a 14-story building, with an initial thrust of 1.5 million pounds. Its second stage, under construction for NASA by Douglas, will use a cluster of liquid hydrogen-oxygen engines of unique design.

The world knows a man can rocket into space and return. Can he survive for long periods? Douglas studies give a strong affirmative. Zero gravity and artificial G require further study. Radiation is a continuing problem, but reports from Discoverer XVII, one of 46 space projects launched by the Douglas Thor rocket, show the threat less serious than was first thought.

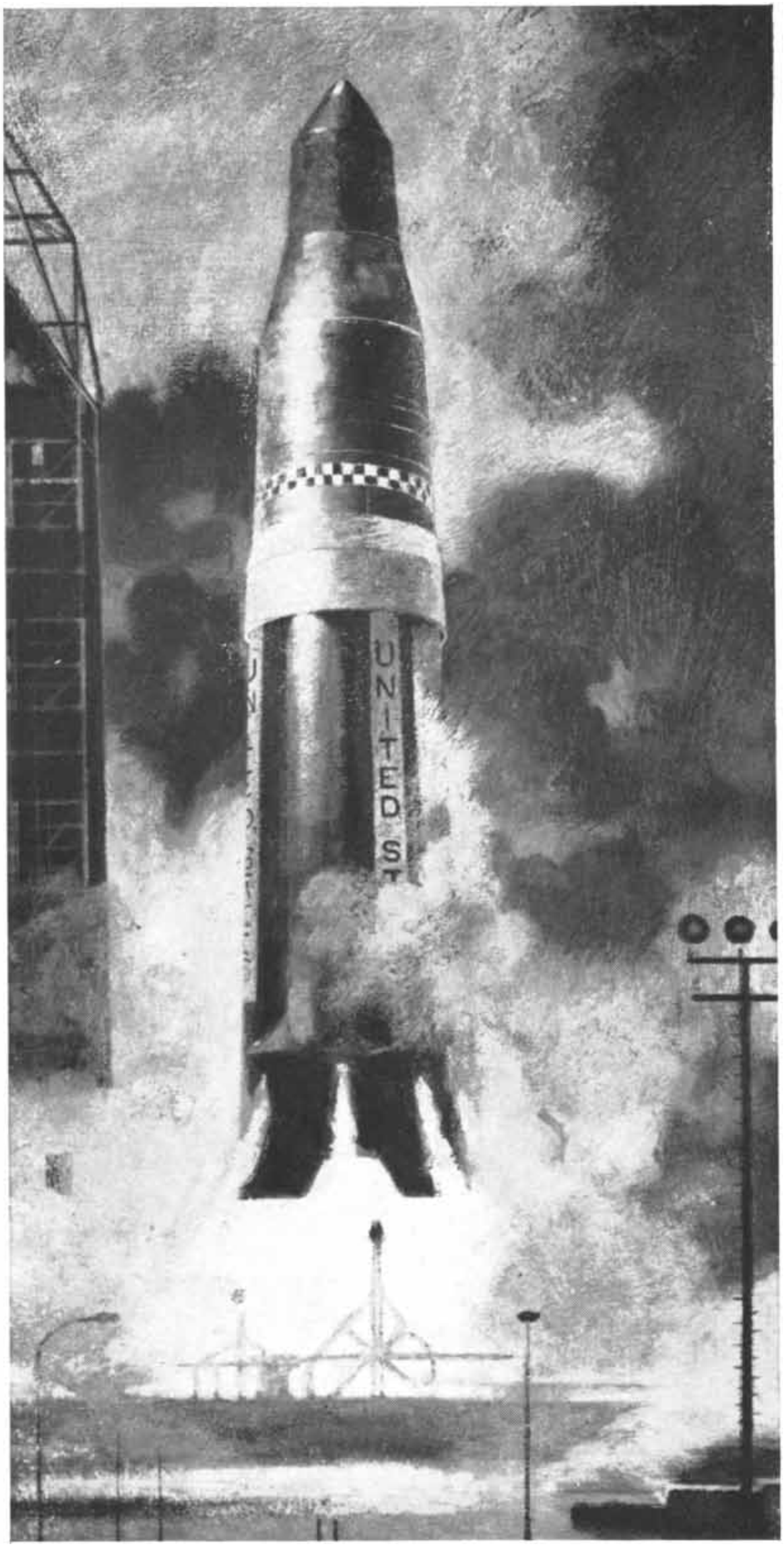
The cost of space travel? A breakthrough in nuclear power, which Douglas engineers confidently predict, should cut the operational cost of a trip to the moon to about $900 per passenger. Other power sources, already under study, may even open such stars as Sirius and Alpha Centauri to travel.

The DC-8 Jetliner, an example of Douglas aero-space leadership

Few of us will ever be lunar commuters, but growing millions are learning about a new kind of travel through the DC-8 jet.

Here is an airplane that slices through time at 10 miles a minute, opens the world to all who have an urge to get up and go places.

Next trip, fly a DC-8 jet, newest of which is the DC-8 Series 50, fastest long-range jetliner in the sky.



Douglas is building Saturn's 2nd stage.

DOUGLAS

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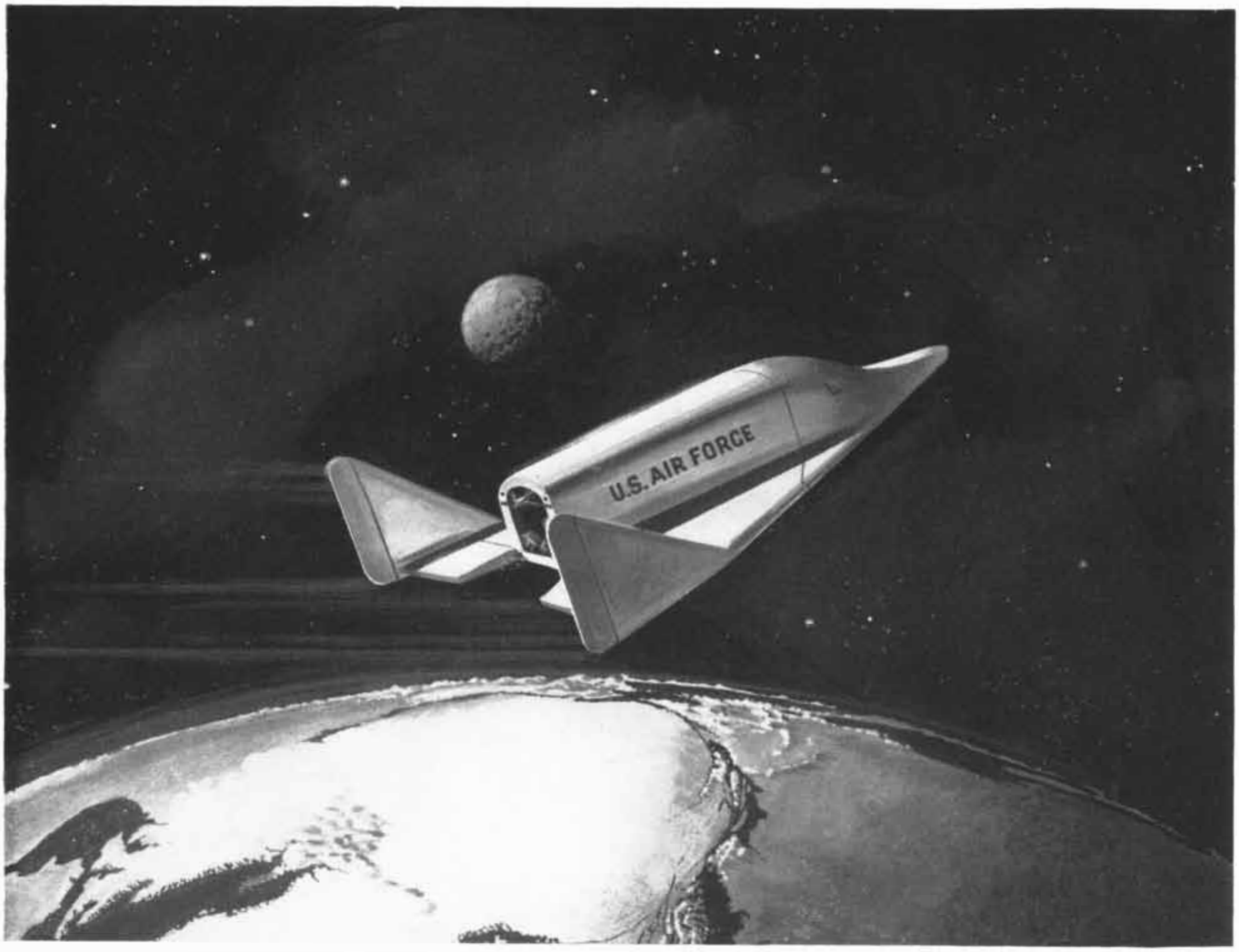


SPACE GLIDER. Drawing of Dyna-Soar space glider, which will combine extreme speed of a ballistic missile with controlled and accurate flight of a manned aircraft. Designed to be rocketed into space, where it could travel at speeds approaching 18,000 mph, Dyna-Soar will be able to re-enter earth's atmosphere and make conventional pilot-controlled landing. Boeing is system contractor for Dyna-Soar, now being developed by U. S. Air Force with cooperation of National Aeronautics and Space Administration.

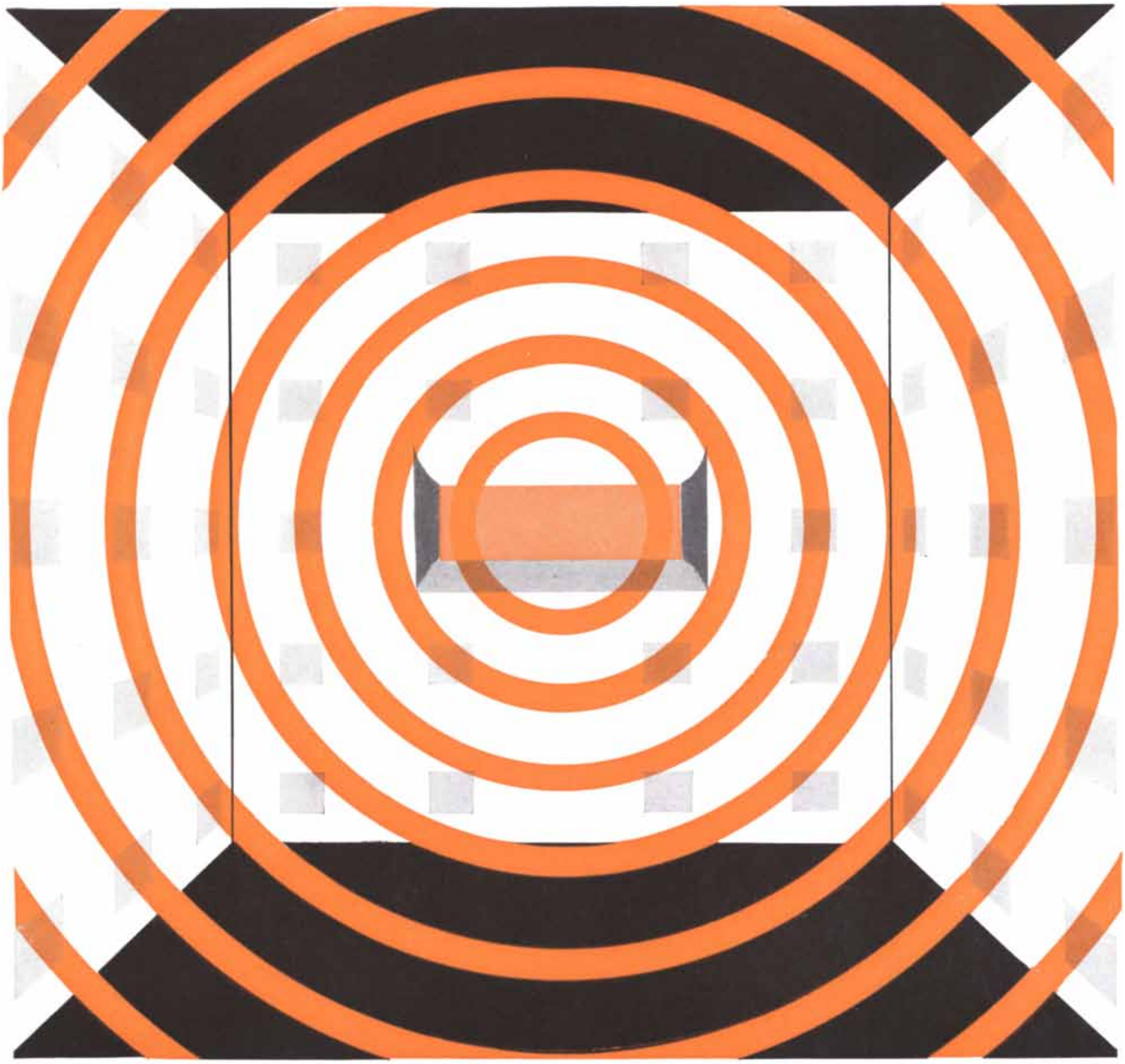
Capability has many faces at Boeing

THREE-ENGINE JET. Scale model of America's first short-range jetliner, the Boeing 727. Already, 117 Boeing 727s have been ordered by American, Eastern, Lufthansa and United airlines for delivery beginning late in 1963.

PLASMA PHYSICS. Boeing Scientific Research Laboratories scientist has verified experimentally, for the first time, a theory concerning ionized gas—important in future harnessing of thermonuclear power.

AUTOMATIC SKY FIGHTER. Supersonic Boeing Bomarc missile, now operational, is the United States Air Force's push-button defense weapon against airborne missiles and attacking bombers. New Bomarc "B" models have scored test intercepts up to 446 miles from base at altitudes of more than 100,000 feet.

BOEING



Ceramic Engineers at Ramtite mix imagination with Alcoa Aluminas to produce super refractory: 90-RAM

An example of the outstanding refractories The Ramtite Company has developed for steel mills is 90-RAM—a 90 per cent alumina ramming mix. Originally used to line laboratory furnaces in Ramtite's own research department, 90-RAM proved its dependability in 60 months of trouble-free service. Now it is being used in many of the largest steel mills for such versatile applications as continuous heating furnace hearths; facing of burner walls and side walls in slab reheating furnaces; forge heating furnace hearths; ferrous and nonferrous melting furnaces; soaking pit slag lines and in several parts of basic open hearth furnaces.

Advantages of 90-RAM include excellent resistance to very high temperatures, abrasion and deformation. In addition, 90-RAM can be laminated to other refractories, forming a monolithic bond which makes it ideal for facing and relining refractory surfaces.

In meeting the needs of steelmaking and other high-temperature operations with a family of refractory materials, Ramtite *mixes imagination with Alcoa® Aluminas*—for excellence in refractory performance at reasonable cost.

Alcoa is not a source for finished refractories. It can supply in unlimited quantities the high quality aluminas that make modern refractory performance possible. Write to Aluminum Company of America, Chemicals Division, 701-L Alcoa Building, Pittsburgh 19, Pennsylvania.

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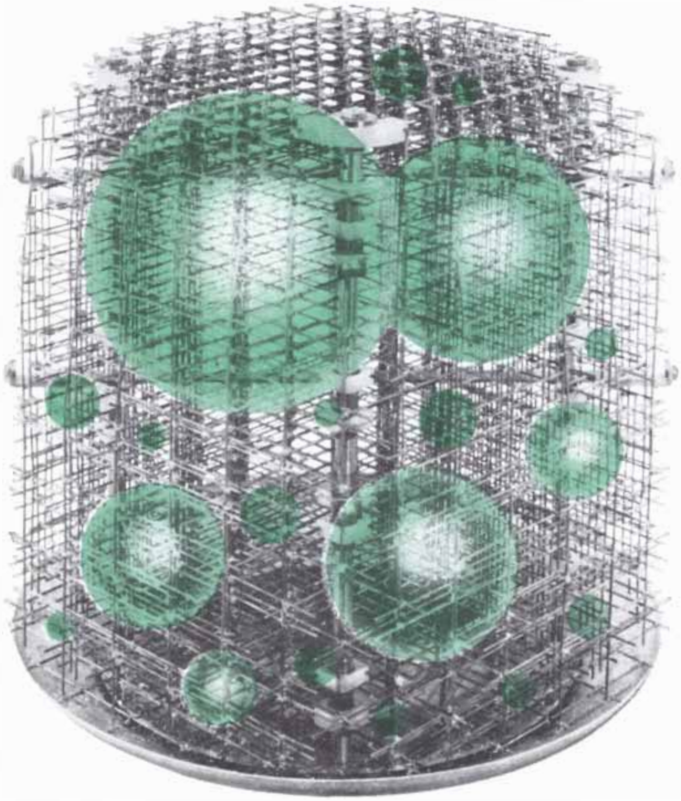

Another measure of the competence of Liquidometer in advanced instrumentation

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whatever a liquid's state or attitude, whether still or in agitation, the volume indication is the same with the Liquidometer Matrix Liquid Quantity Gauge. A capacitor type measuring probe — intercellular in construction — is the heart of the system. In addition to actuating an indicator, output can be telemetered, used for control purposes, or fed into computers. Potential applications: measuring liquid oxygen for astronauts; gauging liquids in advanced rocket propulsion systems; all-attitude gauging of aircraft fuels. Technical details in Booklet 694.

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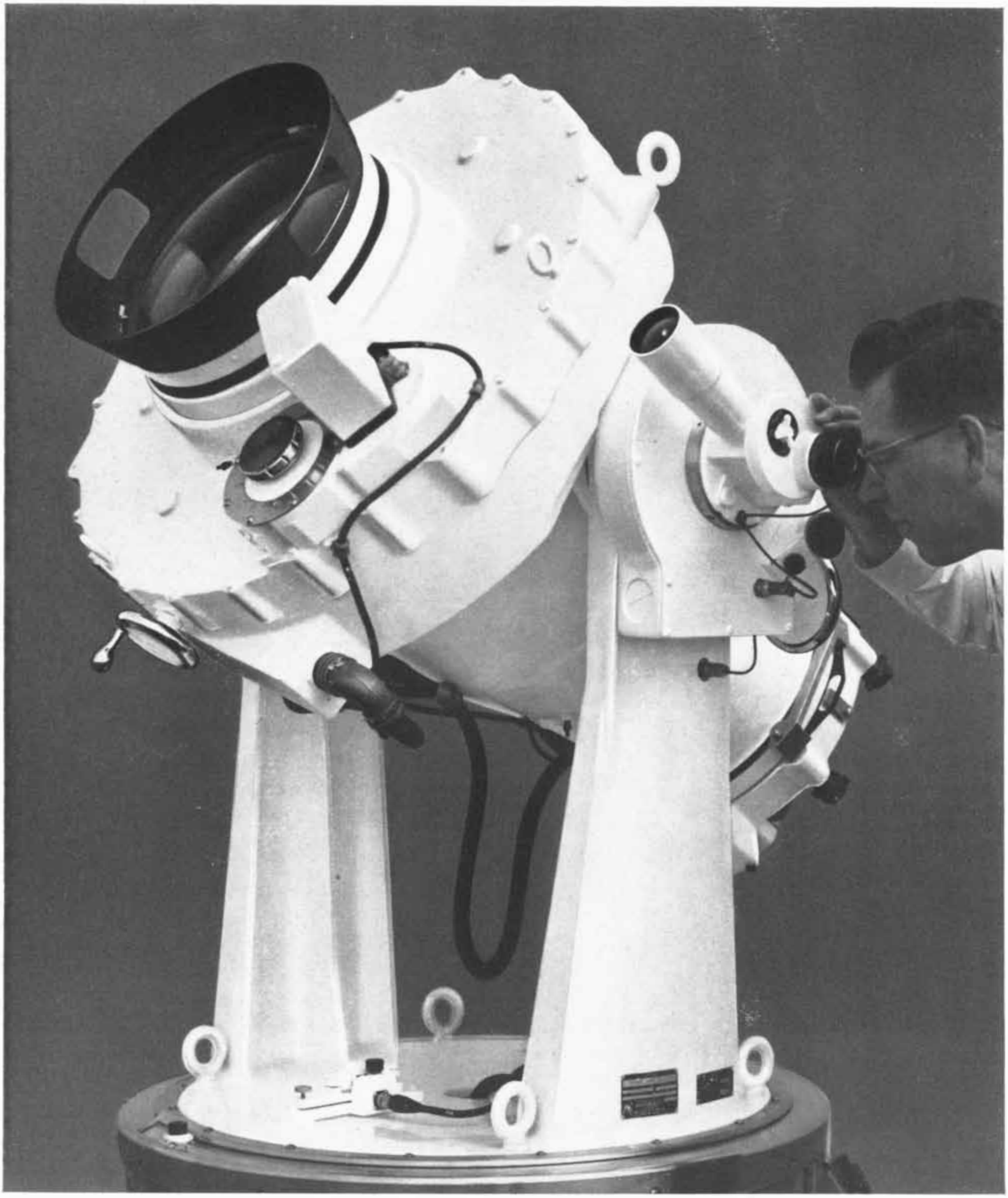

This camera watches the birdie

This is a ballistic camera, designed to photograph a missile in flight, and check its trajectory against a precise background of stars to detect the slightest deviation from course. It is the largest accurate ballistic camera ever built. Its 8-element, 600-mm, f/2 lens has an accuracy of 1 part in 200,000. Though the shutter is 12 inches in diameter, it opens and closes in 2 milliseconds. The entire instrument, including its unique lens and shutter, was designed and manufactured by the Nortronics Division of Northrop.

NORTHROP

NEW FROM DU PONT...
a thermoplastic "Teflon" film that's easy to fabricate

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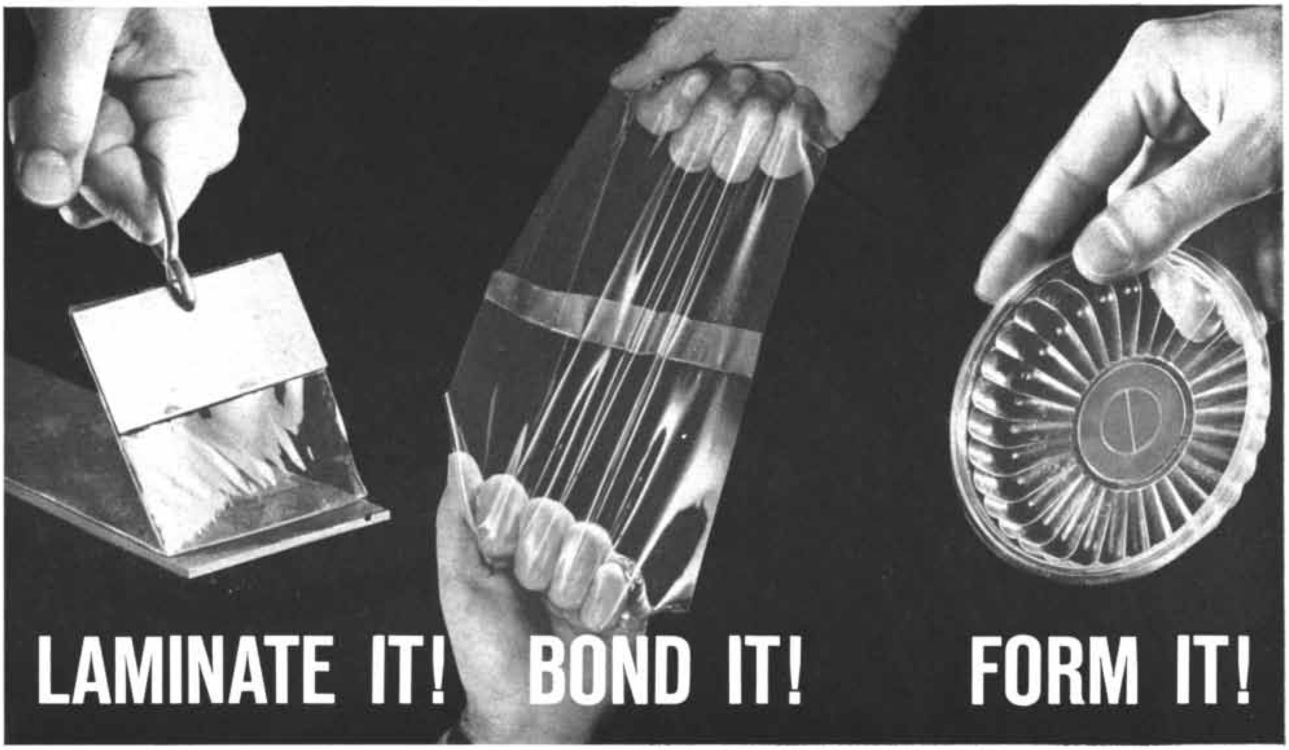

New "TEFLON"* FEP-fluorocarbon film has nearly *all* the unique advantages of "TEFLON" TFE with one big plus. It's a true thermoplastic that can be easily formed and sealed. One type of this new film can be applied *with* adhesives, another can be laminated and heat-bonded *without* them.

Here are just some of the advantages of "TEFLON" you get in this new film • Unique antistick and low-friction properties • Chemically inert to practically all known chemicals • Electricals are high (up to 4,000 volts/mil dielectric strength) and *stay* high • Performance stays virtually constant from −250°C. to over 200°C.

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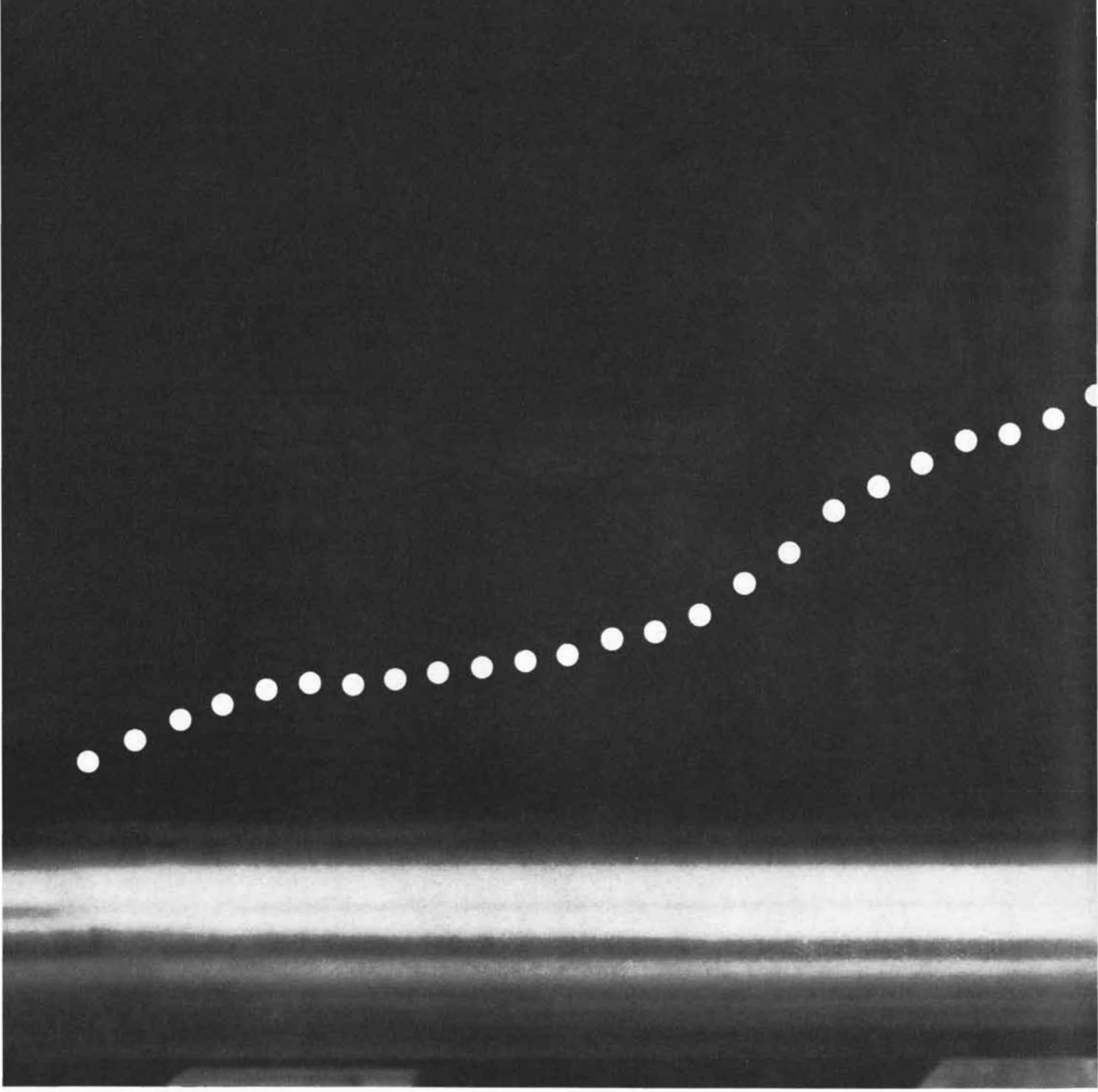
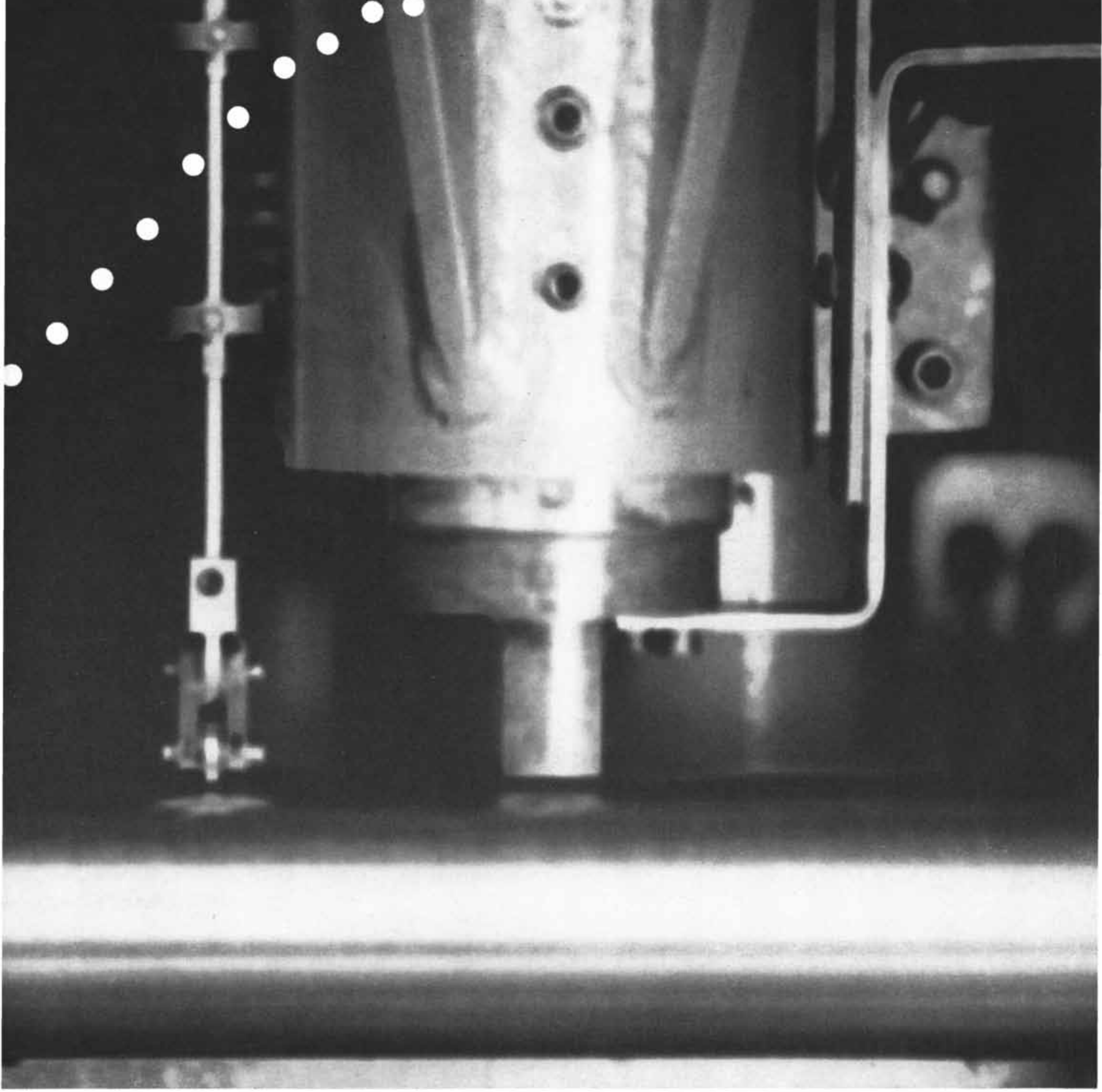


TAKING THE SHIMMY OUT OF THE SHAFT

Straightening is a necessary step in the manufacture of millions of shafts used by the automotive industry. The reason? Straightening is cheaper than manufacturing the shafts directly to the high tolerances required. The forces needed to straighten any production run of shafts are usually nonlinear. The difficulty of programming such forces has long held back the design of an automatic straightening machine. Moreover, each series of shafts requires its own straightening curve, depending on its size, type of alloy and heat treatment.

Now a way has been found to straighten shafts automatically with the aid of the Perkin-Elmer Adjustable Function Generator. This instrument makes it possible to quickly set up a nonlinear function, forming a visible curve. The Adjustable Function Gen-



Automatic Straightening Press by General Automation Manufacturing, Inc., Troy, Michigan

erator controls the straightening machine's ram, which bends the shaft in conformity with this curve. The curve can be changed at the touch of a finger. Different series of shafts can be fed into the machine one after the other after a simple change in the shape of the curve.

The Adjustable Function Generator is derived from the Vernistat® a.c. potentiometer—an extremely accurate and ultra-precision potentiometer manufactured by Perkin-Elmer. Like P-E electronic-optical systems, these electrical components are precise measuring devices. Perkin-Elmer instruments are doing other vital jobs for industry and defense, such as analyzing chemicals . . . aiming and tracking guided missiles.

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Scientists and engineers interested in challenging careers are invited to write Perkin-Elmer. All qualified applicants will be considered regardless of race, creed, color or national origin.

THE AUTHORS

EDWARD L. GINZTON and WILLIAM KIRK ("The Two-Mile Electron Accelerator") are respectively deputy director and head of the technical information division of Stanford University's accelerator project. Ginzton, professor of applied physics and electrical engineering at Stanford, was born in Russia in 1915, came to the U.S. as a boy and was graduated from the University of California in 1936. He received his Ph.D. from Stanford in 1940 and was associated with Russell and Sigurd Varian and W. W. Hansen in the development of the klystron tube before and during the war. He joined the Stanford faculty in 1946; as director of the Microwave Laboratory there he was active in the design and development of linear accelerators, including the billion-electron-volt Mark III machine now in operation. Kirk was born in Buffalo, N.Y., in 1927 and received his A.B. in history from Cornell University in 1952. After several years in industry he went to Stanford in 1956 as Ginzton's assistant in the Microwave Laboratory.

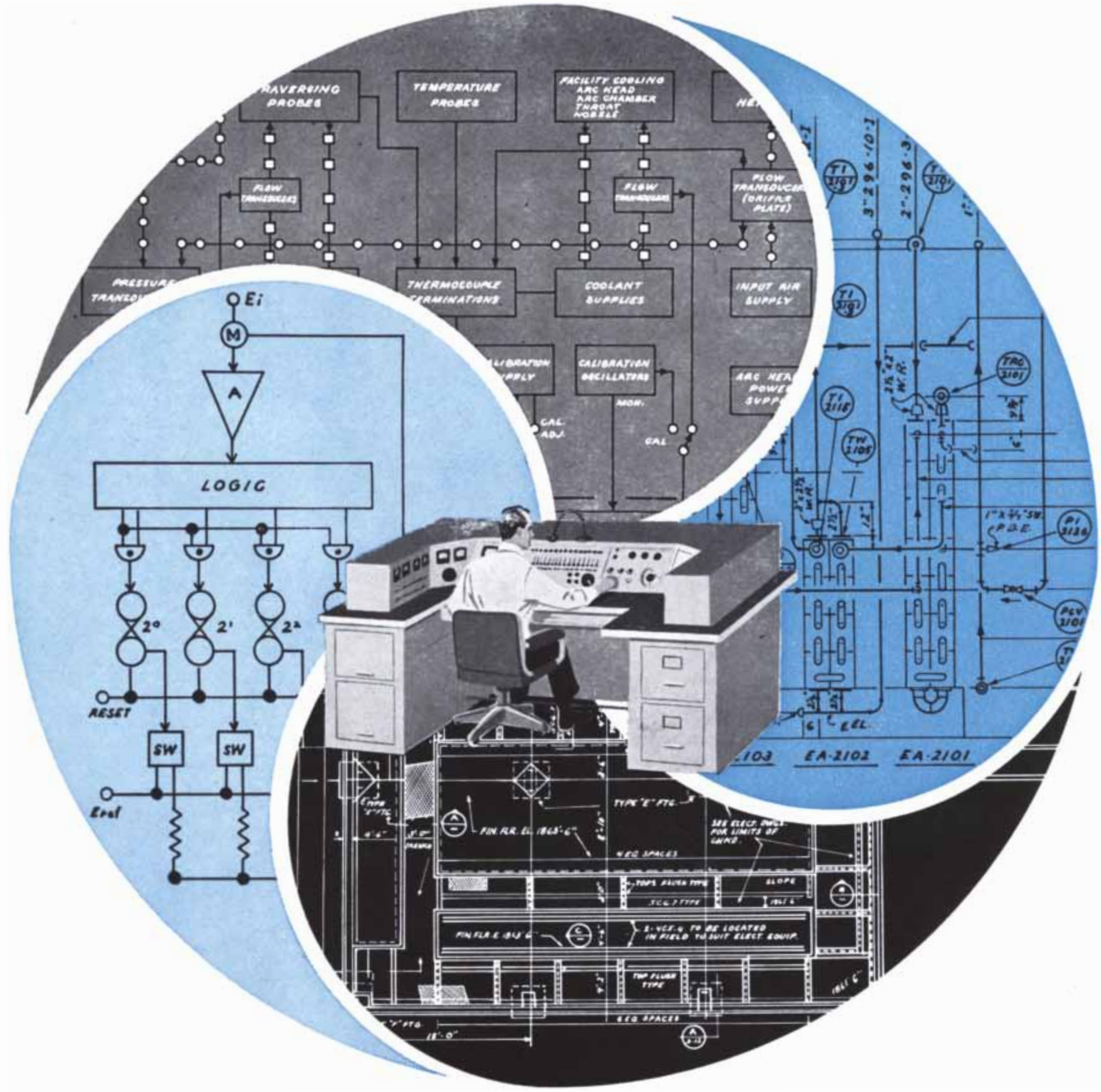
VIRGIL E. BARNES ("Tektites") is professor of geology and director of tektite research at the University of Texas, and a research scientist-engineer in the Bureau of Economic Geology there. He did his undergraduate and master's-degree work at the State College of Washington and received his Ph.D. in geology at the University of Wisconsin in 1930. After serving as a research fellow with the American Petroleum Institute and as topographic engineer with the U.S. Geological Survey, Barnes went to the University of Texas in 1935. At the present time, supported by funds from the National Science Foundation, he is examining the occurrence and origin of tektites around the world.

A. G. BEARN and JAMES L. GERMAN III ("Chromosomes and Disease") are respectively associate professor and physician, and research associate and assistant physician at the Rockefeller Institute. Bearn, a native of England, was graduated in 1946 from Guy's Hospital Medical School of the University of London, trained at Guy's, served in the Royal Air Force and came to the Rockefeller Institute in 1951. His initial work there on a liver disease that turned out to be inherited led to a general interest in genetics and disease. (His article "The Chemistry of Hereditary Disease" appeared in the December 1956 issue of SCIENTIFIC AMERICAN.) German was born in Sherman, Tex., in 1926. He was graduated from the Louisiana Polytechnic Institute in 1945 and received his M.D. degree from Southwestern Medical College in 1949. After internship and residency he began research in 1956 at the National Institutes of Health. He came to the Rockefeller Institute in 1958 and has worked with Bearn on various aspects of human genetics.

B. F. SKINNER ("Teaching Machines") is Edgar Pierce Professor of Psychology at Harvard University. He majored in English at Hamilton College (A.B. 1926) and, he says, "always planned to be a writer. Shortly after graduation I discovered the unhappy fact that I had nothing to say, and went on to graduate study in psychology hoping to remedy that shortcoming." Skinner received his M.A. in psychology from Harvard in 1930 and his Ph.D. there in 1931. He was a National Research Council Fellow and a Junior Fellow at Harvard until 1936, when he joined the psychology department at the University of Minnesota. In 1945 he became chairman of the department of psychology at Indiana University and in 1948, after a year as William James Lecturer at Harvard, joined the faculty there. In addition to technical articles Skinner has published six books, including a utopian novel, *Walden Two*.

GEORGE A. BARTHOLOMEW and JACK W. HUDSON ("Desert Ground Squirrels") are colleagues in the department of zoology at the University of California at Los Angeles. Bartholomew received his A.B. and M.A. degrees from the University of California and, after wartime service as a scientist with the U.S. Navy, obtained his Ph.D. in 1947 at Harvard University. He then went to U.C.L.A., where he is professor of zoology. Bartholomew is now in Australia on a Guggenheim Fellowship and a National Science Foundation grant to study the physiology of marsupials and reptiles in Queensland. Hudson was graduated from Occidental College in 1948 and received his M.A. there the next year. While teaching biology at Occidental he did doctoral research under Bartholomew at U.C.L.A., receiving his Ph.D. in 1960. He is now a lecturer in zoology there.

RALPH M. EVANS ("Maxwell's Color Photograph") is director of the Color Technology Division of the East-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man Kodak Company. He started with Kodak in 1928 after receiving his B.S. degree in physics from the Massachusetts Institute of Technology. Except for six years with other firms in the photographic field, he has remained with Kodak ever since, working on color-process development and color control. Evans' primary interest has been in the visual effects involved in color photography, *i.e.*, "subjective photography"; his allied hobby is visual psychology. He is the author of three books on color and color photography and holds numerous patents in the field.

ALLEN M. SCHER ("The Electrocardiogram") is associate professor of physiology at the University of Washington School of Medicine. Born in Boston in 1921, he was graduated from Yale in 1942 with a B.A. in English. After the war, during which he served in the Marine Corps, he held an Atomic Energy Commission predoctoral fellowship and received his doctorate in physiology from Yale in 1951. He joined the staff of the University of Washington School of Medicine in 1950. Scher's interest in the subject of this article grew out of his suggestion to a medical student that mapping the pathway of electrical excitation in the heart would make a good research project; the student lost interest, but Scher went on to investigate the problem. In addition to continuing work in this field, he is now studying blood-pressure regulation and blood flow in the kidneys.

J. H. ACLAND ("Architectural Vaulting") is associate professor in the School of Architecture at the University of Toronto. A native of Toronto, he took a degree in architecture at Syracuse University in 1942. After military service he practiced architecture in London for a time, then taught design, planning and history at the University of Utah School of Architecture. His interest in medieval buildings and towns—which he suspects "stemmed from my first view of Amiens Cathedral from the back of a Canadian army truck" during the war—took him to Europe for a year on a Ford Foundation fellowship, then to the University of British Columbia and in 1956 to the University of Toronto to teach the history of architecture.

ERNEST NAGEL, who in this issue reviews René Dubos' *The Dreams of Reason: Science and Utopias,* is John Dewey Professor of Philosophy at Columbia University. He has written frequently for SCIENTIFIC AMERICAN.

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This sidewalk is wired for snow

Nickel alloy electric heating cables in the concrete melt snow as fast as it falls!

No shoveling, no salting, no customer accidents on slippery sidewalks at *this* suburban branch of a Pittsburgh department store. Electric heating cables keep the sidewalks clear of snow and ice during even the worst winter weather.

Saves maintenance costs. In addition to taking the bother out of blizzards, the system eliminates the cost of conventional sidewalk clearance. And further savings are realized because the heating cables — made of 80% Nickel — require no maintenance.

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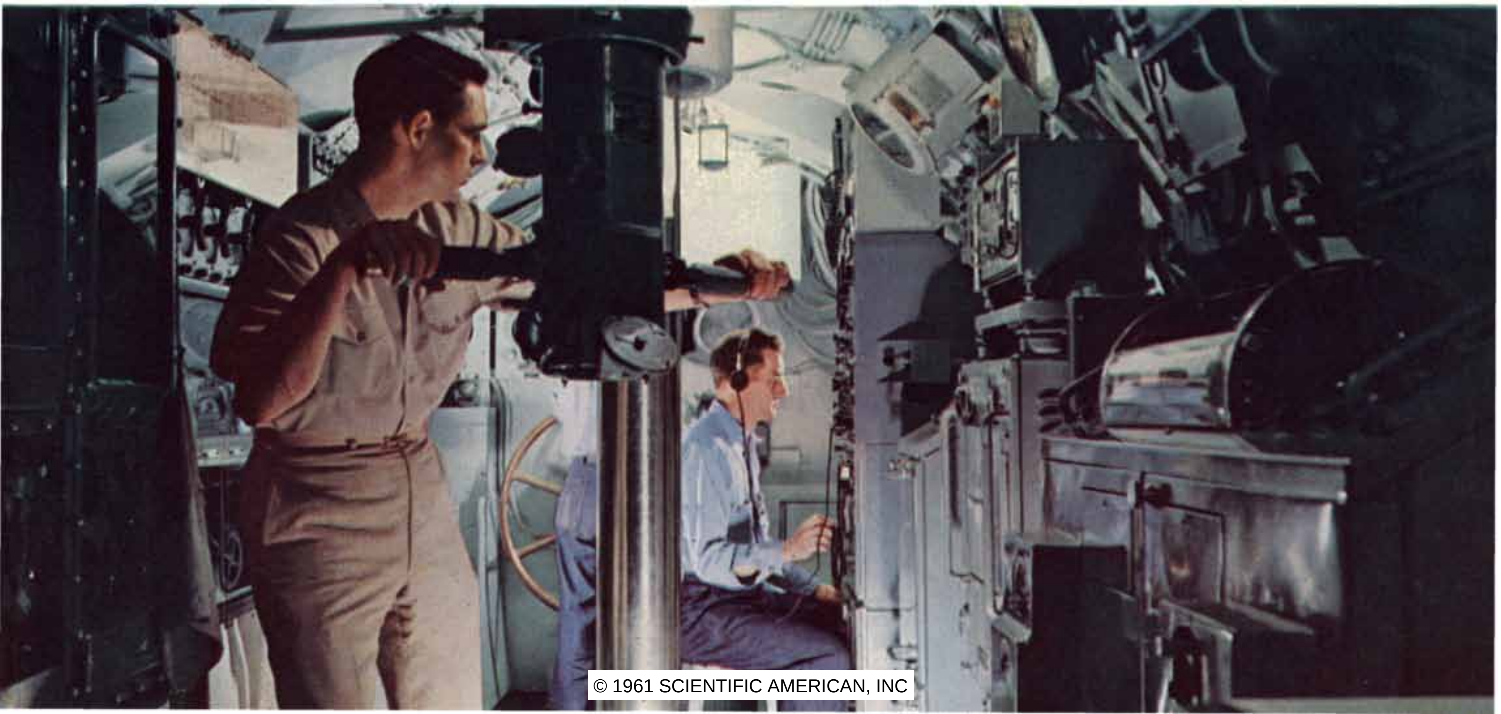

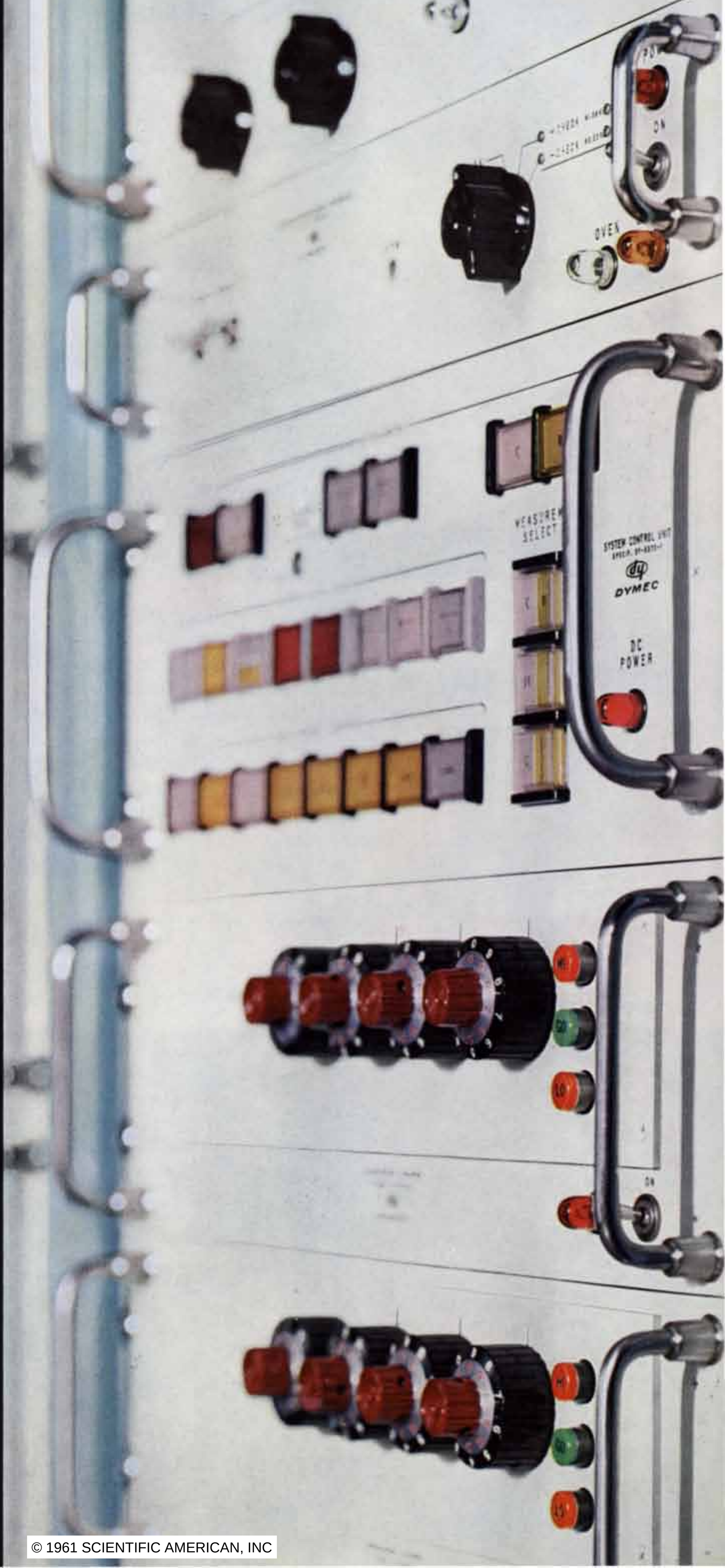

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depends in good measure on constantly increasing the reliability of electronic components. Only through precise quality control measurement of hundreds of thousands of components can reliability be increased to the degree required for ICBM readiness. Such measurements must be repeated and recorded over periods of months, even years.

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Here are some facts you should know:

With Tenite Polyester, Eastman launches a new plastic material. Today, it is already being made into biaxially oriented film by Terafilm Corporation, Stamford, Connecticut. This is an extraordinary plastic film—an extraordinary *polyester* film.

It can be applied to many of the familiar uses for plastic films. But it will also accomplish many unusual tasks with impressive results, chiefly because Tenite Polyester itself possesses such unusual properties. This table will give an idea of some test results:

Typical Physical Properties of 1-mil Film

	25°C	—50°C
Density, g/cc	1.226	
Refractive index	1.59	
Tensile—Yield Strength, psi	10,000	15,000
Strength at break, psi	17,000	20,000
Elongation at break, %	45	40
Modulus, 10^5 psi	4.0	4.5
Tear strength, g/mil	6	
M.I.T. fold endurance, cycles	10,000	
Burst strength, psi	56	
Moisture absorption—24 hr at 25°C, %	0.3	
Water vapor permeability—g-mil/100 in²/day	1.8	

Flammability	Will not sustain flame due to melting (ASA burning rate)
Color	Brilliant water-white
Resistance to degradation by steam—	No change after 8 days at 110°C and 100% R. H.
Heat-distortion temperature, 2% at 50 psi	170°C
Dielectric strength, 1-mil, 500 v/sec, 60-cycle	6,500 v/mil
.5-mil, 500 v/sec, 60-cycle	9,000 v/mil
Corona resistance, 1-mil, 2,000 volts, 60-cycle	150 minutes
Insulation resistance, 100°C, 100 volts, 5-min electrification	$> 10^4$ megohm microfarads
Dissipation factor, 1.0 kc, 100°C	0.006
Capacitance increase, %, 100°C	2.0

You might compare these figures with those on hand for any other plastic film. But there are additional facts well worth knowing, and they can best be evaluated by seeing the film and reading about what it can do. Generally, the story adds up to this:

Unusual Performance

Film of Tenite Polyester plastic is brilliantly clear and glossy. It has excellent dimensional stability along with high heat-distortion temperature and low moisture absorption.

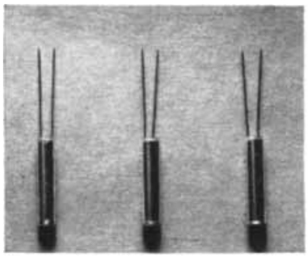
These properties suggest its possible use as a "boil-in-bag" package. It has also been tried experimentally for packaging popcorn, where corn, oil, and salt are sealed in a transparent pouch and popped in three minutes of heat from infra-red lamps.

Other possible applications include metallic yarns (the film can be metalized as well as laminated to foil), magnetic tape, page protectors in notebooks, and laminated protective surfacing for automobile kick plates, in which its scuff-resistance is important. Film of Tenite Polyester is suited to laminating, stamping, printing, and vacuum forming.

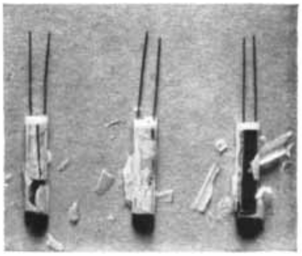
New Electrical Benefits

It is in the electrical field that the properties of this film have proved most exciting. It possesses a high dielectric strength along with an extremely stable dissipation factor and dielectric constant. These properties, together with excellent resistance to chemicals and moisture, provide important new benefits when the film is used as an insulation winding for wire, cable, capacitors, and coils.

Eastman laboratories tested capacitors made from



Tenite Polyester



Other Film

film of Tenite Polyester plastic in comparison with those made of another polyester film. In both tests, the capacitors were uncased and were held at 110°C. and 100% humidity. Results after eight days are shown here. After 21 days, the capacitors made from Tenite Polyester were still intact. The properties demonstrated by these tests mean substantial savings in making capacitors; the case of a conventional capacitor contributes a major part of its cost.

See for Yourself

All these properties add up to an impressive list of benefits for users of film. In making your own appraisal firsthand, you may wish to have samples and detailed information. Just write Terafilm Corporation, Canal and Ludlow Streets, Stamford, Connecticut, extruders of Tenite Polyester supplied by EASTMAN CHEMICAL PRODUCTS, INC., subsidiary of Eastman Kodak Company, KINGSPORT, TENNESSEE.

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John Dewey...on ideas at work

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—*The Quest for Certainty*, 1929.

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The Two-Mile Electron Accelerator

Congress has provided funds for a machine that will use radio waves to accelerate electrons down a 10,000-foot pipe to energies of more than 20 billion electron volts

by Edward L. Ginzton and William Kirk

During its recent session Congress authorized the construction of a large particle accelerator, a linear electron machine two miles long that will be built at Stanford University under the sponsorship of the Atomic Energy Commission. The accelerator will at first produce an intense beam of electrons at an energy of 20 Bev (billion electron volts), will ultimately be capable of an energy of 40 to 45 Bev, will take six years to build and will cost $114 million. It will be the largest electron accelerator and the most expensive accelerating machine of any kind yet built. In this article we shall describe the Stanford accelerator and discuss some of the reasons why it was chosen as the next major U.S. effort in the field.

Accelerators are the chief instruments of high-energy physics—the branch of science that deals with matter in its elementary forms. They are not only the "microscopes" with which matter is examined but also the means by which most elementary forms of matter are created for study in the laboratory. (Of the 30 elementary particles now known only three—the proton, neutron and electron—are present in atoms of ordinary matter.) Increasing the size of a machine—that is, the energy of its particle beam—increases its resolving power as a microscope. So far as can now be seen, there is no obvious upper limit to the process. Moreover, bigger machines may expand the list of particles, creating forms of matter presently unknown. Again no one can say where the limit lies, if it exists at all.

All accelerators operate by subjecting electrically charged particles to the force produced by an electric field. In the circular machines (cyclotrons and synchrotrons) the particles are constrained by powerful magnets to move in spiral or circular orbits so that they pass repeatedly, many thousands of times, through the region containing the accelerating field. In linear accelerators the particles pass just once down a straight tube, and no guiding magnets are required. There are two versions of the linear design: the standing-wave machine, in which the tube is split into many segments and the accelerating field exists across the gaps between segments; and the traveling-wave machine, in which the field moves down the tube with the particles in the form of an electromagnetic wave [see "The Linear Accelerator," by Wolfgang Panofsky; Scientific American, October, 1954].

As electron accelerators the circular machines have an inherent limitation. When high-speed electrons travel a curved path, they give off X rays. The higher the energy of the particles, the greater the proportion of energy that is lost in radiation. Up to a few Bev the energy loss is tolerable; at energies above about 10 Bev it may become prohibitive. Electron synchrotrons rated at about six Bev are now under construction in Cambridge, Mass., West Germany and the U.S.S.R.

The linear design is free of radiation losses no matter how high its energy. As between the standing-wave and traveling-wave types, the latter is better suited to the acceleration of electrons. Accordingly the Stanford machine will be a traveling-wave linear accelerator.

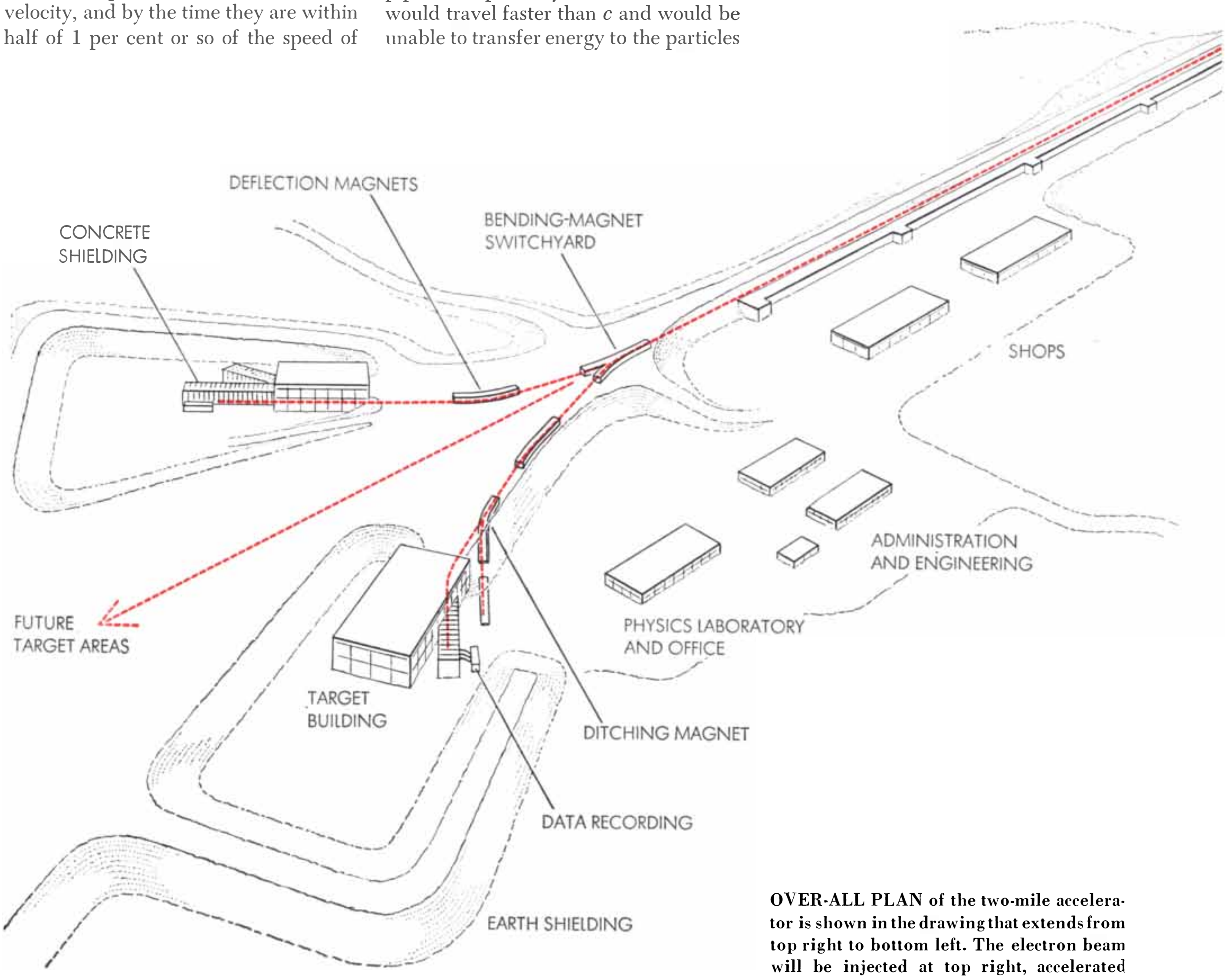
In the design of this machine the accelerating field—a radio wave of extremely high frequency—is provided by a series of very large klystron tubes similar to those used in high-powered radar transmitters. The output of the tubes is fed at 10-foot intervals into an evacuated copper pipe four inches in diameter and 10,000 feet long. Electrons are injected into one end of the pipe from an electron "gun" like that in a television picture tube, and they move down the pipe on the wave, in a manner analogous to a surfboarder riding an ocean wave.

To understand the process in somewhat more detail it is useful to form a picture of an electromagnetic wave in the accelerator pipe. At any given instant the wave will produce a steadily varying electric force, the direction of which reverses in successive portions of the pipe. In other words, with respect to electrons moving through the pipe the wave consists of successive regions of accelerating and decelerating force. The wave can be represented schematically as a sine curve, with the crests indicating maximum accelerating force and the troughs indicating maximum decelerating force [*see illustration on page* 53]. If now the wave itself also moves down the pipe, it will tend to push the electrons ahead of it, gathering them in bunches at the accelerating crests. Ideally, as the electrons gain speed under the influence of the continuous force, the wave should speed up in exact synchronization, so that the particles remain always at the point of maximum accelerating force. In practice, however, satisfactory operation can be obtained even if the electron and wave velocities differ slightly.

Because of their small mass, electrons subjected to even a moderate accelerating field rapidly reach a very high speed. They leave the injecting gun at half the speed of light in a vacuum (c), and by the time they reach an energy of five Mev (million electron volts) they are already traveling at .995 c. In accordance with the theory of relativity, the mass of the particles increases with their velocity, and by the time they are within half of 1 per cent or so of the speed of light the rate of mass increase is extremely steep. At five Mev the mass of the electron is still not much larger than its mass at rest. At 20 Bev, an energy 40,000 times greater, the mass is just about 40,000 times the rest mass, whereas the speed is increased only about half of 1 per cent to .9999999997 c. In short, after the first few feet the electrons travel at almost constant speed through the pipe, and the subsequent energy gain appears primarily as an increase in mass.

In order to supply energy continuously the accelerating field must travel at a velocity close to that of the particles. Some slippage between the two is allowable, so long as the particles stay near the wave crests (the points of maximum accelerating force). To bring the wave velocity close enough to that of the particles, the inside of the pipe is designed with a series of ridges. These have the effect of slowing the electromagnetic waves traveling through the pipe. If the pipe were perfectly smooth, the waves would travel faster than c and would be unable to transfer energy to the particles [see "Things That Go Faster than Light," by Milton A. Rothman; Scientific American, July, 1960]. A proper choice of the dimensions of the ridged structure slows the wave to the desired velocity. The first few feet of the pipe can be tapered so that the field velocity increases smoothly from .5 c, the speed of injection of the electrons, to its final velocity of something more than .99 c.

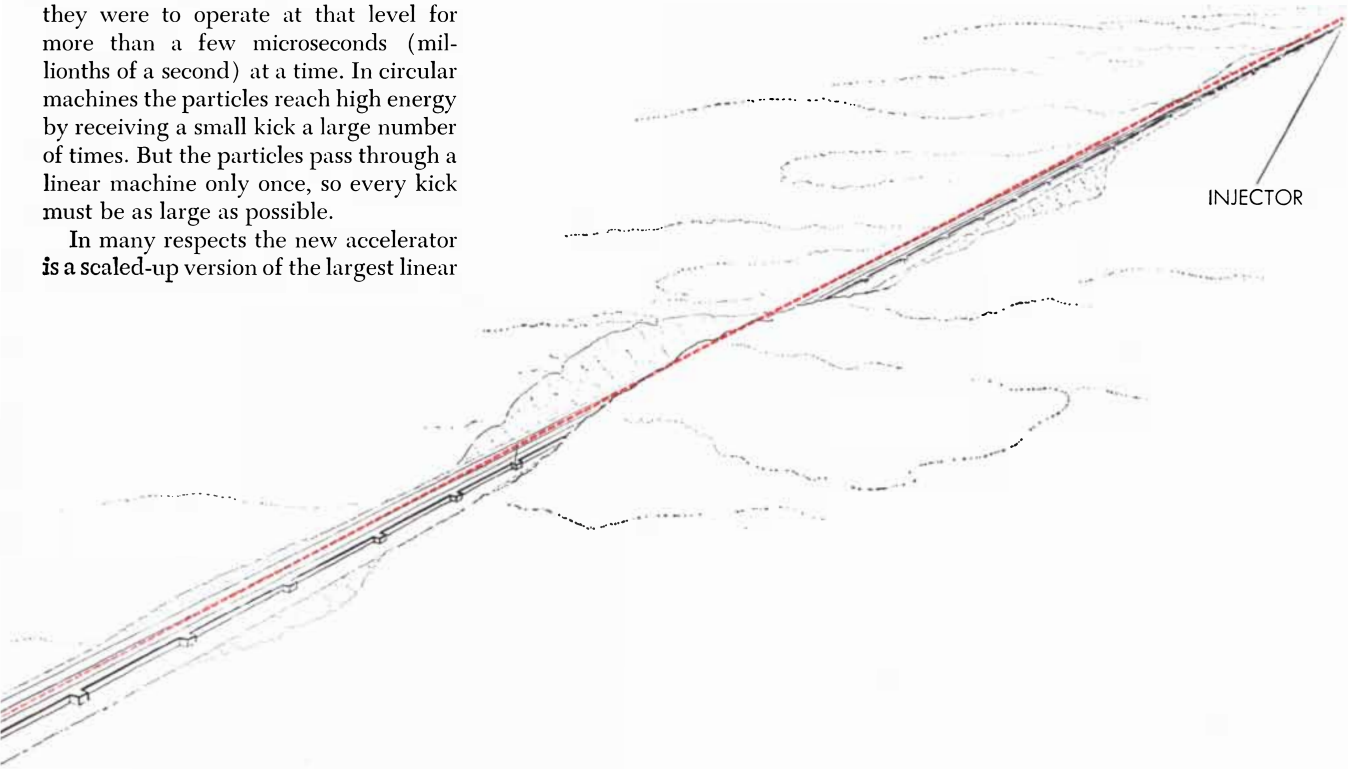
Like all large linear accelerators, the new machine will be operated as a pulsed device, with the klystron tubes delivering power in very short bursts. This is because of the enormous quantity of power demanded from the tubes, an amount that would burn them out if

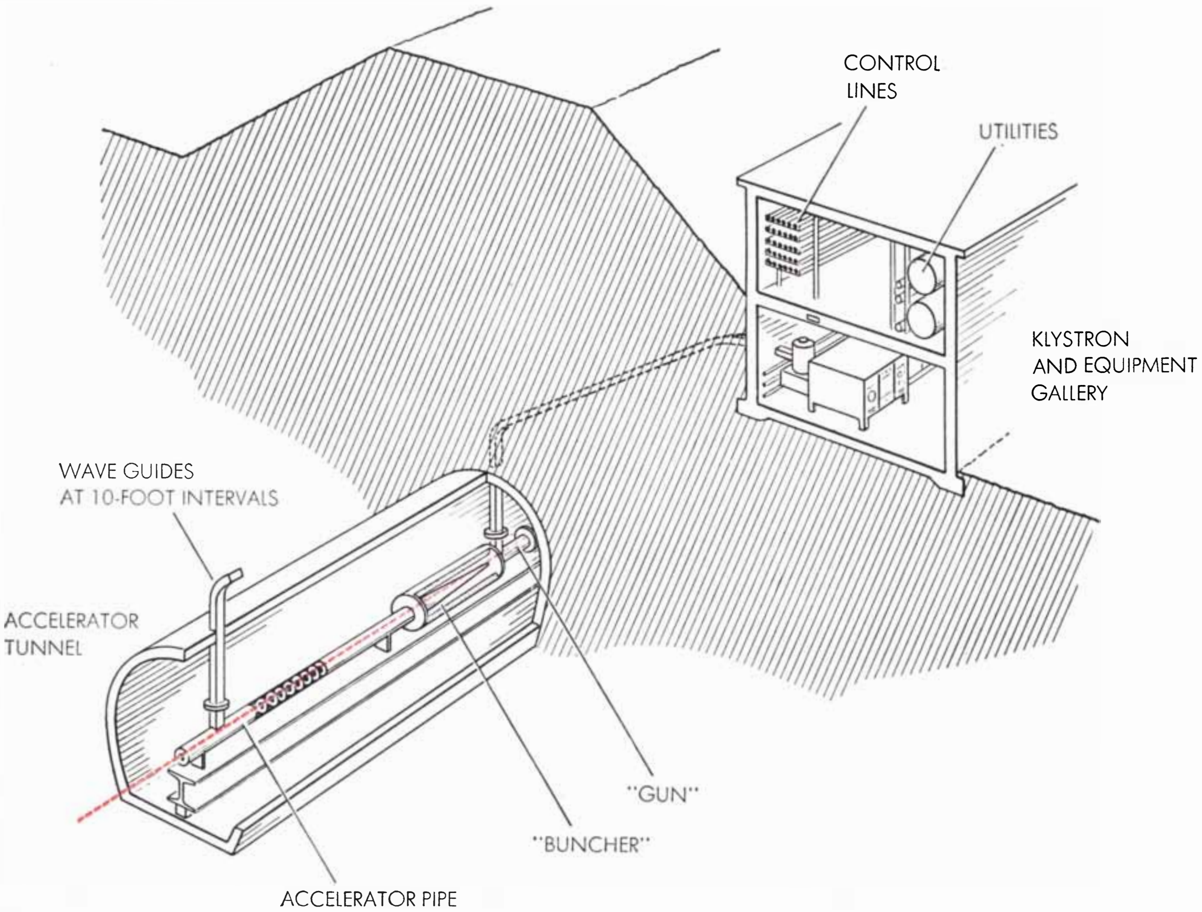


OVER-ALL PLAN of the two-mile accelerator is shown in the drawing that extends from top right to bottom left. The electron beam will be injected at top right, accelerated

they were to operate at that level for more than a few microseconds (millionths of a second) at a time. In circular machines the particles reach high energy by receiving a small kick a large number of times. But the particles pass through a linear machine only once, so every kick must be as large as possible.

In many respects the new accelerator is a scaled-up version of the largest linear





down the 10,000-foot tube and deflected into separate beams by the bending-magnet switchyard. They will impinge on targets in the buildings at bottom left. At bottom right is a detailed cutaway drawing of the "breech" end of the machine. The electrons will be introduced into the pipe by an electron "gun" and accelerated by a radio wave fed into the pipe by wave guides at 10-foot intervals. The radio wave will be generated by large klystron tubes in a gallery running parallel to the pipe for almost its full length.

device now operating: the Mark III electron accelerator at Stanford. This machine has been in routine use since 1952 and has made some important contributions to high-energy physics. It was the successful experience with the Mark III that led in 1954 to the first studies of the feasibility of the two-mile accelerator, and then to the formal proposal of such a machine in 1957.

The Mark III is 300 feet long and is fed at 10-foot intervals by klystrons, each delivering 17 million watts in two-microsecond pulses 60 times a second. The electrons passing down the tube gain a little more than three Mev per foot; the maximum energy is about one Bev. In its initial stage the two-mile accelerator will have klystrons spaced 40 feet apart, each delivering up to 24 million watts in 2.5-microsecond pulses. With this arrangement the energy gain will be one to two Mev per foot and the maximum energy will be about 20 Bev. Later the number of klystrons can be quadrupled, if desired, increasing the gain to perhaps 4.5 Mev per foot and the top energy to more than 40 Bev.

In both the first and second stages it will be possible to operate at any energy down to one Bev and at pulse rates from one to 360 per second. Even though the beam will be on for only a small portion of the total time, its high intensity will give the Stanford accelerator much the strongest average particle stream of any large accelerator. In the first stage the average beam current should be about 30 microamperes at 20 Bev, and this will go up to 60 microamperes at 40 Bev in the second stage. For comparison, the average beam current of the 30-Bev proton synchrotron at the Brookhaven National Laboratory is about .01 microampere.

It may prove possible to accelerate several different beams of different energies at the same time. This would be done by placing as many as six electron guns at various points along the tube and programing them so that electrons from different guns are injected into the machine and accelerated on successive klystron pulses. The beams would then be sorted out by a magnet at the end, which would deflect electrons of different energies through different angles.

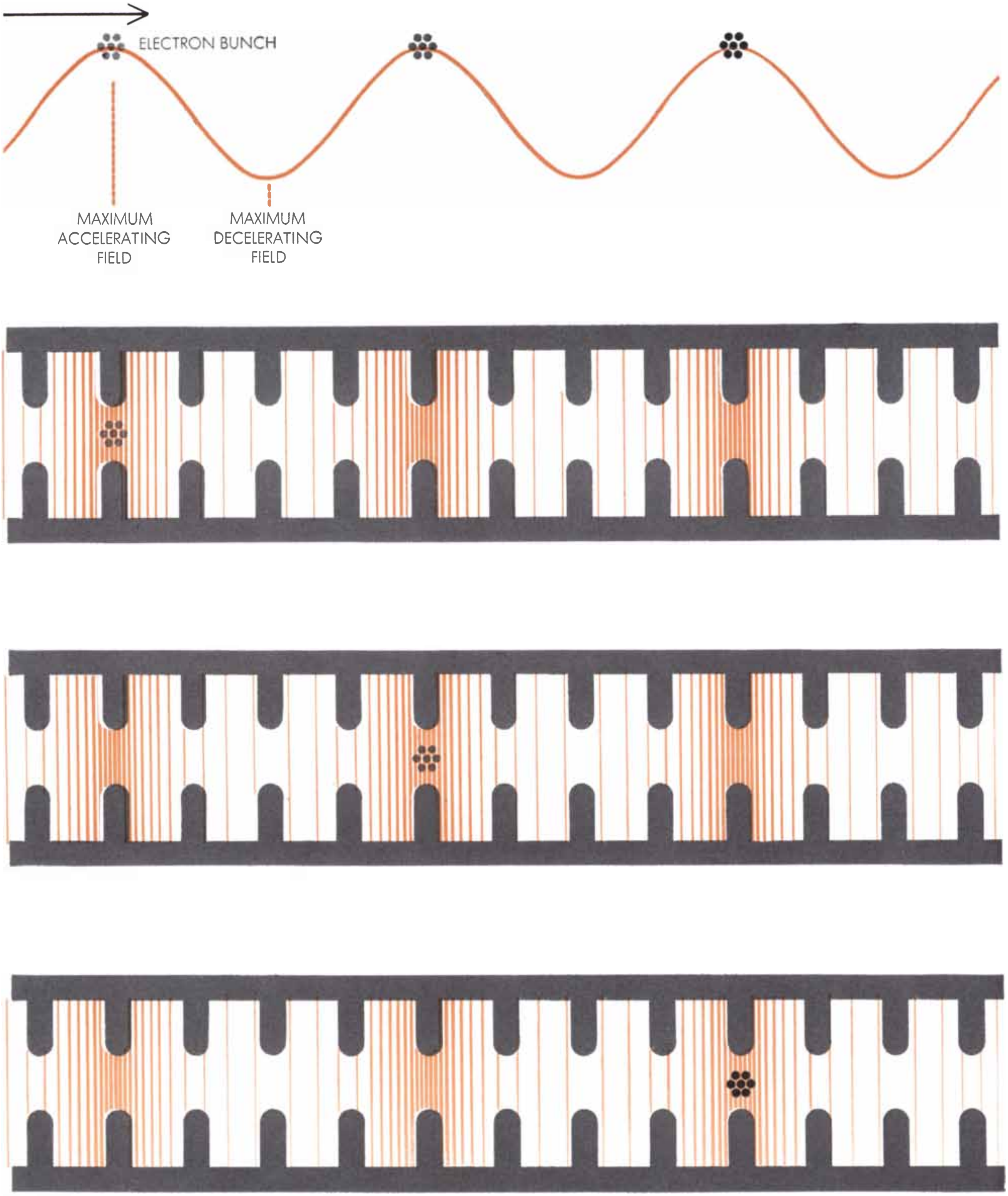
Such refinements aside, the two-mile accelerator will be much like 32 Mark III machines placed end to end, except that the accelerator pipe will be separated from all other equipment and all operating personnel by about 35 feet of earth radiation-shielding. A gallery running parallel to the tunnel will house the klystrons and associated equipment. Since the useful operating life of each klystron tube will probably be about 2,000 hours, the replacement rate with the initial complement of 240 tubes will be about three klystrons a day. Accordingly the klystron gallery will often be inhabited by service crews, as well as by members of the operating staff. Very little service will be needed in the accelerator tunnel; there should be no occasion to enter it oftener than perhaps once every few weeks. The separation of the klystron gallery from the radiation in the accelerator tunnel makes it possible to plan continuous research operation, 24 hours a day for extended periods, with all normal adjustment and servicing being done while the machine is running.

So much for the accelerator itself. To the physicists who will use it, this piece of costly and intricate hardware is simply a spigot for energetic electrons. They are chiefly interested in the business end of the installation, where the electrons are put to use. As the illustration on the preceding two pages shows, the beam will pass from the accelerator proper through a further length of vacuum piping into a large switchyard. There a series of large deflection magnets can direct the beam to any of several target buildings. Two buildings are planned initially. The total land reserved for experimental use is more than 100 acres, which means that at least three more target areas can be added later. With a number of widely separated experimental areas it will be possible to shield each from the others and therefore to proceed with setting up several experiments while the beam is in use in a particular building. Much of the equipment used in high-energy experiments is massive and hard to move, and it will often take more time to set up an experiment than to perform it. For example, it will not be uncommon to stack concrete shielding blocks to a thickness of 35 feet or more inside the target buildings.

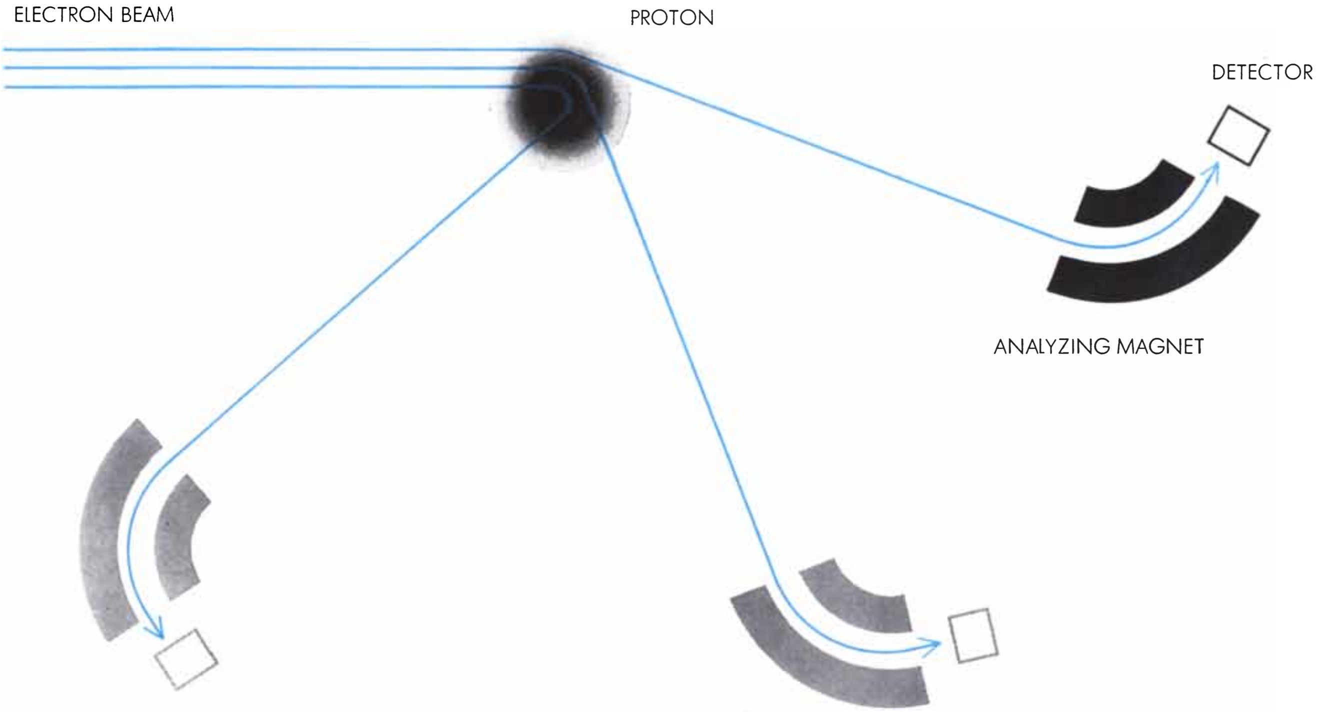
So far as their application to research is concerned, accelerators differ in five principle characteristics: the kind of particle accelerated, the beam energy, the average beam current or intensity (number of particles accelerated per second), the fraction of the total time that the beam can actually be delivered to a target, and the ease with which the beam can be brought out of the machine and directed into experimental areas. The major distinction between the two-mile machine and others of comparable energy is that it produces a beam of electrons rather than protons. The research programs of electron and proton machines are complementary; each kind of machine has applications for which it is especially well suited. The other notable characteristics of the Stanford accelerator are its high energy, high intensity and the experimental flexibility arising from the fact that the beam emerges naturally from the machine and can be transported over long distances to any of several widely separated research areas. Efficient extraction of the beam from circular machines is often a difficult problem. The main experimental disadvantage of the Stanford machine lies in the fact that its beam will actually be on for only about .06 per cent of the total operating time. This brief duty cycle, much shorter than those in circular machines, means that some special measuring techniques will have to be developed.

Even though the duty cycle is short, certain visual detecting devices do fit in quite well. Bubble chambers operate on a cycle requiring about a second of recovery time between the successive photographs of particle tracks. With the help of a pulsed magnet, one in every 500 or so beam pulses from the two-mile machine could be deflected to a bubble chamber. No one would miss an occasional pulse, and it would produce enough interesting events to keep the bubble chamber happy.

What sort of experiments will be done with the big electron machine? Although it is possible to foresee the general directions the research program may take, no specific prediction can be taken too seriously. Only occasionally in the past have the most important applications of an accelerator turned out to be those for which it was originally intended. For example, an important use of the accelerators in the energy range of 300 to 500 Mev that were built soon after World War II has been the production and study of pions (pi mesons). But the pion was not discovered until after the construction of most of these machines had begun. In the planning of the Cosmotron at the Brookhaven National Laboratory the energy was set at three Bev before it was found that this energy was well suited to the study of the so-called "strange" particles that are now a large part of the Cosmotron research program. (A notable exception to the rule is the Bevatron at the University of California: the energy of this machine was deliberately set at 6.3 Bev so that antiprotons could be created.) Subject, then, to



ACCELERATION OF ELECTRONS can be achieved by sending pulses of high-frequency electromagnetic energy through a straight, evacuated tube. The sinusoidal curve at top shows how electrons become bunched where the field strength of the accelerating part of the electromagnetic wave is at a maximum. As the electrons ride the accelerating crest of the traveling field, moving almost at the speed of light, they gain energy continuously. For the Stage I Stanford machine this energy will reach a peak of 22 billion electron volts, and for the Stage II machine, more than 40 Bev. As the electron gains energy it also gains enormously in mass. This is suggested above by the increasing blackness of the balls symbolizing electrons at three successive instants. (For clarity, electron bunches are shown at only one of the field maxima in each diagram.) The finger-like shapes projecting into the tube represent disks that hold the velocity of the electromagnetic field very slightly below the velocity of light so that it will match that of the electrons.



ELECTRON-PROTON SCATTERING is typical of experiments in which increased "resolving power" can be obtained by increasing the energy of the electron beam. The purpose of the experiment is to infer the size of the proton and the way its electric and magnetic properties are distributed. Electrons are deflected at different angles depending on how close they pass to the center of a proton. The experiment requires an analyzing magnet to select a beam of electrons having nearly the same energy and a detector to count them. Magnet and detector are moved radially around the target to obtain sample counts at various angles.

some uncertainty, the main applications of the two-mile accelerator seem to fall into five classes.

The first of these is the investigation of processes induced by electrons and by photons (quanta, or "particles," of electromagnetic radiation). When a high-energy electron penetrates matter and is slowed down or stopped, most of the lost energy of motion is emitted in the form of X-ray or gamma-ray photons. An electron accelerator can therefore provide either a beam of electrons or a beam of photons. When a photon beam is to be used, the electron beam from the accelerator is first directed against a preliminary target called a radiator (which in some cases is simply the front of the main target), where some of the electrons strike the target material and emit photons. If a separate radiator is used, the electrons that pass through it can then be "ditched" by using a magnet to deflect them away, usually down, from the path leading to the experimental target.

Every elementary particle, including the electron and the photon, can take part in the creation of other elementary particles. Creation is a collision process—that is, it can occur only when a particle carrying sufficient energy comes very close to another particle. Depending on their type, the two original particles interact in different ways to form new ones. Protons interact primarily through the strong nuclear force, which is still poorly understood. Electrons and photons, however, interact by means of the electromagnetic force, for which a complete, quantitative theory exists. For this reason creation experiments involving electrons and photons are usually easier to interpret than those done with proton beams.

Although all the particles known today can be created by electrons with an energy of about six Bev, observations on creation processes at energies well above the required minimum values should provide valuable information. This has already proved true in the study of the pion. Since any individual electron or photon has only a small probability of entering into a creation process, an intense electron beam is needed to make such experiments feasible.

The second class of experiments is the study of the structure of atomic nuclei and of the individual nucleons (protons and neutrons) that compose them. Using the Mark III accelerator, Robert Hofstadter and his associates at Stanford have already obtained some of the most precise measurements to date of the size and structure of atomic nuclei and of the proton and neutron. The spatial distribution of the electric and magnetic properties of the particles can be deduced from the patterns in which they deflect or scatter electrons. In these scattering experiments the accelerator is employed essentially as a microscope.

With higher electron energies available from the two-mile machine it should be possible to penetrate deeper into the particles and so examine them in greater detail. Although there is no obvious upper limit to the energy of the probing electrons in this work, as the energy increases the experiments will become more difficult to perform and the results may be more difficult to interpret.

By way of illustrating the experimental difficulties, part of Hofstadter's auxiliary equipment with the one-Bev Mark III is a large "spectrometer," or analyzing magnet, that is rotated around the target on a five-inch naval gun mount, the whole rig standing more than 20 feet high and weighing more than 100 tons [see "The Atomic Nucleus," by Robert Hofstadter; SCIENTIFIC AMERICAN, July, 1955]. A similar spectrometer for 20-Bev electrons would have dimensions 20 times as large and is therefore clearly impractical; new methods will have to be developed for analyzing the scattered electrons.

The problem of interpreting electron-proton scattering data at high energies arises in part from the increased complexity of the mathematical models that will be used to describe the structure of the proton. When the present models are extended to predict what will happen at energies above a few Bev, large discrepancies appear. To show how far apart the models can get, the probability of backward scattering at six Bev that is predicted by one current model is more than a billion billion times larger than the figure predicted by another model. The experiments will, of course, help establish which model is more nearly correct, but the lack of understanding implied by this absurd example makes it uncertain how adequate present theory will be to reveal the significance of experimental data obtained at higher energies.

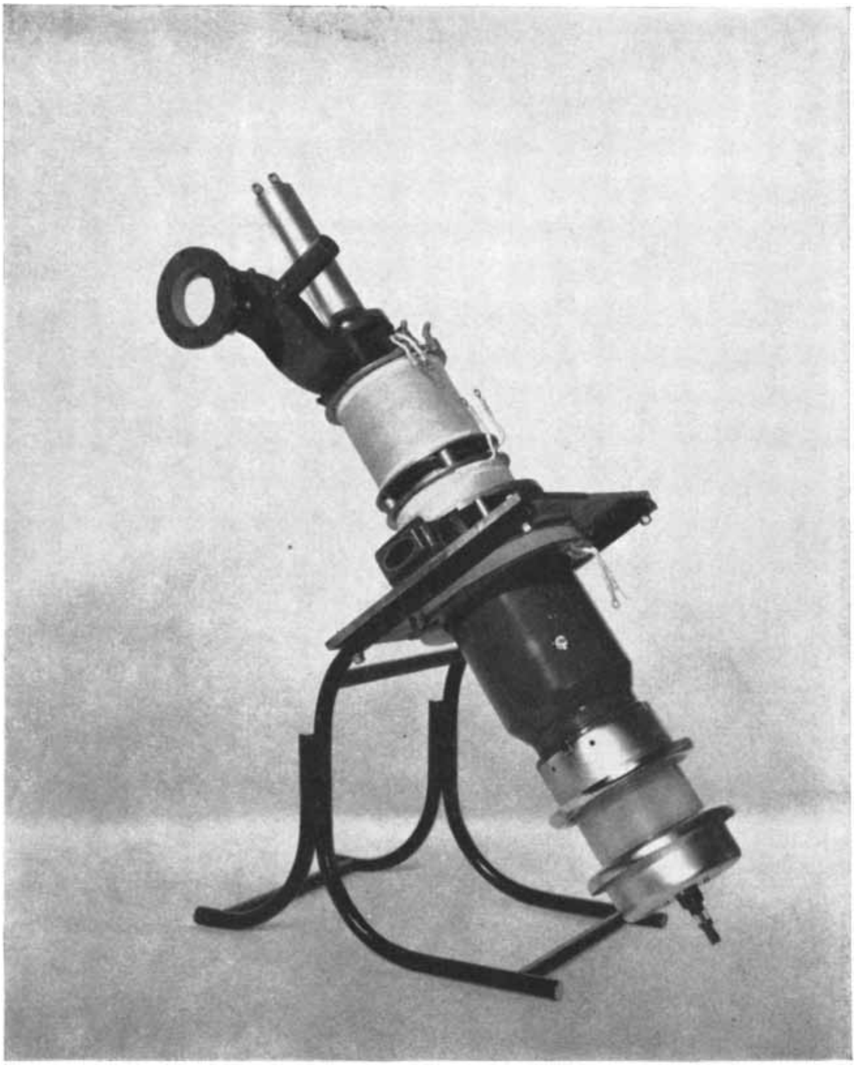
A third application for the two-mile accelerator lies in experiments with beams of the various secondary particles that can be created by the high-energy electrons. Secondary particles (pions, antiprotons, neutrinos and so on) can be produced by either proton or electron machines. In general, each proton will create many more secondary particles than will each electron or photon, and for this reason it was originally expected that secondary-particle work would not play as large a part in the research program for the two-mile machine as in those for the large proton machines. Recent calculations have shown, however, that the photon production process may produce many more secondary particles with energies nearly as high as the energy of the primary beam than had been expected. If so, high-energy secondary-particle experiments will have a prominent place in the program of the Stanford machine.

The general objective of secondary-particle experiments is the systematic study of the properties and interactions of all the elementary particles. A great many experiments are possible within this broad area. Two possibilities will be briefly discussed here.

As regular readers of this magazine are aware, the so-called weak interactions between elementary particles have recently attracted a great deal of attention in physics [see "The Weak Interactions," by S. B. Treiman; Scientific American, March, 1959]. One particle, the neutrino, interacts only by means of the weak force, and there has been a great deal of interest in trying to observe the effects of neutrino beams on matter. Although neutrino-induced events are extremely rare, their probability increases with increasing energy, and the combination of high energy and high intensity provided by the two-mile machine would produce enough high-energy neutrinos to make experiments of this kind possible. Present calculations indicate that the intensity of high-energy neutrino beams obtainable from the Stanford accelerator should be greater than those from any other machine now operating or under construction.

If the accelerator's energy is eventually increased to its highest level, 40 to 45 Bev, it will be possible to study the structure of some of the secondary particles themselves by the reverse of the usual scattering process. Instead of putting the probing electrons into a high-energy beam and bouncing them off the nucleons under study, the stationary electrons in target atoms could be used as probes to delineate the structure of high-energy pions or muons (mu mesons) directed against them. (Electrons, like protons, are always present in any target, but the effects of electron-electron scattering are either not measured or are subtracted from the data when the intended target particles are protons or nuclei.)

The fourth major area in which the Stanford accelerator may be particularly effective is in the extension of electromagnetic theory. So far no discrepancies between theory and experiment have been observed where only the electromagnetic force is involved. Since the present electromagnetic theory has been so satisfactory over the full range of energies now available, it is of consider-



KLYSTRON POWER TUBE, about three feet long, is one of 30 used in the present billion-electron-volt accelerator at Stanford. Power emerges from the round window at the upper left. The two-mile accelerator, in Stage I, will require 240 klystrons of similar design.

able interest to see if it will remain valid at higher energies—which is loosely equivalent to saying at shorter distances. To force two particles to come very close to each other requires very high energies. Moreover, since close-approach events are rare, high intensities are needed to produce enough events to get statistically meaningful results.

Experiments in this area may be among the most fundamental in the whole program. One way to state the question to be examined is to ask if there is a certain distance in nature within which the usual laws of physics no longer apply. It is possible, for example, that light may travel over very short distances at a velocity greater than *c*.

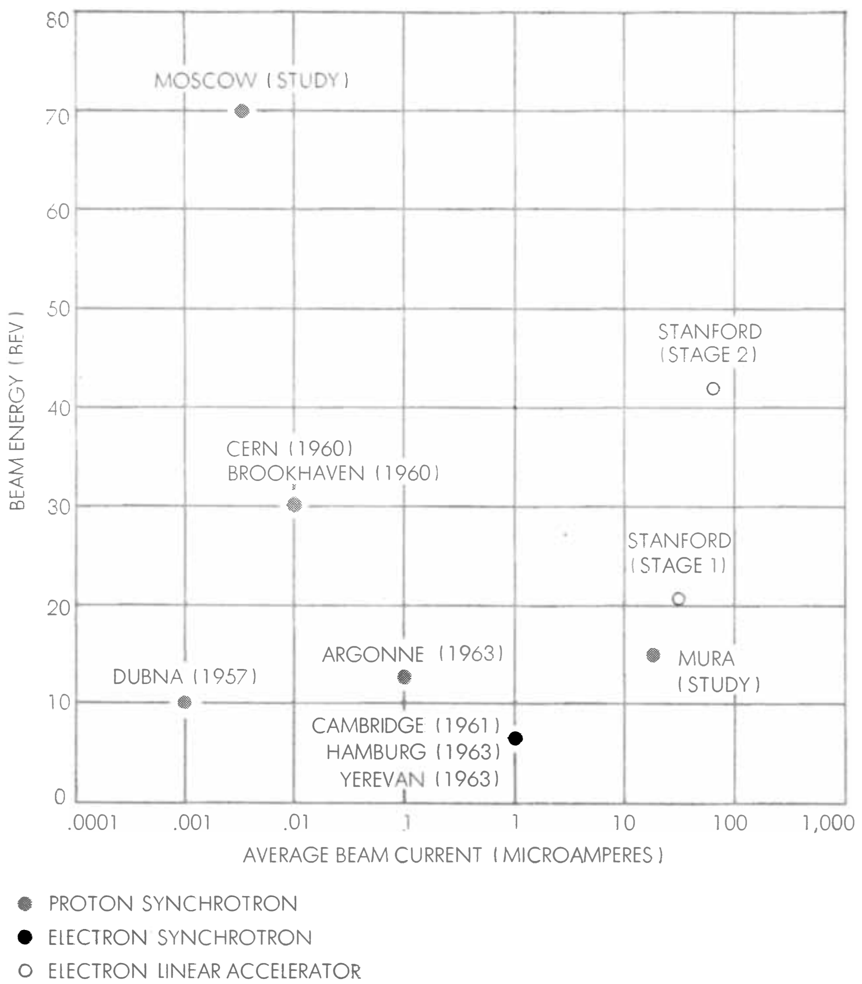
Since the laws at issue involve a purely electromagnetic interaction, the investigation is better suited to electron machines than to proton ones. A typical experiment would be to measure electron scattering from target electrons at energies above 10 Bev. A beam of muons (which in their properties appear to be heavy electrons) could also be directed against target electrons at very high energies.

A further possible experiment of the same type involves the scattering of positrons (the positively charged antiparticle of the electron) by electrons. To obtain a beam of positrons from the two-mile machine, electrons would be injected and accelerated in the usual way to an energy of 100 Mev or so. Then the electron beam would be directed against a one-inch slab of copper inside the accelerator tube; some of the electrons would emit photons, and some of the photons would create electron-positron pairs. Emerging from the far side of the copper slab would be a mixed beam of electrons, positrons and photons, together with some neutrons and protons that had been knocked out of the copper nuclei. By adjusting the phase of the electric field in the accelerator a reasonable fraction of the positrons could be picked up by the traveling wave and accelerated to full energy through the rest of the machine. Most of the electrons beyond the radiator would face a decelerating field, the protons move too slowly to be accelerated, and of course the neutral particles are unaffected by the electric field.

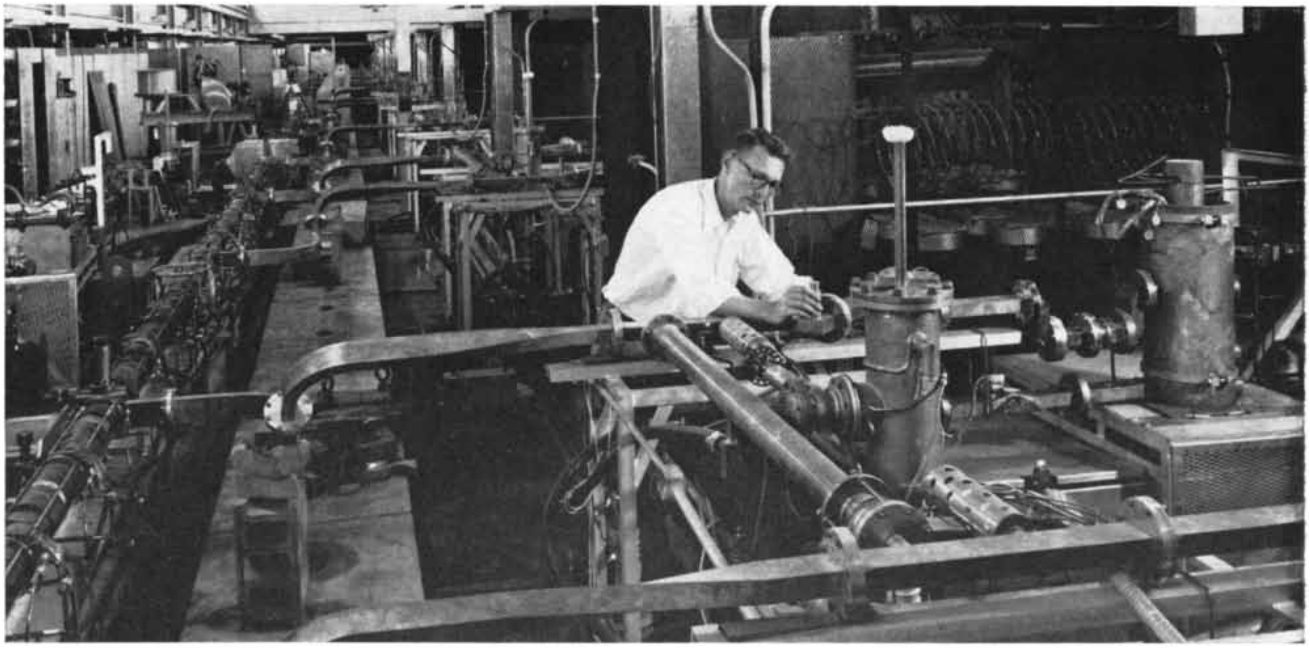
At the end of the machine a magnet would deflect the positron beam toward the target. The other particles reaching the magnet would be deflected at the wrong angle or not at all. The positron beam should attain an intensity perhaps as great as one-thousandth that of the normal electron beam.

Finally, one of the most interesting assignments for the two-mile accelerator could be a systematic search for new particles. Whether or not any exist—and, if so, how many—is quite uncertain, but there is a growing suspicion that there may be a considerable group of particles with extremely short lifetimes. Although it is not now evident what kind of experiments and what energy will serve best to find such particles, a high-energy, high-intensity electron accelerator is clearly well suited to the search. If a new particle were created by photons, for example, it would be easier to calculate the details of the reaction and therefore to predict what should be observed than in the case of creation by protons. Accordingly the detection and identification of the new particle would be simplified. This is again a result of the fact that the electromagnetic interaction of the photon is quantitatively understood, whereas the strong-force interaction of the proton is not.

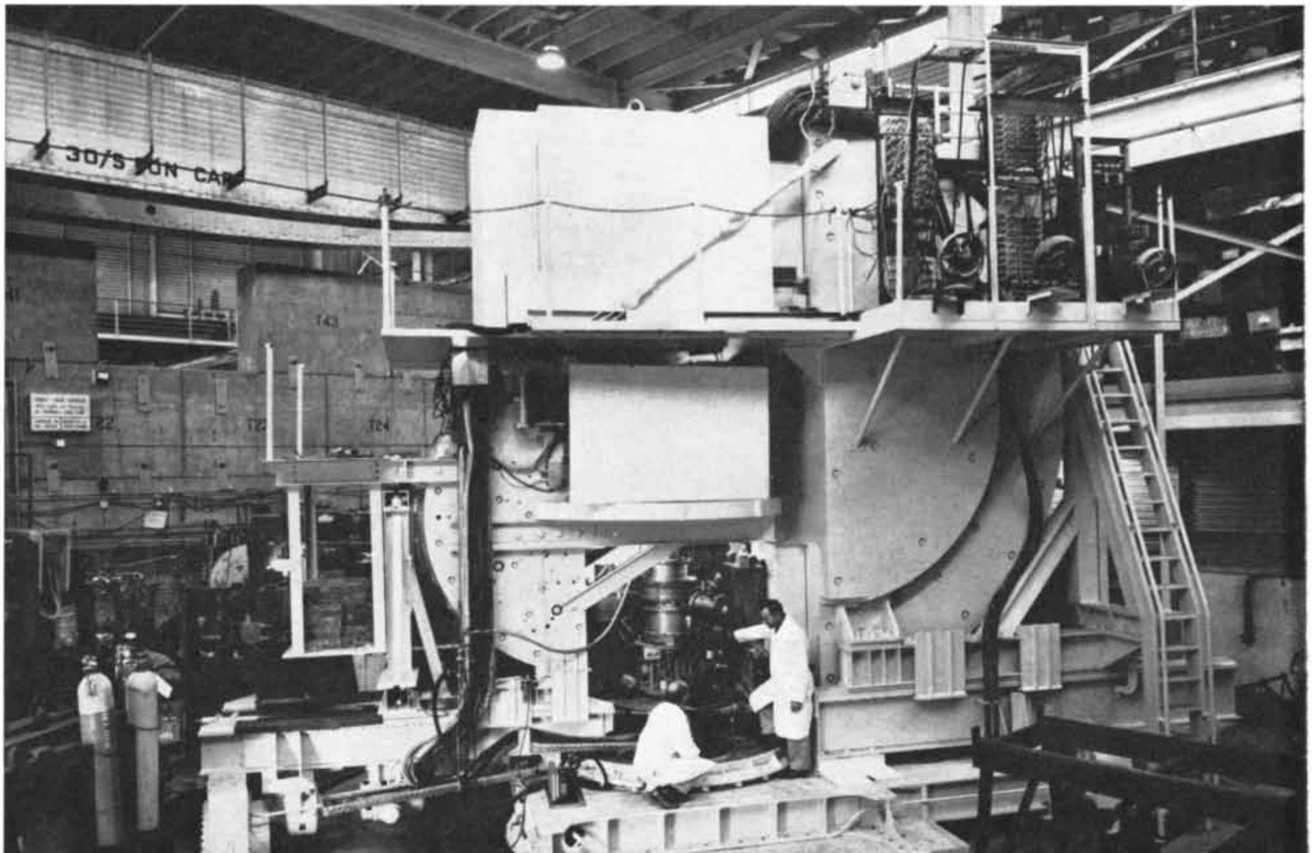
To conclude this summary of possible experiments we want to re-emphasize the difficulty of predicting the directions that particle-physics research will take during the next ten years. Often in the past the advent of a new accelerator extending into higher energy ranges has turned up something entirely unexpected. Since the two-mile machine will be the only electron accelerator operating above 10 Bev, it will be surprising if it does not bring to light phenomena that are at present unforeseen. Perhaps "disappointing" is a better word than "surprising." The fact that we cannot now set down exactly how the accelerator will be used is one of the best reasons for building it.



HIGH-ENERGY ACCELERATORS recently completed, under construction and proposed range in energy from six to 70 billion electron volts. All but the proposed Stanford machine are of circular type. A linear machine is better suited for electron energies above 10 Bev. Dubna is in the U.S.S.R., as is Yerevan. CERN is the European Center for Nuclear Research, Geneva. MURA stands for Midwestern Universities Research Association.



STANFORD MARK III LINEAR ACCELERATOR was placed in operation in 1952 with an energy rating of 350 million electron volts. When lengthened to 300 feet in 1960 its rating was increased to about 1 Bev. Electrons are accelerated in the cylindrical tube at the extreme left. The bent pipes of rectangular cross section carry electromagnetic energy from the klystrons along the right.



ELECTRON-SCATTERING SPECTROMETERS, used with the Stanford Mark III accelerator, provide data for calculating the size and structure of atomic nuclei and of the proton and neutron (*see illustration on page 54*). The electron beam enters through the concrete wall at left and passes into the target chamber (*above squatting man*). Electrons scattered by the target emerge at all angles. The two large half-circle magnets, which can be rotated around the target, bend electrons of similar energy so they strike counters.

TEKTITES

These glassy stones are found in several parts of the world. There is much evidence that they are solidified droplets of molten rock that were splashed into the air by the impact of giant meteorites

by Virgil E. Barnes

Occasionally, in certain parts of the world, the lustrous sheen of a glassy black object lying among rocks and pebbles attracts the eye. When one picks it up, it proves to be a stone of equally distinctive shape. A teardrop, a dumbbell, a rod, a disk or a peculiarly flanged button, it looks like a bit of liquid rock that was splashed from its place of origin and chilled to solidity in midflight. Such stones are called tektites, after the Greek word *tektos*, meaning molten. They are most often about the size of a walnut, but they range from considerably smaller to as large as a grapefruit. Held up to the light, they are translucent and are generally yellowish brown; those from Czechoslovakia are a beautiful clear light green. The tektites scattered throughout a particular region have been found to have the same age, and geological evidence assigns different ages to tektites from different regions.

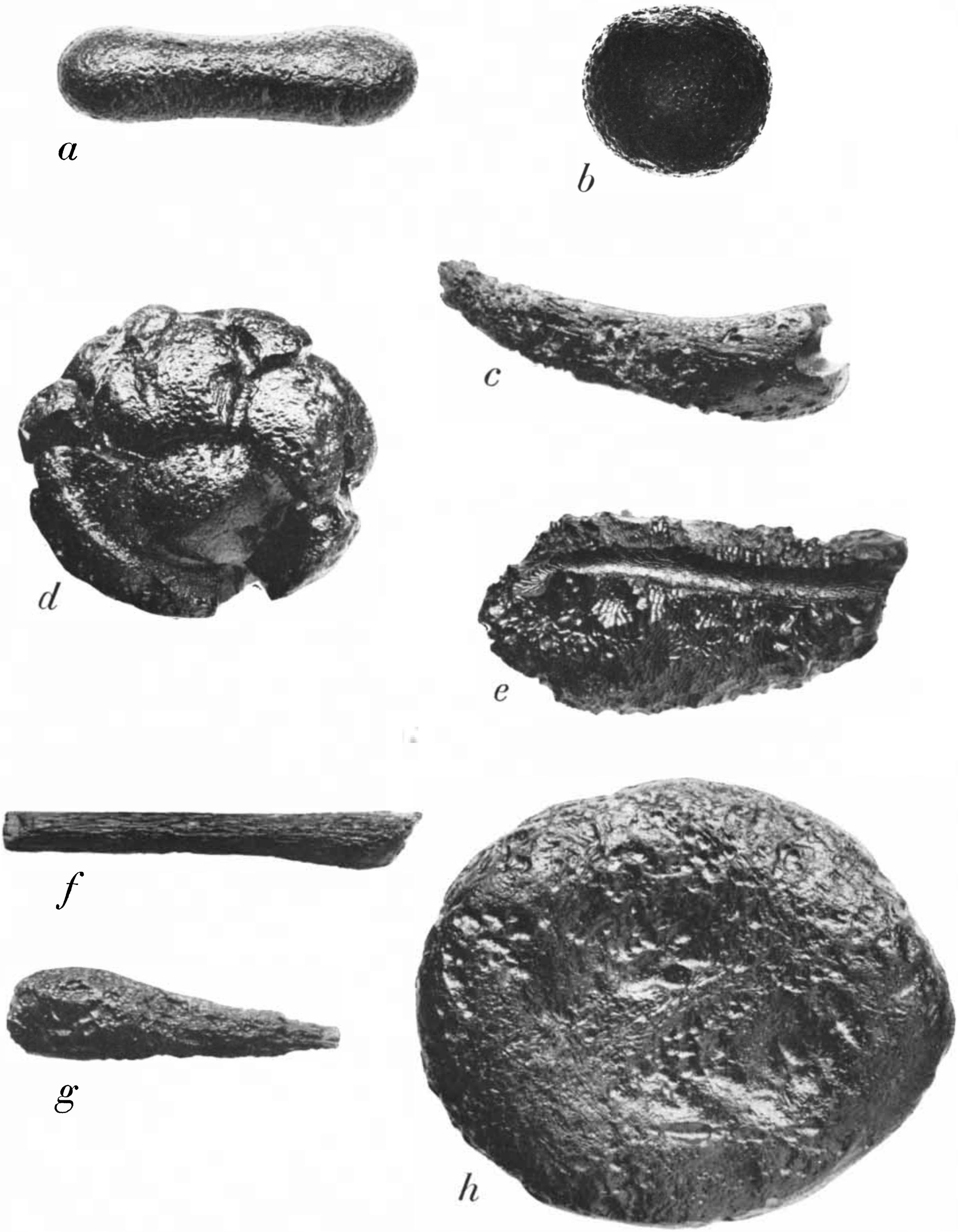
Primitive peoples have usually concluded that tektites fell from the sky and have cherished them as objects of mystery and magic. The first mention of tektites in the scientific literature, in 1787, put them down as a special kind of volcanic glass—a distant relative of obsidian. Some people who reflected on them thought that they might be the product of prehistoric glass manufacture. Others suggested that they were fulgurites (sand or soil melted and fused by lightning) or the residue of the final drying out of blobs of silica gel left behind by the evaporation of highly siliceous water. None of these ideas proved tenable, and toward the end of the last century investigators settled on the explanation seized by primitive men—that tektites come from the sky, *i.e.*, that they are a kind of meteorite.

Today speculation about the origin of tektites has taken a new turn. They are thought to belong to the accumulating body of physical evidence for the immense catastrophes caused in ages past by the impact of large meteorites on the earth. As such, they are to be regarded as droplets of molten rock thrown high into the air and outward over long distances from the impact site. L. J. Spencer of the British Museum first advanced this idea in 1933. More recently Harold C. Urey of the University of California at La Jolla has suggested that the impacting bodies may have been asteroids or comets. But the question of their origin is still in controversy. Some workers argue that the impacts occurred on the moon and that tektites are droplets of rock that splashed off the moon onto the earth.

A fully satisfactory explanation of the origin of tektites must agree with all the facts that can be established about them: their chemical composition, the peculiarities of their structure and their distribution over the face of the earth. My own investigations began in 1936 with the mineralogy and chemistry of tektites, as the key to the identification of the parent materials from which they came. That there is a gap in chemical composition between meteorites and tektites was immediately clear. Tektites proved to be much more closely related to the crustal rock of the earth, more specifically to the sedimentary rocks that cover most of the continents. This is true not only for their bulk material, which is silica, but also for minor elements. A few tektites show similarities to igneous rock, but to igneous rock rich in silica.

These findings weigh just as heavily against a lunar origin for tektites. Igneous rocks were, of course, the first rocks at the surface of the earth. In the gravitational field of the earth, which is so much stronger than that of the moon, there was a sorting out of elements by weight that brought lighter materials, including silica, to the surface. In whatever molten period the moon experienced there could have been no comparable separation of the constituents of its rock. It is likely that the density of the material at the surface of the moon differs little from the density of the moon as a whole. Material of this high density and low silica content could not even give rise to the few tektites that approximate the composition of the igneous rocks at the earth's surface. Much less could the airless and waterless moon be the parent of the preponderance of tektites that reflect the even higher concentration of siliceous minerals in the soils and sediments that result from the weathering of the earth's igneous rock. Except in a few areas, the trend on the surface of the planet is toward increasing similarity in the composition of the soil. The glasses fused from the soil by lightning and by arcs from broken power lines in widely separated parts of the world are remarkably similar to one another and more nearly resemble tektite glass than any other material known.

One other controversy centering on the chemical composition of tektites has only recently been settled. Glassy materials with a high nickel content have been found in and close to the site of meteoritic impact. The relatively low nickel content of tektites has caused some observers to argue that they could not have originated in the same sort of event. In tektites from Java and from Indo-China, however, William D. Ehmann of the University of Kentucky has



EIGHT TEKTITES, shown actual size, display a variety of shapes. Four of them (*"a," "b," "d" and "e")* are from the Philippines, the rest from Indo-China. Specimen *a* is a "dumbbell," *b* a sphere, *d* a sphere deeply etched by erosion; *e* shows a groove and other features caused by erosion. Specimen *c* is a teardrop form with a notch left by a bubble; *f* is an elongated teardrop that has been broken; *g* is a teardrop. Specimen *h* is a disk that is thinner at the center than at the edge. All these forms resemble cooled drops.

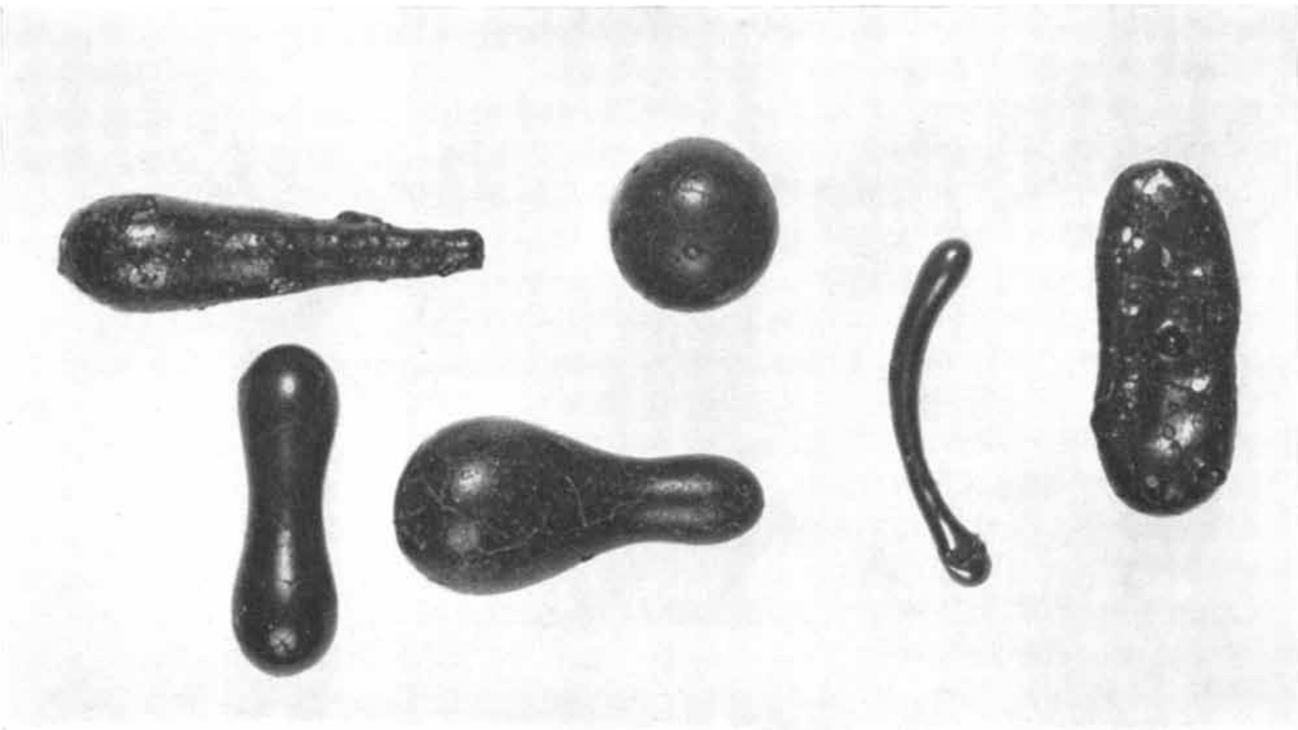
found nickel contents within the range of impact glasses. And E. C. T. Chao of the U.S. Geological Survey has found spherules of nickel-iron in a Philippine tektite. Conversely, on a visit to the Al Hadidah meteorite craters in Saudi Arabia last year, I found numerous bits of ordinary impact glass with the shapes of dumbbells, spheres, teardrops and so on—all of the splash forms that are observed in tektites.

If tektites are made of terrestrial material, the next question is: How were they made? In 1940 I identified glassy particles contained in tektites as being fused quartz. This was a decisive clue to the temperature at which they formed. Quartz melts at about 1,710 degrees centigrade (3,110 degrees Fahrenheit). Other evidence indicates that tektites were formed at even higher temperatures. From investigation of their magnetic properties Irving Friedman and his associates in the U.S. Geological Survey have concluded that tektites must have been melted at 2,500 degrees C. That even this temperature may have been exceeded is shown by the almost total absence of the glasses of high-melting-point minerals. Zircon, the mineral that has the highest melting point of all (2,430 degrees C.) is universally present in rocks in the range of the chemical composition of tektites. But I have examined some 14,000 fused quartz particles in tektites and have found no trace of glass from zircon or other minerals, except perhaps for a few particles too small to identify in certain tektites from Texas and in glass from the Libyan desert. One can only conclude that these minerals diffused in the molten tektite droplet without leaving a visible trace. A high temperature of formation also accounts for the extremely low water content of tektites (.002 to .008 per cent), especially as contrasted with that of the minerals of the earth's crust. Glass from the crater of the first nuclear bomb, at Alamogordo, N.M., is almost as free of water and was fused from the same kind of material.

Such high temperatures are not attained naturally on earth except by lightning or by the impact of meteorites. Since lightning produces only thin tubes and films of glass, the temperature clue points strongly to meteoritic impact.

The physical structure of tektites supplies additional clues to the circumstances under which they were formed. Placed between crossed polarizing sheets and examined in transmitted light, translucent tektites and thin plates cut from more opaque specimens exhibit distinctive patterns of internal strain. From these patterns it is clear, in the first place, that tektites are not fragments of larger pieces but are now essentially the same size and shape as when they were formed. The internal strain is exactly the kind one would expect to find in a small body that had cooled down from the molten state. Because heat flows outward, the surface of such a body solidifies first, while the inside is still expanded by heat and liquid. As the inside cools it necessarily begins to shrink. But the outside is now rigid and frozen in the expanded dimensions of the molten state. As a result tensional strain develops between the interior and the surface. If the strain is sufficiently strong, vacuum bubbles form.

Polarized light reveals a second significant strain pattern in the interior of a tektite. This shows up as an alternation of dark and light bands that parallel the contorted and folded flow layers of glasses of widely different composition that constitute the substance of the object. The layers are visible even in ordinary light because they refract the light at different angles. The presence of these layers is evidence that tektites were molten for only a few minutes at most, because otherwise the different materials would have mixed and diffused into one



BITS OF GLASS formed by the impact of a meteorite near Al Hadidah in Saudi Arabia display cooled-drop forms closely resembling those of tektites. These specimens are enlarged four diameters. Consisting of fused sand, they were thrown only a short distance from the site of the meteorite impact. They differ from tektites in certain of their physical and chemical characteristics.

another. As inspection in polarized light reveals, the differences in their coefficients of expansion set up powerful strains between them.

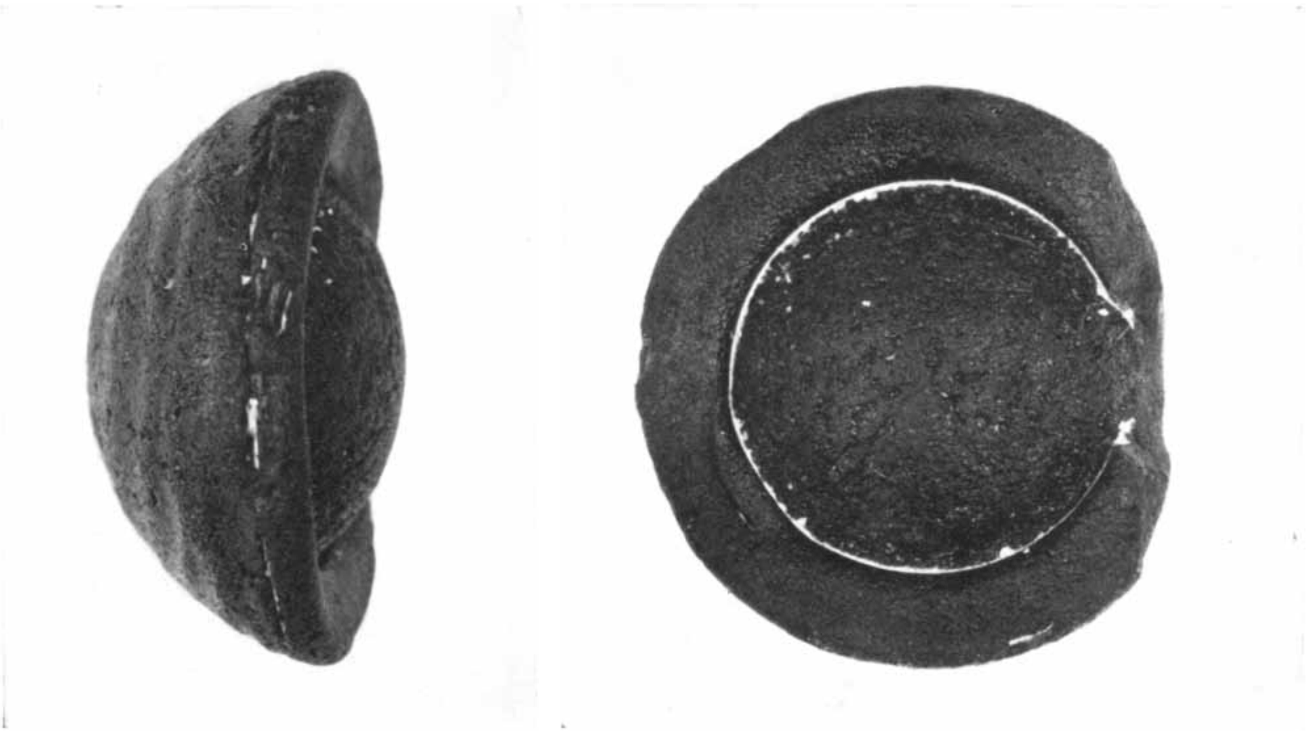
A simple experiment suggests the speed at which tektites must have cooled from the molten state. The stress patterns and even the flow layers can be essentially obliterated by heating a tektite to a temperature of 1,605 degrees C. and keeping it there for 30 minutes. By the end of this period the composition of the specimen has approached uniformity. At the higher temperatures at which tektites must have formed, the various layers would have tended to blend together much more rapidly. Since the flow structure is distinct, one must conclude that tektites cooled very quickly. As the evidence for high temperature points to the melting of rock in the dissipation of the enormous energy transferred to the earth by the impact of a large body from space, so the evidence for rapid cooling fits the picture of a droplet of molten rock splashed from the point of impact and congealing in its flight through the atmosphere.

The peculiar internal structure of some Australian tektites presents impressive evidence for high temperature and rapidity of cooling. From thousands of specimens in museum collections, I recently had an opportunity to select a few for sectioning and internal inspection. I chose these specimens for their unusual surface features. Microscopic examination of plates cut from them revealed that the surface features are the manifestation of light-colored, finger-like inward extensions several millimeters in length. The index of refraction of these fingers indicates that they are more siliceous than the surrounding glass. Moreover, they are coated by tiny particles that appear to be segregated bits of glassy silica similar to fused quartz. These structures could have been formed only at high temperatures and preserved by rapid cooling thereafter.

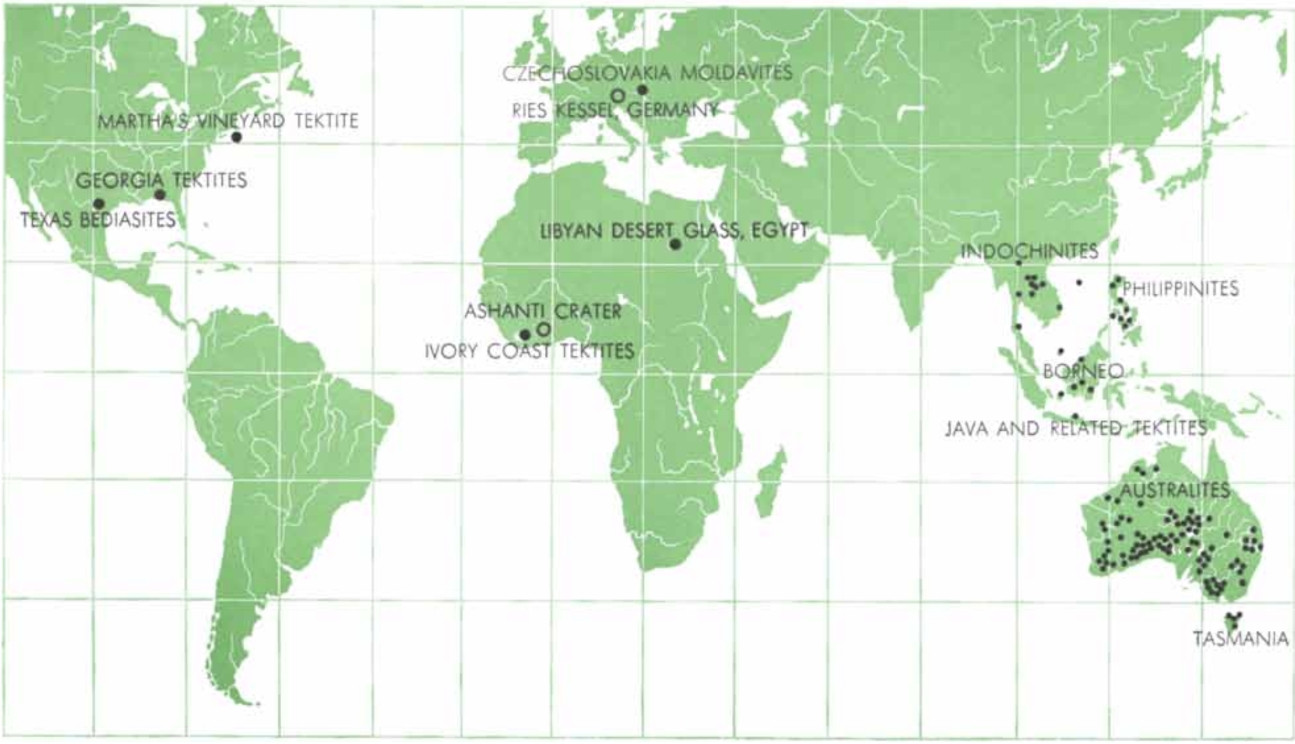
The Australian tektites present a special problem because they show evidence of two periods of melting. In common with other tektites they have dumbbell, oval and other rounded shapes, but these primary shapes appear to have been modified. The buttons, for example, bear flanges around their peripheries. It is apparent that these tektites assumed their primary shape on first cooling from the molten state and then underwent a second partial remelting.

The most plausible explanation is that the remelting of these tektites was induced by friction with the atmosphere. Indeed, they show evidence of remelting on only one side or face—the side or face that pointed forward in the direction of flight and so was exposed to greatest friction. The first melt products would have been stripped away by ablation. Then, as the object slowed, some glass would have flowed toward the lee and formed a flange. In the Australian tektites that I cut into sections the finger-like extensions of highly siliceous material reach inward only from the rear surface; some were under flanges. It is apparent that removal of glass from the forward surface by ablation also removed the fingers in this area.

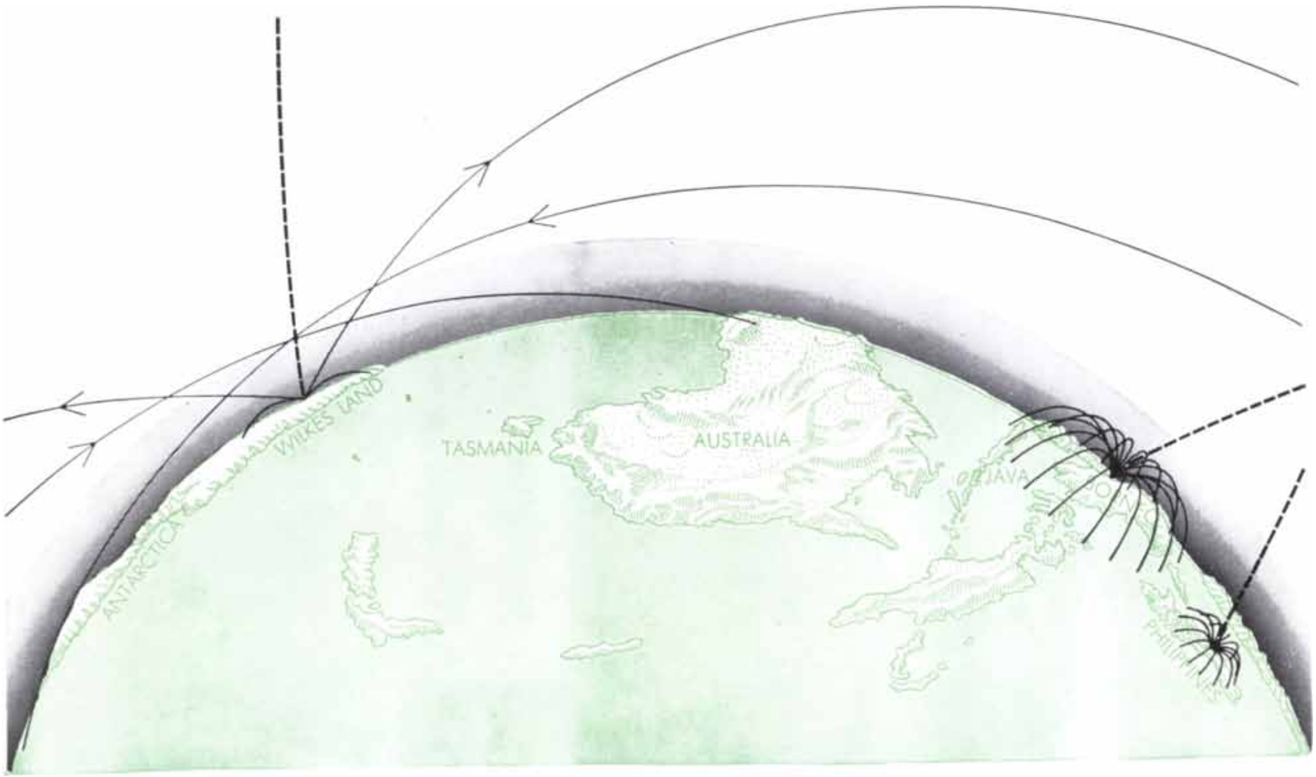
This reconstruction of the partial remelting that modified the Australian tektites has given rise to two opposing accounts of the primary formation of these objects. Because of their obviously terrestrial composition, one explanation argues that they were splashed from the earth into space by a huge explosion and acquired their secondary shape on reentry into the atmosphere. The other holds that they were blasted off the moon and were remolded during their first and only passage through the earth's atmosphere. George Baker of the Commonwealth Scientific and Industrial Research Organization in Australia has measured the mass, dimensions and radii of curva-



FLANGED AUSTRALIAN TEKTITE, called a button, shows evidence of high-speed flight through the atmosphere. Its smooth, ridged front surface (*at left in photograph at left*) appears to have been shaped by friction with the air. The flange formed when melted material flowed to the rear. Rear surface of specimen is shown in photograph at right. Enlargement is 3½ diameters.



"STREWN FIELDS" of tektites are shown here on world map. The open circles (*"Ries Kessel"* and *"Ashanti Crater"*) mark sites of meteorite impacts that may have produced the nearby strewn fields. Martha's Vineyard tektite is single fragment, found recently.



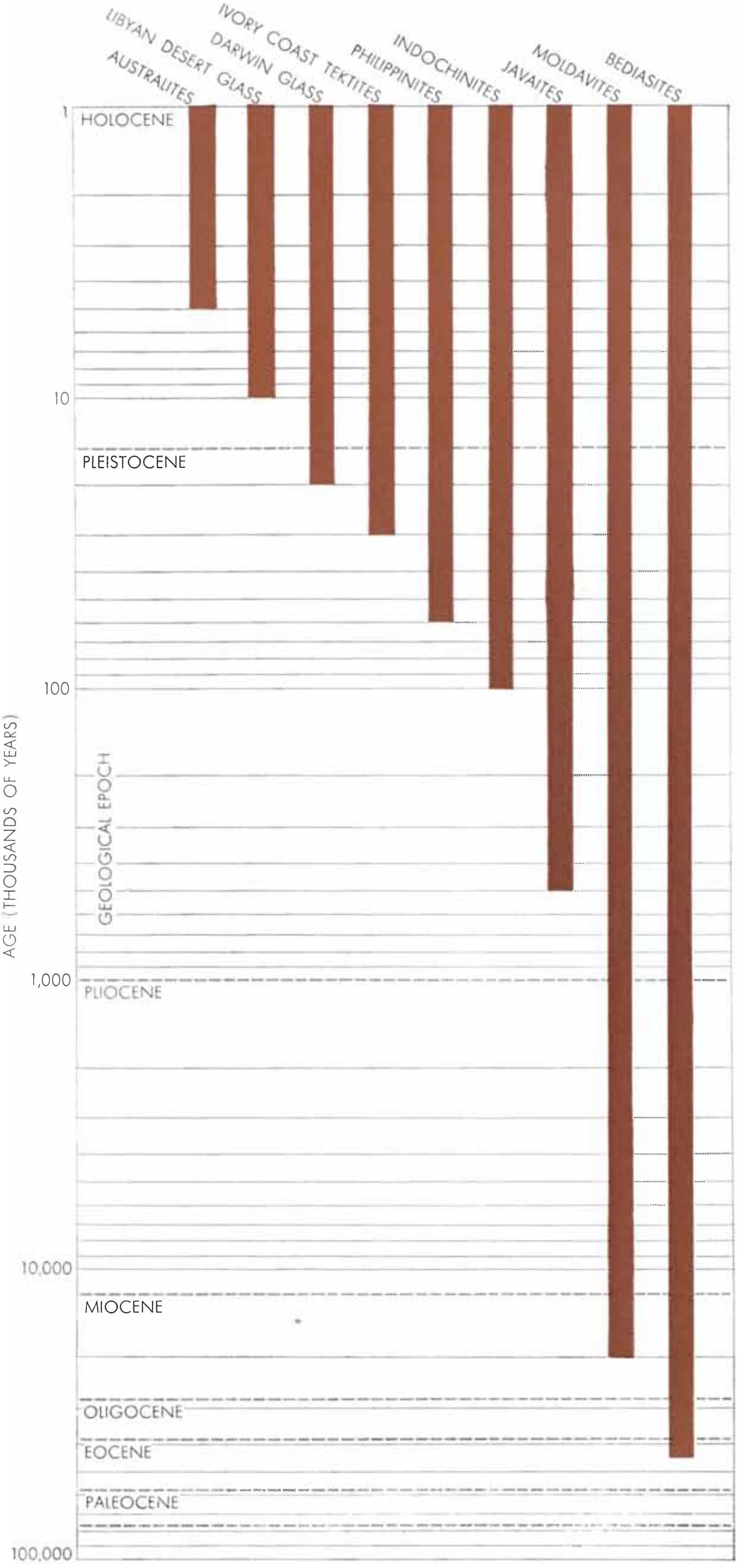
BIRTH OF STREWN FIELDS is represented in this diagram. Meteorites crash to earth (*broken lines*) and, regardless of angle of impact, send up cone-shaped showers of fused material. Some of resulting tektites fall into water, others on land. The hypothetical Wilkes Land impact may have sent australites into orbit around the earth. The orbits are represented here by only two flight paths, one ending in Australia, the other in the ocean. The event would have strewed tektites in a circle with a radius of about 3,500 miles from the impact site. The three events shown here are not thought to have occurred simultaneously. Impact sites for them are unknown.

ture of complete, well-preserved buttons. From Baker's data for two specimens, along with the study of another Australian tektite in the British Museum, Dean R. Chapman of the Ames Research Center of the National Aeronautics and Space Administration has calculated the speed and angle of entry of these three objects into the atmosphere. Chapman finds that the moon was their most likely place of origin and goes on to the general conclusion that the moon was somehow "involved in the act of hurling tektites to the earth." Signs of ablation, however, are mostly confined to the Australian tektites. Chapman's computations have no relevance to tektites from other regions of the world, which show no evidence of entry or re-entry into the atmosphere from outside.

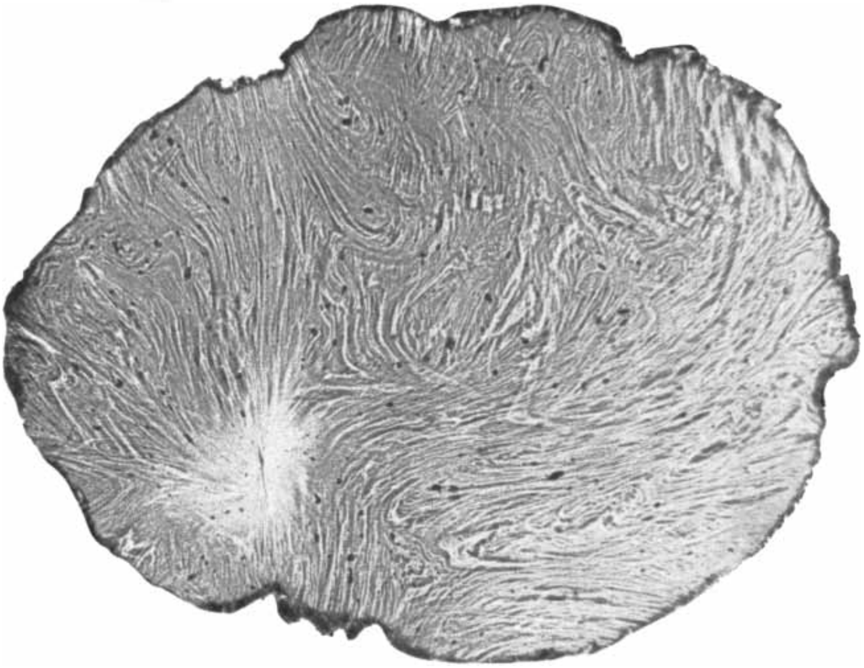
It is in the geographical distribution of tektites that one must ultimately search for the clues to settle the question of their origin. The tektites of the various regional groups are more or less widely scattered, the Australian tektites having the broadest distribution. The members of each group, however, have distinctive characteristics associating them with others of their kind; most have been given family names. Those found in Czechoslovakia are called moldavites after the Moldau River; those found in Texas are called bediasites after a tribe of Indians; those from Java, Indo-China and the Philippines are designated javaites, indochinites and philippinites respectively. The Australian tektites are naturally enough called australites.

From the evidence of the associated geology, the various groups have been clearly identified as belonging to single showers, and no tektite has been shown to be younger or older than the members of its group. Geologists have also assigned ages to the groups, ranging from about 45 million years in the case of the Texas bediasites and about 20 million years for moldavites to perhaps as little as a few thousand years for the australites, the youngest and freshest shower. The geological antiquity of the older groups is supported by radioactive-decay determinations employing the ratio of potassium 40 to argon 40, made independently by J. Zahringer of the Max Planck Institute for Physics in Heidelberg and John H. Reynolds of the University of California.

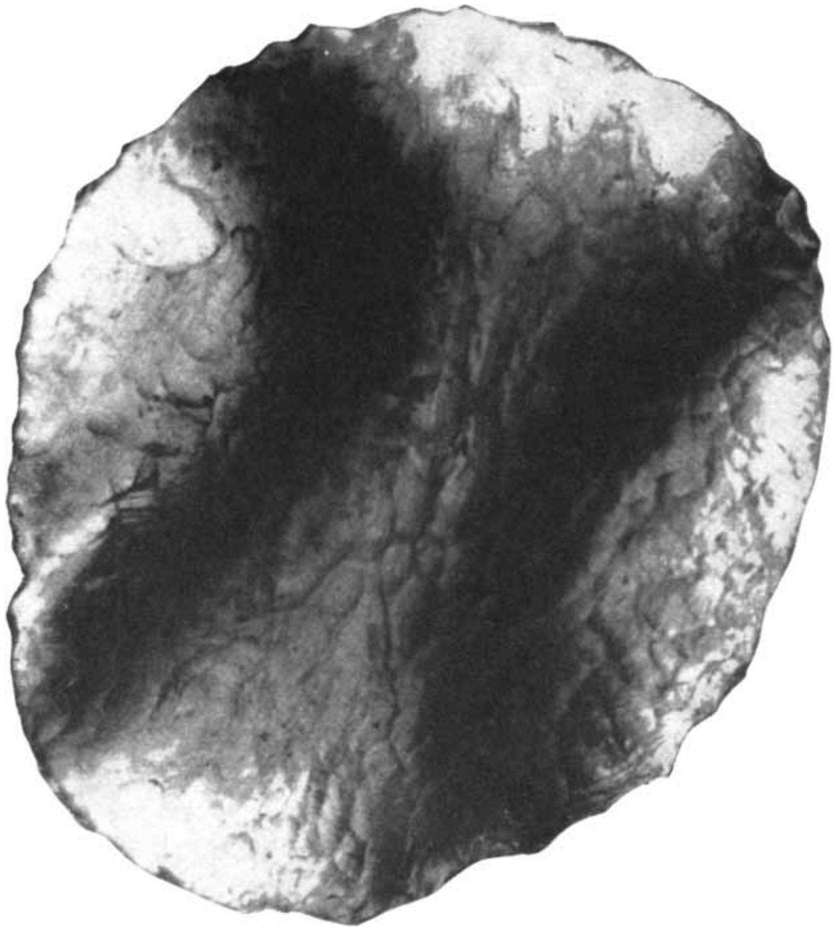
Until recently one of the objections to the idea that tektites originated with the impact of meteorites or other extraterrestrial bodies on the earth has been the lack of apparent impact sites. In the case of the most ancient sites, geological proc-



ESTIMATES OF AGES of tektites in strewn fields are based on ages of rocks with which they are found. The antiquity of the three oldest groups has been confirmed by radioactive-decay determinations employing the ratio of potassium 40 to argon 40 in the tektites.



FLOW PATTERN within a tektite shows that the glass is made up of many layers having different composition. The distinctness of the patterns shows that the tektite cooled quickly.



STRAIN PATTERN within a tektite shows up plainly when tektite is placed between two crossed polarizing sheets. Pattern shows that tektite is the same size as when it was formed.

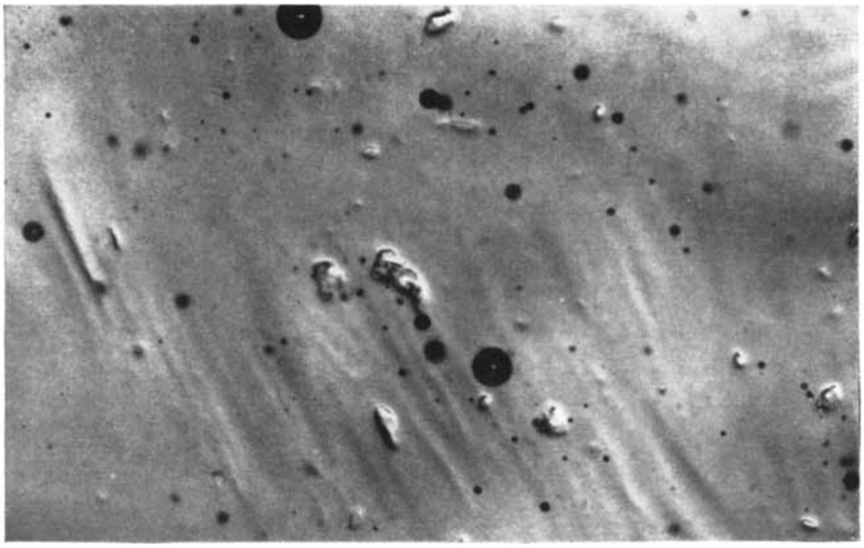
esses would long since have erased the more obvious surface evidence. Ancient sites can now be located, however, by more persistent clues. One is coesite, a kind of quartz that is formed at high pressure. Another is the shatter cone, a kind of fracture in rock that Robert S. Dietz of the Naval Electronics Laboratory has associated with the sites that he has named astroblemes [see "Astroblemes," by Robert S. Dietz; SCIENTIFIC AMERICAN, August]. The Ries Kessel formation in southern Germany has been identified as a fossil meteorite crater in this way, and Alvin J. Cohen of the Mellon Institute in Pittsburgh has postulated that this is the site from which the moldavites of Czechoslovakia were splashed. The Ashanti Crater in Ghana is possibly large enough to account for tektites found on the Ivory Coast. For the impact that showered the bediasites on Texas about 45 million years ago one would probably have to search the floor of the Gulf of Mexico or the Gulf coastal plain under a mile or so of sedimentary deposits. In the case of the philippinites and indochinites, the impact scars might be found among the numerous volcanoes and calderas (collapsed craters) of the Philippine Islands. Urey has suggested that an impact of sufficient size could initiate a volcanic event that would hide the scar. South of Manila is the Taal caldera, 20 miles in diameter, which may well have had such an origin.

The discovery of a terrestrial impact site that will explain the australites, however, presents an embarrassing problem. The event would have had to be of sufficient magnitude to blow out a segment of the atmosphere along with the shower of tektites that were remolded upon re-entry. Such an impact would dig a crater of the same order of magnitude as the so-called Vredefort Ring in South Africa. This formation, with an inside diameter of 30 miles and an outside diameter of 130 miles, has been identified by Dietz as an astrobleme. It was formed so long ago (250 million years) that its associated tektites have disappeared. The australites, on the other hand, have been shown by Baker to be no more than 5,000 years old. If they were formed in a terrestrial catastrophe, the crater must still be somewhere in evidence.

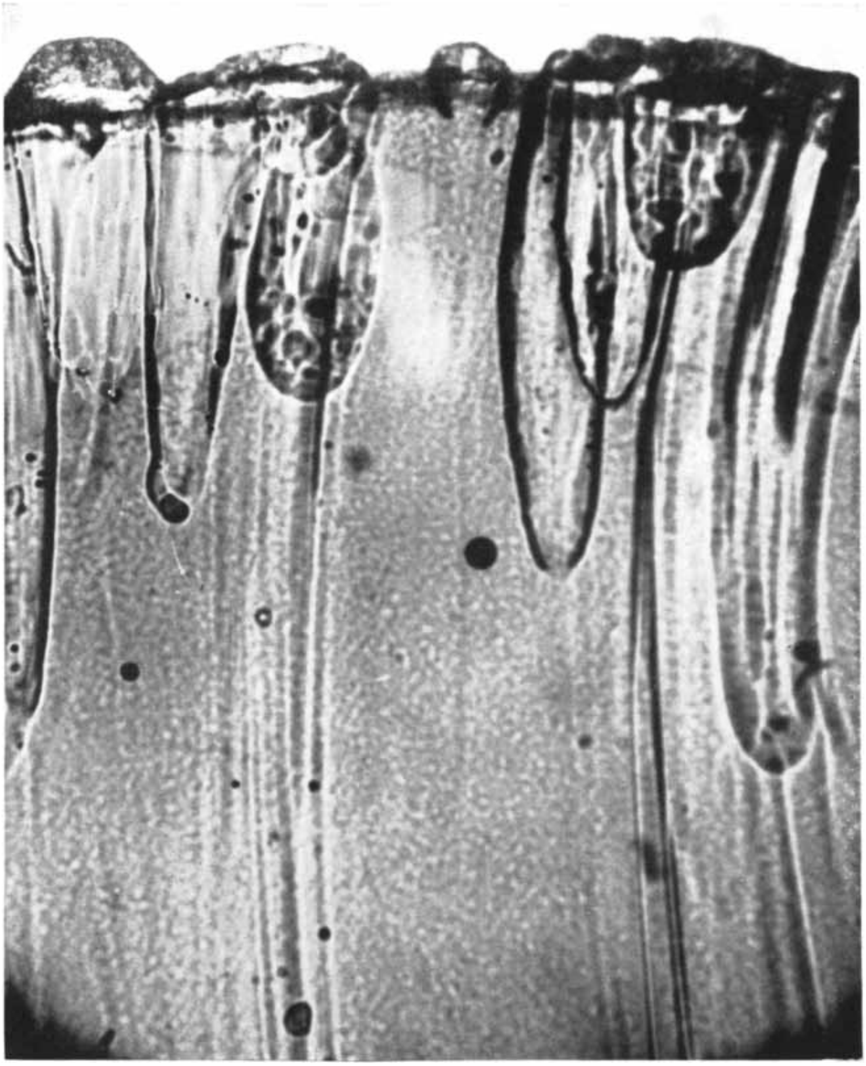
But no crater of such size and age is known anywhere on earth at the present time. Nor could the body have made its impact in the sea, for it would have rolled up a wave high enough to wash over the continent of Australia (and over other land masses as well), destroying the results of ages of evolution. Obviously such destruction did not occur, unless one pair of each of the Australian marsupials survived in the Ark. The impact must accordingly have taken place on land.

There remains one terra incognita where the crater may yet be found. When the distribution of australites is plotted on the map, it is easy to visualize that the impact may have occurred somewhere in Wilkes Land in Antarctica, 3,000 to 3,500 miles from the periphery of the australite shower. The distance is about right, for the radii of tektite showers would in each case be proportional to the altitude to which the material was blasted from the surface of the earth. In order to have been ablated the australites would have had to travel several times higher than the other tektites, which show no remelting and traveled neither so high nor so far. Chapman argues, however, that if the australites did originally come from the earth, they must have orbited around it in order to come in at an angle of re-entry low enough to account for the degree to which they were eroded by the atmosphere [*see bottom illustration on page 62*].

During the past year I have visited the area of a far milder episode. Here I found tektites in close association with other direct evidence of an impact. With the aid of Kaset Pitakpaivan of the Thailand Royal Department of Mines, I explored a region of that country in which deposits of a strange glassy material had been reported. We examined four such deposits, finding in one of them as much as 50 pounds of chunky tektite glass in an area a yard or two across. That these are fragments of still larger masses is indicated by the absence of internal strain patterns. This type of tektite, now known to be distributed over a distance of 220 miles, is interspersed with tektites of the usual kind. It is apparent that both types of tektite were formed by the same event: the impact of an asteroid or comet. The impact produced an explosion of sufficient magnitude to form and distribute tektites like those found elsewhere in the world. The accompanying heat and shock wave either fused the larger masses of glass in the sites where they were found or they were hurled from the point of impact by the explosion. The Thailand deposits add additional weight to the accumulating evidence that makes it increasingly certain that tektites are terrestrial in origin and must be counted among the mementos of past collisions between the earth and the rubble of the solar system.



FUSED QUARTZ PARTICLES are the white, apparently raised areas seen here in a thin section of a tektite. The black dots are vacuum bubbles. Enlargement is 22 diameters.



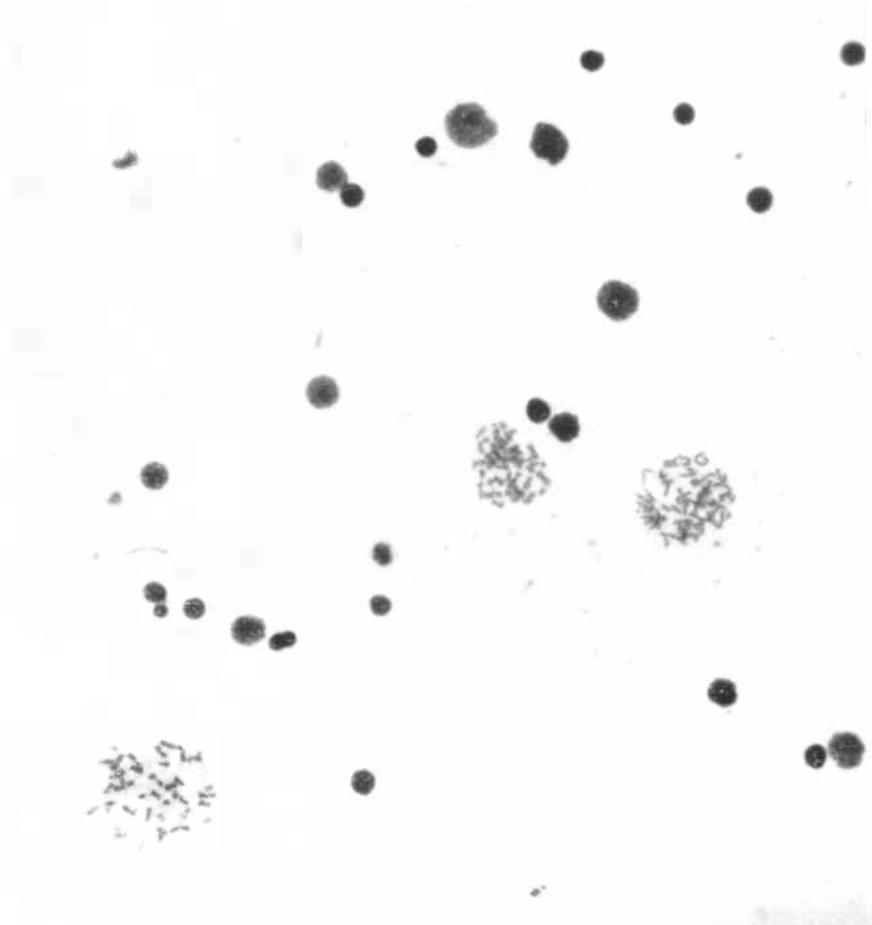
"FINGERS" IN AUSTRALITES are rich in silica. This indicates that very high temperature of formation caused other constituents to evaporate. The tiny black dots within the fingers are even richer in silica than the surrounding area. Enlargement here is about 25 diameters.

Chromosomes and Disease

Advances in the visualization of human chromosomes have made it possible to link chromosomal abnormalities with certain diseases and have opened up a new frontier in the study of human heredity

by A. G. Bearn and James L. German III

The congenital malformation called mongolism blights one in approximately 650 births. Ever since the condition was identified in the 1860's by the British neurologist Langdon Down concerned physicians and investigators have been seeking its cause. For many years mongolism was described as a hereditary disease, the result of some unknown defect in the "germ plasm." Investigators dissatisfied with such vague explanations have argued the opposite view that the disease is environmental, and have correlated its incidence with accidents to the developing embryo during gestation.

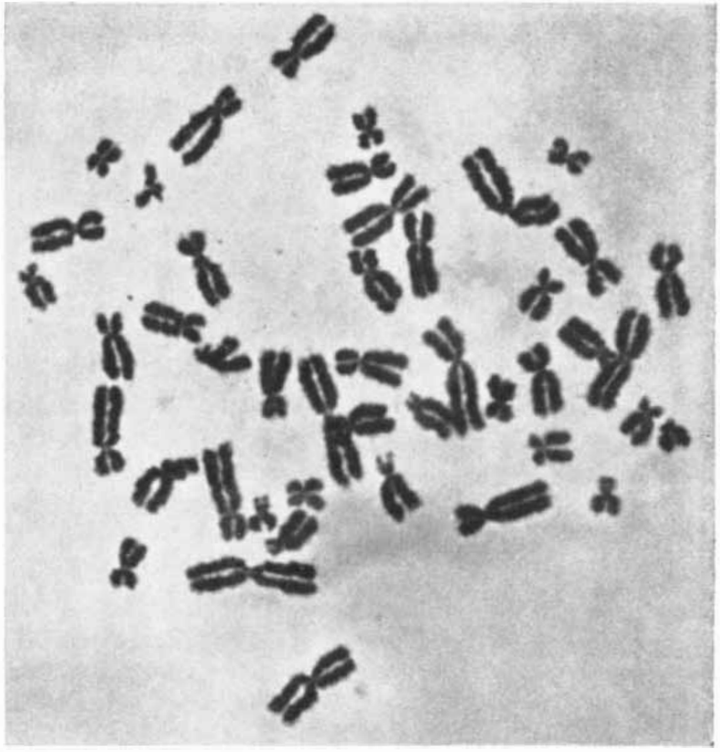


HUMAN BLOOD CELLS, raw material for chromosome study, are shown on a slide (magnified 360 diameters) after preparation and staining. Scattered groups of rodlike chromosomes of white cells are visible during mitosis, or cell division. Dark globular particles are white cells that are not undergoing division. Mitosis at lower left is suitable for analysis.

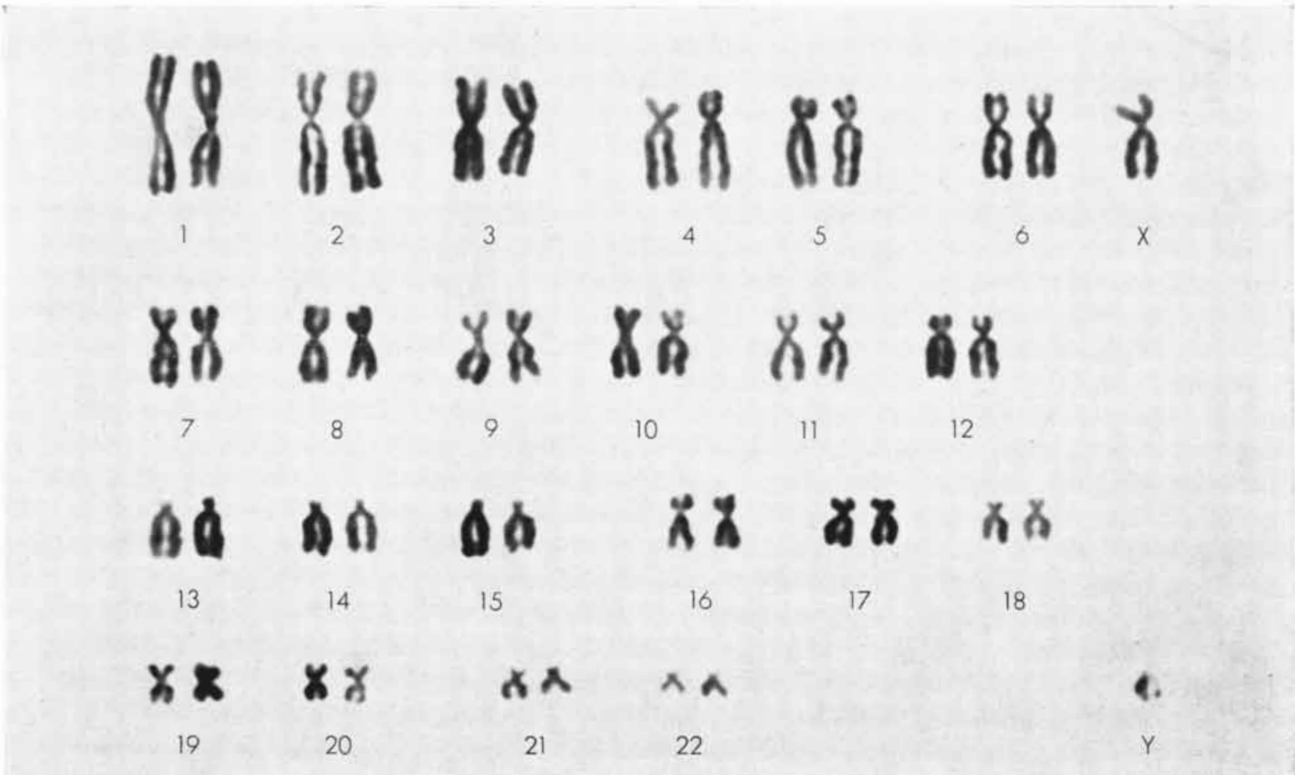
The explanation of mongolism is now at hand. The disease is neither typically hereditary nor environmental, as these terms are commonly employed. It arises from a defect in the mechanism by which the hereditary material is passed on from parent to offspring. This leaves certain questions unanswered: for example, whether the defect in the genetic mechanism is itself hereditary or environmental in origin. The explanation is nonetheless of great significance, for it is among the first findings to come from direct investigation of the genetic apparatus of the human cell. The techniques of cell genetics have hitherto been restricted to more easily studied cells of lower animals and plants.

Over the past 60 years the science of cell genetics has made profound contributions to an understanding of the hereditary process. It was only five years ago, however, that geneticists were able to establish the number of chromosomes in the human cell. These are the structures in the cell nucleus that encode the hereditary plan; the normal number in the human cell proved to be 46. Soon afterward came the discovery that mongolism is associated with the presence of 47 chromosomes. Similar gross abnormalities in the chromosome complement of the tissue cells have since been established in other diseases of man. This is only the beginning. To look through the microscope at the chromosomes of man is to see the very stuff that human life is made of. Without a doubt a new chapter in human biology has opened.

The history of cell genetics can be said to date from 1903, when Walter S. Sutton, a graduate student at Columbia University who later became a sur-



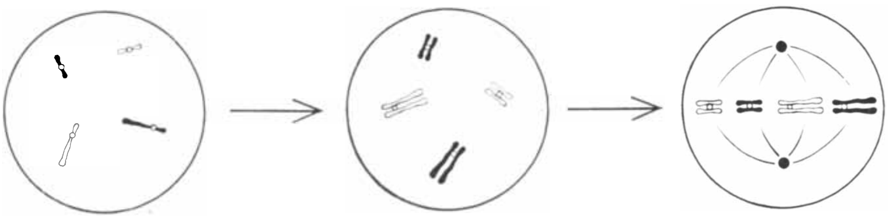
ACCURATE CHROMOSOME COUNT is feasible only after cells have been exposed to a hypotonic (low-concentration) salt solution that swells them and disperses the chromosomes. The chromosomes at the left were treated with a colchicine derivative to arrest cell division at metaphase, when chromosomes are in their most visible form. But they are still too tangled to be counted or measured. Those on the right have also been treated with salt solution. They are distinct structures that can be counted and measured.



KARYOTYPE, an arrangement of chromosomes according to a standard classification, is used to demonstrate a subject's chromosome complement and reveal abnormalities. Homologous chromosomes in a photomicrograph of a mitotic cell like the one at top right on this page are identified by over-all length, position of the "centromere" where the two strands join and other characteristics, and then cut apart and grouped in a karyotype. This normal male karyotype has X and Y sex chromosomes and 22 "somatic" pairs.

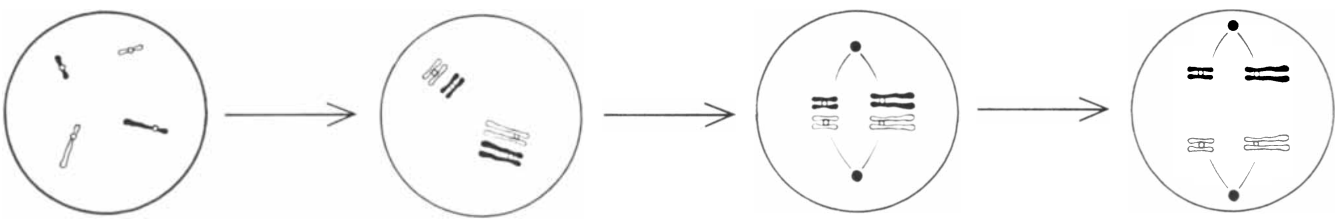
geon, pointed out in a classic paper the striking parallelism between the inheritance of genetic traits and the behavior of chromosomes in cells. Subsequent investigations by Thomas Hunt Morgan and A. H. Sturtevant, also at Columbia, showed that the units of heredity, the "factors" of Gregor Mendel, must be arranged in linear order on the chromosomes.

These findings stimulated study of the chromosomes in various animals and plants. Investigators soon discovered that whereas the number of chromosomes varies in different organisms—from two in some species of worm to 300 in some protozoa—the number in the cells of any one species is constant. It was a relatively simple matter to count the chromosomes of organisms, notably the fruit fly, in which the chromosomes are few and large. In species in which they are small and numerous, however, the task was burdensome, and different investigators reported different results. This was the case with human chromosomes in particular, although the count of 48 obtained by T. S. Painter of the University of Texas in the early 1920's was accepted in the literature.

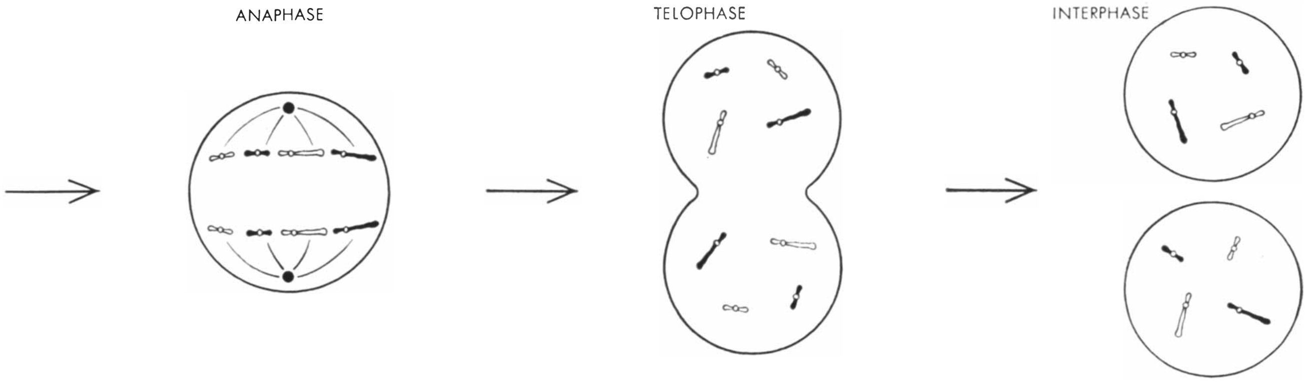


MITOSIS, the process by which body cells divide, is diagramed here for a hypothetical cell with four chromosomes: two homologous sets of two each. They are shown schematically at interphase (*left*), between cell divisions. By prophase each chromosome has repli-

Meanwhile geneticists working with more favorable material were able to establish in the behavior of the chromosomes the mechanisms that account for the segregation and independent assortment of traits first postulated by Mendel. Each cell of an organism, including the germ cells that give rise to sperm and eggs, bears two sets of chromosomes. The "homologous" chromosomes of each set (with the exception of the chromosomes that determine sex) are similar in appearance and carry genes affecting the same traits; one set is contributed by each parent. When the germ cells divide in the two-step process called meiosis, the chromosomes are replicated only once, before the first division. In the second division the two sets of chromosomes pull apart or segregate to produce sperm or eggs (gametes) with only one set of chromosomes each. As a result the gam-



MEIOSIS, the process by which germ cells divide to produce sperm and eggs with only half the full number of chromosomes, occurs in two stages diagramed here in simplified form. Before meiosis the germ cell has the full number of chromosomes (*left*). During prophase each chromosome, now replicated, pairs up with its homologue and assumes a visibly two-stranded form. At metaphase the homologous pairs line up with each other and in anaphase one member of each pair, without splitting, goes to each pole. The new

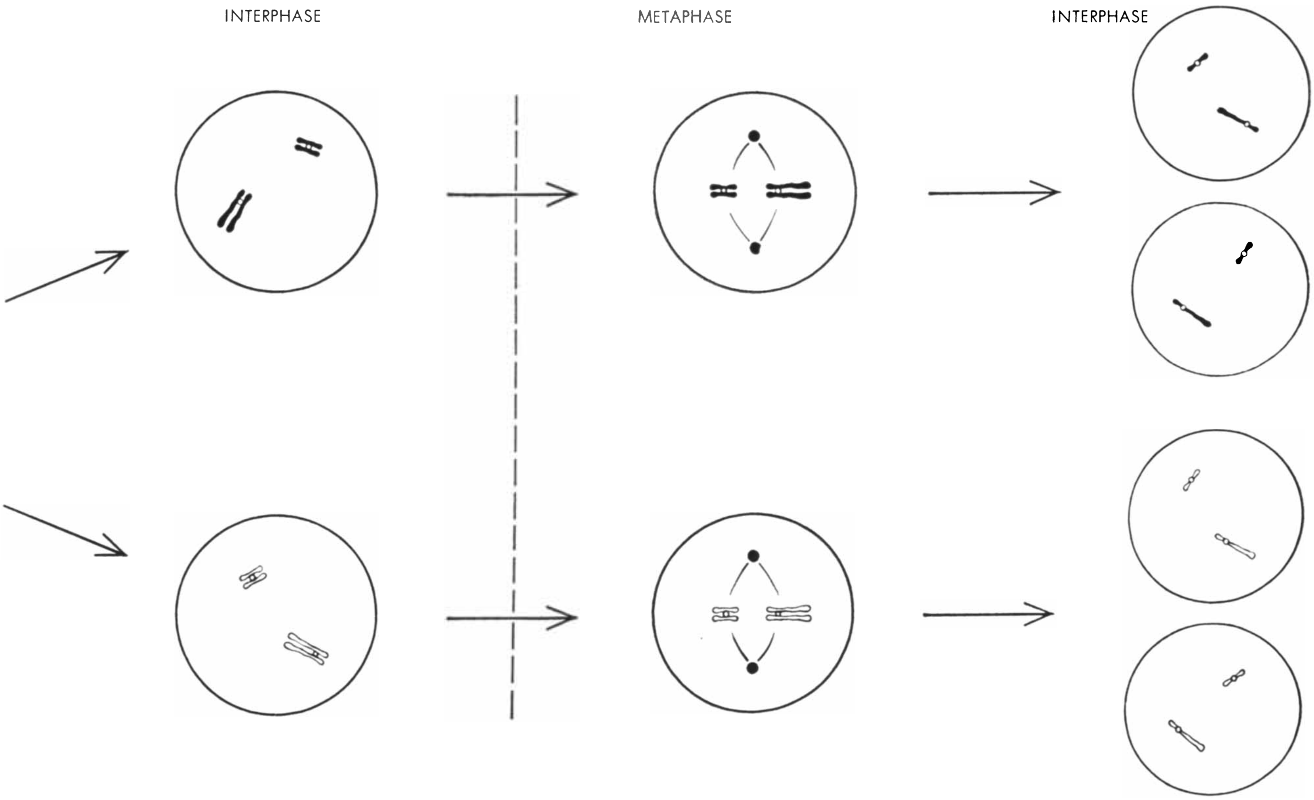


cated, forming two strands joined at the centromere. At metaphase the twin-stranded chromosomes line up at the equator of the cell. At anaphase the strands split apart and move toward opposite poles. In telophase the cell splits to form two daughter cells. These, seen at interphase (*right*), each have four chromosomes, the same number as the original cell, and are exact genetic copies of the original.

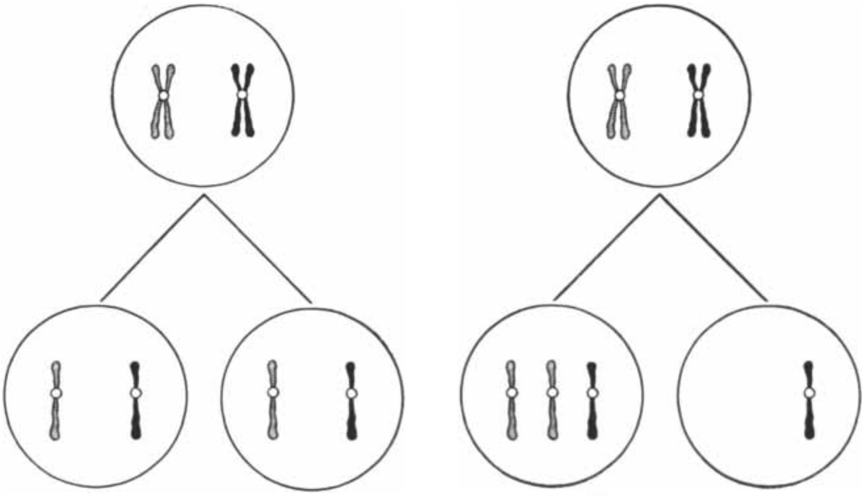
etes are "haploid": they contain exactly half the number of chromosomes of the precursor germ cells [*see illustration at bottom of these two pages*]. The subsequent union of the gametes produces a fertilized egg (zygote) with the full "diploid" number of chromosomes characteristic of the species, and the organism that then arises by mitotic division of the zygote exhibits a combination of traits inherited from its two parents [*see illustration at top of these two pages*].

The idea that human cells contain 48 chromosomes was first upset in 1956, when J. H. Tjio and Albert Levan of the Institute of Genetics at Lund in Sweden reported that cells from a normal embryo showed 46 chromosomes. All doubt was dispelled soon afterward by C. E. Ford and J. L. Hamerton of the Radiobiological Research Unit at Harwell in England. They found 46 chromosomes in the male germ cells and also 23 pairs of chromosomes during the appropriate stage of meiosis. At long last the chromosome number for man was unequivocally established.

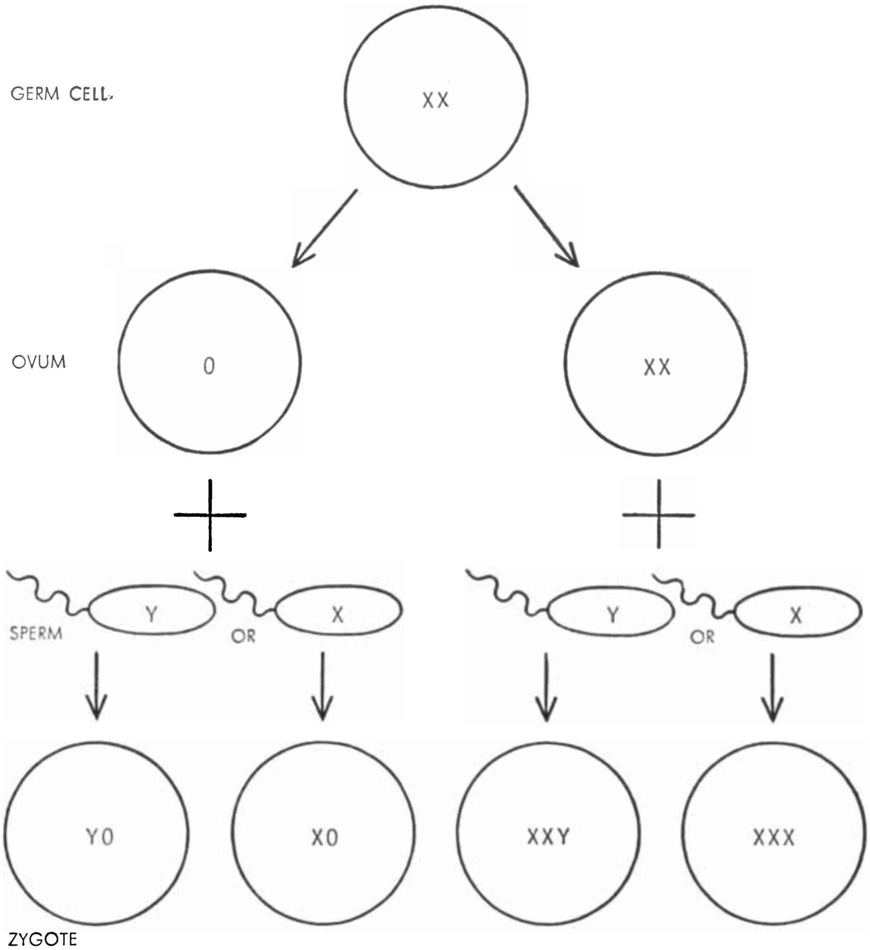
Two major advances in the technique of cell biology stood behind this work. One was the discovery that colchicine, a plant alkaloid used in the treatment of gout, arrests cell division at the



cell, shown at interphase, therefore has only one member of each pair. (The line-up at metaphase can vary, so various combinations of maternal and paternal chromosomes can be found in the new cells.) In the second stage of meiosis (*right of broken vertical line*) there is no further replication of the chromosome. The twin-stranded chromosomes simply line up as in mitosis and divide. The four cells that result, precursors of the sperm and eggs (gametes), each contain two chromosomes, or half the original number.



NONDISJUNCTION is one means by which a cell can come to have the wrong number of chromosomes. Here it is diagramed in the case of one homologous pair. The chromosomes have replicated in preparation for division. Normally the two strands separate to opposite poles of the cell and one passes to each new cell (*left*). In nondisjunction (*right*) the strands of one chromosome fail to disjoin; two abnormal cells result, one with three of the involved chromosomes (trisomy) and the other with one (monosomy). Through a similar process in meiosis either a sperm or an egg can be produced with too many or too few chromosomes.



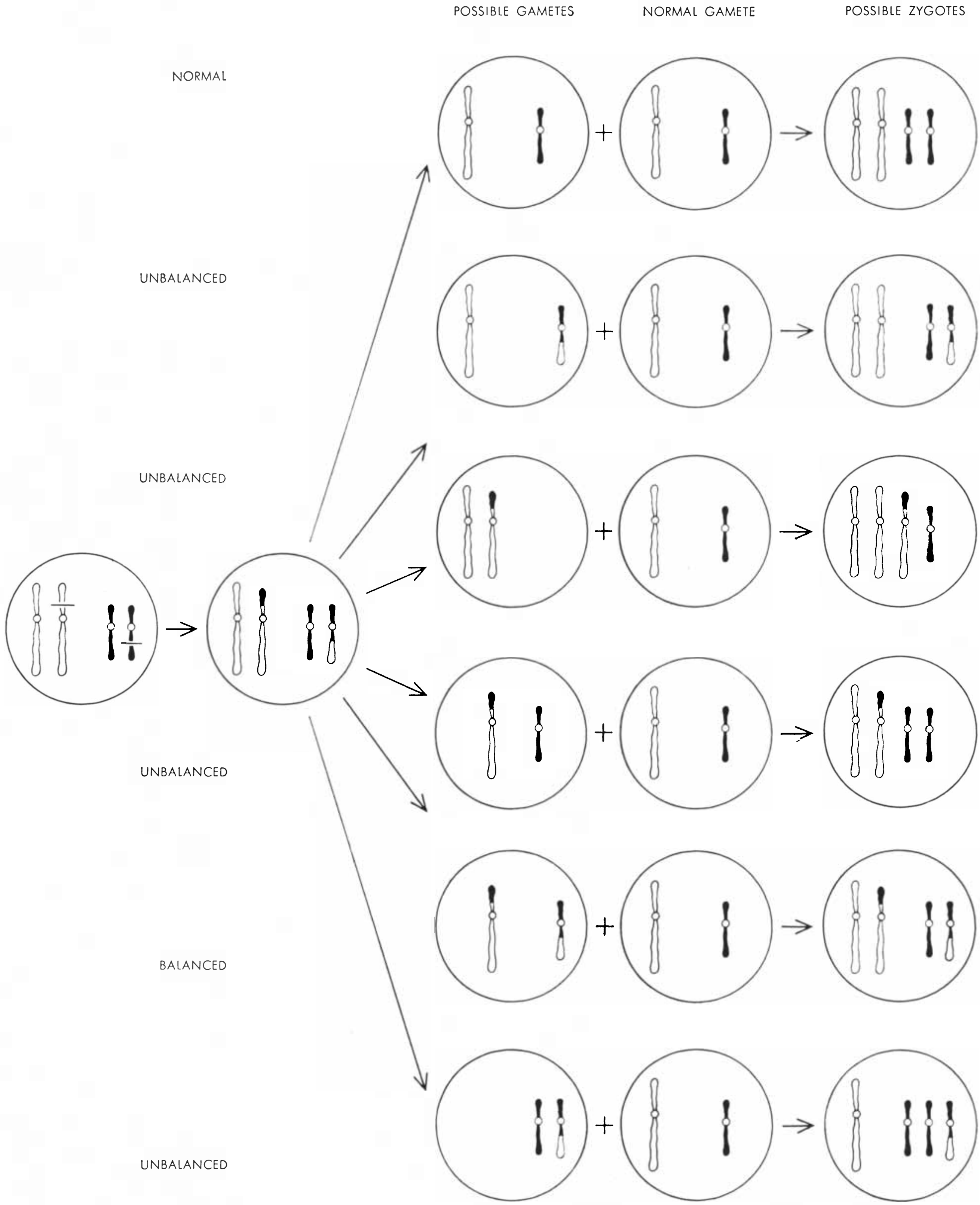
NONDISJUNCTION IN MEIOSIS would explain several diseases. If two chromosomes end up in one ovum, fertilization by an X or a Y sperm will produce one of the abnormal zygotes shown. Y0 content apparently results in a nonviable zygote. X0 is found in Turner's syndrome, XXY is characteristic of Klinefelter's syndrome and XXX is a "superfemale."

metaphase, when the chromosomes are ready for separation by the mitotic apparatus and have assumed their most visible form. But even at metaphase human chromosomes are normally too bunched together for effective study. T. C. Hsu, working with Charles M. Pomerat at the University of Texas, solved this problem in 1952. He placed human cells in a hypotonic saline solution—that is, a solution of low salt concentration and hence a lower osmotic pressure than that of the fluid inside the cells; the cells swelled and the chromosomes dispersed, becoming discrete shapes that could be clearly distinguished and accurately counted [*see illustrations on page* 67].

What investigators needed now was a convenient source of human cells. The usual practice was to culture cells from the bone marrow or from a small piece of skin. Such methods are still of great value [see "Single Human Cells in Vitro," by Theodore T. Puck; SCIENTIFIC AMERICAN, August, 1957], but successive samples cannot be obtained without considerable discomfort to the patient, and in long-term cultures it is sometimes difficult to avoid alterations in the chromosome complement.

Blood is the most convenient tissue to sample, and as early as 1935 the Soviet biologist G. K. Khrushchev had reported the successful culture of white blood cells. These cells do not ordinarily divide, but in 1958 P. C. Nowell of the University of Pennsylvania School of Medicine discovered a way to get white cells to undergo mitosis. He found that a substance extracted from red kidney beans, which agglutinates red blood cells and allows the white cells to be harvested and cultured, would also stimulate the white cells to divide in the culture medium. The substance in the extract of red kidney beans that is responsible for this remarkable effect has not yet been identified.

Equipped with the new techniques, investigators proceeded to pair the homologous chromosomes of the human tissue cell, primarily on the basis of their over-all length and the position of the centromere: the site at which the twin strands of a replicated chromosome are held together at this stage of mitosis. They labeled the sex chromosomes X (female) and Y (male) in accordance with the custom adopted for other species, and numbered the remaining "somatic" pairs from 1 to 22 in order of decreasing size. (Some investigators, it should be said, feel it is still presumptuous to assign specific numbers to chromo-



IN TRANSLOCATION parts of two nonhomologous chromosomes of a germ cell break off (*left*) and are relocated (*second from left*). In meiosis abnormal pairing of these anomalous chromosomes is likely; instead of a normal gamete (*top of first column*), meiosis could produce any of the other five gametes shown. The second from the bottom has a normal gene content abnormally positioned, but the four others have too much or too little "black" or "white" gene content. If these gametes were fertilized by normal gametes, the six zygotes at the right could result. Unbalanced zygotes could develop into individuals displaying abnormal traits; the balanced version might produce a normal individual some of whose gametes might nevertheless be abnormal, that is, a "carrier" of abnormality.

somal pairs in view of the variability in their appearance.)

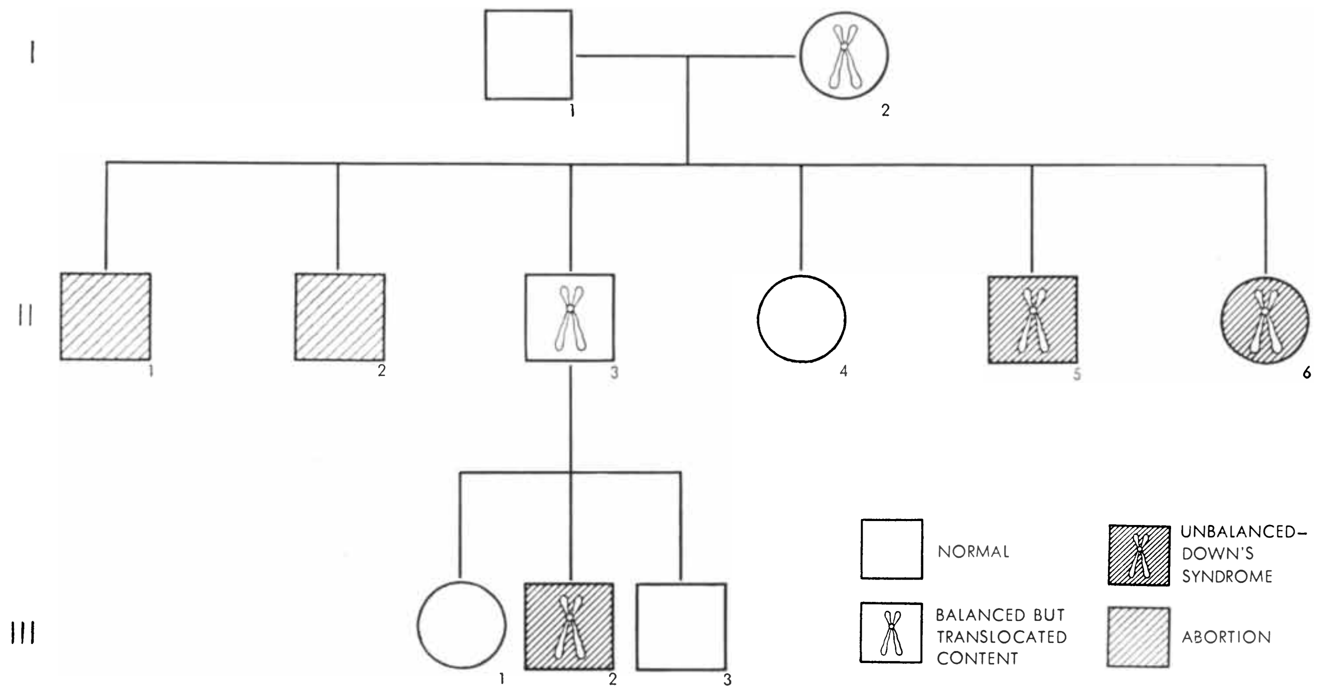
As the first step toward relating the now identified human chromosomes to their genetic function, investigators began to look for abnormalities in chromosomal configuration in individuals with congenital disorders. Such a possibility had already been suggested in connection with mongolism by several investigators in the 1930's. Indeed, Ursula Mittwoch of L. S. Penrose's laboratory at University College London had even examined the cells of a patient with the syndrome in 1952, but she had found the "normal" number of 48 chromosomes. Thanks to the new techniques for chromosome study available in 1959, Jérôme Lejeune, Marthe Gautier and Raymond Turpin of the University of Paris were able to show that the somatic cells of patients suffering from mongolism have 47 chromosomes rather than the normal 46.

The mechanism by which an individual's cells might come to have an extra chromosome was already familiar to cell biologists. Working with fruit flies in 1913, Calvin B. Bridges of Columbia University had demonstrated a failure, called nondisjunction, in the normal process of segregation at meiosis. In addition to three pairs of somatic chromosomes, the female fruit fly has a pair of X chromosomes (the male has an X and a Y chromosome). Normal meiosis in the female produces an ovum with a single X chromosome; normal meiosis in the male, a sperm with an X or a Y chromosome. On rare occasions, Bridges found, the two X chromosomes of a female germ cell fail to "disjoin" in the first stage of meiosis. One of the ova produced by the next division accordingly receives both X chromosomes. Subsequent fertilization by a normal Y-bearing sperm gives rise to an exceptional fly, female in appearance but with a chromosome complement of XXY.

Apparently a similar accident during meiosis in the human germ cell can give rise to a mongoloid infant. In this case, however, the nondisjunction involves not the X chromosome but a small somatic chromosome: Number 21. The ovum with two 21's is fertilized by a sperm also bearing a 21; the result is a zygote with three, instead of the normal pair, of these chromosomes. This is called "trisomy" of chromosome 21.

The question remains: What is it that causes this abnormality in the mechanism of heredity? It has long been known from vital statistics that the risk of bearing a mongoloid child rises steeply with the age of the mother: the mean age of mothers of affected children is 37; at the age of 45 the risk is nearly 3 per cent. (Down named the disease for the supposedly Oriental cast of the facial features associated with it, but it has recently been suggested that it might better be known as Down's syndrome.) This suggests that the abnormal meiosis is triggered by some time-linked mechanism, perhaps the overaccumulation of some metabolic product in the ovum of the older woman or even the activation of a "latent" virus. Another possibility is that the afflicted mothers bear a gene that increases the frequency of nondisjunction; such a gene is well known in the fruit fly. The ultimate cause of nondisjunction and the specific effect of maternal age on its incidence remain to be established.

The very same anomaly that Bridges found in the chromosomes of the fruit fly actually showed up in another constitutional disorder of human beings that was linked to an abnormality of chromo-

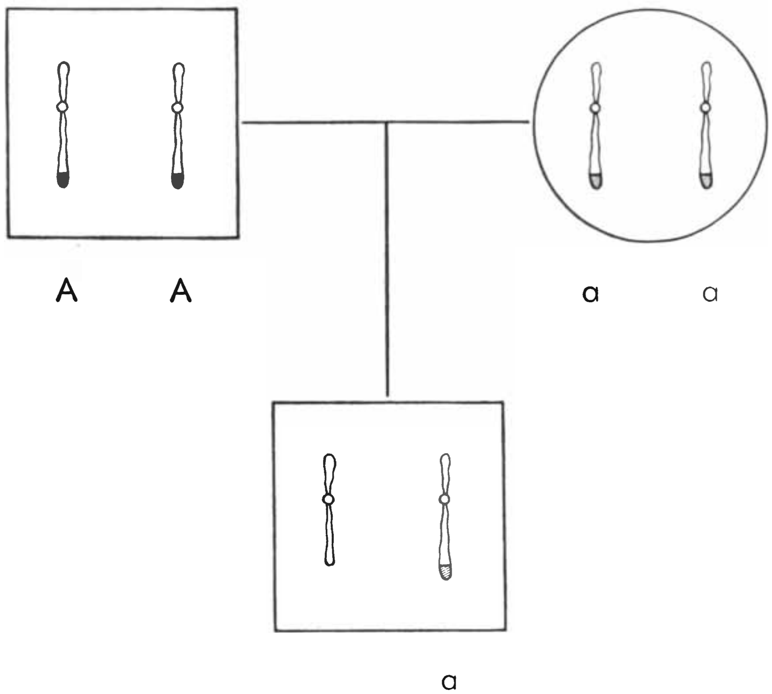


HYPOTHETICAL PEDIGREE shows the transmission of an abnormal chromosome complement that can cause Down's syndrome, or mongolism. A woman (*Generation I, Number 2*) bears translocation chromosomes with balanced gene content; she appears normal but is a "carrier." Two of her children inherit unbalanced gene content and have Down's syndrome (*see karyotype on page 75*); other abnormal chromosome arrangements may account for her two abortions. Another son (*II, 3*) appears normal but bears translocation chromosomes with balanced content. One of his sons (*III, 2*) inherits unbalanced gene content and has Down's syndrome.

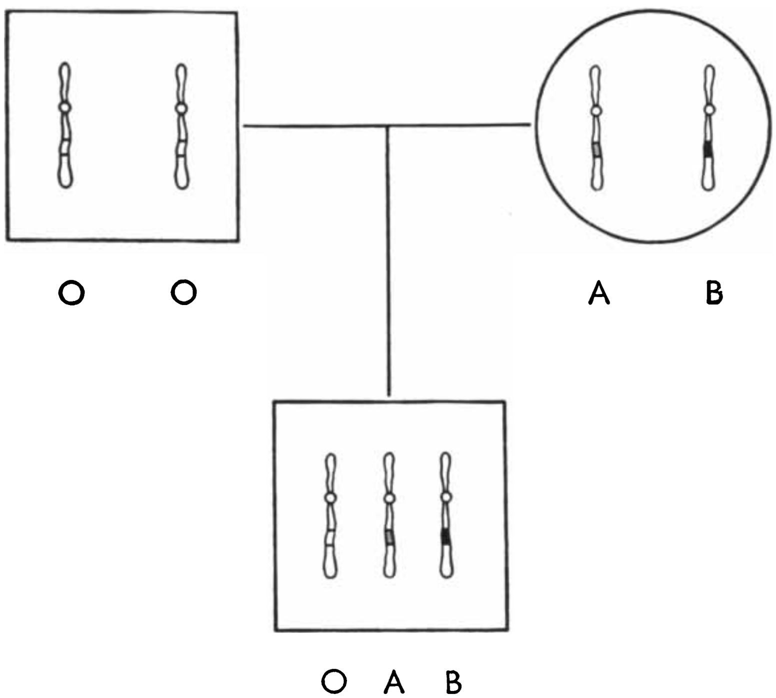
some complement. This was Klinefelter's syndrome, named for Harry F. Klinefelter, Jr., the U.S. physician who described it. It occurs once in about every 400 live male births and is characterized in the adult by tallness, enlargement of the breasts, atrophy of the testes and virtual nonproduction of sperm. The syndrome is sometimes associated with severe mental defect and is the cause of about 1 per cent of institutionalized male mental cases. Most of the patients who have been studied show a chromosome complement of two X chromosomes and one Y chromosome: XXY. Bridges' XXY flies were female; an XXY human is a sterile male.

An XXY zygote could result, of course, from nondisjunction during meiosis in either the father or the mother; an abnormal ovum would supply two X chromosomes and the normal sperm a Y, or an abnormal sperm would contribute an X and a Y to the X of the ovum. In one case it has been possible to establish in which parent the failure occurred. This victim of Klinefelter's syndrome was color-blind; it was also determined that he had a color-blind mother and a father with normal vision. The gene for color blindness is sex-linked (*i.e.*, it lies on the X chromosome) and recessive (*i.e.*, its effect is negated by another X chromosome with a normal gene). The color-blindness gene must therefore have been carried by both of the mother's X chromosomes; it could not have been carried by the father's X chromosome or the father would have been color-blind. It followed that the patient inherited both X chromosomes from his mother. In other instances, however, it is likely that the patient inherits an X chromosome as well as a Y from his father as the result of nondisjunction in meiosis of the sperm, and only the normal one-X complement from his mother. Additional cases have been identified recently, with XXXY and XXXXY cells. The genes on the little Y chromosome should not be underestimated: even when it is outnumbered four to one, the patient still has masculine characteristics.

If nondisjunction occurs in the mother, the XX ovum need not, of course, be fertilized by a Y-bearing sperm. What would be the consequence of fertilization by an X-bearing sperm, yielding an XXX zygote? When this occurs in fruit flies, the resulting "superfemales" appear remarkably normal. When it happens in the human species, as Patricia A. Jacobs and her co-workers at Western General Hospital in Edinburgh discovered, some of the XXX females are normal and fer-



DELETION is a chromosomal abnormality that might be correlated with an observed trait as an aid in mapping the location of human genes. In this hypothetical example, a son of a father with genes *AA* and a mother with *aa* should bear *Aa*, and the dominant *A* should mask trait *a*. If the son displays trait *a*, gene *A* may be missing. One explanation would be deletion of a segment of chromosome. If part of a chromosome can be shown to be deleted, the site of that deletion indicates the normal location of the genes in question, *A* and *a*.



TRISOMY could similarly identify the chromosome (although not the exact site) bearing a given gene. Assume that a father is blood group O (genes *OO*). The mother is blood group AB (genes *A* and *B*). Their son is also blood group AB. Since he inherits an *O* gene from his father, he must have three blood-group genes (*ABO*) instead of the usual two, and so the location of blood-group genes must be on whichever of his chromosomes is trisomic.

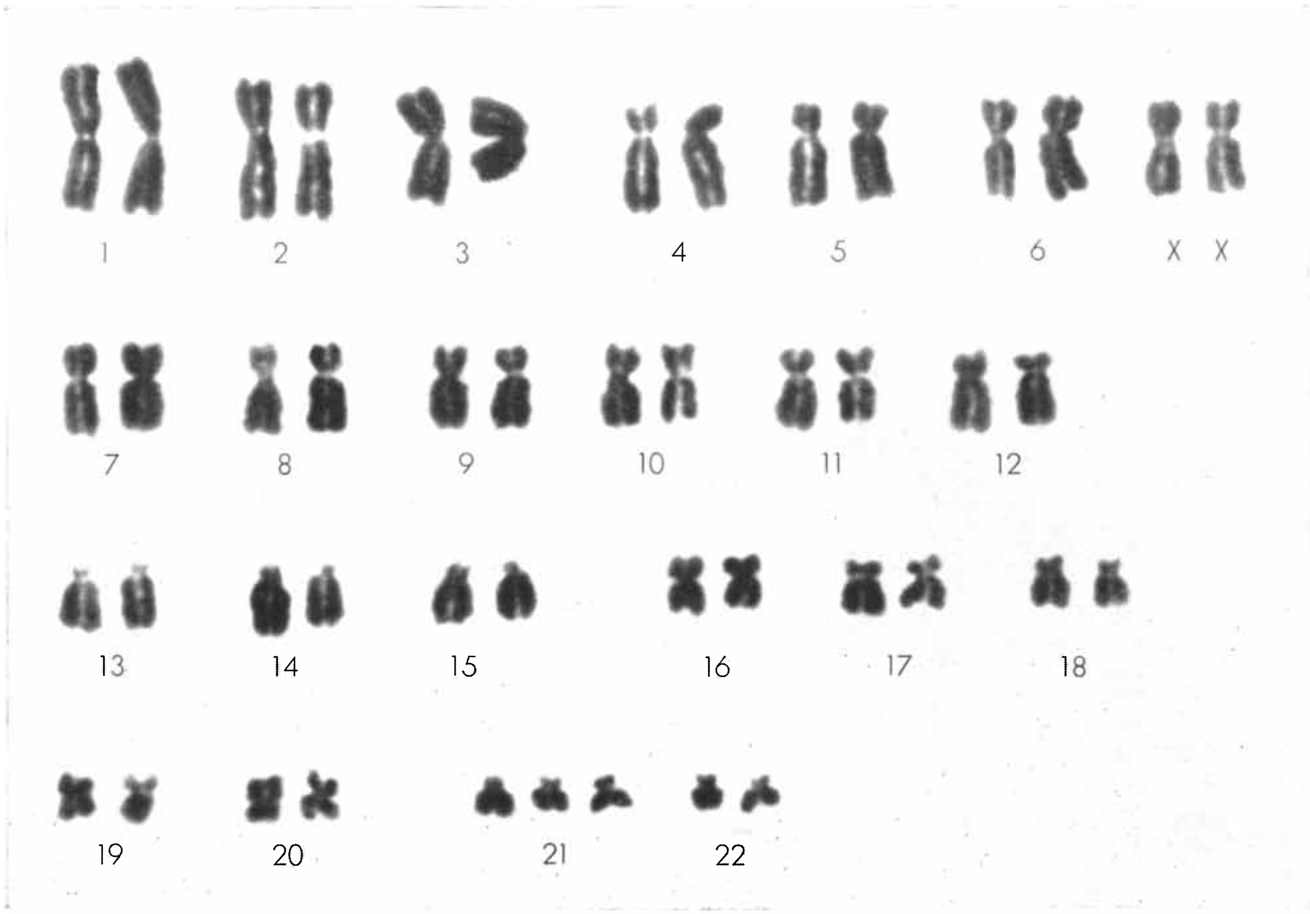
tile but many are mentally defective and infertile. The same investigators have reported that more than 40 per cent of one group of patients with otherwise inexplicable primary amenorrhea—failure to begin to menstruate—have demonstrated abnormalities of the sex chromosomes.

If nondisjunction can result in ova with two X chromosomes, it can also produce ova with no X chromosome at all. When such a gamete is fertilized by an X-bearing sperm, the zygote will have only one sex chromosome—it is called X0. Such individuals have been found. Female in appearance, they lack many secondary sexual characteristics; they may also display congenital defects such as unusually short stature, a "webbed" neck, malformation of the aorta, deafness and mental deficiency. This syndrome was clearly described by Henry Turner of the University of Oklahoma School of Medicine in 1938, but it was not until 1959 that Turner's syndrome was found to be the consequence of an X0 chromosome constitution. A final possibility would be fertilization of an ovum with no X chromosome by a Y-bearing sperm. This would produce a Y0 zygote, but such a chromosome complement is apparently incompatible with life—at least no such individuals have been found.

Inevitably consideration of abnormality of endowment with sex chromosomes brings up the problem of hermaphroditism. A true hermaphrodite combines the basic characteristics of male and female, having both testicular and ovarian tissue in the sex organs. It was anticipated, with good reason, that hermaphrodites might turn out to be "mosaics," some of whose cells were XX and some XY [see "Genetic Mosaics," by Aloha Hannah-Alava; Scientific American, May, 1960]. In nearly all instances, however, examination of the cells of hermaphrodites has disclosed 46 chromosomes, and the XX constitution characteristic of a normal female. There seems to be no simple chromosomal explanation for hermaphroditism.

It is nonetheless clear that human mosaics do occur. They are the product of nondisjunction not in meiosis of the parent germ cell but in mitosis of the somatic cells at some point in embryonic development. Mosaicism is, after all, a statistical concept. Cell division can go awry at any time and result in cells with the wrong complement of chromosomes. Presumably these cells are usually at a disadvantage and are eliminated; nevertheless, there may be a small number of aberrant cells in every individual. The term "mosaic" is reserved for cases with two sizable populations of cells with different chromosome complements, arising from mitotic nondisjunction soon after the fertilization of the ovum. Several patients with Down's syndrome have been recognized as mosaics. Mosaicism seems particularly common in disorders of the sex chromosomes, a finding that may merely be related to the recognizability of sexual anomalies.

Simple variation in count is, of course, the most easily identified chromosomal anomaly. The number of such anomalies is finite in each species; it is a function of the number of its chromosomes. In spinach, with six pairs of chromosomes, for example, all the possible trisomics have



TRISOMY OF CHROMOSOME 21 is revealed in this karyotype of a patient with Down's syndrome. During meiosis both Number 21's of the mother, instead of just one, went to the ovum. Fertilization added the father's homologous chromosome, resulting in trisomy.

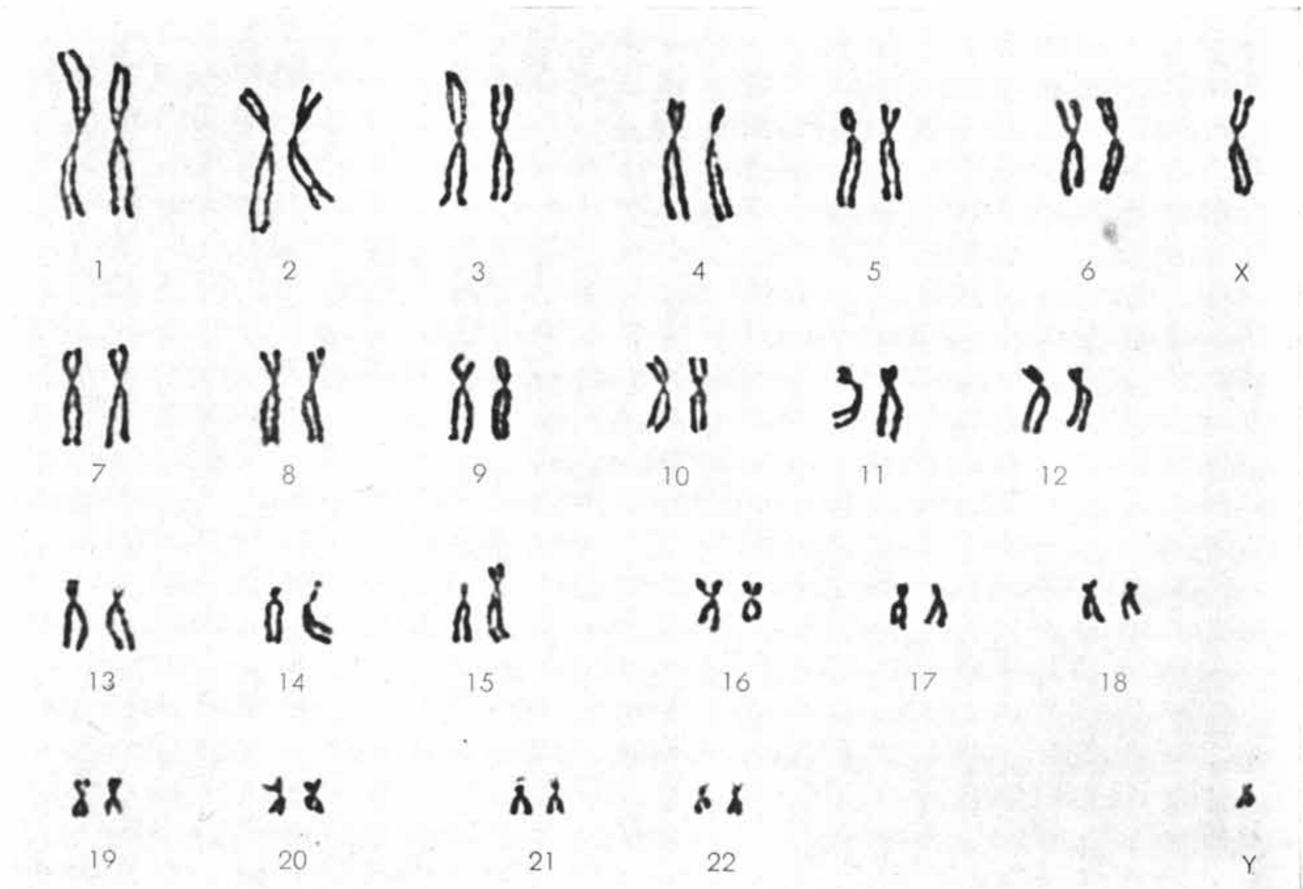
been found and associated with characteristic changes in the appearance of the plant. With 23 pairs of chromosomes man can exhibit a larger but still finite number of trisomic and monosomic anomalies.

Aberrations can occur, however, in the structure of the chromosomes as well as in their number. The number of such variations is essentially infinite. Two principal types are deletions and translocations. In deletions a piece of a chromosome breaks off and is lost. Such abnormalities, particularly if they involve sizable amounts of the genetic material, could be expected to be lethal in many cases, and large deletions are in fact not commonly found.

In translocation, breakage is followed by relocation of the fragments. A reciprocal translocation involves breaks in two nonhomologous chromosomes and thereafter a mutual exchange of the fragments. Depending on how the chromosomes behave during meiosis, some gametes will be formed with a normal, although displaced, gene content—in other words, a balanced translocation. But translocation may also give rise to gametes that have deficiencies of certain genes and duplications in others [*see illustration on page 71*]. Some offspring of gametes that carry translocations may therefore be normal and some may not. When the germ cells of even the apparently normal person who bears a balanced translocation later undergo meiosis, an unbalanced gamete may result. In human pedigrees a translocation often manifests itself when a disease is transmitted by unaffected individuals whose collateral relatives show the disease [*see illustration on page 72*].

The first recognizable translocation was found in 1959 by Lejeune in a mentally deficient boy with congenital abnormalities of the backbone. The boy's cells had only 45 chromosomes, including one that was longer than its homologue. Lejeune suggested that part of the missing chromosome had been relocated, thus explaining the extra length of the abnormal chromosome; the remaining fragment had been eliminated. Recent reports that some patients suffering from Down's syndrome have a normal number of chromosomes may be explained by translocation. In these cases the extra chromosomal material, usually present as an extra "free" chromosome (trisomy of chromosome Number 21), is translocated to another chromosome. The result is Down's syndrome with only 46 chromosomes. The disease would seem, therefore, to be related not so much to the number of chromosomes in the cell as to the extra chromosomal material.

Malignant cells frequently have abnormal chromosome counts, and there has been controversy about whether the chromosomal anomalies cause the abnormal growth or—as has seemed more likely—are the consequence of malignancy. A recent finding bears directly on this controversy. The white cells of a person with acute leukemia may show a variety of numerical and structural chromosomal abnormalities. This observation fits the view that malignancy gives rise to aberrations in the chromosomes. On the other hand, patients with a different disease, called chronic myelogenous leu-



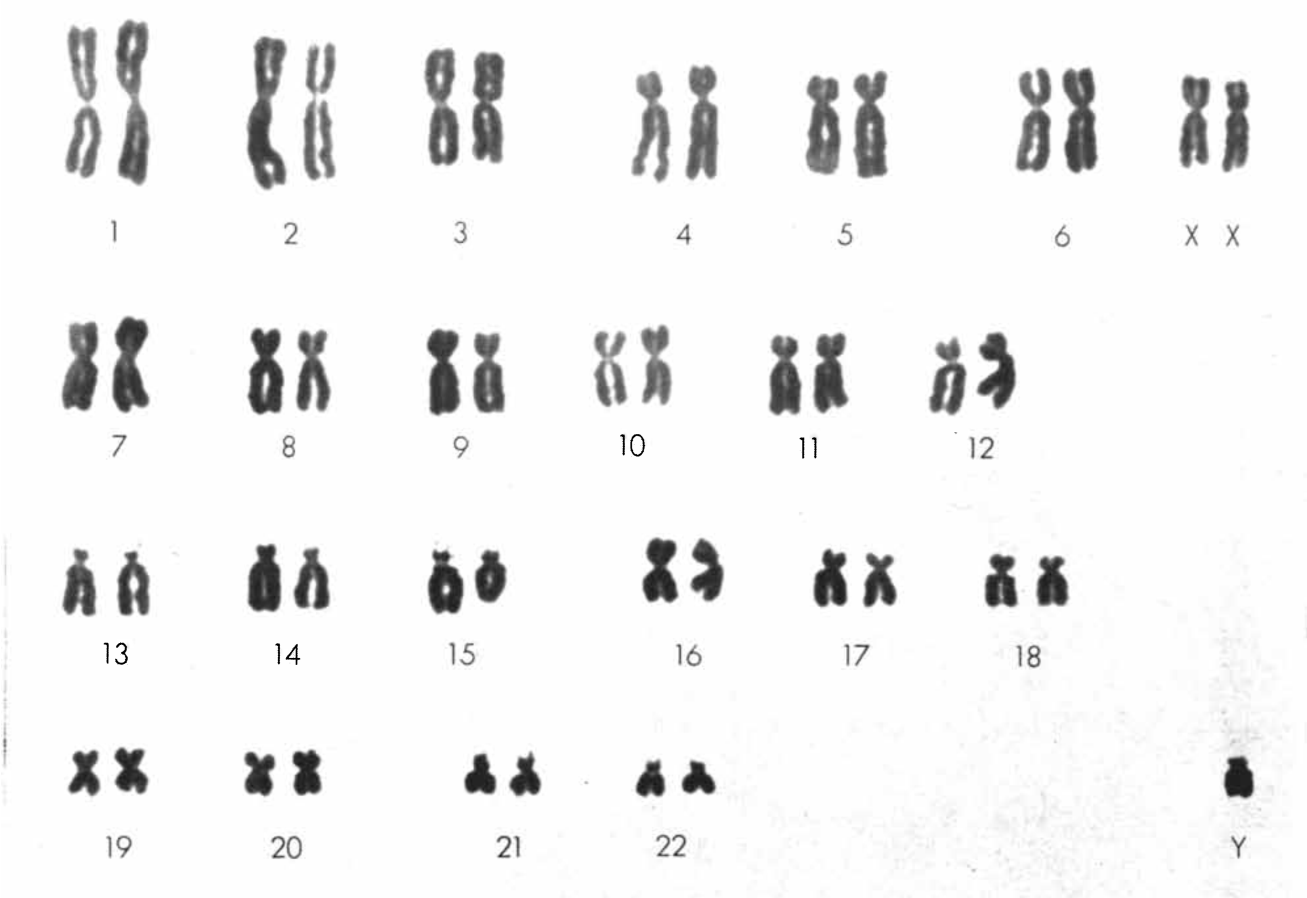
"ESSENTIAL TRISOMY" OF 21, again resulting in Down's syndrome, occurs when extra Number 21 material is translocated instead of appearing in trisomic form as on the opposite page. In this case the extra material has been translocated to a Number 15.

kemia, have what appears to be a unique chromosomal aberration: a deletion of a small part of one of the smallest chromosomes, tentatively identified as Number 21, the same chromosome associated with Down's syndrome. This close correlation between a specific anomaly and a disease warrants careful investigation. The association of abnormal white cell formation with chromosome 21 is strengthened by the fact that acute leukemia is many times more common in patients with Down's syndrome than it is in the general population.

The identification of constitutional defects with chromosomal abnormalities is perhaps of more direct interest to medicine than to genetics. The geneticist has broader objectives. With the techniques for study of human chromosomes now available, he looks forward to the vast task of "mapping" the chromosomes of man—that is, establishing the location of the genes on the chromosomes, much as has been done in the fruit fly. In this connection investigators will look for correlations between more ordinary traits and recognizable aberrations in the chromosomes. A normally recessive trait associated with gene *a*, for example, might be observed in a child whose parentage is such that the gene should have been suppressed by the homologous gene *A*. If this child is then found to have a deletion of part of a chromosome, the deletion would explain the loss of the *A* gene and would simultaneously indicate the normal site of the genes *a* and *A* [*see illustration at top of page 73*].

To take another example, an unusual inheritance of blood type might be correlated with an observation of trisomy: One might find a child with blood group AB whose parents were O and AB. This could happen if the child had inherited three blood-group genes. These genes would have to be located on the child's trisomic chromosome [*see bottom illustration on page 73*].

For many fundamental genetic studies the cells of other organisms with fewer and larger chromosomes will continue to serve investigators better than human cells. But questions relating specifically to man can be settled only by the study of his cells. Autoradiographs of human cells made after they have been supplied with radioactive nucleic acids show that different segments of the chromosomes replicate at different times; it should be possible to learn whether there is a pattern or significance to the sequence of replication. It will also be interesting to study, in long-term tissue cultures, cells in which the chromosome complement has been altered and to watch for the biochemical consequences of those changes—to determine, in other words, which chromosome directs the synthesis of which enzyme. As more is learned about the detailed mapping of human chromosomes, the biochemical effects of chromosomal aberrations and the degree of chromosomal variation in healthy people, many of the presently obscure aspects of such diverse subjects as malignancy and evolution may be illuminated.



KLINEFELTER'S SYNDROME is usually characterized by two X chromosomes and a Y, instead of XX (normal female) or XY (normal male). This can come as a result of nondisjunction of sex chromosomes during gametogenesis in either the father or the mother.

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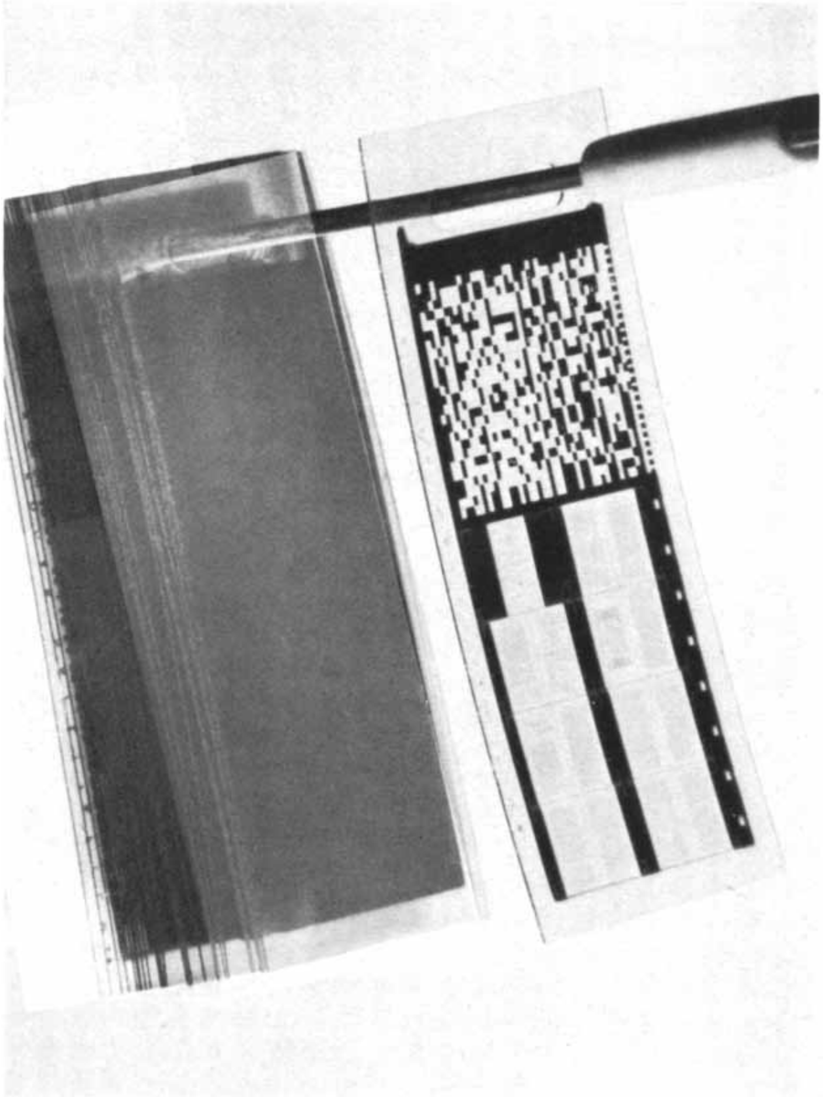
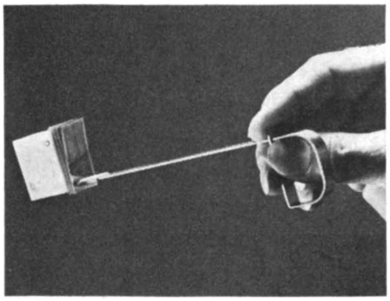


*For sale in conventional printed form at 70¢ by the Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C. This richly detailed 283-page document comes down to a little "stick" of Minicard chips like this:



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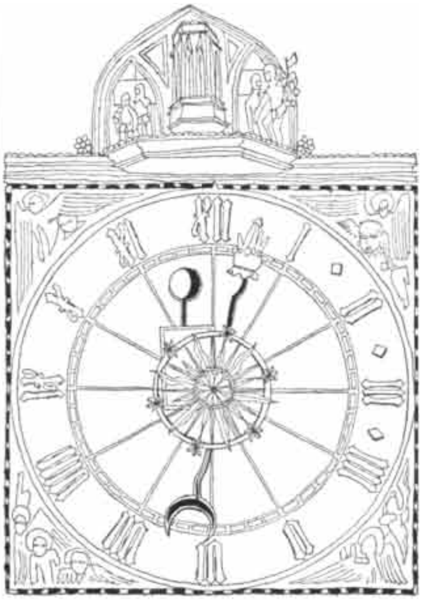


Peace at Stowe

A varied agenda of "intercontinental" enterprises, modeled on the successful precedent of the International Geophysical Year, has been laid before the scientific community of the world. Put forward as "a way to create trust among nations," the program is the work of the seventh Conference on Science and World Affairs (COSWA), which gathered 41 scientists from 12 different countries in Stowe, Vt., early in September under skies darkened by mounting distrust among nations.

Among the principal items on the COSWA agenda are:

A world-wide survey of the oceans, including their "contents," in three dimensions.

A deep-drilling program that would integrate the U.S. Mohole project with parallel Soviet enterprises in this field and provide for exchange of technique, personnel and core samples.

Internationalization of the moon under "the basic principles of the International Antarctic Treaty" and corresponding co-ordination of national space-exploration programs.

Development of methods, such as the promotion of the turnover of the ocean waters, to elevate the world's fisheries "from a hunting industry to an agricultural technology."

A "globular cluster of 'Big Science' centers," including an "accelerator of not less than 300×10^9 electron volts," an "ultra high-flux reactor (10^{16} neutrons/cm^2/sec.)," a high-capacity computer costing "perhaps as much as $\$100 \times 10^6$" and a prospective "very large thermonuclear device" for investigations in plasma physics—the whole to represent "a capital investment of the order of $\$5 \times 10^9$." "The astute location of such a striking epitome of science," the conferees agreed, "could have extraordinarily great significance in improving the tone of the present political situation." Some suggested Berlin might be the location.

The conference at Stowe was the seventh in the series of meetings that began at Pugwash, Nova Scotia, in 1957 and that at various times has brought scientists of the U.S., the U.S.S.R., the United Kingdom, China and other nations together as individuals for private discussion of ways "to foster the constructive use of science and help in preventing its destructive use." On adjournment of the seventh conference, the conferees reconvened at Stowe for an eighth conference, in which "common understanding was reached on a number of important issues" surrounding the enforcement of general and complete disarmament.

Cleared Wires

Project West Ford, an Air Force plan to place about 75 pounds of short, hairlike wires in a polar orbit 2,300 miles above the earth, will not interfere with radio or optical astronomical observations, according to a special panel of the President's Science Advisory Committee. Once in orbit, the wires would spread out to form a tenuous belt about five miles wide and 25 miles thick, which would provide a reflecting "surface" for communications experiments. Ever since it was proposed two years ago, the project has drawn objections from astronomers. Late in August the International Astronomical Union urged that the wires not be launched until the Air Force had published a full description of the plan, with calculations of expected orbital lifetime. This has now been done.

The President's panel emphasized the following considerations: The 350 million wire dipoles in the belt would have to be multiplied by 100,000 to interfere significantly with observations by radio astronomers. Even when they are reflecting powerful signals from the ground, the wires will produce only a weak source of interference localized both in space and in frequency. Because the belt will be at low altitude, it will move with respect to the stars so that even the weak interference will not be continuous in any direction. The wires will not affect optical observations from the ground because they will increase the brightness of even the darkest part of the sky by less than 1 per cent. The panel conceded that "if the most optimistic estimate of the darkness of the sky proves correct," the belt might interfere with certain telescopic observations that could be made from a satellite. If so, the observations could be made away from the belt. The orbiting wires will not harm any satellites, manned or unmanned, that have protection against the natural micrometeorites that already exist in space around the earth. Finally, the special panel reported, the wire filaments will probably be destroyed by atmospheric friction within four to eight years. But even if they are not, "the amount of material used in the experiment (less than a five-hundredth of an ounce over each square mile under the belt two months after launch) is very small compared with the total amount of material in space near the earth."

The report, approved by Jerome B. Wiesner, special assistant to the President for science and technology, was signed by John W. Tukey and Martin J. Schwarzschild of Princeton University, Edward M. Purcell and Fred L. Whipple of Harvard University, John W. Findlay of the National Radio Astronomy Observatory, Paul Herget of the University of Cincinnati and Rudolf Kompfner of the Bell Telephone Laboratories.

A number of astronomers around the world are now studying the detailed plans for Project West Ford as published by the Air Force; they will report to the International Astronomical Union and the U.S. National Academy of Sciences. The U.S. Government has said that no more wires will be launched after West Ford until the effects of the project have been fully evaluated.

New Particle

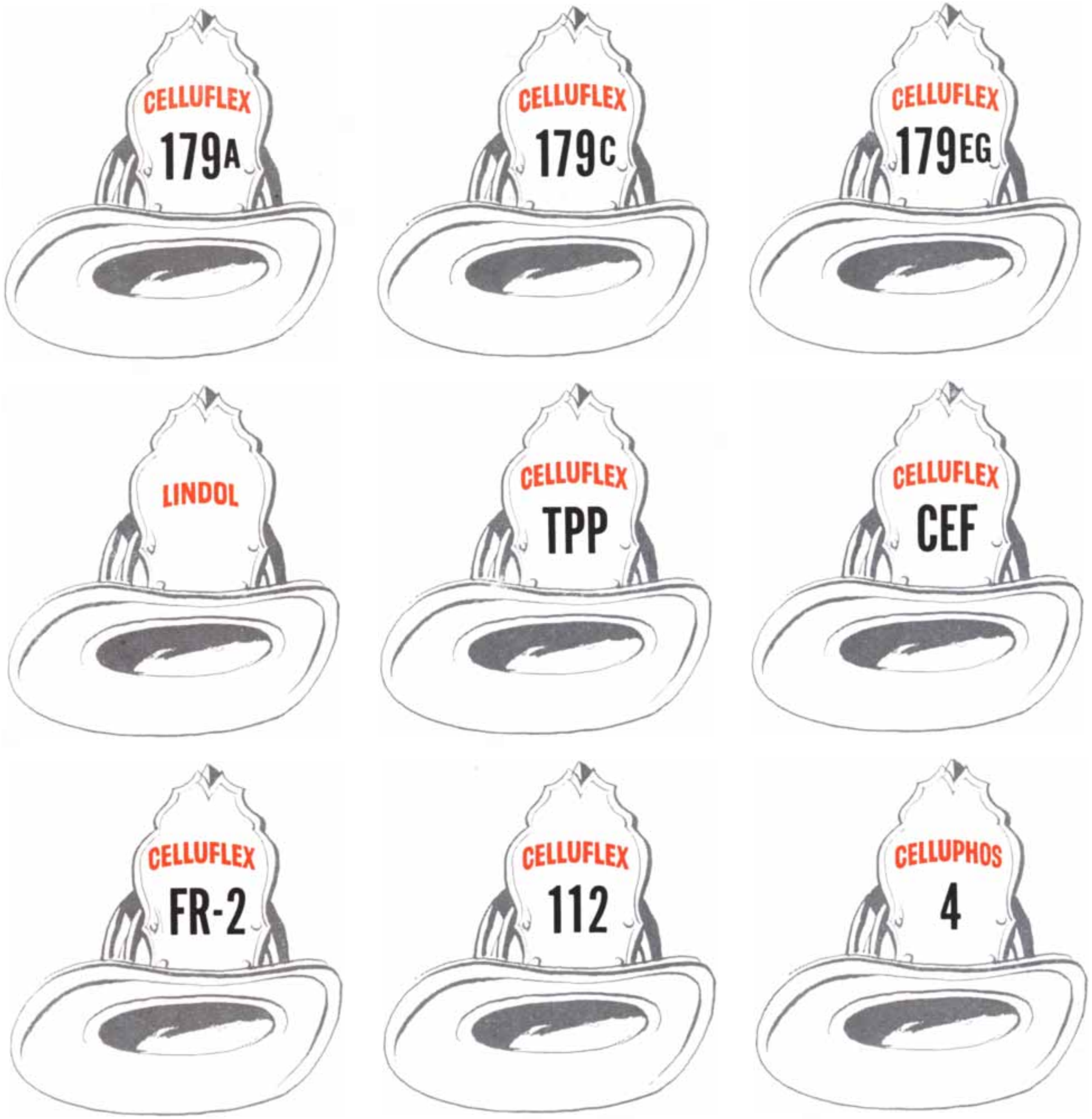
A new elementary particle, the existence of which had been predicted, has been discovered at the Lawrence Radiation Laboratory of the University of California. Called the omega meson, the new particle has a mean life of about 10^{-22} second, a mass 1,540 times that of the electron, and no electric charge. The discovery was reported in *Physical Review Letters* by B. C. Maglić, Luis W. Alvarez, Arthur H. Rosenfeld and M. L. Stevenson.

Theoretical physicists had conjectured that the omega meson and a companion particle, the rho meson, were needed to explain certain characteristics of the neutron and proton first reported two years ago by Robert Hofstadter and his associates at Stanford University. When the Stanford workers measured the size of the cloud of electrification surrounding the proton and neutron by means of high-energy electrons, they found that its "electrical size" was somewhat smaller than its "nuclear size." This suggested that the cloud of electrification might contain, in addition to the familiar pi meson, or pion, two heavier types of meson: the rho and the omega. It was conjectured that the rho meson could be positive, negative or neutral; the omega meson, only neutral.

The two new mesons would be so short-lived that even the charged forms of the rho would vanish before creating tracks in a bubble chamber, which has become the principal device for seeking particles. The neutral rho and omega could not leave tracks in any case. If the particles existed, they could be detected only by inference. Theory suggested that the rho meson would decay into two pions (one positive, one negative) and the omega meson into three pions (one positive, one negative and one neutral).

Bubble-chamber photographs show many particle collisions that yield anywhere from two to eight pions. If one measures the direction and curvature of pion tracks, one can determine what physicists call the effective mass of the total system of pions. If many such systems are analyzed, one expects to find a spectrum of masses forming a typical distribution curve. The search for the rho and omega mesons consisted of making "kinematic" analyses of many pion-producing systems. If a distribution curve derived from such a study showed a "spike" on it (that is, an unexpected number of systems of nearly the same effective mass), one could infer that the pions in the spike were decay products of an unseen particle.

By this procedure the rho meson was discovered independently in a number of laboratories last year. The Lawrence Radiation Laboratory workers finally found the omega by studying the pion tracks produced when antiprotons created by the Lawrence Laboratory's



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Bevatron were annihilated in collision with protons inside a 72-inch hydrogen bubble chamber. After some 30,000 photographs of bubble-chamber events had been inspected, the study was narrowed down to 800 sets of pion tracks, which were analyzed with the aid of semiautomatic measuring machines and a large digital computer. Calculations indicated the presence of about 80 omega mesons and about 240 rho mesons in the 800 reactions. The two types of meson seem to be produced independently of each other.

Whether or not the rho and omega mesons deserve to be called particles is more or less a semantic question. Sometimes they are referred to as "particle systems" or "excited states." Within the past year Lawrence Laboratory workers have found a number of other such systems or states, but they have not yet been fitted into so clear a theoretical framework as have the rho and omega mesons. Thus the puzzle of the elementary particles continues to grow more baffling.

The Shape of the Equator

A quiet debate is in progress over the shape of the earth's waistline. It began with the publication early this year by Imre E. Izsak of the Smithsonian Astrophysical Observatory of data derived from the artificial satellites *Vanguard II* and *Vanguard III* indicating that the Equator is not a circle but an ellipse with its long axis 1,400 feet longer than its short axis. Soon afterward William M. Kaula of the National Aeronautics and Space Administration estimated on the basis of Minitrack observations of *Vanguard I* that the equatorial ellipse was only 10 per cent as much out of round. A third study, made by Yoshihide Kozai of the Smithsonian Observatory, arrived at a similar conclusion from examination of data from *Vanguard I, Vanguard II* and *Sputnik I*. Most recently James R. Newton of the Johns Hopkins Applied Physics Laboratory has put the equatorial bulge—which is centered in the Atlantic and Pacific oceans—back up to 1,000 feet on the basis of Transit satellite observations.

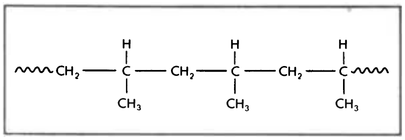
Soon after the launching of the first artificial satellites geophysicists were able to show that the earth is slightly pear-shaped in north-south profile and to measure the flattening at the poles (long predicted on theoretical grounds). Both findings are now accepted. The precise ellipticity of the Equator is another matter. Investigators have been unable to agree on a figure, although it has an important bearing for the me-

Basic Research at Sun Oil Company

Structure of polymerization catalysts

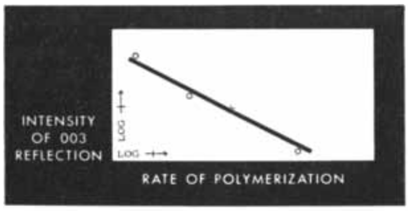
Dr. Richard S. Stearns
Section Chief
Univ. of Wisconsin, B.S., Univ. of Chicago, Ph.D, 1947. American Chemical Society, Sigma Xi

One of the problems now being pursued by Dr. Richard S. Stearns is the determination of the structure of the polymerization catalyst obtained by reacting a transition metal halide with an organometallic compound. The approach taken is to synthesize a new catalyst structure. Then the mechanism is studied whereby monomer units interact at the catalyst surface to form polymers which may be highly crystalline. In some crystalline polymers the spatial configuration of each unit exactly repeats that of the previous unit producing long chains of flawless structure as in *crystalline* polypropylene, the structure of which may be represented in two dimensions as follows:



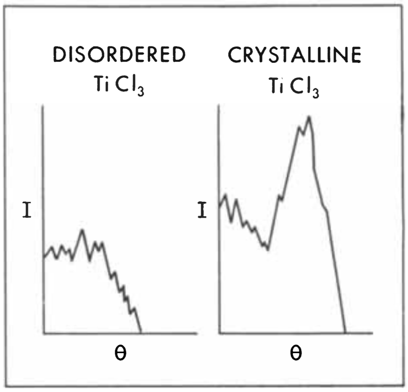
The results achieved in this polymerization closely approach the high specificity found in biological synthesis.

Dr. Stearns is also investigating the kinetics of the polymerization of various olefins and dienes. The study includes correlation of the specificity of the polymerization reaction, in terms of the number of spatially identical units in sequence with details of the catalyst structure obtained from spectroscopic, NMR and X-Ray techniques. It has been found, for instance, that the rate of propylene polymerization is a function of the degree of disorder in the $TiCl_3$ crystal. (See Fig. 1 below)



(*Fig. 1*)

The disorder in the $TiCl_3$ crystal structure is obtained from the integrated intensity of the X-Ray diffraction band due to the 003 reflection, as shown below in Figure 2.



(*Fig. 2*)

4-Methylpentene-1

Dr. Lewis W. Hall, Jr.
Research Chemist
Upsala College, B.S. Purdue University, MS, Ph.D, 1959 American Chemical Society, Philadelphia Catalyst Club, Sigma Xi, A XE

As part of Dr. Hall's continuing program of research on petroleum as a chemical raw material, he has been trying to find and develop new uses for propylene. Several patents have reported dimerization of propylene in the presence of an alkali metal to yield the terminal olefin 4-methylpentene-1, an interesting monomer. Dr. Hall's detailed study of this reaction was the beginning of his search for new and better catalysts.

After gaining a fundamental understanding of the dimerization of propylene, he discovered that sodium alkyls, particularly amylsodium, are useful catalysts for this reaction. The sodium alkyls pose somewhat of a problem in that they are also active isomerizing agents for the terminal olefin product. Research has shown that the isomerizing effect of the alkyl can be considerably reduced by complexing the alkyl with inorganic salts such as sodium iodide. In addition it has been determined that the reactivity of the alkyl-salt complex is somewhat less than the uncomplexed alkyl.

What is Sun's "Scientific Ladder?"

There are many scientists and engineers who are not interested in careers leading primarily to administrative or managerial responsibilities. However, they are obviously interested in attaining the professional and material rewards usually associated with a managerial career.

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It is a means whereby highly productive researchers, with exceptional talents in the sciences or engineering, may devote all their energies to the technical and scientific areas of research. Scientists on this ladder are given broad latitude in selection and conduct of their work.

The prestige of Sun's scientific ladder is determined by the stature of those on it. Hence, very high standards are maintained in the screening of those who seek it, as well as those who desire to stay on it.

This route of professional advancement and progress is parallel to and on the same plane as promotion in the managerial structure of the Research and Engineering Department. Rewards and responsibilities of the scientific ladder are equal to those of the managerial group. In each case these are related to the individual's capabilities and capacities—managerial and/or scientific.

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PROMOTING PROGRESS THROUGH RESEARCH

chanical strength of the earth's crust. One geophysicist has pointed out that part of the difficulty comes from the fact that most satellite observations have been made on small segments of orbit; moreover, the quantity being measured is very small. A 1,400-foot departure from perfect roundness in a circle with a diameter of 8,000 miles is a deviation of one part in 30,000. Neither Planck's constant nor the charge of an electron has yet been determined with a precision greater than one part in 10,000.

Ultrasonic Amplifier

A semiconducting device that amplifies ultrasonic, mechanical vibrations has been developed at the Bell Telephone Laboratories. Described by A. R. Hutson, J. H. McFee and D. L. White in *Physical Review Letters*, its operation depends on the fact that certain semiconductor materials, notably cadmium sulfide, exhibit two additional properties: photoconduction, an increase in conductivity when exposed to light, and piezoelectricity, the production of an electric field when the crystal is put under mechanical stress.

When an ultrasonic wave travels through a cadmium sulfide crystal, the vibratory forces, acting through the piezoelectric effect, set up an oscillating electric field that moves along with the acoustic wave. In the dark, cadmium sulfide is an insulator, and the electric field produces no current, but if a dim light shines on the crystal, it releases a small quantity of mobile charge carriers—electrons and "holes"—and these collect in bunches along the varying electric field. A few months ago White predicted that the bunched charge carriers could feed energy into the acoustic wave if they were made to travel through the crystal faster than the mechanical vibrations. Now, together with Hutson and McFee, he has verified the prediction. By applying a steady voltage to a cadmium sulfide crystal they accelerated the charge carriers and obtained a stronger acoustic vibration from the crystal than they had fed into it. In fact, with a strong enough direct-current voltage, they could make the crystal break into acoustic oscillations without feeding in any mechanical vibration.

Circulating ultrasonic waves are used to store information in computers. In present memory circuits, however, the waves quickly die out and so they can retain information only for short periods. An ultrasonic amplifier would make possible an indefinite storage time. Since ultrasonic mechanical vibrations can be

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converted by transducers to electromagnetic waves and vice versa, the new amplifier and oscillator may find application in electrical as well as acoustic circuits.

Vaccine Problems

Recent advances in virology have added a new complication to the manufacture of poliomyelitis vaccines. A year and a half ago Maurice R. Hilleman of the Merck Institute for Therapeutic Research uncovered a virus that he termed "the vacuolating agent" because it produces vacuoles in monkey cells under suitable conditions; although the virus had been present in nearly all the monkey-kidney cultures used in manufacturing poliomyelitis vaccine, it previously escaped detection. The discovery raised a serious question concerning live-virus poliomyelitis vaccines, since there seemed no simple way to eliminate either the vacuolating virus (now also called SV-40) or other undetected viruses that might be lurking in live-virus preparations. There were no fears as to the possible presence of the virus in Salk vaccine; the formaldehyde used to inactivate the poliomyelitis virus would also, it was believed, inactivate any other viruses that the vaccine might contain.

Early this year live SV-40 turned up in batches of Salk vaccine from two manufacturers. Then Bernice E. Eddy of the National Institutes of Health found a transmissible agent—now suspected to be SV-40—in monkey-kidney cultures that causes tumors when injected into newborn hamsters.

The contaminated lots of vaccine were kept off the market in accordance with long-standing Federal rules requiring Salk vaccine to be free of contaminating viruses. Both manufacturers, moreover, suspended the production of Salk vaccine pending the installation of procedures to guarantee the elimination of SV-40 virus. Such procedures were meanwhile being developed by investigators and manufacturers interested in live-virus poliomyelitis vaccine. Essentially they consist of systematically testing monkey-kidney cultures for SV-40 before they are used to grow poliomyelitis virus and discarding any containing the unwanted agent.

The procedure works well enough for the Public Health Service to have licensed in August the Sabin live-virus vaccine that produces immunity against the poliomyelitis virus of Type 1; licensing tests of the vaccine against Type 2 and Type 3 virus are currently under


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way. In the case of the Salk vaccine, however, the pretesting and discarding of contaminated cultures is not so simple a procedure because far larger quantities of monkey tissue are required for the preparation of killed-virus vaccine.

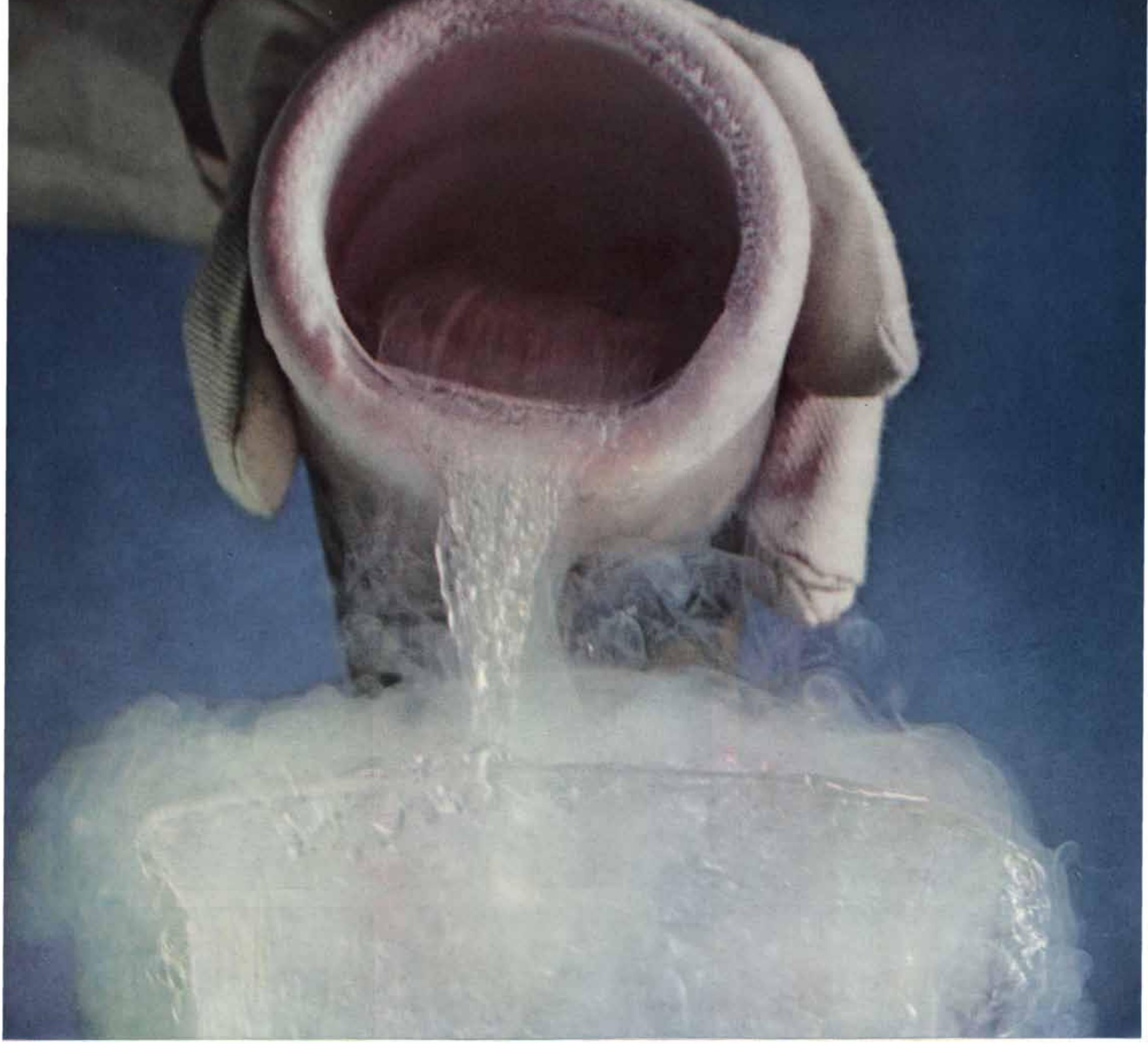
Spokesmen for the Public Health Service point out that all lots of licensed vaccine produced since May have been free of SV-40. It is unlikely that many lots of Salk vaccine released before that could have been contaminated; the SV-40 virus only occasionally survives the inactivation process. In any event there is no evidence that poliomyelitis vaccine has ever caused a tumor either in a test monkey or in a vaccinated individual.

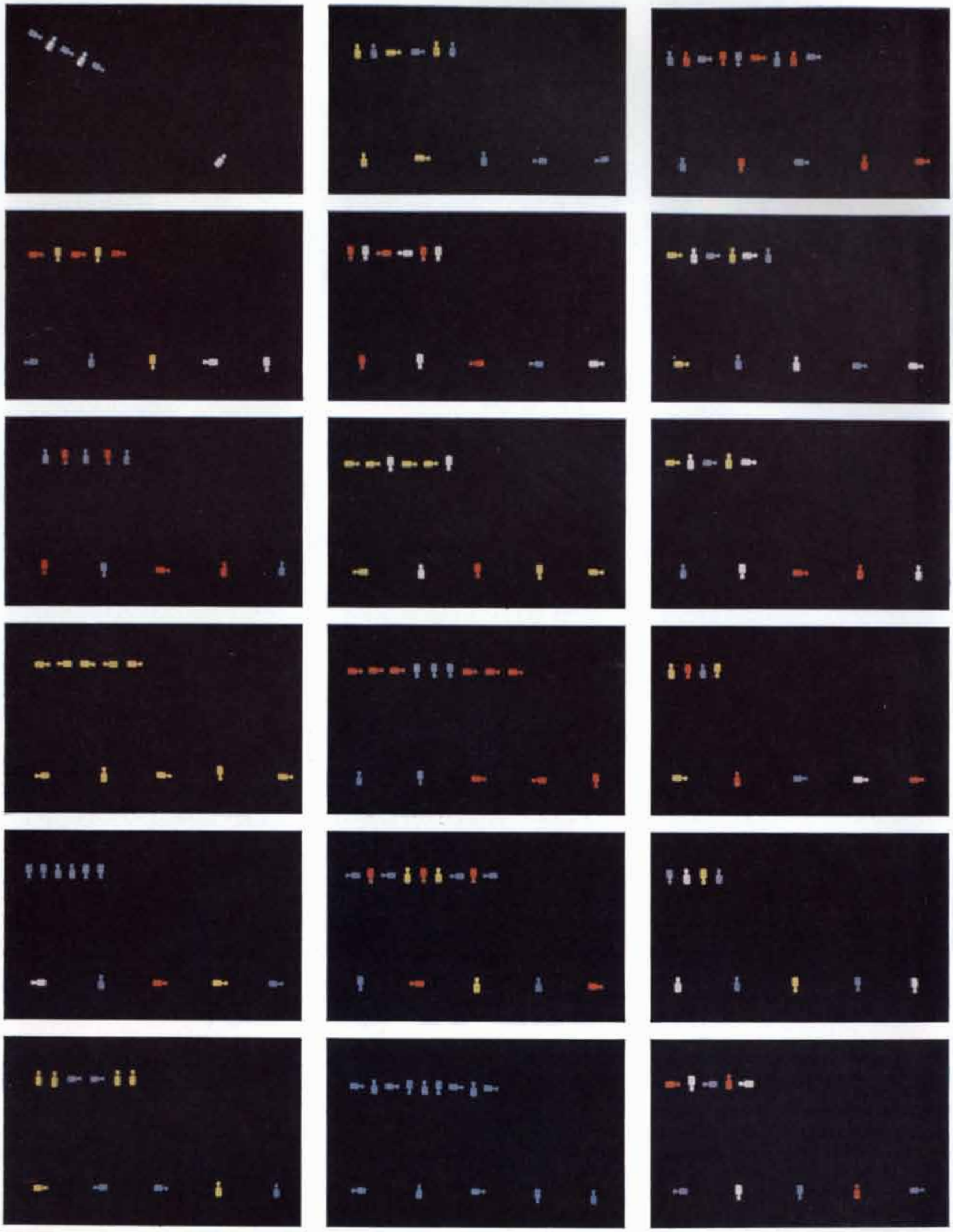
Chemical Desalting

A "novel approach" to the problem of extracting fresh water from salt water has been announced by the Koppers Company, Inc. The only chemical method being developed commercially, it is based on the tendency of water molecules to cluster around molecules of certain insoluble substances, forming ice-like crystals called hydrates. Because hydrates form at higher temperatures than true ice, they offer a way to freeze out salts with a smaller expenditure of energy for cooling. Preliminary studies indicate that the "process is feasible and will produce water competitively with any process currently envisioned," says the company.

The pilot plant now being designed will operate on the following cycle: sea water is cooled to 35 degrees Fahrenheit and mixed in a reaction vessel with propane, a volatile organic liquid. Hydrate crystals form, with a ratio of about 17 molecules of water to each molecule of propane, and heat is given off. This heat is absorbed by excess propane, which vaporizes. After being washed free of salt the crystals pass to a decomposing chamber. The vaporized propane is also pumped into this chamber under pressure; it condenses, releasing heat, which melts the hydrate crystals. The two immiscible liquids—pure water and propane—are separated as they flow out of the chamber, and the propane is sent back to the reaction vessel.

Preliminary calculations and experiments have indicated that the process could make fresh water at a cost of less than 50 cents per 1,000 gallons in a plant that produces 10 million gallons a day and converts 40 per cent of the incoming sea water. Koppers is designing a pilot plant in co-operation with the Office of Saline Water of the U.S. Department of the Interior.





INDUCTIVE REASONING is taught by a machine that presents a sequence of colored shapes across the top half of a screen and requires the student to select the shape below it that extends the sequence. The machine itself is shown on the opposite page. These 18 patterns have been selected from more than 200 that progress in difficulty by very small steps. The program, designed by E. R. Long and James G. Holland of Harvard University, is suitable for children as young as six, yet adults may be taxed by some of the examples shown here. For the child who has been led up to them by tiny steps, however, they seem simple. The correct responses, starting at the top of the left column and reading down, are: 4 (meaning fourth position from the left), 3, 1, 1, 2, 3; 2, 3, 5, 2, 3, 4; 2, 1, 1, 2, 5, 3.

TEACHING MACHINES

These devices introduce a basically new element into pedagogy. The essence of their operation is that they enable the student to learn in small but rigorous steps, each of which is rewarding

by B. F. Skinner

Scarcely any area of human activity has been more resistant to scientific analysis and technological change than education. Although our homes, offices, factories and means of transportation have been transformed within a generation, the typical classroom and techniques of teaching have hardly changed in a century. True, the birch rod is gone, desks are no longer screwed to the floor, blackboards are green, textbooks are colorful and there is often a television set, motion-picture projector or tape recorder somewhere in the room. But the methods whereby a teacher is supposed to impart knowledge to a roomful of pupils have changed scarcely at all. Indeed, a number of critics are persuaded that there has been an actual decline in teaching effectiveness within the past 30 or 40 years. Be that as it may, too many young people pass through our school systems without achieving a satisfactory command of reading, spelling, arithmetic and the use of the English language—to list only the most basic subjects. Too many pupils become discouraged, develop "blocks" and leave school as soon as the law permits. Many others, aware of their marginal competence, hang on bravely; motivated by family and social pressure, they manage to finish four years of college after surviving what can only be described as a punishing ordeal. A few students—all too few—surmount the inadequacies of our traditional teaching methods and get a certain amount of pleasure and satisfaction from the educational process.

Could things be otherwise? There is no dearth of suggestions for improving education. We must pay salaries that will attract and hold good teachers. We should treat students as individuals and group them according to ability. We must bring textbooks and other materials up to date, particularly in science and mathematics. And so on. It is curious that such suggestions rarely deal with the actual processes of teaching or learning. They make no attempt to analyze what is happening when a student listens to a lecture, reads a book, writes a paper or solves a problem. They do not tell us how to make these activities more productive. In short, the methods of education are generally neglected. (The use of films and television does not constitute a new method; it is merely a way to amplify and extend old methods, together with their shortcomings.)

Fortunately recent advances in the experimental analysis of behavior suggest that for the first time we can develop a true technology of education. This technology, following the practice of the experimental laboratory, will use

MACHINE FOR TEACHING INDUCTIVE REASONING presents a pattern at the top of a screen and below it a selection of responses on separate panels that are activated by touch. When the student responds correctly, he is "reinforced" (rewarded) by hearing a musical chime and seeing a light; part of his reward is seeing a new problem flash on the screen.

instrumentation to equip students with large repertories of verbal and nonverbal behavior. Even more important, the instrumentation will be able to nurture enthusiasm for continued study. The instruments that will help our schools to accomplish all this are called teaching machines.

Simple models of such machines have been widely advertised and even sold door to door. They do not give a very good picture of what the teaching machine movement is all about, and there is a real danger that teaching machines will be overpromoted and misused before their real merits and limitations have been properly appraised. Like a high-fidelity phonograph, a teaching machine is no better than the material fed into it. Devising a program for a teaching machine is still very much of an art, but it is an art that can be improved by the scientific analysis of millions of hours of recorded data: responses made by animals confronted with stimuli presented to them by laboratory teaching machines and responses made by human operators on machines specially designed for educational purposes.

Like all useful machines, the teaching machines developed slowly from the need to do a job more effectively than it could be done otherwise. They have evoked all the reactions, including the hostile ones, that we have learned to expect from a new kind of machine. Some people see the machines as a threat to the teacher, which they are not. Some fancy that they will make education a cold, mechanical process. Others fear that they will turn students into regimented and mindless robots. Such fears are groundless. The purpose of a teaching machine can be simply stated: to teach rapidly, thoroughly and expeditiously a large part of what we now teach slowly, incompletely and with waste effort on the part of both student and teacher. Some of the machines also hold the promise of teaching behavior of a kind and subtlety that until now has seemed beyond the reach of explicit teaching methods.

Animal-teaching Machines

The machines I shall describe had their origin in the laboratory devices my associates and I have built at Harvard University and elsewhere over the past 30 years. With these devices and suitable experimental methods we have learned much about the way animal behavior can be shaped into intricate patterns by the use of reward, or, as we prefer to call it, reinforcement.

Much of our work has been done with the pigeon, a healthy, docile animal with good color vision, whose behavior can be studied over many years. Our methods have also been used successfully with other species, such as rats, dogs, monkeys, apes and man.

Many aspects of this work are relevant to education, but I shall discuss in particular certain practices that, in connection with teaching machines, have come to be referred to as "programing." What is involved is the arrangement of a series of very small steps through which an organism can be led into the acquisition of complex forms of behavior. With these techniques a new form of behavior can be shaped as a sculptor shapes a lump of clay.

In a typical classroom demonstration a hungry pigeon is permitted to move about in a small enclosed space with transparent walls. On one wall is mounted a food magazine: a magnetically operated dish of grain that can be raised within reach of the pigeon when the demonstrator presses a hand switch. Students watch the behavior of the pigeon for a few minutes to get some idea of the kinds of behavior exhibited under these circumstances. They then decide on a response to be shaped—a response that has not been observed up to that point.

Let us say they would like to see the pigeon turn clockwise in a single continuous swift movement. The demonstrator cannot merely wait for this response to occur and then reinforce it, allowing the successful responses thus reinforced to emerge as in "trial and error" learning. The final form of the response must be programed, and when this is skillfully done, the response can be produced within a minute or two.

The demonstrator first reinforces any response that contributes to movement in a clockwise direction, such as turning the head to the right or stepping forward with the left foot. After the pigeon has

RHYTHM-TEACHING MACHINE requires a student to tap in unison with or echo a pattern of beats. To be reinforced by a light and a bell his response must fall within time limits set by a device (*foreground*) that both generates patterns and monitors responses.

eaten the offered grain it will repeat this response almost immediately, and again the demonstrator reinforces. Reinforcement can then be withheld until the response has a broader scope—until more of a clockwise turn is made. It requires some skill to select extensions of the desired movement while avoiding extinction of the response, but a pigeon that has already been conditioned to eat from the food magazine and has adapted to the novelty of the experimental space seldom requires more than two minutes to learn a clockwise turn—a single, complete and swift movement ending with reinforcement.

If this response is then extinguished and a counterclockwise turn is shaped, the clockwise turn can be recovered and the pigeon taught to pace a figure eight, also within a few minutes. The power of the technique has to be seen to be believed.

Another kind of shaping has to do with the stimulus control of behavior. The pigeon can be reinforced for responding on some occasions and not on others. For example, if the pigeon has been conditioned to peck a small plastic window on one wall of the experimental space, we can project colored lights on this "key" and reinforce the bird for pecking green but not for pecking red. In this way the color vision of the pigeon can be sensitively measured [see "Experiments in Animal Psychophysics," by Donald S. Blough; SCIENTIFIC AMERICAN, July].

A notable example of the power of effective programing has recently been demonstrated in the Harvard laboratories by Herbert S. Terrace, now at Columbia University. Terrace has shown that pigeons can learn subtle discriminations without making any error whatsoever. He programs the behavior in the following way. When the pigeon pecks a red key for the first time, it is reinforced and the key is quickly darkened. A dark key differs too much from a red key to evoke a response immediately. The experimenter watches for a suitable opportunity to restore the red color to the key, preferably when the pigeon is turning away from the darkened key. The pigeon at once responds and is reinforced. The darkened key can then be presented for a longer period of time without evoking a response, although restoring the red light brings out a response immediately. Eventually the pigeon responds to a red key and shows no inclination to respond to the dark key no matter how long it remains dark.

A faint green light is then added to the darkened key. Over a period of time this green light is made more and more intense until it is equal in intensity to the red. Although some pigeons may make an exploratory peck at the bright green key, these responses are quickly extinguished and some pigeons never make such errors at all.

Terrace has carried the program an

TEACHING MACHINE FOR MUSIC familiarizes a student with musical tones and teaches him to repeat what he hears. A correct response is its own reinforcement. The program begins with single notes and builds up slowly in range and complexity. The program sequence, here being arranged for the student by hand, will eventually be punched on paper tape for automatic presentation.

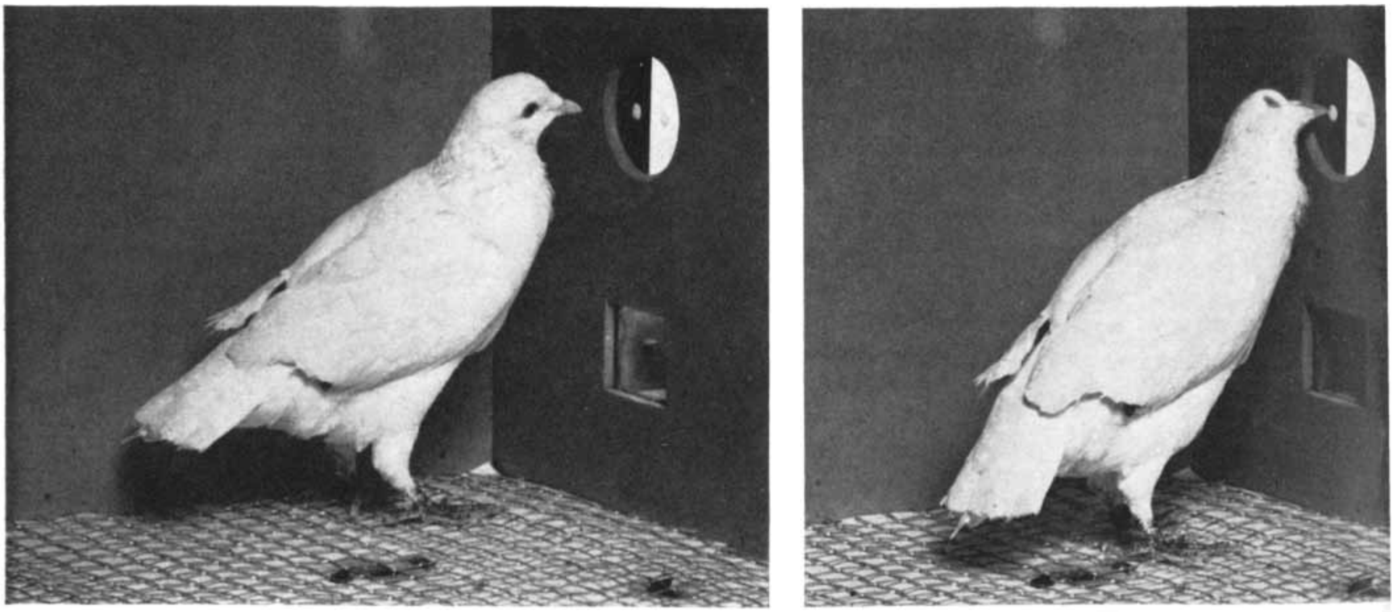
important step further. He has been able to teach a pigeon to respond, virtually without error, to a pattern of vertical stripes and not to a pattern of horizontal stripes. These stimuli are much alike and would normally produce considerable generalization—that is to say, a large number of errors—while the discrimination is being established. Terrace begins by establishing the easier discrimination between red and green and then superimposes vertical stripes on the red key and horizontal stripes on the green key. The pigeon responds to the red key with vertical stripes and not to the green key with horizontal stripes. The color is then gradually removed from both keys until only the stripes remain. The pigeon responds correctly to the vertical stripes and has never at any time responded to the horizontal stripes. The experimenter has transferred the discriminative control from one set of stimuli to another through a series of stages so designed as to minimize unwanted responses.

Still another kind of programing has to do with probability of response. We found early in our research that it is not necessary to reinforce every response to maintain a high level of activity. Reinforcements can be, and in real life almost always are, intermittent. The ways in which reinforcements can be scheduled are many, and the results are quite complex but orderly. For example, we can reinforce an animal after it has made a fixed number of responses (called a fixed-ratio schedule), or after an average number of responses (variable-ratio schedule), or for the first response occurring after a fixed amount of time has elapsed following a previous reinforcement (fixed-interval schedule), or after a variable amount of time has elapsed (variable-interval schedule). The performances of an organism vary sensitively with these schedules, and of course with the values chosen—the number of responses required or the amount of time that elapses before reinforcement. Each type of schedule at a given value elicits its own distinctive performance [*see illustrations on page 96*].

The performance generated by a given schedule of reinforcement can also be brought under stimulus control. A pigeon pecking a key will give one performance on one schedule when the key is red, another performance on another schedule when the key is green, and so on. In experiments at Harvard, Charles B. Ferster and I were able to set up as many as nine different performances appropriate to nine different schedules of reinforcement under the control of appropriate stimuli. We see this effect in ourselves as different situations, different kinds of work or play and different friends and associates reinforce our behavior on different schedules. Our shifting enthusiasms and interests are the result.

Particular schedules of reinforcement allow us to sustain behavior at various levels of strength for long periods of time, limited only by the physical exhaustion of the organism. Placed on a schedule eliciting a low frequency of response, pigeons have worked day and night for weeks and even months. They can even be induced to respond thousands of times (in one case 73,000 times in the first five hours) after reinforcement has been suspended. But this state of "dedication" must be programed by leading the organism gradually into a relatively unrewarding schedule.

With suitable programing, then, we can shape the "topography," or character, of behavior, establish a given level of activity and lead an animal to discriminate between different stimuli—and all this practically without errors. Under operant conditioning, as we call it, organisms have shown themselves capable of remarkable achievements. Within the past 20 years our laboratory animals have exhibited complexities and subtleties of behavior probably never before reached by members of their species. It is not that we have produced better rats, pigeons and monkeys; we have constructed better environments—environments with much greater capacity to generate and sustain behavior. Until the potentialities of these methods have been investigated, it is meaningless to say that a given organism cannot acquire a given form of behavior. When we say that an organism has failed to solve a certain problem, it may very well be that we ourselves have failed to construct the necessary teaching program. In particular, no one knows what the human organism is capable of because no one has yet constructed the environment that



BEHAVIORAL TRAINING, technically known as operant conditioning, is accomplished by placing an organism in a carefully controlled environment where it can be reinforced when it makes the response desired. As a rule the reinforcement, usually food, is not provided after each correct response but according to some intermittent schedule (*see illustrations on page 96*). This will push human achievement to its limits.

The technological power of operant conditioning is now widely recognized. In the drug industry, for example, it provides base lines for assessing the effects of new compounds on animal behavior. A minor example of a technological application was our "Project Pigeon" during World War II. Although at the time the U.S. was not well advanced in the design of guided missiles, some attention was being given to suitable homing devices. One system involved the use of pigeons.

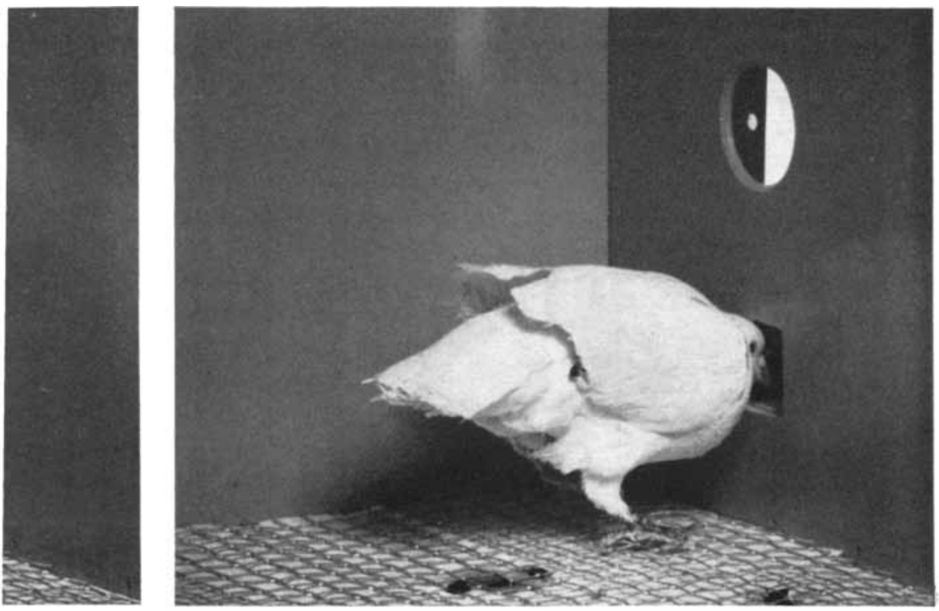
A pigeon held in a jacket before a translucent screen was reinforced for pecking at a projected picture of a particular type of target, such as a ship at sea. By scheduling reinforcements appropriately, we could guarantee steady responding for many minutes, and the pigeon could be prepared for changes in the size and aspect of the target. Signals originating at the edges of the screen that the pigeon pecked were delivered to guidance servomechanisms. To guarantee against any momentary disruption of performance, three pigeons were used to send a much more reliable and steady signal.

The guidance mechanism was intended to operate in this way. Three lenses in the nose of the missile would throw on three screens a picture of the area toward which the missile was directed. If the missile was on course, all three pigeons would peck the exact middle of their screens. If the missile went off course, the target pattern would move toward one side of the screen, and a displacement of even a fraction of an inch would generate a correcting signal. This research was carried on for a period after the war by Project Orcon (short for "Organic Control") at the Naval Research Laboratory.

There is a historical connection between Project Pigeon and our teaching machines. The project had forced us to consider the education of large numbers of pigeons. It is true that the scrap of wisdom imparted to each pigeon would have been small, but the required changes in behavior were similar to those which must be brought about in larger quantities in human students. One great lesson of our experimental work seemed clear: it is unthinkable to try to arrange by hand the subtle contingencies of reinforcement that shape behavior. Instrumentation is essential. Why not teach students by machine also?

Early Teaching Machines

The possibility was recognized as long ago as the 1920's by Sidney L. Pressey, a psychologist at Ohio State University. He designed several machines that automatically tested a student by presenting him with a series of questions keyed to multiple-choice answers. If the student selected the right answer by pressing a button, the machine moved on to the next question. If he was wrong, the error was tallied and he had to continue to choose until he had hit the right answer.



pigeon, photographed in the laboratory of Donald S. Blough at Brown University, has learned that it will be reinforced if it pecks the brighter of two spots of light. The sequence shows it observing the two stimuli, pecking the brighter and picking up its reward.

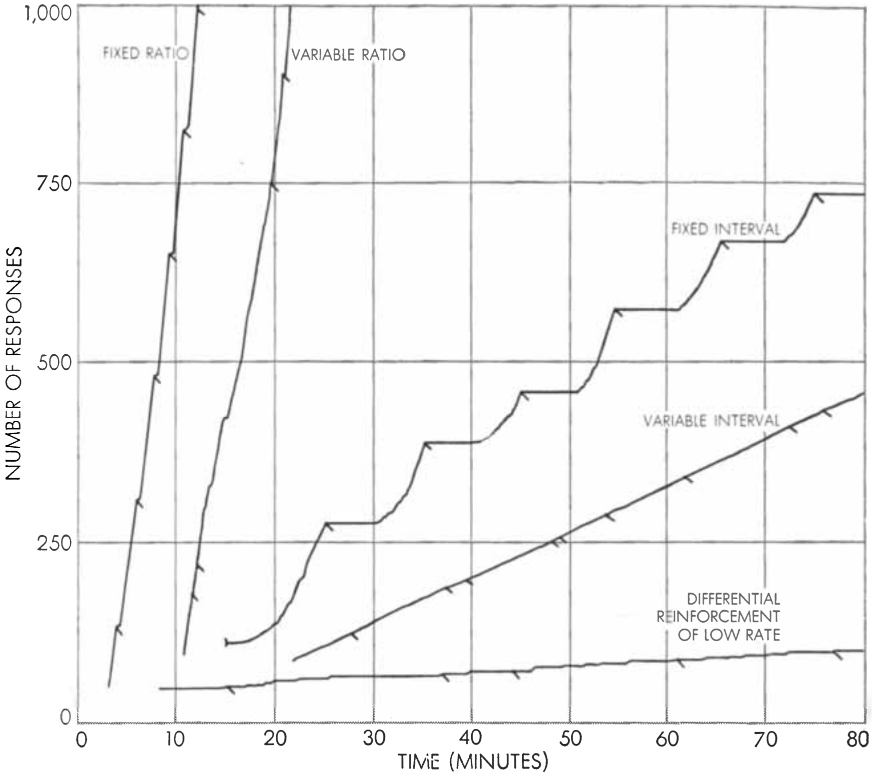
Pressey recognized that a device that informed a student immediately of his success, or lack of it, would do more than test the student—it would teach him. Pressey also saw that machine instruction would allow each student to proceed at his own pace.

The "industrial revolution in education" that Pressey envisioned stubbornly refused to come about. Receiving no encouragement from educators, Pressey wrote in 1932 that he was "regretfully dropping further work on these problems." Cultural inertia aside, Pressey's machines had limitations that probably contributed to their failure. They were mainly testing devices to be used after some amount of learning had already taken place elsewhere. They did not use the principles of programing that later emerged from the study of operant reinforcement.

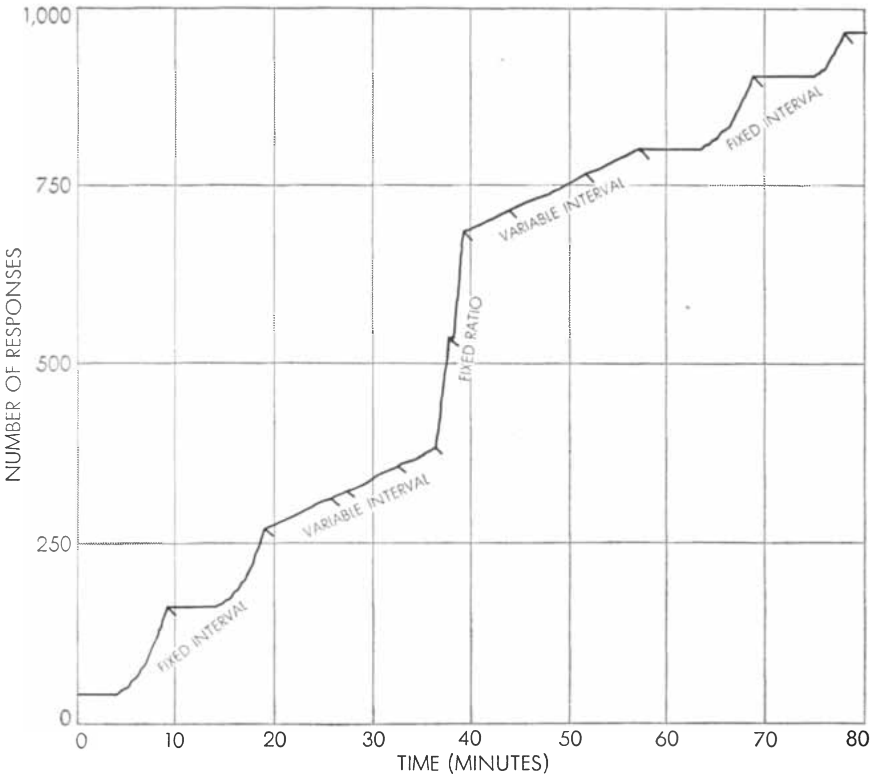
A useful teaching machine will have several important features. Except in some kinds of stimulus learning, the student should compose his response, rather than select it from a set of alternatives, as he would in a multiple-choice scheme. One reason for this is that we want him to recall rather than merely recognize—to make a response as well as see that it is right. An equally important reason is that effective multiple-choice material must contain plausible wrong answers, which are out of place in the delicate process of shaping behavior because they strengthen unwanted responses. (Our ability to remember wrong facts—because we recall having read them somewhere—is notorious. Every wrong answer on a multiple-choice test increases the probability that a student will someday dredge out of his imperfect memory the wrong answer instead of the right one.)

An effective program of instruction also imposes a requirement on a machine not satisfied by those of Pressey. The student must pass through a carefully arranged sequence of steps, often of considerable length. The machine, therefore, must have a high capacity and must be designed so that the student has to take each step and take it in the prescribed order.

For the past three years James G. Holland and I have used a machine that meets these requirements to teach part of a course in human behavior to undergraduates at Radcliffe College and Harvard. Our self-instruction room contains 20 machines and a supply of programs. The students use the room at their convenience as they would a library. During the one-semester course each student spends an average of 15 hours at one of



PIGEON RESPONSE CURVES differ markedly according to the schedule, or rate, of reinforcement. The curves are drawn by pen on moving paper. Each time the pigeon responds the pen jogs upward, creating a cumulative record. Reinforcement is shown by an oblique mark. The highest response rate is elicited when the animal is reinforced each time it completes a fixed number of responses. Similar rates are achieved by reinforcing for some average number of reponses (variable ratio). If rewarded for the first response after a fixed interval, the animal soon learns not to respond early in the interval. When the interval is varied, it works steadily. The lowest response rate results when it is reinforced only after an interval (in this case three minutes) has elapsed since its last response.



MIXED PERFORMANCE CURVE results when a pigeon has been conditioned on different schedules to different stimuli. As the stimuli change, the performance changes appropriately.

the machines, advancing through the equivalent of a 200-page textbook.

The current model of the machine we use has two windows, one for presenting the programed text, the other for accepting the student's response [*see illustration on pages 98 and 99*]. The program, printed on a fan-folded sheet of paper, contains frames for 10 to 15 minutes of instruction. In each frame one or more words are missing. The student writes his response on a continuous strip of paper that moves in phase with the frames of text. By operating a lever he covers each response with a transparent shield (he cannot then change it) and uncovers the correct response. When he is wrong, he punches a hole alongside his written response. This punch makes a mark on the back of the program to report to the program writer that there may be something wrong with the item. The punch also operates a counter that gives the student at the end of the set a score that can be compared with a par score to provide additional reinforcement for successful behavior.

This particular machine is designed for a two-stage response, which should make it possible to abbreviate programs considerably. Each item can be a little harder than the items in a single-response set. The student writes his response and then uncovers not a correct response but additional information. This may tell him that his response is wrong without telling him what the right response is, in which case he has a second chance. Or it may actually give him further information, thereby maximizing the probability that he will be right on a second try. In our present single-response material students are right about 95 per cent of the time. This percentage could be maintained with more difficult material by the use of the two-stage system. Whether we should try to design material that will be error-free, as in the pigeon experiments, or whether there is an optimal percentage of error will have to be decided by experimentation.

Although it is less convenient to go to a self-study room than to pick up a textbook in one's own room, most students feel that machine study has compensating advantages. They work for an hour or so with little effort, and they report that they learn more in less time and with less effort than in conventional ways. An important advantage is that the student always knows where he stands without waiting for a test or a final examination. (The students are not examined on the material but, in our particular course, are responsible for studying a textbook that overlaps it.)

Obviously the machine itself does not teach. It simply brings the student into contact with the person who composed the material it presents. It is a labor-saving device because it can bring one programmer into contact with an indefinite number of students. This may suggest mass production, but the effect on each student is surprisingly like that of a private tutor. The comparison holds in several respects. There is a constant exchange between program and student. Unlike lectures, textbooks and the usual audio-visual aids, the machine does not simply present something to be learned; it induces sustained activity. The student is always alert and busy. Like a good tutor, the machine insists that a given point be thoroughly understood, either frame by frame or set by set, before the student moves on. Lectures, textbooks and their mechanized equivalents, on the other hand, proceed without making sure that the student understands, and they easily leave him behind. Like a tutor, the machine presents just that material for which the student is ready. It asks him to take only that step which he is at the moment best equipped and most likely to take. Like a tutor, the machine helps the student to come up with the right answer. It does this in part through the orderly construction of the program and in part with techniques of hinting, prompting, suggesting and so on, derived from an analysis of verbal behavior. Finally, the machine, like the private tutor, reinforces the student for every correct response, using this immediate feedback not only to shape his behavior most efficiently but also to maintain it in strength in a manner that the layman would describe as "holding the student's interest."

The Reinforcement of Students

Machines such as those we use at Harvard could be programed to teach, in whole or in part, all the subjects taught in elementary and high school and many taught in college. Since it is difficult to write teaching machine programs, bad programs undoubtedly will be written and marketed, but if the market place has its usual effect, we can look forward to the emergence of highly efficient programs in the not too distant future.

People who are unfamiliar with achievements in the field of operant behavior are often puzzled by the effectiveness of a good program. Why do students continue to work more efficiently with such material than with ordinary textbooks, classroom discussions and lectures? The answer goes to the heart of human motivation. Why, indeed, does a student study at all?

Until fairly recently his behavior was mainly aversive; that is to say, he studied to avoid the consequences of not studying. Although many efforts have been made to change that basic pattern, they have not been conspicuously successful. The proper use of positive reinforcement emerging from the experimental analysis of operant behavior makes possible a general improvement in reinforcing conditions. It is not enough simply to show the student the ultimate advantages of an education—the ways of life that are open to educated men. The student himself may cite these to explain why he wants an education, but long deferred incentives provide only feeble motivation for short-term action, as many a student can testify. No matter how much he may *want* to become a doctor or a scientist, he cannot force himself to read and remember the page of text in front of him at the moment. All notions of ultimate utility suffer from the same shortcoming: they do not specify effective contingencies of reinforcement.

The gap between behavior and a distant goal is sometimes bridged by a series of "conditioned reinforcers." In our laboratory experiments it is standard practice to let the movement of a lever, or the pecking of a disk, produce a visual or auditory stimulus, such as the appearance of a light or the click of a food magazine, which is followed by the apportionment of food. In this way the light or click becomes a conditioned stimulus that can immediately reinforce a response.

The marks, report cards and diplomas of education serve as conditioned reinforcers designed to bring eventual consequences somewhat closer to the behavior reinforced. If the marks and cards are "good," they call forth approval from parents, teachers and friends and signify competitive superiority, but they are effective mainly because they signalize progress through the system, leading to some ultimate advantage or reward—if only freedom from further education. Educators often attempt to strengthen the reinforcing value of high marks by making students competitive, but if our concern is for the whole student population, we must recognize that when we use competitive success as a reinforcer someone has to suffer competitive failure.

The study of operant conditioning has shown that we can use positive reinforcement in education without discovering or inventing new reinforcements—we need only to make better use of those we have. Human behavior is remarkably influenced by small results. Describing something with the right word is often reinforcing. Other simple reinforcers are to be found in the clarification of a puzzlement or simply in moving forward after completing one stage of activity.

Everyone knows that children will spend hours playing with mechanical toys, paints, scissors and paper, noisemakers, puzzles—in short, with almost anything that feeds back significant changes in the environment and is reasonably free of aversive properties. The sheer manipulation and control of nature is itself reinforcing. This effect is not conspicuous in most of our schools because it is masked by the emotional responses generated by aversive control.

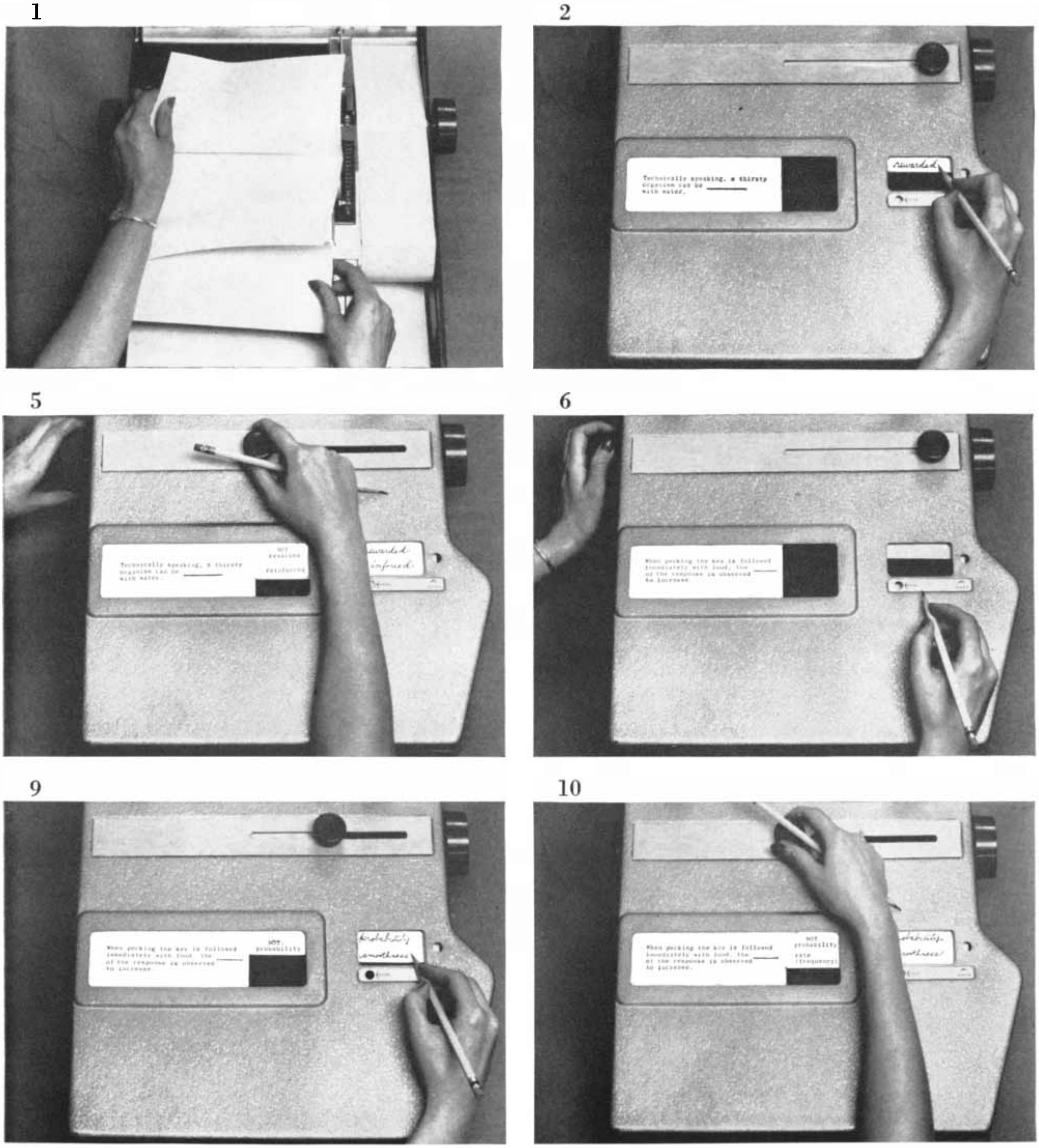
We might say that the human organism is reinforced by any simple gain in competence. When we guarantee a consistent gain by breaking the material to be learned into small steps, we raise the frequency of reinforcement to a maximum and reduce aversive consequences to a minimum. Although these requirements are not excessive, they are probably incompatible with the current realities of the classroom and suggest a need for instrumentation.

Let us take as an example the problem of teaching spelling in the elementary grades. Suppose we want to teach a child to spell the word "manufacture." A minimum program might require six frames of space, presented in sequence in the window of a teaching machine. The child would be required to make a response to each frame. The word to be learned appears in boldface in Frame 1, with an example and a simple definition. The pupil's first task is to copy it. When he has done so correctly, Frame 2 appears, which says: "Part of the word is like part of the word 'factory.' Both parts come from an old word meaning 'make' or 'build.' M A N U – – – – U R E." The pupil writes down the missing letters and proceeds to Frame 3, which, in similar fashion, relates the first part of the word to *manual* and to *hand* and requires the pupil to write down the missing letters in – – – – F A C T U R E. Frames 4 and 5 make the point that the letters *A* and *U* each occur twice in the word. And Frame 6 says: "Chair factories – – – – – – – – – – – – chairs."

Such programs obviously run to considerable length. At five or six frames a word, four grades of spelling may require 20,000 to 25,000 frames, and four grades of arithmetic as many again. If these figures seem large, it is because we are thinking of the traditional contact between teacher and pupil. A teacher clearly cannot supervise 10,000 to 15,000 responses made by each pupil each year. But the pupil's time is not so limited. In any case, surprisingly little time is needed. Fifteen minutes a day on a machine should suffice for each of these programs. It is probably because traditional methods are so inefficient that we have been led to suppose that education requires such a prodigious part of a young person's day.

Granted that machines could "teach" straightforward subjects like spelling and arithmetic, how would they be used to teach a more fundamental and difficult skill such as reading? Here it helps to recognize that no one can teach something called "an ability to read." Rather, we may teach the behavior from which we infer such an ability.

Knowing how to read means exhibiting a behavioral repertory of great com-



TEACHING-MACHINE PROGRAM helps the student to master a large repertory of concepts by presenting them in an orderly sequence of small steps. At each step the student must write a response. This machine, built by the Rheem Manufacturing Company according to the author's ideas, can be programed to provide clues before revealing the correct response. The program is printed on a fan-folded strip of paper and placed in the machine by raising the cover (*1*). Responses are written on a separate roll of paper.

plexity. A pupil can find a letter or word in a list on demand; he reads aloud; he identifies objects described in a text; he behaves appropriately in described situations and so on. He does none of this before learning to read and all of it afterward. To bring about such a change is an extensive assignment.

It is true that all parts of the repertory are not independent. A student may acquire some kinds of response more readily as a result of having acquired others. But ultimately all parts of the repertory tend to be filled in, not because the student is rounding out an ability to read but because all parts are in their several ways useful. They all continue to be reinforced by the world at large after the explicit teaching of reading has ceased.

Viewed in this way, reading can also be taught most effectively with the aid of machines. A pupil can be taught to distinguish among letters and groups of

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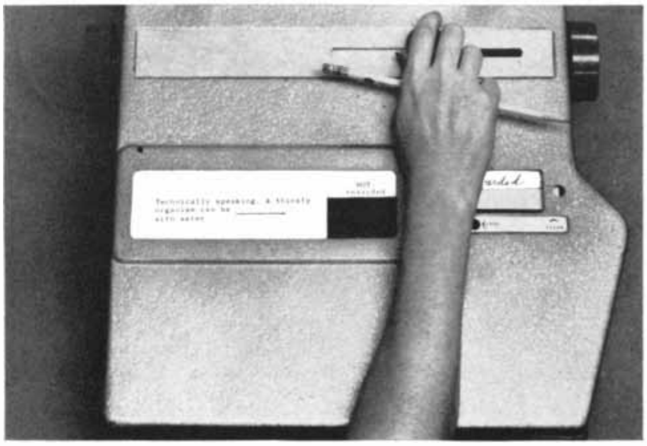

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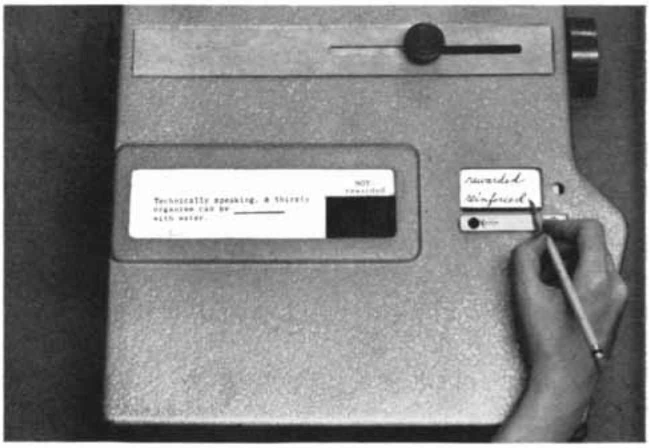

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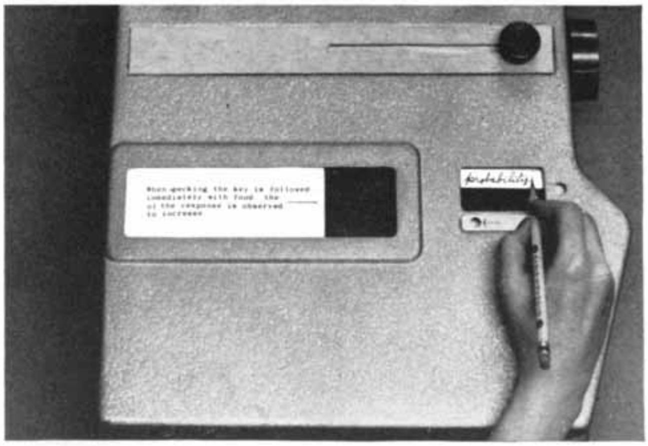

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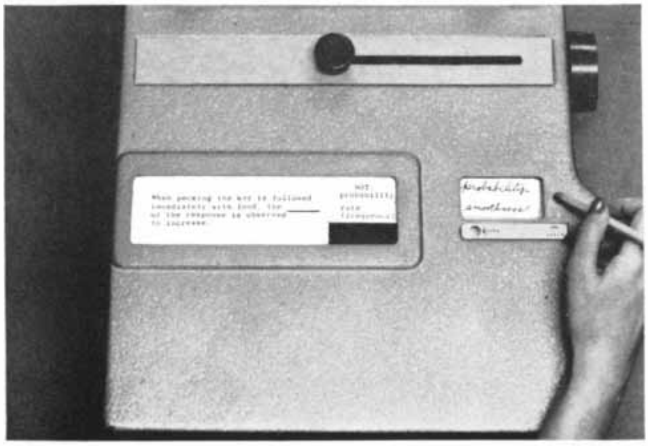

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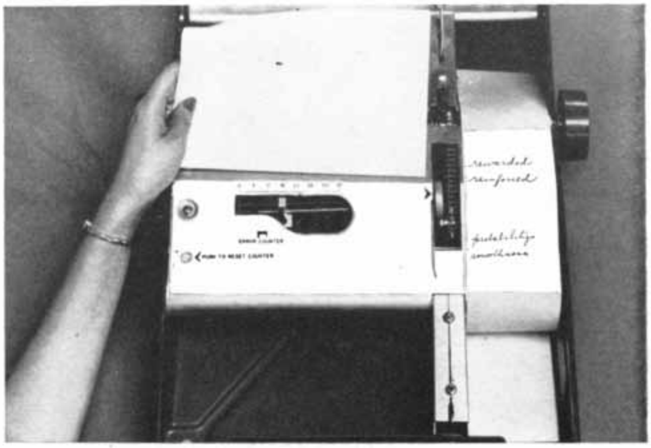


This sequence shows two steps (not successive) in the program developed by the author and James G. Holland for a Harvard course in behavior. Clues appear in Frame 3 and Frame 8. Since the student still wrote the wrong response in Frame 9, he records his error with the tip of his pencil (*11*). This causes a mark to be recorded on the underside of the program (*12*). When a programmer finds many such marks under a given step, he tries to make the step clearer. Eventually, in this way, he elicits nearly error-free responding.

letters simply as visual patterns. He can be taught to identify arbitrary correspondences, for example, between capital and lower-case letters, or between printed and handwritten letters. With the addition of earphones and a tape recorder, the machine will set up correspondences between letters and sounds, between printed words and sounds, and between words, sounds and pictured objects. Traditional ways of teaching reading establish all these repertories, but they do so indirectly and with no serious provision for seeing that each child has mastered every small step in a complicated chain.

Different subjects may require different techniques of machine presentation. For example, to teach subjects such as geography, biology or anatomy, in which names must be related to physical shapes or objects, one can use a "vanishing" technique. In teaching a map the machine asks the student to describe spatial relations among cities, countries, rivers and so on, as shown on a fully labeled map. He is then asked to do the same with a map in which the names have been partially "vanished"—that is, removed in whole or in part. Eventually he is asked to report the same relations with no map at all. If the material has been well programed, he should be able to do so with few, if any, errors.

The reader can easily demonstrate the effectiveness of the vanishing technique by using it to teach a child a short poem. Write a poem of 10 to 14 lines on a blackboard in clear block letters. Have the subject read it aloud without making any effort to memorize it. Now erase a few unimportant letters on each line. Again ask the subject to read the poem. Repeat the process, each time erasing a few more letters and then whole words and phrases, until the poem has vanished. Toward the end even the faint clues of erased letters will be useful, but finally even they should be removed. At each reading the subject makes no effort to memorize, though he may have to make some effort to recall. For a dozen lines of average difficulty, four or five readings should suffice to eliminate the text altogether. The poem can still be "read." Precisely the same technique can be used in a teaching machine. As letters and words vanish from the presentation window of the machine, the student writes them down, with no difficulty, in the response window.

Designing good programs for history, science, English usage and other subjects will not be easy. Whereas a confusing or elliptical passage in a textbook is forgivable because it can be clarified by

SELF-STUDY ROOM at Harvard provides machine instruction for students of Radcliffe College and Harvard who take the author's course in behavior. The room contains 20 teaching machines. During a semester each student spends about 15 hours in this room responding to programs that cover the equivalent of some 200 pages of text. The machines supplement the author's classroom lectures.

a teacher, machine material must be self-contained and wholly adequate. There are other reasons why textbooks, lecture outlines and film strips are of little help in preparing a machine program. These devices are usually not logical or developmental arrangements of material but stratagems that the authors have found successful under existing classroom conditions. The examples the authors use are more often chosen to hold the student's interest than to clarify terms and principles.

Difficult as programing is, it has its compensations. It is a salutary thing to try to guarantee a correct response at every step in the presentation of a subject. The programmer will find that he has been accustomed to leaving much to the student, omitting essential steps and neglecting relevant points. The responses made to his program may reveal surprising ambiguities. Unless he is extremely able, he may find that he still has something to learn about his subject. He will almost certainly find that he needs to learn a great deal more about the behavioral changes he is trying to induce in the student. His goal must be to keep refining his program until the point is reached at which the answers of the average child will almost always be right.

The traditional teacher may find this prospect alarming. Is it sound educational practice to minimize failure and maximize success? There is no evidence that what is easily learned is easily forgotten. If this should prove to be so, retention may be guaranteed by providing material for an equally painless review.

The standard defense of "hard" material is that we want to teach more than subject matter. The student is to be challenged and taught to "think." It is true that those who learn in spite of a confusing presentation of a subject are better students, but are they better because they have surmounted difficulties or do they surmount them because they are better?

If we want to teach students to think, a more sensible procedure would be to analyze the behavior called "thinking" and produce it according to specification. A program specifically concerned with such behavior could be composed of material already available in logic, mathematics, scientific method and psychology.

Teaching Skills

Before we concern ourselves with trying to teach anything so poorly defined as thinking, there is much else that could be done to increase the behavioral repertories of children, even those who are younger than school age. Consider, for example, the temporal patterning of behavior called rhythm. Behavior is often effective only if properly timed. Individual differences in timing skill (often thought to be almost entirely innate) affect the choice of career and of artistic interests, as well as participation in sports. Presumably a "sense of rhythm" is worth teaching, yet nothing is done at present to arrange the necessary contingencies of reinforcement. The skilled typist, tennis player, lathe operator or musician is, of course, subject to noneducational reinforcing mechanisms that generate subtle timing, but many people never reach the point at which these natural contingencies take over.

We have been experimenting with a comparatively simple device that supplies the necessary contingencies [*see illustration on page* 92]. The device produces a rhythmic pattern that the student reproduces by tapping a key. He may tap in unison with the device or echo it during intervals provided for his responses. The machine scores a tap as being correct by flashing a light and a complete correct sequence by ringing a bell. At first the student is allowed a wide margin of error. He can be early or late with each tap, but these specifications are gradually sharpened until the student's performance reaches a satisfactory level of precision. The programing techniques here are exactly parallel to those used in animal research.

Another kind of teaching machine presents a variety of shapes or patterns from which the student is to select a pattern related in some way to a sample displayed. This is a multiple-choice procedure, but it is justified in this case because what is learned is a process of selection from an array. The objective is to teach children to be more sensitive to the visual properties of their environment.

The same kind of device can be programed to teach quite complex behavior such as inductive reasoning. For example, the student can be taught to continue a series of patterns following an orderly sequence [*see illustration on page 90*].

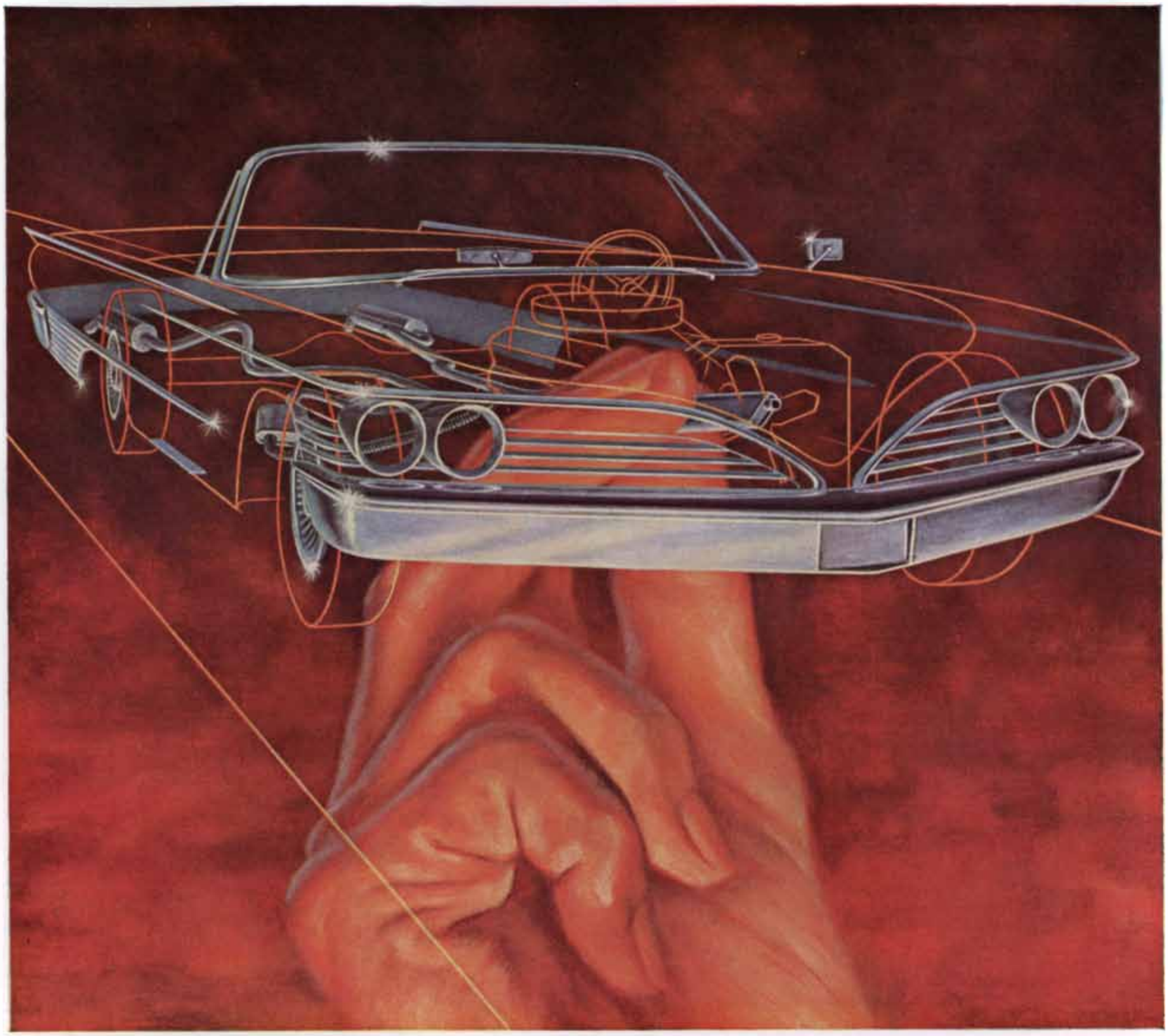
Motor skills such as rhythm, perceptual skills such as matching and intellectual skills such as inductive reasoning are seldom taught directly. It is expected that students will rise to their best level of competence indirectly through the teaching of subject matter. It is also usually assumed that the large individual differences seen in an adult population are due to differences in natural endowment. But we have by no means explored the possibility that they are due to large differences in environmental circumstances, particularly in the early lives of students. The environment of the young child contains poor contingencies to shape and sustain rhythmic and musical abilities, pattern discrimination and so on. Until we have remedied this environmental defect we are in no position to assign differences to genetic limitations. It is quite possible that wide differences in abilities will still survive, including the difference now measured crudely as one of intelligence, but that the whole population can be moved upward in competence and achievement.

The New Role of the Teacher

To arrange all this we must analyze human behavior afresh and design a whole series of educational practices appropriate to the task. Many different types of teaching machine will undoubtedly be needed, and they will raise many practical problems. They will not eliminate the need for teachers or reduce their status. On the contrary, they will enable the teacher to save time and labor while taking on a vastly greater assignment. Even the machines available today free the teacher for more creative classroom functions than that of drillmaster. In assigning certain mechanizable functions to machines, the teacher will emerge in his proper role as an indispensable human being.

Administrative problems will also arise. One of the great sources of inefficiency in modern education is due to our effort to teach a group of students at the same rate. We recognize that this is unfair to the student who is able to move faster, but we have no idea how much damage may be suffered by those who move slowly. There is no evidence that a slow student is necessarily unintelligent, but in our system he quickly falls behind and becomes less and less able to move at the speed adopted by the teacher. With properly designed machines and programs, a slow student free to move at his own normal rate of work may rise to undreamed-of levels of competence.

Grades will have a new meaning, signifying mainly the amount of material the student has covered. Even the architecture of school buildings may have to be changed, and it may no longer be necessary to continue the centralization of school systems. All this will undoubtedly cost money, but it will be money spent in the development of a country's greatest resource, the productivity, happiness and creative development of its citizens.



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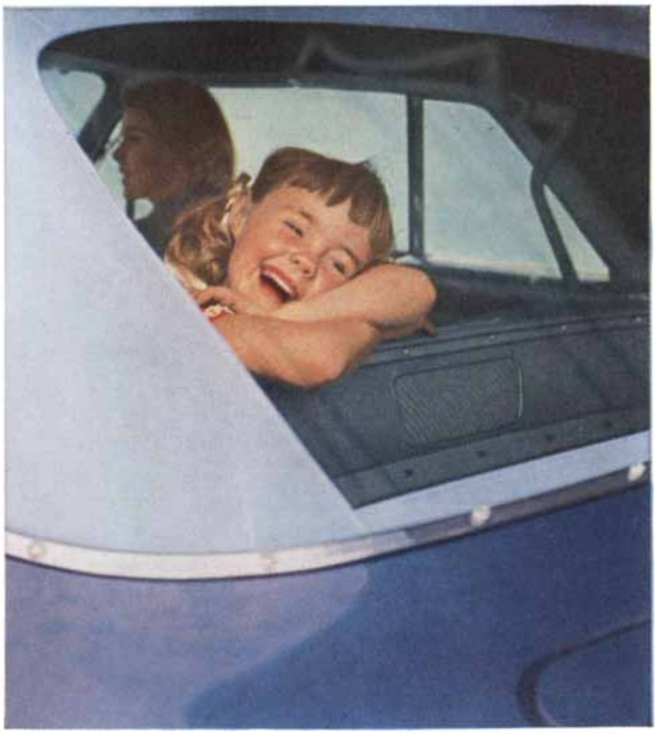

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DESERT GROUND SQUIRRELS

Two little animals of the Mohave Desert have evolved remarkable adaptations to heat and aridity. Each has adapted in its own way, which apparently enables them to live together without competing

by George A. Bartholomew and Jack W. Hudson

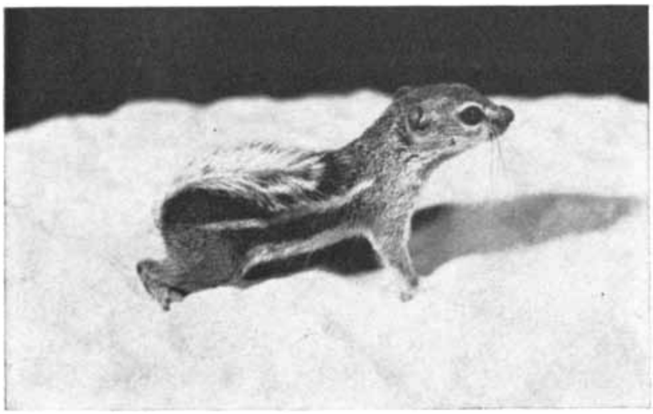
Among the handful of animals that inhabit the hot, dry and sparsely vegetated Mohave Desert of California are two species of ground squirrel: the antelope ground squirrel and the mohave ground squirrel. Both species live in burrows, both are active and aboveground during the day and both feed on the small amount of plant life that is available.

This is an uncommon situation in nature. Species as closely related as these two, and as much alike in their food and habitat requirements, seldom live together even in more favorable environments. In his *Origin of Species* Charles Darwin suggested the reason. "As the species of the same genus usually have . . . much similarity in habits and constitution, and always in structure," he wrote, "the struggle will generally be more severe between them, if they come into competition with each other, than between the species of distinct genera." Implicit in Darwin's statement is a concept now fundamental to biology. It is known as the principle of competitive exclusion and it says, in brief, that two noninterbreeding populations that stand in precisely the same relationship to their environment cannot occupy the same territory indefinitely. They cannot, in other words, live in "sympatry" forever. Sooner or later one will displace the other.

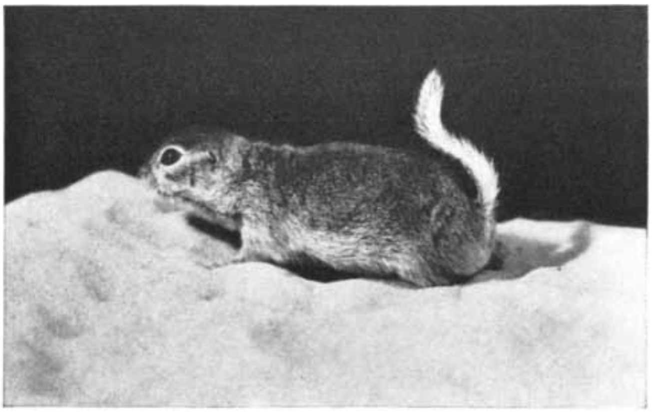
Such a displacement could be under way in the Mohave Desert right now. The mohave ground squirrel may well be a species in the process of extinction. Not only does it have a smaller total population and a narrower geographical distribution than the antelope ground squirrel (which is one of the commonest ground squirrels of the southwestern U.S.); it also appears to be less numerous in the small section of the Mohave Desert to which it is restricted. But since no historical information is available on the population trends of the two animals, there is no way of knowing exactly what the present difference in their number portends.

In any case the mohave ground squirrel is not as yet extinct. This raises a number of intriguing questions. Do the two species have the same way of life and the same relationship to their environment? If so, the competition between them must be severe. Or are there differences in their adaptation to their common environment? If there are, do these differences reduce competition between them sufficiently to permit them, at least temporarily, a period of peaceful coexistence?

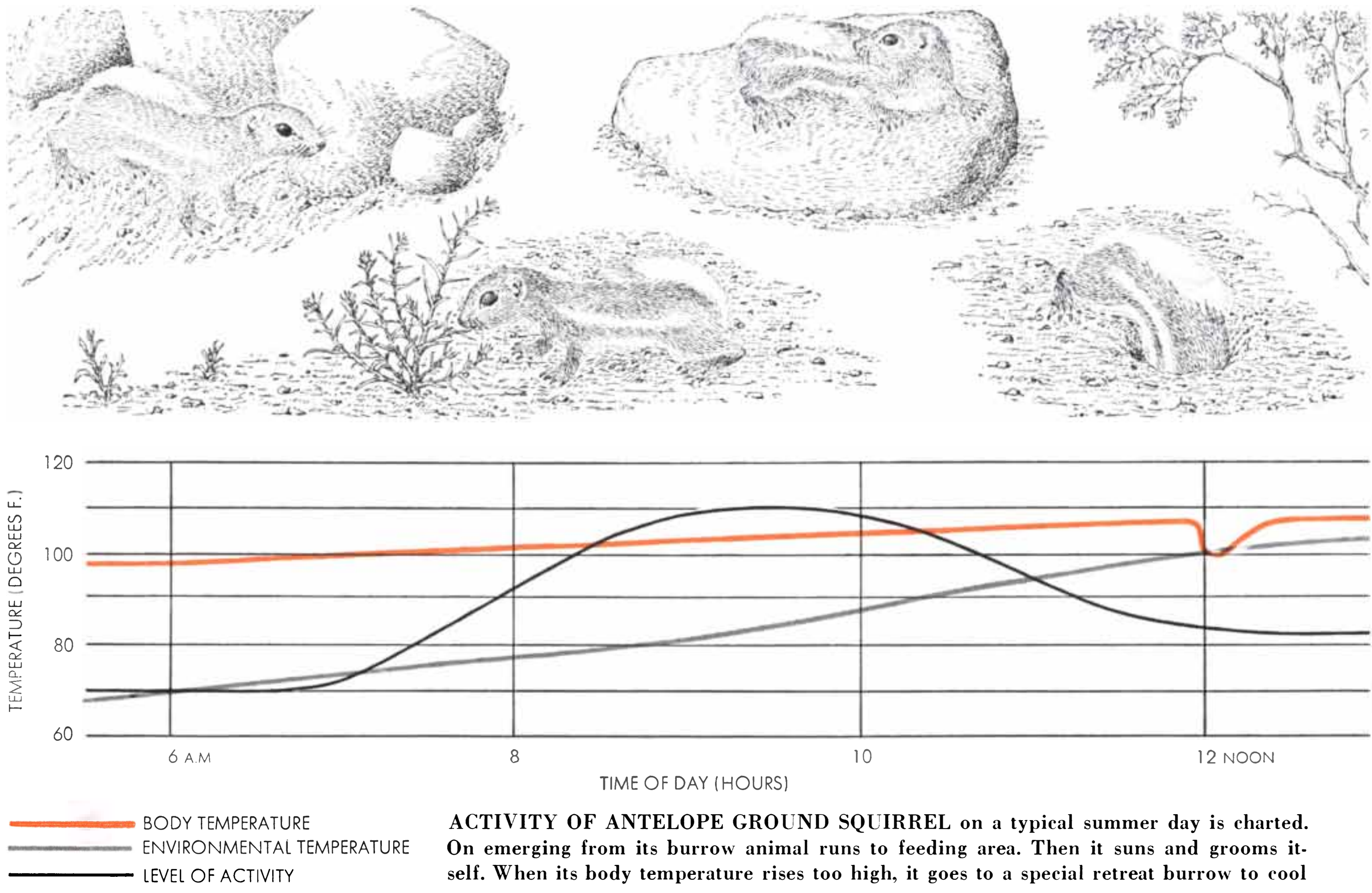
These questions become more intriguing when one considers the nature of the desert environment. Aridity and heat make particularly severe demands on animals, and animals that live in deserts must be equipped with special physiological and behavioral adaptations to meet these demands. The camel, for example, withstands aridity because it can tolerate a high degree of dehydration, can restore its body fluids quickly and can travel long distances in search of water and succulent vegetation. It withstands heat through its tolerance of a wide range of body temperatures and



ANTELOPE GROUND SQUIRREL is found in the Mohave Desert and throughout the southwestern U.S. It is active during the day all year round, in spite of extremes of heat and aridity. Both of these photographs were made in the laboratory by Jack W. Hudson.



MOHAVE GROUND SQUIRREL is found only in one corner of the Mohave Desert. It is active during the day from March to August but remains in its burrow the rest of the year. Before retiring underground it becomes very fat, as this photograph shows.

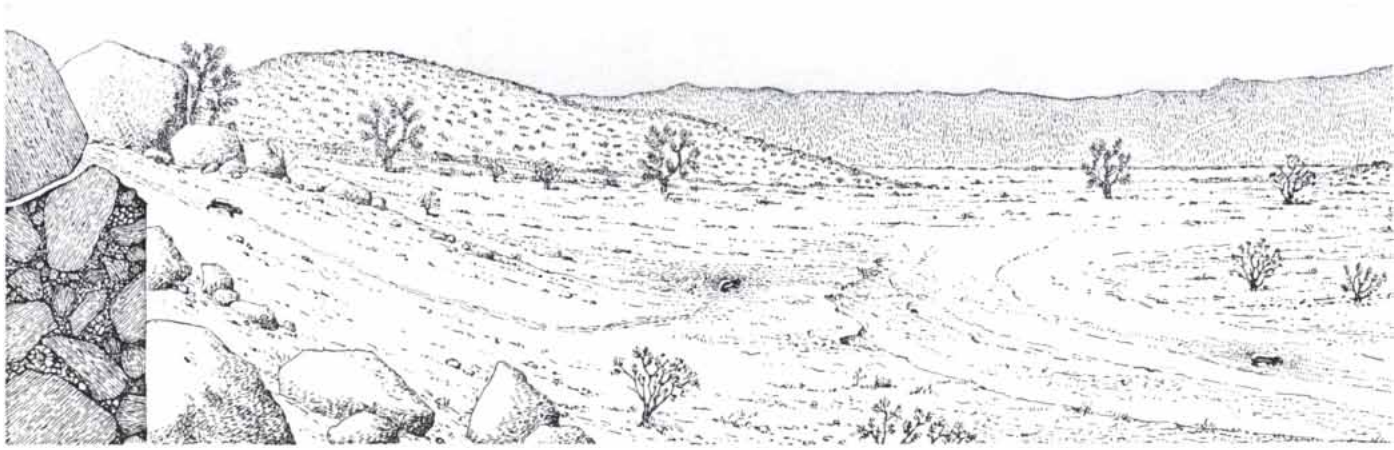


ACTIVITY OF ANTELOPE GROUND SQUIRREL on a typical summer day is charted. On emerging from its burrow animal runs to feeding area. Then it suns and grooms itself. When its body temperature rises too high, it goes to a special retreat burrow to cool

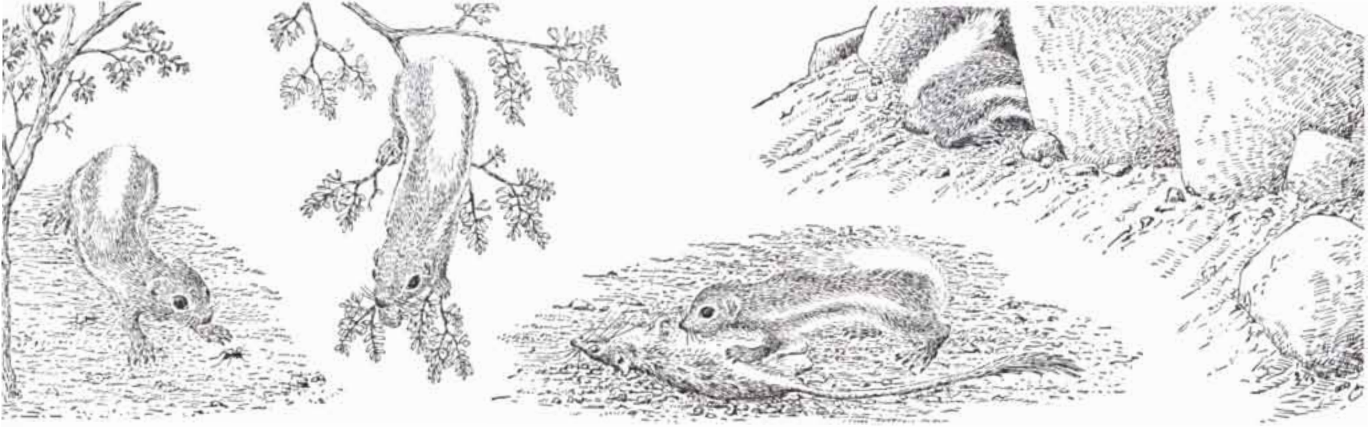
through the insulating qualities of its coat [see "The Physiology of the Camel," by Knut Schmidt-Nielsen; Scientific American, December, 1959]. The desert rat of the U.S. Southwest has adapted equally well but in quite different ways. To combat aridity it conserves its body water; the desert rat's kidney is so efficient that it uses only about a fourth of the amount of water that the human kidney requires to excrete the same amount of urea. This adaptation enables the animal to meet a substantial fraction of its water needs by the oxidation of foodstuff, as opposed to drinking. The desert rat deals with heat by avoiding it: the animal remains in its burrow during the daylight hours, emerging only at night, when the air and soil are cool [see "The Desert Rat," by Knut and Bodil Schmidt-Nielsen; Scientific American, July, 1953].

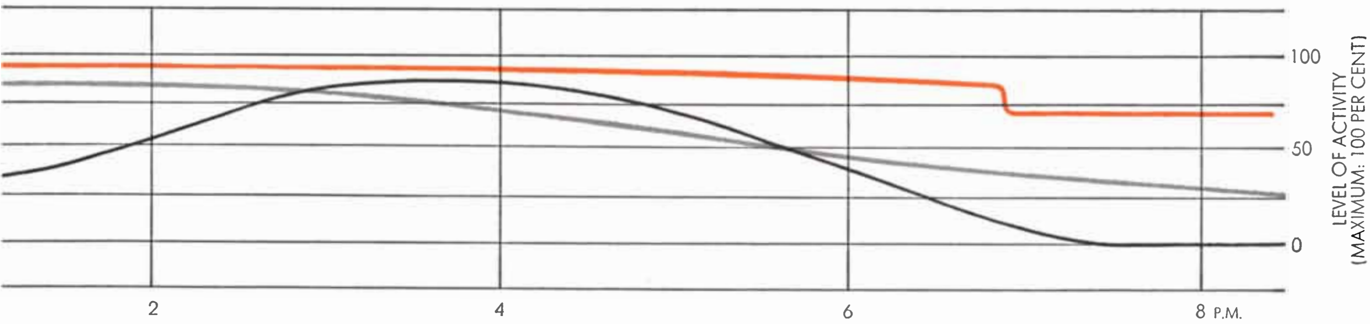
Like the desert rat, most small, burrowing desert rodents are nocturnal. But both the mohave ground squirrel and the antelope ground squirrel are diurnal. They emerge from their burrows near sunrise and forage outdoors throughout the day. They do so even in summer, when the air temperature may reach 110 degrees Fahrenheit or higher, and when the surface temperature of the soil may rise above 150 degrees F. Since the desert is as arid as it is hot, they must sustain their exposure to heat with a minimum loss of water for evaporative cooling.

In appearance and temperament the antelope ground squirrel resembles the



RETREAT BURROW OF ANTELOPE GROUND SQUIRREL is shown at right in this drawing. It is usually dug in soft soil close to desert vegetation and is about one foot deep and 12 to 15 feet long. The animal seems to use this burrow to unload body heat

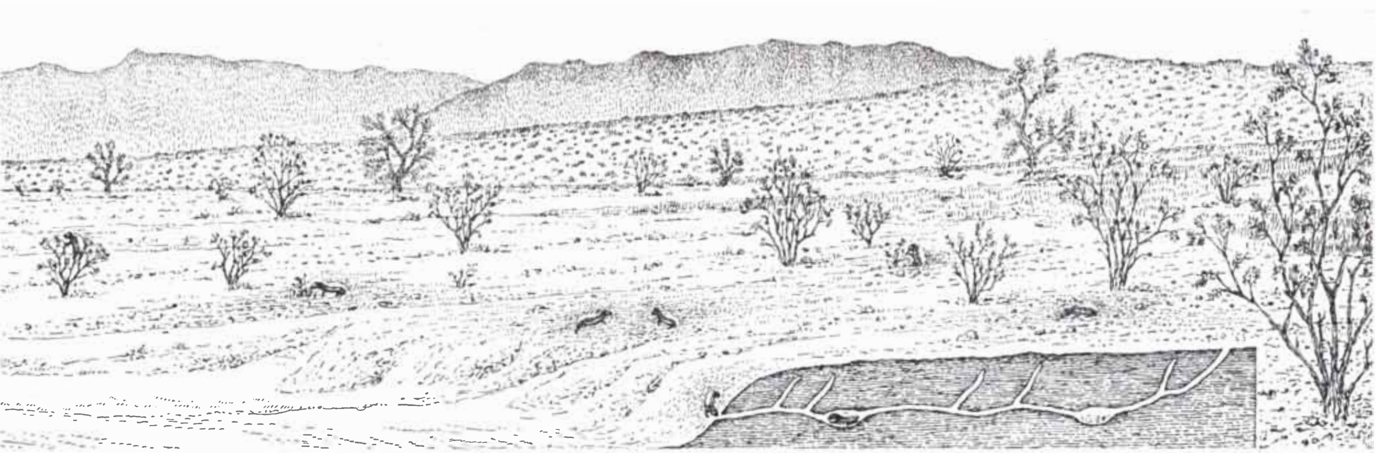




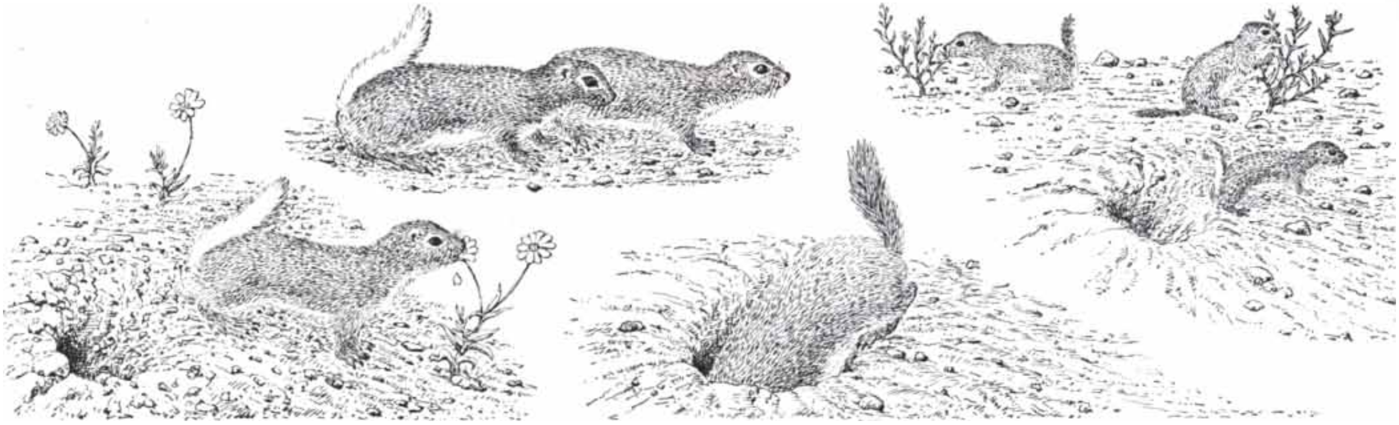
off. In early afternoon it stays in the shade. Before retiring to its home burrow it returns to feeding area, and at any time may catch insects or feed on dead animals. On the graph, dip in body temperature is shown only at noon. But dips occur often, whenever animal goes underground to unload heat. At all other times its temperature is a few degrees above the environmental temperature.

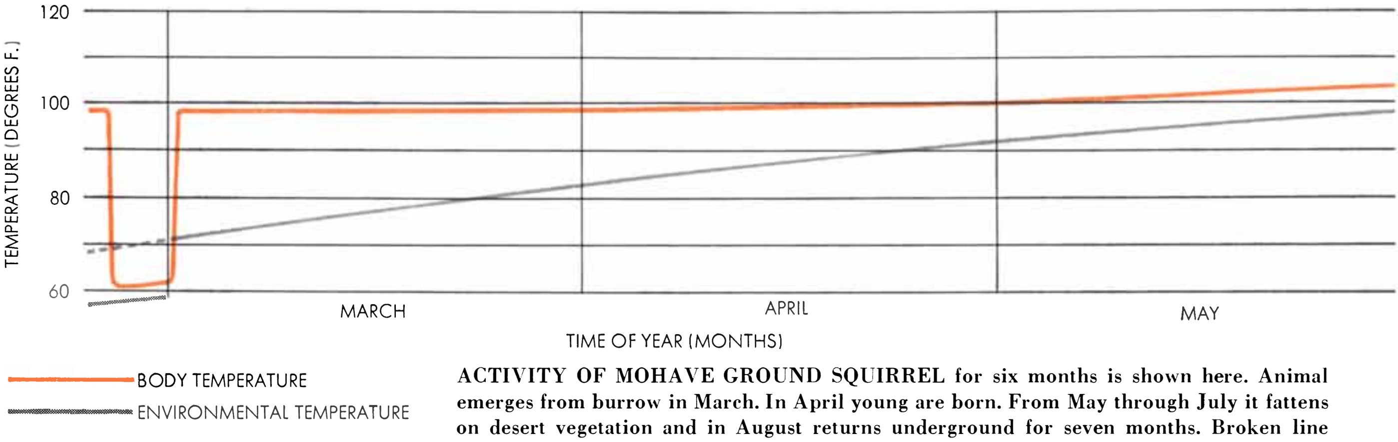
chipmunk. Its body is about six inches long; its weight is about 90 grams. It has two white stripes down its grayish-brown back. It carries its tail high, exposing a white rump; this suggests the appearance of the pronghorn antelope, for which it is named. An extraordinarily active and high-strung animal, the antelope ground squirrel is constantly in motion, dashing from place to place, often traveling hundreds of feet from its home burrow. That it can maintain such hyperactivity even in soaring temperatures is in itself evidence of unusual adaptive mechanisms.

For every animal the ability to adapt to external temperatures depends on two internal factors: the range of body temperatures in which it can function effectively and the rate at which it can produce body heat. Below a lower critical environmental temperature the body loses so much heat that internal temperature can be maintained only if the animal can step up its production of body heat sufficiently. Above an upper critical environmental temperature the body retains so much metabolic heat that internal temperature can be held within the required range only if the animal can get rid of heat, in most cases by evaporative cooling; that is, by sweating or panting at a sufficient rate. Between the upper and lower critical temperatures—in the thermal neutral zone—an animal can maintain its optimum body temperature without having either to increase its metabolic rate or to lose body water. Such stratagems as contracting or dilat-



and to store food, but not as a living place; the dens in the burrow contain neither nests nor fecal matter. The antelope ground squirrel's living burrows have not been excavated. They are probably dug under rocky buttes, like that seen at left side of drawing.



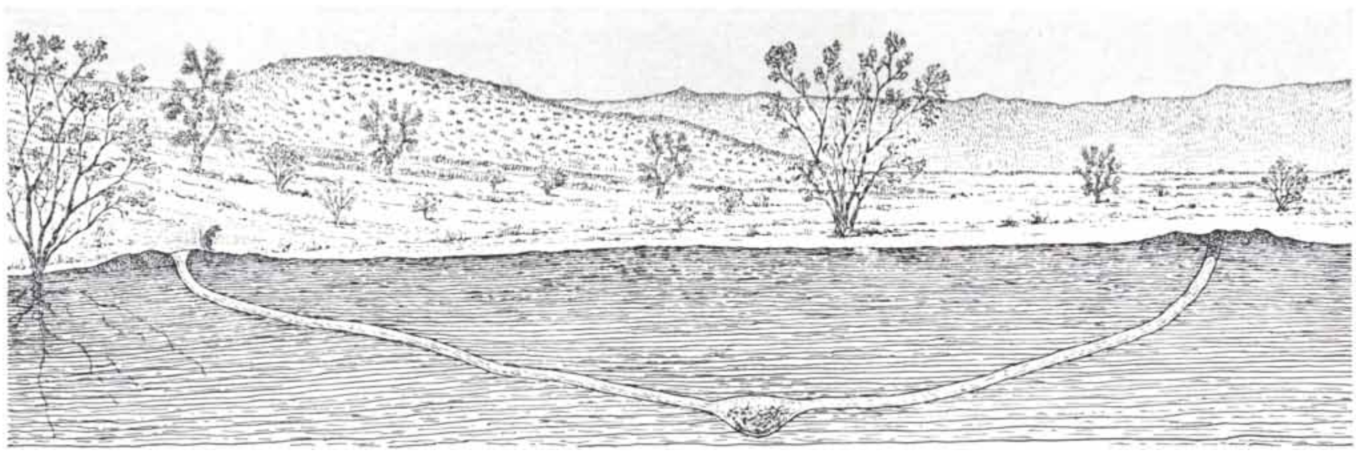


ACTIVITY OF MOHAVE GROUND SQUIRREL for six months is shown here. Animal emerges from burrow in March. In April young are born. From May through July it fattens on desert vegetation and in August returns underground for seven months. Broken line

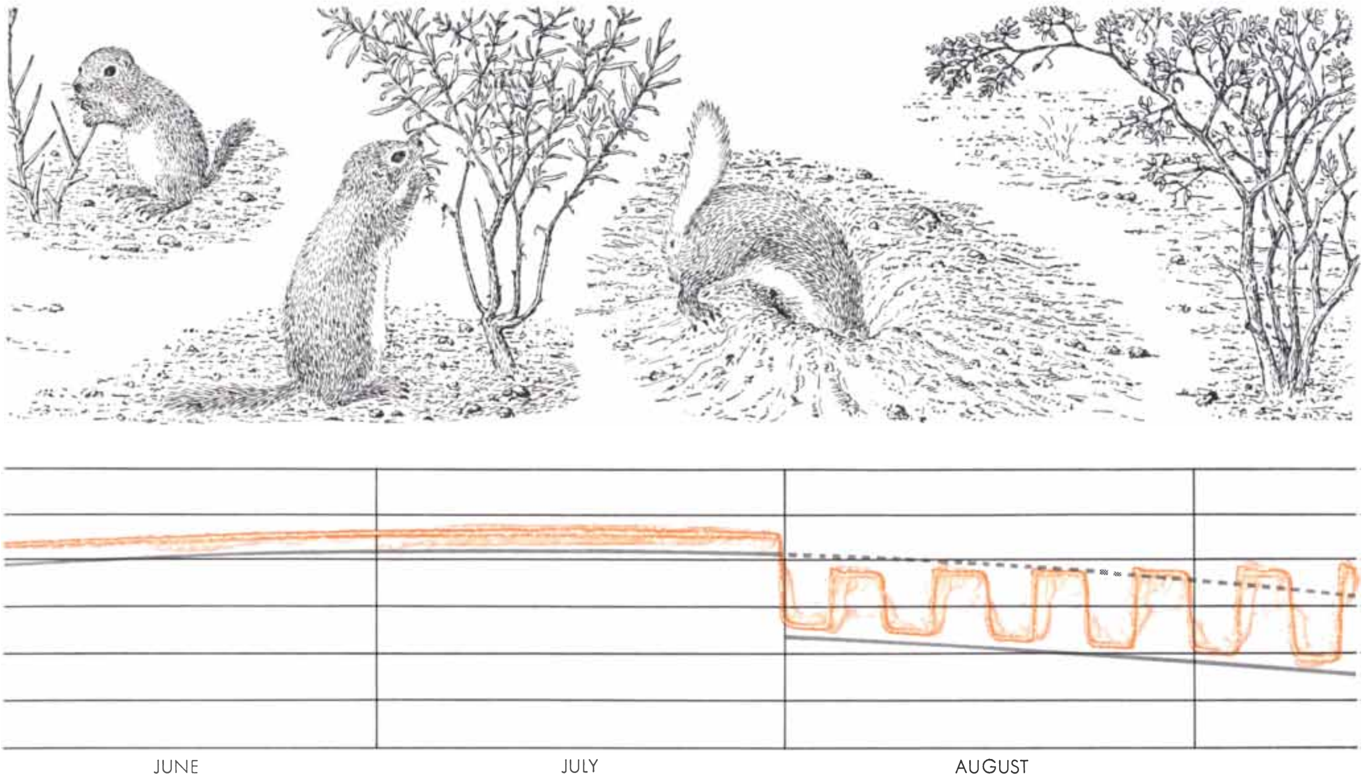
ing cutaneous blood vessels and depressing or raising hair or feathers allow the animal to function at a minimum cost of energy for temperature maintenance.

In terms of this analysis of the adjustment of body temperature to environmental temperature, the adaptation of the antelope ground squirrel is admirable. It has a broad thermal neutral zone and one that accommodates to high environmental temperatures. Between environmental temperatures of 90 and 107 degrees F. its metabolic rate remains virtually constant. No other nonsweating mammal has a thermal neutral zone extending so high [*see illustration on page 112*].

Unlike man, the antelope ground squirrel can tolerate a high body temperature; in other words, it can "run a fever" without debility. It can therefore permit its temperature to rise with the temperature of the environment. Like the camel, it can store heat, and it does not have to dispose of heat until its body temperature reaches an extreme point. The antelope ground squirrel shows no serious discomfort even when its body temperature goes above 110 degrees. Throughout the thermal neutral zone it runs a temperature a few degrees above that of the environment [*see top illustration on pages 108 and 109*]. Instead of expending energy to cool itself and thereby adding to its heat load—as man must do—this animal actually disposes of a portion of its metabolic heat to the lower-temperature environment by



LIVING BURROW OF MOHAVE GROUND SQUIRREL is seen here at various stages and times of year. Burrow is dug in soft sand near the desert plants the animal eats. It is about 18 feet long and three feet deep. First panel shows burrow in early spring,



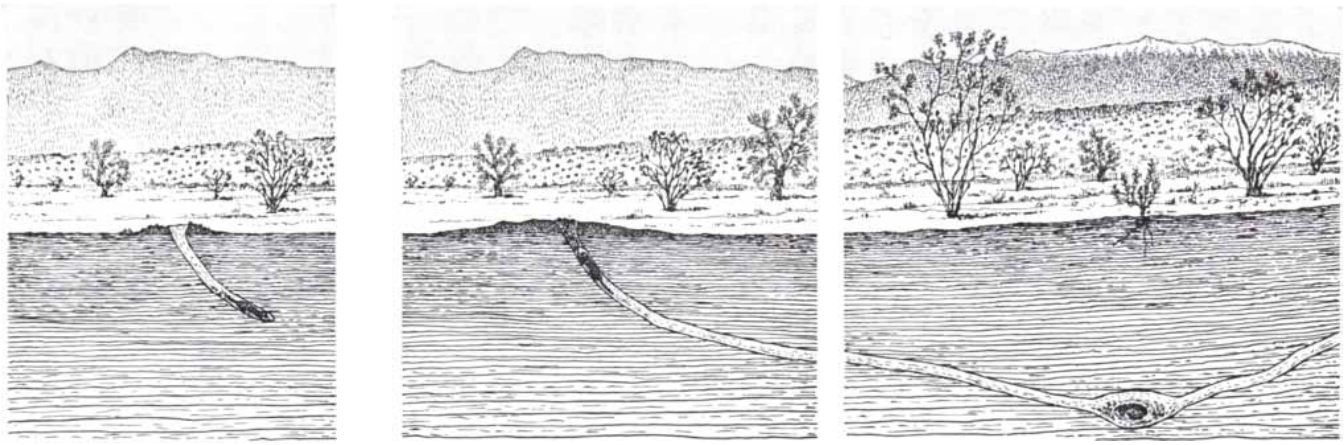
on graph is desert air temperature when animal is in burrow. Gray line under it is burrow temperature then. Rise and fall of animal's temperature in August corresponds to its periods of wakefulness and torpor. Body temperature is always higher than environmental temperature, although when animal is active its temperature fluctuates sharply. A mean body temperature is shown here.

conduction, convection and radiation.

But environmental temperatures in the desert are commonly far higher than tissues can tolerate, and small animals heat up rapidly. The antelope ground squirrel must therefore unload some of its accumulated body heat at intervals during the day. It does this either by flattening itself against the soil in a shaded area or by retreating underground to its burrow. When its body temperature gets dangerously high, it has only to return to the relative coolness of its burrow and remain quiet for a few minutes until its fever has subsided. In our laboratory at the University of California at Los Angeles, antelope ground squirrels have lowered their body temperature from above 107 degrees to about 100 degrees within three minutes after being transferred from an environmental temperature of 104 degrees to one of 77 degrees.

The antelope ground squirrel contends with heat in still another way. Under protracted heat stress it will begin to drool. The animal then systematically spreads the saliva over its cheeks and head with its forepaws as though it were grooming itself. On very hot days, when it has had to tolerate air temperatures of 104 degrees or more for several hours, the antelope ground squirrel may be soaking wet around the head.

Drooling, with its high cost in water losses, is a last resort. But even when the temperature is not extreme, the antelope ground squirrel loses a considerable amount of body water. At 100



when animal emerges. Second shows animal digging new burrow. Third shows it closing burrow in August before retiring underground. In last panel it is winter and animal is torpid. Periods of torpor probably last longer in winter months than in summer.

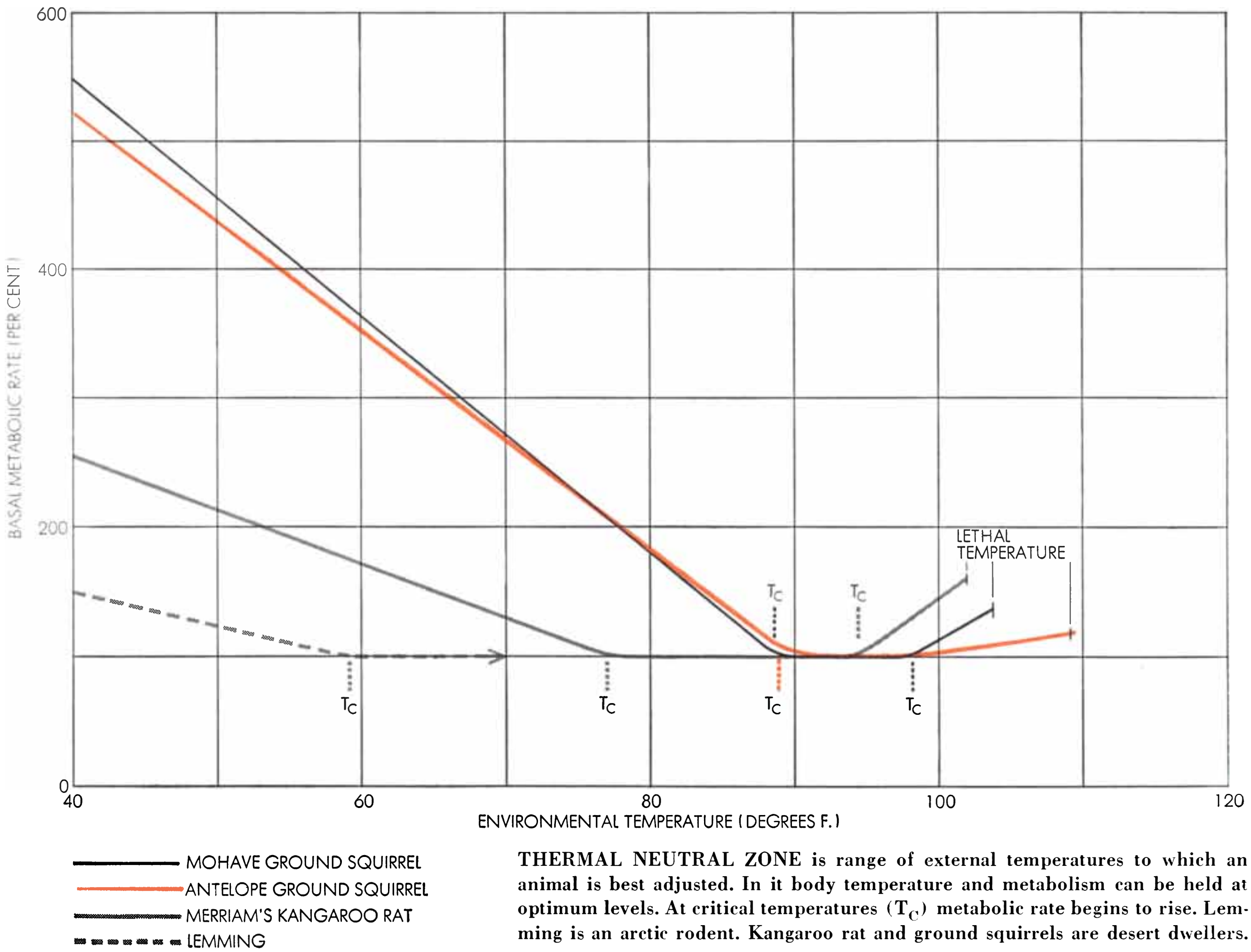
degrees, long before it has begun to drool, this hyperactive animal gives up water equal to 10 per cent of its body weight in respiration and evaporation through its skin in the course of a day. This is 15 per cent of its total body water. Fortunately the animal withstands dehydration well. Although it gives up three times more water every day than it can extract from its food by oxidation, it can survive from three to five weeks on a completely dry diet. If the antelope ground squirrel is to maintain itself in a healthy state, however, it must find sources of preformed water. It is therefore hardly surprising that the animal is omnivorous, eating insects as well as desert vegetation. When it is seen on the highways, as it often is, it is probably feeding on the corpse of some animal, perhaps another of its species that has been hit by a car.

The antelope ground squirrel is able to stretch its scanty water supply because, like the desert rat, it loses a minimal amount of water in the excretion of nitrogenous wastes. On a dry diet this animal can produce urine with a mean concentration of 3,700 milliosmols (the maximum concentration of human urine is about 1,300 milliosmols). The urine of the desert rat is somewhat more concentrated. But the antelope ground squirrel's urine is still 10 times more concentrated than its body fluids. Its ability to turn salty water to physiological use is even more impressive. The desert rat can maintain itself on sea water; the antelope ground squirrel can drink water approximately 1.4 times saltier than sea water and still remain in good health. No other mammal can process water of such high salinity. This capacity is important in the desert, where the little surface water that is available is usually highly mineralized.

The structure of the animal's kidney explains its efficient use of water. As in several other desert mammals, the renal papilla—that part of the kidney which contains the ascending and descending kidney tubules—of the antelope ground squirrel is extremely large, extending as far down as the ureter [*see illustration on page 114*]. In the formation of urine the kidney first extracts a filtrate containing all the constituents of blood except proteins and blood cells. This filtrate is then converted to urine by the selective reabsorption of water and essential solutes in the kidney tubules. The longer the tubules, the greater the amount of water they can absorb and the greater the amount the body retains. As the antelope ground squirrel's tolerance for high body temperatures constitutes its major physiological adaptation to heat, so the efficiency of its kidney embodies its major adaptation to aridity.

Considering the success with which the antelope ground squirrel occupies its narrow desert niche, how does the mohave ground squirrel manage to find a place beside it? The question cannot be fully answered, because less is known about the life history of the mohave ground squirrel. This in itself is significant, because it appears that the mohave ground squirrel manages to persist largely by staying out of the way of the antelope ground squirrel.

Of the two animals the mohave ground squirrel is the bigger and fatter, and it has the temperament that goes with its more generous proportions. Its body length is about six and a half



THERMAL NEUTRAL ZONE is range of external temperatures to which an animal is best adjusted. In it body temperature and metabolism can be held at optimum levels. At critical temperatures (T_C) metabolic rate begins to rise. Lemming is an arctic rodent. Kangaroo rat and ground squirrels are desert dwellers.

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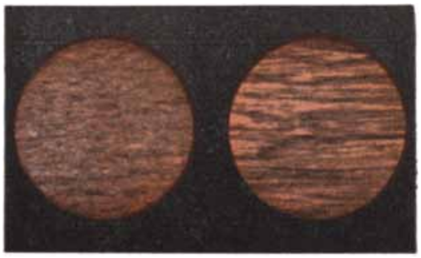

Compare superfine-grain structure of Duraflex, left, to regular phosphor bronze, right.

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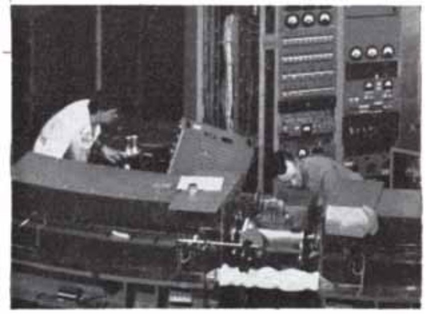
ANACONDA HOLLOW CONDUCTORS ASSIST IN CORNELL ONE-BEV SYNCHROTRON OPERATION



Anaconda hollow copper conductors for Cornell's 1-BEV synchrotron.

Cornell University's one billion electron volt synchrotron—an electron accelerator used for research purposes—employs Anaconda hollow copper conductors to carry heavy current loads through the bias reactor.

Rugged applications like this require heavy-duty conductors, water-cooled for efficient use. Thus, Anaconda produced copper conductors measuring 32-feet by 2-inches by 1-inch, with 1/2-inch diameter hollow cores, for the Cornell synchrotron. The hollow conductors were joined and wound into large coils. Copper cross section was doubled in the coil return section to reduce resistance. For effective cooling, connections were designed that permitted water to be run through the coils in any combination of series or parallel—as required.

Hollow Conductors also serve industrial users

Anaconda supplies a wide variety of hollow conductors in sizes and shapes that complement industrial needs. (See photo.) Fluid-cooled copper components permit compact electrical systems which still can handle high current densities. For example, in ceramic magnet manufacturing, water-cooled windings produce high flux densities needed for compact system operation. In generators, cooling the stator bars can greatly increase output without adding to frame size. Other applications for Anaconda hollow conductors include: nuclear physics magnets, power rectifiers, and induction furnace coils.

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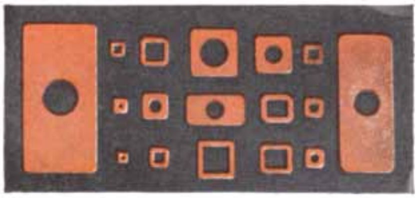

Cross sections of typical hollow conductors.

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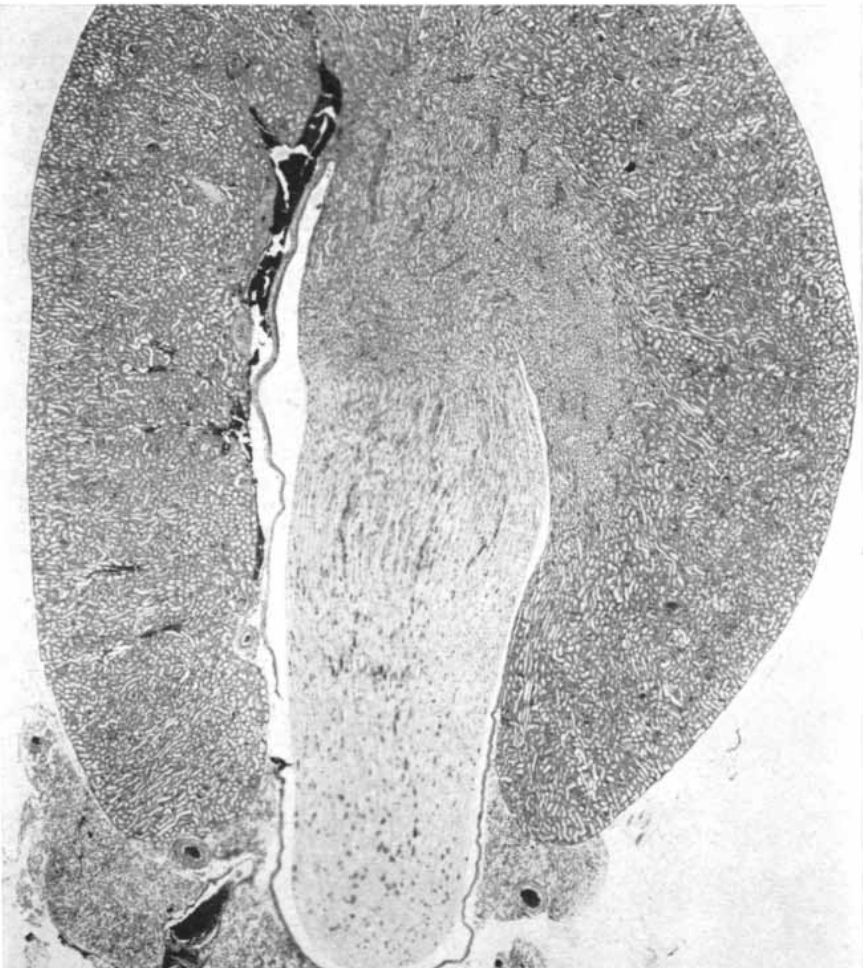
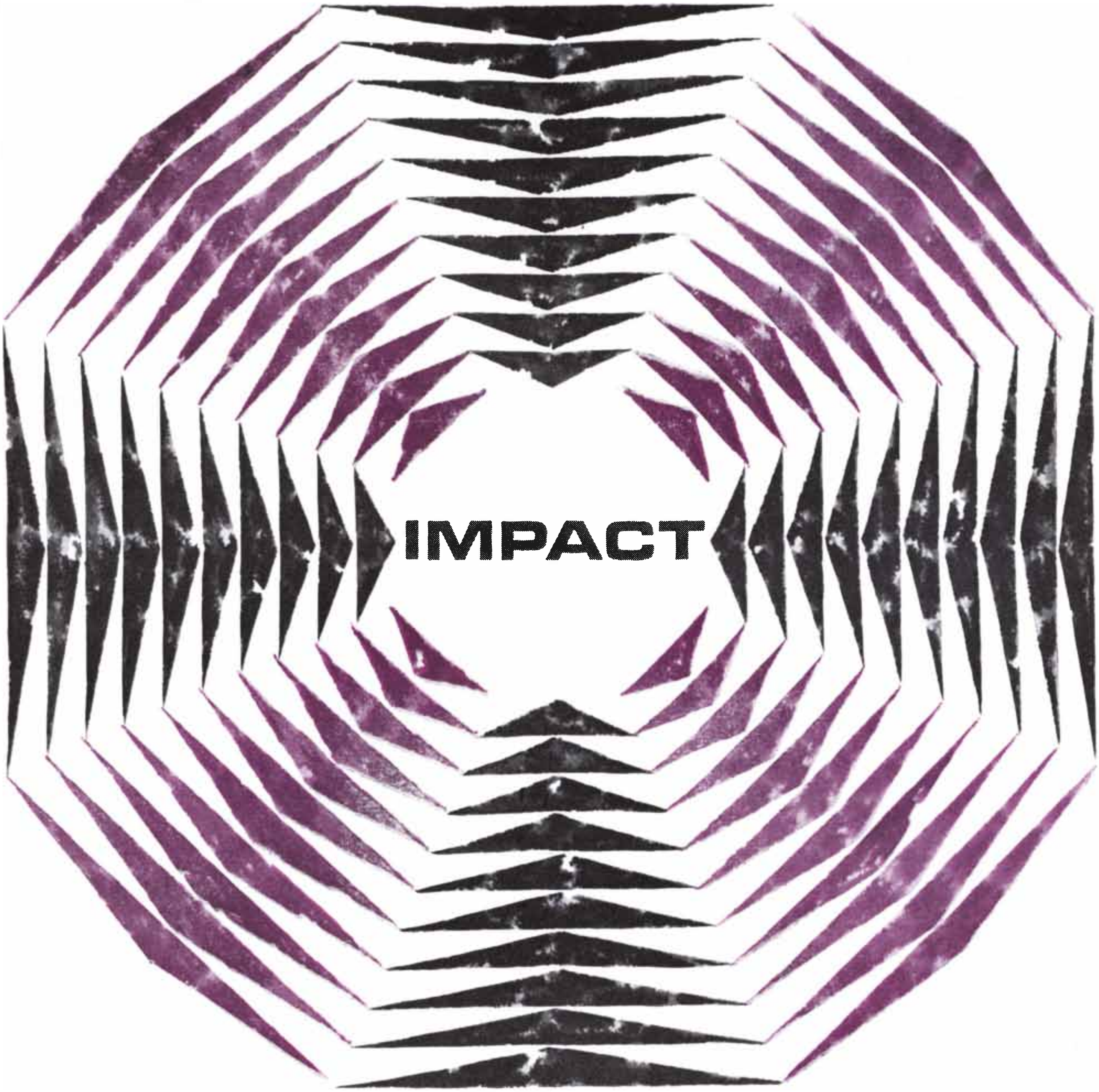
inches; its weight in its natural habitat, about 150 grams. In temperament it is placid, docile and sedentary. This little brown animal seldom wanders far from its home burrow, which it digs in loose sand, generally in the shade of the desert plants that provide it with its food. For more than half the year, from August to March, it remains in its burrow. During the spring months, when the desert vegetation is at its annual peak, the mohave ground squirrel emerges to reproduce and to fatten itself in preparation for its return underground.

The major proportion of the mohave ground squirrel's life is therefore normally concealed from observation. Fortunately it seems to show a comparable pattern of behavior in the laboratory. Here, as in its natural habitat, the animal is active throughout the day from March to August. During the remainder of the year, however, even at room temperature, and in spite of the continuous availability of food and water, it is intermittently torpid for periods lasting from several hours to several days. If food and water are at hand, it will eat and drink in its periods of wakefulness. If they are not, it does not seem to be disturbed. We do not know whether or not in its natural habitat it stores food in its burrow. We do know that it is usually thin in early spring, when it emerges from its burrow, and that it can add as much as 100 grams to its body weight in the period before its retirement underground. We also know that in the laboratory, where the animal becomes exceedingly fat, it loses an appreciable amount of weight during its period of dormancy only if no food and water have been made available to it.

Since this pattern of intermittent dormancy extends from late summer to early spring, it involves what would normally be considered two separate processes—hibernation and the summer dormancy



SECTION OF KIDNEY of antelope ground squirrel is magnified 20 times in this micrograph by Hudson. Mass outlined in white is papilla, containing renal tubules. In this species it is very large. This permits reabsorption of much water and production of concentrated urine.


IMPACT


TUNG-SOL

called estivation. Our studies indicate, however, that in the mohave ground squirrel the two processes are merely aspects of the same physiological phenomenon. From early August to the end of February, whether the temperature in the laboratory is one that would normally be associated with estivation or whether it is one at which hibernation would be expected to occur, the same events take place. As the animal becomes torpid, its oxygen consumption and its body temperature drop sharply. Then both level off, and the body temperature stabilizes at the environmental temperature or very slightly above it. During the time the animal is dormant its torpor is more pronounced than deep sleep, its breathing is suspended for long periods and its heart rate is profoundly reduced. On arousal it restores its body temperature to normal through increases in breathing movements, acceleration of heartbeat, shivering (which releases heat) and increased oxygen consumption. In the laboratory arousal may come about spontaneously or it may be induced by a touch or a sound. In either event it is extremely rapid. Although the animal can take as long as six hours to enter torpor, it can wake in less than one hour. Oxygen consumption can reach its peak in 15 to 20 minutes, and body temperature can rise from 68 to 86 degrees in 20 to 35 minutes.

Such rapid alterations in temperature do not occur during the five-month period in which the mohave ground squirrel is active. Even then, however, its body temperature is remarkably variable and fluctuates over a broad range. We have measured a deep-body temperature as low as 88 degrees in individual animals engaged in normal activity, and yet the animal does not seem to suffer any ill effects from body temperatures as high as 107 degrees. Its thermal neutral zone does not, however, extend as high as that of the antelope ground squirrel. The metabolism of the mohave ground squirrel begins to rise at an environmental temperature of about 98 degrees. Its tolerance for high body temperatures is of major adaptive value in June and July, when the desert is particularly hot.

Obviously the mohave ground squirrel's dormancy serves the function traditionally associated with hibernation: it conserves energy. At an environmental temperature of 68 degrees the oxygen consumption of a dormant mohave ground squirrel is only about a tenth that of the same animal active at the same temperature. Fat is undoubtedly the major energy source. Since the oxidation of one gram of fat requires two liters of oxygen, a simple calculation shows that a torpid squirrel, weighing 300 grams and consuming oxygen at a rate of .08 cubic centimeter per gram per hour, will burn .29 gram of fat a day. Some 50 grams of fat would therefore supply it with all its energy requirements for 172 days; this is just half the fat supply it usually accumulates in the active months of the year. According to this calculation a mohave ground squirrel should be able to remain torpid for a whole year if it did not arouse at all. We do not know, of course, how much its energy requirements are increased by periods of arousal during the months of dormancy. Not being able to observe the animals in their burrows, we do not know how long these periods last. But from laboratory evidence we deduce that the cycles of torpor and wakefulness are repeated every week, with three to five days spent in torpor. The mohave ground squirrel should therefore be able to get along on its accumulated fat.

Energy conservation is not the only function that dormancy serves. Like the antelope ground squirrel, the mohave ground squirrel loses considerable body water in evaporative cooling and, like the antelope ground squirrel, it must have preformed water in its food. The sedentary mohave ground squirrel does not go in search of water; it gets its water almost entirely from the desert plants it eats. During the period the animal is underground this vegetation is in decline and the desert is at its driest. Thus dormancy is an important adaptation to seasonal aridity.

The mohave ground squirrel's seven months of estivation and hibernation serves still another function: it minimizes competition with the more active and abundant antelope ground squirrel. During the time the mohave ground squirrel is aboveground the food and water available are probably adequate to sustain both animals. But during its months of dormancy both food and water are in short supply.

The two animals have adapted well to desert life—the antelope ground squirrel by its tolerance for high body temperatures and the efficiency of its kidney, and the mohave ground squirrel by its avoidance underground of the most rigorous months of the year. One may conclude that these adaptations are sufficiently different to permit the two animals to live in sympatry in spite of Darwin's stern injunction.

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Maxwell's Color Photograph

A hundred years ago the great physicist projected a photograph in full color. How this was done has been something of a puzzle. The mystery has now been cleared up by repeating his experiment

by Ralph M. Evans

In 1861 the great British physicist James Clerk Maxwell exhibited the world's first trichromatic color photograph during a lecture before the Royal Institution in London. Using separate projectors, he superposed three images produced by photographing a colored ribbon separately through red, green and blue filters. Each image was projected in the color in which it had been photographed. It appears that Maxwell invoked photography to demonstrate that a full spectrum of colors could be produced by using light of just three colors, which would support the trichromatic theory of color vision put forward by Thomas Young around 1800. It also seems he wished to prove that the appropriate colors for such a demonstration were red, blue and green, not red, blue and yellow (as a number of investigators then believed). Maxwell suggested that the images on his photographs represented "the red, the green, and the blue parts [of the colored ribbon] separately, as they would be seen by each of Young's three sets of nerves separately."

There is one puzzling thing about Maxwell's demonstration: it should not have worked. It is quite certain that the photographic emulsions available to Maxwell in 1861 were sensitive only to the extreme blue end of the spectrum and not sensitive at all to spectral green, yellow and red. How, then, did Maxwell get the "green" and "red" separation images (actually black and white positive transparencies) to put in his "green" and "red" projectors?

There is no doubt that Maxwell's demonstration was successful enough to delight and impress his audience. Maxwell's own account, confirmed by others, is that "when these [projected separation positives] were superposed, a coloured image was seen, which, if the red and green images had been as fully photographed as the blue, would have been a truly-coloured image of the ribbon." Thereby Maxwell acknowledged some deficiency in the red and green images, but a later generation of photographic experts was left mystified as to how he could obtain any red and green images at all. Recently my associates and I at the Color Technology Division of Eastman Kodak reproduced Maxwell's experiment according to the records of the day, and we believe we can account for the images that, in principle, it should not have been possible to make.

The photographic details of the experiment were recorded not by Maxwell but by Thomas Sutton, a teacher and lecturer on photography to whom Maxwell turned for technical assistance in preparing the lecture. During his career Sutton was, for a period, editor of a lively publication called *Photographic Notes,* and he later designed a wide-angle lens that was remarkable for its time.

Sutton's subject was "a bow made of ribbon, striped with various colours," which he placed on a background of black velvet and photographed in bright sunlight. The photographic emulsion used by Sutton was wet collodion incorporating silver iodide as the sensitive material. Silver iodide is sensitive only to radiation having a wavelength shorter than about 430 millimicrons, a wavelength that lies in the extreme blue region of the visible spectrum. The normal eye is sensitive to radiation lying between 400 and 700 millimicrons. The color (more properly the hue) we recognize as green lies roughly between 480 and 560 millimicrons, yellow between 560 and 590, orange between 590 and 630, and red beyond 630. To all these wavelengths silver iodide is insensitive.

For red, green and blue filters Sutton used glass cells filled with colored solutions of metallic salts; for a yellow filter he used a piece of "lemon-coloured glass." We cannot identify the yellow glass, but its exact nature is not crucial to the experiment. Sutton's own description of his filters and exposures is as follows:

"1st. A plate-glass bath, containing the ammoniacal sulphate of copper which chemists use for the blue solution in the bottles in their windows, was first placed immediately in front of the lens. With an exposure of six seconds a perfect negative was obtained. This exposure was about double that required when the coloured solution was removed.

"2nd. A similar bath was used, containing a green solution of chloride of copper. With an exposure of twelve *minutes* not the slightest trace of a negative was obtained, although the image was clearly visible upon the ground glass. It was therefore found advisable to dilute the solution considerably; and by doing this, and making the green tinge of the water *very* much paler, a tolerable negative was eventually obtained in twelve minutes.

"3rd. A sheet of lemon-coloured glass was next placed in front of the lens, and a good negative obtained with an exposure of two minutes.

"4th. A plate-glass bath, similar to the others, and containing a strong red solution of sulphocyanide of iron was next used, and a good negative obtained with an exposure of eight minutes.

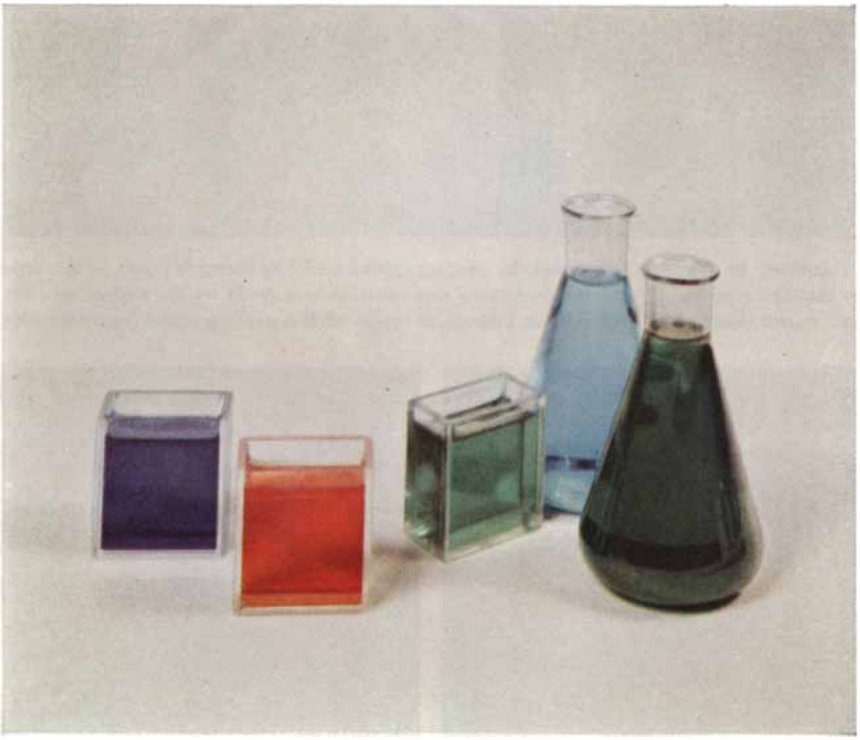
"The thickness of fluid through which the light had to pass was about three-quarters of an inch.

"The negatives taken in the manner described were printed by the Tannin process upon glass, and exhibited as transparencies. The picture taken

FIRST THREE-COLOR PHOTOGRAPH was exhibited in 1861 by James Clerk Maxwell. He projected in register through separate red, green and blue filters black and white transparencies that had been made by photographing a ribbon through filters of the same three colors. This reproduction was made by the author on Ektacolor Print Film from copies of Maxwell's original transparencies.

MAXWELL'S SEPARATION POSITIVES look like this when printed in blue, green and red ink to simulate light of the color in which they were originally projected. The photographs were made at Maxwell's request by Thomas Sutton, a writer and lecturer on photography. For filters Sutton used solutions of metallic salts: ammoniated cupric sulfate for blue, cupric chloride for green and ferric thiocyanate for red (*see bottom illustration on next page*). Unbeknown to Sutton, his photographic emulsion was insensitive to green and red light. How he was able, nevertheless, to obtain "green" and "red" separation negatives is explained in the text.

MAXWELL TYPE OF COLOR PHOTOGRAPH was made by the author with interference filters to simulate the liquid filters used by Sutton. The author's film, like Sutton's, was sensitive only to the extreme blue end of the spectrum. The black and white separation negatives obtained with this film were printed, through color filters, on Ektacolor Print Film.



SUTTON'S FILTERS were solutions of metallic salts in glass cells. For blue he used ammoniated cupric sulfate (*far left*), for red, ferric thiocyanate (*second from left*), and for green, cupric chloride (*remaining samples*). The solutions in the cells represent the concentrations used by Sutton. The two flasks show how cupric chloride shifts to bluish-green on dilution. For transmission characteristics of Sutton's filters see top illustration on page 122.

through the red medium was at the lecture illuminated by red light, that through the blue medium by blue light, that through the yellow medium by yellow light, and that through the green medium by green light; and when these different coloured images were superposed upon the screen a sort of photograph of the striped ribbon was produced in the natural colours."

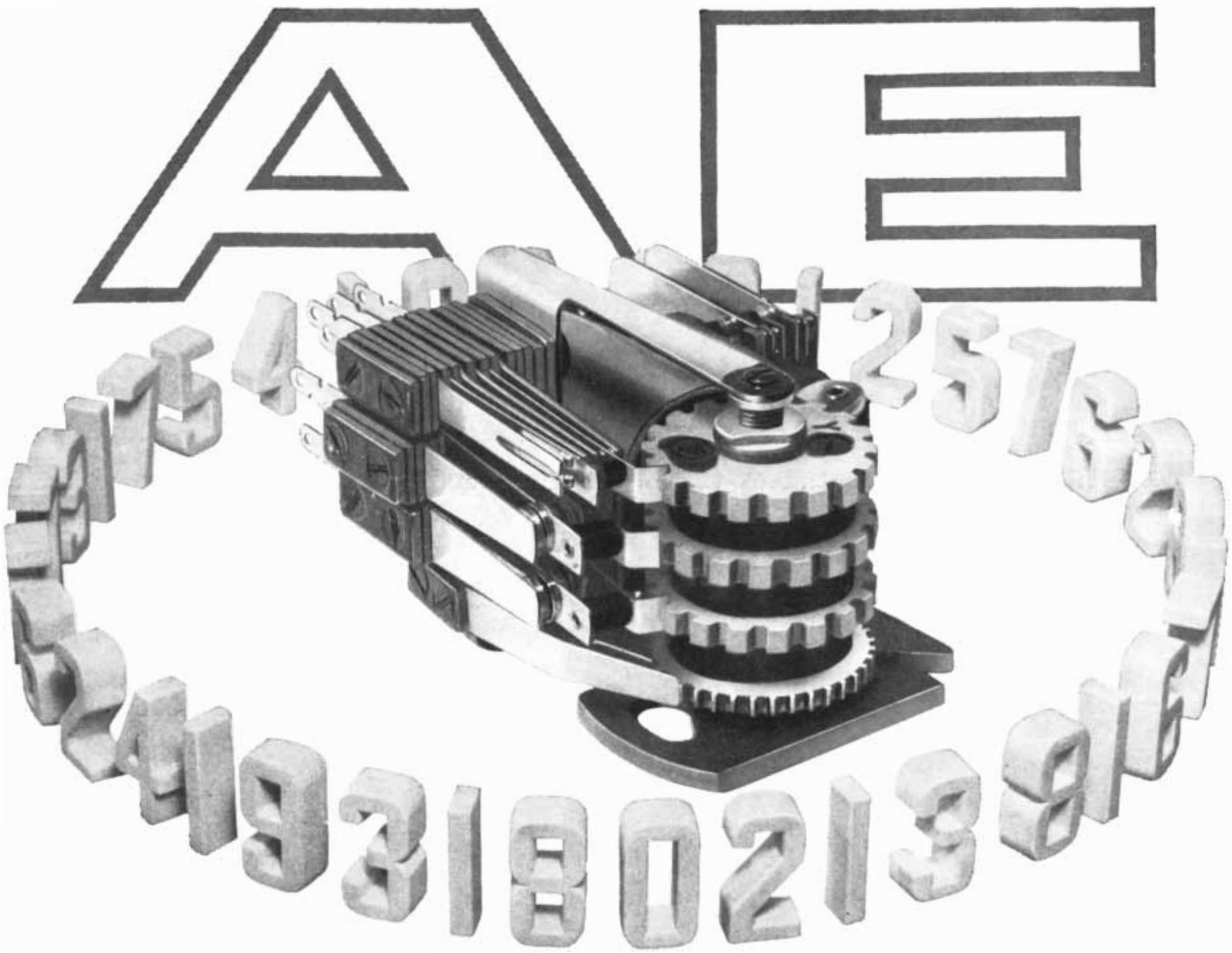
In spite of Sutton's statement it is quite clear from other sources that the positive from the yellow filter was *not* used by Maxwell at his lecture. In fact, in a separate demonstration he used colored lights to show how red and green combine to create yellow.

In 1940 Douglas A. Spencer of Kodak Limited reported that the original positives used by Maxwell were still in existence at the Cavendish Laboratory of the University of Cambridge. Spencer borrowed these positives and published a color reproduction showing how the projected picture might have appeared to those attending Maxwell's lecture. In this reproduction one can see reds, greens, blues and purples, and the background is distinctly green.

In pursuing the problem we were able to obtain another set of copy positives through the courtesy of Spencer, the Cavendish Laboratory and Kodak Limited. A new color reproduction made from these positives appears at the top of the preceding page. Considering that the original emulsions were sensitive only to blue, it is rather curious that blue does not emerge very prominently in the picture. Since the original colors of the ribbon are unknown one cannot say whether the low content of blue is an artifact or not.

It seemed that the best way to solve the mystery of the red and green images would be to attempt to repeat Sutton's procedure. To do this it was desirable (though not essential) to have a photographic material with the same sensitivity as that used by Sutton. A material with a sensitivity cutoff at about 430 millimicrons was specially made for the experiment by my colleague Burt H. Carroll of the Kodak Research Laboratories.

The new emulsion was of course much "faster" than that used by Sutton, but this presented no difficulty. The problem was to re-create, in proper strength, the chemical solutions that Sutton had used as filters. His account does not describe their concentration. Nevertheless, he provided the one essential clue needed when he stated that with the blue



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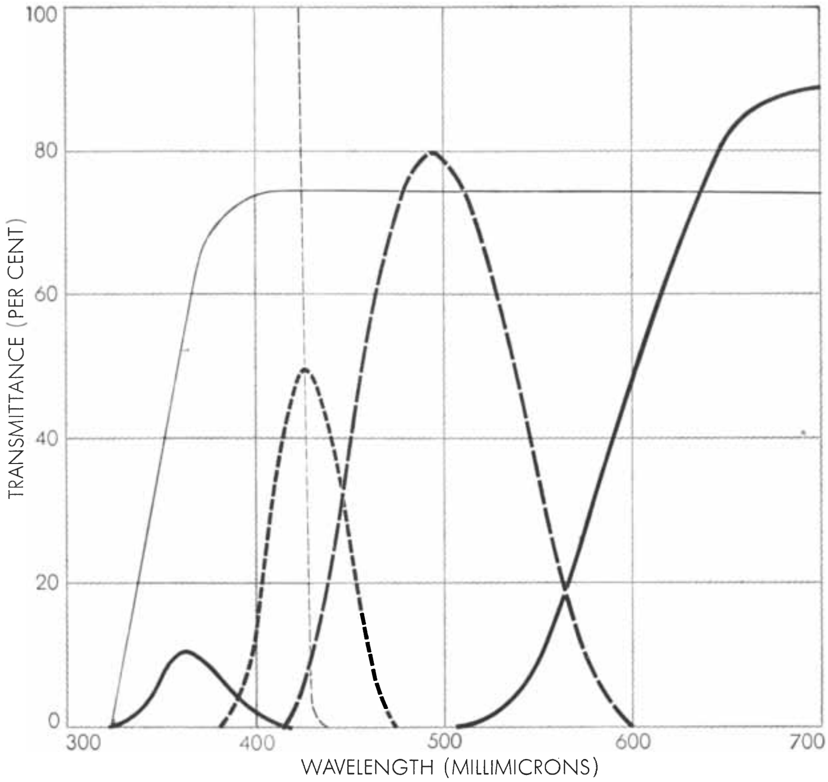
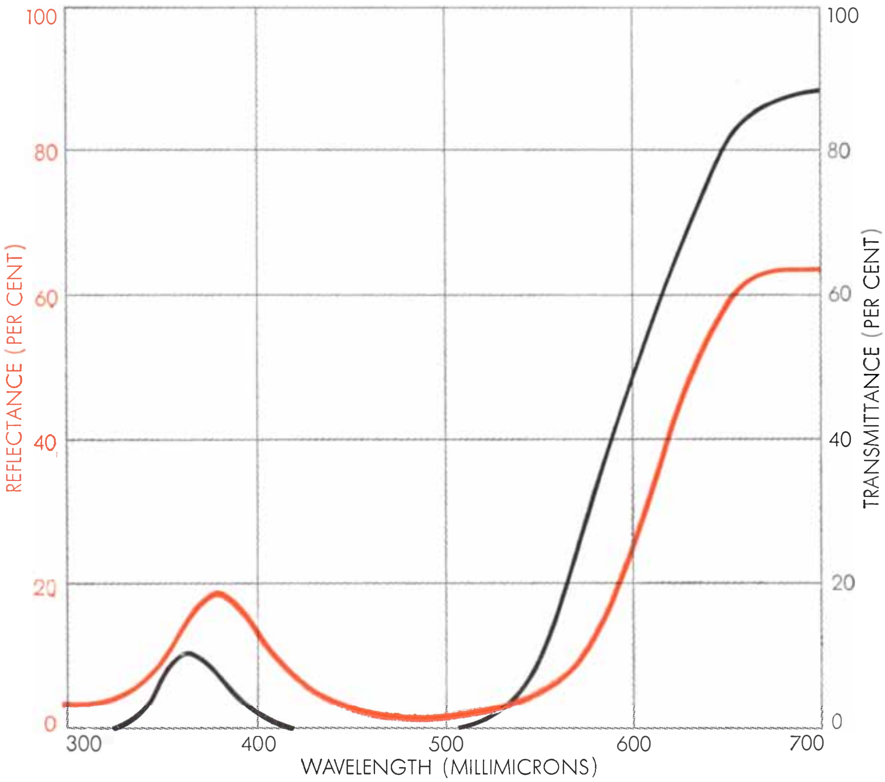


SPECTRAL SENSITIVITY of Sutton's photographic plates was limited entirely to wavelengths below 430 millimicrons. The shaded area, defined in part by the transmissivity of the lens, shows the wavelengths that could affect Sutton's plates. His filters passed varying amounts of these wavelengths ranging from ultraviolet to blue.



SPECTRAL ANALYSIS OF RED CLOTH used in the still life on page 120 shows that it reflects a sizable amount of ultraviolet light at around 380 millimicrons. It was presumably light of this wavelength, not red light, that Sutton recorded through his red filter.

liquid filter the exposure was twice what it was without any filter: six seconds compared with three seconds.

Accordingly we made up solutions of different concentrations, using the same metallic salts that Sutton had used, until our exposures for red, green and blue were in the same ratio as Sutton's exposures. To produce the "blue" image the concentration of ammoniated cupric sulfate ("ammoniacal sulphate of copper") was adjusted until a picture taken through a three-quarter-inch cell of the solution produced a "perfect" negative when the exposure was twice what it was when no filter was used. To produce the green image the concentration of cupric chloride was decreased until a "tolerable negative was eventually obtained" at an exposure 120 times that with the blue filter. The dilution was so great that the solution no longer looked deep green but was bluish-green. Chemists have long known that the color of cupric chloride changes in this way as the solution is diluted. Finally we prepared a red filter from ferric thiocyanate ("sulphocyanide of iron") that produced a "good negative" with an exposure 80 times that with the blue filter.

When we used these filters to photograph a still life containing a variety of colored fabrics and projected the individual black-and-white positive transparencies through colored filters, as Maxwell did, the resulting picture was a surprisingly colorful reproduction of the original scene. It is true that some of the hues were considerably shifted in quality; nevertheless, we were able to obtain blues, greens, yellows, reds and purples. If desired, the separation negatives (or positives) can be printed on standard color film to create a color transparency. Such a transparency is reproduced at the top of page 120. In this case the separation negatives were made with interference filters that simulated the effect of Sutton's liquid filters.

Now for the explanation. It is clear that our film, like Sutton's, was sensitive only to extreme blue and ultraviolet. The fact that images were obtained not only with the blue filter but also with the green and red filters indicates that all the solutions transmitted light of wavelengths shorter than 430 millimicrons. In other words, the only radiation acting on the emulsion was light in the extreme blue end of the visible spectrum and still shorter wavelengths of invisible radiation extending into the ultraviolet. Our lens, which was much like Sutton's, transmitted ultraviolet out to about 325 millimicrons. The

A MANAGEMENT REPORT FROM MR. RICHARD A. WILSON, CORPORATE VICE PRESIDENT AND GENERAL MANAGER, ELECTRONICS GROUP

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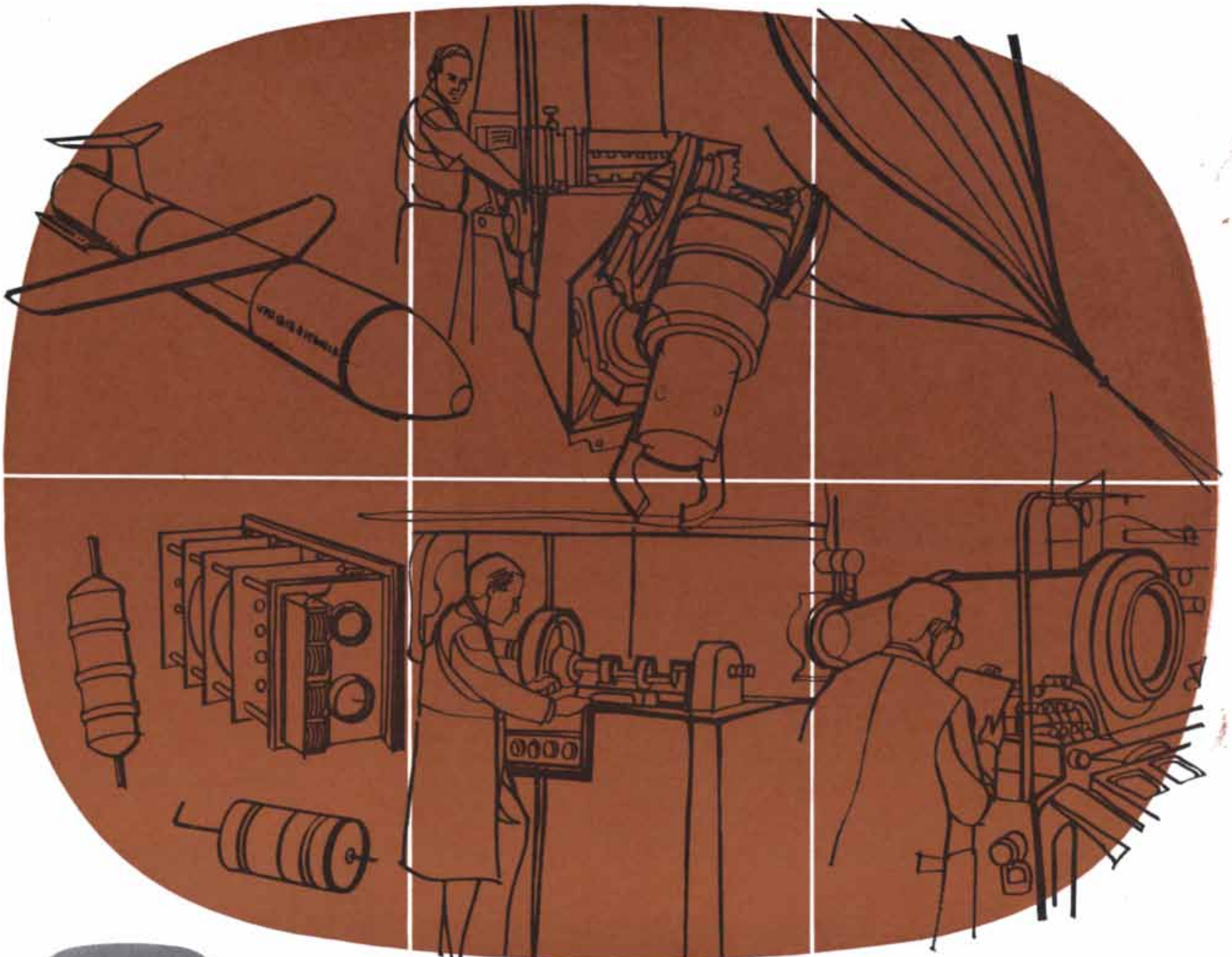

General Mills

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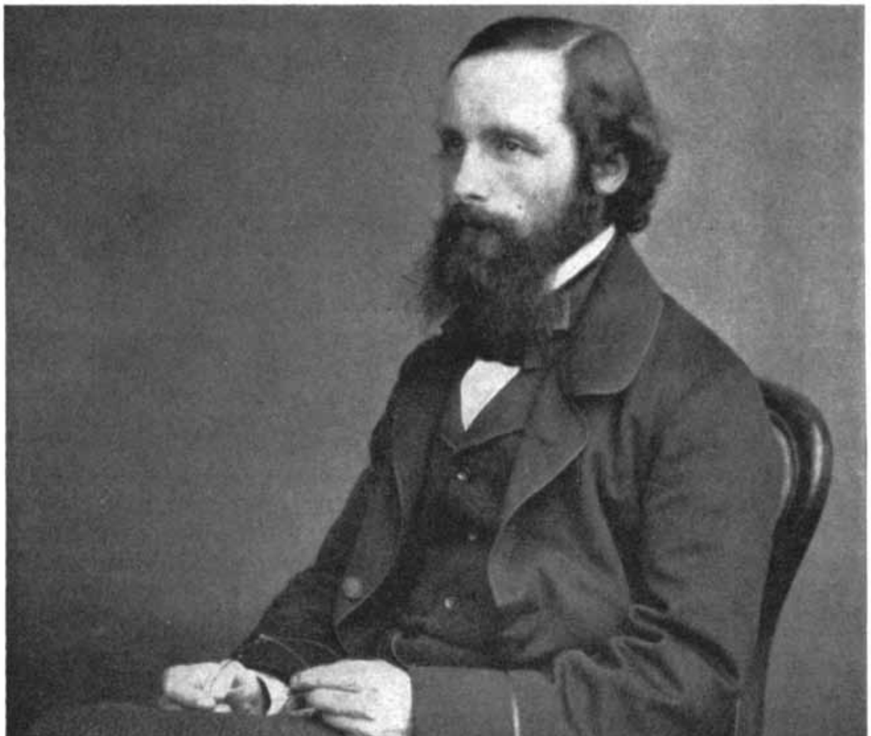
1620 Central Avenue, Minneapolis 13, Minnesota wavelengths transmitted by the lens and the three solutions, as diluted, are shown in the spectrophotometric curves at the top of page 122.

It is at once apparent that the three filters rather neatly divide the blue and ultraviolet regions of the spectrum into three distinct bands, although the green is contained within the blue. Quite by chance the filters Sutton selected to divide the visible spectrum act also as separation filters for a relatively narrow wedge of short-wavelength light. It must be remembered in looking at these curves that the green exposure was 120 times and the red 80 times the blue exposure. The curves have not been multiplied by these factors.

One can now see how blues can be separated from other colors and how a good green could be separated from blue. But offhand it would seem that anything colored red would not register at all. As it happens, many red dyes reflect not only the wavelength we see as red but also a good deal of ultraviolet light [*see bottom illustration on page 122*]. As a result a red object can produce a strong image on the "red" plate not because it is red but because it is more ultraviolet than objects that to our eyes look blue and green. We do not know, of course, what red dyes were actually used in the ribbon photographed by Sutton. Moreover, there is no record of the actual colors of the original ribbon; hence we cannot be sure that the areas of the ribbon that registered most strongly on Sutton's red plate were actually red and not some other color with a high reflectivity in the ultraviolet. It seems unlikely, however, that Maxwell would have shown the photograph if the reds had not been in the right place. If so, they were created by an ultraviolet-red dye in the ribbon—a happy accident that neither Maxwell nor Sutton could have foreseen.

One can conclude from an examination of Maxwell's positives that a number of other forces were at work to add color to his projected picture, in addition to the fact that the filters achieved a separation in wavelength. In the first place the "tolerable" green negative was badly underexposed. In the second place the range of contrast in the three negatives is quite different. The



JAMES CLERK MAXWELL, who lived from 1831 to 1879, was the leading color authority of his day. In his lecture before the Royal Institution in 1861 he invoked photography to support the trichromatic theory of color vision proposed by Thomas Young around 1800.

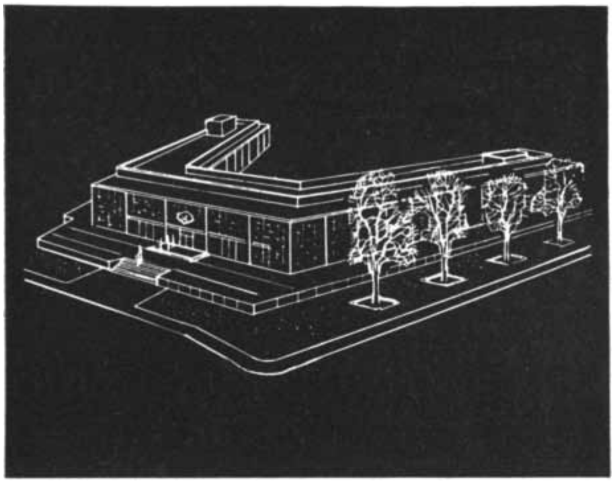
net effect of these technical shortcomings would be to add colors not actually present in the original. For example, the black velvet background may have looked green in the picture as Maxwell projected it.

Moreover, Maxwell's positives, still at the Cavendish Laboratory, are quite yellow. If they were yellow at the time of the 1861 lecture, a still further variation of contrast—and hence of color—would have been introduced. We cannot be certain of the light sources in Maxwell's "magic lanterns," but the typical magic lantern of the day was the famous limelight, in which a block of calcium carbonate was heated to incandescence by an oxyhydrogen flame. Being very hot, such lights are much bluer than the incandescent lamps used today in home projectors. It is also possible that Maxwell's projectors contained electric carbon arcs, which would have produced a light even hotter and bluer than limelight. In either case the yellow color of the positives would have made the picture that was projected through the blue filter much more contrasty than the one projected through the red. The one projected through the green filter would have been of intermediate contrast.

The effects obtained were not all due to contrast and density mismatches, however. The existence of true color separation among the red, green and blue pictures can be demonstrated by superposing the negative of one image, say the red one, over the green or blue positive. If one uses negatives of various contrasts, it should be possible to "blank out" a positive if negative and positive are really alike. But no combination of negatives made from the Maxwell positives will result in such blanking out. There is less separation between the green and blue than between the blue and red, as we would expect. Somewhat ironically, considering Maxwell's main thesis, the yellow-filter negative was essentially the same as the green, and probably could have been substituted for it with little change in the result.

Although our interpretation of Maxwell's experiment seemed plausible, a lingering doubt remained. Was it possible that Sutton's collodion plates might have had some trace of red and green sensitivity? It is now known that under certain unusual circumstances such sensitivities can occur even without using sensitizing dyes, which were not discovered until 1874.

These doubts were happily dispelled by a discovery we made one day when we were studying the copies of the Maxwell transparencies. In making the pho-



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To carry out synthetic organic chemistry studies to provide new compounds of potential therapeutic interest. Must have Ph.D. degree and a minimum of 1-2 years' synthetic organic chemistry experience.

RESEARCH PHARMACOLOGIST

Will supervise administration of new drugs to animals for determination of acute LD 50's and to observe gross pharmacological effects. Additional responsibilities will include carrying out chronic toxicological studies on new compounds of interest. Must possess a Ph.D. degree and previous toxicological experience.

RESEARCH BIOCHEMIST

To carry out studies on metabolic effect and fate of new drugs. Applicants should possess a recent Ph.D. degree and some experience in drug metabolism research.

RESEARCH BIOCHEMIST

Will be responsible for organizing and conducting a research program in protein chemistry, enzyme chemistry, metabolic chemistry, analytical biochemistry, or physical biochemistry. Should possess Ph.D. in biochemistry, microbiology or biology plus previous hospital or pharmaceutical research experience.

ASSISTANT RESEARCH PHARMACOLOGIST

To conduct studies in screening new drugs and assisting in complete pharmacological evaluation. Should possess a B.S. in pre med with graduate work in physiology or pharmacology.

ASSISTANT RESEARCH BIOCHEMIST

Will be responsible for carrying out clinical chemical investigations in connection with laboratory evaluations of new drugs. Should possess a B.S. in chemistry or biology plus experience as a medical technologist.

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tograph Sutton had used "a portrait lens of full aperture." This could only have been a Petzval lens, and this lens did not cover the plate used; that is, the image formed was confined to a circle of somewhat smaller area than the plate. We noticed that the diameters of these circles were not all equal. The blue positive had the smallest diameter, the green a larger diameter and the red the largest. It was apparent that Sutton had refocused for each color of light and that for red light the lens had been farthest from the plate.

This immediately explained something else that had been rather baffling: the red image was by far the least sharp of the three images. Sutton had focused his camera for visual red light but had photographed by invisible ultraviolet.

The pieces of the puzzle thus all fit together nicely. But we are still left mystified on a crucial point. It seems strange that Maxwell, one of the leading authorities on color of his day, could have been unaware of the fact that wet collodion plates were not sensitive to green and red. Yet we are forced to believe that this is so. He would hardly have suggested the demonstration had he known it. And Sutton certainly did not know of the lack of sensitivity to green. In fact, he considered this an important discovery growing out of the experiment. He wrote: "We now see why it is so difficult to reproduce by photography the details of green objects in shadow.... The photographer who turns his camera towards a view in which the foliage is not well lighted, must not therefore be disappointed if, instead of masses of fine detail, he discovers in his negative hideous patches of clear glass."

Collodion emulsions had been discovered only 10 or 12 years earlier and were so much more sensitive than any previous photographic materials that perhaps it was assumed they had *some* sensitivity to all wavelengths even though obviously much less for the long wavelengths than for the short. Spectrophotometry was certainly not developed to the point where Maxwell and Sutton could possibly have guessed the true explanation of their results.

Be that as it may, the principle devised by Maxwell and put into practice by Sutton was a valid one for producing a color photograph. And because of the fortuitous circumstances we have described, the experiment worked, allowing Maxwell to invent three-color photography almost 15 years before there were sensitizing dyes that would have made his experiment "possible."

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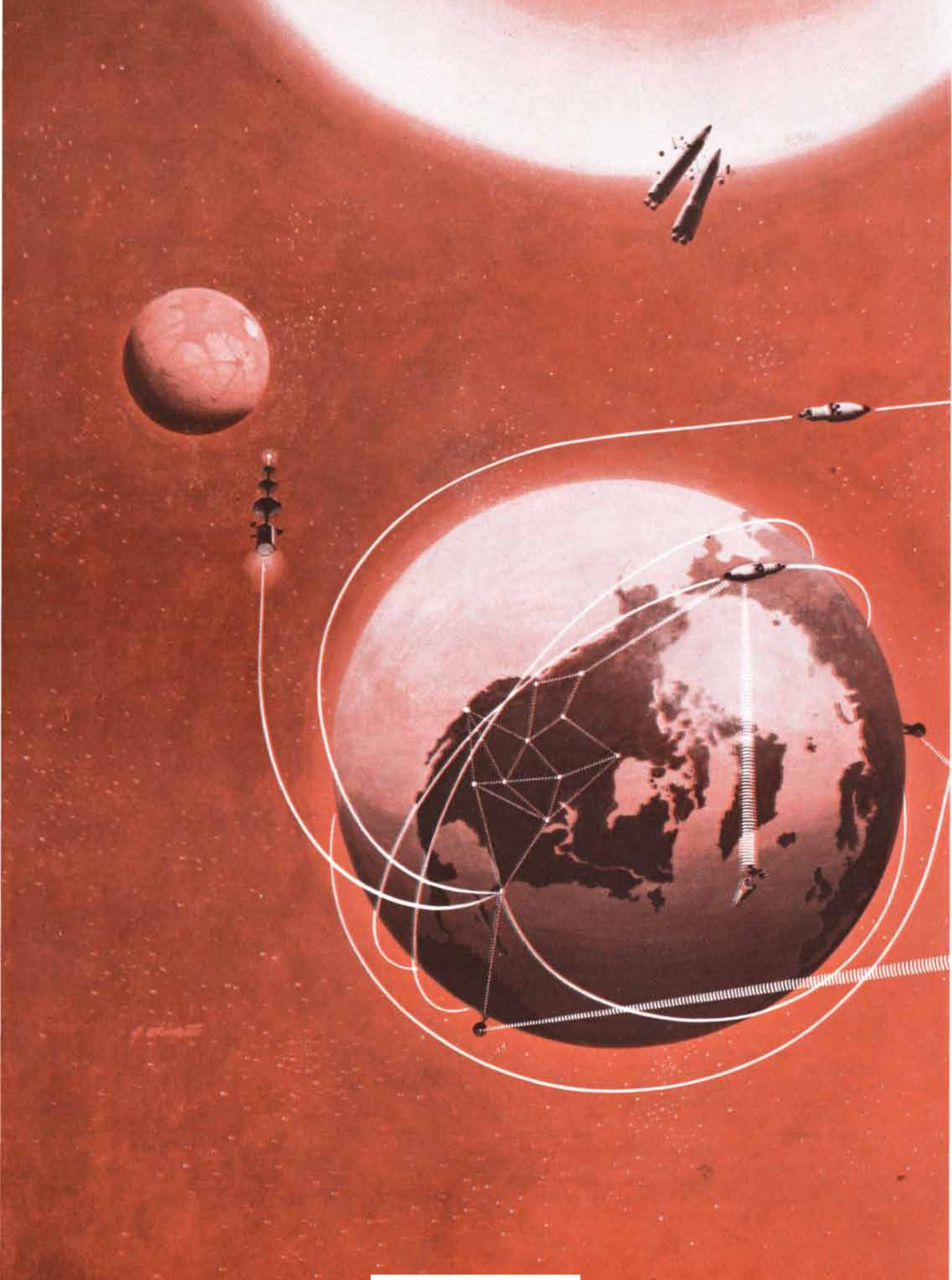

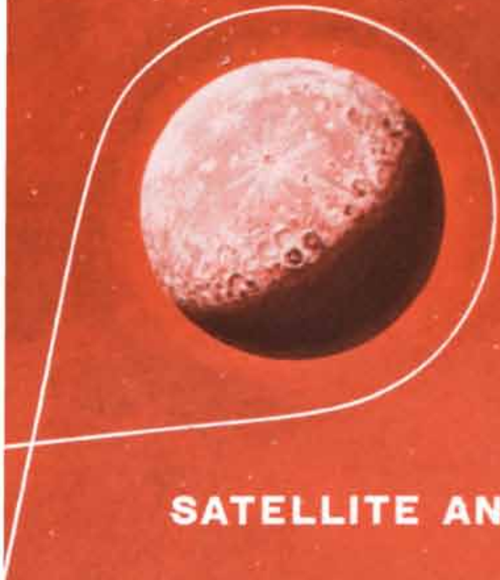

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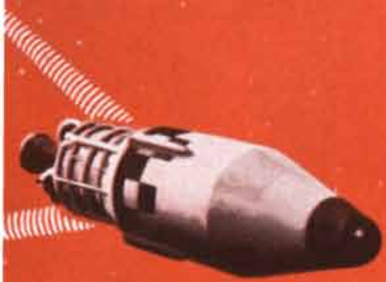

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THE ELECTROCARDIOGRAM

For 60 years physicians have used this record of the electrical activity of the heart for diagnosis. New investigations show how it is related to the electrical events that co-ordinate the heart

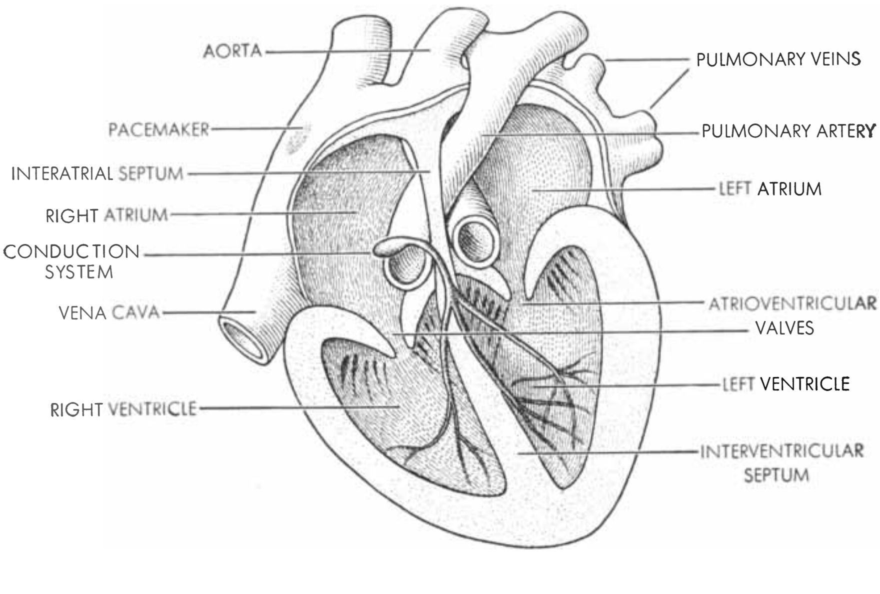
by Allen M. Scher

For more than half a century physicians have been recording variations in electrical potential on the surface of the body and using them to make increasingly complete and reliable diagnoses of conditions of the heart. As often happens in medicine, practice has moved ahead faster than research. Physicians can read electrocardiograms with confidence because thousands of these records have been correlated with other findings in the clinic and in autopsy. In the past this fund of empirical knowledge has concealed a meager understanding of electrical activity inside the heart.

Now, it appears, understanding has begun to overtake practice. Several groups of investigators using, among other ingenious techniques, electrodes fine enough to measure potentials inside a single cell have arrived at an electrochemical explanation for the function of both nerve and muscle [see "How Cells Communicate," by Bernhard Katz; Scientific American, September]. In our laboratory at the University of Washington School of Medicine we have developed a fine multitip extracellular electrode with which we have been observing electrical events within the muscle of the heart. Our studies are tracing the pathway of the wave of electrical excitation that controls and co-ordinates the rhythmic contractions of heart muscle. What contribution such direct study of cardiac potentials can make to diagnostic electrocardiography is not yet clear. But it considerably enhances the picture of the physiological events that give rise to the electrocardiogram.

During the recording of a conventional electrocardiogram the body acts as a volume conductor, as though it were a container of salt solution. Such a conductor extends the potential field around a current source in a manner analogous to the extension of a magnetic field around a magnet. Just as a piece of iron that is not in direct contact with the magnet is attracted or repelled by the proximity of a magnetic pole, so distant recording electrodes, affixed to the skin with a conducting paste, respond to the potential field set up by the action of the heart. A typical electrocardiogram shows a characteristic potential change in time. The various waves are known respectively as the P wave, the QRS complex and the T wave, after the designations given them near the turn of the century by Willem Einthoven, the Dutch physician who devised a galvanometer sensitive enough to permit routine recording of the electrocardiogram.

The onset of the P wave closely follows the firing of the pacemaker, a knot of highly specialized muscle cells that sets the rhythm of the heart. The P wave is produced by the movement of a wave of electrical activity through the auricles, or atria: the two thin-walled chambers at the top of the heart. A single mass of muscle forms the outer walls of these chambers, and the inner space is partitioned by a sheet of muscle called the interatrial septum. Electrical activity always precedes mechanical contraction, and almost immediately after the wave of electrical activity moves through a portion of atrial muscle, the muscle contracts. During contraction the blood contained in the atria flows into the ventricles: the lower chambers of the heart.



INTERIOR OF HUMAN HEART is shown in this cutaway diagram. Anatomical features mentioned in the article are labeled. Conduction system consists of specialized muscle.

From the right atrium oxygen-poor venous blood flows into the right ventricle; simultaneously from the left atrium oxygen-rich blood from the lungs moves into the left ventricle. The atria are separated from the ventricles by a ring of electrically inert connective tissue that contains the atrioventricular valves.

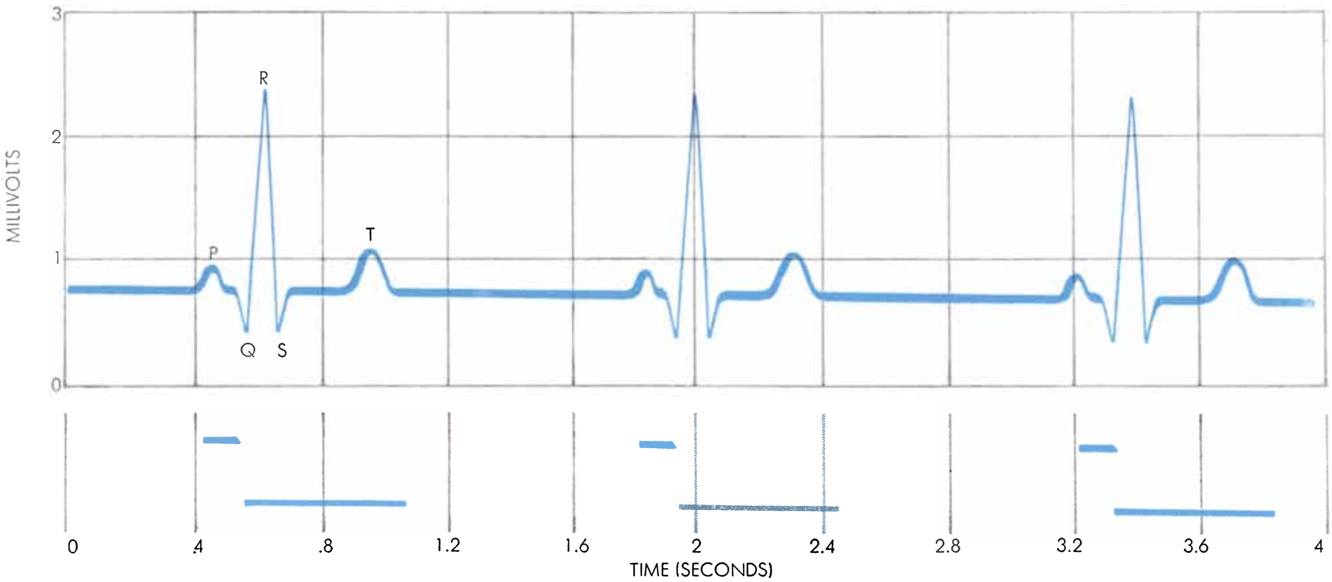
After the P wave there intervenes a pause of 80 milliseconds. During this interval the atrioventricular node and the attached conducting bundles, which furnish the only electrical connection between the upper and lower chambers of the heart, carry the wave of excitation to the ventricles. The electrocardiogram now records the QRS complex. This is produced by the electrical activity of the massive muscles of the ventricular walls and of the interventricular septum. This electrical activity leads to contraction of the two ventricles; the right ventricle discharges venous blood into the pulmonary artery and the left ventricle discharges arterial blood into the aorta for distribution to the systemic arteries. Then follows the T wave, which marks the recovery of the ventricles for the next cycle.

The potential changes recorded by the electrocardiogram represent the summation of the electrical activity of thousands of individual cardiac-muscle cells. As in all muscle cells, the contraction of these cells is initiated by potential changes that occur across the cell membrane. Between the interior of the resting cell and its external environment there is a difference in electrical potential that is set up by a difference in the concentration of ions in the interior of the cell and in the fluids that bathe the cells. Inside the cell the concentration of sodium is low and that of potassium high with respect to the concentrations of these ions outside. A chemical "pump" somehow maintains the concentration gradients and a consequent potential of 80 millivolts across the membrane of the resting cell; the inside of the cell is negative with respect to the outside [see "How Things Get into Cells," by Heinz Holter; SCIENTIFIC AMERICAN, September]. When a cell goes into the active, or depolarized, state, there is a rush of ions across the membrane and the inside now becomes about 30 millivolts positive with respect to the outside. How this "depolarization" of the membrane triggers mechanical contraction remains unexplained.

When any cell in the heart depolarizes, current flows into it from adjacent cells. The current flow lowers the resting potential of adjacent cells, and these cells thereupon depolarize explosively. Thus, like a flame sweeping through gunpowder, a wave of excitation sweeps through the entire mass of muscle. Excitable cells, unlike grains of gunpowder, spontaneously return to the polarized resting condition and are ready to become active again. Nerve cells spend less than .001 second in the depolarized state after firing. Heart cells are comparatively slow to recover; they remain in the depolarized state for a quarter of a second to half a second before returning to the polarized, resting and relaxed state.

From the point of view of the recording electrode of an electrocardiograph each segment of heart muscle acts as if it were a large single cell. A resting cell —and resting tissue—induces no potential at the electrode. Generally speaking, the influence that an aggregation of charges exerts on an electrode is a function of the distance to the electrode. The positive charges on the outer surface of the membrane closer to the electrode obviously exert a larger influence than do the negative charges on the inner surface of the same portion of membrane. But the negative charges on the inner surface of the membrane on the opposite side of the cell are closer to the electrode than the positive charges on the outer surface of this portion of membrane. The positive and negative charges in resting tissue therefore cancel each other.

The movement of a wave of activity through heart tissue causes potential changes at the electrodes. As the wave of activity starts, an electrode near its origin registers a negative potential representing the combined influence of the negative charges accumulating outside the depolarized muscle cells closest to it and the negative charges inside the cells in the still-resting tissue beyond. Conversely, an electrode near the termina-



NORMAL ELECTROCARDIOGRAM shows well-defined P wave, which brings on contraction of atria, followed by QRS complex, which causes contraction of ventricles. Colored lines on time scale show duration of atrial and ventricular contractions respectively.

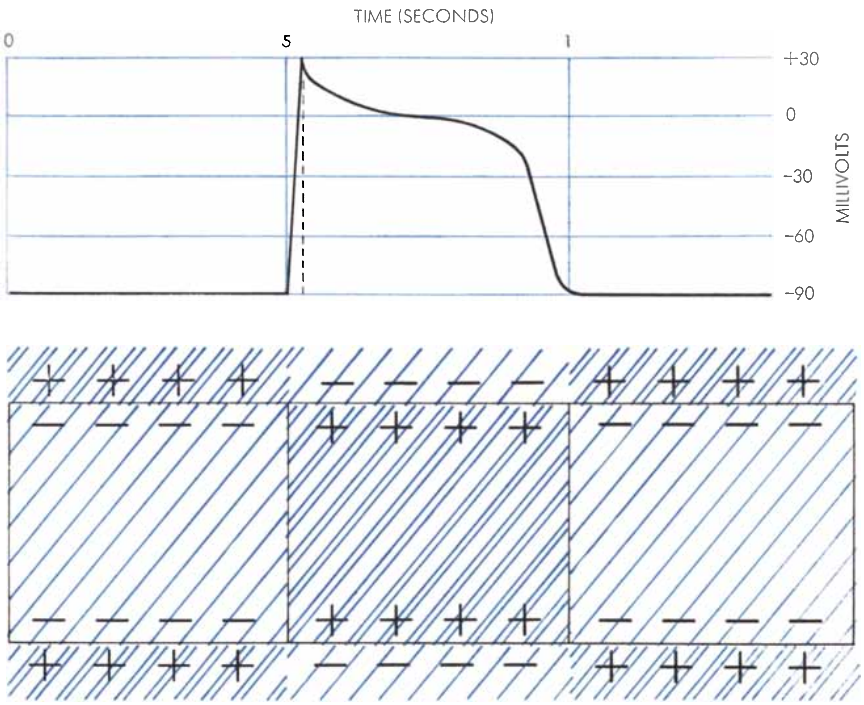
tion of activity registers a positive potential set up by positive charges outside the cells of the resting tissue closer to it and the positive charges inside the more distant cells that have been fired by the approaching wave. An electrode affixed to the skin or planted directly in the heart thus "sees" the movement of a wave of activity as a sequence of potential changes. It records receding activity as a negative potential and approaching activity as a positive potential [*see illustrations on opposite page*]. From the shape of the potential recorded at any given point on the body, therefore, one may determine the direction in which the wave of activity traveled through the heart with respect to that point.

The electrocardiograph, like any other electrical amplifier, has two input electrodes. Its output is a record of the difference in potential between them. For many records it is necessary to null one of the two inputs, to make it effectively indifferent to potential change. This is accomplished by a network that connects electrodes placed at three extremities of the body to a single side of the input amplifier. The potentials at these three sites are thereby averaged to approximate a zero potential to which the positive or negative change recorded by the active input can be compared.

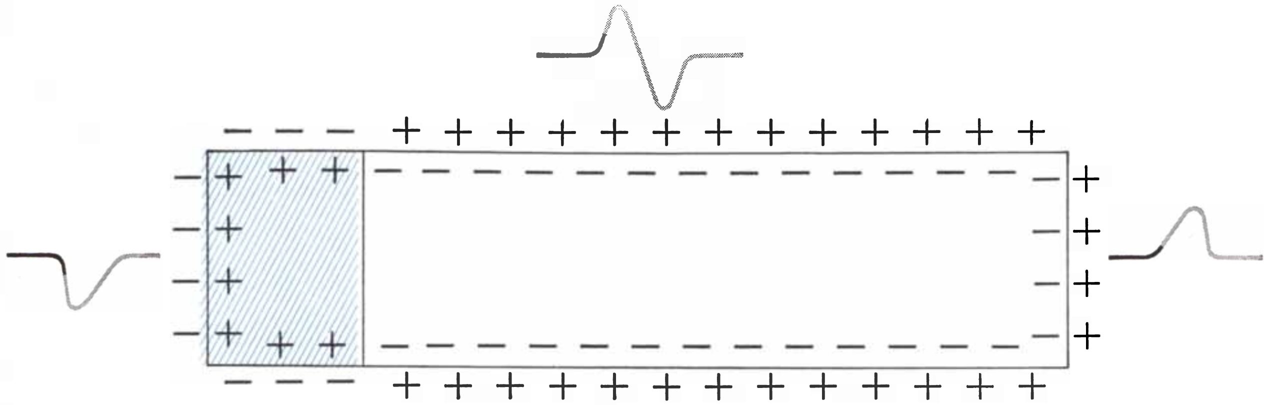
The shapes of the waves recorded on the surface of the body from the thin-walled atria were sufficiently clear to enable the English physiologist Sir Thomas Lewis to plot the pathway of atrial activity in 1914. Later work in other laboratories has not significantly modified his conclusions. The spontaneous firing of the pacemaker cells located on the right atrium induces the depolarization of the nearest resting cells, and the flow of current into these fires the next nearest cells in turn. The boundary between resting and depolarized cells thus sweeps through the entire atrium in about 80 milliseconds, at a speed of approximately .4 meter per second. Moving roughly parallel to the free walls of the atria and the axis of the interatrial septum, the wave travels in a plane away from the right arm and toward the left leg with little motion perpendicular to this plane [*see top illustration on page 136*]. The smooth and orderly motion, summed up in the P wave of the electrocardiogram, gives rise to negative potentials on the chest above the atria and positive potentials below. Recovery or repolarization of the atria does not show up in a body surface electrocardiogram, because the potentials are small and are hidden in the QRS complex.

From the intricate shape of the QRS complex, on the other hand, one can tell little about the flow of electrical activity through the massive musculature of the ventricles. Early investigators (notably Frank N. Wilson of the University of Michigan Medical School, the father of modern electrocardiography, and Richard Ashman and Manuel Gardberg of Louisiana State University School of Medicine) made some shrewd deductions, but it was clear that the information furnished by body surface potentials would have to be supplemented by direct observation of electrical activity in the heart. To make such observations we constructed a compound electrode consisting of 15 fine tungsten wires, the tips of which are exposed along a shaft at one-millimeter intervals. Inserted perpendicularly to the wall of the heart in a laboratory animal, this electrode makes it possible to record potential changes across the thickness of the muscle as the wave of activity sweeps by. A large number of insertions are necessary to study the entire heart, and the readings at each point are recorded simultaneously along with a "time reference" potential from a fixed point in the heart. The activity is registered by the multitip electrode in one of two ways: by picking up the potential between each of the tips and an electrode at a distant point on the body, or by recording the sharp "pip" that occurs when the wave is midway between each pair of tips along the length of the electrode. With as many as 70 insertions, and therefore with readings from as many as 1,050 points, we have been able to chart in three dimensions the multidirectional pathway of the ventricular potential changes. Our studies are corroborated by the work of Demetrio Sodi-Pallares at the National Institute of Cardiology in Mexico and D. Durrer at the University of Amsterdam.

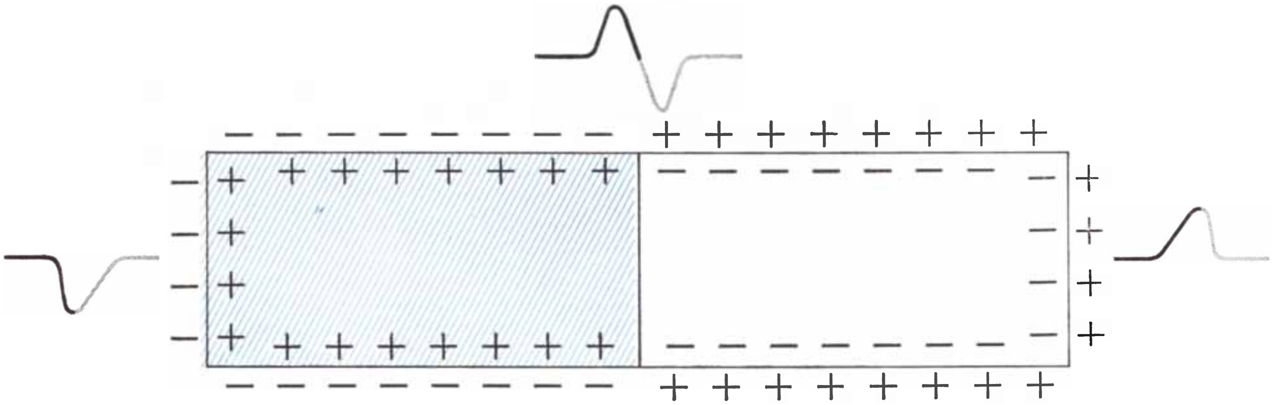
Direct observation by this means shows that the first regions in the ventricles to become excited are at the terminations of the conduction system, which originates from the atrioventricular node. The original excitation at the pacemaker is relayed to these electrical conduits by the wave of activity that sweeps through the muscles of the atria. The right and



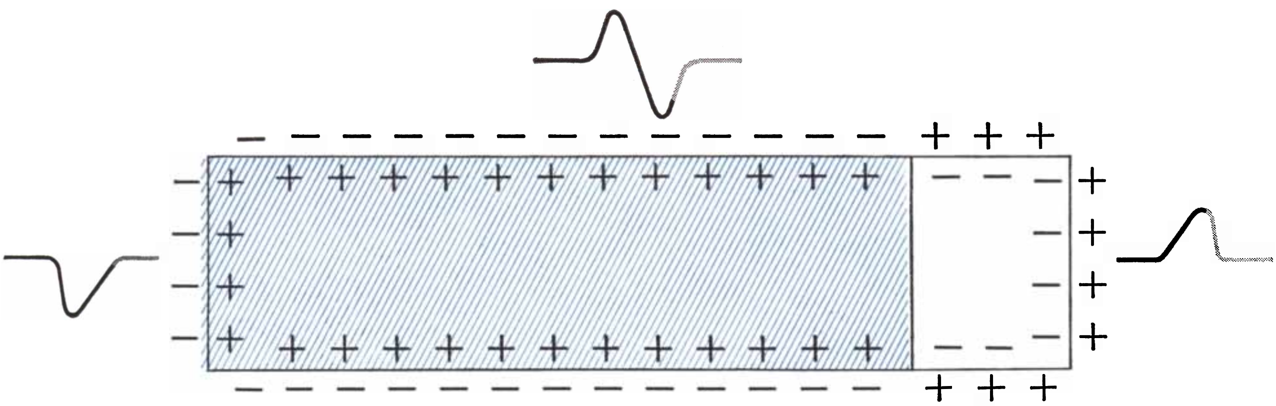
DIFFERENCE IN ELECTRIC CHARGE inside and outside cell membrane sets up a potential. Resting cells (*left and right*) have low internal sodium concentration (*hatching*) and high potassium concentration. Outside the opposite situation prevails. When cell becomes active (*center*), sodium ions flow into it, reversing the charge distribution; the outside is negative, the inside positive. Cell is now depolarized. Current flows into it from adjacent cells that have not been depolarized in this cycle and they rapidly become active. The potential changes recorded from an active heart-muscle cell are shown at top. At rest its interior is 90 millivolts negative with respect to the exterior. In active state it is 30 millivolts positive. It needs half a second to return to resting state. Broken line indicates duration of same potential changes in a nerve fiber, which recovers in less than .001 second.



WAVE OF ACTIVITY moves from left end of muscle strip to right end. Above, only the small block of tissue at far left is in active state (depolarized). Black sections of the three curves show a negative potential at left end of strip, a slight positive potential at center and smaller positive potential at right edge. The gray sections of the curves indicate changes that will follow.

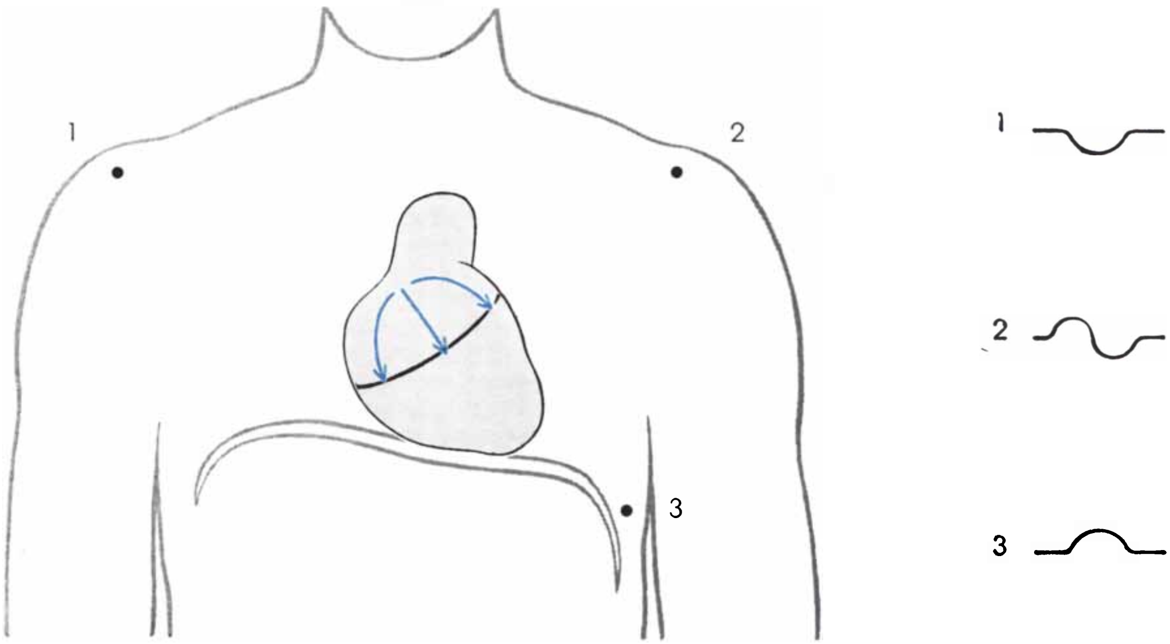


WAVE MOVES ON to center of strip. Strong negative potential is being recorded at left-hand electrode; in the center the positive potential is now approaching zero, while at the right a high positive potential is being recorded as the active wave approaches.

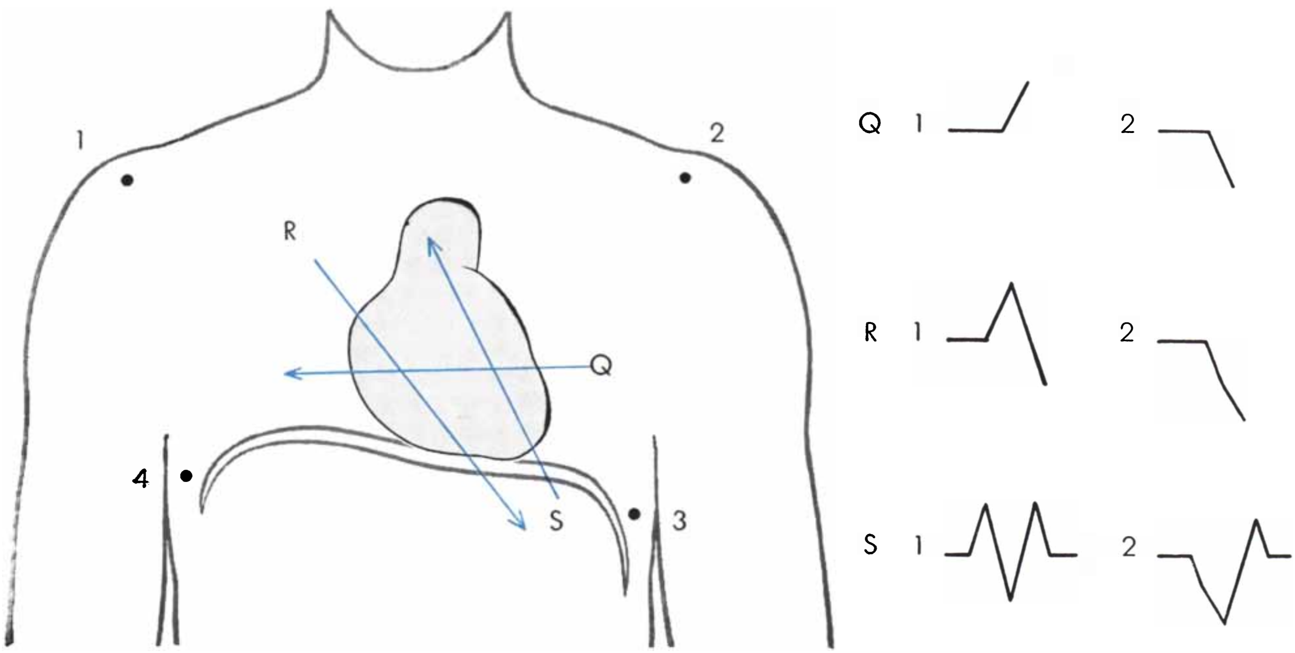


AS WAVE NEARS RIGHT END, potential at left is zero. At the center it is now negative, returning to zero. The electrode at the right end of muscle strip registers a positive potential that will return rapidly to zero as the wave passes out of the region.

left conduction bundles of the system descend on each side of the interventricular septum and radiate from there over the inner surface of the ventricles. The units of the conduction system are so small that their activity goes undetected by recording electrodes on the surface of the body. Ventricular excitation, as shown by the multitip electrode, begins in the inner surface of the heart on either side of the septum about halfway between the top and bottom of the chambers. The activity at first spreads inward toward the center of the septum from both sides. Because there is more active tissue on the left side of the septum, the left-to-right movement exceeds the right-to-left movement. This leads to the potential change recorded by the electrocardiogram in the first part of the usually triphasic QRS complex.



ATRIA ARE DEPOLARIZED by wave that moves downward and to the left (*colored arrows*). P waves produced by this activity (*far right*) are negative when recorded at left shoulder (*1*), positive and negative from electrode at *2* and positive when recorded at *3*. These differences come about because the activity wave is moving away from *1*, toward and away from *2* and toward the electrode at *3*.

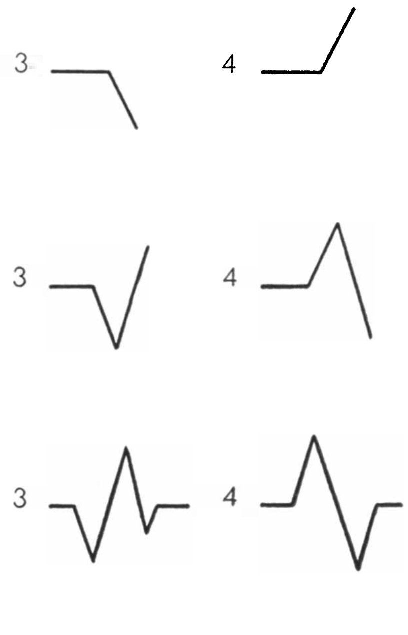


MOVEMENT OF DEPOLARIZING WAVE through the ventricles (*colored arrows*) produces a variety of curves of potential change when recorded through electrodes located at four different spots around the heart. The changes of potential are so complex that the

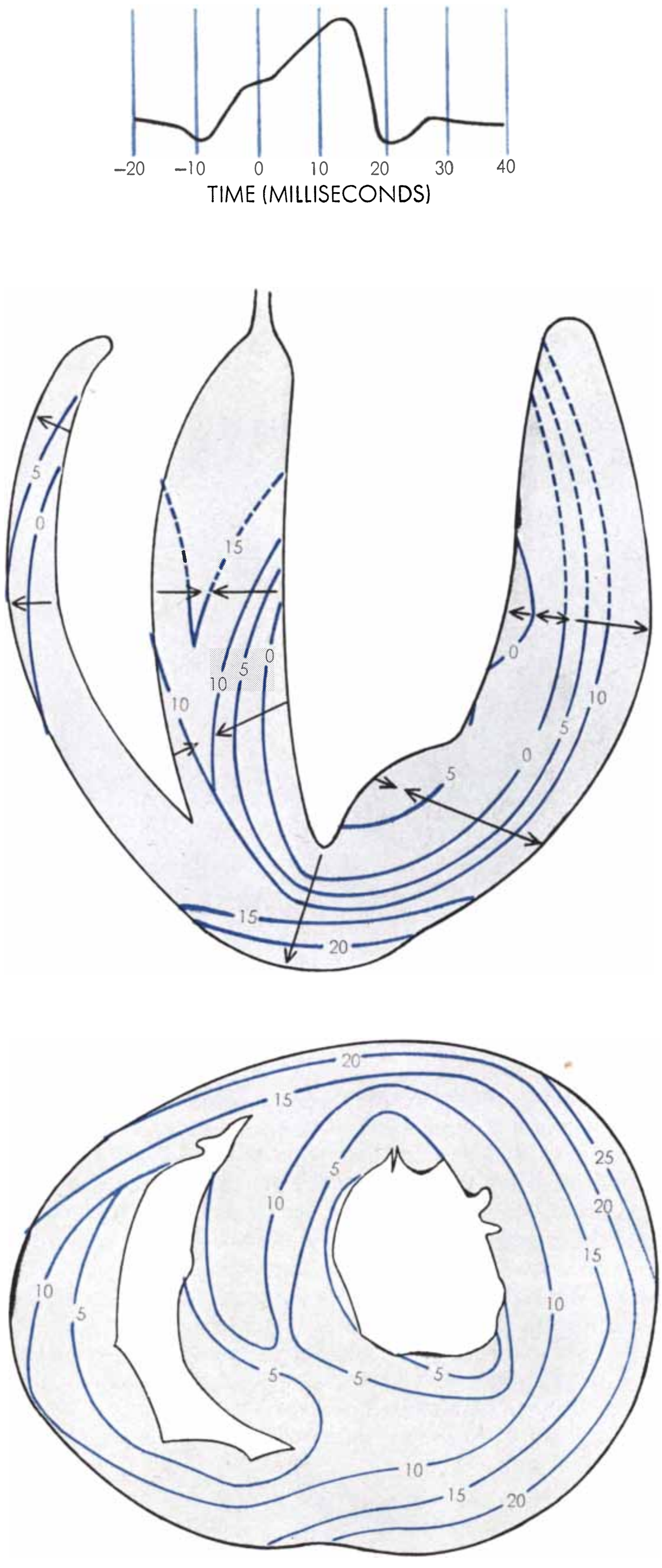
Soon after the earliest signs of activity in the septum, the fibers of the conduction bundles distribute the excitation over the inner surface of the lower and middle portions of the free walls of the ventricles. The branching of these fibers is so extensive that the lining of the ventricles in this region depolarizes almost simultaneously. As a result the only direction in which the wave of excitation can move is outward, toward the outer surface of the heart. This activity adds up to a single wave directed downward toward the tip, or "apex," of the heart and generates the second phase of the QRS complex.

The conduction bundles, which carry impulses at a speed of one or two meters per second, thin out toward the top, or "base," of the ventricles and do not reach the upper regions of the septum or of the ventricular walls. These regions are therefore the last to depolarize. They are excited during the S wave of the QRS complex by a wave conducted through the muscle and moving upward to the base at .4 meter per second.

The three phases of ventricular activity—from right to left in the septum, inside out in the walls, and toward the base of the ventricles through the walls and the septum—overlap in time and succeed one another smoothly. In the electrocardiogram the QRS shape varies considerably, depending on where



movement of the Q, R and S waves cannot be analyzed by this standard technique.



WAVE OF EXCITATION moves in the directions indicated by the arrows in vertical section of the ventricles (*middle*). Electrodes that measured the wave were inserted along the axes of the arrows. At bottom is a horizontal section of the ventricles. Numbers and contour lines indicate time at which the wave reached a specific region. Electrocardiogram is at top.

the electrodes are placed on the body. Furthermore, the patterns recorded from the same sites on two normal people may vary, due to such anatomical peculiarities as differences in the distribution of the conduction tissue, the thickness of the heart walls and the position of the heart in the chest.

During the first phase of ventricular depolarization as it is seen by the electrocardiograph, the wave moves approximately toward the right arm, and an electrode placed there records a positive potential. Because the left arm is virtually perpendicular to the direction of travel, an electrode there records little activity. The electrode on the right side of the chest, like the one on the right arm, records approaching activity; the electrode on the left side of the chest, receding activity. In the second phase the wave can be considered to be moving toward the left leg, since this is the sum of all the inside-out activity in the walls. The electrode on the right arm records a large amount of receding activity and that on the left arm a lesser amount. The electrode on the right side of the chest also records receding activity, while that on the left indicates a large amount of approaching activity. With the wave moving toward the head in the final phase of ventricular excitation, the electrodes on the arms record approaching activity and the electrodes on the chest record receding activity.

The T wave, which corresponds to repolarization, or electrical recovery, of the ventricular muscles, still presents a puzzle. In a human electrocardiogram this wave has the same polarity as the QRS complex in recordings from many body surface points. It should, of course, be opposite in sign, because the potential changes across the boundary between resting and active tissue are opposite to each other during depolarization and repolarization. This suggests that the pathway of repolarization in the human heart may take a different—perhaps opposite—direction from depolarization. Alternatively, one might conclude that repolarization does not spread from cell to cell as a result of current flow. Instead, the sequence in which the cells repolarize may be determined by metabolic events and have only a statistical direction. Experimental studies with animals cannot yet answer this question because no animal has a T wave like that in man.

Certain forms of cardiac abnormality are simply and unequivocally demonstrated by the electrocardiogram. For example, the P wave and the QRS complex normally occur at the same frequency, and the latter follows the former at a

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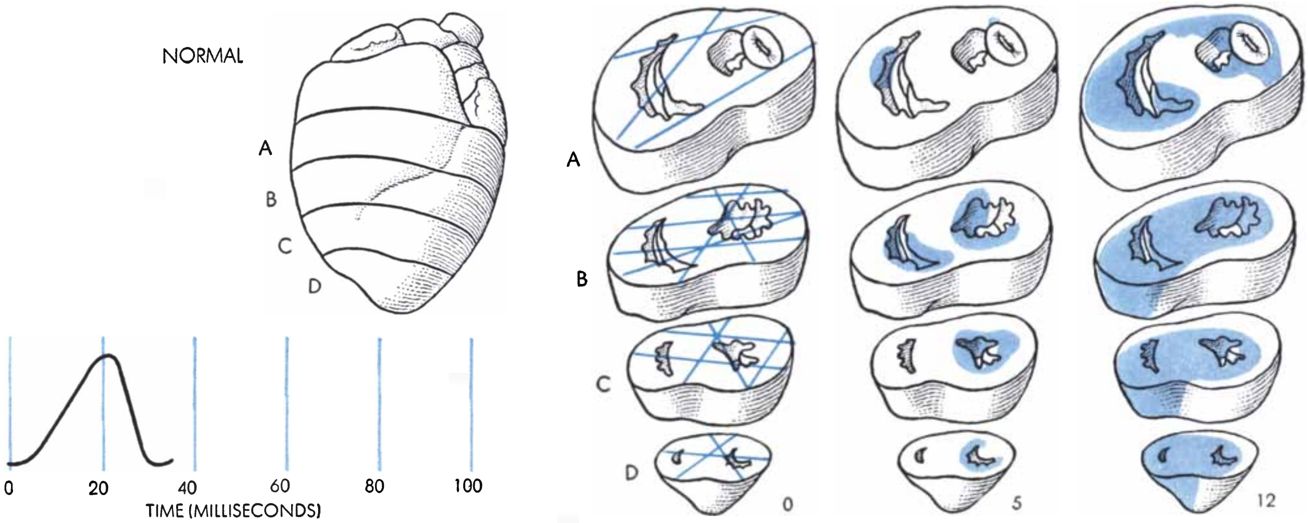
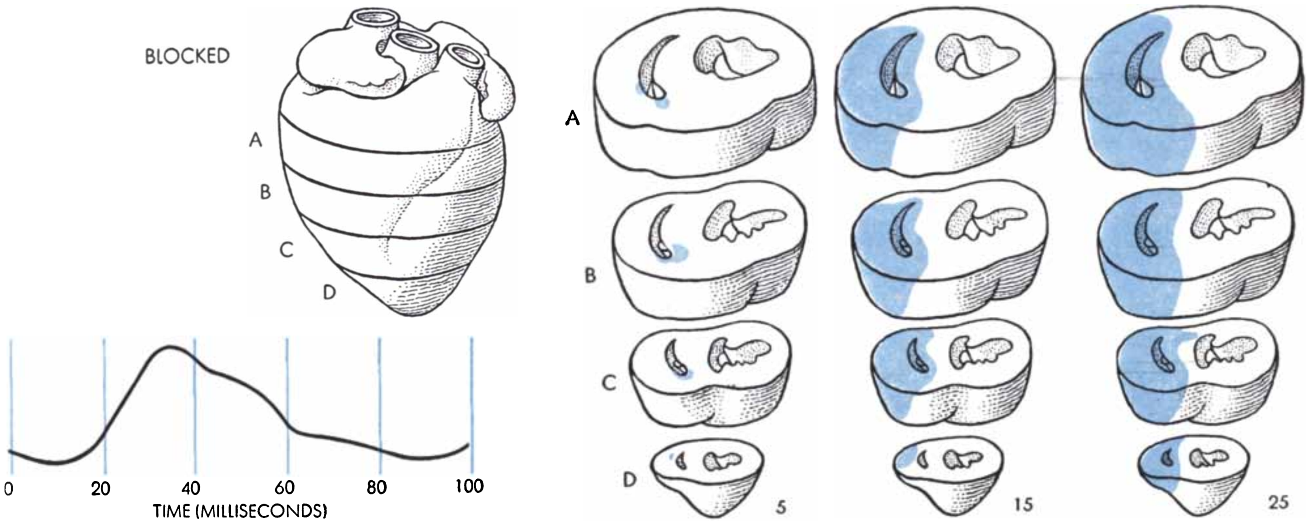
constant interval. In many disorders of cardiac rhythm this relationship is altered either by loss of the one-to-one relationship of the waves or by an abnormality of the interval between the waves. Another type of defect, referred to as a conduction defect, can arise from damage to the specialized conduction tissue of the atrioventricular node or conducting bundles. If the defect blocks the action of the conduction bundle leading to the right ventricle, the depolarization of the left ventricle will appear normal, but since the wave of activity can reach the right ventricle only by traveling slowly across the interventricular septum, it will show up late. The QRS complex is prolonged and characterized by movement of activity from left to right in its terminal portion.

In coronary thrombosis, the most common form of "heart attack," the electrocardiogram yields direct information about the extent of damage immediately following the episode. Normally the electrocardiogram does not show potentials except during the P, QRS and T waves; in the intervals between these electrical events the potential is zero. But when segments of ventricular muscle are deprived of oxygen by loss of blood supply, as occurs in coronary thrombosis, the pen does not return to the pre-QRS base line. This potential is called "current of injury" and arises from the fact that the cells are partly depolarized by oxygen deprivation.

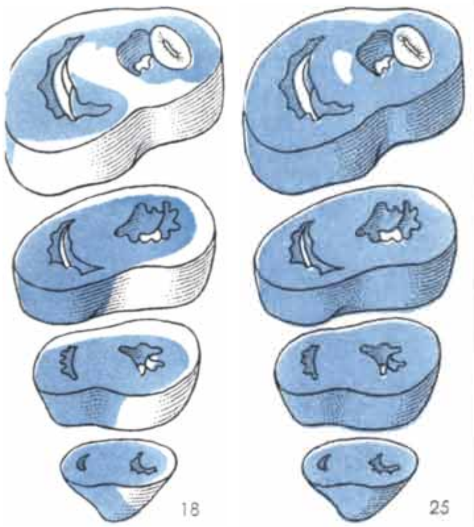
Later, when the injured muscle has been replaced by electrically inactive



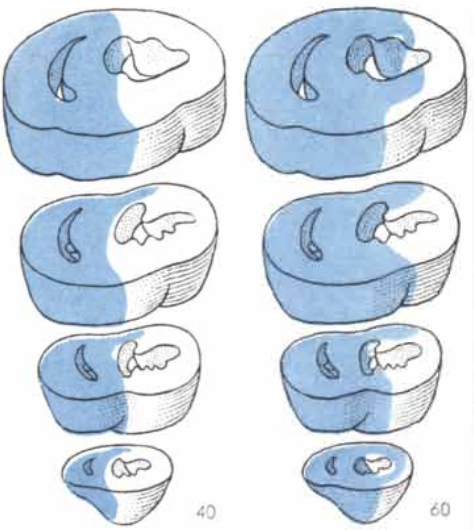
DEPOLARIZATION IN VENTRICLES is shown in four cross sections of normal dog heart. Top of section *A* is at the atrioventricular valve. The complete cycle goes smoothly to completion in about 30 milliseconds, as seen in the electrocardiogram at left. Crisscross lines in the sections at zero milliseconds show locations of electrodes implanted for author's observations. The color in the sec-



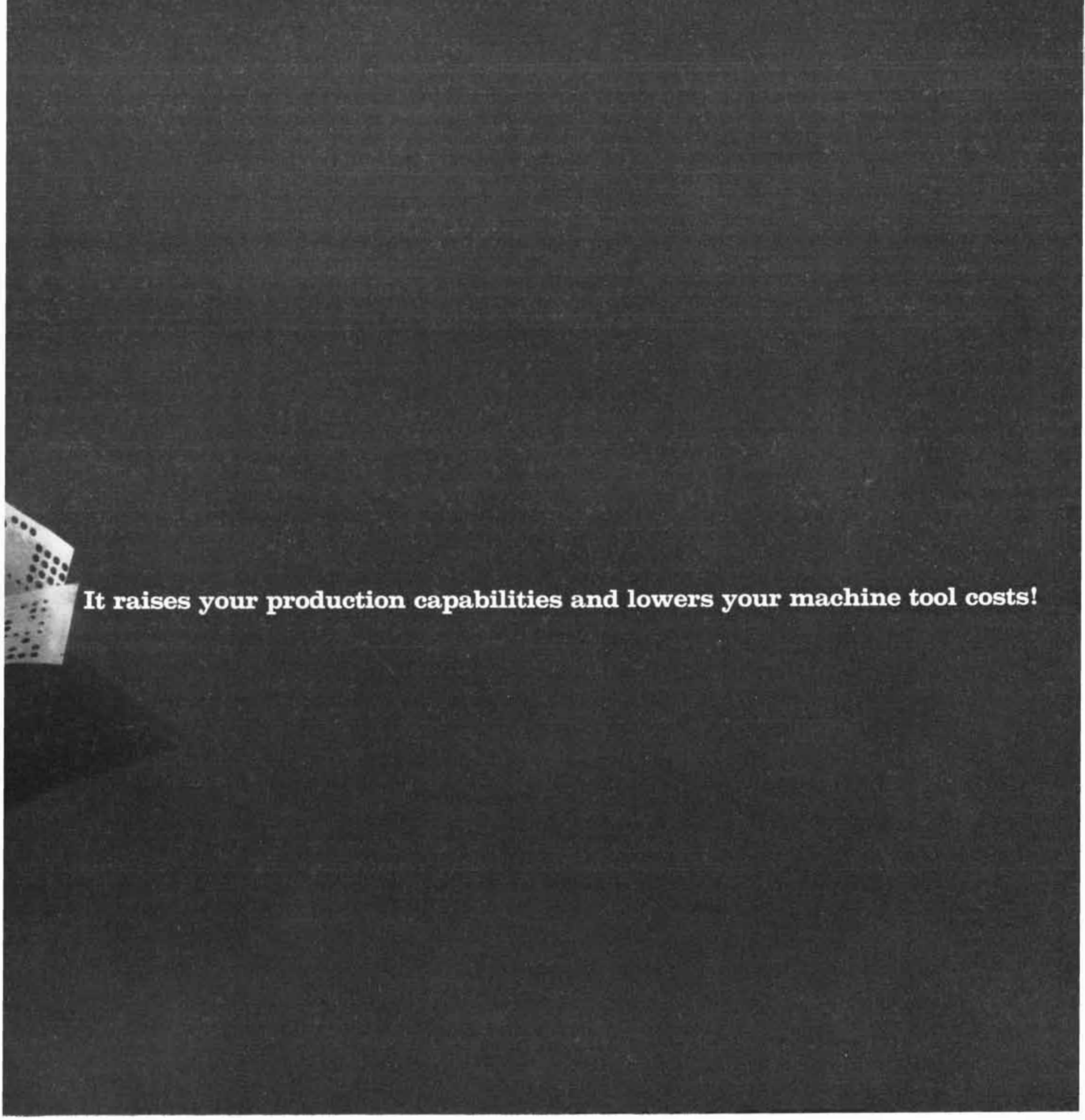
DAMAGE TO HEART can change pattern of depolarization. In this case the left conducting bundle has been cut. Activity begins around right cavity of dog heart, but can reach left side only by spreading slowly across septum as depolarization of one cell triggers activity in the next. The QRS complex is prolonged and characterized by delay in the movement of activity. The electro-scar tissue (a condition termed chronic myocardial infarction), the potentials normally contributed by the destroyed muscle will be absent from the electrocardiogram. The interpretation of the electrocardiogram in this phase of the affliction is more complex, but useful criteria of damage have been accumulated through experience with many patients. This clinical experience is gradually being supplemented by understanding of the details of function that underlie the normal electrocardiogram.



tions at 5, 12, 18 and 25 milliseconds represents the spread of depolarization in ventricles as the QRS complex takes place.



cardiogram plainly reflects this abnormal condition. The cycle takes 90 milliseconds instead of 30 milliseconds for completion.



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Architectural Vaulting

Once vaulting was essential for the construction of large buildings. With the advent of steel it gave way to rectangular structures. New problems of architecture, however, have again focused attention on it

by J. H. Acland

Architecture is shelter; in the simplest terms, a roof over one's head. Indeed, the earliest man-made shelters, whether huts or tents, were just that: roofs that sprang directly from the ground. The idea of raising the protective canopy on walls came later. Since these beginnings structural systems have emerged, for the most part, as varying responses to the problem of spanning a space.

In the mode of construction that has dominated the public architecture of the 20th century the problem is solved in the most primitive way. A flat roof rests on horizontal beams, which are supported by vertical columns. With timber, concrete or steel for the skeleton, this design can lift a roof to a considerable height and can provide a large unobstructed area beneath it. Nevertheless, an increasing number of architects are coming to realize that the skeletal cage is not always the ideal answer, practically or aesthetically, to every building need. Working chiefly in reinforced concrete, they are moving toward more open and flexible designs [*see illustrations on pages 152 and 154*]. Having purposely abandoned the simple beam, they are forced back to methods devised by earlier builders for spanning large open areas. The striking shell structures that are now appearing all over the world bear a fundamental relation to the cathedrals of the Middle Ages. Vaulted roofs, after an almost total eclipse, are back in the mainstream of architecture. Retracing the evolution of vaulting, therefore, helps to put in perspective the developments of today.

The masonry arch goes far back in the earth, brick and stone construction of Middle Eastern civilizations. The first type to appear was the corbeled arch, made by stepping horizontal blocks outward one above the other; this type of arch was derived from the compacted clay beehive huts of the Neolithic period. But the later vaulted form, composed of wedge-shaped units radiating outward from a roughly semicircular curve, also has a long history: it appears in culverts in a Mesopotamian palace at Eshnunna dating back to about 2300 B.C.

In the arid, treeless region that the eastern Mediterranean even then was becoming, timber grew increasingly scarce and builders learned to roof over ordinary houses as well as palaces with domes and half-cylinders, or barrel vaults, of sun-dried brick. A simple beam or a flat roof fails by bending downward at the center; this places a tensile stress on the lower members of the structure. By curving the roof upward the pull of gravity on the heavy masonry shell was converted to compression stress, which stone or brick withstands well [*see illustration at upper left on page 146*]. This also meant that the supporting structure below had to withstand not only a vertical downward load but an outward horizontal thrust as well. The walls of Middle Eastern buildings, built thick to keep out the heat of the Mediterranean sun, were well adapted to restrain this thrust.

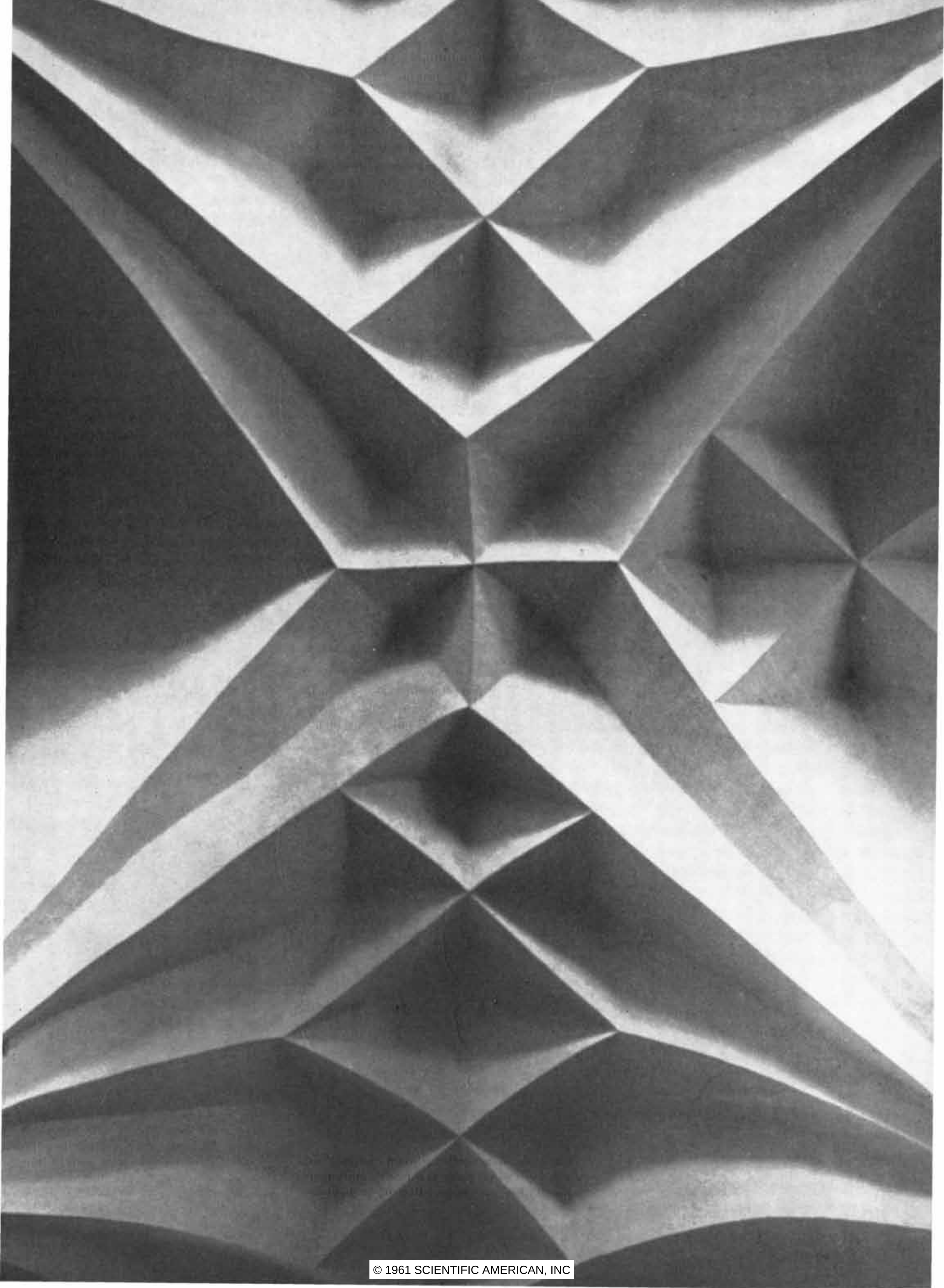
As the center of civilization shifted westward to Italy, the Eastern style of building came with it. Imperial Roman architecture, justly renowned for its engineering, used the vault and dome on a heroic scale. The discovery of the pozzuolana earths (after the town of Pozzuoli), which form a hydraulic cement when mixed with slaked lime, gave the Romans a material almost as strong as modern concrete. It was also a material well suited to the employment of unskilled slave labor. A few trained construction workers erected light wooden forms on which they constructed arched ribs of fired tile or brick; then the slaves had only to lift and pour concrete. Many of the huge monolithic domes and vaults made by this process are standing today.

The Romans did more than simply magnify the structures they inherited. They made a fundamental addition: the cross vault, consisting of two barrel vaults intersecting at right angles [*see illustration at upper right on page 146*]. Although Hellenistic builders used the cross vault at Pergamon in the early second century B.C., the Romans were the first to exploit it in an important way.

Fusing a pair of barrel vaults accomplishes three main purposes. It lets light in through the sides of a dark tunnel without weakening it, as cutting out windows would do. Secondly, it converts a structure calling naturally for continuous support along its length into one that is adapted to point support. Four piers, at the ends of the groin where the two component cylinders intersect, are all that are needed to hold up a cross vault. Finally, the sharp folding at the groins stiffens the structure, allowing a reduction of the mass.

Generally speaking, the Romans covered rectangular spaces with vaults, reserving the dome for circular buildings. In the further evolution of the Roman style in the Eastern Roman Empire, on the other hand, domes became the standard form of roof. To fit them on rectangular walls Byzantine designers had to de-

CELLULAR VAULT of Saxony and eastern Europe in the late 15th and early 16th centuries was a reaction against increasingly elaborate ribbing and panels. The vault was a folded plane built of brick and surfaced with stucco or plaster. This one is the Church of St. Francis at Bechyne in Czechoslovakia. In its merging of structure and decoration it suggests today's concrete vaults.

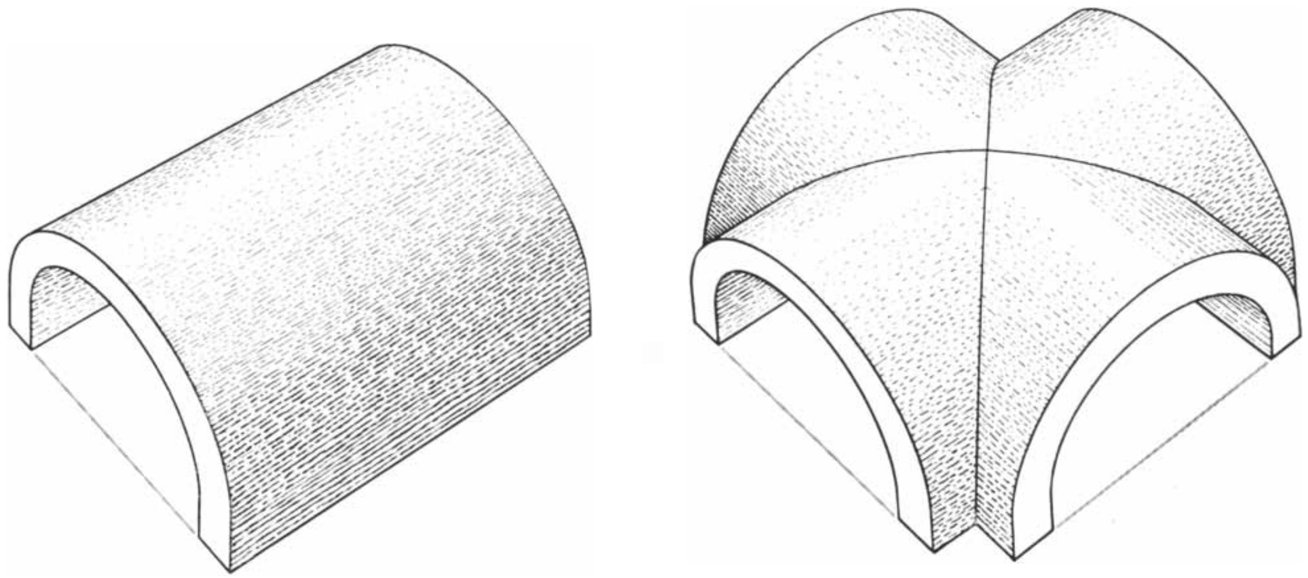


velop the triangular section of vaulting called the pendentive [*see top illustration on page 150*].

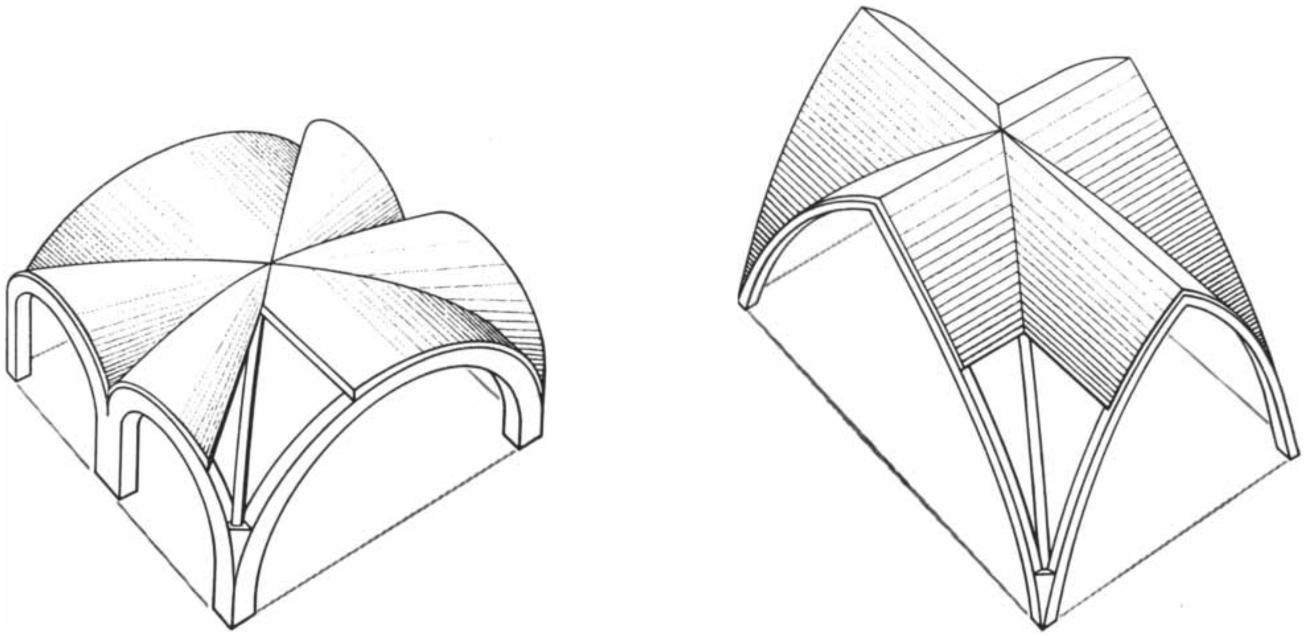
After the fall of Rome, architecture declined in western Europe along with the other arts. The Mediterranean changed from a highway to an embattled frontier, and out of the barbarous confusion came two new approaches to structure. In the south small-stone rubble construction contrasted sharply with the timber-framed structures of the forested north.

When Christian missionaries moved northward, they brought with them the Mediterranean mode of building. The "white robe of churches," in the phrase of a contemporary scholar, that was flung across Europe in the 11th century was of southern inspiration. The prototype of this Romanesque style, which had originated three or four centuries earlier, was close to the ultimate in simplicity: a rectangular rubble box surmounted by a massive barrel vault of rubble and mortar, some 18 inches thick. Narrow, slotted windows provided adequate lighting in the sunny southern climate without unduly weakening the walls.

Soon the simple open rectangular plan of these early churches became inadequate to the increasingly elaborate ritual. To provide a return path for the procession passing down the center of the church to the altar, aisles were added on each side of the nave, or main compartment. Since the heavy, rather weak arch of rubble and mortar spanned only a limited distance—25 feet at most—the



EVOLUTION OF THE VAULT is traced in the drawings on these two pages. The simple barrel vault (*left*) was one of the earliest masonry shells. The Romans developed the cross vault (*right*), which let in more light and was adapted to support on four piers.



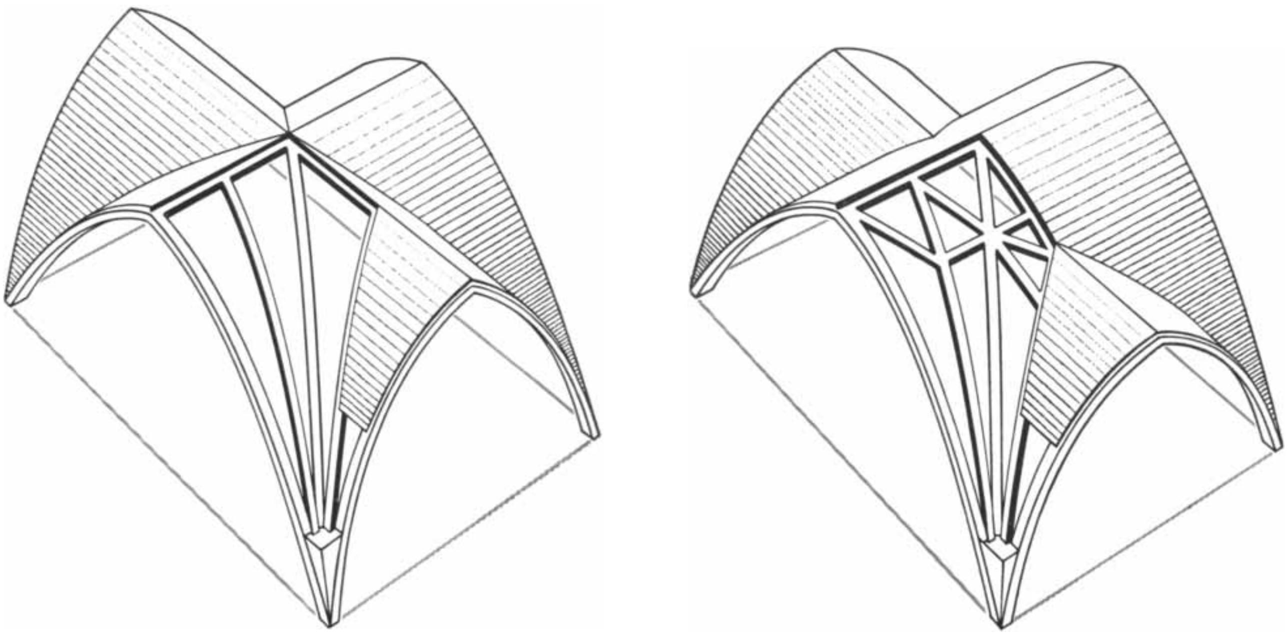
INTRODUCTION OF RIBS where vaults intersected permitted more flexible designs, including the Romanesque sexpartite vault (*left*). The French invention of the pointed Gothic arch (*right*) made it possible to roof oblong areas without stilts or distortion.

aisle had to be covered with separate, smaller vaults. This then became the fundamental design of the abbey and the cathedral: an oblong of nave and aisles, usually crossed by a shorter rectangular transept and ending in a semicircular apse with adjoining chapels.

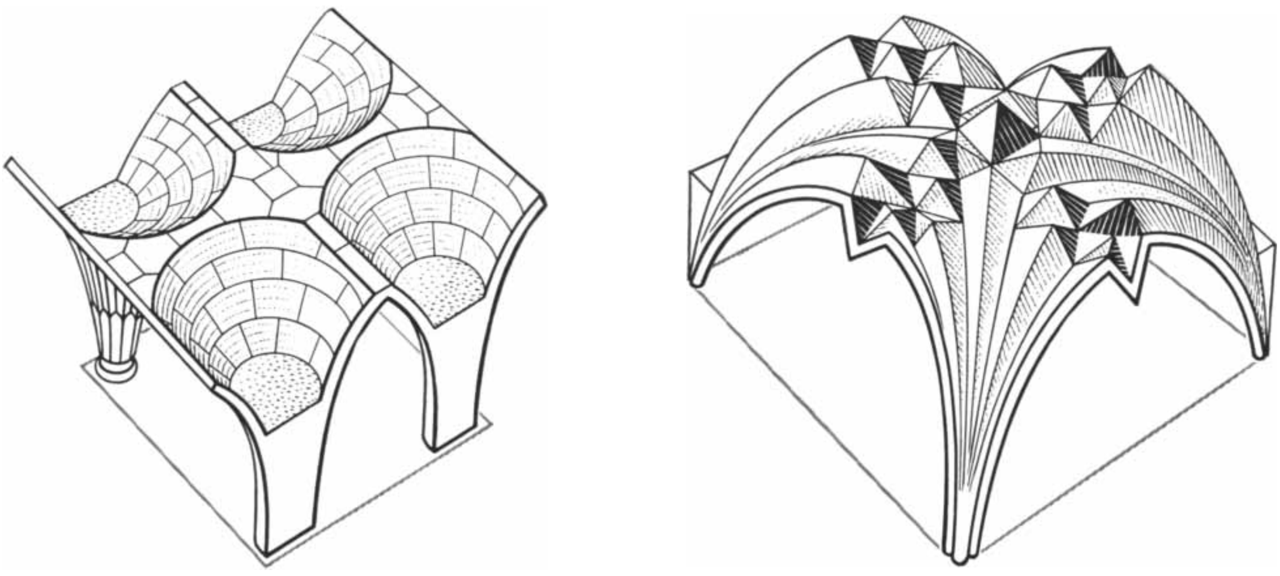
With the addition of the aisles (which had galleries above them) and with a tendency to larger structures, the lighting problem grew more difficult. The narrow windows in the outer walls provided illumination for the aisle but not much for the central nave. And the heavy barrel of the nave vault overhead could not be pierced without weakening it.

Another drawback of the barrel vault over the nave was that it no longer rested on the continuous outer walls but on the series of columns that separated the nave from the aisles. As has been mentioned, the barrel vault is not well adapted to point support. Thus the form, although it provided a simple and dignified way to focus on the altar, had become structurally inept. In the middle of the 11th century masons began to experiment with other ways to throw an arch of masonry over the nave.

One of the earliest ideas, but one bearing a startlingly modern look, was an inspiration of the monks at the monastery of St. Philibert at Tournus in Burgundy. They turned the barrel vault around, running it transversely across the nave. A series of vaults provided space for clerestory (that is, "clear story") windows along the length of the nave above the aisle, flooding the church with light



PROLIFERATION OF RIBS brought lighter construction, with walls of glass and stone panels on a supporting cage. Extra "tierceron" (*left*) and "lierne" ribs (*right*) were added; the vault became a rich, interlacing grid that could be given varied shapes.



SHELL VAULTING returned in the form of conical fan vaults (*left*), which retained ribs only as decorative additions, and in cellular "crystalline" vaults (*right, and photograph on page 145*), folded shells of brick that were both structural and decorative.

[*see illustration at bottom left on this page*]. Moreover, the lateral thrust of each section was counteracted by that of the next. This invention, so suggestive of the design of present-day factory roofs, solved at one brilliant stroke the problems of lighting and the containment of thrust. Yet few other builders used it, probably because it broke the nave into a series of transverse sections, interrupting the sweep from entrance to altar.

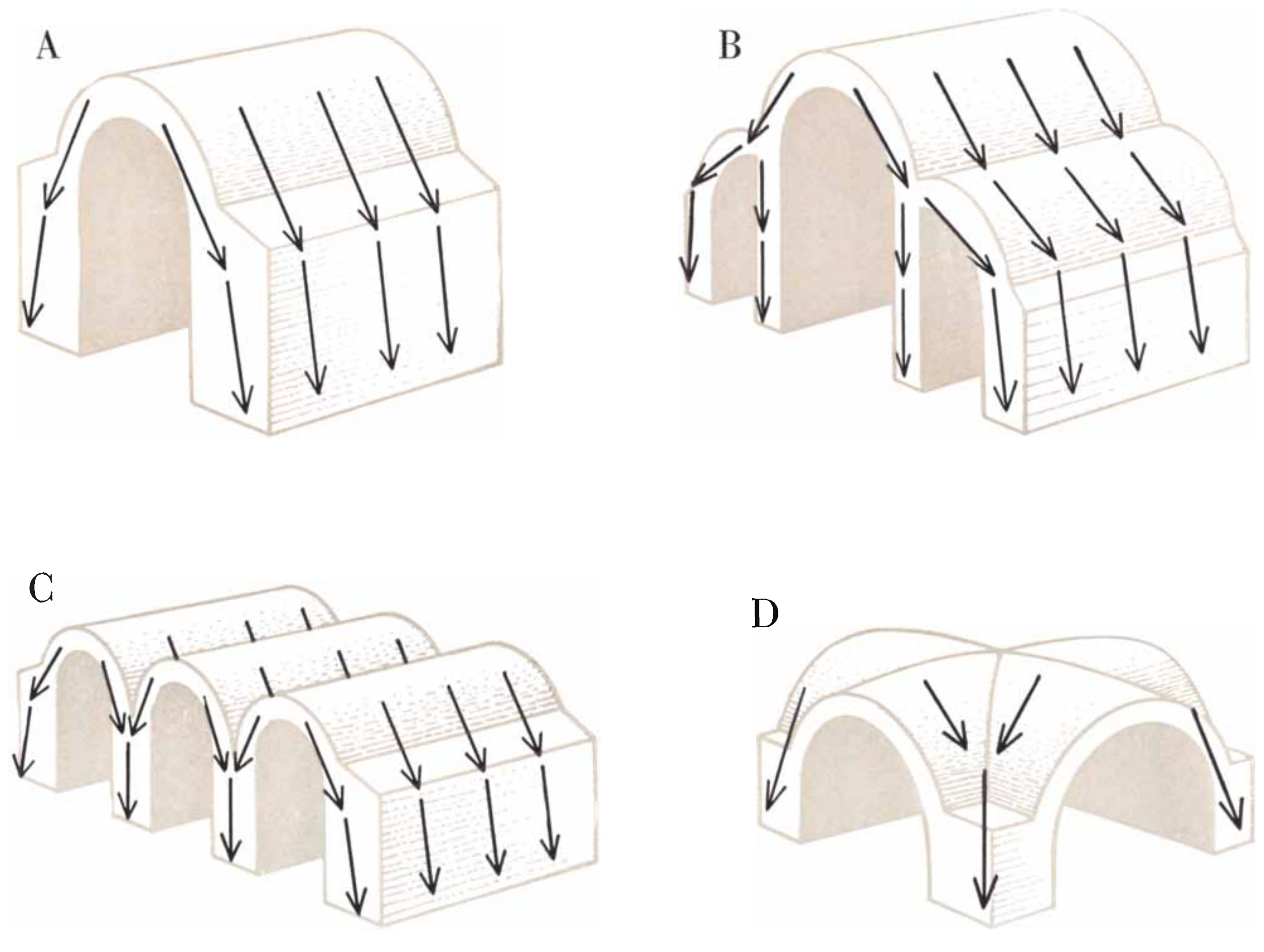
Instead, in Burgundy and the Rhineland, the medieval masons turned universally to the cross vault and ran into a variety of difficulties. A brief look at this structure shows where the trouble lay. In its original, and simplest, form the cross vault consisted of two intersecting semicircular barrel vaults of equal radius set on a square compartment [*see illustration at upper right on page 146*]. The diagonal curves in which the two cylinders intersect are flattened ellipses, an inherently weak form of arch.

A square vaulting compartment in the nave, moreover, did not fit easily into the plan of the churches. Since the aisles were narrower (generally half as wide) and their cross vaults smaller, the supporting columns for the aisles had to be set closer together than those for a square nave compartment. In some of the earlier Romanesque churches the masons did use alternating sets of piers and columns, the former supporting both nave and aisle vaults, the latter just the aisle vaults. This rhythm tended to destroy the unity of the design, and later builders compressed the nave compartments into oblongs to match their length to that of the aisle vaults.

When they did so, they had to use barrels in which the transverse radius was shorter than that along the length of the nave. Now the top of the smaller, transverse arch could not intersect the top of the large arch unless the smaller cylinders were raised on stilts. Stilted arches were in fact used over the clerestory windows in several buildings, but they produced an awkward twisted groin.

In an effort to solve this problem it became common practice to conceal the joint along the groins of the cross vault with a stone molding. Soon the masons realized that the piece of decoration could serve as a supporting member, or rib. They could erect it first and then use it as a scaffolding to which the curved vaulting panels could be fitted. To support the diagonal rib subsidiary shafts were run down the outside of the piers.

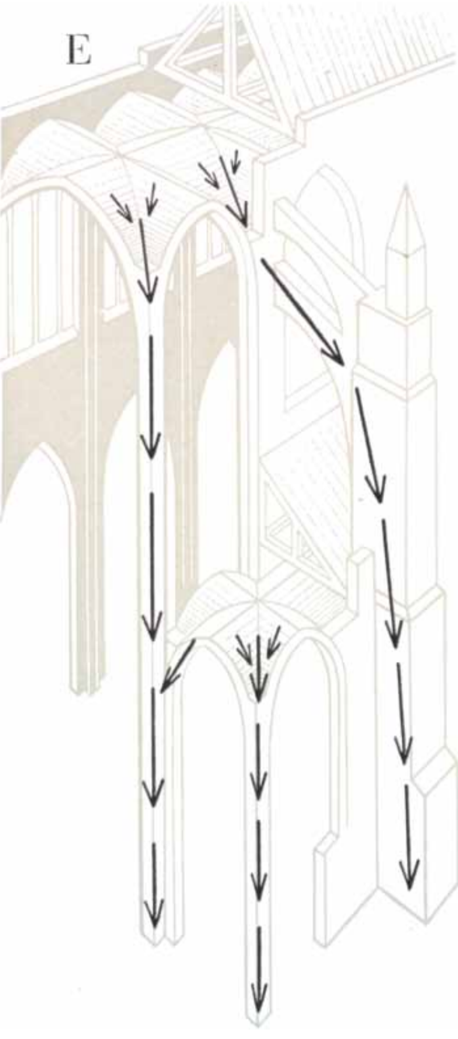
The ribbed vault eased the designers' geometrical difficulties to a considerable extent. Previously the curvature of the intersecting barrels had to be shaped with great accuracy to avoid serious mismatching along the groins. Now the builder could erect the rib on an accurate curve and compensate for minor irregularities by adjusting the curvature of the vaulting plates. In some designs the diagonal ribs were rounded up to



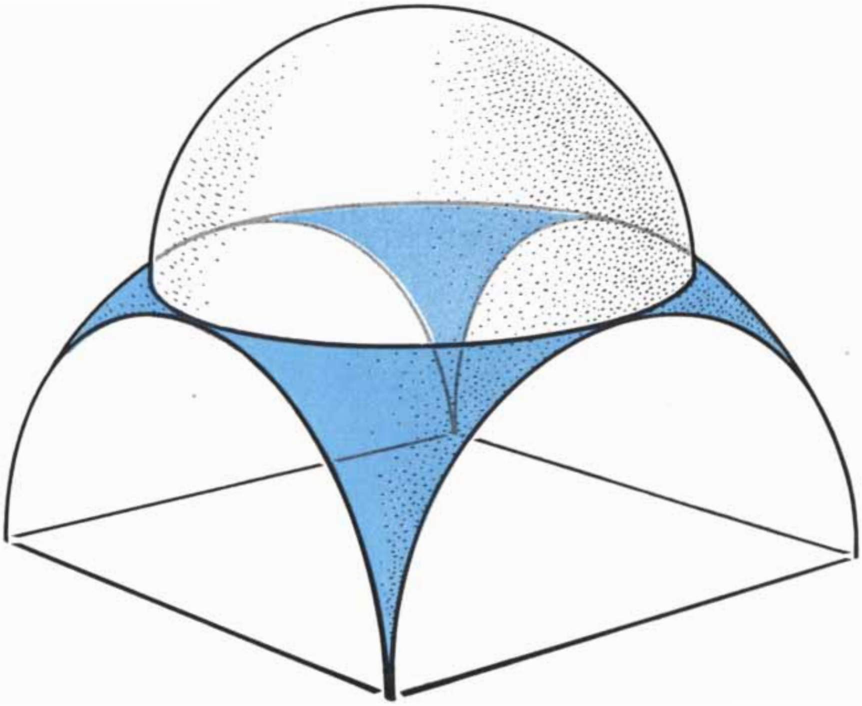
TRANSMITTING THRUST from the roof to the ground was the basic engineering problem for vault builders. In the barrel vault (*A*) the walls had to be thick to support lateral thrusts. Side vaults (*B*) took over some thrust and also provided aisles. In one experiment, much like a modern factory building, lateral thrust was shared by a series of transverse vaults (*C*). The cross vault semicircular shape to make them stronger. The resulting compartments became in effect a dome on pendentives.

An ingenious, if rather elaborate, solution to the oblong compartment was the sexpartite vault, probably invented by Norman masons in Caen about 1115. Each diagonal rib arched between a column on one side of the nave and the second column farther along on the other side. Thus the diagonals formed a square compartment. Then a transverse rib was placed between the intermediate columns, passing through the intersection of the diagonals [*see illustration at bottom left on page 146*]. When the vaulting plates were inserted between the ribs, the result was a square compartment divided into six parts.

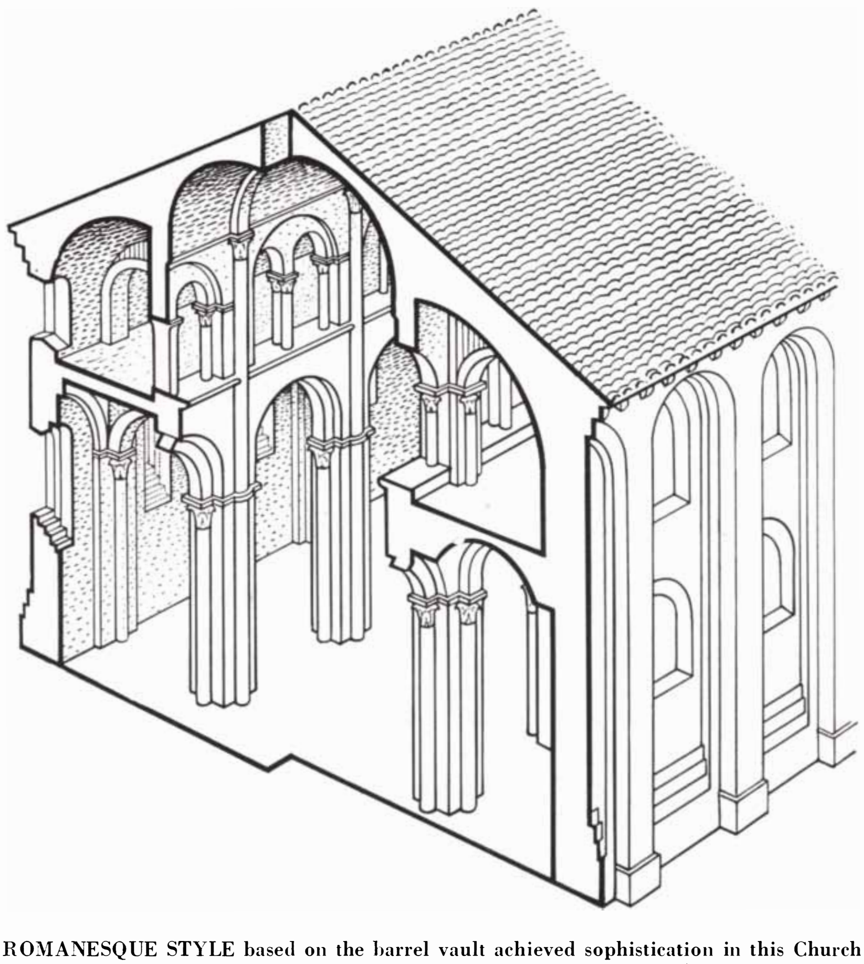
At the same time that they were experimenting with forms of vaulting, Romanesque designers were building larger and loftier structures. As the walls grew higher they needed extra reinforcement to retain the concentrated lateral



(*D*) directed thrust to four points. The famous Gothic flying buttress (*E*) relieved the walls of much of the load-bearing function.



BYZANTINE STYLE favored domed roofs. But the dome, used by the Romans on circular walls, did not fit on rectangular walls until the Byzantines developed triangular sections of vaulting known as pendentives (*color*) to fill the space between vaults and dome.



ROMANESQUE STYLE based on the barrel vault achieved sophistication in this Church of Santiago de Compostela in Spain. This was essentially a central barrel vault with two side vaults. each surmounted by a half-barrel to stiffen the high clerestory walls. Buttressing pilasters strengthened the outer walls, the windows of which were still necessarily small.

thrust of the vaults. Buttressing piers, or pilasters, were added at intervals along the outer walls. Clerestory walls were stiffened by arching to them a half-barrel vault from the outer wall of the aisle over the aisle vaulting [*see bottom illustration on this page*]. In effect this was a continuous flying buttress, and later, to meet the point thrusts of cross vaulting, it was broken up into separate flying buttresses, which were hidden by the timber roof over the aisle vault.

The legacy of the Romanesque builders, then, included external buttressing, the ribbed vault and piers surrounded by densely clustered shafts. In northern France in the 12th century these elements were incorporated into a new, open style of architecture now called Gothic.

Any great human achievement arises from a subtle combination of motives and influences. In my opinion the chief driving urge behind the development of the Gothic was the effort to adapt the heavy-walled box of the south to a more northerly climate. The Romanesque, which never did quite die out in Italy and Spain—the dark, magic cave, rich with color and redolent of incense—became a dank, murky dungeon when transplanted to the north. It was inevitable that the masons there, with the model of light wooden frame buildings all around them, should have brought the spirit of frame construction to ecclesiastical architecture.

So far as the vault itself was concerned, the designers made one fundamental change that eliminated the awkwardness of the oblong cross vault and that has become virtually the trade-mark of the style: they sharpened the rounded arches of the Romanesque vaults into a point [*see illustration at bottom right on page 146*]. The pointed arch, unlike one with continuous curvature, could be adjusted to cover any span at any height. Therefore the French masons were able to go back to the simple four-part vault with two diagonal ribs. Along with the evolution of form had come an increasing skill in stonework. From the 18-inch-thick rubble tunnel of the early Romanesque vault the Gothic masons had arrived at a stone fabric no more than four inches thick, formed into folded curving surfaces that connected the ribs.

Viewed from the inside, the ceilings of the French cathedrals seemed almost to be suspended by magic. The massive walls of the Romanesque churches had disappeared, replaced by a filigree of glass and thin stone mullions both in the aisles and in the clerestory. The vertical dimension was everywhere emphasized. Closely packed piers formed a continuous sweep from entrance to altar. All the thrust of the vault, poised more than 100 feet above the floor, was apparently supported by the delicate ribs leading to slender shafts that clustered around the piers.

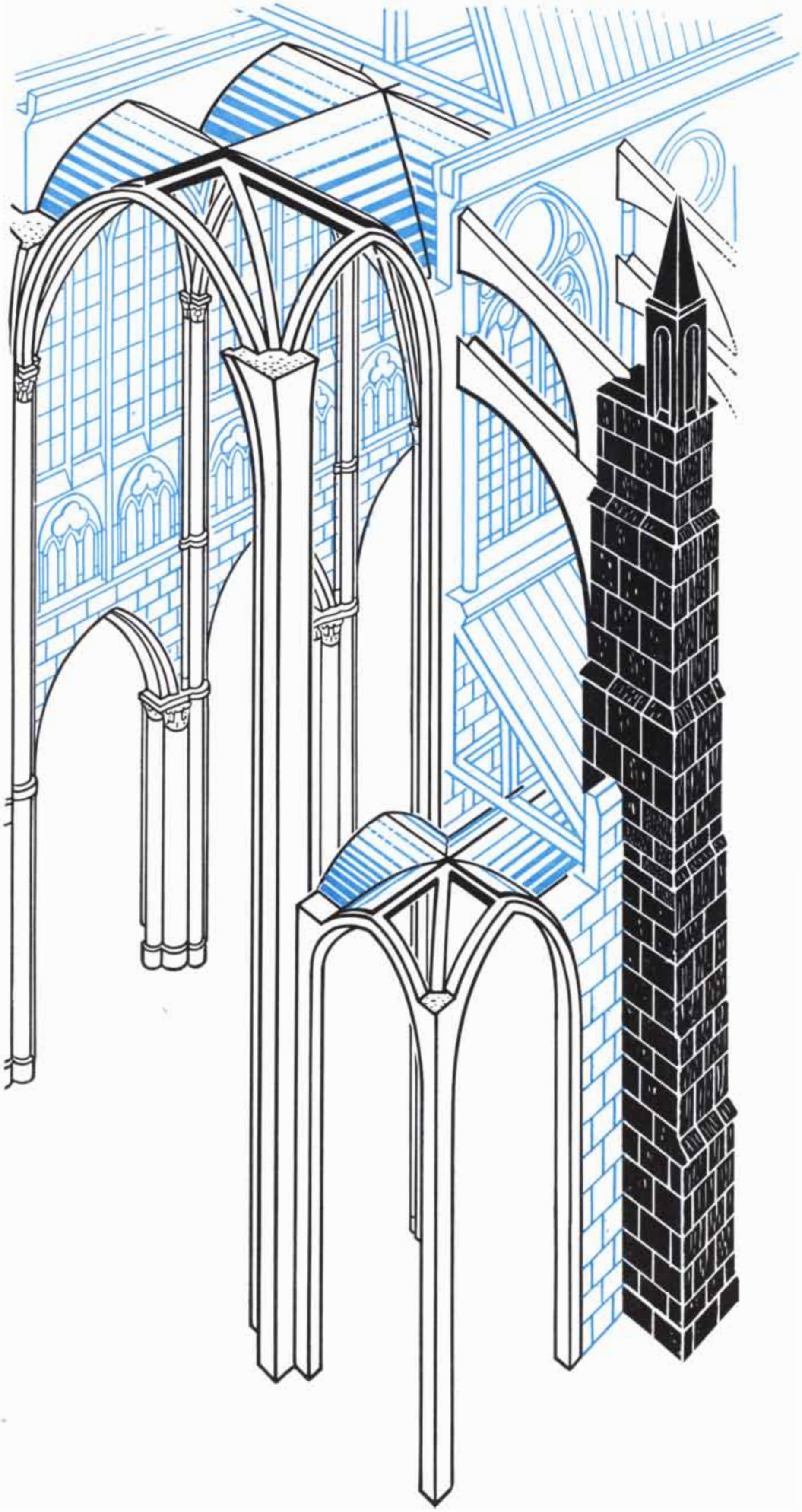
Outside the building the supporting mass was still there. In effect the wall had been sliced into sections that were turned transversely to form a permanent scaffolding of buttresses. Arched braces —flying buttresses—sprang from the top of these supports to carry down the lateral thrust of the vaults.

The open cage of masonry was a much more exacting form than the heavy Romanesque box. Almost all the work now required highly skilled craftsmen. Where the Romanesque designers had proceeded by cut-and-try methods, the Gothic builders turned to careful geometrical analyses of the structure and used detailed drawings to guide the actual construction. Although the geometric and arithmetic rules they used were largely derived empirically, the computations rested on a breakdown of the ribbed cage into its analytic elements.

When the French had brought their invention to its full flowering, as in the 13th-century cathedrals at Amiens and Reims, their creative impulse was apparently exhausted. During the next 200 years or so they concentrated merely on pushing the design to ever more open and wiry construction.

The English, however, continued to experiment with the vaulted form. Even more than the Continental builders, they were used to thinking in terms of wooden construction. Their "carpenter's Gothic" tended to break every plane surface into a simulated half-timber frame. In the vault the rib became an end in itself rather than just a means of support. Extra "tierceron" ribs were added first, springing from the supporting columns. Later these members were interconnected with short "lierne" ribs [*see top illustrations on page 147*]. Soon the ribs had proliferated far beyond any structural need. Eventually, when carried far enough, the crisscross of decorative ribbing again came to serve a structural purpose: the vault was now essentially a grid of linear elements that could assume any shape whatever.

Paradoxically, the same tendency also led in the opposite direction. The dense clusters of shafts that spread outward from the top of the columns became fused, so to speak, into the fan vault. This actually consisted of upturned conical shells of stone [*see illustration at bottom*

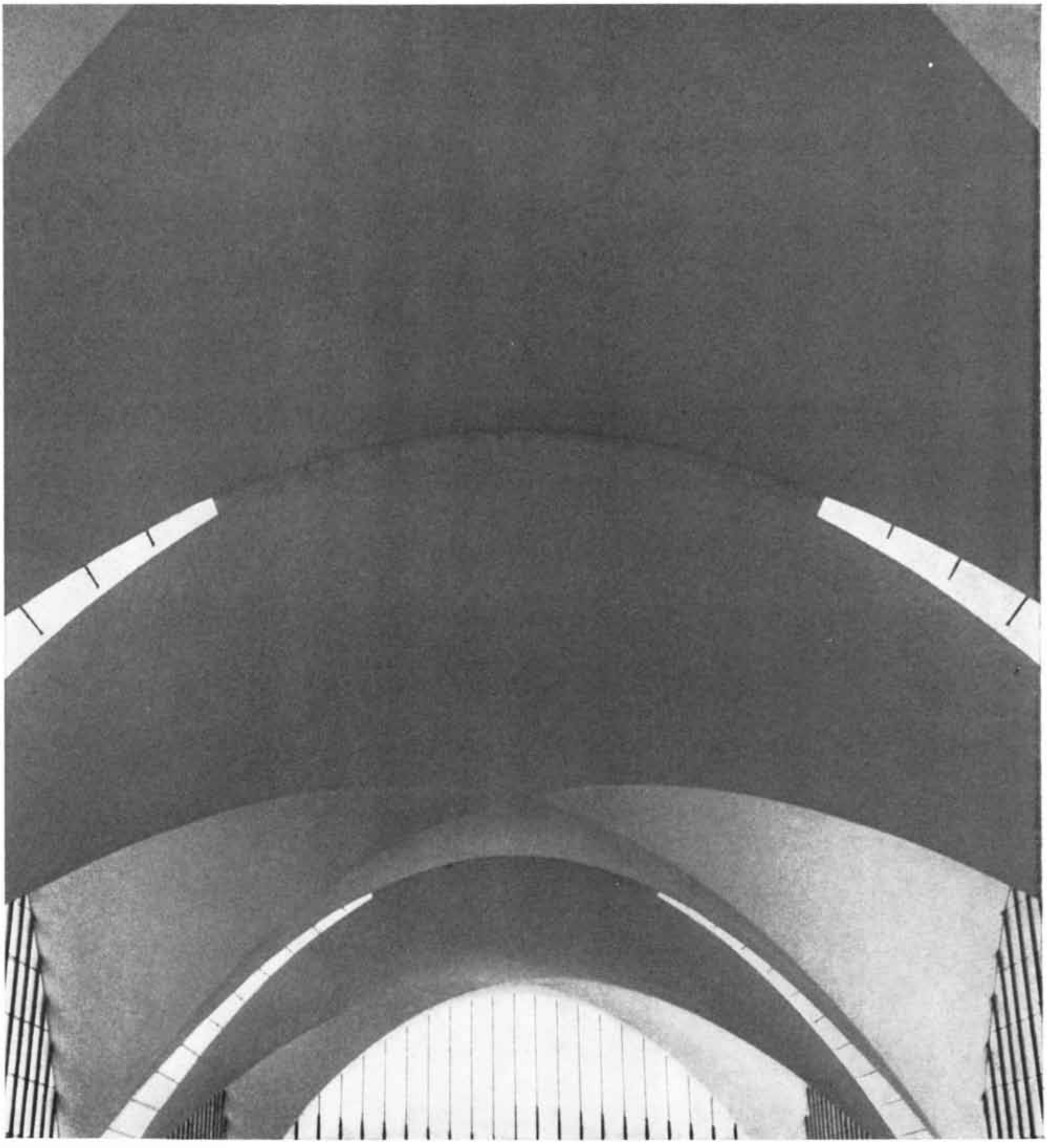


GOTHIC STYLE brought needed light into northern churches. This drawing, based on Amiens Cathedral, shows how the roof and the delicate curtain walls of glass and sculptured stone (*color*) were supported. Ribs in the form of pointed arches carried vertical loads to clustered shafts. Flying buttresses transmitted thrust to exterior buttresses (*solid black*).

left on page 147], a return to the mass shell structure of the early vaults. Ribs were still there in abundance, but only as a linear pattern cut into the surface.

The later Middle Ages was a time of surprising mobility. The English Gothic, with its highly decorated vaults, quickly spread over central Europe in the 14th century, from Norway to the Mediterranean. In the south this influence was combined with a reaction to the French structural approach. Here the solid walls returned, but in the much thinner masonry that was now possible. The cathedral became a simple box pierced by tall, narrow windows. Residual buttresses remained at first, but not for long. Builders learned that wrought-iron bars stretched across the high vaults had enough tensile strength to contain the lateral thrust. Inside the boxes, however, the ribbed vaulting patterns grew steadily richer and more involved.

At length there came a complete turning away from the framing system of rib and panel. In the late 15th century Arnold of Westphalia devised a new "crystalline," or cellular, vaulting system of folded planes with no ribs at all. In the first half of the 16th century the style spread from Saxony into Poland and what are now the Baltic States and



CONTEMPORARY VAULTING uses reinforced concrete. For his warehouse in Mexico City Félix Candela twisted the groined cross vault to stiffen the structure. The roof is a series of intersecting, self-supporting hyperbolic paraboloids only 1½ inches thick.

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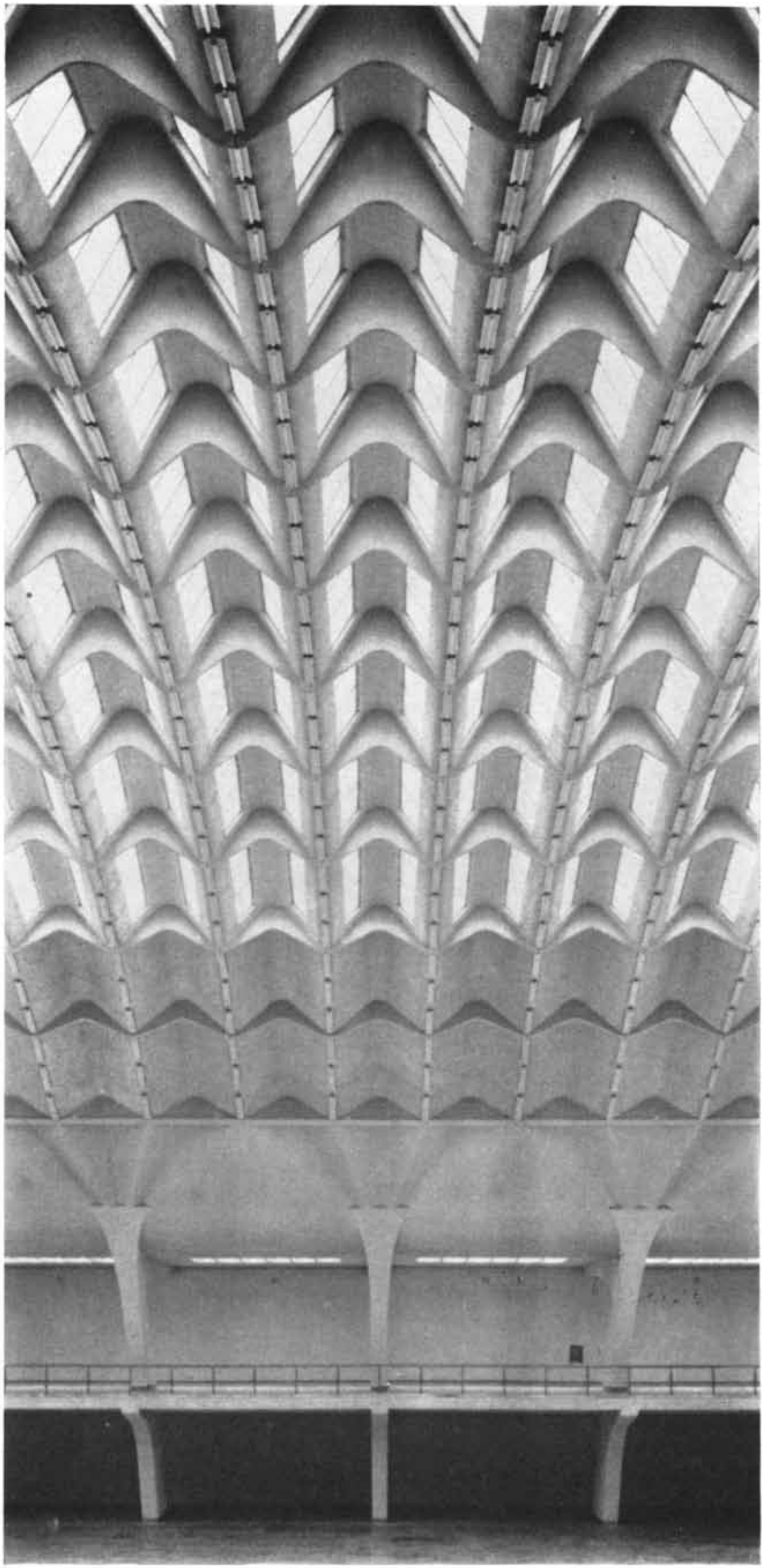

BARREL VAULT roofs the Exhibition Hall at Turin in Italy by Pier Luigi Nervi, one of the great practitioners of contemporary ferroconcrete construction. Forked buttresses fan out to support the corrugated vault composed of precast shell units braced by V-shaped fins.

Czechoslovakia. Built of brick shells and covered with dead-white plaster, these vaults rival in technical virtuosity the most advanced ferroconcrete work of today [*see illustration at bottom right on page 147*]. It is a pity that the onrush of the Renaissance, bringing with it an alien Mediterranean style, swamped this flexible and versatile medium of design.

With the end of the Middle Ages the development of structure that has been outlined in this article essentially came to a stop. As the forms of architecture changed, first back to massive simplicity in the classical revival of the Renaissance, then to the decorated styles of baroque and rococo, builders continued to use the constructional techniques that had been brought to so high a degree by the Gothic masons. Although the craft of building changed little, there was progressive development of a solid body of theoretical stress analysis. Without the 18th-century achievements of Philippe de La Hire and Charles Augustin de Coulomb in France, the structural triumphs of the 19th century would have been impossible.

Not until the 19th century was there another basic change. Then the glass-covered iron frame was introduced in structures such as railroad stations, markets and exhibition halls. This marked the beginning of the builder's preoccupation with the process of construction. Today the industry is organized almost entirely around factory-produced modular elements that are riveted, bolted or welded into place on the site. The result is the all-pervading curtain-walled steel cage that sacrifices economy in operation, comfort and aesthetic variety to efficiency in erection of the buildings.

As was mentioned at the beginning of this article, a reaction has begun. It is seen in the later works of Frank Lloyd Wright and Le Corbusier and in the concrete-shell designs of Félix Candela and Pier Luigi Nervi, to name a few. To the wealthy and advanced technologies of North America and western Europe the choice of style is still mainly aesthetic. But to underdeveloped countries struggling to equip themselves with factories, schools and hospitals the revolution in design is a sheer necessity. They have neither the steel and components to construct the standard 20th-century building nor the fuel to squander on heating and cooling it. The builder must turn to a different handling of structural mass, which may well involve the use of curved surfaces and folded planes to span large areas. The vault is regaining its central place in architecture.

does

$$X^n + Y^n = Z^n$$

?

Pierre de Fermat's last theorem states that the above equation has no solutions in which x, y, and z are positive whole numbers if "n" is a whole number greater than two. Mathematicians have yet to prove him wrong.

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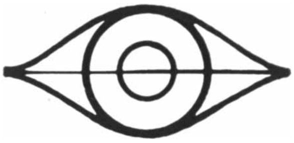

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MATHEMATICAL GAMES

Wherein geometrical figures are dissected to make other figures

by Martin Gardner

Many thousands of years ago some primitive man surely faced, for the first time in history, a puzzling problem in geometrical dissection. Perhaps he had before him an animal skin that was large enough for a certain purpose but of the wrong shape. It had to be cut into pieces, then sewed together again in the right shape. How could it be done with the least amount of cutting and sewing? The solution of just such problems provides recreational geometry with an endlessly challenging field.

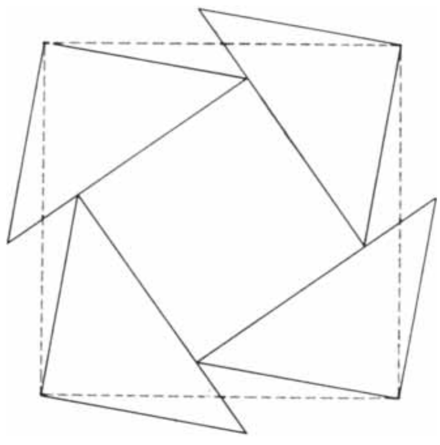
Many simple dissections were discovered by the Greeks, but the first systematic treatise on the subject seems to have been a book by Abul Wefa, a famous 10th-century Persian mathematician. Only fragments of his book survive, but they contain many gems. The illustration on this page shows how Abul Wefa dissected three identical squares into nine pieces that could be reassembled to make one single square. Two squares are cut along their diagonals and the four resulting triangles are grouped around the uncut square as shown. The dotted lines show how four more cuts complete the job.

It was not until this century, however, that geometers began to take seriously the task of performing such dissections in the fewest possible number of pieces. Henry Ernest Dudeney, the English puzzlist, was one of the great pioneers in this curious field. The illustration on page 160 shows how he managed to solve Abul Wefa's three-square problem in as few as six pieces, a record that still stands.

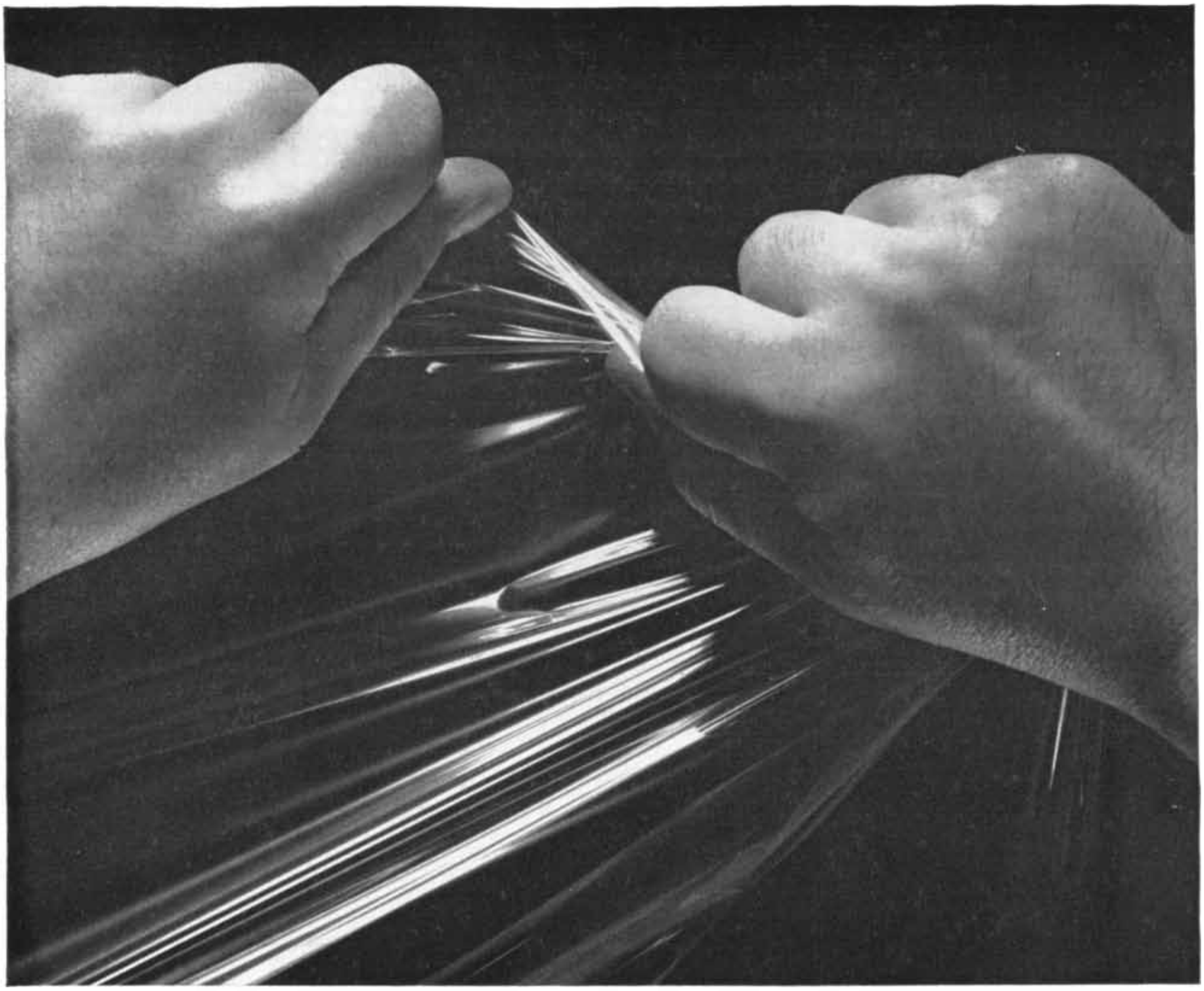
There are several reasons why modern puzzlists have found the dissection field so fascinating. First, there is no general procedure guaranteed to work on all problems of this type, so one's intuition and creative insight are given the fullest possible play. Since no profound knowledge of geometry is called for, it is a field in which amateurs can, and in fact do, excel the professionals. Second, in most cases it has not been possible to devise a proof that a minimum dissection has actually been achieved. As a result, long-established records are constantly being shattered by new and simpler constructions.

The man who has broken more previous dissection records than anyone living today—he is the world's leading expert on such problems—is Harry Lindgren, an examiner of patents for the Australian Government. He has studied all types of dissection, including plane figures with curved outlines and three-dimensional solid forms (so far as I know, no dissector has yet explored the higher dimensions!), but most of his attention has been focused on the polygons. It is not hard to prove that any polygon can be sliced into a finite number of pieces that will re-form to make any other polygon of the same area. The trick, of course, is to reduce the number of required pieces to the minimum.

The chart on page 162, supplied by Lindgren, shows how some of the records stand at present with respect to seven of the regular polygons and six other polygons of irregular but familiar shapes. The box where a row and column intersect gives the smallest number of pieces known that will form the two polygons indicated. Asymmetrical pieces



Nine-piece solution to Abul Wefa's problem



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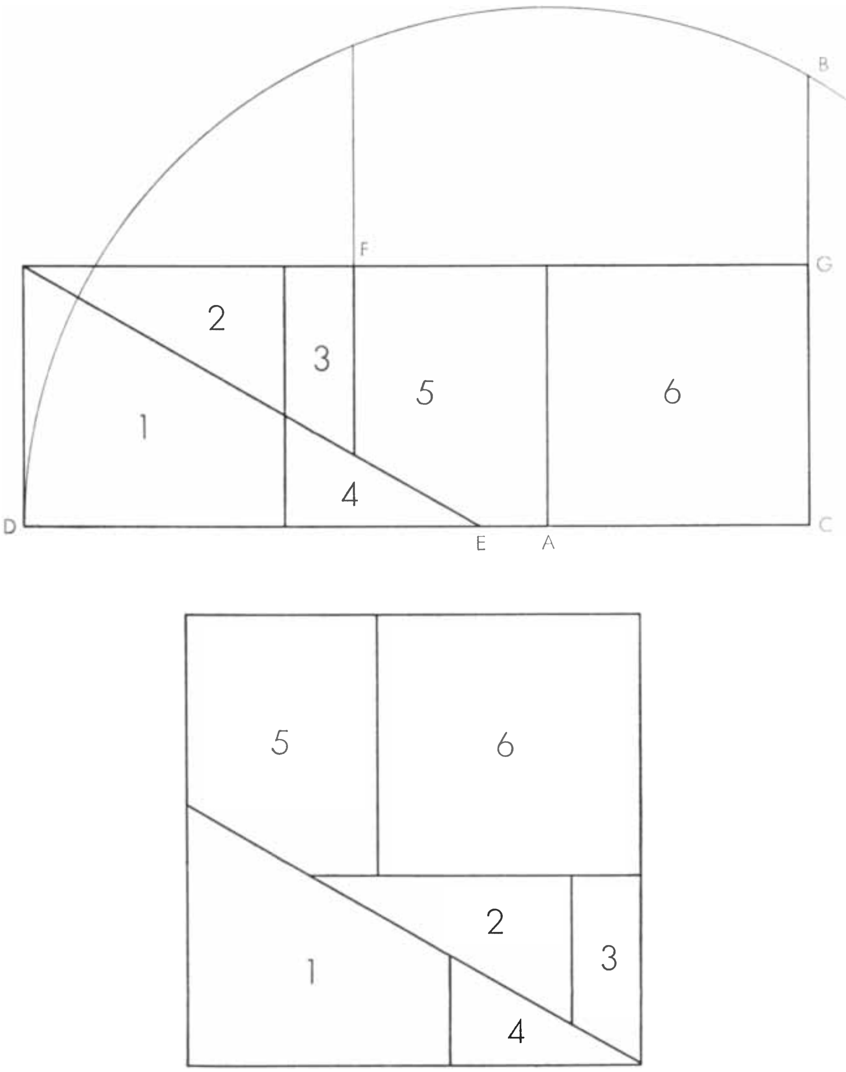
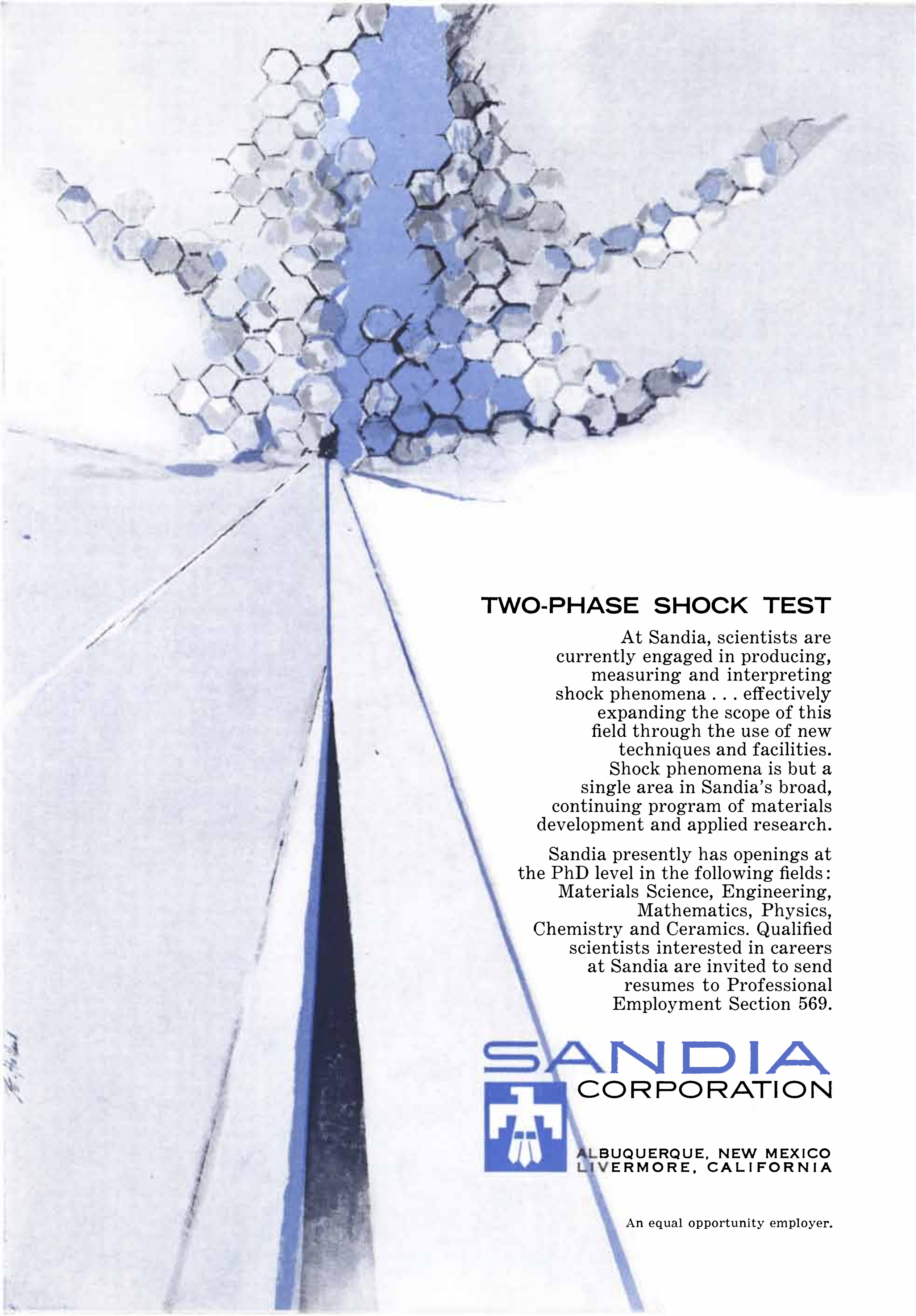
can always be turned over if necessary, but a dissection is considered more elegant if this is not required. Five of the more striking of these dissections are shown in the illustration on page 164. Four are the discoveries of Lindgren; the fifth, the dissection of a Maltese cross to a square, Dudeney attributes to one A. E. Hill. Lindgren's dissection of a hexagon to a square differs from a better known five-piece dissection published by Dudeney in 1901. In cases such as this, where there is more than one way to obtain the minimum number of pieces, alternate dissections are almost always completely unalike. The dissection of a dodecagon to a Greek cross, published by Lindgren in *The American Mathematical Monthly* for May, 1957, is one of his most remarkable achievements. It will be interesting to see how much this chart is altered in the next 10 years as gaps are filled in and previous records lowered.

How does one go about trying to solve a dissection problem? It is impossible to discuss this fully here, but Lindgren has revealed his own methods in two articles ("Geometric Dissections") that appeared in *The Australian Mathematics Teacher* (Vol. 7, pages 7–10, 1951; Vol. 9, pages 17–21, 1953), and more recently in a paper entitled "Going One Better in Geometric Dissections," in the British *Mathematical Gazette* for May, 1961.

One of Lindgren's methods is illustrated at the top of page 167 with respect to a Latin cross and square. Each figure (the two must of course be equal in area) is first cut in some simple way so that the parts will form an endless strip with parallel sides. No cutting is necessary to form such a strip with the square (this strip is shown with broken lines), and the cross requires only one cut to form the strip drawn with heavy lines. Both strips should be drawn on tracing paper. One is now placed on the other and



Six-piece solution to same problem. Draw circle with center at A. BC = DE = FG.



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turned in various ways, but always with the edges of each strip passing through what Lindgren calls "congruent points" in the pattern of the other strip. The lines that lie on the area common to both strips give a dissection of one figure into the other. The strips are tried in various positions until the best dissection is obtained. In this case the method yields the beautiful five-piece dissection shown, by which Lindgren went one better than the previous record of six.

Another method of Lindgren's can be applied if it is possible to make each polygon an element in a tessellation that fills the entire plane. By adding a small square to an octagon, for example, one obtains the tessellation shown with solid lines in the illustration at the bottom of page 167. Superposed on it is a tessellation (shown with broken lines) formed by combining a large square, its area equal to that of the octagon, with a small square of the same size as before. This leads to the dissection of an octagon to a square in five pieces, a dissection first discovered by the English puzzlist James Travers and published in 1933.

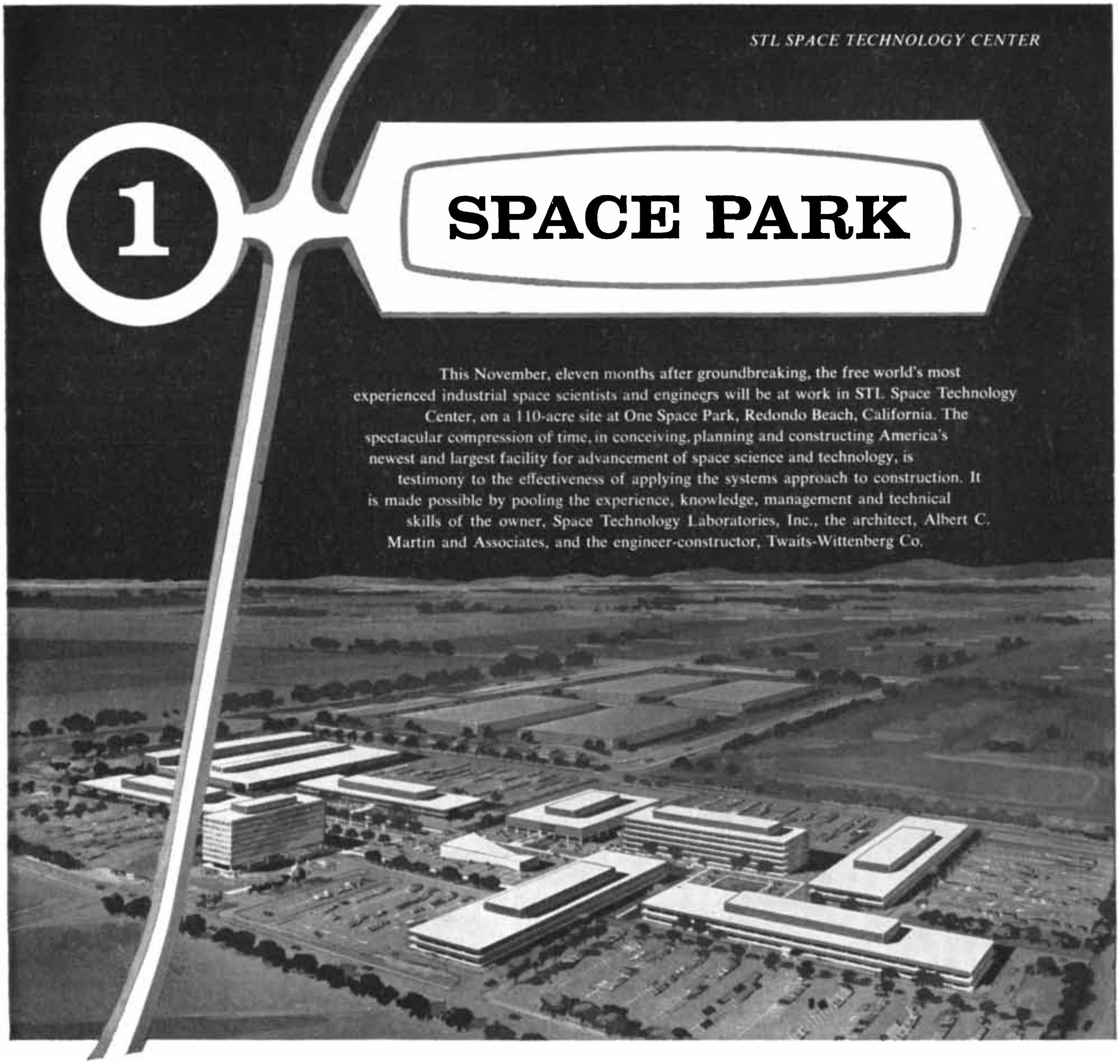
Some notion of Lindgren's virtuosity is conveyed by the fact that he has managed to dissect a square into nine pieces that form either a Latin cross or an equilateral triangle; a square into nine pieces that form either a hexagon or an equilateral triangle; and a square into nine pieces that form either an octagon or a Greek cross. He has also discovered how to cut a Greek cross into 12 pieces that form three smaller Greek crosses, all alike. "Going one better in this case was not easy," he writes with characteristic British understatement, referring to a previous 13-piece record by Dudeney. Cutting a Greek cross to form *two* smaller crosses of the same size is a much easier task that was accomplished by Dudeney with five pieces. Whether he used Lindgren's method of superposed tessellations is not known. In any case, as Lindgren points out, the Greek cross lends itself admirably to dissection by this method. By superposing two such tessellations as shown in the illustration at the top of page 168—one tessellation formed by repetitions of the large cross, the other by repetitions of the small one—Dudeney's solution is immediately apparent.

Few people can examine a dissection such as this one, Dudeney once wrote, "without being in some degree stirred by a sense of beauty. Law and order in nature are always pleasing to contemplate, but when they come under the very eye they seem to make a specially strong appeal. Even the person with no geometrical knowledge whatever is induced after the inspection of such things to exclaim, 'How very pretty!' In fact, I have known more than one person led on to a study of geometry by the fascination of cutting-out puzzles."

The geometrical-dissection field is one of the few branches of recreational mathematics that have found an application around the house. In 1956 Baker's Angel Flake Coconut issued a promo-

SQUARE	4											
PENTAGON	6	6										
HEXAGON	5	5	7									
HEPTAGON	10	9	11	11								
OCTAGON	8	5	9	9	13							
DODECAGON	8	6										
GREEK CROSS	5	4	7	7	12	9	6					
LATIN CROSS	5	5	8	7	12	8	7	7				
MALTESE CROSS		7						9				
SWASTIKA		6						8		9		
FIVE-POINT STAR		8										
SIX-POINT STAR	5	5										
EQUILATERAL TRIANGLE												

Dissection records as they stand today



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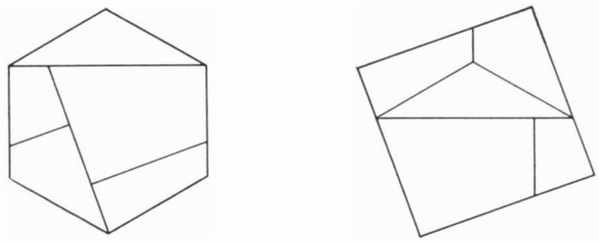
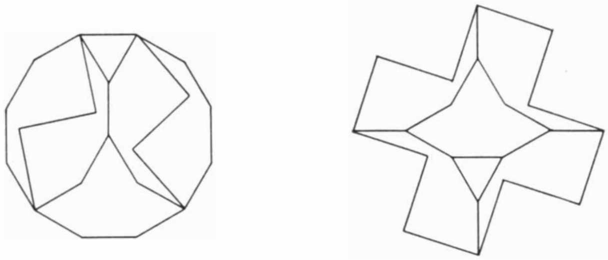
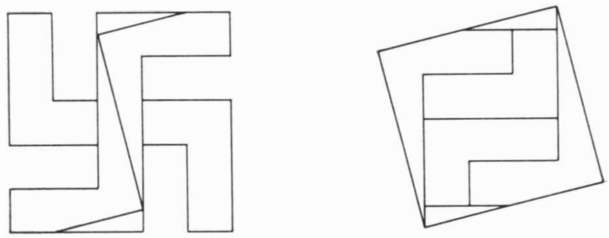
Closely related to the field we have



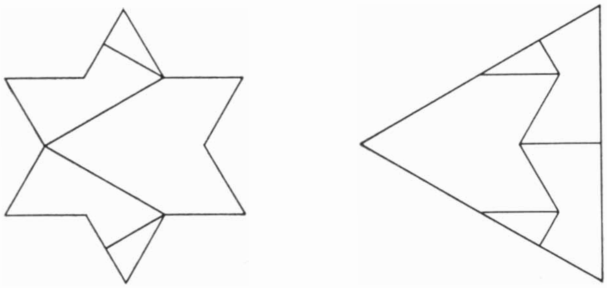
HEXAGON TO SQUARE (FIVE PIECES)



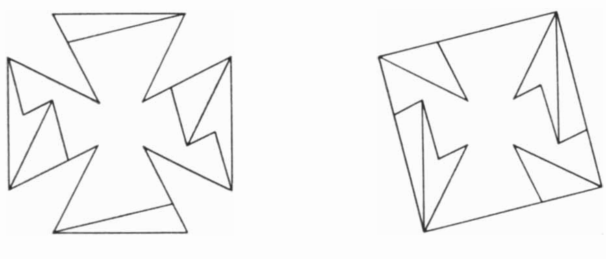
DODECAGON TO GREEK CROSS (SIX PIECES)



SWASTIKA TO SQUARE (SIX PIECES)



SIX-POINTED STAR TO EQUILATERAL TRIANGLE (FIVE PIECES)



MALTESE CROSS TO SQUARE (SEVEN PIECES)

Some surprising dissections

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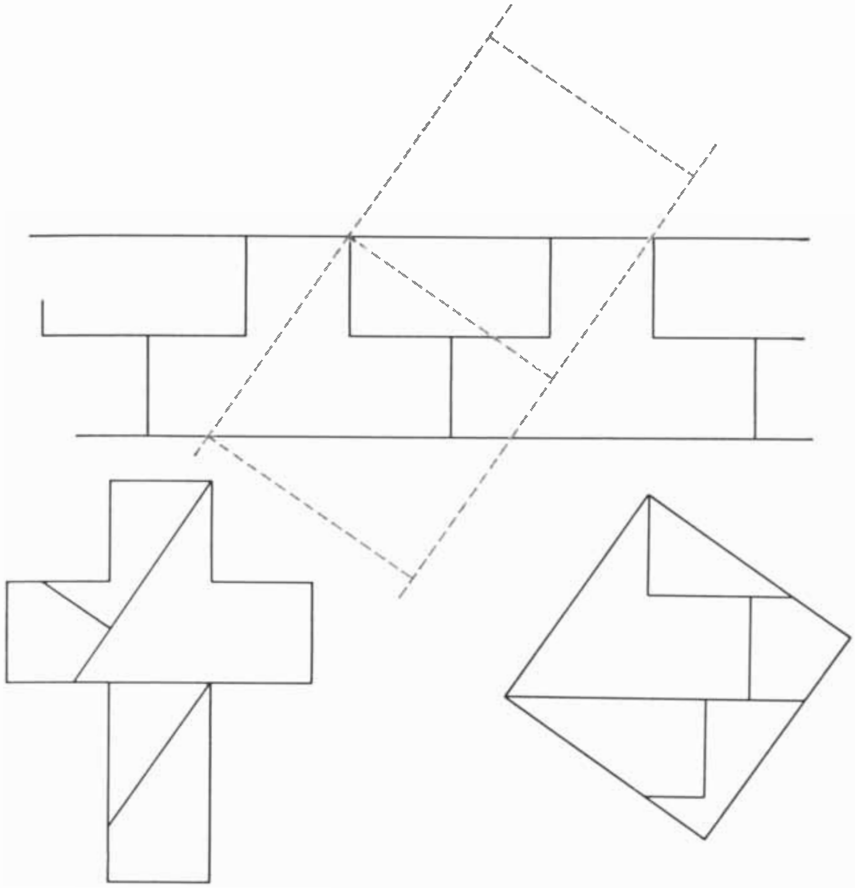
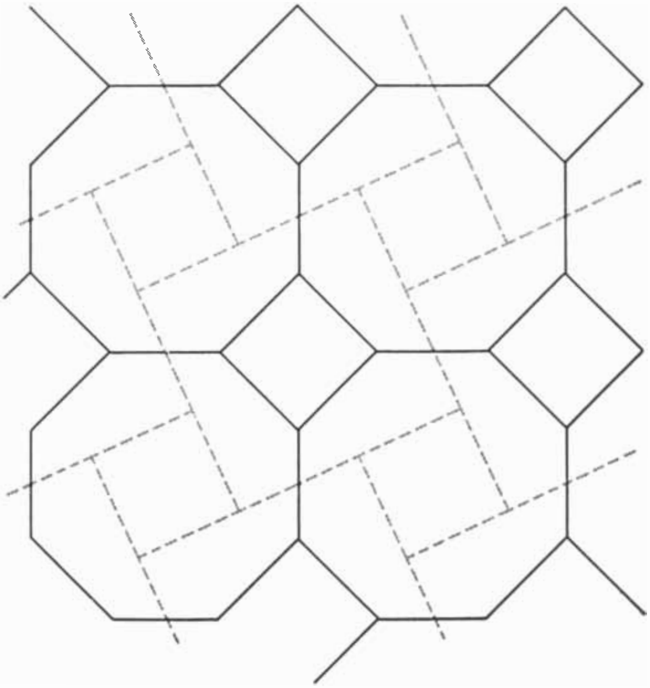
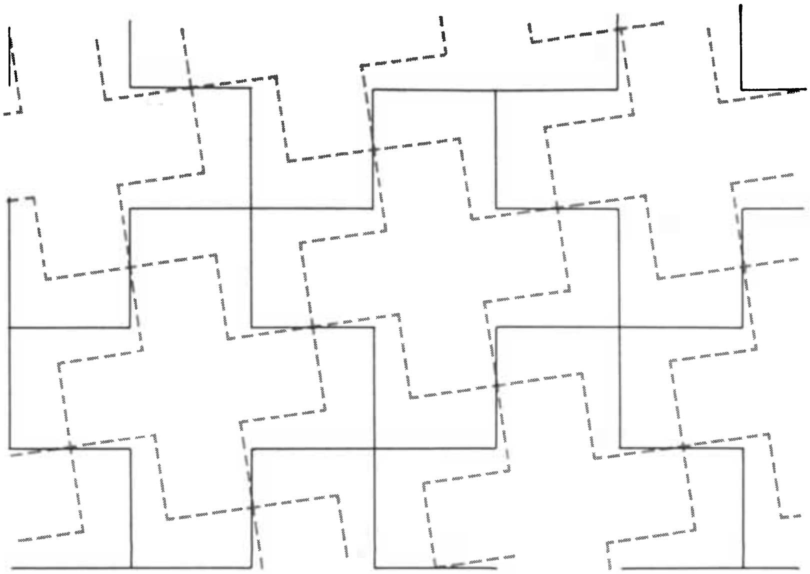


A five-piece dissection of a Latin cross to a square, obtained by Lindgren's strip method

been discussing are those mechanical puzzles, usually made of wood, plastic or cardboard, in which various polygonal shapes are to be fitted together to form certain figures. The ancient Chinese solitaire game of tangrams (discussed in *The 2nd Scientific American Book of Puzzles & Diversions*) belongs to this category. The best of such puzzles are those in which the number of pieces is relatively small but the figures are difficult to make. Such puzzles are not easy to devise. If you take a polygon and slice it more or less at random into smaller pieces, you



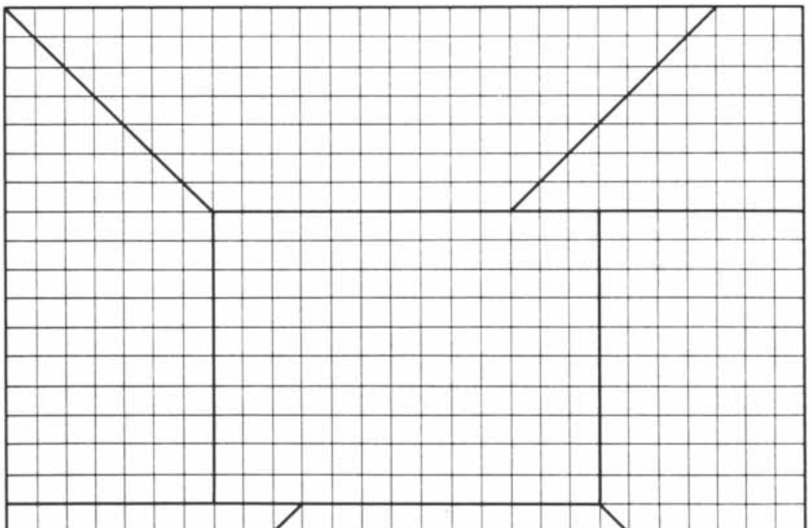
A five-piece dissection of an octagon to a square, obtained by Lindgren's tessellation method



Tessellated Greek crosses are dissected into smaller Greek crosses

are not likely to create a good puzzle because one usually has no trouble in putting the pieces back together properly. To my mind, the best of such puzzles (best, that is, in the disproportion between how easy it looks and how hard it really is) is the *H* puzzle diagramed in the illustration below. The reader is urged to trace the lines on a sheet of heavy cardboard, cut out the pieces carefully and try this puzzle on himself and his friends. It is not well known and it is amusing to time people to see how long it takes them. Pieces may be turned over and used on both sides, so it is a good idea to paint both sides of all pieces the same color.

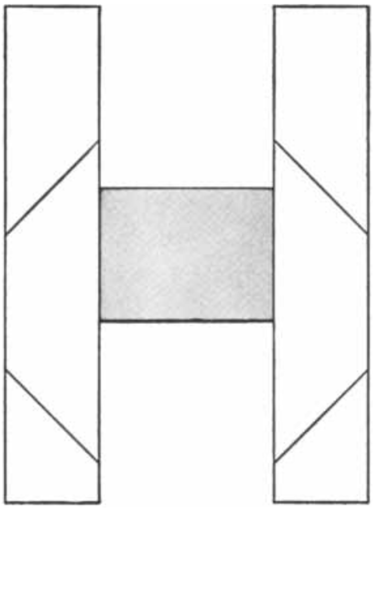
The puzzle is not to form the rectangle but to form a capital *H*. The best way to present the puzzle is as follows. Arrange the seven pieces as shown in the illustration on the opposite page. Now remove the rectangle that forms the horizontal bar of the *H* (the bar is shown shaded in



A rectangle that is dissected into an H *(see illustration on opposite page)* the illustration). The remaining six pieces must now be rearranged to form a slightly smaller replica of the previous *H*. Its proportions will not be exactly the same, but they are reasonably close. All corners of the capital *H* must be right angles, as before. The solution is annoyingly difficult but great fun to discover, so I shall withhold it until next month.

Last month's problem was to find an integral fraction, with no more than three digits above the line and three below, that gives the best possible approximation for the mathematical constant *e*. The answer is 878/323. In decimal form this is 2.71826..., the correct value for *e* to four decimal places. (Note to numerologists: Both numerator and denominator of the fraction are palindromes, and if the smaller is taken from the larger, the difference is 555.) Removing the last digit of each number leaves 87/32, the best approximation to *e* with no more than two digits in the numerator and two in the denominator.

I had hoped to be able to explain the exact technique (first called to my attention by Jack Gilbert of White Plains, N.Y.) by which such fractions can be discovered—fractions that give the best approximations for any irrational number—but the procedure is impossible to make clear without devoting an entire column to it. The interested reader will find the details in Chapter 32 of the second volume of George Chrystal's *Algebra*, a classic treatise recently reprinted by Dover Publications, Inc.



This H *can be made into a smaller* H

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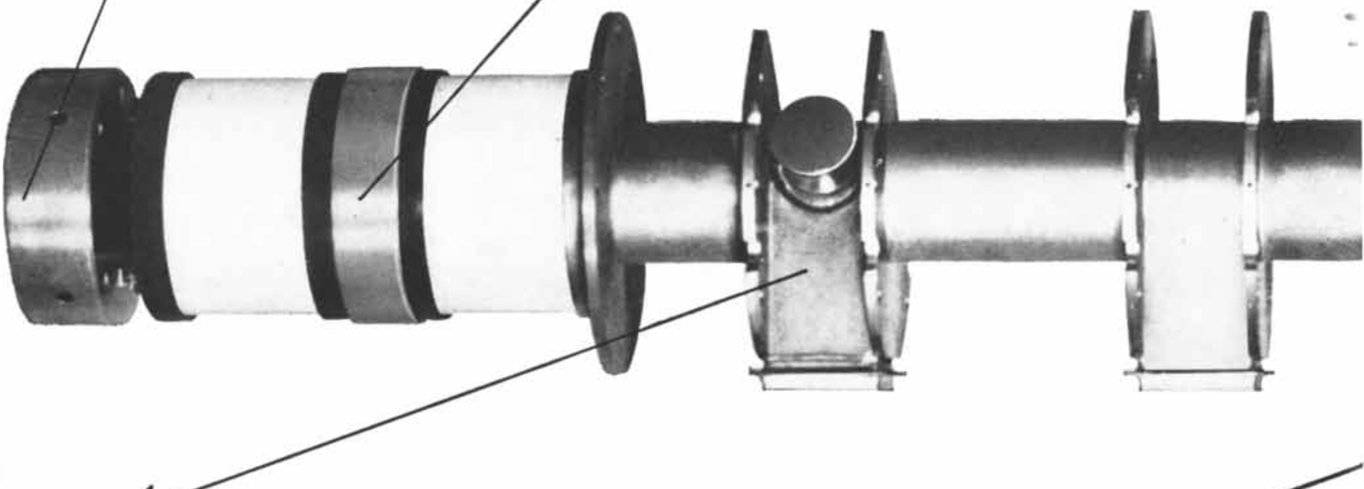

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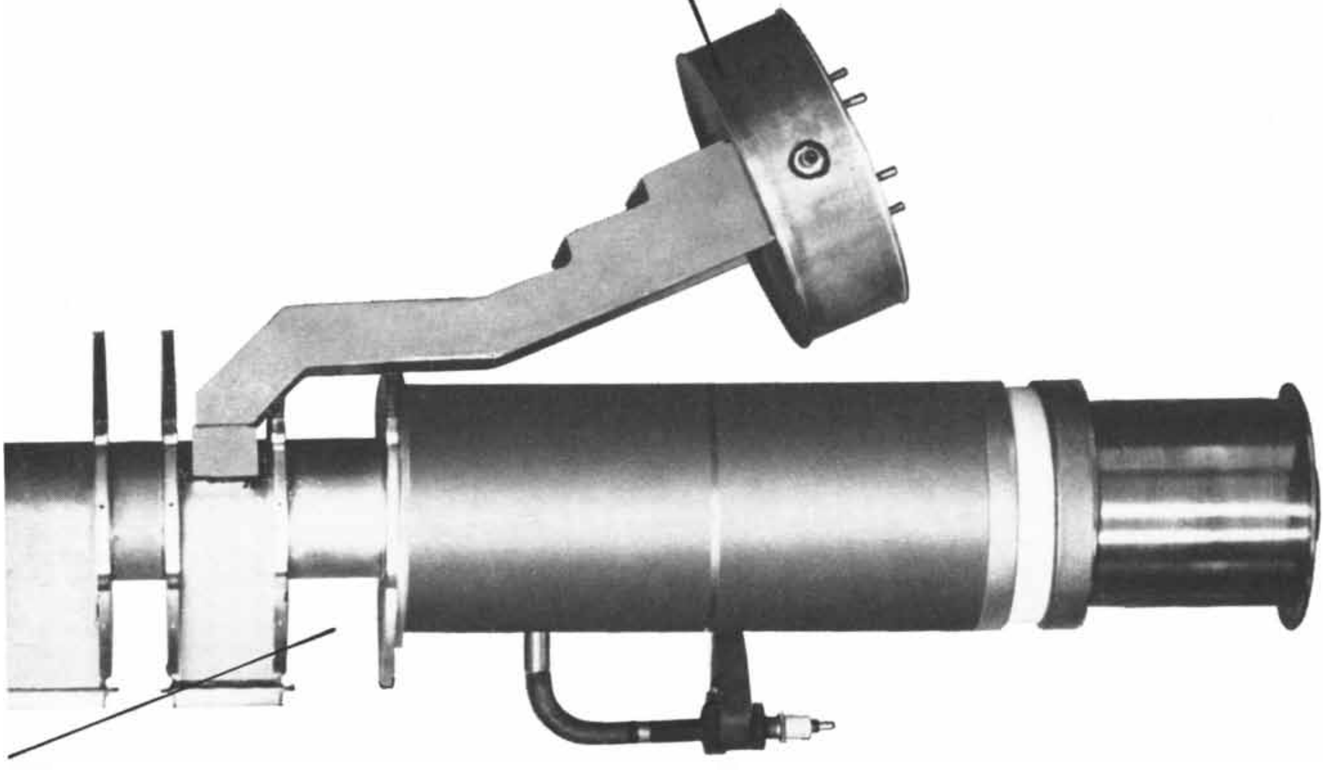

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THE AMATEUR SCIENTIST

A high school student builds a plasma jet generator that attains solar temperatures

Conducted by C. L. Stong

Gas that flows into an enclosed electric arc from the sides and out through an axial perforation in one of the electrodes emerges as a jet of high-temperature plasma, a mixture of ionized particles hotter than the surface of the sun. The hot plasma can be raised to still higher temperature if the jet is directed through a moderately strong magnetic field and a second arc. At this higher temperature substantially all the gas molecules are broken apart and their constituent atoms lose one or more electrons.

Matter in this state opens the way to a number of engrossing experiments [see "The Plasma Jet," by Gabriel M. Giannini; SCIENTIFIC AMERICAN, August, 1957]. Solids exposed to the plasma promptly evaporate—even tungsten, the most refractory substance known. Metals and ceramic compounds that do not mix readily at low temperatures can be evaporated by the plasma and condensed as a composite substance. The plasma itself is highly reactive and on cooling can form interesting compounds. In addition, gases of low atomic mass can be accelerated to impressive velocities. Accordingly the apparatus holds promise as an engine for driving spaceships. It was this property that fascinated Jimmy McAleer, a high school student of Mobile, Ala. At 16 he decided to construct a plasma jet apparatus and determine its thrust. The project went so well that he wound up at the top in this year's National Science Fair.

"A plasma jet is not difficult to build," he writes, "after you solve two problems. First, you have to learn the construction details: the size and shape of the parts, the kind of materials to use, the amount of current required by the arcs, the precautions to take and so on. In my case this was not easy. I located several general descriptions of the apparatus in our local library, but the details had to be discovered at the workbench. This required more experience than I had, so I enlisted the help of David Martin, an electrical engineer, as my adviser on the project and conferred with Father L. J. Eisele, S.J., of Spring Hill College in Mobile and F. E. Marsh of Bell Aerosystems in Buffalo, N.Y.

"The second problem is to learn how to adapt ordinary supplies to the special requirements of the apparatus. For example, I found that the main arc, the one that generates the plasma, required 150 amperes of direct current at about 50 volts. At this voltage and current the arc consumed 7.5 kilowatts, a power requirement considerably beyond the capacity of ordinary house wiring. I finally hit on the idea of using a string of automobile storage batteries connected in series. Moreover, the voltage had to vary inversely with the current to maintain the arc in stable operation. To induce this drooping voltage characteristic I inserted a carbon welding rod in the circuit to act as a ballast resistor. During the first experiment the rod became white hot and burned up, so I submerged the next rod in a bucket of water. The heat brought the water to a boil in about three minutes—which did not matter because the arc never operated that long at one stretch.

"After talking with my advisers, I decided to use helium for the gas because it is both inert and of low atomic mass. Hydrogen has lower atomic mass than helium and therefore can be accelerated to a higher velocity, but it can also combine with air to form an explosive mixture. I also thought of using nitrogen, primarily because it is inexpensive and does not explode. But the atomic mass of nitrogen is greater than that of helium and it can react with ionized carbon in the plasma to form the poisonous gas cyanogen. In the course of asking about these and other gases in our local welding shops I learned that helium cylinders returned to the gas suppliers for refilling normally contain a little gas, more than enough to supply the plasma jet for several operating cycles. One shop agreed to let me drain the 'empties' without charge.

"All the other materials used in constructing the jet were purchased at hardware and automobile-accessory stores or were salvaged from scrap. The parts were made and assembled with hand tools, with three exceptions: I had access to a lathe at school for machining a steel sleeve that supports the negative electrode of the main arc and for drilling an accurately centered hole in the positive electrode. And a local welding shop helped by brazing some of the parts."

During his summer vacation Jimmy visited New York City and brought his apparatus along so I could see how he put it together. It consisted of two major parts: the plasma assembly, a water-cooled arc chamber in which a slender carbon rod is supported in axial alignment with a perforated carbon electrode; and the accelerator assembly, composed of an electromagnet and a second pair of electrodes at right angles to the field of the electromagnet, as shown in the schematic diagram on the next page. Gas enters the chamber at slightly more than atmospheric pressure and escapes through the perforated electrode, a short length of thick carbon rod. The arc forms between the inner end of the perforation and the tip of the solid electrode. The magnetic and electric fields of the accelerator lie in two planes, each perpendicular to the jet. The apparatus will operate in any position but is usually run with the jet pointing up so the heat is carried away by rising air. The plasma emits intense ultraviolet radiation that extends into the region of soft X rays and must therefore be shielded by a housing of thick sheet metal equipped with a window of ruby glass, as shown in the drawing on page 177.

The apparatus requires three separate sources of direct current; these can be automobile storage batteries or a combination of batteries and an arc welding generator. The principal arc operates at

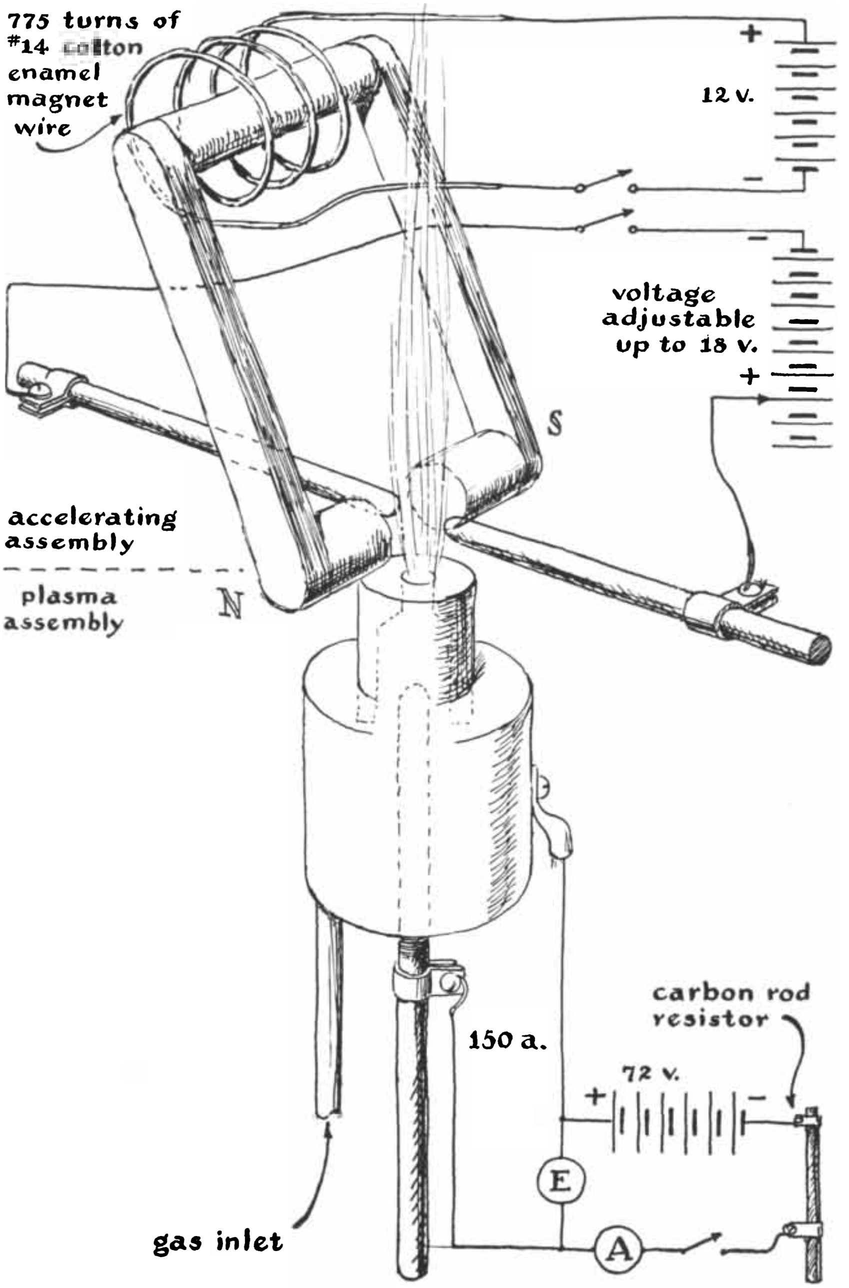
150 amperes and, with the included ballast resistor, requires a 72-volt source. Jimmy found that a bank of 12 fully charged six-volt batteries connected in series will supply power for eight duty cycles of three minutes each. The electromagnet of the accelerator draws 12 amperes at 12 volts from a second bank of batteries. The accelerator electrodes require about 15 amperes. This current is taken from a string of three batteries and is adjusted to the desired value experimentally by shifting the connection of the positive lead (by means of a battery clip) to one or another of the cells.

The arc chamber may be constructed of heavy copper or bronze pipe of three different diameters, closed by end plates in the form of perforated disks cut from sheet stock of about the same weight as the pipes. Only one dimension is critical: the inside diameter of the smallest pipe should make a snug fit with the perforated carbon rod. The inside diameters of Jimmy's tubes are 1 inch, 2½ inches and 3½ inches. The lengths are ⅞ inch, 1¼ inches and 2 inches respectively. His end plates were cut in the proportions shown by the cross-section drawing on page 178 and brazed to the tubing. Water enters the cooling chamber tangentially through an inlet of ⅛-inch copper tubing, as shown. Brass studs were threaded into the end plates and brazed to support a disk of Transite, an asbestos composition board, which closes the back of the cooling chamber. These studs were made long enough to engage a pair of strap-iron brackets that support the assembly above the base of the housing. A similar pair of studs extends from the upper end plate for attaching the Transite base of the accelerator assembly. Gas enters the chamber through a ⅛-inch copper tube brazed to the steel sleeve that supports the solid electrode. The sleeve is drilled as shown to make a running fit with the ¼-inch welding rod of carbon that acts as the negative electrode.

The positive electrode is a 1½-inch length of heavy-duty carbon welding rod one inch in diameter. The cut ends were dressed to a right angle on a lathe. A ¼-inch hole, accurately centered, was then drilled axially to a depth of ¼ inch in one end of the electrode and a ¾-inch hole was drilled from the opposite end to meet the ¼-inch hole. The action of the arc causes the positive electrode to erode rapidly and it must be replaced after about three minutes of operation. The spent electrode is driven from the tube by means of a wooden punch and a new electrode is then forced into the tube. The high current drawn by the arc requires that the resistance of the contact between carbon electrode and cooling chamber be made as low as possible. Hence, the fit between the two should be tight and the copper kept clean.

The arc assembly is attached to a base of Transite by two strap-iron brackets, as shown in the drawing on page 177. Electrical, water and gas connections enter the housing through holes in the base as shown. The negative electrode is moved up and down by a flexible cable of the type used to actuate carburetor chokes in automobiles. The plunger of the choke cable serves as a control for striking the arc and adjusting its length.

The core and pole faces of the electromagnet were cut from soft steel shafting and assembled to the accelerator base by a pair of angle brackets as shown in the drawing on page 180. The coil draws about 150 watts and is designed for a three-minute duty cycle every 15 minutes. The plane that includes the center of the magnet should cut the plasma about ½ inch above the end of the positive electrode. The axis of the accelerator arc is located about ⅛ inch higher. The steel core of the electromagnet is fitted with spool ends of For-



Schematic diagram of Jimmy McAleer's plasma jet

How to show the sky in stereo

Up till now, radar has literally been blind in one eye. It lacked one of the prime dimensions—depth perception. Conventional radar could only show objects in two dimensions. Either direction and distance *or* height and distance.

This limitation often makes radar lag behind the pace of modern aircraft—forcing planes to slow down in the busy intersections over airport areas.

But now the other eye has been opened. Hughes' new 3-dimensional—or stereoscopic—radar presents a scaled-down "cylinder of sky." Watching this radar, you could see the earth, the air space above and aircraft represented with a definition never before possible. The result: planes could move through busy intersections with new speed and safety.

This new radar display console—called Stereoscan—has two Hughes Tonotron* picture tubes which are combined to make this startling 3-dimensional view possible. Because they remember images—they produce a radar picture where the "blips" leave contrails like a jet. It is these patterns that clearly show the direction *and* altitude *and* distance which separates the planes.

This improved radar display is also more accurate, easier to view and can be used under normal room lighting.

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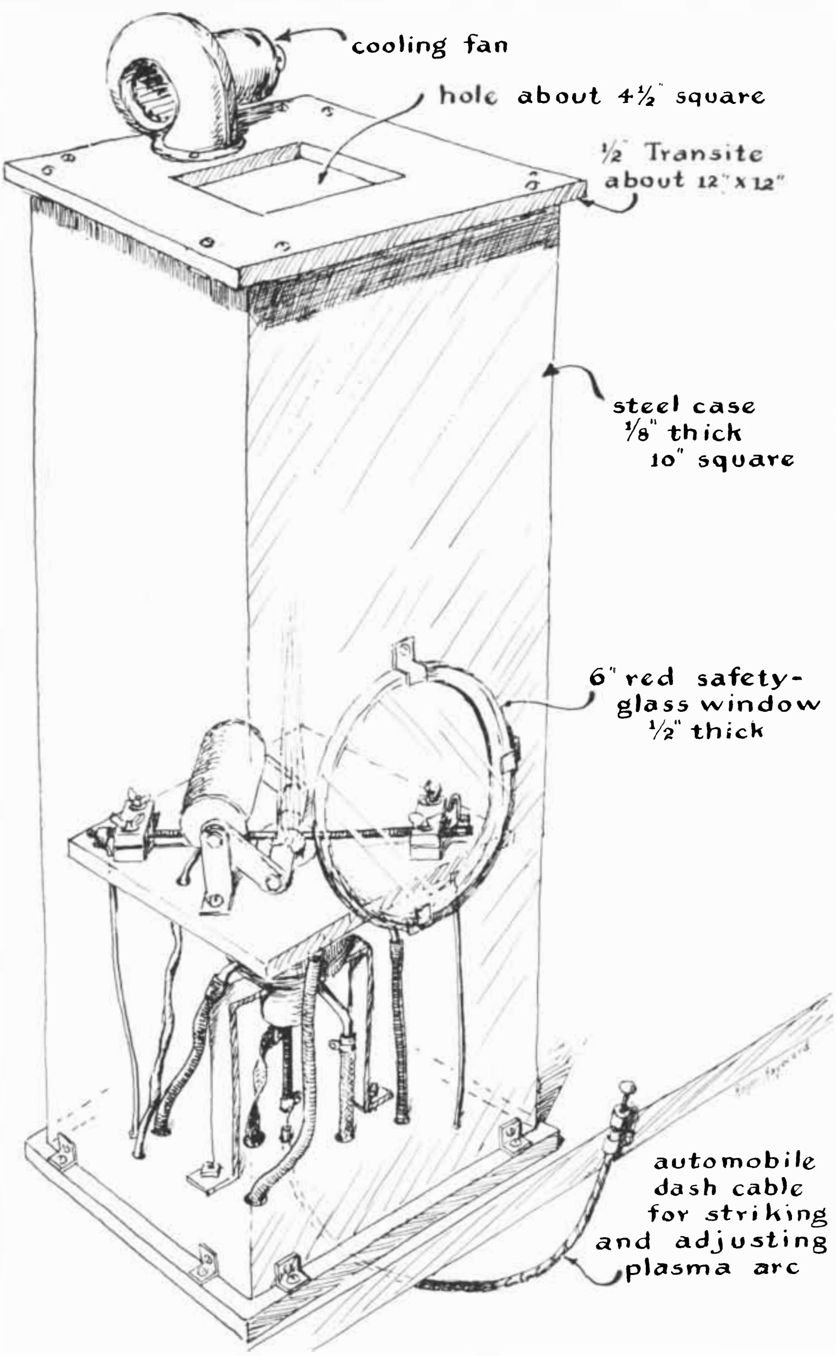


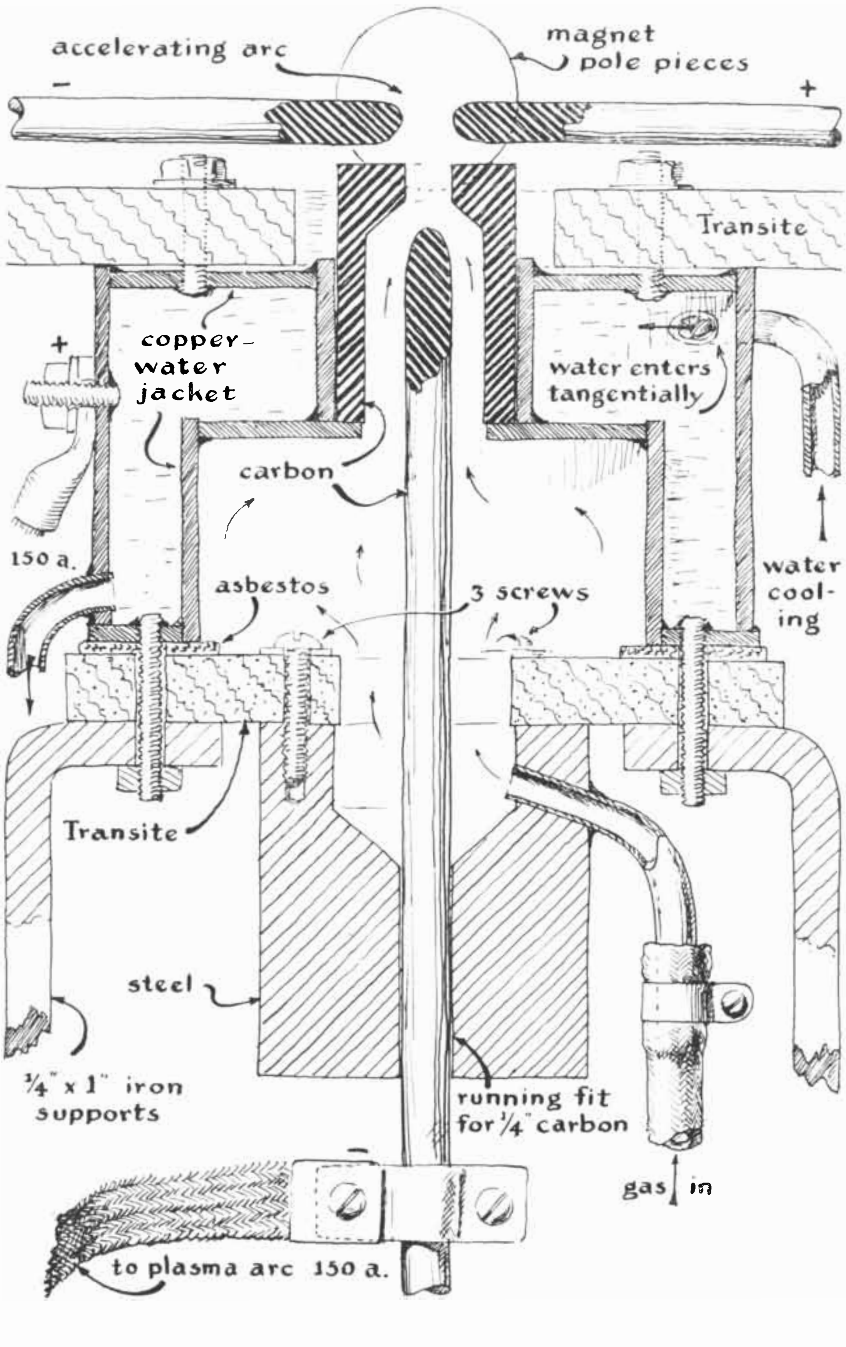
Assembled jet enclosed by sheet-metal shielding

mica and insulated by a single wrapping of plastic tape. The outer layer of the winding is similarly taped and, in addition, wrapped with a double layer of asbestos paper fastened in place by heat-resistant cement. The electrical connections to both the coil and accelerator electrodes (¼-inch welding carbons) are made by heavy flexible leads of the type used for wiring automobile headlights. The tips of the accelerator electrodes are spaced about ⅜ inch apart.

The positive lead of the plasma arc is standard automobile starter cable and the negative lead is flexible copper braid of the kind used for grounding the battery to the frame of automobiles. The saddle clamp for attaching the braid to the negative electrode of the plasma arc is made of ⅛-inch strap copper about ½ inch wide. The U bends in the halves of the clamp must make a good fit with the carbon. The clamp should be attached to the negative carbon rod so that it is within about ⅛ inch of the steel supporting sleeve when the rod is in contact with the positive electrode. This minimizes the portion of carbon rod that conducts current but allows the electrode enough upward movement so the arc can be struck.

The dimensions, shape and materials used for constructing the housing are not critical. The enclosure should be large enough and sufficiently well ventilated to dispose of the heat, and for safety must be made of materials sufficiently opaque to shield the experimenter from radiation. Doors of the shielding material may be provided for exposing materials to the plasma as required.

For convenience, an instrument panel should be provided that includes at least one voltmeter and one ammeter for monitoring the power drawn by the plasma arc, together with on-off switches for each of the three circuits. The panel can also serve as a mounting for the plunger that actuates the negative electrode. Jimmy's panel was made of plywood. He used separate voltmeters and



Cross-section diagram of the plasma jet

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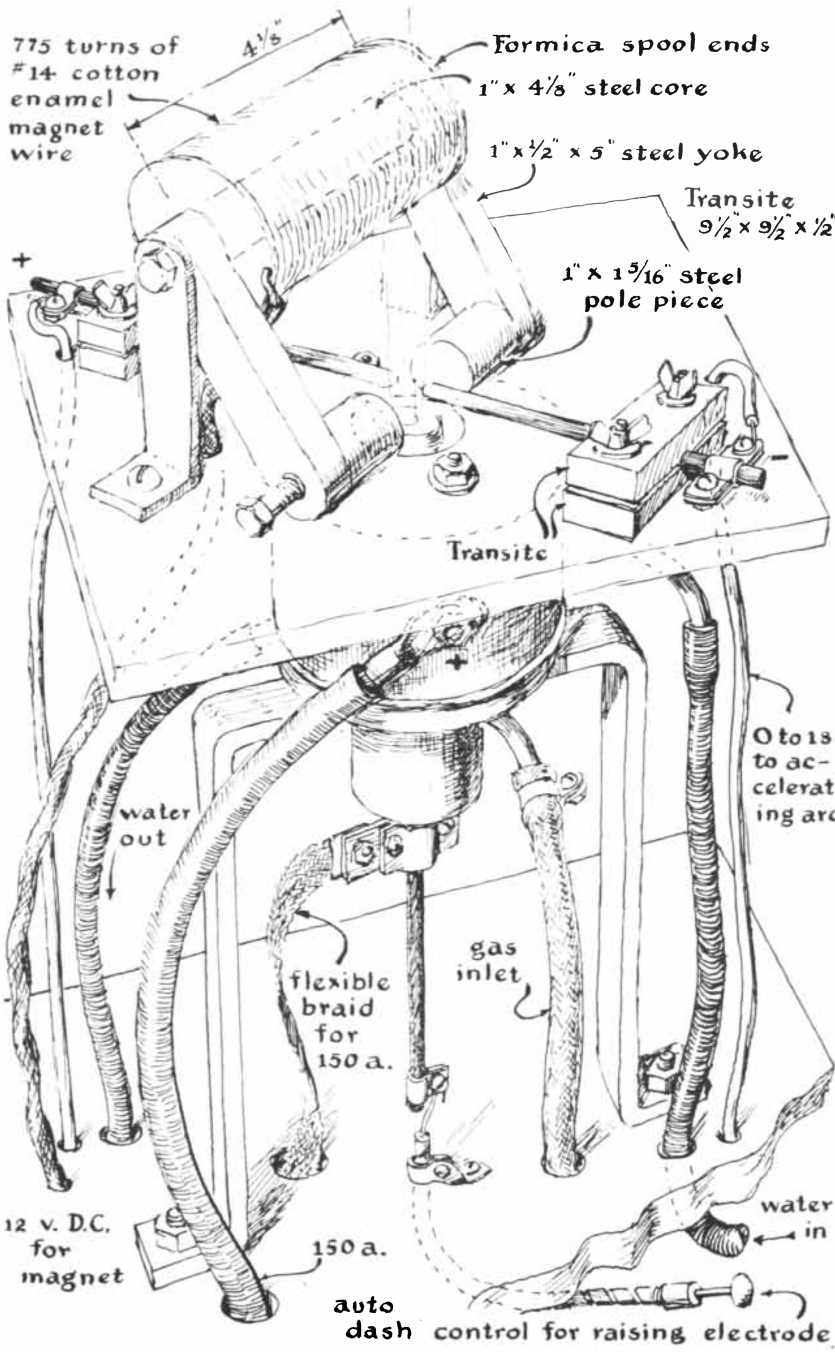
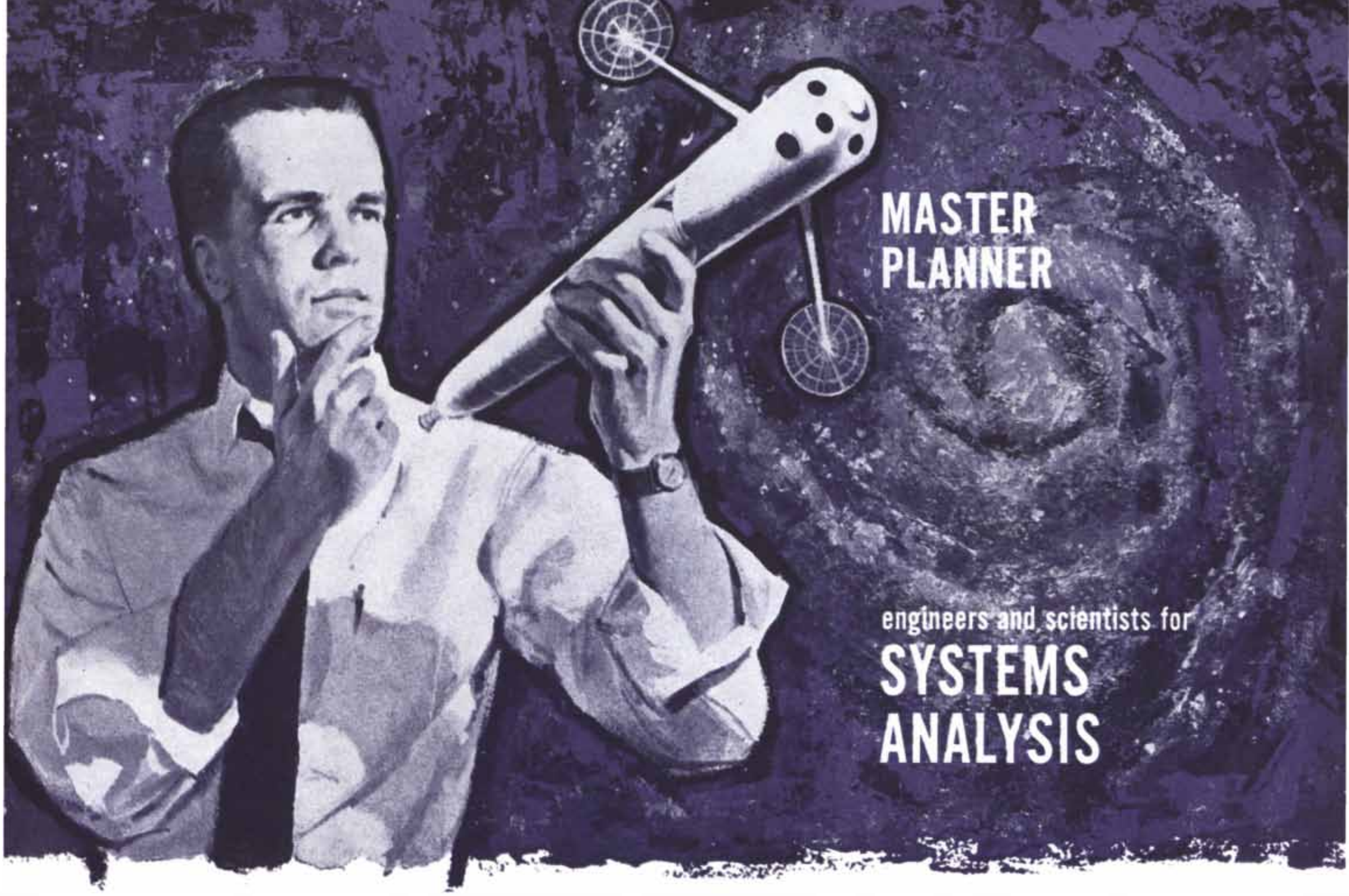


Accelerator unit mounted above the plasma assembly

ammeters to monitor the accelerator circuits, but the panel could be equipped with appropriate shunts and instrument switches for monitoring all circuits sequentially with one voltmeter and one ammeter.

"You must follow a definite sequence of operations when starting up the apparatus," Jimmy writes. "I learned this the hard way. After assembling the parts of my first jet and making sure that the connections were hooked up properly, I struck the main arc. In seconds the arc chamber was reduced to a splatter of molten copper in the bottom of the housing. I had neglected to turn on the cooling water! This must be done first. (I used a small centrifugal pump to circulate water through the chamber from a three-gallon reservoir. A two-minute duty cycle raises the temperature of the water from 60 degrees Fahrenheit to about 160 degrees.) The gas is then turned on and adjusted to a flow rate of about 20 liters per minute. (I calculated the rate of flow in terms of pressure,



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measured with a homemade manometer.) The arc is then struck by operating the choke plunger, its length adjusted for stable operation and a reading made of the current. If the current is higher or lower than 150 amperes the apparatus is shut down. Then the effective length of the ballast resistor is adjusted in the appropriate direction by moving one of its contacts, saddle clamps like the one that connects the flexible copper braid to the negative electrode of the plasma arc.

"When it is operating smoothly at 150 amperes, the plasma, as viewed through dark ruby glass, resembles a welding flame about four inches long. According to the articles I have read its temperature is on the order of 15,000 degrees F. The electromagnet of the accelerator is then switched on. This makes the plasma flame spread and bend toward one side, accelerating it. Voltage is then applied to the accelerator electrodes and adjusted until the jet is straight and as long as possible—about eight or 10 inches. The jet becomes quite noisy when power is applied to the accelerator and emits a characteristic hissing sound when the accelerator voltage is properly adjusted.

"I wanted to measure the thrust of the jet directly, and still intend to do so. My first measuring apparatus did not work, however. It consisted of a baffle linked to a spring balance, and I hoped to determine the thrust by measuring the force the jet exerted against the baffle. But the plasma vaporized every baffle that I made, including those of alumina and zirconium oxide. I wanted to enter the apparatus in our local science fair and did not have time to develop a reaction balance. So I decided to measure the temperature and compute the thrust. I borrowed an optical pyrometer, with a maximum scale of 3,700 degrees F., from a local steel firm, but the tungsten filament of the pyrometer did not come even close to matching the intensity of the plasma stream. I then placed a heavy wire of tungsten in the plasma. It vaporized instantly. This meant that the temperature had to be above 6,173 degrees Kelvin, the boiling point of tungsten. So I decided to settle for this value and compute the equivalent thrust.

"Reference texts state that the energy of molecular vibration is equal to half of the product of the mass of the molecule multiplied by the square of its velocity. The energy is also equal to three halves of the product of the absolute temperature multiplied by Boltzmann's constant.

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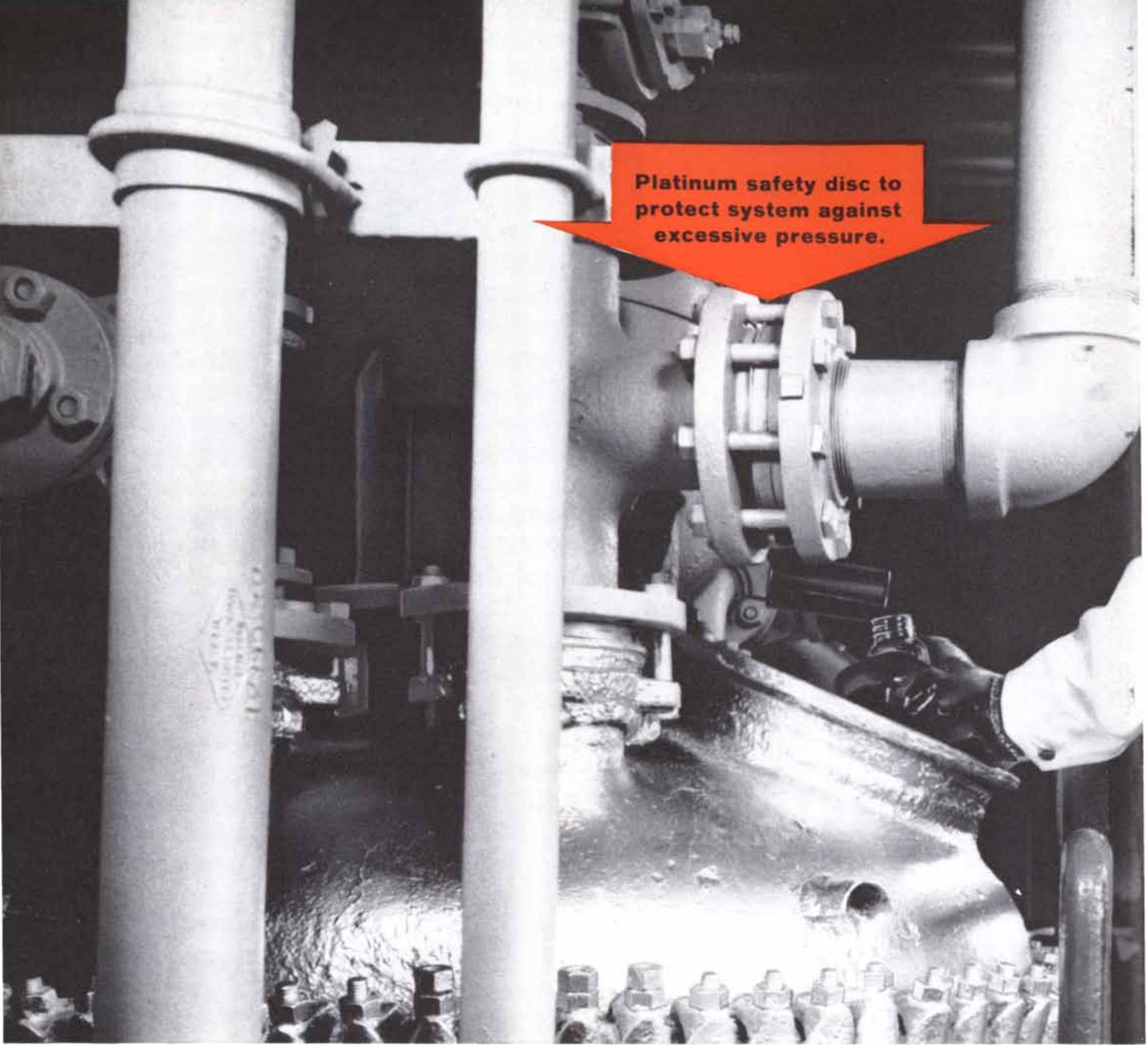
The velocity is therefore equal to the square root of three times the product of Boltzmann's constant and the temperature divided by the mass of the molecule. Boltzmann's constant is equal to 1.38 times 10^{-16}, and the mass of the helium atom is 6.68 times 10^{-24} grams. At a temperature of 6,173 degrees the velocity of the particles is therefore 6.19 times 10^5 centimeters per second, or 22,400 feet per second.

"The thrust exerted by a jet is equal to the product of the rate of propellant flow in pounds per second and the velocity in feet per second divided by the acceleration of gravity (32 feet per second per second). In the case of my jet the propellant flow is .00013 pound per second. The force is therefore equal to .00013 times 22,400 divided by 32, which amounts to .09 pound.

"Another criterion frequently used to indicate the effectiveness of rocket fuels is 'specific impulse,' which is the thrust developed by burning one pound of fuel in one second, or the ratio of thrust to the mass of fuel flow. It is expressed in seconds. For the assumed temperature (6,173 degrees Kelvin) the specific impulse of my jet is equal to .09 divided by .00013, which comes out to 700 seconds. Actually 6,173 degrees is a very conservative assumption. At the more likely temperature of 30,000 degrees the figure would be on the order of 1,500 seconds. In contrast, the specific impulse of conventional chemical fuels such as zinc and sulfur is listed at 20 seconds, that of hydrogen peroxide and hydrazine at 240 seconds, and oxygen and hydrogen at 345 seconds.

"I am now constructing another setup for measuring the thrust directly. Turning the jet so that its axis is horizontal, I have suspended the entire assembly as a pendulum bob at the bottom of a four-foot curtain rod. The suspension hinge is a feeler-gauge leaf .004 inch thick. Cooling water is lifted from a reservoir by a siphon attached to the pendulum rod and is discharged into a catch basin. The electrical leads run up the pendulum rod to small containers of mercury that are connected to the power sources. The gas flows to the jet through a length of thin-walled, flexible tubing. During an initial test run the jet deflected the assembly more than an inch out of plumb. Now I plan to run a thread from the bottom of the suspended jet assembly over a small pulley to a weight pan. Then I hope to measure the thrust by loading the pan just enough to pull the assembly back into plumb and weighing the load on an analytical balance."



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Sulfamethazine, a broad spectrum sulfa used primarily in the veterinary field, is manufactured at American Cyanamid Company's Bound Brook plant. Highly corrosive materials handled in the reactor used in production runs of an intermediate, put the entire processing system under constant corrosion attack.

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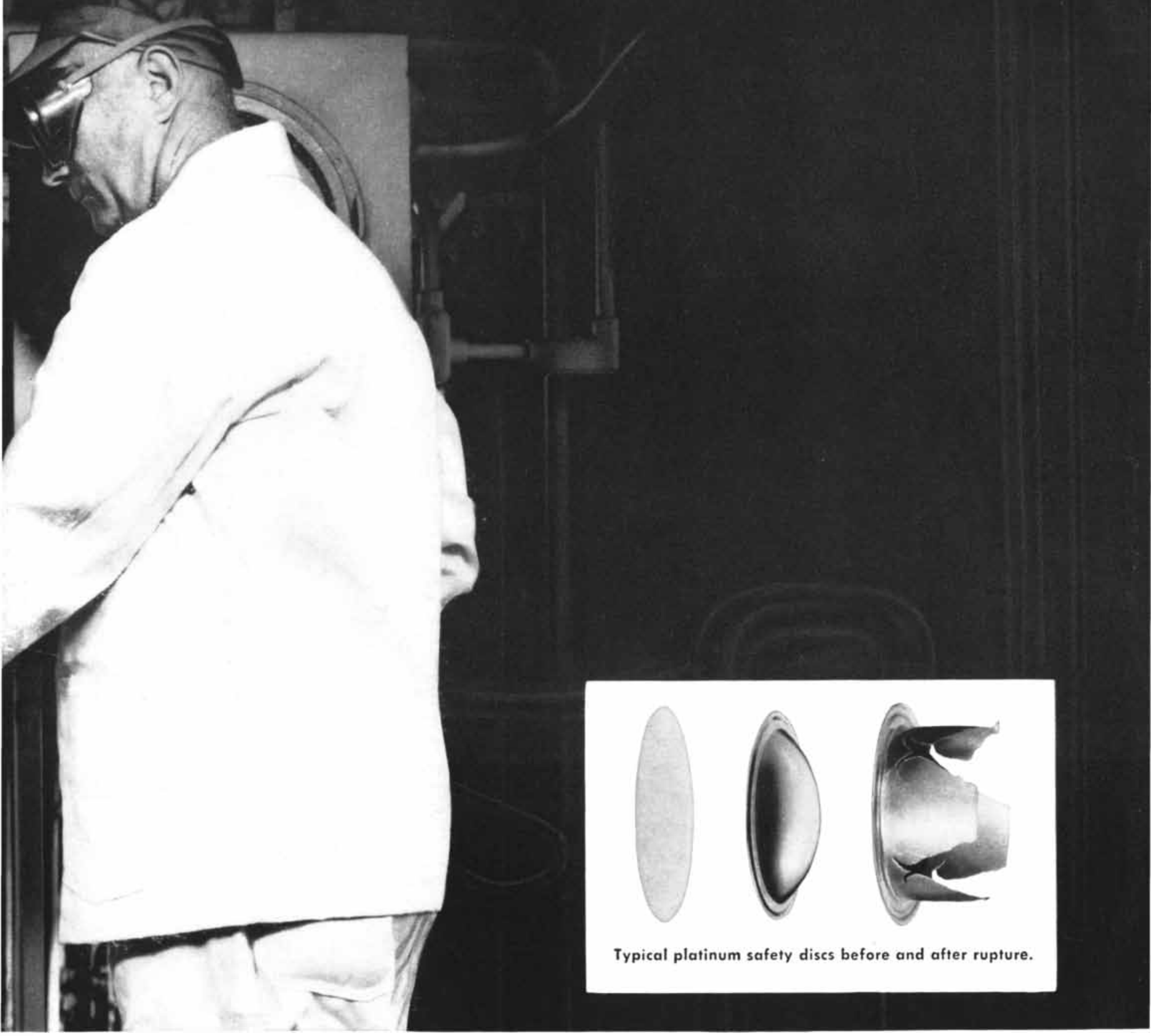

Typical platinum safety discs before and after rupture.

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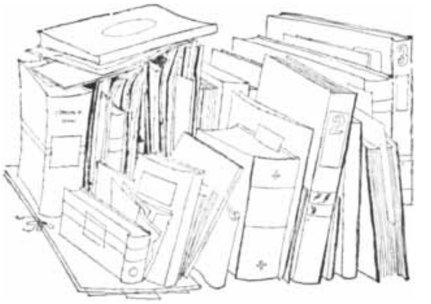

BOOKS

Does the view that science can solve all problems hamper the pursuit of science?

by Ernest Nagel

THE DREAMS OF REASON: SCIENCE AND UTOPIAS, by René Dubos. Columbia University Press ($5).

This gracefully written, frequently wise but occasionally puzzling book is based on the George B. Pegram Lectures that René Dubos delivered at the Brookhaven National Laboratory in 1960. Its title is borrowed from a famous etching by Goya that portrays a man with his head buried in his arms on a desk, surrounded by nightmarish figures of bats, owls and a witch's cat; on the side of the desk is a legend that in translation reads: "The sleep of reason produces monsters." Dubos does not place the usual interpretation on this inscription: that men become prey to superstitions and fears when their reason slumbers. He takes it to mean, though without saying why he rejects the customary reading, that utopian beliefs in endless progress toward human perfection, to be attained by a science geared to developing increasingly powerful technologies, are undisciplined dreams of reason—dreams which if acted on create monstrosities and become grave threats to the continuance of an intellectually emancipating science. In consonance with this interpretation he devotes a good fraction of his book to a critique of various programs that rest on what in his opinion is at bottom an irrational confidence in the ability of scientific reason to solve all the problems of mankind.

This critique is, however, only ancillary to the book's main objective. In his opening autobiographical chapter Dubos, now an eminent microbiologist, reveals that as a young student in France he looked on science as a body of principles and facts that had been acquired to satisfy a natural desire to understand the world. He also confesses that "the utilitarian aspects of science have never loomed large in my vision, and, while I recognize their importance in the abstract, my intellectual and emotional involvement in them has always been lukewarm." Indeed, he argues at length that the evaluation of science in terms of its contributions to technology is a distinctively modern tendency which began with the Renaissance; and while he acknowledges that scientific discoveries were used in earlier centuries to control the course of events, he describes Francis Bacon as the first important advocate for the systematic mastery of nature through science and as the real prophet of our technologically minded civilization.

Dubos is no longer as confident as apparently he once was that science has significantly advanced our understanding of the world. But he continues to believe that the classical image of science, which represents scientists as dedicated seekers of comprehensive truth for its own sake, gives a juster account of the motives animating their investigations than does the conception that the chief impulse in their work is the desire to achieve practical ends. He examines the familiar accusation that as a result of increasingly narrow specialization scientists have become learned ignoramuses, with a trained insensitivity to realms of experience centrally important to the rest of humanity. He maintains that, on the contrary, scientific activity has always been strongly influenced by the aspirations and philosophical beliefs of mankind, and that contemporary scientists in particular are profoundly concerned with the broad implications and social consequences of their work. His book thus disputes the much discussed view that the sciences and the humanistic studies represent two disparate cultures. Dubos thinks scientists are partly responsible for the hostility that professional science often encounters, in good measure because of their disinclination to communicate to laymen the nobler but less intelligible aspects of their discipline. His book attempts to help remedy this failure, and its primary aim is to show that in essence science is a humanistic enterprise.

Dubos' basic criticism of utopian blueprints inspired by a vision of science is that they mistakenly assume that the circumstances of human life are indefinitely stable and thereby fail to allow for the new problems that continually arise with the ongoing changes taking place in the physical and social environment. For example, his informative chapter "Medical Utopias" argues that although many familiar diseases may be eradicated, unpredictable modifications in man's surroundings generate new ailments, so that the burden of disease is not likely to decrease, even if it is assumed that major medical advances are bound to continue. He therefore thinks it is a dangerous illusion to suppose that health, conceived as freedom from pain and debility, is a human birthright that medical science can secure, and more generally that "science will find a way" to solve all our problems. He believes, moreover, that while extreme adversity is certainly not conducive to human weal, a measure of stress and risk is indispensable for the development of human excellence.

Dubos' discussion of the dream that science can create an untroubled heaven on earth is full of sage observations, and his central criticism of this illusion is undoubtedly sound. It is nevertheless questionable whether any important thinker who projected an ideal future was quite as naïve in doing so as Dubos assumes. The great utopian writers from Plato on (not excluding Condorcet, whose ideas Dubos examines) were obviously perturbed by certain features of their own societies that they believed to be unjust or otherwise undesirable. The primary concern behind their visions is therefore best understood as having been directed toward convincing a wide public that these features were indeed deplorable, persuading their audiences that those specific evils were remediable and proposing ways for correcting those evils, rather than toward eliminating once and for all every source of human discontent. A similar interpretation is needed to do justice to the intent of those who advocate the systematic use of science for satisfying the needs and realizing the hopes of mankind. Accordingly Dubos' criticism of ostensibly utopian schemes for harnessing science to utilitarian ends is not so decisive as may first appear. The criticism is conclusive only on the premise that by remedying one evil we are sure to create a greater one.

Dubos certainly does not accept this premise as a universal truth, although he rightly notes that no assured grounds exist for the belief that the fresh problems which may emerge when old ones are resolved will undoubtedly be less grave and easier to solve. But he gives far less emphasis to the equally sound point that there are no compelling general reasons for the contrary belief. Surely the question of whether a proposed remedy for a difficulty will produce a more serious problem, or whether a new difficulty will be overcome, can at best be settled case by case, and for the most part only in the light of attempts at solving the specific problem. In fact, a sober doubt colors Dubos' exposition of the contention that the ideal role of science is to be the servant of man. "It has not yet been proven," he declares, "that this ideal is the best for human life. . . . It is much too early to be sure that Galileo, Watt, and Edison have contributed more lastingly to human advancement and happiness than have Socrates, Lao-tze and Francis of Assisi." And in acknowledging the wealth and conveniences that are the partial fruits of the Industrial Revolution, he nevertheless wonders "whether man would have deliberately started [it] if he had been able to visualize beforehand what its costs and consequences would be."

These queries are perhaps best construed as expressions of a mood rather than as implicit evaluations of the contributions that applied science has made to human welfare, because it is by no means clear what kind of evidence Dubos thinks is required to answer them. In any event, he is no King Canute who believes it is possible to reverse the mounting tide of technological innovation. Indeed, just because he recognizes that scientific discoveries will continue to have far-reaching effects on human destiny, and in spite of his avowed skepticism about the ability of science to foresee and meet successfully the specific problems of tomorrow, he maintains that scientists cannot afford to ignore the ethical problems raised by the utilization of scientific knowledge. "It is for society," he writes, "to decide what goals it wishes to reach and what risks it is willing to take. But it is the task of the scientific community to formulate as clearly as possible and to make public the probable consequences of any step that it takes and of any action that it advocates."

In his discussion of the relations between scientific and humanistic studies Dubos traverses some familiar but unavoidable territory. This discussion is nevertheless uniformly interesting, contains much salutary good sense and takes some surprising turns. Two main arguments can be disentangled in his defense of the conviction that science is properly one of the liberal arts: the first deals with the individual springs of action that generate scientific inquiry; the other, with the tacit assumptions and intellectual products of science. In the first argument Dubos tries to show that by and large the dominant motive underlying the great creative advances in science is a passion for an adequate grasp of the nature of things rather than for the practical mastery of nature's processes. He concludes in effect that in this respect scientists are akin to workers in the creative arts and philosophy, and he suggests that science would be more widely appreciated as a humanistic discipline if this fact were better known.

Although the available evidence is fragmentary, it strongly supports this account of the motives that actuate scientists. But the impulses that move men to choose research as a career are diverse, and, as Dubos clearly recognizes, they are frequently mixed even in one individual. In any event such considerations are hardly a reliable basis for judging the character of the scientific enterprise. There is ample material in this book to make it evident that the eventual fruits of a systematic investigation are not always the ones for which the investigation had been instituted, and that the unintended consequences of scientific research, as of other deliberative human action, are often at odds with the ends explicitly sought. The argument from the motives and aims of scientists is at best a weak reed.

It would of course be absurd to deny that the ideas scientists have about their fundamental objectives play no part in determining the nature of their enterprise and of its social consequences. For example, such ideas may help shape the public expectations as to what are the most worth-while fruits that science can yield, and may thereby influence the allocation by society of the human and material resources essential for the conduct of various types of systematic inquiry. Dubos is therefore on firm ground in maintaining that if scientists place chief stress on the invention of technolo-

gies as the ultimate goal of science and make no effort to develop in a larger public a keen appreciation of its humanistic significance, in the long run they may be performing a grave disservice to their discipline as well as to the human race. On the other hand, he tends to minimize, if not to ignore entirely, the role of a technologically oriented science in making available to unprecedented numbers the great artistic and intellectual achievements of the human spirit that in the past only a privileged few could enjoy. Clearly the ideal of science as the servant of man can also play a part in creating a broadly based humanistic culture.

Dubos comments on a number of important issues in presenting his views on the theoretical achievements of various sciences. He reminds his readers that the technical problems investigated in one specialized branch of scholarship, whether scientific or humanistic, can rarely be understood by students in another branch; and he doubts whether humanistic studies are more meaningful to the general public than scientific ones, since both deal explicitly with matters normally too esoteric to be of wide interest. He believes, nevertheless, that scientists can communicate with nonspecialists, though at a "higher level of discourse," by relating their work to pervasive human concerns, and in particular by indicating the relevance of their findings to comprehensive philosophical questions (such as the duality of mind and matter, the existence of free will or the nature of causality). This is the substance of his views on what he calls "the humanness of science." But in arguing for them Dubos leaves unanswered some crucial questions. He does not consider, for example, whether (and, if so, how) the broad implications of scientific discoveries can be presented to a public presumably unfamiliar with the theoretical and experimental foundations of those discoveries without creating serious misconceptions or dogmatically held convictions. Nor does it occur to him to ask, in spite of the incredibly uncritical beliefs on social and philosophical issues that even distinguished scientists so frequently hold, whether as a rule scientists are competent to explore and clarify the social and philosophical import of their findings. Dubos apparently forgets that considerable training and much concentrated effort are prerequisites not only for serious work in natural science but also for responsible views on social and philosophical questions. The harvest of genuine public enlightenment that is likely to result, if his recommendations on how to make manifest the humanness of science are accepted at face value, seems meager.

He is even less satisfactory and more puzzling in discussing the allegedly dubious assumptions of natural science that he calls "illusions of understanding." Although he reiterates throughout the book that science is a quest for understanding, he nevertheless declares: "As to understanding the nature of the universe and of the human condition, it is questionable whether we have progressed much during the past two thousand years." According to him science can at most be credited with rendering aid in dispelling errors and fears, but not with supplying "deep" understanding. To support this judgment he mentions some changes in fundamental physical concepts that modern researches have made necessary, and describes at greater length some poorly understood biological phenomena. Moreover, he thinks that recent discoveries that controvert some basic assumptions of classical physics may justify "in the long run" the many distinguished English scientists of preceding centuries who retained an orthodox religious faith. He also offers a critique of current trends in biology, asserts that "despite the triumphs of molecular biology, it has not yet been proven that the living body is only a machine and that life is merely a complex integration of known physicochemical forces," and he declares that while evolutionary theory may describe the stages in the development of hierarchically organized living systems, it "provides no understanding of how and why."

Nowhere does Dubos explain just what he means by "understanding," "deep" or otherwise, or indicate the standard of progress he is using. In advancing these views he may therefore be asserting perhaps nothing more than the undeniable truism that our knowledge of nature's mechanisms is incomplete and that when measured against the immensity of our ignorance it is pitifully small. In any event it is far from clear why either conceptual changes resulting from important advances in knowledge, or the existence of still unsolved problems in an active field of research, should count as supporting evidence for the claim that there has been little progress in understanding and that the understanding already achieved is shallow. Nor is it evident how science could have helped to dispel error except by discovering what is not error but truth. It is also difficult to see how further discoveries in physics can possibly justify religious


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convictions that do not rest—and were explicitly denied as resting by many of the English physicists who held them—on the findings of physical inquiry.

The doubts Dubos expresses about mechanistic biology are connected with his denial that biological phenomena are predictable from currently recognized physicochemical forces, as well as with his marked sympathies for "holism" and the doctrine of emergence. Accordingly, although he does not believe that these phenomena contradict any known laws of physical science, he makes a vigorous plea for supplementing the "analytical approach" to living things, which seeks to break them ultimately into components describable in physicochemical terms, by a "more synthetic approach," which tries to view them in their entirety as organically integrated systems exhibiting characteristic patterns of response to their total environment. Dubos is patently sound in insisting that living organisms manifest distinctive types of organization and behavior, which are important objects for investigation and which can be studied without analyzing them into more elementary physicochemical processes. He is also correct in disclaiming that he is thereby flirting with any form of traditional vitalism.

Nevertheless, the grounds for his assertion that the mechanistic assumption in biology "has not yet been proven" are obscure. To be sure, we do not at present know all the detailed physicochemical processes that sustain the activities of living organisms, there is no indefeasible guarantee that we will eventually acquire such knowledge, and it may well be that before we can acquire it new laws of inanimate processes will have to be discovered. Conceivably this is the basis for Dubos' assertion; if so, he is stating a commonplace that no one disputes. He also appears to believe, however, that the mechanistic assumption would be proved only if biological phenomena could be predicted from established laws of inanimate matter. But this requirement for a proof confounds explaining (or understanding) a phenomenon with predicting it—we can at present explain what makes earthquakes but we cannot predict them. The requirement is also logically impossible to fulfill. Physicochemical laws contain no terms referring to characteristics unique to living systems, because these laws deal with characteristics common to both living and nonliving things. Statements describing biological phenomena obviously do contain such terms. It follows that no conclusions about the occurrence of biological phenomena can be deduced (and hence such phenomena cannot be predicted) from laws exclusively concerning physicochemical processes. For example, the laws of particle mechanics do not suffice for deducing the behavior of clocks, unless these laws are supplemented by assumptions concerning the special properties manifested by aggregates of particles occurring in certain organized combinations. Similarly, a mechanistic explanation of biological phenomena is possible only if it takes into account the specific organization of physicochemical processes in living organisms. No defender of the mechanistic assumption can reasonably be asked to prove it by requiring him to do what is thus clearly impossible. Whether or not Dubos is making this demand, he does not hesitate to acknowledge the mechanistic assumption as an extraordinarily fruitful one, nor does he offer a single positive reason to challenge its truth. It is therefore puzzling why he counts the assumption among the illusions of the understanding.

Dubos' apparently negative estimate of the understanding provided by Darwinian theory is equally perplexing, and his assertion that Mendelian and biochemical genetics "have served merely to verify the theory and to elaborate its details" surely undervalues what these experimental studies have contributed. Undoubtedly evolutionary theory, even in its current form, is incomplete in various ways, and its power to make precise predictions is in general not very great. However, though it supplies no answers, or only incomplete answers, to many questions concerning the development of life, it would be patently absurd to maintain that the theory provides no answers whatsoever. It is hardly necessary to say that the basic mechanisms described in evolutionary theory and Mendelian genetics go a long way toward explaining, for example, the formation, extinction and present diversity of biological species. Dubos is therefore indulging in what may be only rhetorical exaggeration when he declares that evolutionary theory "does not account for the emergence of man from the inanimate world." Although the theory may not *fully* account for man's emergence, neither does it leave that fact a total mystery.

Dubos concludes his book with an eloquent statement of his conviction that nature contains far more than has yet been established by analytic reason. Moreover, he shows beyond dispute that vague intuitive apprehensions of "nature in the round" are frequent sources of creative scientific ideas that eventually guide painstaking scientific analyses. He therefore suggests that, without abandoning the ideals of clarity and precision, it would be well to recognize "that in the long run knowledge might be enriched by cultivating the awareness that almost everything is relevant to everything else." This recommendation is dubious advice. On the contrary, it is well to recognize that the human understanding is emancipated from its illusions only by cultivating the awareness, often at painful cost, that most things are irrelevant to most other things. Indeed, Dubos returns finally to the enlightened conception of science for which his book is a persuasive plea when he declares: "The world of living as well as of lifeless things revealed by scientific investigation is incomparably grander than anything that emerges from abstract thought or from the most vivid imagination."

Short Reviews

THE DAWN OF CIVILIZATION, edited by Stuart Piggott. McGraw-Hill Book Company, Inc. ($28.50). A panoramic survey (225,000 words) of human cultures in early times. Fourteen leading British archaeologists, among them Grahame Clark, M. E. L. Mallowan, Sir Mortimer Wheeler, Seton Lloyd and G. H. S. Bushnell, have contributed articles on man in the Stone Age, the beginning of village and urban life, Mesopotamia and Iran, ancient Egypt, the sea peoples of the Levant, the early settlement of Anatolia, the civilization of Crete, the beginnings of China, the diverse traditions of Southeast Asia, the nomads of the steppes, barbarian Europe, the first Americans. An outstanding feature of this impressive volume are some 940 illustrations (172 in color), which include original reconstructions, plans, halftones, line drawings, maps and charts. The reproduction of most of these is admirable, and the pictorial matter as a whole strongly supports the underlying theme of man's development as a social animal. Nothing so lavish, so comprehensive and so well designed to answer the general reader's curiosity about the constantly growing body of archaeological knowledge has yet appeared.

SYMBOLS, SIGNALS AND NOISE, by J. R. Pierce. Harper & Brothers ($6.50). An uncommonly good study of the nature of communication, the concepts of information theory, the brilliant pioneer work of Claude Shannon, the relation of information theory to physics, cybernetics, psychology, art. Pierce's book, which appears in the "Harper Modern Science Series," is designed for the general reader and therefore demands no specialized knowledge. But the subject is subtle and complex, no more susceptible to thorough clarification without the use of mathematics than, say, the theory of relativity. Pierce has met the problem head on by introducing the essential symbols and equations while defining and explaining their meaning every step of the way. In short, this is a self-contained essay which almost any thoughtful person prepared to concentrate can follow from the first page to the last. There are, it may be granted, many writings on communication theory, even a number of popularizations, but Pierce's volume presents the most satisfying discussion to be found of the technical business as well as of the more digestible generalizations and philosophical speculations. Illustrations.

INDUCTIVE PROBABILITY, by John Patrick Day. The Humanities Press ($8). Induction and the questions connected with it are as alive and interesting subjects today, as important to philosophers and logicians, as they were in the time of David Hume. Here in a lucid and balanced essay the author examines the philosophy of probability, the nature of inductive reasoning and inductive logic. While the discussion is primarily addressed to the professional philosopher, it is so little burdened with mathematics and the apparatus of formal logic that the nonspecialist can follow and enjoy the arguments if only he has the stomach for hard problems and hard thinking. This book auspiciously opens a new series, edited by the British philosopher A. J. Ayer, called "The International Library of Philosophy and Scientific Method," successor to a similar and justly celebrated series established by C. K. Ogden.

MICHAEL FARADAY: A LIST OF HIS LECTURES AND PUBLISHED WRITINGS, compiled and edited by Alan E. Jeffreys. Academic Press Inc. ($7). Historians of science and people interested in the life and work of Faraday have long felt the need for a careful and comprehensive list of his writings. Despite minor flaws, this compilation comes very close to meeting the need. Faraday's range of interests was wide and his productivity immense. His first lecture, in 1816, was on "the general properties of matter"; almost half a century later he was reporting on "the electric light now in operation at Dungeness [lighthouse]" and on "the revenues and management of certain colleges and schools." In between he lectured to children on the chemical history of the candle, discovered the laws of electrolysis, contributed to the Royal Society dozens of papers describing his immortal researches on electricity and magnetism, wrote a book on chemical manipulation, examined the nature of musical sound, considered the cause of the twinkling of the stars, discovered benzene, worked on the liquefaction of chlorine, experimented on the relation of magnetism and light, developed a new kind of heavy glass, made new steel alloys, concerned himself with such practical matters as the ventilation of mines, the building of a tunnel under the Thames, the preservation of paintings in the National Gallery, the manufacture of guns, the action of gunpowder on lead, steam-boiler explosions, the artificial production of rubies, the use of gutta-percha in electrical insulation, artesian wells. This is the merest sample of his activities. Jeffreys' bibliography justifies the labor spent on it by giving the reader an impressive conspectus of the achievement of this almost tireless, marvelously imaginative man. Illustrations.

THE MOON: OUR NEAREST CELESTIAL NEIGHBOUR, by Zdeněk Kopal. Academic Press Inc. ($4.50). An account for the general reader of what is known about our nearest celestial neighbor: physical properties, appearance, the nature of moonlight, theories explaining the moon's origin and the forces which formed craters, mountains and plains, conditions and problems which moon voyagers can expect to encounter, the many unsolved questions about the moon and other celestial bodies that lunar stations may help to answer. The author, professor of astronomy at the University of Manchester, writes simply, with an occasional old-fashioned courtliness; he is particularly good at presenting the ingenious chains of inference by means of which astronomers and astrophysicists of many countries have woven together observations and hypotheses to form a remarkably detailed picture of the earth's natural satellite.

THE COIL OF LIFE, by Ruth Moore. Alfred A. Knopf, Inc. ($5.95). A popular account of major discoveries of the last 200 years in biology, biochemistry and allied sciences, including Lavoisier's work on respiration, Bichat's on tissues, Schleiden's and Schwann's on the cell, Pasteur's on bacteria, Mendel's on heredity, Morgan's on chromosomes, Muller's on mutations, Crick's and Watson's on deoxyribonucleic acid, Pauling's and Sanger's on proteins, Szent-Györgyi's on muscle. Though Miss Moore is a capable journalist who is interested in science and has written books on evolution and geology, she is not, unfortunately, always clear in her explanations of scientific ideas and methods. Indeed, there are times when it seems she herself does not fully grasp the topic she is discussing. This makes for unsatisfactory passages, confusing and irritating to the reader, a circumstance in no way alleviated by Miss Moore's insistence on dramatizing all scientific labors, many of which, however important, are simply not dramatic.

A SHORT ACCOUNT OF THE HISTORY OF MATHEMATICS, by W. W. Rouse Ball. Dover Publications, Inc. ($2). Ball's history, though reissued as late as 1908, is a work whose coverage came to a close with the latter part of the 19th century. This is a standard survey, readable, full of excellent material, but in many respects outdated. It is nevertheless an agreeable introduction to the subject for beginners, and its appearance as an inexpensive paperback is cause for satisfaction.

THE ASCENT OF DHAULAGIRI, by Max Eiselin. Oxford University Press ($5.75). An unpretentious, straightforward, highly enjoyable account of the ascent of the "white mountain" of the Himalayas, altitude 26,975 feet. One of the unusual features of this great climb was the use of an airplane—which crashed before completing all the work which had been hoped for it—to carry supplies to high depots. In spite of this disaster, the expedition was successful and six men attained the summit.

THE AIR WE BREATHE, edited by Seymour M. Farber and Roger H. L. Wilson. Charles C Thomas ($14). Proceedings of a University of California symposium on the effect of the air he breathes on man's health. Engineers, physicians, chemists, town planners, statisticians participated in the discussions as part of a co-operative approach to the vexing questions of atmospheric pollution. The topics under scrutiny included smog and fog, dust and disease, chemical irritants, the hazards created by the atomic energy industry, tobacco and lung cancer. On this last problem there was a good deal of logic-chopping statistical talk which merely confused the issues with dubious subtleties.

LIFE OF THE PAST, by George Gaylord Simpson. Yale University Press ($1.45). Paper-bound reissue of the best nontechnical book on paleontology that has appeared. Simpson, a brilliant writer and first-class scientist, is concerned here not only with the identification of objects called fossils but also with paleontology as part of the attempt to provide the principles and interpretation of the history of life. A splendid, broadening essay.

SOCIAL LIFE IN EARLY ENGLAND, edited by Geoffrey Barraclough. Barnes & Noble, Inc. ($4.50). A collection of short essays originally published as individual pamphlets, covering English social history from the Roman settlement to the Reformation. Leading specialists discuss, among other things, Roman Britain, the manor and the village, monasteries and castles, arms and armor, the English house, medieval money and trade routes. Maps and illustrations.

THE CHEMISTRY OF URANIUM: THE ELEMENT, ITS BINARY AND RELATED COMPOUNDS, by Joseph J. Katz and Eugene Rabinowitch. Dover Publications, Inc. ($2.95). A paperback of a book first published in 1951, a critical survey of information about uranium and its binary compounds. Thousands of references to the literature, many tables, charts and figures and comprehensive treatment make this the most complete compilation of its kind.

FROM GALILEO TO THE NUCLEAR AGE, by Harvey Brace Lemon. The University of Chicago Press ($2.95). Paper-backed reprint of Lemon's well-known physics textbook, first published almost three decades ago, which is so attractively written and so happily planned for continuous reading that it has over the years appealed to a wide audience outside the classroom. Good illustrations.

Notes

THE HISTORY OF THE CALCULUS AND ITS CONCEPTUAL DEVELOPMENT, by Carl B. Boyer. Dover Publications, Inc. ($2). A soft-cover reprint of an able history of what is perhaps the single greatest mathematical tool.

ROOTS OF REVOLUTION, by Franco Venturi. Alfred A. Knopf, Inc. ($12.75). A massive, well-written, penetrating survey by a leading authority on Russian revolutionary history of the Populist and Socialist movements in 19th-century Russia.

ELEMENTARY PARTICLES, by Enrico Fermi. Yale University Press ($1.25). Paper-backed edition of Fermi's 1950

Silliman Memorial Lectures dealing with significant results of the field theories of elementary particles.

Our National Park Policy, by John Ise. The Johns Hopkins Press ($10). A critical history and analysis of U.S. National Park policy by a pioneer student of the subject. He deals with the early parks (1872–1916), with the activities of the National Park Service (1916–1959), and with special park problems such as wildlife, concessions, financing the parks, wilderness areas.

The Viruses: Vol. II, edited by F. M. Burnet and W. M. Stanley. Academic Press Inc. ($15). The second volume of this treatise deals with plant and bacterial viruses and includes chapters on the tobacco mosaic virus, the biochemistry of plant viruses, the intracellular multiplication of bacterial viruses, the genetics of bacterial viruses.

The Higher Arithmetic, by H. Davenport. Harper Torchbooks ($1.35). An inexpensive reprint of a sound, plain, altogether admirable account of elementary number theory.

Hydrodynamics, by Garrett Birkhoff. Princeton University Press ($6.50). Revised edition of Birkhoff's critical analysis of the foundations of hydrodynamics, with particular reference to the relation between theory and experiment.

Time and Eternity, by W. T. Stace. Princeton University Press ($1.45). A reissue in paper covers of an essay on the philosophy of religion.

Feudal Society, by Marc Bloch. The University of Chicago Press ($8.50). A translation from the French of a superb monograph on feudalism, the last work of a famous scholar who joined the Resistance, was captured, then tortured and murdered by the Gestapo in June, 1944.

Space Research, edited by Hilde Kallmann Bijl Interscience Publishers, Inc. ($24). Proceedings of the First International Space Science Symposium, held at Nice in 1960, including papers on the earth's atmosphere, the ionosphere, tracking and telemetering, solar and cosmic radiation, interplanetary dust, the moon and the planets.

Demographic and Economic Change in Developed Countries. Princeton University Press ($12). A collection of papers delivered at a conference held at Princeton University in 1958 on the interrelations of demographic and economic changes in industrialized countries.

THE PHYSICAL EXAMINATION OF METALS, by Bruce Chalmers and A. G. Quarrell. St. Martin's Press, Inc. ($32.50). Second edition of an account of the principal physical techniques (apart from radiography) which provide information about the properties of metals and alloys.

SPACEFLIGHT TECHNOLOGY, edited by Kenneth W. Gatland. Academic Press Inc. ($11). Papers presented at a 1959 space flight symposium organized by the British Interplanetary Society. The topics include launching vehicles, reentry problems, propulsion systems, space-vehicle cabins, instrumentation, tracking and communication, navigation, exploration of the moon. Illustrations.

WAVE PROPAGATION IN A TURBULENT MEDIUM, by V. I. Tatarski. McGraw-Hill Book Company, Inc. ($9.75). A leading Russian monograph which describes the phenomena associated with the propagation of electromagnetic and acoustic waves through atmospheric turbulence.

HANDBOOK OF PHYSIOLOGY, by R. J. S. McDowall. J. B. Lippincott Company ($12.50). The 43rd edition of a standard work which began with the first edition in 1848. Physiology is approached through a consideration of anatomy, biochemistry, biophysics, physical chemistry and biology.

PHOTOGRAMMETRY, by Bertil Hallert. McGraw-Hill Book Company, Inc. ($11). A general survey of fundamental principles of photogrammetry and its procedures in practice.

BIOGRAPHICAL MEMOIRS, National Academy of Sciences, Volume 35. Columbia University Press ($5). Among the subjects whose memoirs appear are Anton Julius Carlson, Edward Lull Cochrane, Edwin Joseph Cohn, Samuel Randall Detwiler, Robert Emerson, Karl Spencer Lashley, Leo Loeb and George Malcom Stratton.

ONE TWO THREE . . . INFINITY, by George Gamow. The Viking Press, Inc. ($1.65). Gamow's well-received popularization of basic theories of modern science: mathematics, physics, astronomy, cosmology, genetics. Paperback.

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