SCIENTIFIC AMERICAN

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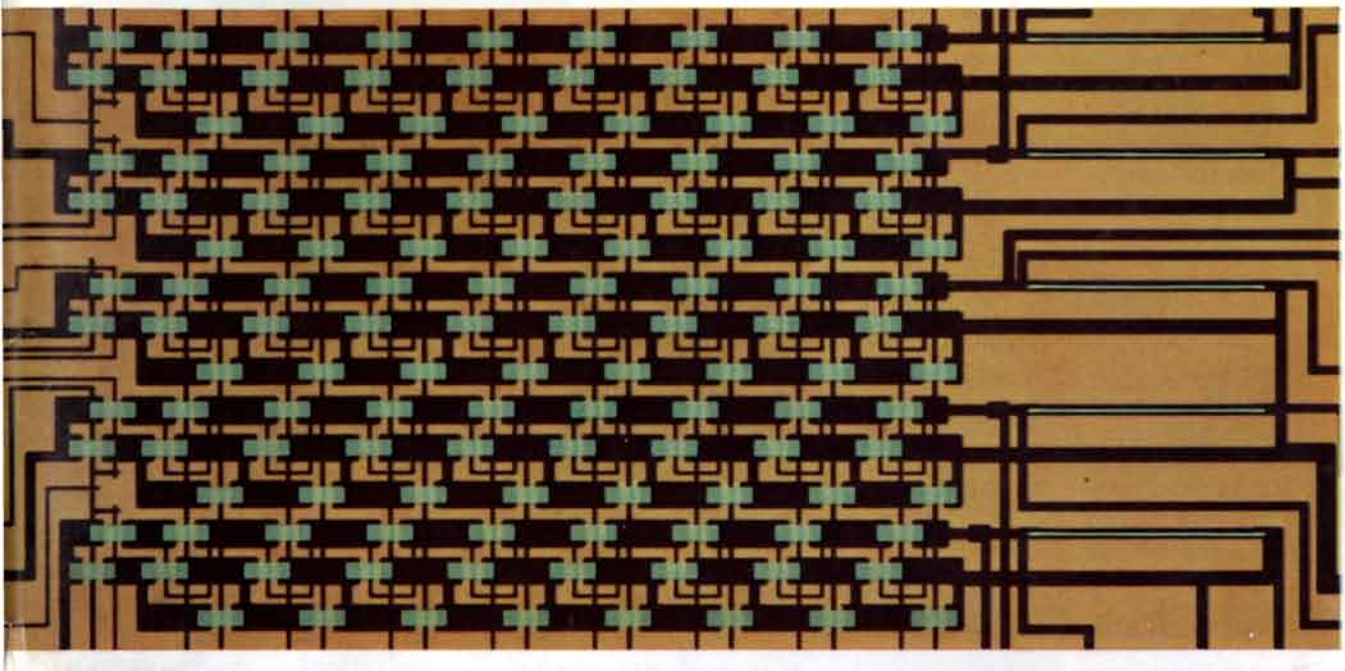

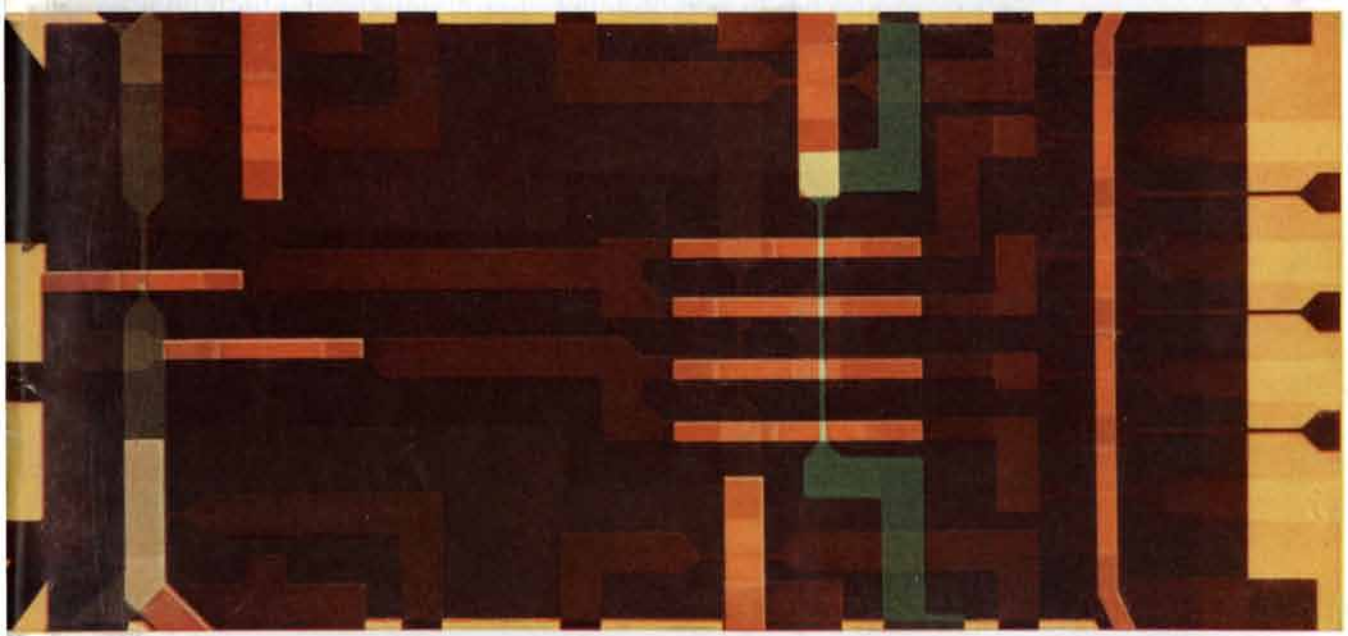

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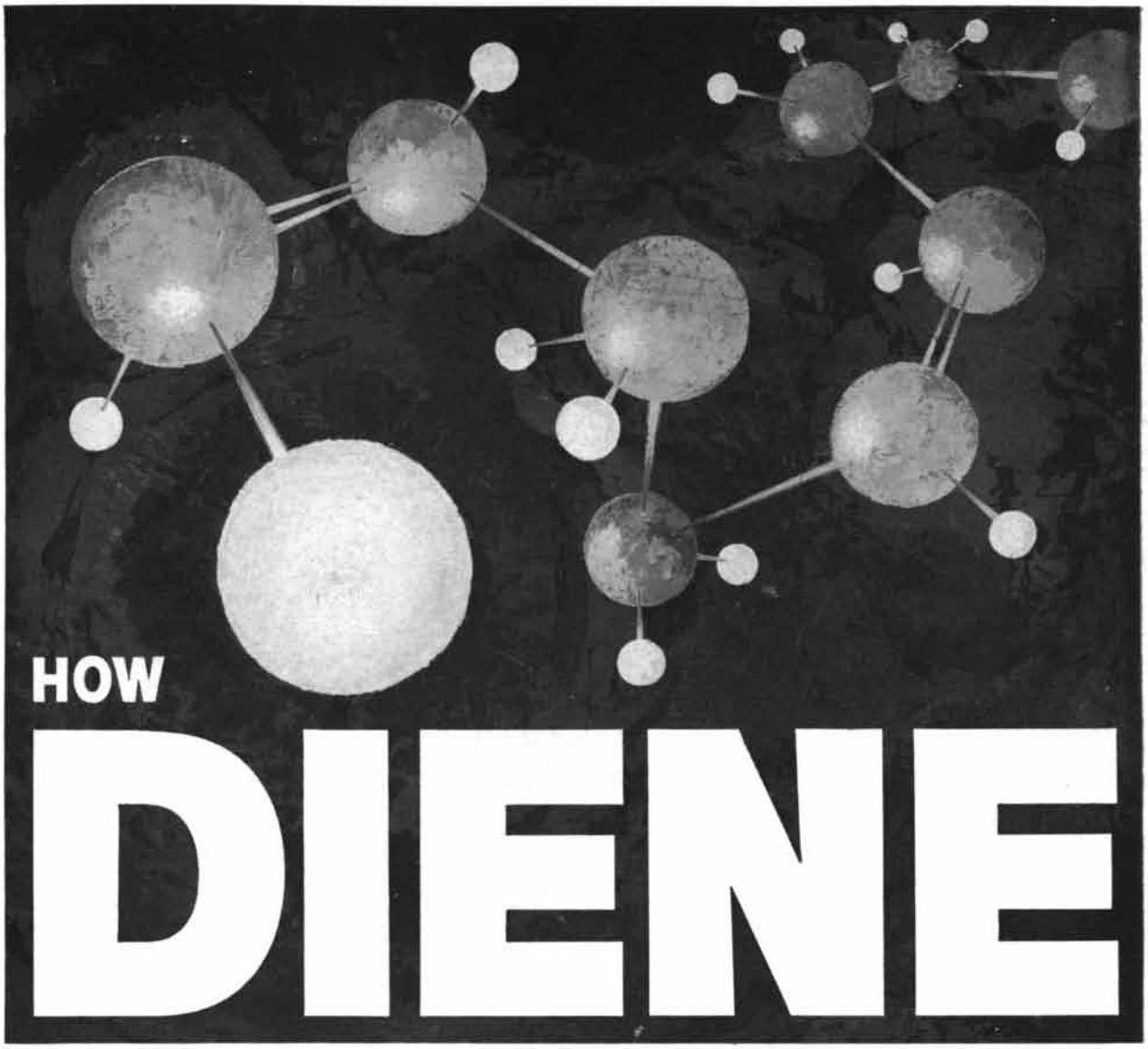

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Established 1845 **SCIENTIFIC AMERICAN** July 1961 Volume 205 Number 1

ARTICLES

DEPARTMENTS

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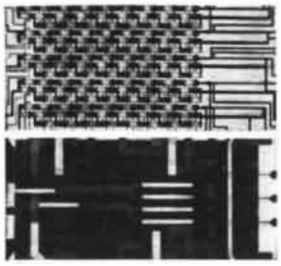

THE COVER

Shown on the cover are photographs of two computer elements designed to operate at the temperature of liquid helium. When such an element is immersed in liquid helium, its circuits become superconductive; that is, they conduct current without resistance. With elements operating on this principle it should be possible to build computers having considerably greater capacity than those now in operation (*see page 124*). The element at the top is a "memory plane"; the element at the bottom, a "decoder." Both of the elements have been enlarged about four times.

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In terms of its powerful influence on men's minds, this kind of foreign aid will cost very little; indeed it will be largely a bonus of tomorrow's global communications system. Satellites will open up thousands of new microwave channels. Commerce and industry will use these channels, paying communication tolls no higher than today's. But many frequencies will be available for the struggle against ignorance and poverty—and tyranny.

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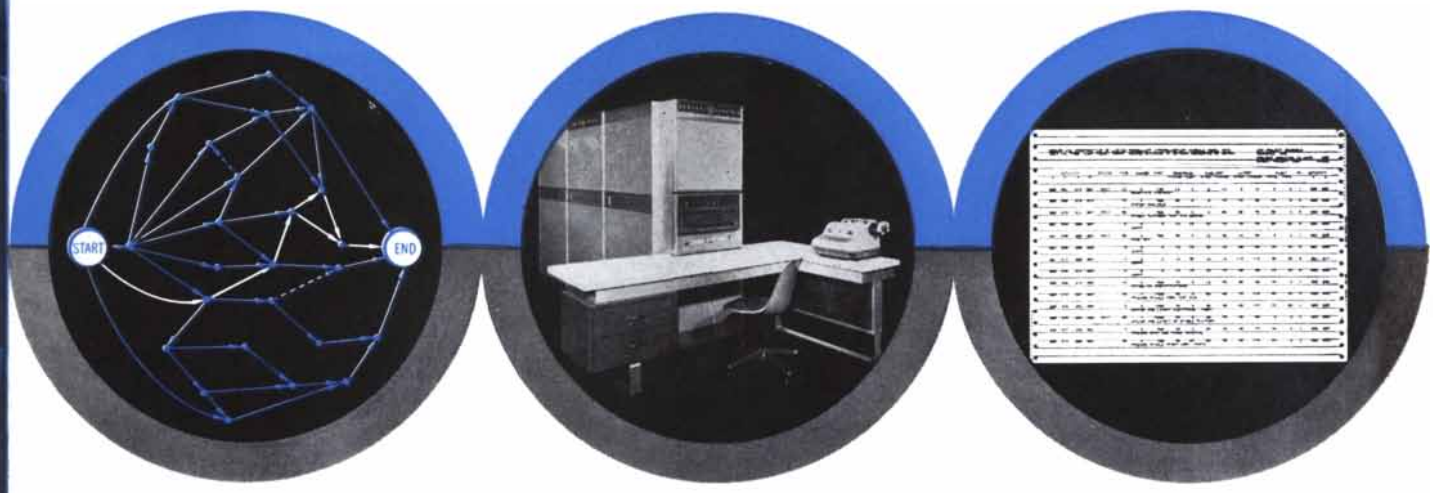

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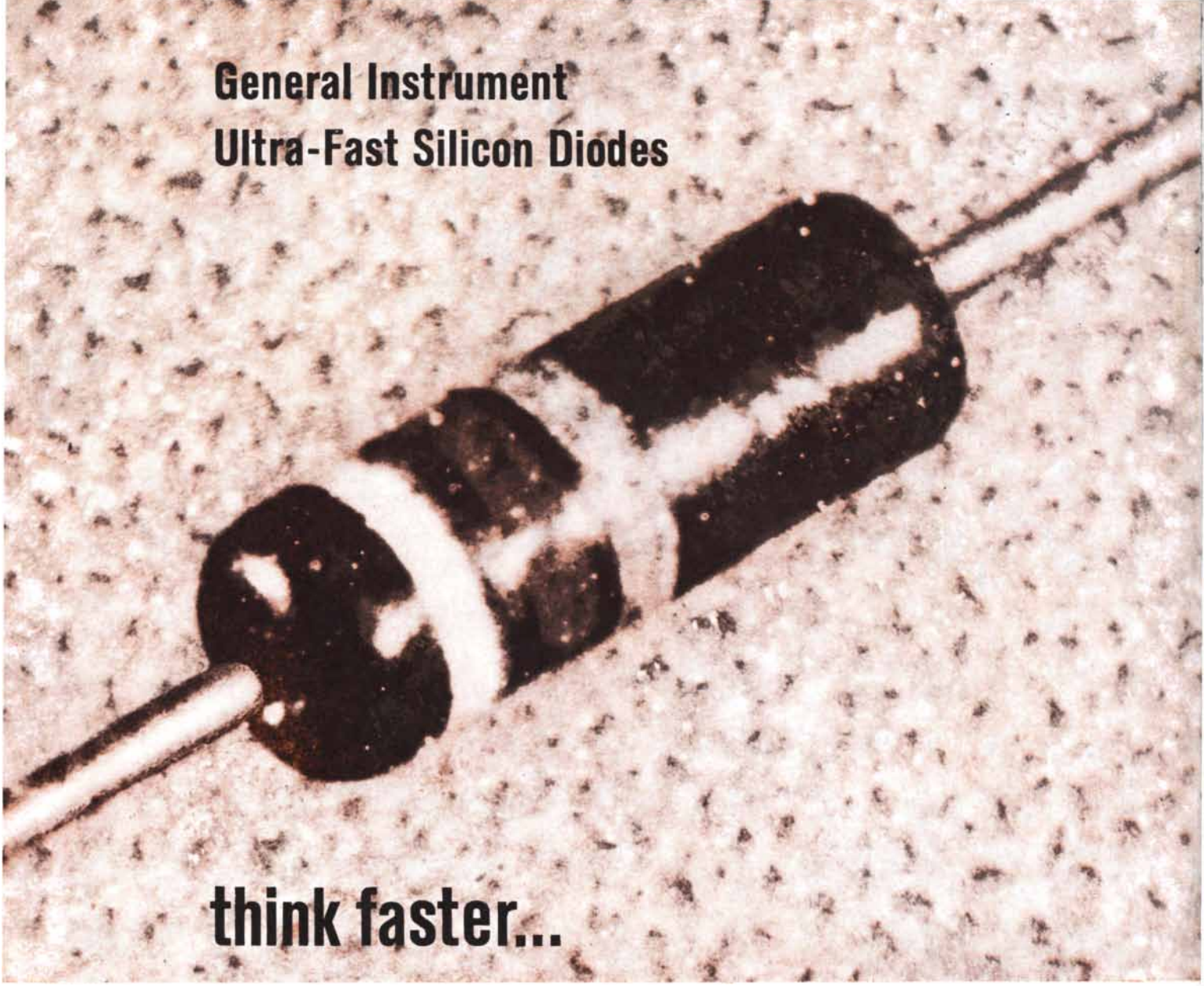

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The versatility of an electronic 'brain' is frequently governed by its 'thinking' speed. The semiconductors that make extreme speed possible, however, often do so by compromising other essential characteristics. ■ Aware of this truth, General Instrument has developed a series of highly reliable computer diodes which not only achieve speeds of two nanoseconds, but also permit circuit designers, for the first time, to combine ultra-fast computer switching with several other attractive parameters. For example, the combination of needed high conductance with capacitance less than 2 pf is possible with General Instrument's new SP106 ultra-fast diode. ■ This concern for speed, versatility and uniformity of product permeates the manufacture of all General Instrument semiconductors, whether they have custom or industry-standard characteristics. If you would like more specific information about ultra-fast silicon diodes or if you would like to participate in the exciting research that made the SP106 and the others in its series possible, write today to Department SA-71, General Instrument Semiconductor Division, 65 Gouverneur Street, Newark 4, New Jersey. ■

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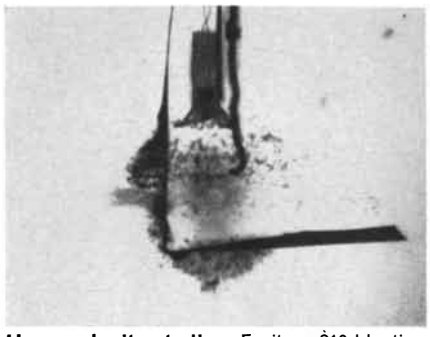
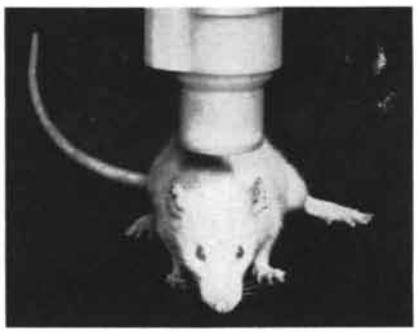
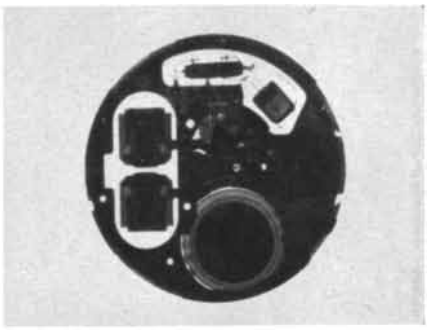


Hypervelocity studies: Fexitron 210 blasting cap photo, taken at 0.03 microsecond, 100 kv, showing 7 mil particles at 16,000 f.p.s.



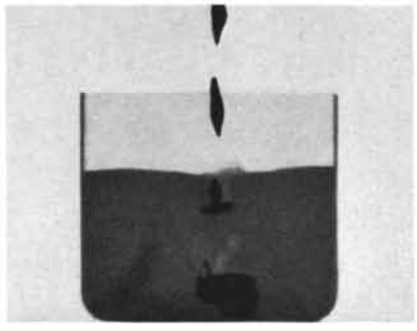
Radiation effects: Studies now are possible at dose rates of 10^8 R/sec with Fexitron 210 and Fexitron 215; 10^9 R/sec with Fexitron 201.



Non-destructive testing of small components: Photo of electronic watch taken by Fexitron 210; 2 mil resolution.

high speed x-rays

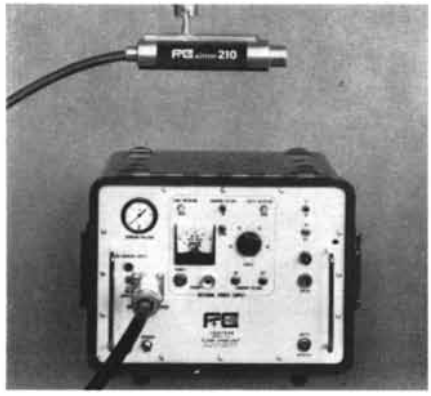
Biomedical x-rays: Short exposure avoids motion blur. Fexitron units can be carried to bedside, in rescue operations, to remote areas.



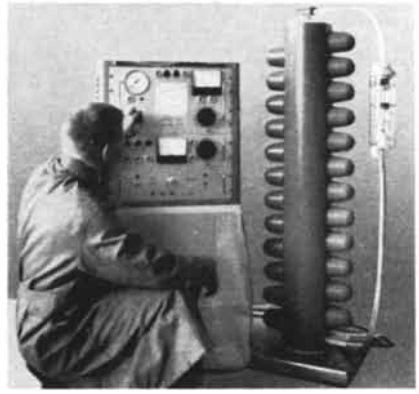
Metal forming: Analysis of dynamic processes in metal forming now possible with Fexitron 215.

Ballistics: Radiograph of bullet at end of gun barrel; Fexitron 201 will expose film through 3″ of steel.

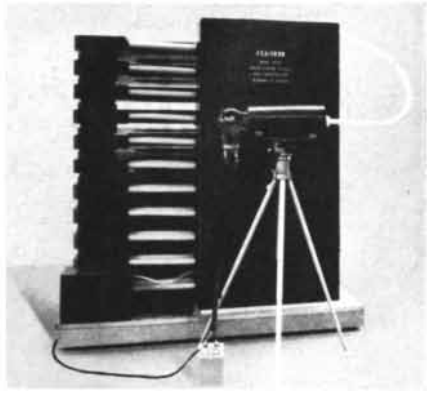
Write or telephone for information on the Fexitron x-ray systems



FEXITRON 210: 0.03 microsecond; 100 kv; 1 mm. source size; 40 lbs.; penetrates 1″ of aluminum; price $2,480.



FEXITRON 215: 0.05 or 0.15 microsecond; 300 kv; 5 mm. source size; 160 lbs.; penetrates 4″ of aluminum; price $8,732.



FEXITRON 201: 0.2 microsecond; 600 kv; 9 mm. source size; 64″ high; penetrates 6″ of aluminum; price $23,553.

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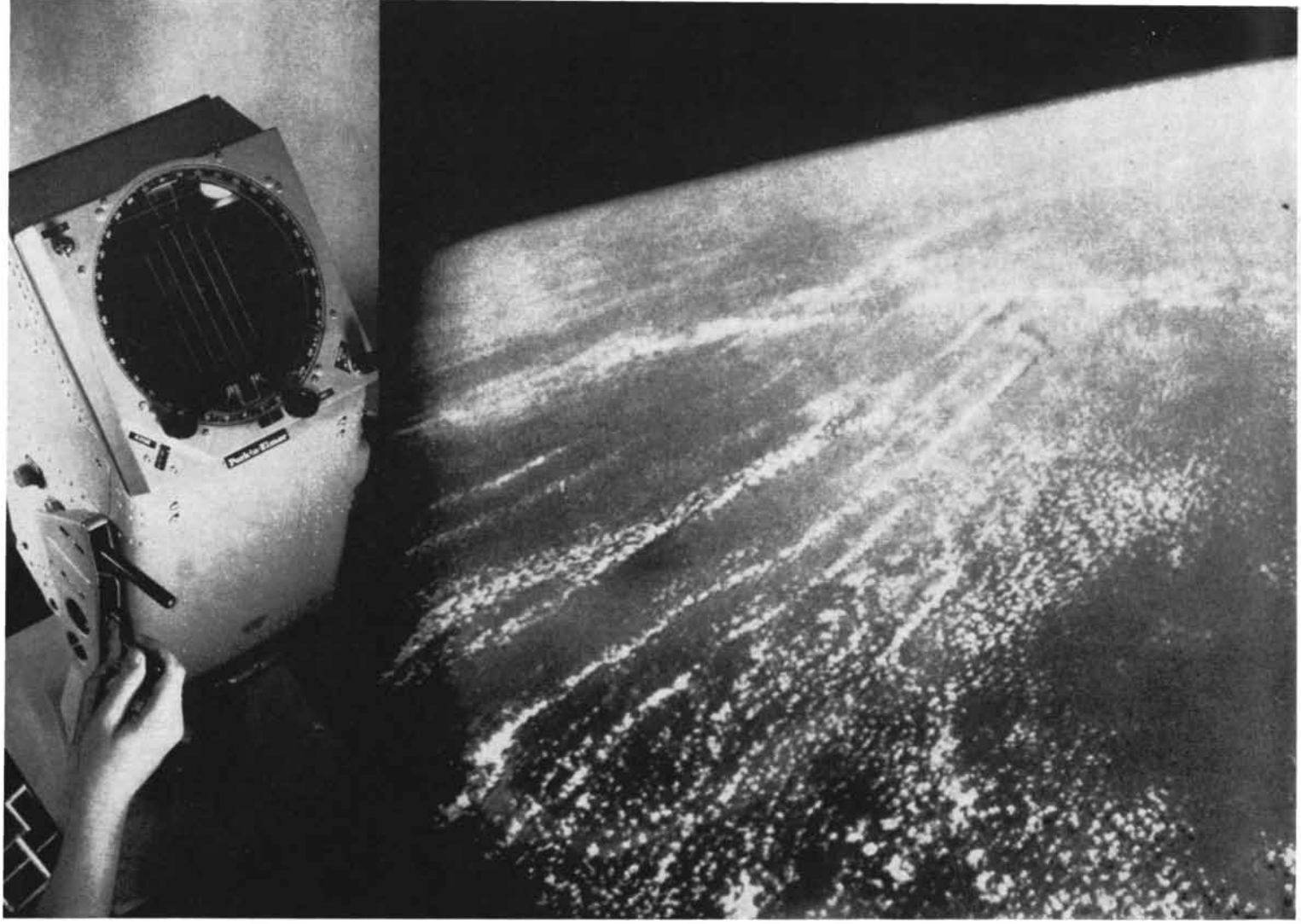

May 5, 1961—First released photograph taken from NASA Freedom 7 Mercury capsule duplicates Cmdr. Shepard's view of eastern coastline of the United States. Astronaut's view through Perkin-Elmer periscope covered 1600 miles.

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LETTERS

Sirs:

In "The Mathematician as an Explorer" [SCIENTIFIC AMERICAN, May] Sherman K. Stein describes his exploration of the "memory wheel" problem, that is, the problem of constructing sequences of digits containing all possible combinations of a certain length without repetition. Apparently the author did not know that these sequences have found direct application in several aspects of communication theory and have in fact been studied in some detail by electrical engineers in recent years.

Since Stein has made this problem seem unnecessarily formidable, your readers may be interested in a simple, direct and general procedure by which the undersigned solved a form of the memory-wheel problem. The problem arose in conjunction with the design of sequential machines (types of automata) for use in generating error-correcting codes. (Stein's "road maps" correspond to "state diagrams" in these machines.) Since we were considering codes other than binary, we were looking for sequences made up of the integers $0, 1, \ldots, p-1$, which contained all possible n-tuples without repetition. It turned out that for the case where the number of integers, p, is a prime, a simple algebraic solution can be found.

From the theory of Galois fields (a branch of algebra invented before 1832 by the brilliant French mathematician Évariste Galois and apparently considered passé by modern mathematicians) it can be shown that the crux of the memory wheel problem lies in the choice of a special polynomial, $q(x)$, whose coefficients are selected from the integers $0, 1, 2, \ldots, p-1$. This polynomial, besides having other special properties, must be one of the divisors of the expression x^m-1, a fact that was suggested in Stein's article.

Once an appropriate polynomial has been found, the required memory-wheel sequence is generated by forming $1/q(x)$ by a process of long division. In the division process, arithmetic must be performed modulo-p. (In modulo-5 arithmetic, for example, $2+3=0$.) Although we have not given here the procedure for selecting the appropriate polynomial, suffice it to say that the generation of these sequences has warranted enough attention among communication engineers for tabulations of the appropriate polynomials to have been published up to orders as high as 34.

T. E. STERN
B. FRIEDLAND

Department of Electrical Engineering
Columbia University
New York, N.Y.

Sirs:

It was a pleasure to learn that electrical engineers too have found memory wheels of use and construct them with Rees's algebraic technique. Clearly these wheels should be listed in the as yet unpublished *Facts that Every Research Scientist Should Know*. Such a book would go far in breaking down the exaggerated barriers we put between the fields of knowledge.

But it was not a pleasure to read: "... the theory of Galois fields ... apparently considered passé by modern mathematicians ..." Let me help knock down one of those aforementioned barriers. Modern mathematicians, like modern engineers a very practical bunch, will use any tool that serves their purpose. In particular, Galois fields are standard equipment for every algebraist in the world. Rees used them; they are used in the construction of orthogonal Latin squares ["Mathematical Games"; SCIENTIFIC AMERICAN, November, 1959]; they and their generalizations, near-fields, are used in constructing geometries with only a finite number of points on a line. They frequently appear also as parts of larger algebraic structures.

Each reader has the right to decide what is "unnecessarily formidable." A highway system and its inspector involve, mathematically speaking, much less structure than the field of power series in one variable with coefficients from a Galois field, and yet they make it clear to a wide group of readers that the memory wheels exist. The highway systems were the context of deBruijn's beautiful work in which he went on to find the number of memory wheels. My goal was not that of Professors Stern and Friedland, the methodical construction of memory wheels for error correcting. My goal was to take the proverbial "intelligent layman" inside mathematics.

SHERMAN STEIN

Florence, Italy

Sirs:

As a lifelong student of the art and science of printing telegraphy, I have been extremely interested in the practical aspects of arrangements of binary quintuplets. I was therefore especially interested in Sherman K. Stein's article "The Mathematician as an Explorer" [SCIENTIFIC AMERICAN, May]. Particularly interesting was his quotation from I. J. Good, suggesting the application of memory-wheel techniques to the construction of teleprinters.

The application to which I presume Good alludes appears in a Western Electric tape teletypewriter used very early in this century and in its European counterparts, and it is known here as the "combination-wheel and seeker" mechanism. The combination wheel is, of course, a mechanically coded memory wheel, and the seekers form a device for locating the desired quintuplet on its periphery, thus indexing the desired character for printing.

When, as a young boy, I first encountered a description of this system, I recall naïvely remarking on the good fortune of the designers of the machine in being able to find such a sequence. It is reassuring in retrospect to be informed by Dr. Stein that number theory had assured them of not one but 2,048 such solutions.

D. A. KERR

Lakewood, Ohio

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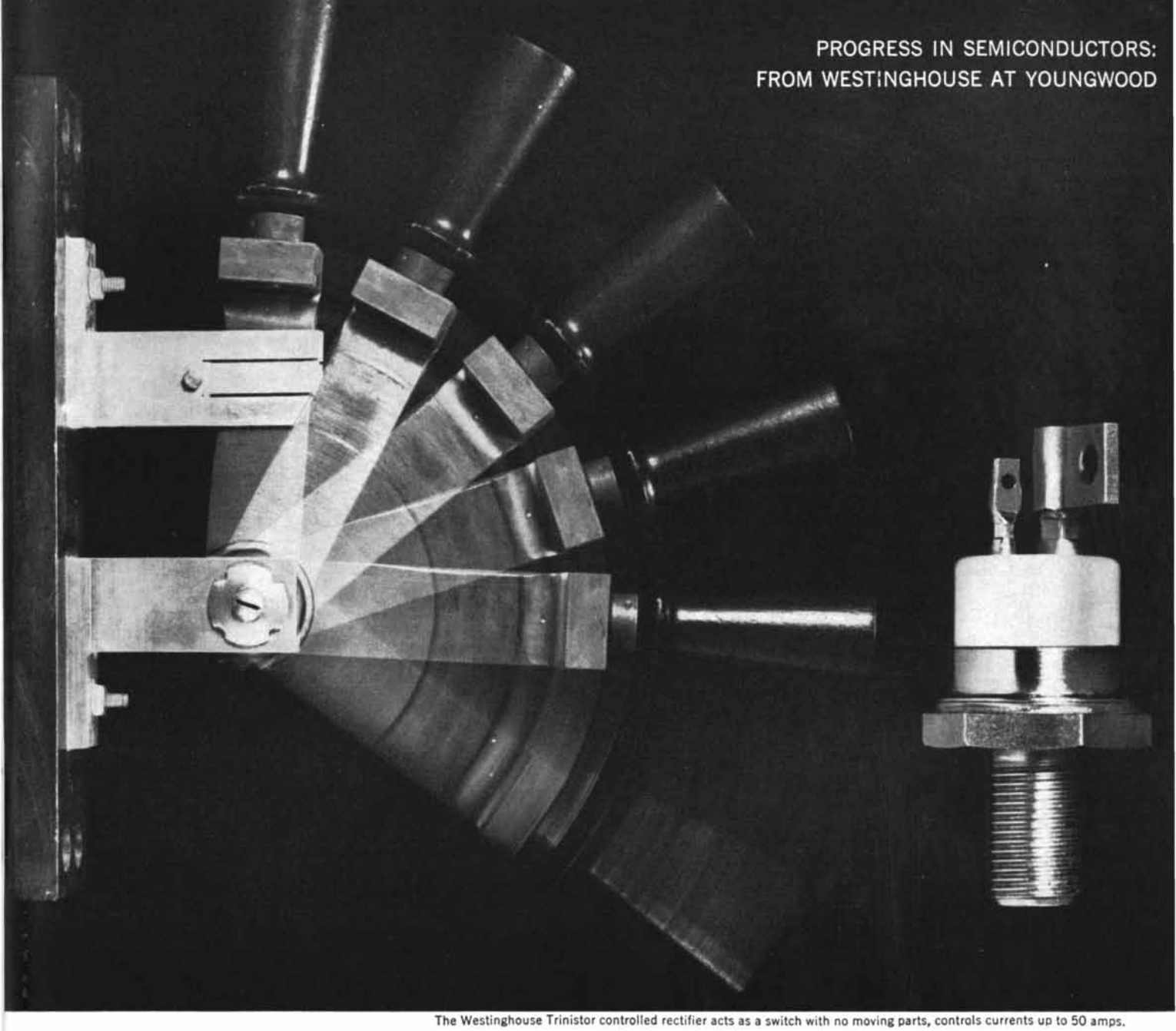

The Westinghouse Trinistor controlled rectifier acts as a switch with no moving parts, controls currents up to 50 amps.

Westinghouse power switching device opens new frontiers in electrical control systems

Industry today places exacting demands on electrical control systems. They must be precise and fast in operation, high in power output yet compact in size and above all—reliable. And these requirements must be provided at low cost. To obtain all of these advantages, more and more systems engineers are turning to the Westinghouse Trinistor[T] controlled rectifier. The impact of this device on industrial controls will be no less than that of transistors in the electronics industry.

A Trinistor unit is basically a controlled switch—a very fast and dependable switch with no contacts and no moving parts. It can be closed and opened in a matter of microseconds with a few milliwatts of control signal. But the power controlled by this switch can be many kilowatts. The Type 809 Trinistor unit, for example, has a current rating of 50 amperes at voltages to 400 volts—and a voltage drop of less than 1 volt at full current. Other Westinghouse Trinistor controlled rectifiers are available for lower current applications.

The high sensitivity, speed, reliability and power capacity of the Trinistor family make them ideally suited for many electrical and electronic applications. For example, in regulators they replace bulky and expensive magnetic amplifiers. In servo systems they replace slow, unreliable rotating amplifiers. In the case of inverters, Trinistor units are opening up whole new areas of endeavor by making the large scale generation of power at high frequencies both practical and economical.

If your business involves the design or utilization of electrical or electronic controls, we suggest you investigate the Trinistor controlled rectifier. For complete information, please call or write: **Westinghouse Electric Corporation, Semiconductor Department, Youngwood, Penna.** SC-1044

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

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For additional reasons why your company can benefit from a San Diego location, mail the coupon below or direct specific questions to: Harold V. Pederson, Industrial Dept. Manager, San Diego Chamber of Commerce. All inquiries are treated in strict confidence.

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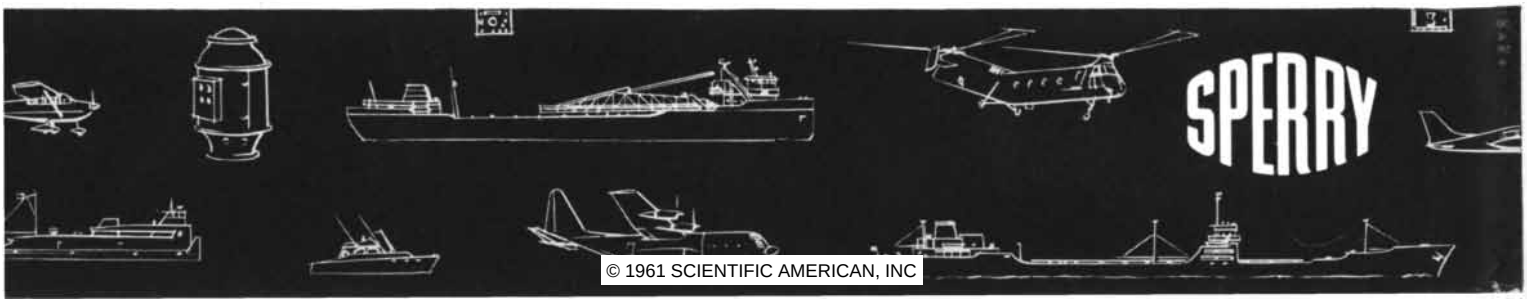
With 50 years of professional experience, Sperry field engineering puts a unique support capability at the service of Sperry customers world wide. General offices: Great Neck, N.Y.



LOOK

it's all one piece!

Opening and closing this one-piece carrying case demonstrates the remarkable "hinge" property of TENITE POLYPROPYLENE

Flexed a million times in one continuous laboratory test, a molded specimen of Tenite Polypropylene—the Eastman plastic with the "built-in hinge"—showed never a crack. That's why this case can have its base, cover, and handle molded as a unit, with obvious savings in design, fabrication, and assembly.

Made for a child's typewriter, the case is well able to take slam-bang treatment that will come its way. The high abrasion resistance demonstrated in this use gives long life to the beauty of many products made from Tenite Polypropylene, and also suggests its use for gears, bearings, and similar hard-working parts.

In addition to being injection molded, Tenite Polypropylene can be extruded into film, sheeting, and monofilaments, and in special formulations is adaptable to blow molding, where its exceptional strength permits thin walls. The film is sparkling clear, heat-sealable, printable, and an effective moisture barrier—important features in packaging. Rigid sheet is readily thermoformed on standard equipment into large-scale sections or skin packaging.

As extruded wire covering, Tenite Polypropylene exhibits excellent electrical and thermal properties. And formulations combining weatherability, low-temperature flexibility, and high tensile strength may be used to produce monofilaments that are ideal for such applications as webbing for outdoor furniture.

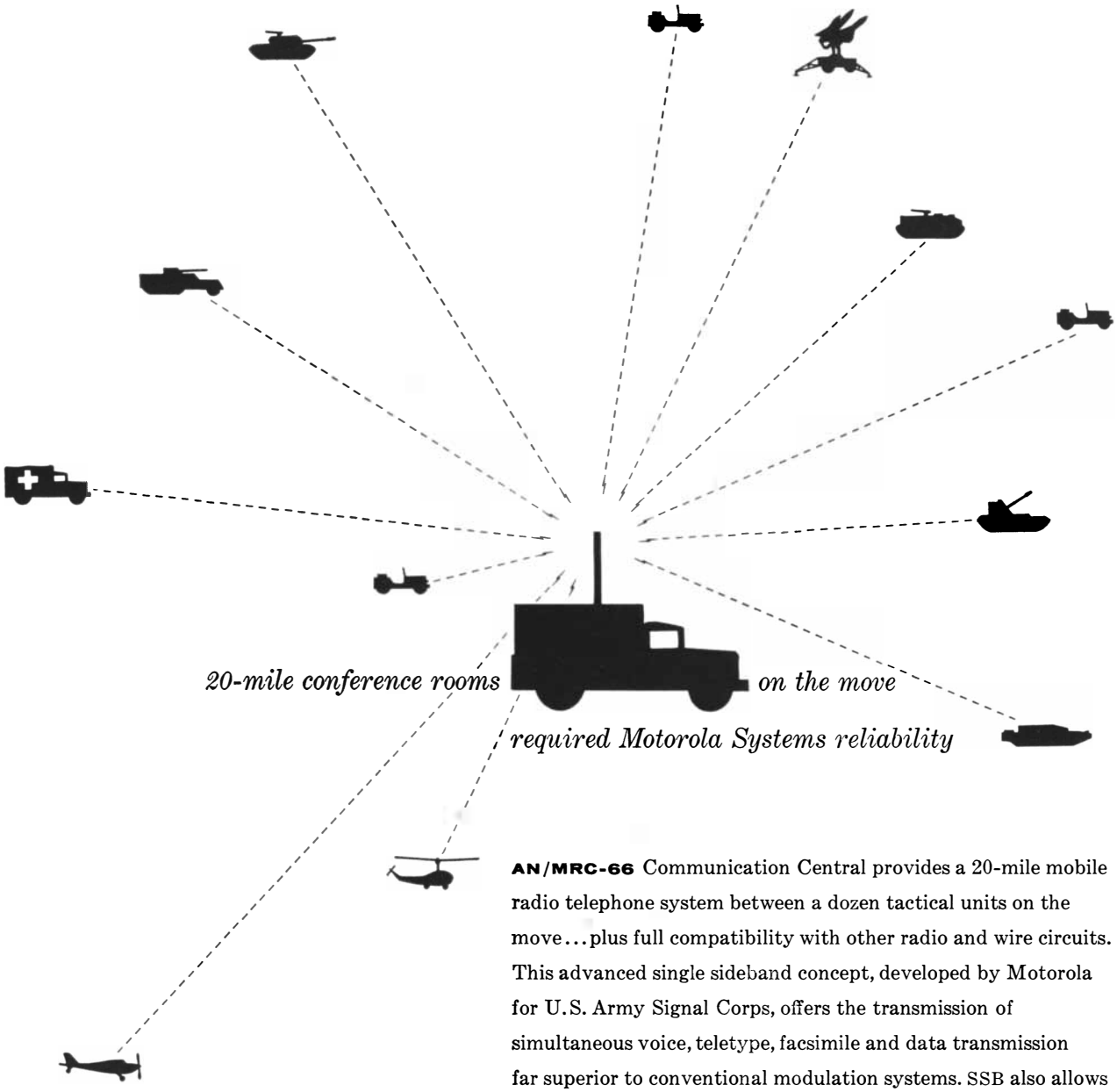
With the lightest weight of any solid plastic, Tenite Polypropylene gives the greatest product yield per pound. As for colors, thousands of vibrant hues are available in Tenite Polypropylene—or in color concentrates for mixing with uncolored plastic to produce the desired color when molded or extruded. Eastman experience in coloring plastics extends over 25 years, with additional background in color photography and textile dyes. In applying this plastic to your product ideas, you can call on the aid of Eastman's technical representatives and its extensive laboratory facilities. For information on Tenite Polypropylene or any other plastics in the Tenite family—butyrate, acetate, propionate, or polyethylene—write EASTMAN CHEMICAL PRODUCTS, INC., subsidiary of Eastman Kodak Company, KINGSPORT, TENNESSEE.

Carrying case molded by manufacturer of the "Tom Thumb" typewriter, Western Stamping Company, Jackson, Michigan.

TENITE®

POLYPROPYLENE

an Eastman plastic



20-mile conference rooms *on the move*

required Motorola Systems reliability

AN/MRC-66 Communication Central provides a 20-mile mobile radio telephone system between a dozen tactical units on the move... plus full compatibility with other radio and wire circuits. This advanced single sideband concept, developed by Motorola for U.S. Army Signal Corps, offers the transmission of simultaneous voice, teletype, facsimile and data transmission far superior to conventional modulation systems. SSB also allows more channels in a given portion of the crowded RF spectrum and more systems in a given area. ☆ Automatic Output Control insures uniform signal reception regardless of whether vehicles are deployed 100 feet or 10 miles from the Central. Three operating modes—Normal, In-Channel Net and Emergency Net—enhance the basic system flexibility. ☆ Simplification inherent in Motorola's concept and modular design affords the highest possible degree of reliability and maintainability in the field. Detailed information is available on request.

Military Electronics Division **MOTOROLA**

Qualified technical personnel are invited to apply

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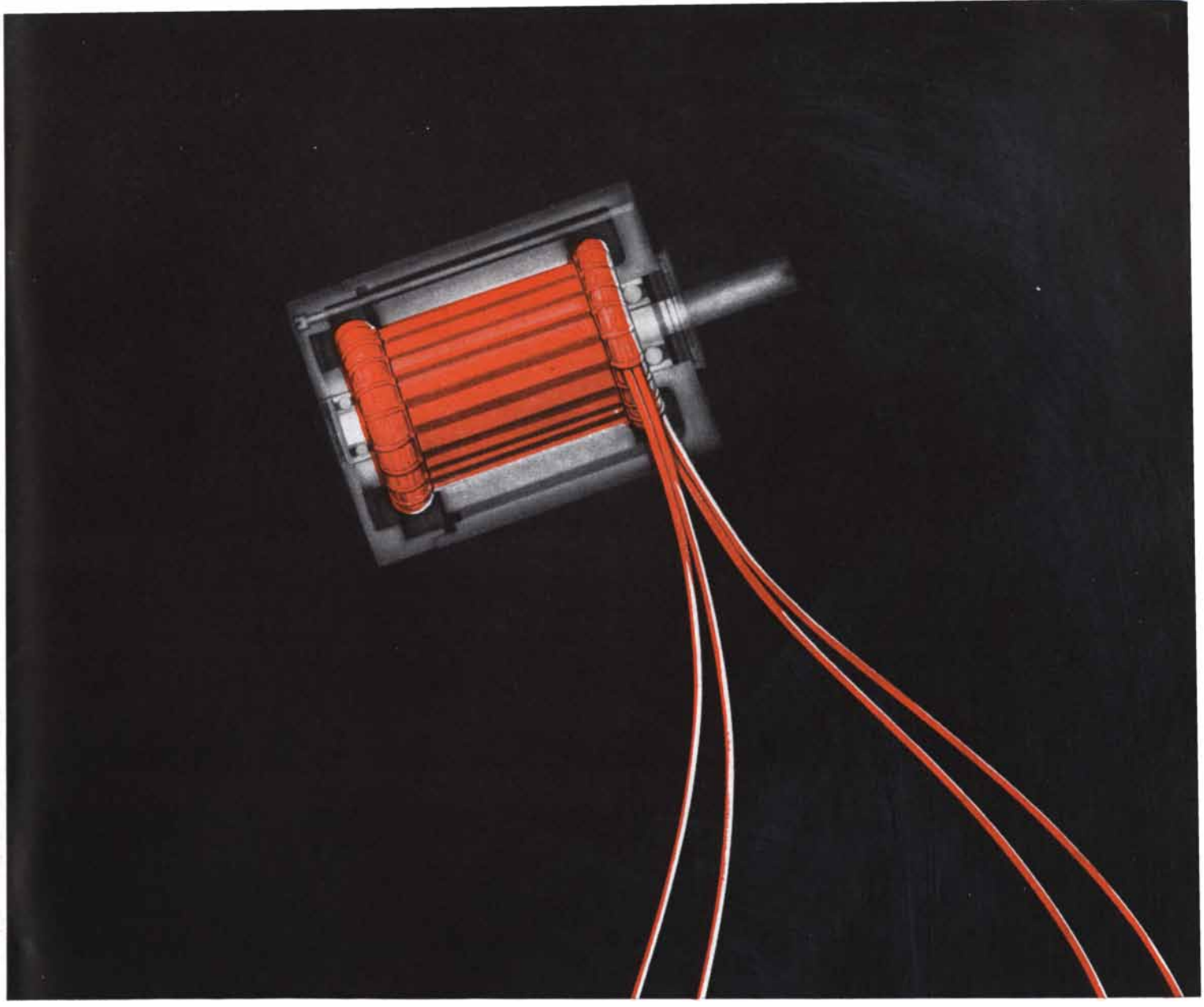

X-ray photograph of miniaturized motor (actual size) manufactured by Air Marine Motors, Inc., Amityville, L. I., N. Y.

THE INSIDE STORY: how motors lose weight and live longer

Space and weight were at a premium in this new motor, designed to drive a camera on a missile-tracking radar antenna. Requirements were for a synchronous motor, 1/40 hp at 8,000 rpm, to withstand 180°C. for a minimum of 2,000 hours' life. With conventional insulation, a unit 3⅞ inches in diameter weighing over 3 lbs. would have been required. Using cell insulation of a Du Pont TEFLON TFE fluorocarbon resin—magnet wire and lead wire insulated with TEFLON—the designer meets the specifications with a motor 2 inches in diameter weighing less than 1 lb.

Smaller size, lower weight and longer, trouble-free service for electrical and electronic equipment are made possible by the high insulating properties of TEFLON resins. In addition, virtually universal chemical inertness, resistance to temperature extremes, and very low coefficients of friction make TEFLON resins—both TFE and FEP—invaluable wherever severe environmental conditions prevail. Find out more about the many mechanical and electrical designs that have been improved by the use of these unique engineering materials. Write to: E. I. du Pont de Nemours & Co. (Inc.), Room S-7, Du Pont Building, Wilmington 98, Delaware.

In Canada: Du Pont of Canada Limited, P.O. Box 660, Montreal, Quebec.

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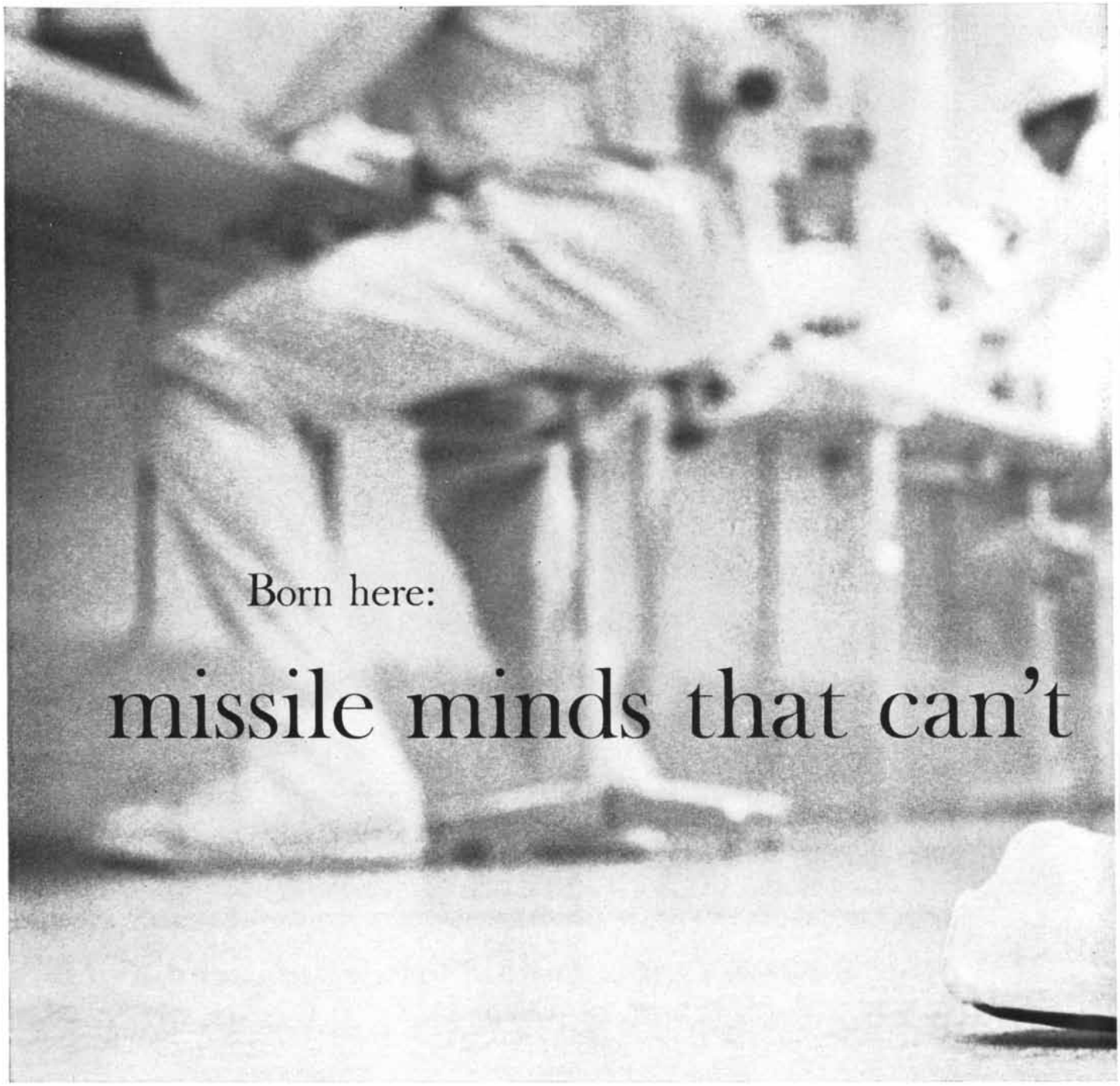
TEFLON is Du Pont's registered trademark for its family of fluorocarbon resins, including TFE (tetrafluoroethylene) resins and FEP (fluorinated ethylene propylene) resins.

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



Garbed like surgeons, Hughes engineers and technicians assemble accelerometers in this "clean room." Here, the air is a thousand times freer of dust than an air-conditioned office. In fact you literally "taste" the clean air!

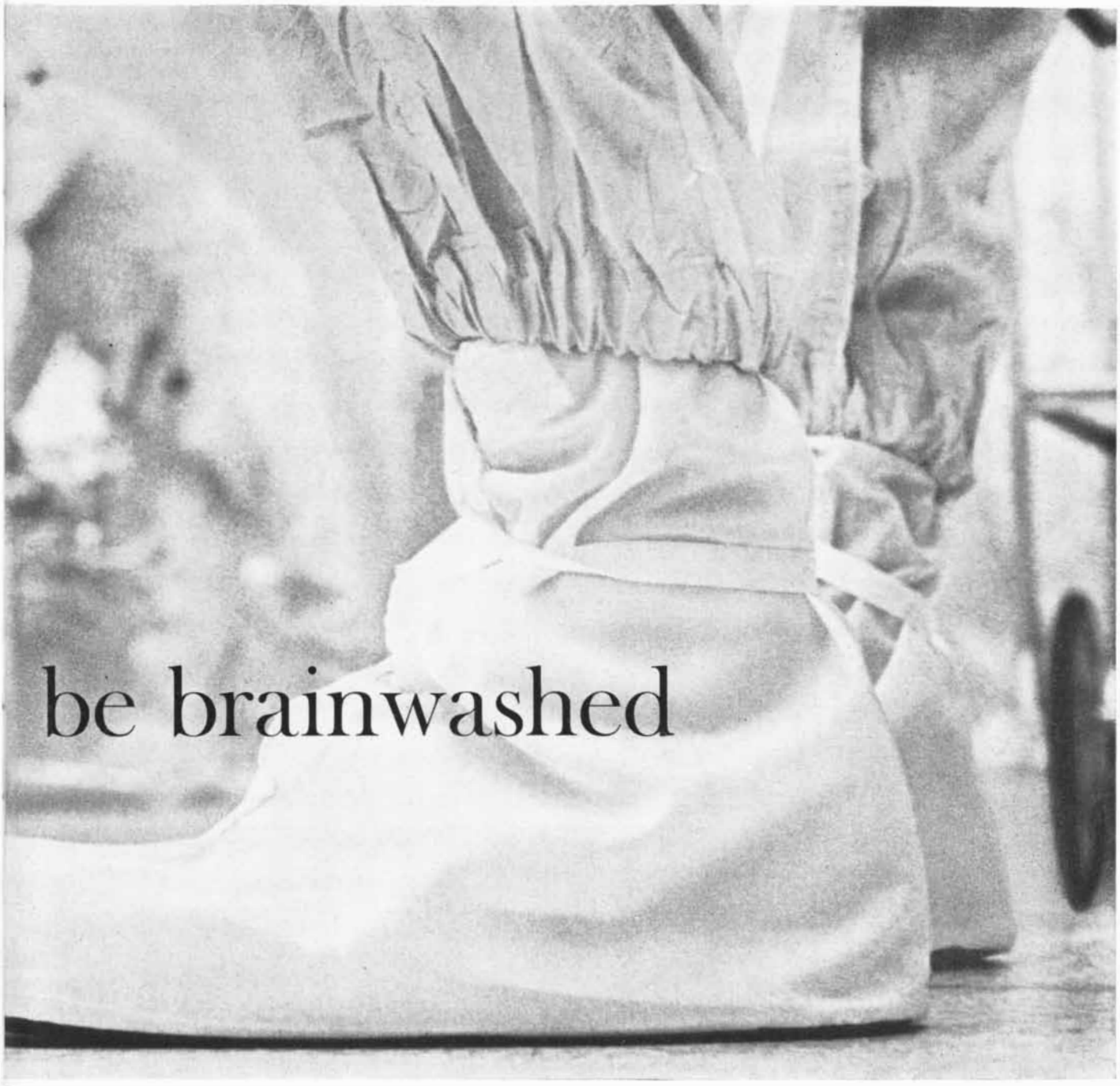
Accelerometers built in this room are so sensitive they can measure movements we cannot see. In missile inertial guidance systems they can sense acceleration of .003 of an inch per second per second.

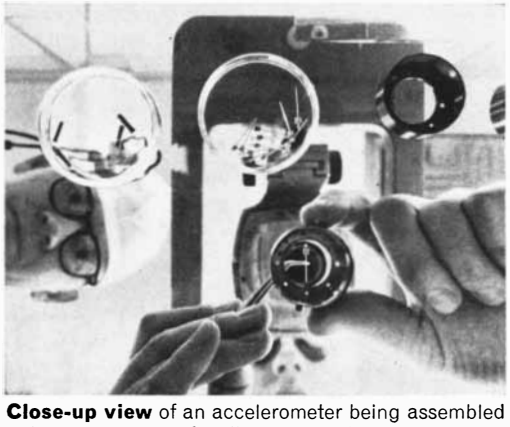
But a tiny speck of dust between their micro-finished surfaces could make them useless for the "mind" of a missile.

This type of accelerometer combined with gyroscopes and advanced electronics results in an inertial guidance system which is completely self-controlled—it cannot be "brainwashed." It needs no commands from the ground. It is invulnerable to "jamming" which might throw it off course.

Hughes is now applying its complete systems experience to all pertinent areas of creating inertial guidance systems: inertial components, computers, platforms, support equipment, advanced systems studies.

Hughes inertial guidance systems "marry" the latest developments in *both* electronics and mechanics. With this effort Hughes adds another facet to its broad scientific and production capabilities. This experience may be useful to you. We may have the answer to your problem. The result could be profitable for both of us.





Close-up view of an accelerometer being assembled in the Hughes dust-free "clean room."

Creating a new world with electronics

HUGHES

HUGHES AIRCRAFT COMPANY

50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

JULY, 1911: "Among the most remarkable recent additions to the modern equipment for clinical diagnosis are the so-called heart stations, now in operation at the Presbyterian and Mount Sinai hospitals in New York and at the Johns Hopkins Hospital in Baltimore. The new apparatus represents the most refined diagnostic instrument at the service of the heart specialist. The principle upon which the new method and apparatus are designed consists in the observation of certain electrical currents that accompany and are intimately related to the characteristic phases of the heart's action. The chief credit for the development of this method must be given to Waller, an Englishman, and especially to Einthoven, the noted Dutch physiologist. The latter it is who, in 1903, in his laboratory at Leiden, devised the so-called string galvanometer, the most essential feature of the new apparatus. With the aid of this remarkable instrument the physician can see and record the oscillations that the string undergoes as the result of the electric currents generated in the human heart. While the coarser features of the characteristic movement of the galvanometer string can be followed by eye, for purposes of obtaining an exact record of all the finer features it is necessary to resort to photographic registration. The record thus obtained is called 'electrocardiogram.'"

"As already reported in this journal, Capt. Amundsen, who left Norway ostensibly for the Arctic regions, where he proposed to make a five-year drift across the Polar Sea, recently turned up, to the surprise of the scientific world, in the Antarctic. His change of plans has now been explained by Dr. Nansen in a letter to the London *Times*. It appears that he wrote to Nansen from Madeira that, owing to the diminished popular interest in the North Pole since the successful result of Peary's last expedition, he felt convinced that he would not be able to raise sufficient money for the proposed voyage in the Arctic. He therefore decided upon the more popular and less expensive plan of vying with Scott, Filchner and the others in a dash for the South Pole. A press dispatch, dated June 17, states that Pedro Christophersen, a Norwegian in business in Argentina, has agreed to finance Amundsen's expedition to the extent of $50,000."

"Modern progress is not without its drawbacks, as would appear from the fact that after being familiar with mountain sickness, we are now to have the 'aviator's sickness' inflicted upon us. This expression does not mean any slight upon the numerous contingent of aeroplane flyers; it refers to an actual sickness that is felt by aeronauts. When mounting in the air, they find that breathing becomes shorter when at 5,000 feet height, and this effect is more noticeable than with ordinary balloons. The heart is noticed to beat faster, but generally there are no palpitations, and there is only a slight ill feeling. Buzzing in the ears is noticed only at a greater height, about 6,000 feet, although Legagneux felt a cracking noise in the ears when flying lower than this."

JULY, 1861: "The public has been painfully startled by the sudden death of Mrs. Longfellow—wife of the distinguished poet—which took place at Cambridge, Mass., on the 10th inst. The cause of this afflicting event is thus related: Mrs. Longfellow was seated in her library, and in the act of making seals with sealing wax. A bit of paper lighted and fell upon her dress, which caught fire, and before the blaze could be extinguished she was terribly burned. She was attended by Drs. Wyman and Johnson of Cambridge, but their efforts were vain to alleviate her intense suffering or to save her life. The dresses commonly worn by ladies in warm weather are composed of muslin and suchlike inflammable materials. Although we have, on several occasions, urged the preparation of ladies' dresses with non-inflammable agents, we regret to state that very little attention has been given to our admonitions. We trust that the subject of safety-clothing will hereafter receive more attention from ladies. Their own safety and good sense demand this."

"It is difficult for us to realize the fact, but we all know that any soldier is in five times more danger of dying from malarious disease than of being killed in battle. What malaria is nobody knows. It may consist of organisms, either animal or vegetable, too minute for even the microscope to detect; or it may be some condition of the atmosphere in relation to electricity or temperature or moisture; or it may be a gas evolved in the decay of vegetable matter. The last is the most common hypothesis, but it is by no means proved and it has some stubborn facts against it. There is no doubt, however, that malaria is some mysterious poison in the atmosphere and that it is confined strictly to certain localities."

"A very large capital is now invested in gold mining in Australia. The number of miners engaged in obtaining gold is 107,572, of which there are 60,874 Europeans and 28,100 Chinese. There are 294 steam engines of the aggregate power of 4,137 horses; also 3,957 horse puddling machines, 354 horse gins and 128 water wheels. These are all used in the alluvial workings. Besides these, there are used in the quartz mining and crushing 420 steam engines, equal to 6,696 horse-power, 6 water wheels, 40 horse crushers and 184 horse gins. The aggregate ratio of the mining plant (machinery, &c.) is about $6,000,000."

"City passenger railways, which were greatly opposed at first in England, are now becoming quite popular. The two tracks—only about two miles long—laid down by Mr. Train in London have been very successful. No less than 170,000 persons were carried over them in seven weeks. The Board of Trade has made a very favorable report upon them, and two other roads, of greater length, are now being constructed in the British metropolis. In Bristol, Portsmouth and Exeter arrangements are now being made for introducing the system."

"A new art of coloring plates of metal by electricity was described at a late meeting of the French Academy of Sciences by M. Becquerel. This *savant* commenced his experiments upon the electro-chemical coloring of metals in 1843. His object was to deposit upon plates of gold, silver and copper uniform layers of the oxyd of lead, which, according to the duration of the operation, produces beautiful colors. With a little practice M. Becquerel was able to produce all the different shades of colors that he desired. It has been very difficult to render such colors permanent, but this has at last been accomplished, and M. Becquerel exhibited several samples of these to the members of the Academy."

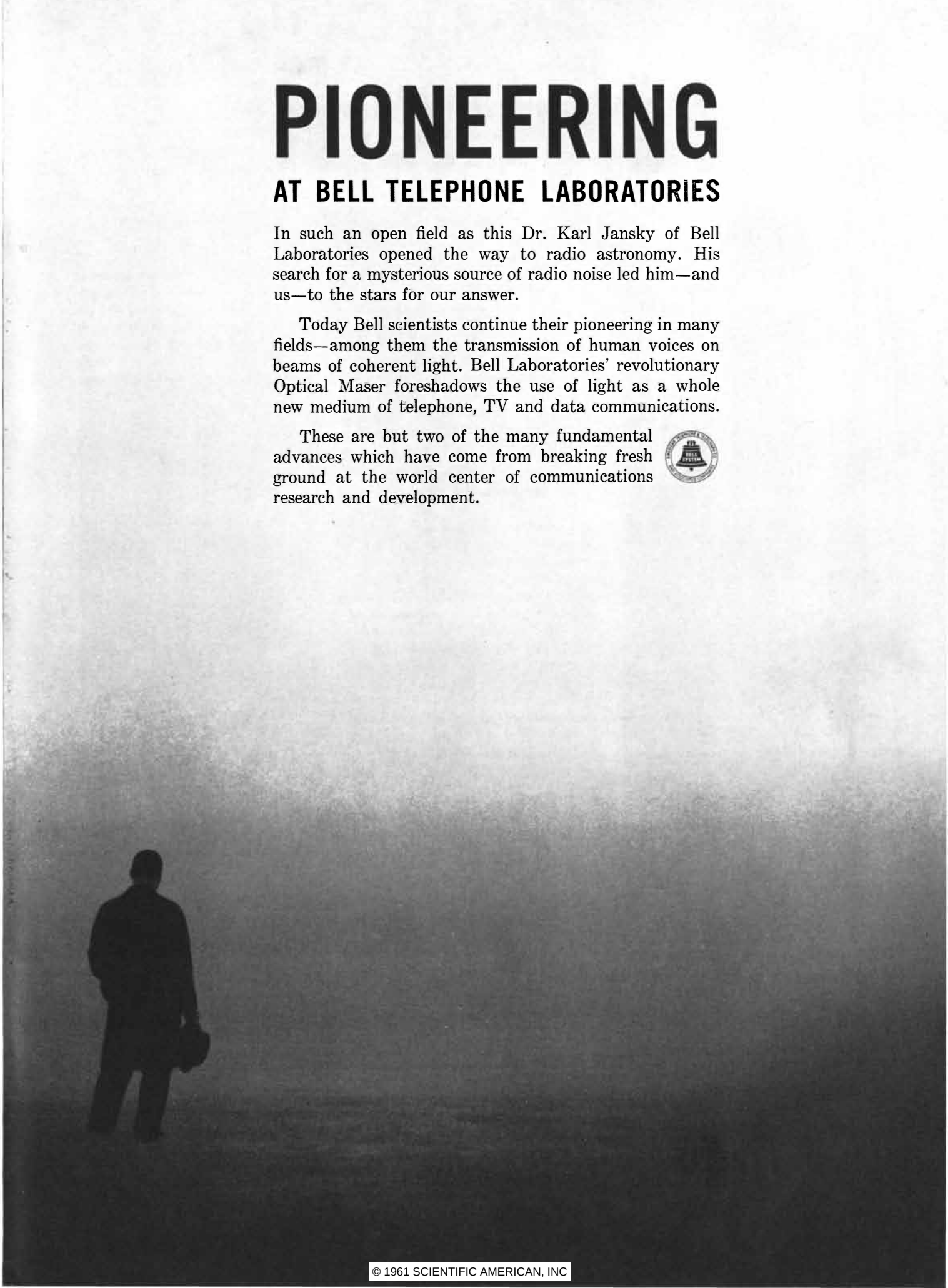
PIONEERING

AT BELL TELEPHONE LABORATORIES

In such an open field as this Dr. Karl Jansky of Bell Laboratories opened the way to radio astronomy. His search for a mysterious source of radio noise led him—and us—to the stars for our answer.

Today Bell scientists continue their pioneering in many fields—among them the transmission of human voices on beams of coherent light. Bell Laboratories' revolutionary Optical Maser foreshadows the use of light as a whole new medium of telephone, TV and data communications.

These are but two of the many fundamental advances which have come from breaking fresh ground at the world center of communications research and development.



News from Allied Chemical:

Dissertation on diisocyanates. Our National Aniline Division has just published a booklet describing the origin and development of those polymer-formers which make possible that new family of materials, urethane foams. It tells why and how these foams foam.

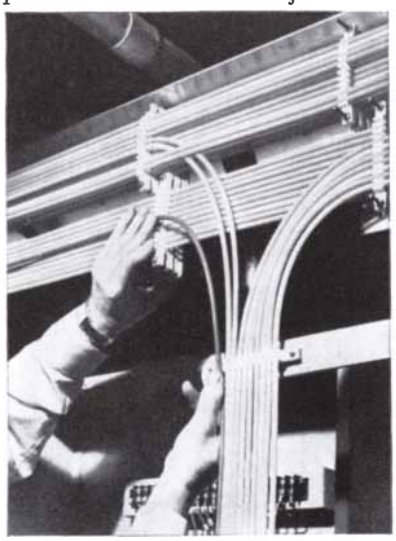
Egg bouncing from 12-foot drop shows cushioning properties of flexible urethane foam.

It points out the tremendous density variations—from 1 to 60 pounds per cubic foot in weight. It lists present applications—mattresses, apparel interlinings, refrigerator insulation—forecasts exciting new uses such as prefabricated wall panels for homes. Two Allied products besides National's NACCONATE® diisocyanates and ACTOL® polyethers go into urethanes: polyester resins from our Plastics Division and GENETRON® blowing agents from General Chemical. *Booklet is informative—and free.*

New uses for colored papers. If you're engaged in the business of promoting or selling via word or picture, you'll be interested in a new brochure published by our National Aniline Division. It demonstrates a 2-color process reproduction utilizing a tinted paper which approximates a full-color effect. It also features a treatise by leading color authority Faber Birren entitled, *The Age of Reason for Color.* Purpose of the brochure: to point out the advantages in using *tinted papers and color-related inks* (instead of traditional black on white) for greater legibility, less eye fatigue, emotional and psychological effect. *Brochure is yours for the asking.*

Uncommon uses for calcium chloride. This common compound is now finding many new uses. There are at least seven ways in which it can save time and money in the drilling of oil wells . . . Neutral Sulfite Semi-Chemical papermakers use it to strengthen their product at the delicate "wet web" stage . . . and its many uses as a processing chemical encompass such diverse products as portland cement, metallic sodium, petroleum, synthetic detergents and herbicides. If a low-cost, hygroscopic, exothermic compound, in flake or liquid form, might help *your* product or process, look into our Solvay Process Division's SOLVAY® Calcium Chloride. *A wealth of technical literature is available.*

Cost-savings in instrument-air control. Literally miles of tubing are often needed to convey air impulses between control panels and field instruments in chemical processing and petroleum refining. Until lately, copper was *the* material used. Now, a new plastic offers to do the job more



Even right-angle bends are easy to form with tubing made of flexible PLASKON *Nylon.*

cheaply—often better. It's extrudable PLASKON® Nylon, a special form of polycaprolactam (nylon-6), from our Plastics Division. Available in a flexible grade (with no sacrifice of tensile strength) PLASKON Nylon tubing offers many advantages over copper: half the cost in sizes under ¾″; one-eighth the weight; flexibility; continuous lengths; color-codability. Booklet is available describing advantages and installation methods, including a cost analysis of a 125,000-foot installation at our Hopewell, Virginia, plant. *Write for it.*

For literature on any of the above-mentioned items, just write, on your company letterhead, to Allied Chemical Corp., Dept. 71-S, 61 Broadway, New York 6, N.Y., or telephone HAnover 2-7300.

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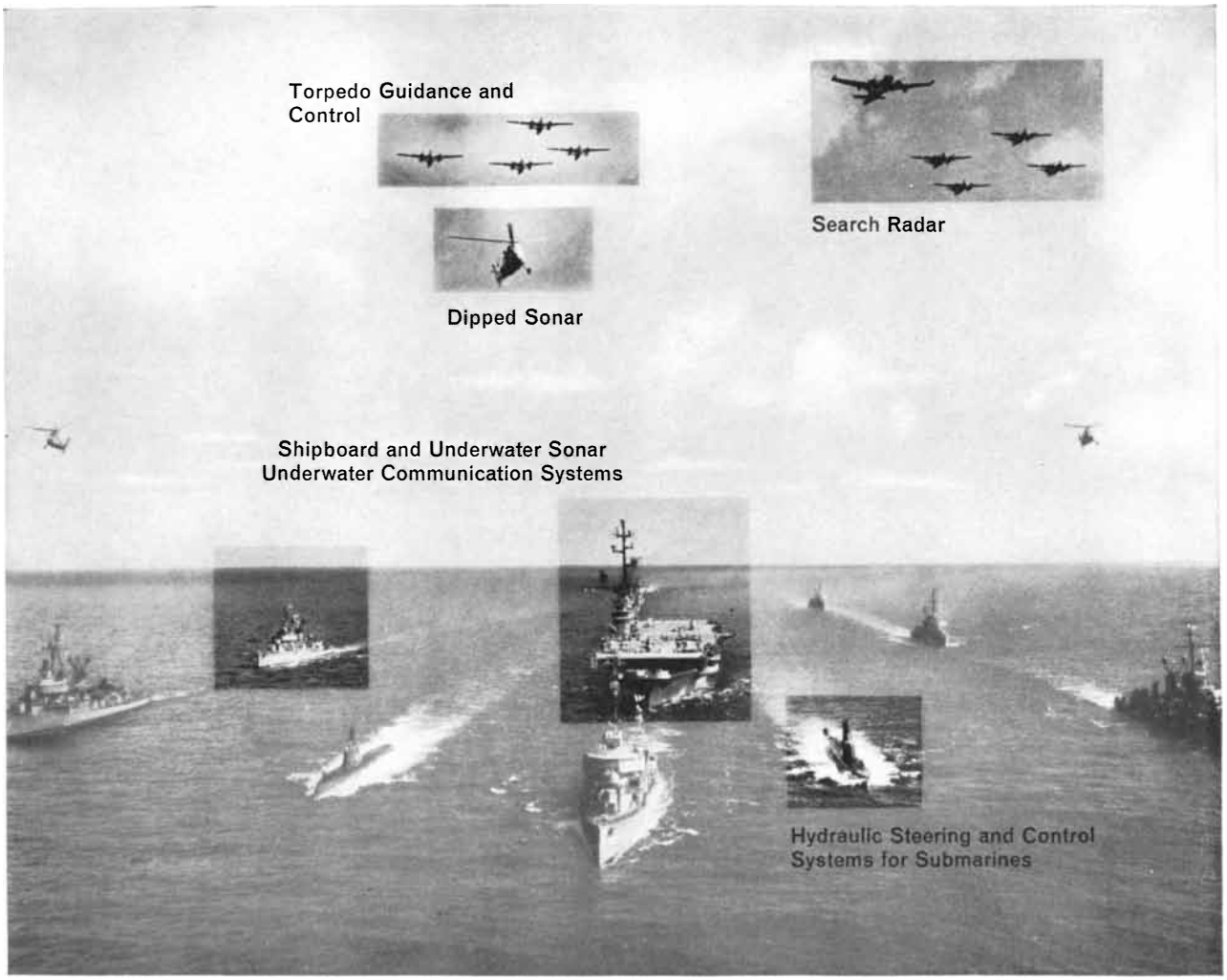

ABOVE, ON AND UNDER THE SEA—BENDIX SERVES THE NAVY'S ANTI-SUBMARINE WARFARE TEAM

Ready around the clock to help prevent surprise submarine attack, the U. S. Navy's Anti-Submarine Warfare Task Group is an integrated team working in every area of modern defense—in the air, on and under the sea.

Helping the Anti-Submarine Task Group man the nation's seaward defenses is a wide range of specialized equipment—including airborne radar, shipboard and airborne sonar, underwater ordnance, surveillance, navigation, and communication devices—developed by our Bendix-Pacific Division.

In the air, Bendix radar equipment helps carrier-based patrol planes and helicopters scan the seas for surface and underwater vessels. Establishing an underwater listening post for the Navy's air arm is a lightweight sonar system which is "dipped" from a helicopter. This system gives the sonar operator visual range and bearing information as well as audio signals. For safer landings on aircraft carriers, the new Bendix® radar altimeter measures the height of planes over carrier decks with extreme accuracy.

Under the sea, Bendix® sonar equipment permits nuclear, killer, and radar picket submarines to detect enemy submarines at long range. Many of the Navy's newer submarines are equipped with hydraulic steering and control systems and components furnished by Bendix-Pacific. Some of these craft use approximately 300 control valves in more than 50 different configurations. Bendix also produces guidance and control systems for several types of torpedoes, as well as firing mechanisms for mines and depth charges.

On the surface, Bendix signal processing devices, working in conjunction with sonar detection sets, help ASW ships pinpoint targets . . . strike swiftly and accurately.

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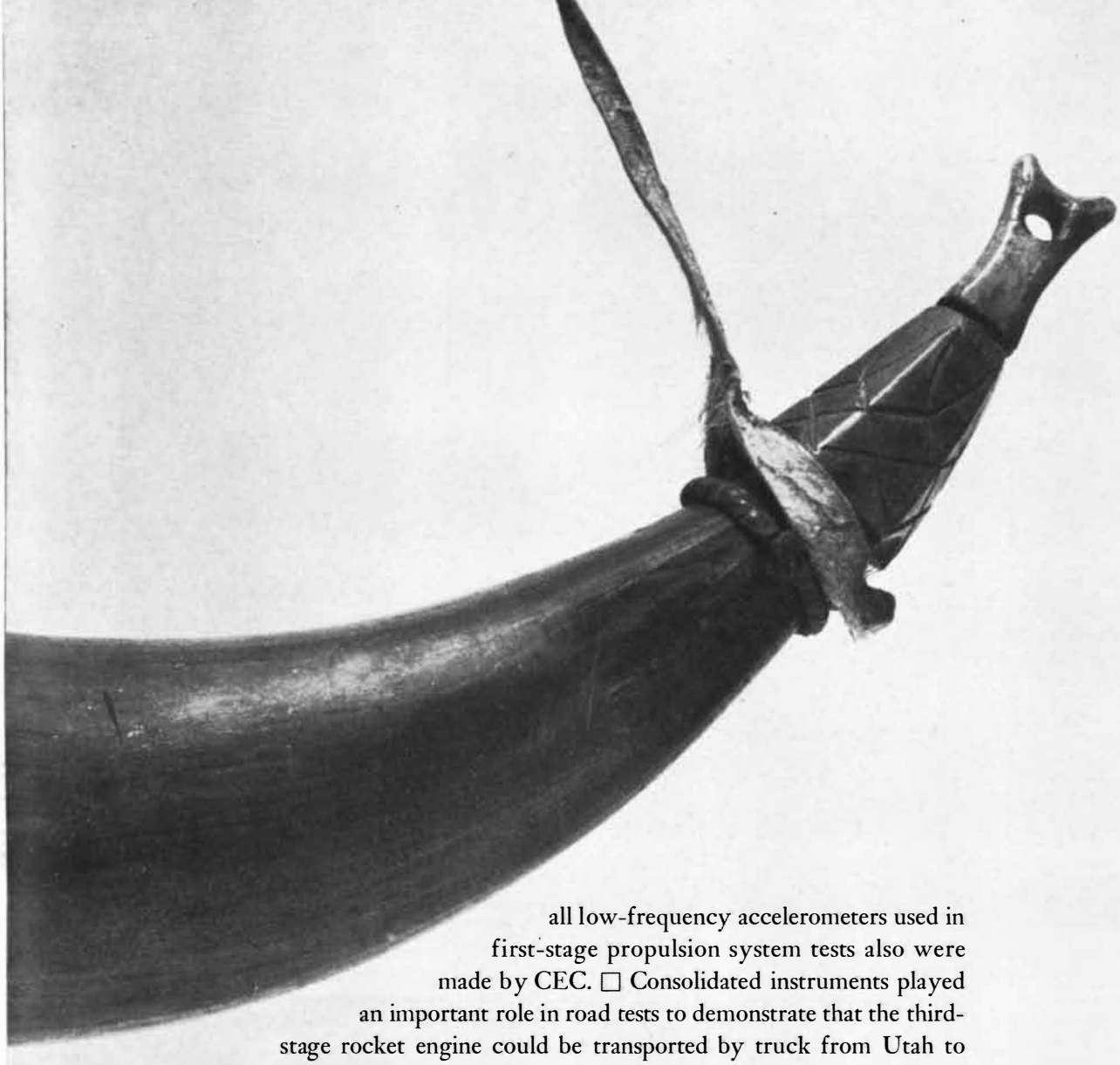
Instant Defense

The Minuteman at Lexington and Concord was ready at a moment's notice to defend his home. Today's Minuteman, a solid fuel, 6325-mile range ICBM—launched from underground silos or railroad cars—can be readied in seconds, to bring a nuclear war home to any aggressor! □ Before and during its successful firing last February, Minuteman was tested on the ground, in transit, in trajectory. Much of this testing—measuring, analyzing, controlling, recording—was done with Consolidated Electrodynamics Corporation instruments. □ Transducers for test units of Minuteman are made by Consolidated. CEC oscillographs are used throughout FM/telemetry, PCM, and various ground support stations for the test program. □ The three data acquisition systems designed for road testing the first-stage rocket engine have relied on CEC print-out oscillographs to record accelerations. Various ground-test pressure transducers and



all low-frequency accelerometers used in first-stage propulsion system tests also were made by CEC. □ Consolidated instruments played an important role in road tests to demonstrate that the third-stage rocket engine could be transported by truck from Utah to such cities as Denver, Las Vegas, and Seattle, and returned to Utah and fired successfully. Three test trucks were equipped with instrumentation to measure shock, vibration, and engine environment. Mounted in the trucks were three CEC mobile instrumentation systems, each made up of a recording oscillograph, two carrier amplifiers, a tape recorder, and Consolidated's newest strain gage accelerometers. Purpose of the tests was to determine if handling and cradling of the engine could be improved and if strain and stress on motor cases were excessive. □ In mobility tests of Minuteman units carried by train, CEC provided all of the accelerometers used to determine the extent of shock and vibration to which the missile is subjected. □ Partners in this important defense project are Boeing Airplane Co., Space Technology Laboratories, Autonetics Division of North American, Thiokol Chemical Corporation, Hercules Powder Company, Aerojet-General Corporation, and Avco Corporation. □ CEC knows. These companies know. The world knows. Keep America's powder horns filled, maintain Instant Defense, and no enemy will dare to attack. That's the promise of the Minuteman.

CONSOLIDATED ELECTRODYNAMICS / pasadena, california **CEC**

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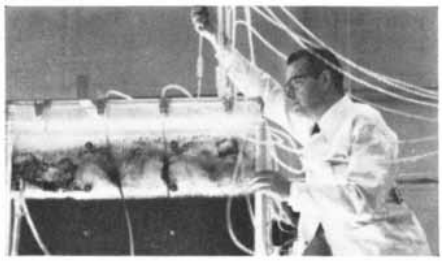
A SUBSIDIARY OF **Bell & Howell** • *FINER PRODUCTS THROUGH IMAGINATION*

TWIN-TURBINE HELICOPTER. The Boeing-Vertol 107—fastest, smoothest-riding commercial helicopter now flying—goes into service with New York Airways this summer. It seats 25 passengers in comfort, cruises at 155 mph and operates with equal ease from land or water. The 107, first twin-turbine helicopter certified by the FAA for commercial service, has also been ordered for service in Japan. Military versions have been ordered by U.S. Navy, Swedish Navy and Air Force, and Royal Canadian Air Force.

Capability has many faces at Boeing

JET-AGE FIRE FIGHTER. Boeing gas turbine engines power fire trucks in San Francisco and Seattle. These 330 hp engines weigh only 335 pounds, propel 15-ton trucks from standing start to 25 mph in 9 seconds.

SPACE GLIDER. Drawing of U.S. Air Force's Dyna-Soar manned space glider, designed to rocket into space, then re-enter the earth's atmosphere for conventional pilot-controlled landing. Boeing is system contractor for Dyna-Soar.



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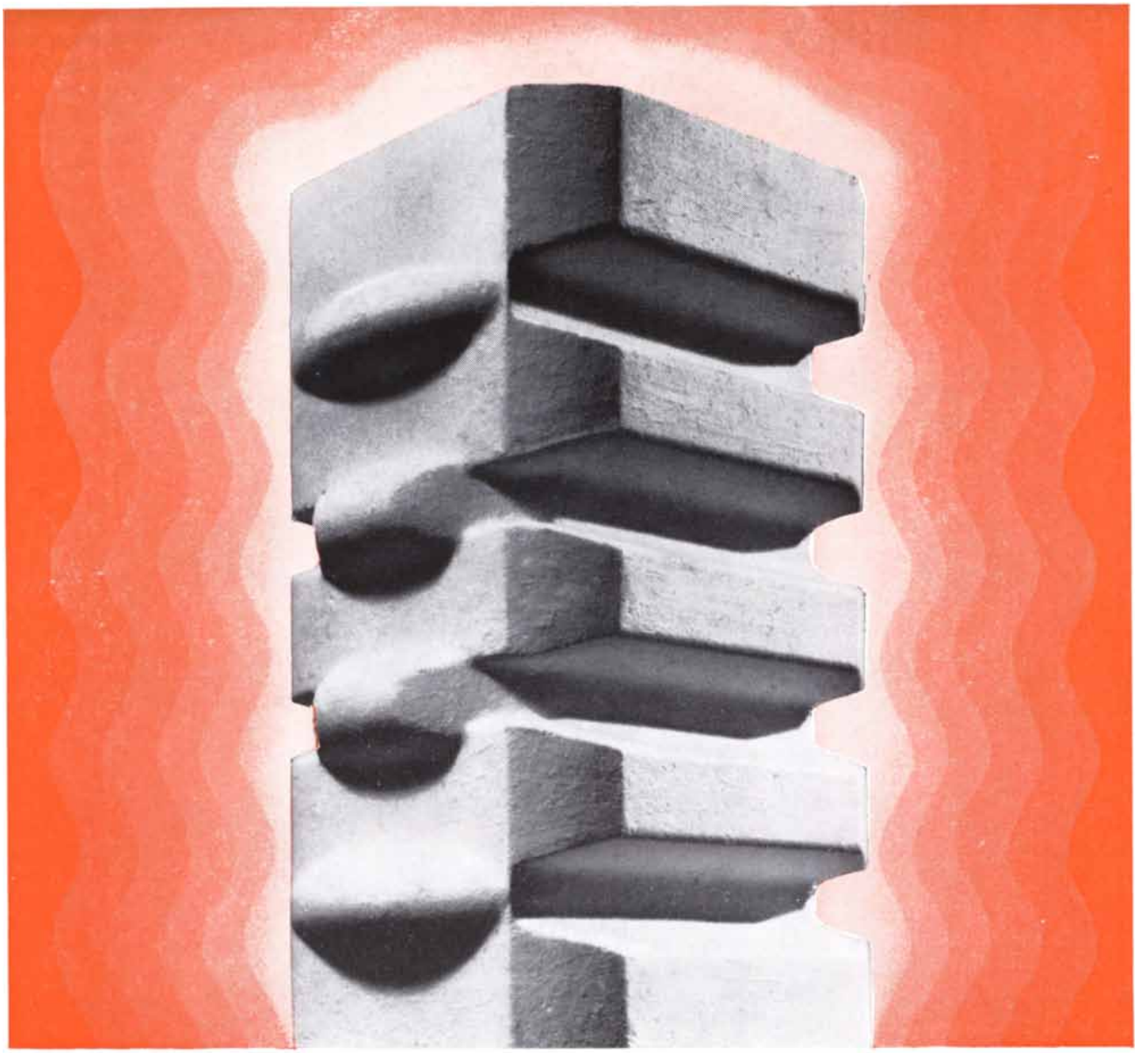

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THE AUTHORS

PHILIP M. HAUSER ("The Census of 1960"), chairman of the department of sociology at the University of Chicago and director of Chicago's Population Research and Training Center, is currently chairman of the Technical Advisory Committee for the census of 1960. He was also acting director of the census of 1950. Hauser took three degrees at Chicago, receiving a Ph.D. in sociology in 1938. From 1938 to 1942 he was assistant chief statistician for population in the Bureau of the Census and until 1947 served as acting director of the bureau. In 1947 Hauser became the U. S. representative to the Population Commission of the United Nations, a position he held until 1952. He has also been a director of the Social Science Research Council and a vice-president of the American Association for the Advancement of Science. This is his second article for SCIENTIFIC AMERICAN; the first, on the census of 1950, appeared in April, 1951.

SHELDON PENMAN ("The Muon") is assistant professor of physics in the Enrico Fermi Institute for Nuclear Studies at the University of Chicago. He took a B.S. in physics while working in a Naval Ordnance laboratory, did graduate work at Columbia University and acquired his Ph.D. there in 1958. Penman, who joined the Enrico Fermi Institute in 1959, has been engaged in research on muons (mu mesons) for the past three years. At present he is doing experimental work on the capture of muons by atomic nuclei.

JOHN P. MERRILL ("The Artificial Kidney") is director of the cardiorenal section at the Peter Bent Brigham Hospital in Boston and assistant professor of medicine at the Harvard Medical School. He received his B.A. from Dartmouth College in 1938, his M.D. degree from Harvard in 1942 and from 1943 to 1947 was a physician in the Army Air Force. Merrill has been engaged in research on the artificial kidney since 1947, when he returned to Peter Bent Brigham as an Established Investigator for the American Heart Association to study the effects of changes in body fluids on heart action. When Merrill and his co-workers found that the artificial kidney provided only temporary relief for patients with chronic kidney disease, they began work on the problem of kidney transplants. The first successful transplant was performed in 1954. In recent years Merrill has employed the artificial kidney chiefly as a research tool. Merrill, who is also an Investigator of the Howard Hughes Medical Institute, was the author of "The Transplantation of the Kidney" in the October 1959 issue of SCIENTIFIC AMERICAN.

MORRIS NEIBURGER and HARRY WEXLER ("Weather Satellites") are respectively chairman of the department of meteorology at the University of California at Los Angeles and director of meteorological research for the U. S. Weather Bureau. Neiburger received a B.S. from the University of Chicago in 1936 and a Ph.D. there in 1945. He worked as a meteorologist for the Weather Bureau from 1930 to 1940, taught for a year at the Massachusetts Institute of Technology and then joined the faculty of U.C.L.A. Wexler took a B.S. degree at Harvard University in 1932 and in 1939 received a D.Sc. from the Massachusetts Institute of Technology. He went to the Weather Bureau as a meteorologist in 1934. Wexler was chief of the Weather Bureau's Scientific Services Division from 1946 to 1955, at which time he took his present position. He was chief scientist of the U. S. Expedition to the Antarctic for the International Geophysical Year.

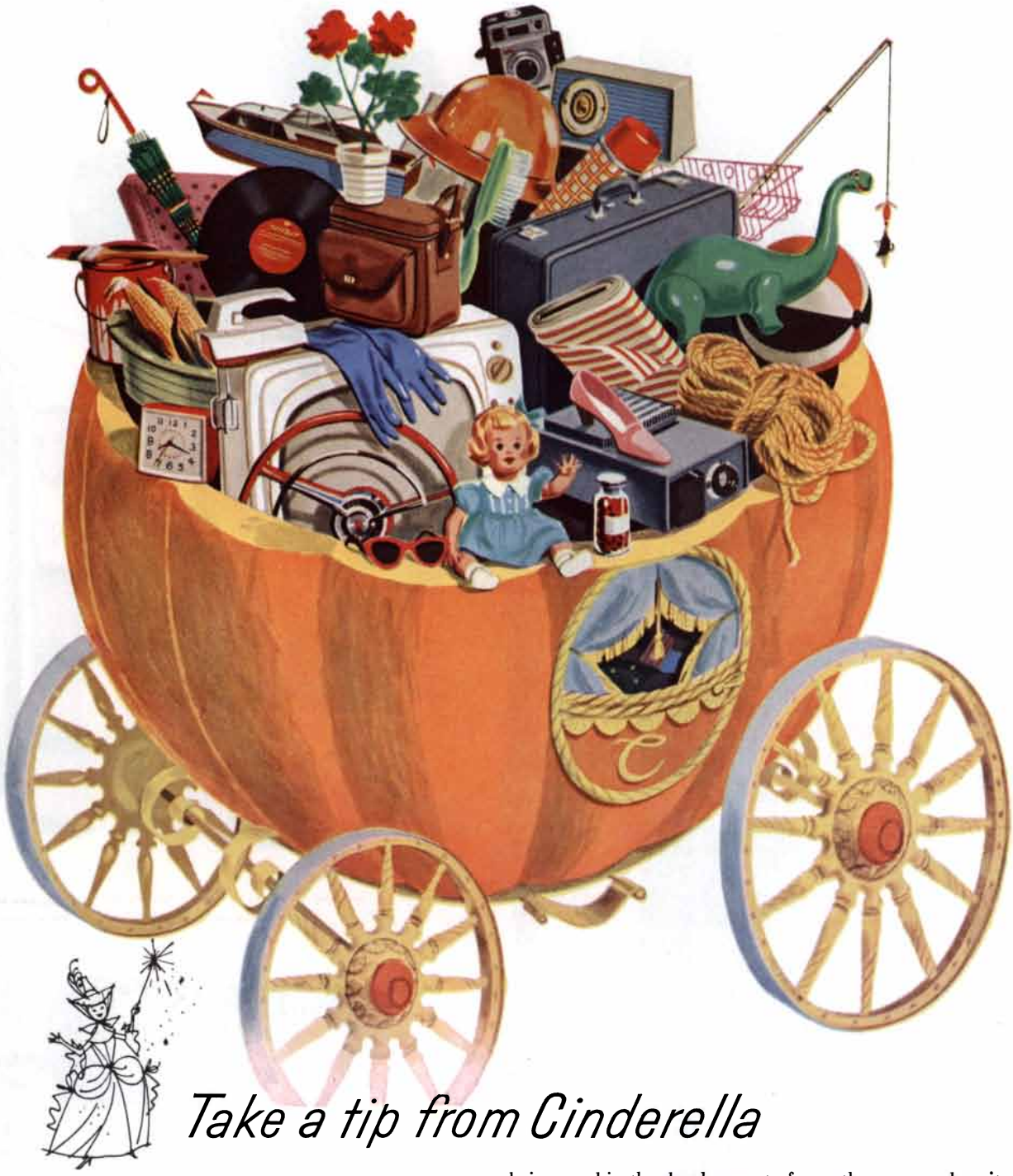
AARON B. LERNER ("Hormones and Skin Color") is professor of medicine and head of the section of dermatology at Yale University School of Medicine. Lerner attended the University of Minnesota, where he first began doing research on pigmentation under the direction of L. Earle Arnow in 1939. He received a B.A. from Minnesota in 1941, a Ph.D. in physiological chemistry in 1945 and an M.D. degree in 1946. After serving for two years in the U. S. Army Medical Corps, Lerner spent a year in the department of biochemistry at Western Reserve University Medical School working with H. G. Wood. From 1949 to 1952 he was assistant professor of dermatology at the University of Michigan Medical School and then went to the University of Oregon Medical School. He joined the faculty of Yale in 1955.

DONALD S. BLOUGH ("Experiments in Animal Psychophysics") is associate professor of psychology at Brown University. As an undergraduate at Swarthmore College, Blough became interested in animal psychophysics while taking a seminar course with the famous Gestalt psychologist Wolfgang Köhler. After receiving his B.A. from Swarthmore in 1951 Blough did graduate work at Harvard University, acquiring a Ph.D. in 1955. He was a research psychologist for the National Institute of Mental Health from 1954 to 1958, at which time he joined the faculty of Brown.

WILLIAM B. ITTNER III and C. J. KRAUS ("Superconducting Computers") are respectively a physicist and an electrical engineer who work for the International Business Machines Corporation. Ittner is manager of cryogenics research and engineering at the IBM Research Center. He attended the University of Chicago, the Massachusetts Institute of Technology and Washington University, received a Ph.D. in radiation physics from the last in 1953 and went to IBM later that year. He is currently directing a program to determine the feasibility of building large, high-speed, low-power computers using superconducting switches. Kraus is head of the Advanced Technology Development Division in the Federal Systems Division of IBM. He was graduated from Polytechnic Institute of Brooklyn with a degree in electrical engineering in 1943 and served in the Army Signal Corps until 1946, working on the operation and maintenance of search and gun-laying radar. After going to IBM in 1953, Kraus worked primarily on the design of radar-mapping and memory-drum equipment for a vacuum-tube data processor used as part of an air-defense system. He became interested in superconducting computers about five years ago, he writes, when "plans for the future generations of computing machines began to evolve."

MARTIN LÜSCHER ("Air-conditioned Termite Nests") is professor of animal physiology at the Zoological Institute of the University of Bern in Switzerland. Born in Basel in 1917, Lüscher attended the university there and acquired a Ph.D. in 1944. After four years of postgraduate research in England and France he joined both the faculty of the University of Basel and the scientific staff of the Swiss Tropical Institute. Lüscher, whose chief research interest is caste differentiation among termites, traveled to East Africa in 1949 to study tropical termites. He took his present position following a second trip to Africa in 1953.

HENRY S. CHURCHILL, who in this issue reviews Lewis Mumford's *The City in History*, is an architect and city planner who lives in Philadelphia. He is the author of *The City Is the People*.



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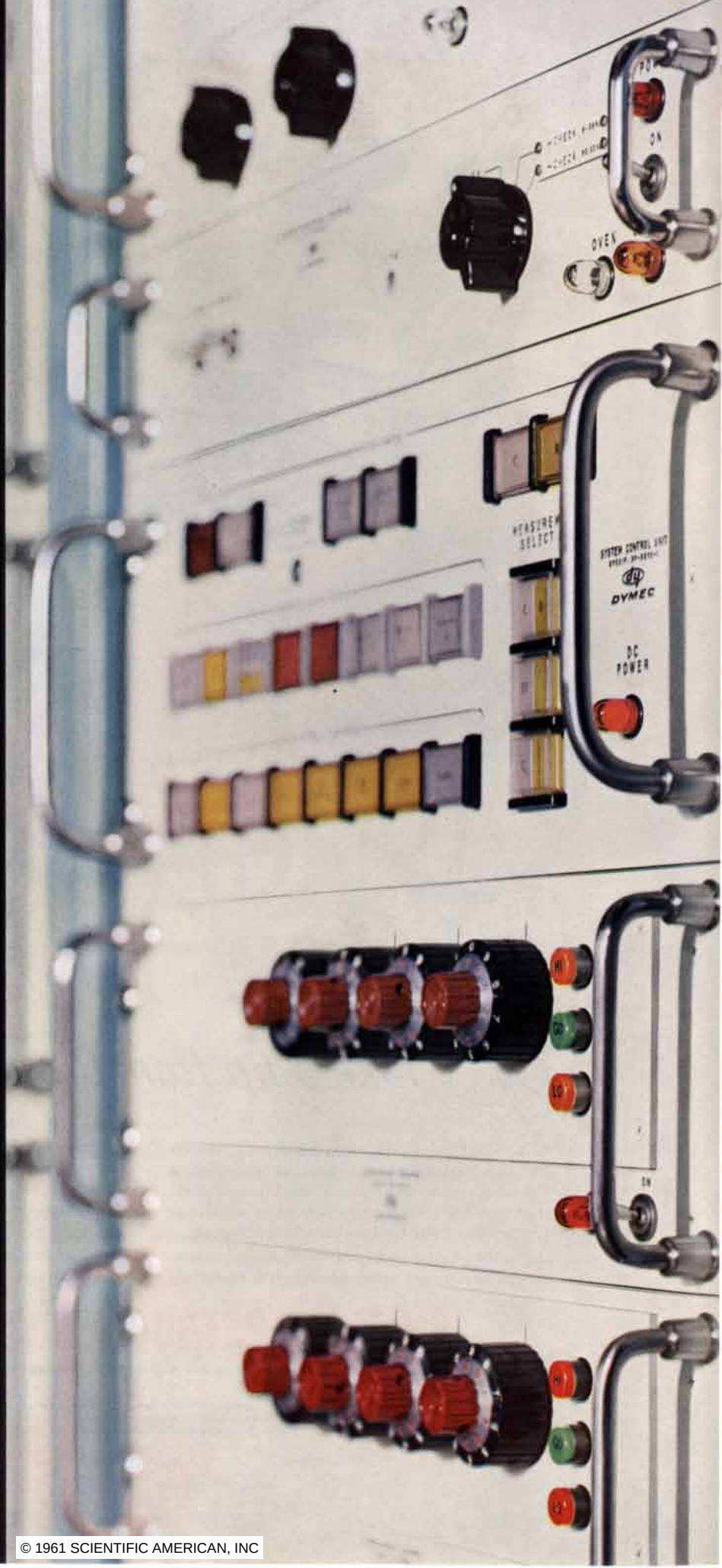

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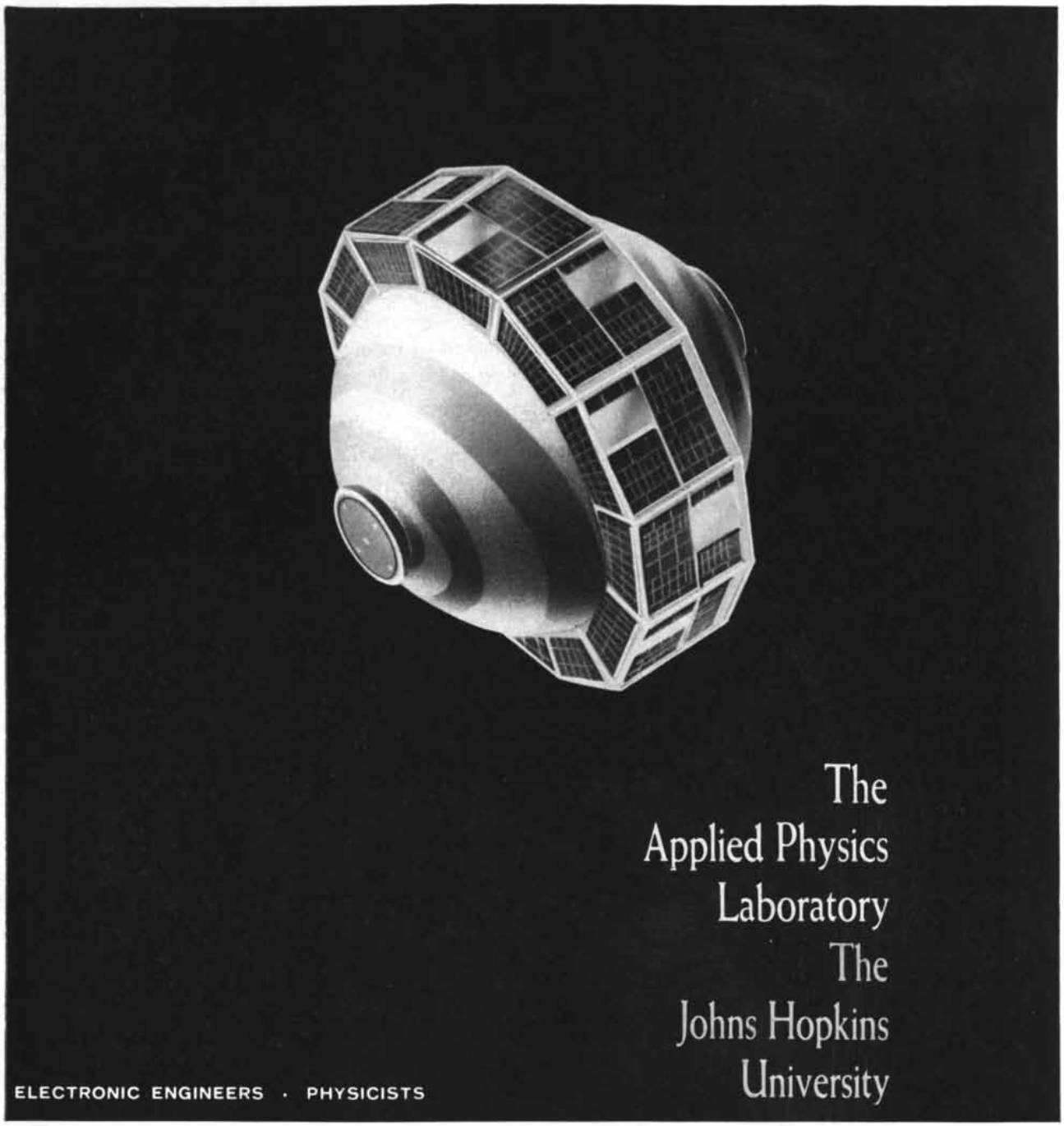

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INCO RESEARCH

Sigmund Freud... on the fateful question

"The fateful question of the human species seems to me to be whether and to what extent the cultural process developed in it will succeed in mastering the derangements of communal life caused by the human instinct of aggression and self-destruction. In this connection, perhaps the phase through which we are at this moment passing deserves special interest. Men have brought their powers of subduing the forces of nature to such a pitch that by using them they could now very easily exterminate one another to the last man. They know this — hence arises a great part of their current unrest, their dejection, their mood of apprehension. And now it may be expected that the other of the two 'heavenly forces,' eternal Eros, will put forth his strength so as to maintain himself alongside of his equally immortal adversary."

— *Civilization and its Discontents, 1930.*

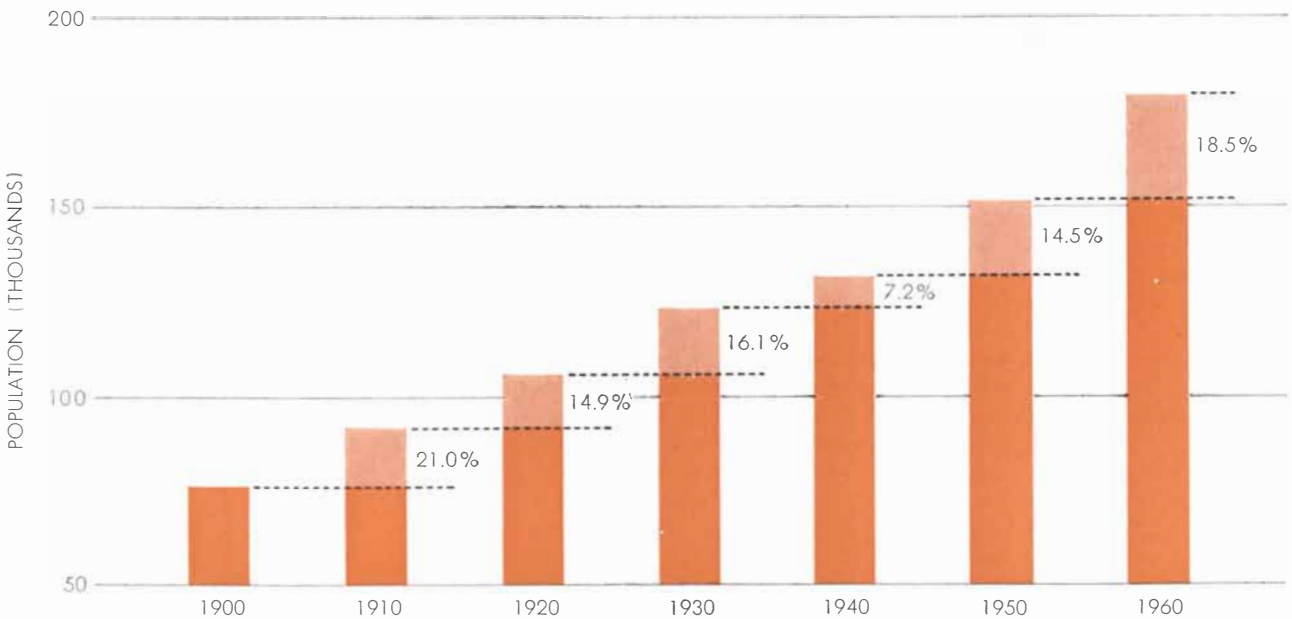
Established 1845 SCIENTIFIC AMERICAN July 1961 Volume 205 Number 1

The Census of 1960

Detailed figures from the decennial head count show the population is concentrated more than ever in metropolitan areas. Families are larger, households smaller and the people both younger and older

by Philip M. Hauser

Article I of the Constitution of the United States sets up a House of Representatives in which the several states are represented in proportion to their population. The decennial census, taken each decade since 1790, furnishes the head count necessary to allocate the seats in the House. Incidental to this function the census also presents the nation with a revealing picture of itself. From the meager information asked of each person, the facts developed about the nation as a whole provide a secure basis for an understanding of the major trends in its life and for the formulation of public policy. The 18th decennial census of 1960 has already served its constitutional purpose; the new total population figures were reported to the President for transmittal to the Congress in advance of the statutory date of December 1, 1960. Now, thanks to recent progress in the technology of data processing, some of the significant details in



INCREASE IN U. S. POPULATION since the 1940 census (*colored bar, identified by year at bottom*) has reversed the population trend reflected in the four earlier censuses taken in this century. The per cent gain in population (*light-colored portion of bars*) was greatest in the first decade (1910 census). For the next three decades the gain fell substantially, reaching its lowest point in the decade of the depression (1940 census). Following the postwar marriage and baby booms, the rate of increase doubled (1950 census). The 1960 census shows that this new population trend is continuing. The per cent gain is the second largest of the century.

the national self-portrait are available for consideration.

The principal findings of the 1960 census may be summarized in a series of seemingly paradoxical statements. The population, for example, stood at a new high (179,323,175 on the day of the census: April 1, 1960). Yet more than half the counties in the U. S. had smaller populations than they had had at the time of the 1950 census. The population was more than ever concentrated in urban regions. Nonetheless, 73 cities, including 11 of the 12 largest, lost population. Americans were younger on the average than in 1950; the median age of the population had declined for the first time in 170 years. But the population was also older, as measured by the proportion of men and women 65 years old or more. The American family was larger than in 1950, but the American household had grown smaller.

On closer inspection these apparent contradictions in the quantitative results yield clear insights into some of the fundamental qualitative changes now taking place in the life of the country. They show that the U. S. is still on the crest of an upsurge in the rate of population growth that began in the 1940's, reversing the historical trend. The remarkable alterations in the distribution and composition of the population reflect the nation's continuing adjustment to the highest level of material well-being ever achieved by man.

Between 1950 and 1960 the population increased by 28 million; this increase was half again as great as the increase of 19 million between 1940 and 1950, the largest previous increase in the nation's history. The percentage gain—18.5 per cent—was the second largest in this century; it is exceeded only by the 21 per cent gain between 1900 and 1910, and it is more than 2.5 times greater than the 7.2 per cent gain in the depression decade of the 1930's.

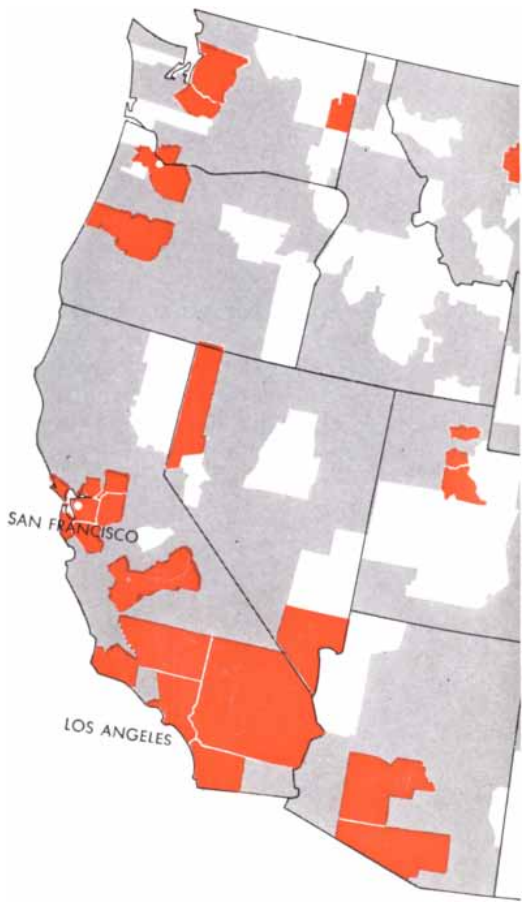
Wartime full employment and economic recovery started the upturn in the rate of population growth during the 1940's. The trend was accelerated by the great marriage and baby booms that followed demobilization. In 1946 the marriage rate reached a peak of 16.4 marriages per 1,000 persons, or 121 marriages per 1,000 unmarried females, as against the corresponding rates of 7.9 and 56 in 1932, at the bottom of the depression. The birth rate since 1946 has hovered close to 25 births per 1,000 people, compared with a low of 17.4 in the depression years. During the 1950's some 41 million babies were added to the population. This increase plus a net immigration of three million (immigrants minus emigrants) was offset by some 16 million deaths to yield the net total population increase of 28 million.

The rate of increase during the 1950's, about 1.8 per cent per year, was equal to the rate of increase of the world population—said to be undergoing an "explosion." This country's rate of increase, however, was the result of a birth rate and death rate far below the world average. Mortality had fallen to such a low level that even though the birth rate was half that of 1800, it was high enough to produce a relatively great growth rate. Should the present birth rate be sustained it will increase the population of the U. S. to 214 million by 1970, to 260 million by 1980 and by 2050—a date that some people now alive will live to see—to one billion!

For the purpose of reapportioning seats in the Congress, the decennial census is concerned with the geographic distribution of the population increase by states. Geographic distribution carries many other social and economic implications as well. In the 1960 census the 13 Western states showed by far the largest increase, continuing a trend established in 1850, when this region first appeared in the census. The population of the West increased by 39 per cent, compared with the 16.5 per cent gain of the South and North Central regions and the 13.2 per cent gain of the Northeast. In absolute number the West gained 7.9 million people, nearly a third of the national total. The South showed almost as large an increase, 7.8 million; the North Central region gained 7.2 million and the Northeast 5.2 million. Although the West is still the smallest of the four regions in population terms, its share of the total national population moved up from 13 to 16 per cent.

The redistribution of the increase in population shows even greater disparities when it is analyzed by states. More than 60 per cent of the national increase was accounted for by the population growth of eight states. California alone gained 5.1 million inhabitants; with continued rapid growth beyond its present total population of 15.7 million, that state will displace New York (16.8 million) as the most populous state in the course of the present decade. Florida showed the second largest increase in numbers (some two million new inhabitants) and by far the largest relative growth (78.7 per cent), moving up from 20th to 10th place in the ranking of the states by population. At the other extreme three states—Arkansas, Mississippi and West Virginia—actually posted decreases in population for the decade.

In this determination of the changes in population distribution by states the decennial census has a direct effect on the distribution of political power in the nation. Since the total membership of the House is fixed at 435, the states that have gained population are entitled to an increase in the number of their representatives at the expense of the others. The West is now due to gain 10 seats, while the Northeast is to be the principal loser, giving up seven representatives. California will gain the most representatives, a total of eight, bringing that state nearly abreast of New York, which is to see its representation reduced by two seats to 41.



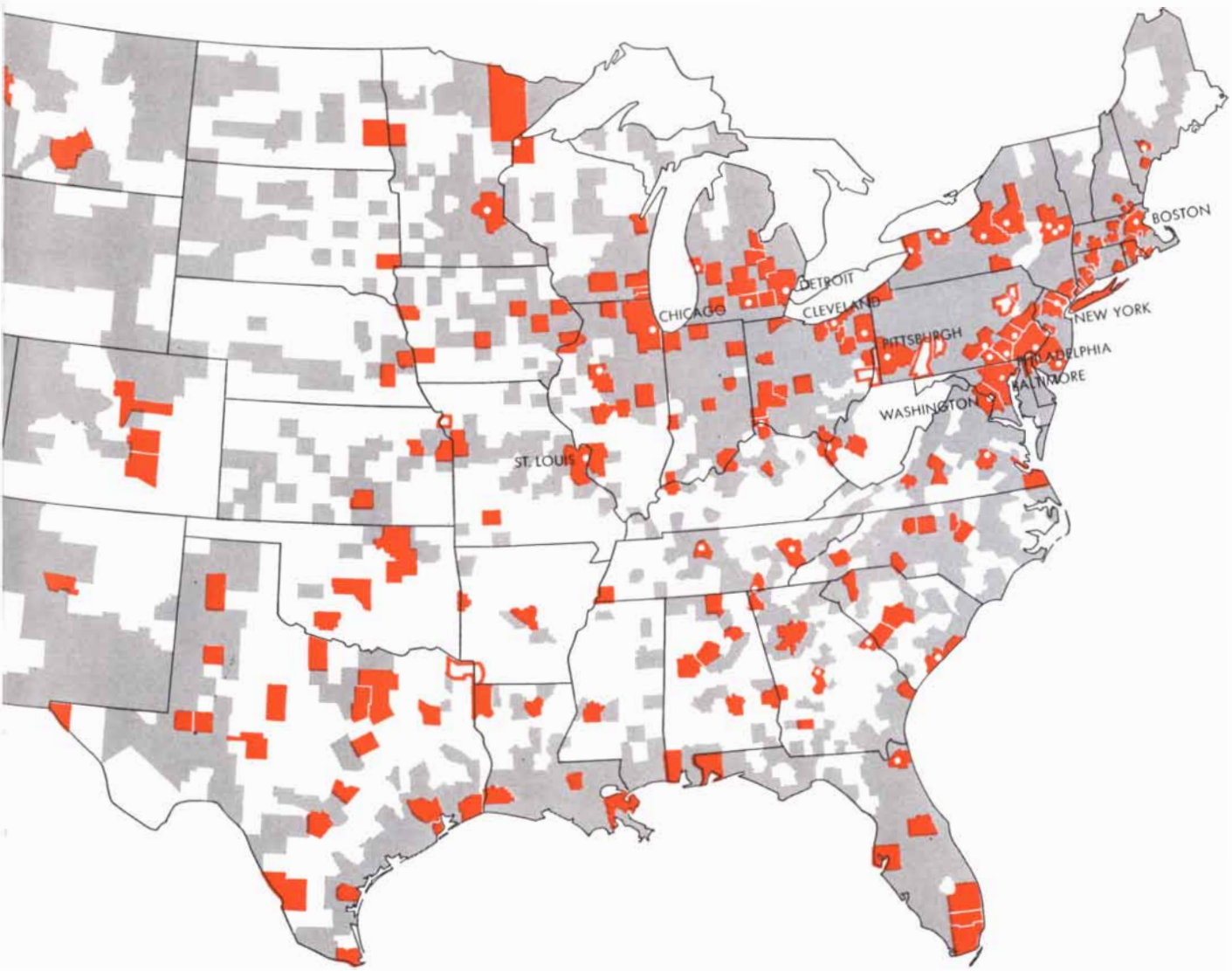
REDISTRIBUTION OF POPULATION in the U. S., when mapped by counties and Standard Metropolitan Statistical Areas (SMSA's), reveals the trend toward in-

Even more important than the shift in political power called for by the results of the 1960 census are the basic social and economic changes that it indicates. Natural increase—the excess of births over deaths—accounts for most of the growth of the national population. On the other hand, it is migration that largely explains the differential growth of states, particularly that of the fastest growing states. Favorable climate and economic prosperity attracted large numbers of people to Florida and California. Conversely, declining resources and economic stagnation underlie the experience of the states that gained little or lost population.

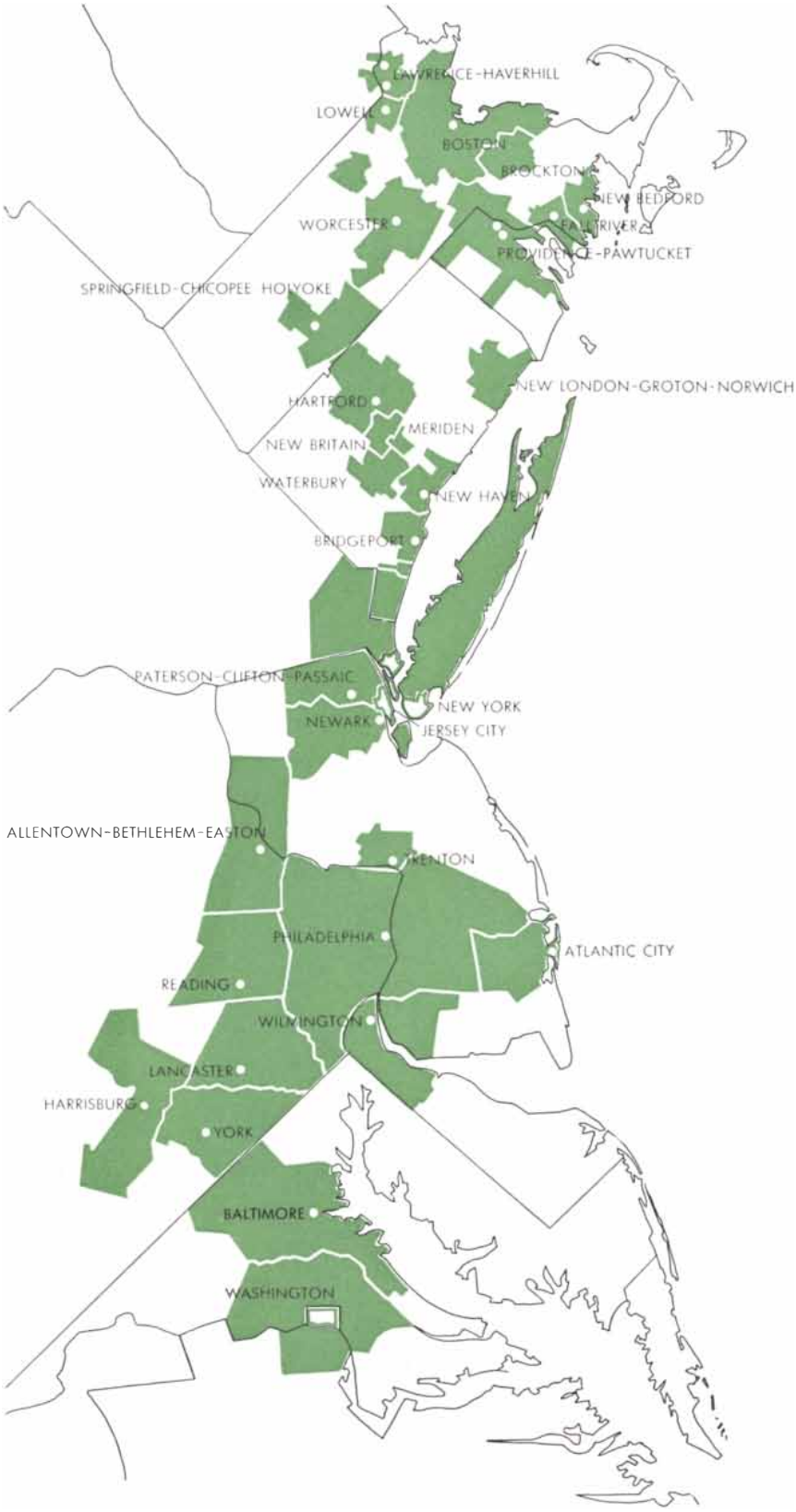
A deeper and more truly nation-wide trend emerges when the redistribution of population is mapped by counties [*see illustration on these two pages*]. The more than half of the counties of the total of 3,072 that lost population in the midst of the national population boom are predominantly the rural counties. Declines in county populations were largely the result of the out-migration of farming people or of residents of economically depressed areas.

As it has ever since 1790, the decennial census once again has shown a greater increase in urban than in rural population. The census draws the dividing line between "urban" and "rural" at communities of 2,500 inhabitants, including as urban also the inhabitants of the urban fringe of cities of 50,000 or more. The increase in urban population between 1950 and 1960 accounts for the entire national population increase; the urban population increased by 30 per cent, while the rural declined about 1 per cent. The urban population accordingly rose from 64 to 70 per cent of the total.

An important and relatively new unit in the statistics kept by the Federal Government is the Standard Metropolitan Statistical Area (SMSA)—in general, any central city of 50,000 or more inhabitants together with the county in which it is located and such adjoining counties as are economically and socially oriented to the central city (or cities). In 1960 nearly 113 million people, 63 per cent of the total population, lived in 212 SMSA's; in 1950 less than 85 million



creased urbanization. Shown here are: (1) counties that lost population (*white areas*), (2) counties that gained (*gray areas*), (3) SMSA's that gained (*solid-colored areas*) and (4) SMSA's that lost (*white areas bordered in color*). The boundaries of individual counties are not shown. More than half the total number of counties lost population. The white dots within the SMSA's represent central cities that lost population. Of the 12 largest cities in the U. S., Los Angeles was the only one to gain in population.



EASTERN MEGALOPOLIS consists of 34 SMSA's and extends from the southeastern tip of New Hampshire to Washington, D.C. All SMSA's except Jersey City gained in population (*colored areas*). Of the 45 central cities they contain, however, 28 lost population; Washington, D.C., and three counties of the New York SMSA are shown as white areas bordered in color; other central cities that lost appear as white dots. The SMSA is a statistical unit used to define populated areas that contain cities of 50,000 or more inhabitants.

people, about 57 per cent of the total, lived in 168 such areas. Thus the increase in the metropolitan population of the country accounts for almost all (97 per cent) of the population increase in the decade.

The 170-year trend toward an urban and industrial way of life now leads to the concentration of the population in a relatively small number of large metropolitan agglomerations. This concentration reflects, of course, the character of the nation's technological development and economic organization. In spite of its many physical and human problems, the large population agglomeration is the most efficient producer and consumer unit mankind has yet devised.

As a statistical unit the SMSA permits the measurement of suburban growth compared with central city growth. The magnitude of suburban growth during the 1950's must be placed in historical perspective to be appreciated. During the first four decades of this century the suburbs absorbed less than one-third of the total population increase. Between 1940 and 1950 the growth of the suburbs represented half of the increase. In the 1960 census the suburban areas account for fully two-thirds of the increase in population over 1950.

The suburban boom explains the population losses of the nation's largest cities. As the internal statistics of many SMSA's show, the boom has been attended by a central-city bust. While the suburban population was rising by 49 per cent (almost three times faster than the nation as a whole), central cities gained only 11 per cent, little more than half the national rate. More than one-fourth of the central cities experienced population losses in the decade. Of the five largest only Los Angeles showed an increase. The other four (New York, Chicago, Philadelphia and Detroit) and the next seven largest cities (Baltimore, Cleveland, St. Louis, Washington, Boston, San Francisco and Pittsburgh) all lost inhabitants. The census data actually understate the relative decline of the central city, because the boundaries of central cities do not remain fixed—there was considerable annexation of territory to central cities during the decade. Central cities that failed to extend their geographic domain actually lost population, shrinking by 4.2 per cent; central cities that grew by annexation showed an increase of 21 per cent, accounting for the entire increase in city population. In general the central cities that lost population were those in the largest and most densely populated SMSA's; their population losses may be attributed in part to a

deliberate effort to reduce such density, that is, to land clearance for urban renewal, expressways, civic centers and other public works.

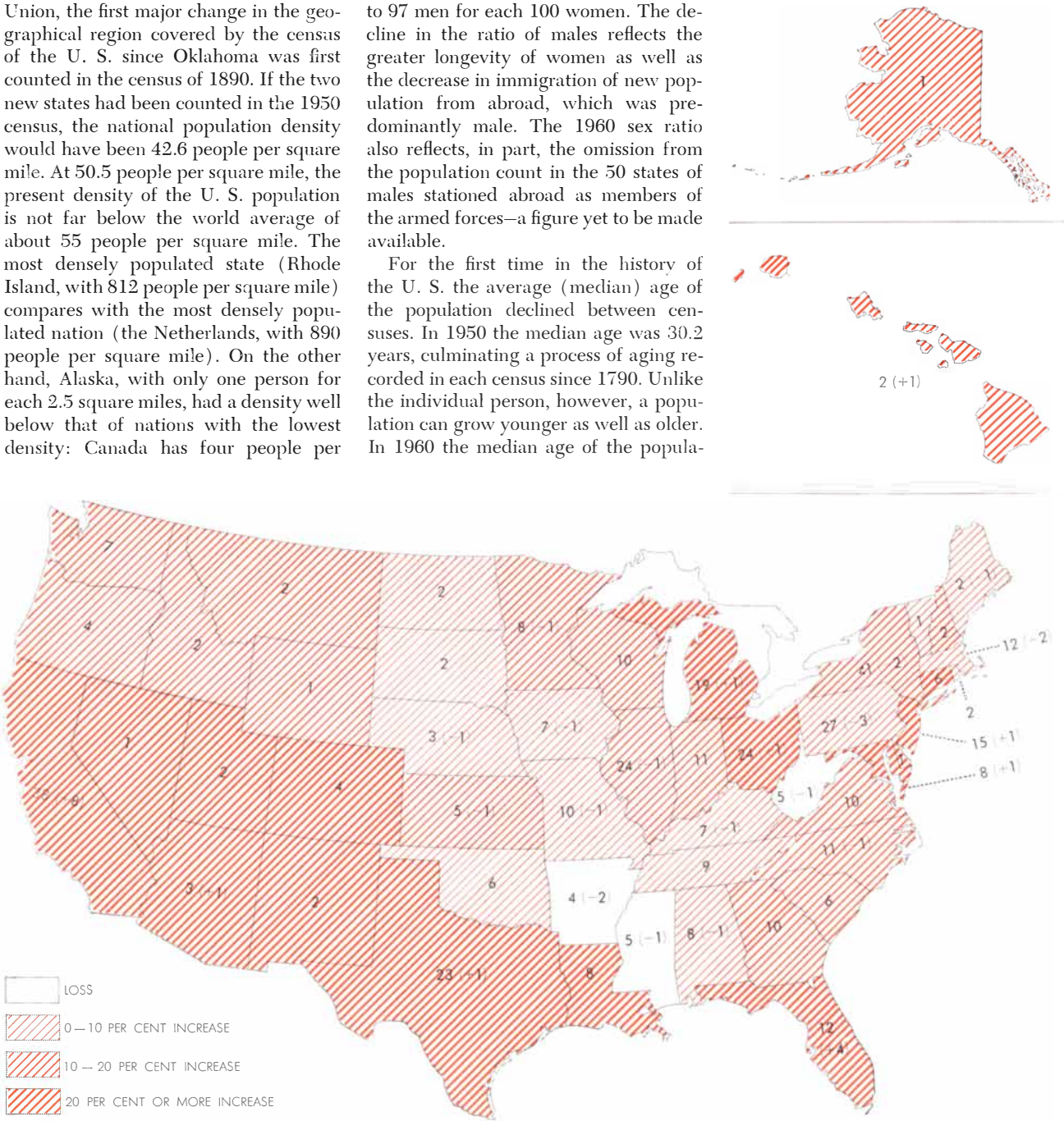
Over the territory of the nation as a whole the density of population has about doubled since 1900, increasing at each census as the population increased. In 1960 the density was 50.5 people per square mile, down a fraction from the 50.7 figure of the 1950 census. The ready explanation for this paradox is the admission of Alaska and Hawaii to the Union, the first major change in the geographical region covered by the census of the U. S. since Oklahoma was first counted in the census of 1890. If the two new states had been counted in the 1950 census, the national population density would have been 42.6 people per square mile. At 50.5 people per square mile, the present density of the U. S. population is not far below the world average of about 55 people per square mile. The most densely populated state (Rhode Island, with 812 people per square mile) compares with the most densely populated nation (the Netherlands, with 890 people per square mile). On the other hand, Alaska, with only one person for each 2.5 square miles, had a density well below that of nations with the lowest density: Canada has four people per square mile, Australia has three and Libya two.

As to the composition of the population, the census has interesting information to offer because it records each person by sex, age, color or race and family or household connection. These data add important dimensions to the picture of the nation.

The U. S. now has a larger female population than male. This situation first appeared in the 1950 census, which showed 99 men for each 100 women. In 1960 the sex ratio had declined further, to 97 men for each 100 women. The decline in the ratio of males reflects the greater longevity of women as well as the decrease in immigration of new population from abroad, which was predominantly male. The 1960 sex ratio also reflects, in part, the omission from the population count in the 50 states of males stationed abroad as members of the armed forces—a figure yet to be made available.

For the first time in the history of the U. S. the average (median) age of the population declined between censuses. In 1950 the median age was 30.2 years, culminating a process of aging recorded in each census since 1790. Unlike the individual person, however, a population can grow younger as well as older. In 1960 the median age of the population of the U. S. was 29.5 years—that is, the average American had grown .7 of a year younger between 1950 and 1960. This decline in median age reflects, of course, the baby boom, which has so greatly increased the proportion of younger people in the nation. The average American, however, was still considerably older than his counterpart in 1800, who was about 16 years old.

The younger population also counted a relatively larger number of old people



POPULATION CHANGE as determined by the 1960 census will be the basis for the reapportionment of representatives to Congress. Population gains and losses are explained in the legend at bottom left. Numbers on the map indicate the representation that each state will have in the next Congress. Numbers in parentheses show gains and losses that will result from reapportionment.

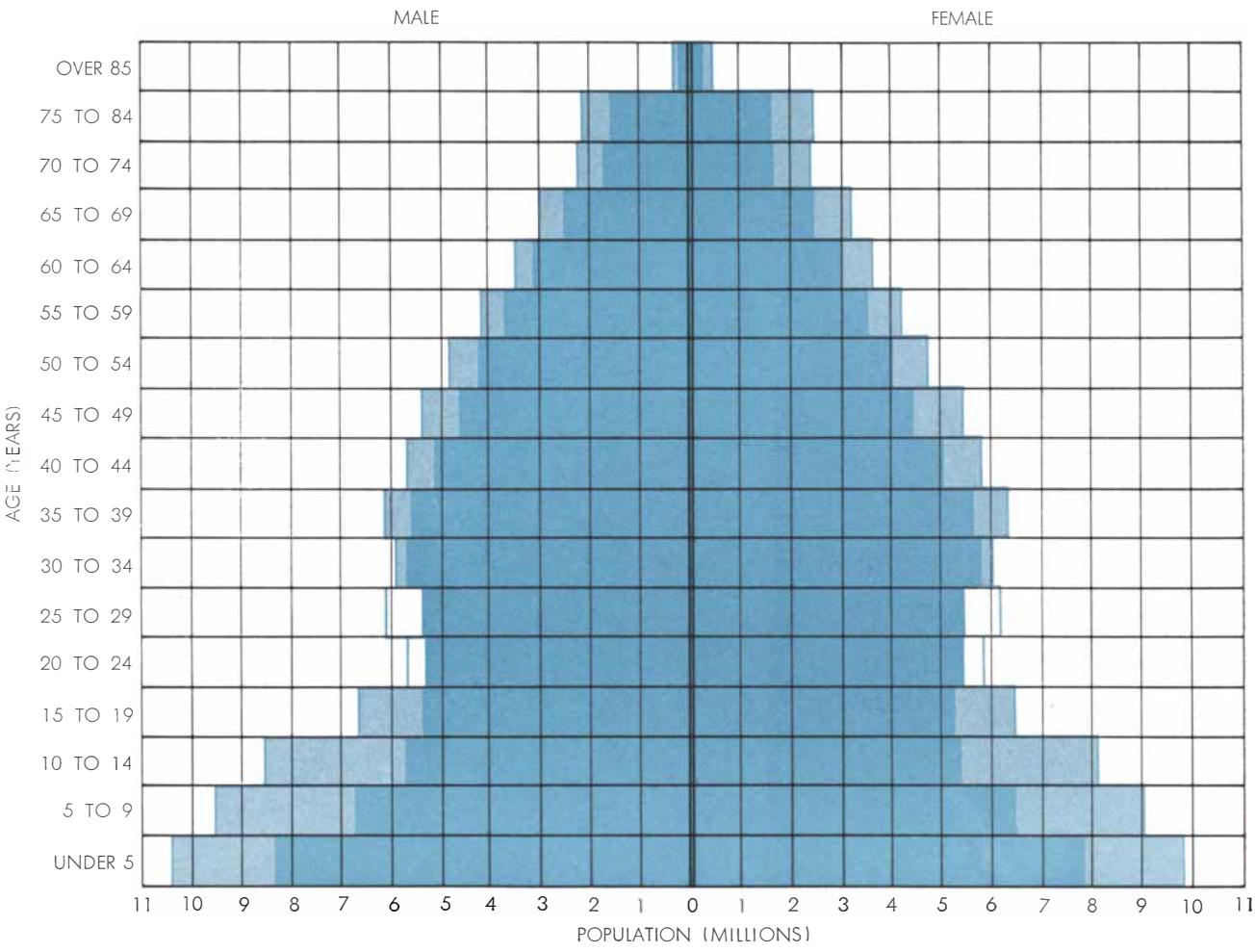
among its members than ever before. By this index the population of the U. S. continued to age between 1950 and 1960. During the decade the number of people 65 years old or older increased by about 35 per cent, a growth rate almost twice that of the nation as a whole. The growth rate of the population under 18 years old, however, was even greater (about 37 per cent), and this accounts for the net decrease in the median age. At the same time the population of intermediate ages—18 to 64 years—increased by only 7.2 per cent, and the 20- to 29-year-old group, reflecting the low depression birth rate of the 1930's, actually declined in number between 1950 and 1960.

These shifts in the age composition of the population had considerable bearing on political and economic developments during the decade. The stress on the educational resources of the country can be measured by the fact that youngsters of elementary school age (five to 14) increased in number by 45 per cent during the decade, from 24.4 to 35.4 million. Those of high school age (15 to 19 years) increased by 23 per cent, from 10.7 to 13.2 million. At the other extreme, the problems of old age came to the fore in national politics during the 1960 presidential campaign.

The question about race on the census form yielded the finding that the nonwhite population of the U. S. continued to increase more rapidly than the white, a trend that began in 1920. Between 1950 and 1960 the nonwhite population increased by about 26.7 per cent; the white increase was 17.5 per cent. The Negro population, which made up almost 93 per cent of the nonwhite, increased by 25.4 per cent during the decade to a total of 18.9 million, or a little more than 10 per cent of the total.

The 1960 census also showed that the Negro migration from the South, which began in large numbers during World War I, continues unabated. As recently as 1910 more than 90 per cent of the country's Negro population lived in the South. In 1960 that figure had fallen to 60 per cent, with 34 per cent living in the Northeast and North Central regions and 6 per cent in the West. The number of Negroes in the North increased during the decade from 4.2 to 6.5 million, or more than 50 per cent; the number in the West about doubled, increasing from less than 600,000 to well over a million.

The Negro migration from the South is also a migration from rural to metropolitan areas. But the Negroes have not participated in the settlement of the suburbs in proportion to their numbers. As relatively new in-migrants, they have been concentrated in the inner central cities of metropolitan areas [see "Metropolitan Segregation," by Morton Grod-



AGE AND SEX DISTRIBUTION of the population as determined by the 1950 census (*dark color*) is compared with the distribution according to the 1960 census (*light color*). In the three lowest age groups males outnumbered females in both censuses. Overall, however, the female population is larger than the male, and the ratio of men to women has shown a decline from what it was in 1950. Small, unshaded areas in the age groups "20 to 24" and "25 to 29" represent population losses in those age groups since 1950.

zins; SCIENTIFIC AMERICAN, October, 1957]. The Negro population of the central cities in the 25 largest SMSA's ranged from less than 3 per cent of the total (Minneapolis–St. Paul) to 54 per cent of the total (Washington). In the five largest SMSA's the central-city Negro population constituted 14 per cent of the total in New York, 23 per cent in Chicago, 26 per cent in Philadelphia, 13 per cent in Los Angeles and 29 per cent in Detroit.

Other nonwhite peoples showed a proportionately high growth rate. Their numbers are, of course, relatively small and subject to some error in counting. Chinese, according to the 1960 census, increased by 58 per cent during the decade to reach a total of 237,000; American Indians, by 47 per cent for a total of 524,000; Filipinos, by 44 per cent for a total of 176,000; Japanese, by 42 per cent for a total of 464,000.

As in 1950, the 1960 census showed that roughly two-thirds of the people 14 years old or older were married. The effect of the postwar marriage boom was reflected in the fact that the population 14 years old or older increased by 12.6 per cent and the number of married people increased at twice the rate of single people: 14 per cent compared with 7 per cent. The effect of the baby boom was reflected in the increase in average family size, from 3.54 to 3.68 people.

While families (defined in the census as consisting of two or more people living together and related by blood, marriage or adoption) increased in size, the average size of the American household (defined as the dwellers of a housing unit) declined from 3.42 to 3.29 people between 1950 and 1960. The shrinkage of the household is another trend that has held in all censuses since the first one. It reflects the continuing transition from the "large," or three-generation, household to the "small," or two-generation, one; and also the considerable increase in one-person households. Adult children, whether married or single, are tending to live apart from their parents and in-laws; the number of people living alone or with nonrelated people increased by 80 per cent to reach a total of 8.4 million in 1960.

HOUSEHOLD RELATIONSHIP	1960 (THOUSANDS)	1950 (THOUSANDS)	PER CENT INCREASE 1950 TO 1960
TOTAL	179,323	150,845	18.9
IN HOUSEHOLDS	174,373	145,116	20.2
HEAD OF HOUSEHOLD	53,021	42,394	25.1
HEAD OF PRIMARY FAMILY	44,670	37,758	18.3
PRIMARY INDIVIDUAL	8,351	4,636	80.1
WIFE OF HEAD	39,210	33,378	17.5
CHILD UNDER 18 OF HEAD	59,582	42,255	41.0
OTHER RELATIVE OF HEAD	19,592	23,020	14.9
NONRELATIVE OF HEAD	2,968	4,069	27.1
IN GROUP QUARTERS	4,950	5,729	13.6
INMATE OF INSTITUTION	1,916	1,574	21.8
OTHER	3,034	4,155	27.0
	INDIVIDUALS	INDIVIDUALS	
POPULATION PER HOUSEHOLD	3.29	3.42	3.8
POPULATION PER FAMILY	3.68	3.54	4.0

SIZE OF FAMILY AND OF HOUSEHOLD followed opposite trends between 1950 and 1960. "Population per Family" (*bottom*) increased 4.0 per cent, while "Population per Household" (or dwellers per housing unit) decreased (*color*) 3.8 per cent. This "household shrinkage" can be compared with increases and decreases in various household categories.

The changes in our population growth, distribution and composition have many implications. There is no doubt that in the short run, at least, rapid population growth has contributed to the expansion of markets and of production to supply them. But the continuation of the present rate of growth could in the long run contribute to chronic unemployment, threaten the standard of living, accelerate intervention by the Government in economic and social affairs and produce a host of deleterious long-run consequences, which would more than offset short-run gains.

The increasing concentration of the population, as measured by greater urbanization, also contributes to the nation's high standard of living and the advance of its educational, intellectual and cultural activities. But it is a key factor in many of the acute problems plaguing our metropolitan areas: physical problems such as urban renewal and transportation; and human problems such as unemployment, crime and delinquency, political corruption and frictions among ethnic groups. The U. S. is only now, during this decade, completing its first half-century as an urban society—a nation in which more than half the people live in urban places.

The rapidly changing age structure, arising mainly from fluctuations in the birth rate, creates serious problems for those concerned with the education and welfare of youth—including the schools at every level, the church, health and welfare agencies and, most important, the family. It has important consequences for labor also, for employers of labor, for producers of consumer goods and services and for the armed forces. On the other hand, the long-run decline in fertility together with the decline in mortality and the increase in life expectancy confront the nation with the task of providing for an ever growing population of elderly people. Finally, the shifting rate of household formation and the changing pattern of household and family size has helped to generate demand for new housing and for goods consumed by households and plays a decisive role in determining the comfort, happiness and security of the individual.

These and many other considerations show how the decennial census has become more than a head count for purposes of apportionment of representation. Even the limited information available at this early stage in the processing of the data reveals significant facts about our changing nation. The facts provide a better basis for understanding the past and future of the U. S. as well as the present and for taking such action as may be required by business, labor and the Government, in fact by every sector of our economy and society, to maintain and advance the general welfare.

THE MUON

This fundamental particle has 200 times the mass of the electron but otherwise closely resembles it. Why it should be heavier is a question physicists have sought to answer in recent experiments

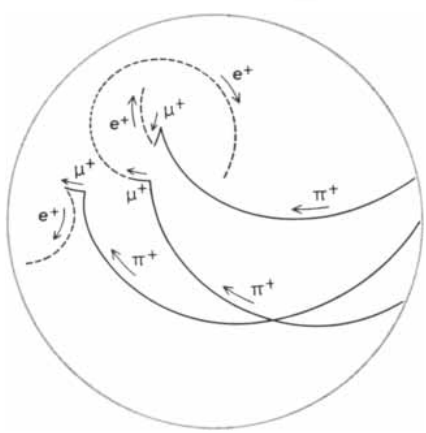
by Sheldon Penman

The advance of physics can be compared to that of an army. Salients are thrust out where the opposition is lightest; troublesome areas are bypassed until the necessary forces are available. An example of this pattern is seen in the physicist's method of attack on the puzzle of the mu meson, or muon, a fundamental particle weighing some 200 times as much as an electron. First of the unstable particles to be discovered (with the exception of the free neutron), most tractable in the laboratory because of its relatively long life (2.2 millionths of a second) and the ease with which it can be produced, the muon has been studied in more detail than any other unstable particle. These investigations have shown that it does not, as do other mesons, interact with other particles by "strong coupling," the kind of force that holds together the particles in the nucleus of the atom. Instead the muon appears in every respect except its instability to be a heavy relative of the electron; like the electron, it interacts with the rest of the universe only through the agencies of the electromagnetic force and the so-called weak-interaction force. (The weak interactions give rise to phenomena such as radioactive decay in which an electron is emitted, and the decay of the muon itself.) This raises a baffling question: If the muon is identical to the electron in its interactions, why should it be 200 times heavier? Physicists believe that the mass of a particle is a consequence of its interactions; when two particles display identical interactions, there is no mechanism that can be invoked to explain a difference in their masses.

The muon was discovered in 1936 in cloud-chamber photographs of cosmic radiation; the discovery was made by Carl D. Anderson and Seth H. Neddermeyer of the California Institute of Technology and independently by J. C. Street of Harvard University. Physicists had been looking for a particle of about this mass since 1935, when its existence was postulated by the Japanese theorist Hideki Yukawa. His calculations had shown that such a particle could explain the enormous strength of the forces that hold together the protons in the nucleus in spite of the mutual repulsion of their positive electric charge. Yukawa reasoned by analogy. The particle that accounts for the electromagnetic force field is the photon, which has no mass. By analogy the nuclear force field should also have its particle, but the particle should have a certain amount of mass. This followed because nuclear forces, unlike electromagnetic forces, extend only a short distance from the nucleus. In fact, the finite range of the nuclear force field indicated that its particle would have a mass about 200 times that of the electron. It soon turned out that particles of this mass—now called mu mesons—existed in embarrassing profusion. The mu mesons in cosmic radiation traveled easily through the atmosphere, penetrated lead plates and could even be detected in deep mines. Such behavior was unbecoming to the hypothetical Yukawa particle. Since it was supposed to give rise to strong forces in the nucleus, it should have interacted readily with the nuclei of any substance through which it passed. It should have penetrated the atmosphere only with difficulty and a lead plate not at all.

Once the low interactivity of the muon had been firmly established, the search for the real Yukawa particle continued. This particle—the pi meson, or pion—was finally found in 1948 as a component in cosmic radiation high in the atmosphere. Its lifetime is so short and it interacts so readily with nuclei that it rarely penetrates the atmosphere and reaches the ground. Indeed, it meets all the specifications of a particle of the nuclear force field. In addition, it is the parent of the muon, decaying with a mean life of 25×10^{-9} second (25 billionths of a second) into a muon and a neutrino. Were it not for this fortuitous lineage the production of a muon would be a rare event indeed.

The protons of the primary cosmic radiation collide and interact with nuclei in the upper atmosphere. These interactions are "strong"; that is, they are identical with those which produce the nuclear force field. They give rise to various nuclear fragments and a profusion of pions; the pions then decay into muons. A particle that does not enter into strong interactions, such as the muon, could not be manufactured by the direct impact of protons on nuclei. Because particle accelerators produce collisions of this sort they create pions in



LIFE OF THREE MUONS is recorded in three short tracks produced by these parti-

abundance, and these, upon decay, yield an abundance of muons.

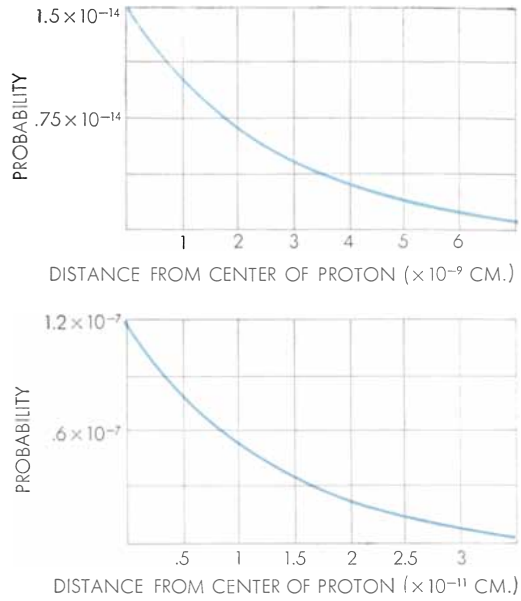
In the decade following the discovery of the pion attention was largely diverted from the muon, first by the pion itself and then by the discovery of a bewildering profusion of other particles: K mesons and the particles lambda, sigma and xi. These particles all share a new quantum property called "strangeness," which sets them apart from all the particles discovered earlier. Strangeness, however, is not much stranger than one of the older quantum properties such as "spin"; like matter and energy, it is a property that is conserved when strange particles enter into strong interactions. When strange particles enter into weak interactions, strangeness is not conserved; no one knows why.

Physicists have found it helpful to show that the particles that enter into weak interactions (putting aside the strange particles) are related by a triangle [*see illustration at bottom of next two pages*]. The two nucleons (the neutron and the proton) occupy one corner; the electron occupies the second corner; the muon, the third. Experimental evidence indicates—though not yet conclusively—that the particles at the corners of the diagram interact with each other with the same strength.

In the first leg of the triangle the connection between a nucleon and an electron illustrates beta decay, in which, for example, a neutron emits an electron and an antineutrino and is transmuted into a proton. This is also the mechanism by which heavy nuclei decay when they emit an electron, and the rate of decay should be an indication of the strength of the interaction. Many other factors enter into the reaction, however, and

cles in the liquid hydrogen of a bubble chamber. Each of three pi mesons (π^+ *in drawing at left*) decays into a muon (μ^+) and a neutrino, which is neutral and leaves no track. Each muon then decays into a positive electron (e^+), a neutrino and an antineutrino.

	ELECTRON	MUON
DATE DISCOVERED	1897	1936
MASS	1	207
MEAN LIFETIME (SECONDS)	INFINITE	2.22×10^{-6}
ELECTRIC CHARGE	−1 (+1)	−1 (+1)
LEPTON NUMBER	1 (−1)	1 (−1)
SPIN	½	½
MODES OF INTERACTION	ELECTROMAGNETIC AND "WEAK"	ELECTROMAGNETIC AND "WEAK"
PREDICTED ANOMALOUS MAGNETIC MOMENT	.0011596	.001165
MEASURED ANOMALOUS MAGNETIC MOMENT	.0011609 ± .0000024	.001145 ± .000022



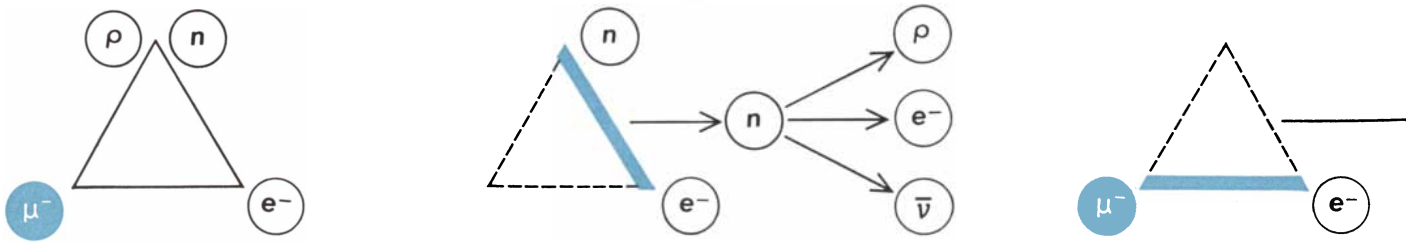
ELECTRON AND MUON differ only in mass, mean lifetime and anomalous magnetic moment (*table at left*). The difference in mass also involves a difference in the probability that either particle will penetrate a nucleus about which it may orbit, as can be seen by comparing the two "probability curves" at right. The probability of finding an electron at a given distance from the center of a proton in the hydrogen atom is plotted in curve at top; corresponding probability for "mesic" atom (muon and proton), at bottom.

radioactive nuclei actually decay at various rates; some last for much less than a second and others have lasted for the life of the universe. It is a triumph of theory that in the face of rates varying from the positively lethargic to the extremely rapid it is possible to extract information about the fundamental process and show that its strength is always the same.

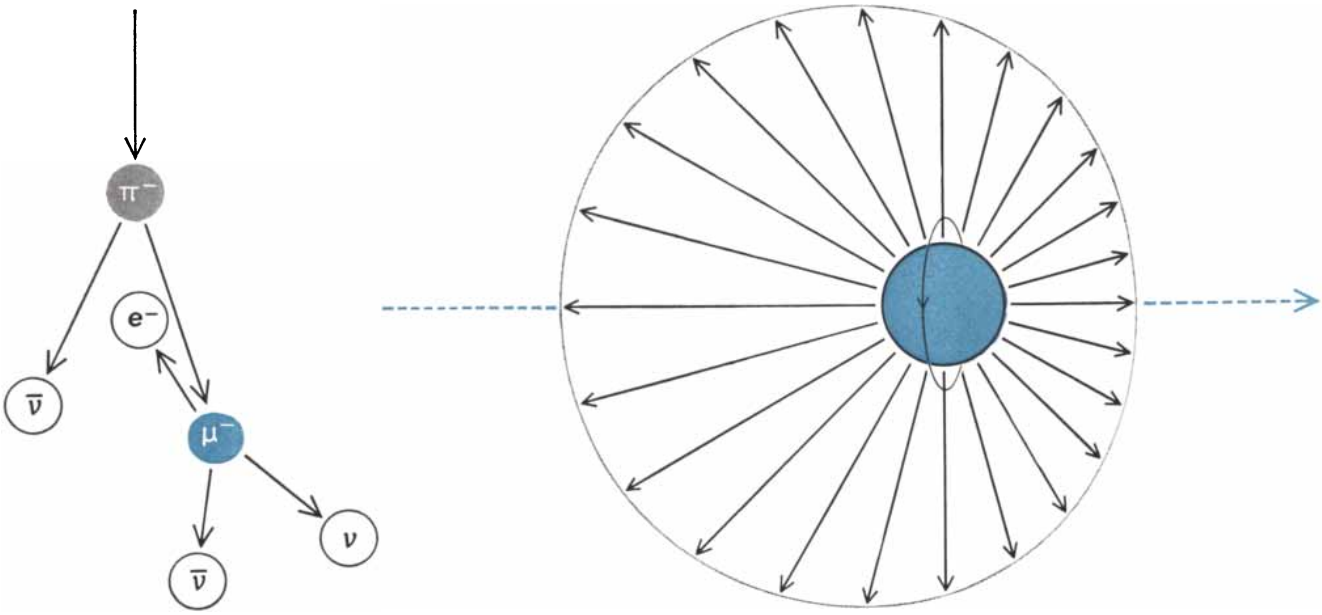
The connection between the muon and the electron in the second leg of the triangle is illustrated by the decay of the muon into an electron, a process that resembles beta decay. Here, however, the outgoing electron is accompanied by not one neutrino but two. When the strength of the interaction of the muon and the electron is compared with that of a nucleon and an electron (on the basis of the rate of decay), there is good agreement.

The third leg of the triangle is the interaction of muon and nucleon. This interaction is illustrated by the phenomenon of muon capture. When a negative muon comes to rest in any substance, it penetrates the cloud of electrons surrounding a nucleus to which it is attracted by virtue of its negative charge. It then behaves exactly like a heavy electron in that it has only certain energy levels, or orbits, around the nucleus; it cascades down through these permissible levels, emitting an X ray with each transition. This is the way ordinary electrons behave in atoms, and the system of a nucleus and a mu meson is called a mesic atom. When the muon has cascaded as far as it can go, it lives out its remaining life in the state of lowest energy, which is an orbit that is quite close to the nucleus. Because the muon is some 200 times heavier than the electron, its smallest orbit is some 200 times smaller than that of the electron around the same nucleus.

Modern physics has of course taught us that we should not think of a particle circling the nucleus as a planet circling the sun but rather as a smear of probability, with the particle much of the time actually penetrating the nucleus [*see illustration above*]. While it is in "orbit" the muon can either decay or interact with a proton in the nucleus, causing the proton to change into a neutron with the emission of a neutrino. As in radioactive decay, the length of time it takes for a muon to interact with a nucleus depends on the particular nucleus involved. Still, also as in radioactive decay, the fundamental strength of the interaction can be deduced. Its value is obtained by studying the rate of capture of muons by many different nuclei. Although the value is



INTERACTION TRIANGLE (*left*) relates particles that enter into weak interactions (leaving aside "strange" particles). In the first leg (*second from left*) a neutron (*n*) emits an electron and an antineutrino, becoming a proton (*p*). Second leg (*third from*



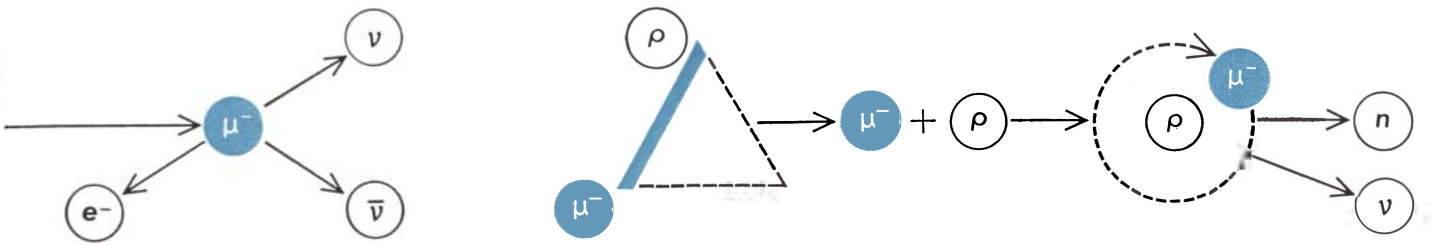
ORIGIN AND DECAY OF MUON (*left*) involves the decay of a pi meson (π^-) and the production of an electron (e^-). The pi meson decays into a muon (μ^-) and an antineutrino ($\bar{\nu}$); the muon decays into an electron, an antineutrino and a neutrino (ν). The muon (*large colored circle at right*) emits an electron preferentially in a direction opposite that in which its spin axis (*broken colored arrow*) points. The probability of an electron's being emitted in a given direction (*black arrows*) is proportional to arrow lengths.

by no means so well known as the value for radioactive decay, it appears to agree well with that for the "universal" weak interaction. There are two ambitious experiments under way, one at Columbia University and the other at the University of Chicago, to measure the rate at which the nuclei of hydrogen—protons—capture muons. In the capture of muons by protons there is no nuclear structure to contend with and the elemental interaction rate can be found. Although the hydrogen is liquefied and its nuclei are close together, the probability of capture is small and the experimental difficulties are formidable. The results of these experiments should go far toward putting this last leg of the triangle on the same footing as the other two.

One can therefore conclude that the muon, in so far as the weak interactions go, behaves like a heavy electron. There are many other similarities. There are, for example, both positive and negative muons, as there are positive and negative electrons. There are no neutral muons and no neutral electrons. The muon's intrinsic angular momentum—"spin"—appears to be 1/2, as is the spin of the electron. Curiously, the experimental evidence for this fundamental property is not strong, but since so many of the detailed properties of the muon satisfy the theory for a particle of spin of 1/2, there seems little reason to doubt that 1/2 it is.

Another similarity between muons and electrons is that they are both "leptons," or light particles. This means that they, together with neutrinos, obey a conservation law stating that the number of leptons in the universe is a constant. This may seem strange inasmuch as there are many processes in which these particles are created and destroyed. If we count correctly, however, assigning the value of +1 to the electron, the negative muon and the neutrino, and a value of −1 to the positron, the positive muon and the antineutrino, then the number of leptons at the beginning and the end of any reaction is the same. During the capture of a negative muon by a nucleus, for instance, a neutrino is emitted. Since both of these particles have a lepton number of +1, the lepton equation balances. When a positive muon decays into a positron, a neutrino and an antineutrino, the total number of leptons is −1 both before and after the decay.

This was essentially the state of knowledge in 1957, and it was hoped that more detailed experiments would show properties of the muon that might indicate the origin of its mass. The big im-



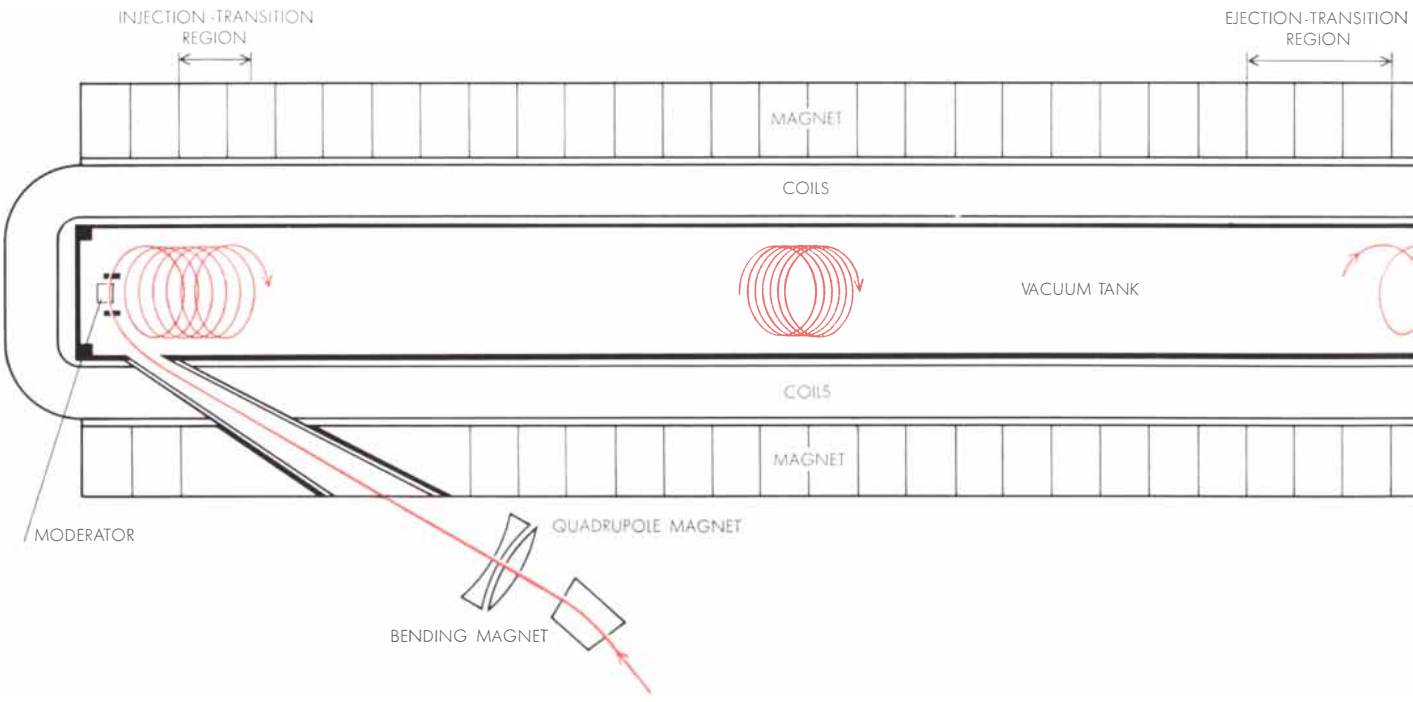
***left*) represents the decay of a muon into an electron, a neutrino and an antineutrino. Third leg (*right*) represents the weak interaction in which a proton captures a muon to form a mesic atom. The proton then turns into a neutron and emits a neutrino.**

petus to muon research came in that year with the discovery of the nonconservation of parity. The "law" of parity had stated that nature does not distinguish between left and right—in other words, that one cannot perceive a difference between an event in nature and its mirror image. The nonconservation of parity suggested itself to T. D. Lee and C. N. Yang when they were pondering what seemed to be a paradox in the decay schemes of the K meson. (K-meson decay seemed to violate parity and, as we now realize, it did.)

The fall of parity had two important consequences in muon research. First, the muon, because it has spin, can be thought of as having an orientation in space, that is, a direction in which the axis of spin points. It must be realized that to speak of the particle as actually turning is meaningless; this would imply that we could somehow measure the motion of points on its surface, which we cannot. The picture is heuristic—useful because it serves to clarify the nature of the particle. If parity were conserved in the production of muons, the beam of particles emerging from an accelerator would have to contain muons with every possible orientation. Actually it was found that the beams contain particles that tend to point along the direction of travel. Moreover, if parity were conserved when a muon decayed, there would be no preference in the direction in which its daughter electron was emitted. It happens that, since nature has no interest in conserving parity, the electron is emitted preferentially in a direction opposite to that in which the spin axis of the muon points. Both of these conservation failures were established in the elegant experiment performed at Columbia University by Richard L. Garwin, Leon M. Lederman and Marcel Weinrich.

As a result of these discoveries workers in muon physics now have a powerful means of studying the particle. Not only do the available muons tend to point in one direction but also it is possible to determine that direction by looking for the electron produced in the decay process. To use an analogy, we are no longer trying to handle screws in the dark with heavy gloves; we are being handed the screws neatly aligned on a tray, with a little searchlight on each that indicates the direction of its head. Consequently it is now possible to make measurements of the muon with a precision approaching the precision achieved in the investigation of atoms.

Almost immediately after the discovery of the breakdown of parity, a series of experiments was initiated at Columbia University, the University of Chicago and most recently at C.E.R.N. (the European Organization for Nuclear Research) to study the magnetism of the muon. Every charged particle possessing spin behaves as though there were a bar magnet lying along its spin axis; the strength of this bar magnet is called its magnetic moment. In the case of the electron, electromagnetic theory can predict the value of the magnetic moment with high precision. It is of great interest to measure the magnetic moment of the muon to determine if the theory that works so well for the electron is applicable. A deviation from the predicted value could give an important clue to the structure of the muon and hence to the origin of its mass. In the proton, for example, the value of the magnetic moment is quite different from the value that would be predicted purely on the grounds of its electromagnetic interactions. In modern particle physics the proton is regarded as continuously emitting and absorbing mesons; because the proton interacts by strong coupling the mesons are pions. These pions are not physically observable; they are called "virtual." Nevertheless, they produce circulating electric currents that alter the magnetic moment of the proton. Since the muon does not enter into strong interactions, any departure from its predicted magnetic moment could



C.E.R.N. APPARATUS, used in so-called g—2 experiment, employed a vacuum chamber 20 feet long between the poles of an 85-ton magnet. Theory says that when a muon is forced to orbit in a magnetic field, its spin axis should precess, or turn at a slightly faster rate than its orbiting rate. The amount of precession is indicated by flight direction of electrons emitted when muons decay in target (*far right; see also illustrations on next two pages*). After muons (*colored line*) enter the vacuum chamber they are slowed

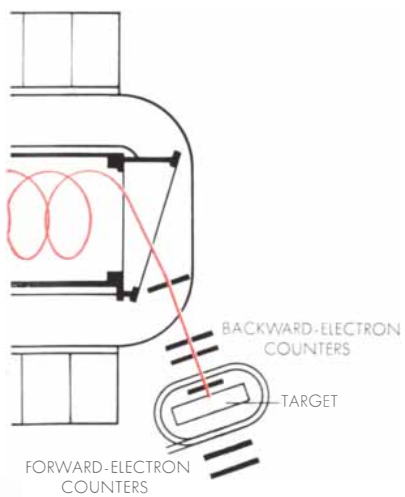
perhaps be attributed to some heretofore unknown feature of the muon's structure or even to an interaction with the field of a particle still undiscovered. As an alternative explanation, a departure in the magnetic moment of the muon could indicate a breakdown in the laws of electromagnetism at very short distances. This could show up in the muon and not in the electron because the muon's greater mass implies that its interactions with the electromagnetic field take place over smaller regions of space. Theorists have speculated for a long time that space, like energy, may not be indefinitely divisible and that a shortest length may yet be found that will limit the applicability of the electromagnetic laws as we know them. While there is no evidence for such a fundamental quantum of length, the magnetic moment of the muon gives the physicist a new tool for probing the question.

The unit of strength of the magnetic moment of a particle is the magneton. Since the definition of the magneton involves mass, the unit is different for each particle. The value of the moment is often expressed in terms of a "g-factor," which dates back to the hoary lore of atomic physics. The g-factor is equal to the ratio of the actual magnetic moment in magnetons to a value that is half a magneton. A major triumph of P. A. M. Dirac's celebrated formulation of quantum mechanics was its prediction that the g-factor of the electron was equal to 2, which agreed with the experiments of that time.

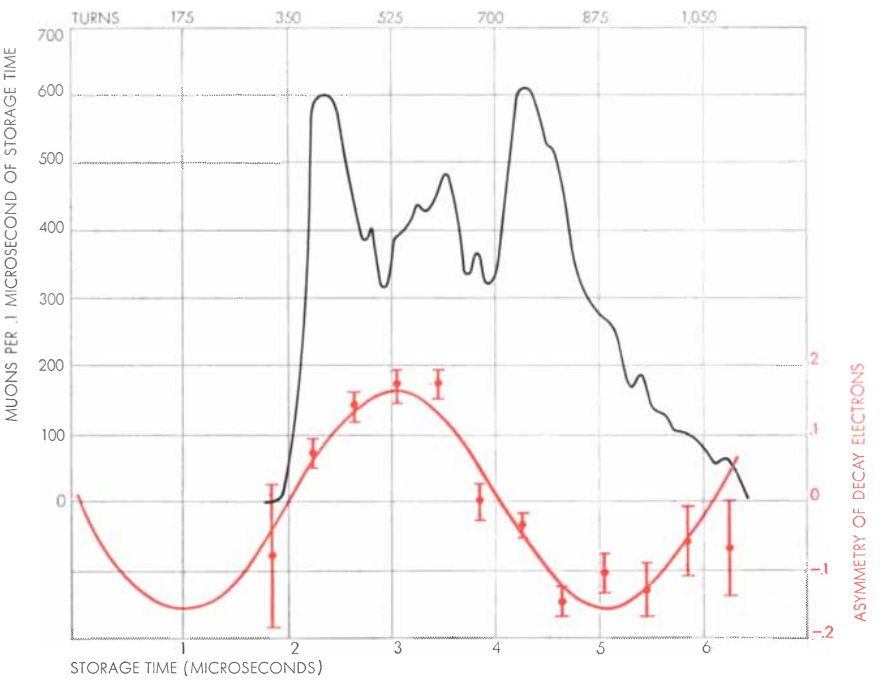
Shortly after World War II more precise experiments, performed at Columbia University by Polykarp Kusch, indicated that the g-factor of the electron actually differed from 2 by about one part in 1,000. The departure became known as the anomalous magnetic moment of the electron. Before long Julian Schwinger of Harvard refined the equations of quantum electrodynamics so that the theoretically predicted value of the g-factor once again agreed with experiment. Small though the anomaly is, it is crucial to an understanding of the interaction of charged particles with the electromagnetic field. The anomaly arises because the electron is constantly emitting and reabsorbing virtual photons, which in themselves are unobservable but which give rise to measurable effects.

The goal of several experiments undertaken since 1957 has been to measure the g-factor of the muon as precisely as possible. There have been two approaches. The first and simplest is to measure the magnetic moment directly. This can be done with high precision, and experiments are now approaching an accuracy of one part in 100,000. Theory, however, does not predict the moment directly; it predicts only the g-factor, and this prediction requires knowing the mass of the muon. Although the mass of the muon has been measured far more precisely than that of any other unstable particle, the measurement is still limited in accuracy to about one part in 10,000. As a result the experimental value for the g-factor is limited to the same order of accuracy. Since the deviation of the g-factor from 2 is only one part in 1,000, a measurement accurate only to one part in 10,000 leaves an uncertainty of 10 per cent, which is much too large to provide a meaningful test of the predicted value.

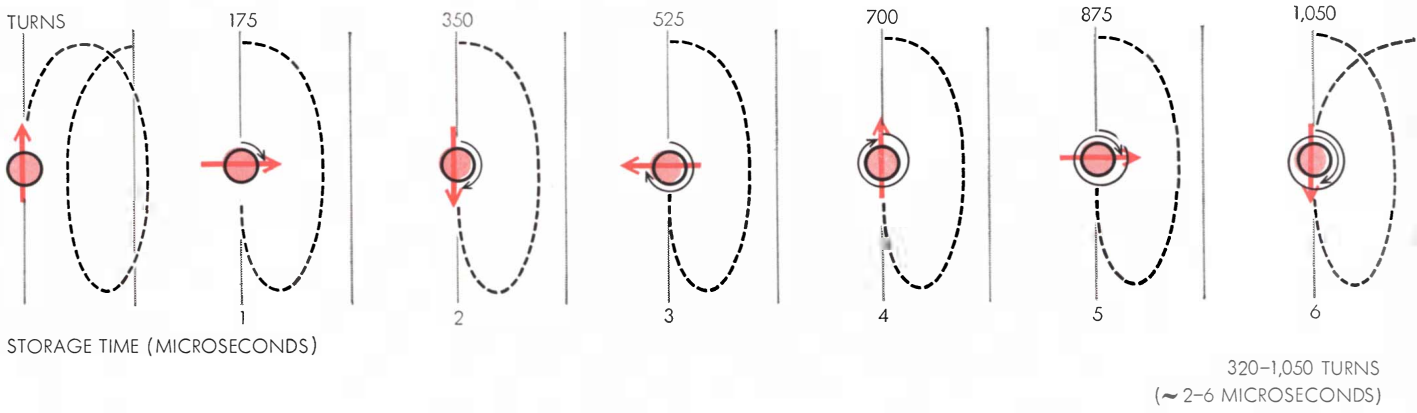
The direct measurement of the muon's magnetic moment has nonetheless been a useful and satisfying achievement. The most recent measurement was carried out at Columbia University by D. P. Hutchinson, J. Menes, A. Patlach, G. Shapiro and the author. To make the measurement one observes the rate at which the spin axis of the muon precesses, or turns, when the particle is brought to rest in a magnetic field. The rate of precession depends on the magnetic moment and the strength of the field. The muons are created by the decay of pions produced in a cyclotron; when the pions decay in flight, they give rise to muons whose spin axes are point-



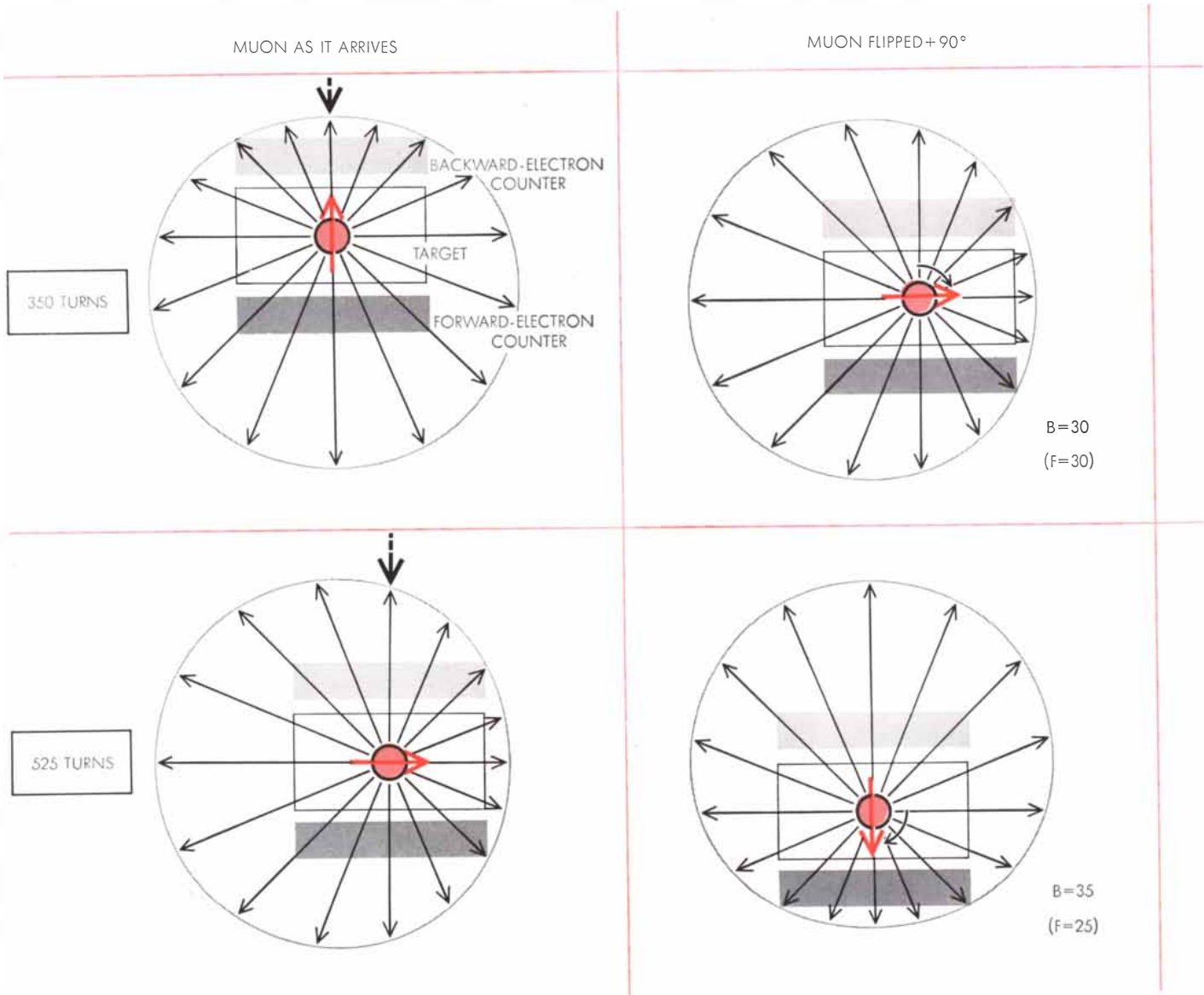
down by a moderator and begin orbiting. Variations in magnetic field force muons to "walk" from left to right while describing their orbits.



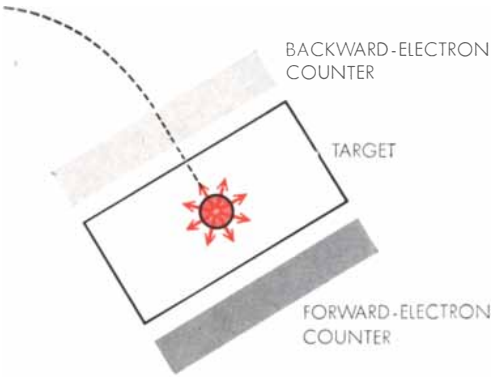
PLOT OF C.E.R.N. RESULTS shows length of time muons spent in the magnet and number of turns they made (*upper curve*) and the asymmetry of the electrons emitted when muons decayed in the target (*vertical colored lines*). The sinusoidal curve that best fits the experimental points determines the muon's anomalous magnetic moment: .001145 ± .000022.



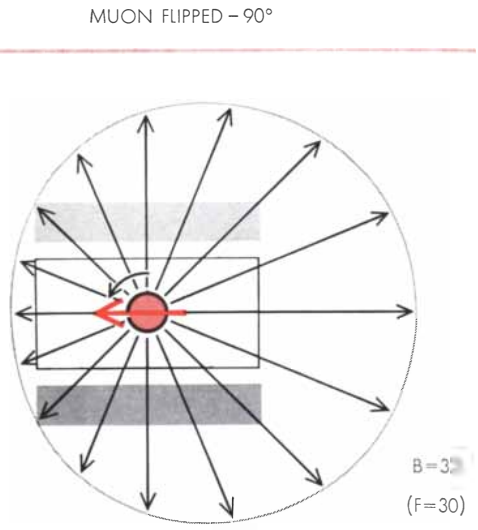
PRECESSION OF MUON SPIN AXIS (*colored arrow*) **in C.E.R.N.** apparatus (*see illustration on preceding two pages*) **is the basis for determining the anomalous magnetic moment of the muon. At start** (*left*) **the spin axis points in the direction in which the muon is traveling. The axis has precessed 90 degrees after 175 turns** (*second from left*) **and 540 degrees after 1,050 turns** (*right*)**. Precession is**

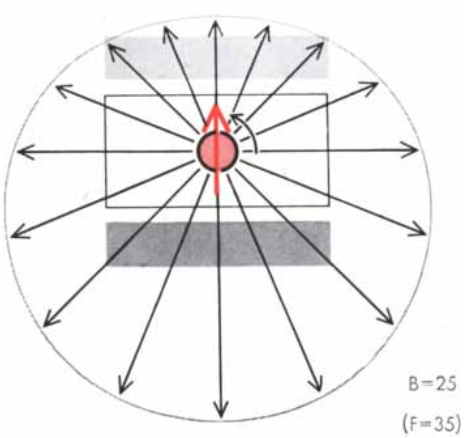


ELECTRONS EMITTED IN MUON DECAY provide the clue to muon precession rate. Muon that has made 350 turns in magnet enters target with spin axis pointing backward. Black arrows radiating from muon are proportional in length to probability of electron emission. To eliminate systematic errors, electron counts are made on groups of muons magnetically flipped +90 degrees and on others flipped —90 degrees. Counts (backward) should be identical for muons making 350 turns (or 700 or 1,050 turns).



calculated from the "storage" time and the direction in which electrons are emitted when muons decay in the target (*see below*).





For muons making, say, 525 turns flipping will produce different counts (*e.g.*, 35 *v.* 25 in backward direction). Forward-electron counts (*parentheses*) show similar behavior.

ing predominantly forward. The muons are then stopped by a target and come to rest with their spin axes perpendicular to the surrounding field of a large electromagnet. Immediately the muons begin their precession.

Electron counters placed around the target record when and in what direction muons decay into electrons. Since the electrons are preferentially emitted in a direction opposite that in which the spin axes of the muons are pointing at the moment of decay, the electrons serve as a searchlight beam that sweeps around at the rate of precession. It is true that the searchlight is turned on only at the instant of decay; nevertheless, if many muons each of which decays after a different length of time are observed, a satisfactory reconstruction of the precession can be made. Since the experiment consists of counting how many turns are made in a given interval of time, and since the muon has a mean life of only 2.2 millionths of a second, it is desirable to use a strong magnet to achieve as high a precession rate as possible. Our experiment used a magnetic field of 15,000 gauss, which gives rise to a precession rate of nearly 200 million times per second. The number of turns can be counted by electronic equipment that compares the muon precession rate with a voltage varying at a precisely known frequency. The equipment is so complicated that systematic errors can easily creep into the measurements unless it is calibrated with great care. Our principal calibration scheme employed an electronically generated artificial signal that mimicked the behavior of muons precessing at a high and accurately known rate.

The most accurate method of measuring the mass of the muon—which must be combined with the magnetic moment to obtain the g-factor—was first devised at Columbia University five years ago by L. J. Rainwater. The precision of the method has recently been refined by other workers at Columbia and Chicago. It consists of measuring the energy of X rays (which, like light, consist of photons) emitted when a negative muon cascades down through its allowable orbits around a nucleus. The energy follows the same laws that govern the energy of the photons emitted by electrons when they make similar transitions, and this energy depends directly on the mass of the particle. Since the muon is more than 200 times heavier than the electron, the photons it emits are correspondingly more energetic. Unfortunately the few hundred photons per second produced by mesic atoms are far too few to activate the conventional X-ray spectrometers that could measure their energy.

There is, however, a way around this difficulty. It happens that when X rays are directed at an absorbing target, rays having a certain narrow range of energies are absorbed much more strongly than rays of slightly less energy. These sharp changes in absorption, known as edges, occur when an X ray has just enough energy to knock an electron occupying a particular energy level clear out of an atom. By coincidence X rays emitted by a muon in a certain step of its cascade from orbit to orbit around a phosphorus nucleus have an energy corresponding to an edge in lead known as the K edge. The edge is not absolutely sharp but changes over a narrow energy interval, which has been accurately measured. By allowing X rays from phosphorus mesic atoms to be absorbed in lead one can determine just where in this energy interval the X-ray line is located. From this it is possible to calculate that the mass of the muon is 206.76 ± .02 times the mass of the electron. While this is a remarkably precise value as mass measurements go, it still leaves a tantalizing uncertainty of 10 per cent in the value of the g-factor.

Quite a different way to get at the g-factor was taken in a remarkable experiment at C.E.R.N. that required the best part of three years to carry out from conception to final completion early this year. The investigators were a five-

$$\text{ASYMMETRY}_{(B)} = \frac{B_{+90^\circ} - B_{-90^\circ}}{B_{+90^\circ} + B_{-90^\circ}}$$

$$\text{ASYMMETRY}_{(B)}\ (350\ \text{TURNS}) = \frac{30-30}{30+30} = \frac{0}{60} = 0$$

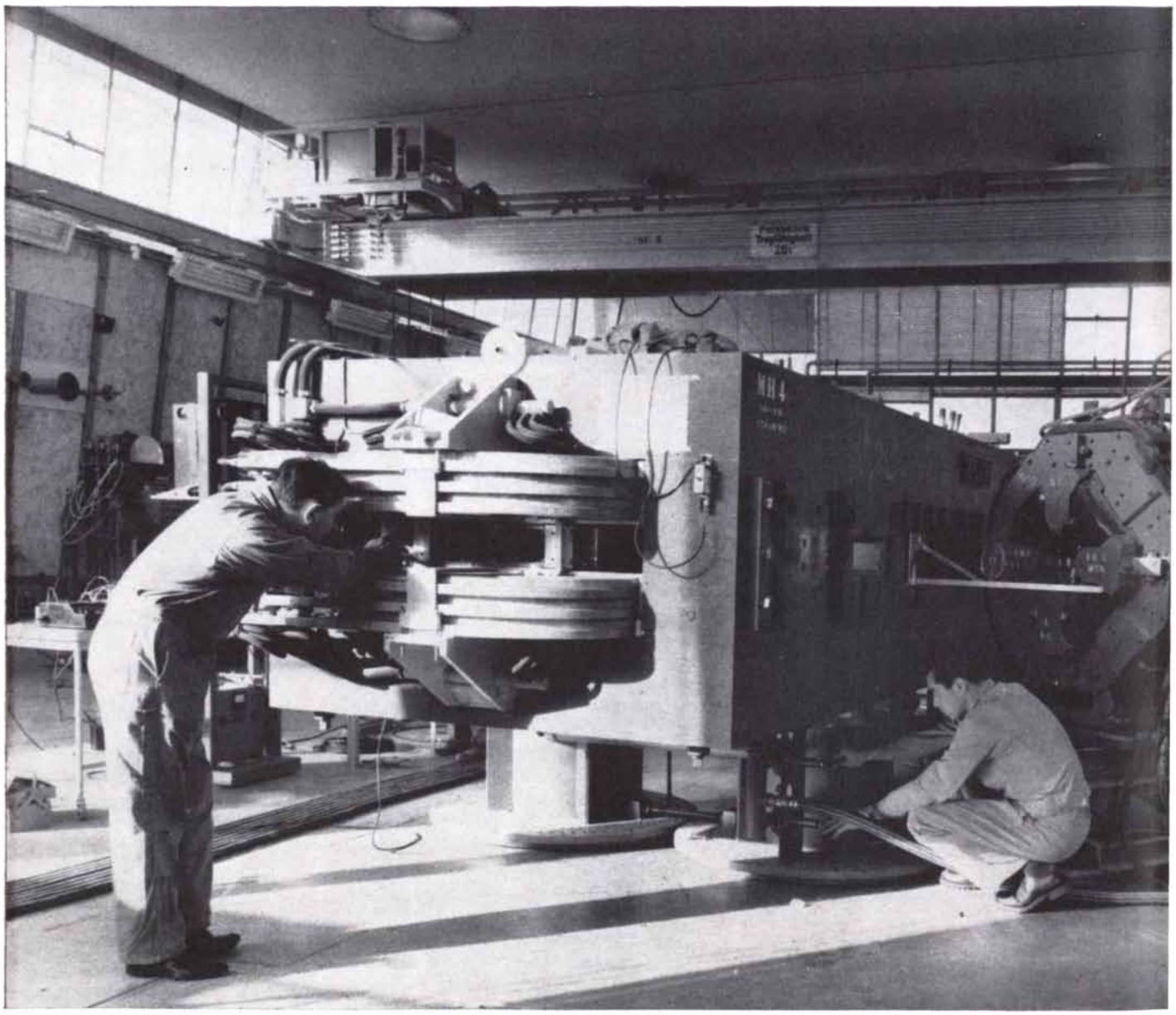
$$\text{ASYMMETRY}_{(B)}\ (525\ \text{TURNS}) = \frac{35-25}{35+25} = \frac{10}{60} = .17$$

ASYMMETRY EQUATION uses electron counts from C.E.R.N. experiment to provide values for the asymmetry curve on page 51. Examples show equation solved for 350 turns and for 525 turns using sample backward counts (*B*) found in the illustration at left.

nation team consisting of G. Charpak and T. Muller (France), A. Zichichi (Italy), J. C. Sens (Netherlands), F. J. M. Farley (United Kingdom), Richard L. Garwin and V. L. Telegdi (U. S.). In this experiment the lack of knowledge of the muon mass was circumvented by measuring directly the deviation of the g-factor from a value of 2, which results in its being called the "g minus 2" experiment. The experiment was suggested in part by a g—2 experiment recently carried out on the electron at the University of Michigan by A. A. Schupp, R. W. Pidd and H. R. Crane.

When a charged particle moves through a magnetic field so that its path is perpendicular to the direction of the magnetic field, it is subjected to a force that makes the trajectory of the particle curve. In a uniform field this orbit will be a circle, and the time required for a particle to complete one turn around the orbit will depend only on the strength of the field and the charge and mass of the particle. The time is independent of velocity (at least until the particles attain velocities close to that of light) because the diameter of the particle's orbit increases with velocity so as to keep the time needed for one revolution constant. This is the principle on which the cyclotron operates, and the frequency with which the particle sweeps out its circular orbit is called the cyclotron frequency.

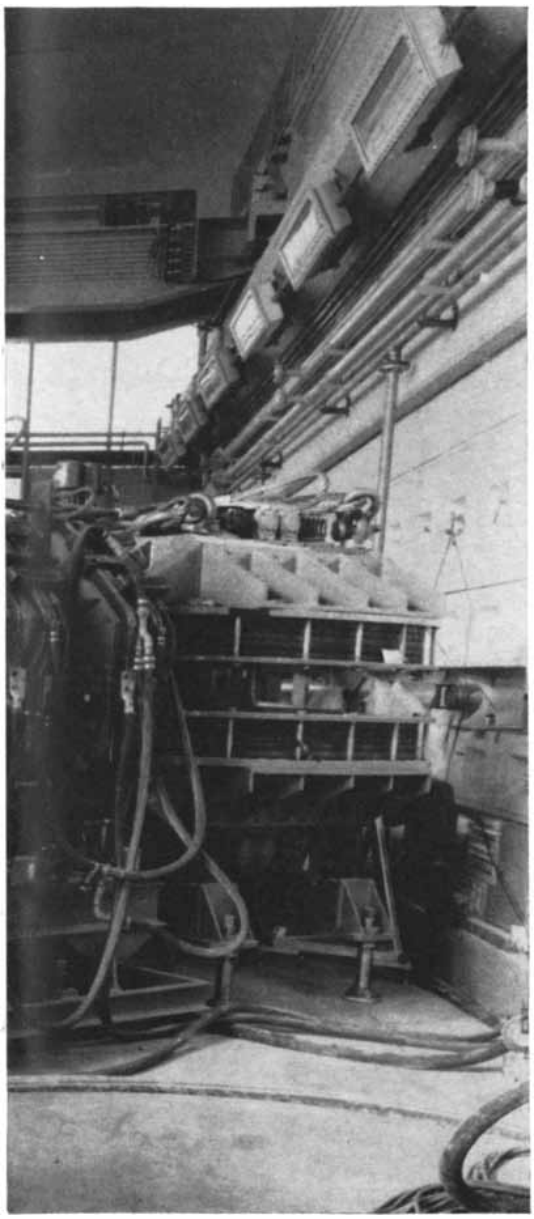
We have already seen that a particle possessing a magnetic moment will precess in a magnetic field. A particle with a g-factor of exactly 2, and with a spin axis pointing in the direction in which the particle is moving when it enters a magnetic field, will precess just enough for its spin to remain pointed along its orbiting path. If the g-factor is different from 2, the cyclotron and precession frequencies will no longer be identical and the spin axis will gradually precess with respect to the trajectory. If



G—2 APPARATUS AT C.E.R.N. was used to determine the muon's anomalous magnetic moment. The man at left is looking between the magnet coils into the region where muons orbit. The muons are produced when pions, created by a cyclotron, decay in flight.

one stops a particle after it has spent a known amount of time in a known magnetic field and measures how large an angle the spin axis makes with the direction in which the particle is traveling, one then knows the amount by which the g-factor deviates from 2.

The principle of the experiment is easily stated. The actual physical realization was quite another matter. Difficult as the electron g—2 experiment was, the muon g—2 measurement was even harder; indeed, many physicists believed it would be impossible. Compared with electrons, muons are available in tiny numbers and their lifetime is extremely short. Moreover, the relatively large mass of the muon calls for strong magnetic fields. The more turns the muon is forced to make, the greater will be its precession from its line of flight and the greater will be the accuracy of the measurement. In the C.E.R.N. experiment a field of 16,000 gauss was used and muons spent from two millionths to six millionths of a second orbiting in the field.



Before entering the big magnet the muon beam is focused by smaller magnet at right.

A magnetic field capable of containing particles that enter with the widely varying momentum, direction and position that characterize a muon beam must be carefully designed and painstakingly adjusted. The C.E.R.N. magnet weighs 85 tons and encloses a vacuum chamber nearly 20 feet long [*see illustration on pages 50 and 51*]. Muons enter at one end of the chamber and are slowed by passing through a beryllium block so that they begin curving into the desired orbit. To prevent the muons from simply describing a circle and striking the block again the magnetic field is shaped so as to produce a "walking" orbit. This is done by making the magnetic field stronger along one side of the vacuum chamber than along the other; where the field is stronger the muon is forced to make a tighter turn and therefore is displaced sideways after each loop of 360 degrees. The field is so shaped that the orbits first walk about two centimeters per turn to get them away from the beryllium quickly. This is followed by a region in which the orbits are packed tightly together (to minimize the length of the chamber), and finally the steps are increased again to give the muon a shove to get it past the fringe field of the magnet. In addition the magnetic field must provide vertical focusing so that particles whose motion is not strictly horizontal will not strike the magnet faces. Upon leaving the magnetic field the muons enter a target where they stay until they decay and emit an electron. Many muons, of course, decay en route and never reach the target.

Two measurements must be provided by the experiment: the length of time each muon spends inside the magnetic field and the direction of the electron emitted when the muon decays in the target. The "storage" time in the magnetic field indicates the number of orbits the muon has made. Muons that happen to take large "steps" can walk through by making as few as 320 or so orbits; those taking very short steps may require over 1,000 orbits. Obviously when two muons enter the magnetic field in rapid succession, there is no way to tell which will move through faster and emerge first. The solution to this is to count only muons spaced far enough apart so that it is physically impossible for the second to overtake the first.

To obtain the second measurement one could try to determine the precise angle at which every decay electron was emitted. Even if this were feasible, however, the electron would indicate only the probable orientation of the muon that had ejected it. Since the direction of emission is probabilistic, it is simpler to count only the decay electrons that emerge in a fixed direction from successive groups of muons. First a little trick is performed. The muons in half the groups, after coming to rest in the target, are turned 90 degrees clockwise by pulsing a small magnetic field around the target. The muons in the other groups are turned 90 degrees counterclockwise. The two directions of pulsing can be expected to yield for each group a slightly different number of electron counts. Turning the muons in this fashion removes the systematic errors that would attend an effort to use two (or more) sets of detectors to count electrons in two (or more) directions [*see illustrations on pages 52 and 53*].

The experiment shows that the g-factor of the muon is $2.001145 \pm .000022$. The theoretical prediction is 2.001165. Experiment therefore confirms, to an accuracy of 1 per cent in the anomalous part of the g-factor, that the muon behaves exactly like a heavy electron. This result also implies that there is no breakdown in the laws of electromagnetism down to distances of 7×10^{-14} centimeters and no fundamental quantum of length greater than 2×10^{-14} cm. In addition it appears that any hope of explaining the mass of the muon by heretofore undetected interactions with fields other than the electromagnetic (such as fields produced by still undiscovered particles) must be abandoned.

The mystery of the muon mass has deepened and at the moment there are no very helpful suggestions as to where physicists can turn for enlightenment. The best hope seems to lie in scattering experiments using the higher energy muons from the new 30-billion-electron-volt accelerators at C.E.R.N. and at the Brookhaven National Laboratory. There is always a chance that something new will turn up in such ultraenergetic collisions. For the time being, however, the muon itself qualifies as a "riddle wrapped in a mystery inside an enigma."

The Artificial Kidney

In it a membrane of cellophane performs many of the main functions of the natural kidney. In addition to its clinical usefulness it is an excellent tool for studying certain physiological processes

by John P. Merrill

It is remarkable that the kidney should have been the first organ for which man devised an artificial replacement. The kidney plays a central role in one of the most complex and subtle of the body's functions: maintaining the stability of the internal environment in the midst of constant physiological activity. The workings of the natural organ are still not completely understood, yet it can now be temporarily replaced by an essentially simple device. Introduced for the treatment of patients in 1945, the artificial kidney has become a standardized piece of lifesaving equipment in hundreds of hospitals. In addition it is proving a sensitive and versatile tool in fundamental physiological research.

The human kidney, a bean-shaped object about the size of a man's fist, has essentially three types of function: (1) it excretes the waste products of metabolism from the blood; (2) it regulates the body's acid-base balance, primarily by excreting sodium and hydrogen ions; (3) it takes part in a number of other physiological processes, including the formation of red blood cells and the regulation of blood pressure. The first two functions can be performed by the artificial kidney, the third cannot.

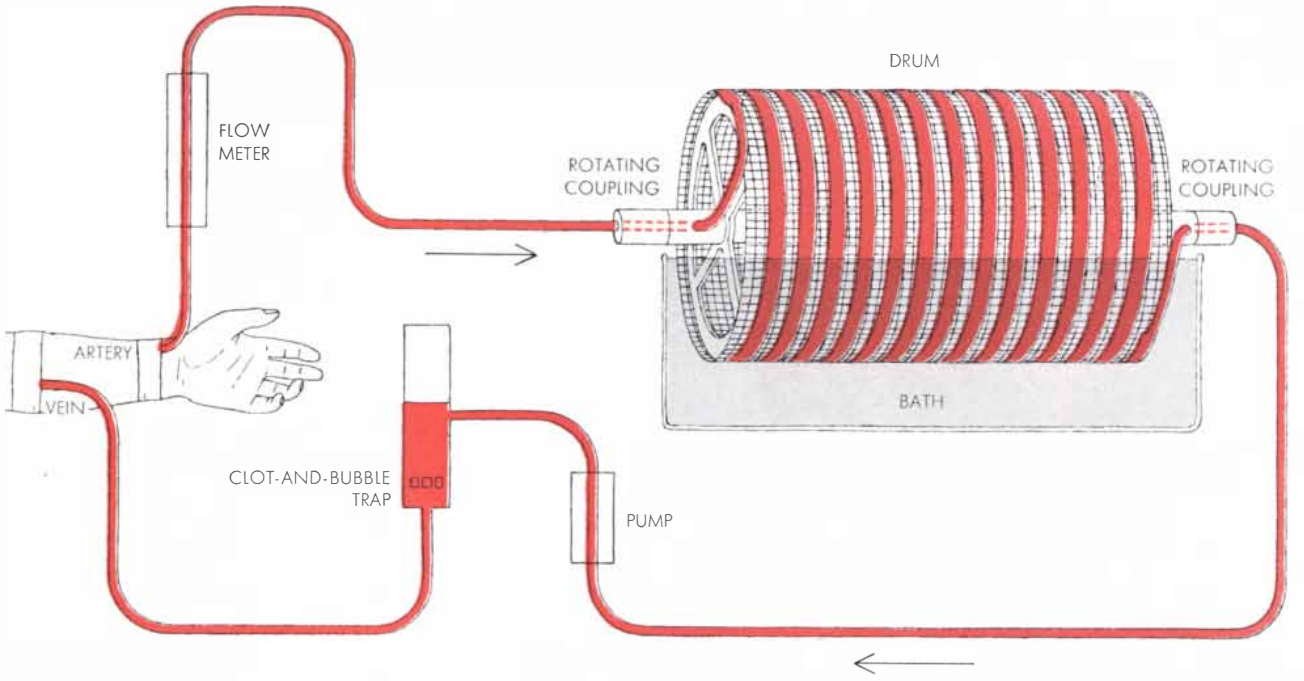
In the natural kidney the work of waste disposal and acid-base regulation begins in the glomerulus, a network of folded capillaries about .2 millimeter in diameter surrounded by a space known as Bowman's capsule. There are about a million of these units in each human kidney. Blood flowing through the capillaries is at higher pressure than the fluid outside them, and the capillary walls contain pores large enough to pass all the constituents of the blood except the blood cells and most of the plasma proteins. As a result most of the water and all the dissolved material in the plasma except its large protein molecules filter out into the capsular space. Each capsule forms the head of a kidney tubule, and the filtrate passes through the tubule, emerging as urine ready for delivery to the bladder. But whereas the glomeruli filter some 190 quarts of liquid per day, only about a quart and a half of urine forms. Almost the entire volume of water, and many of the dissolved substances, are reabsorbed into the blood as the filtrate travels along the tubules. The process is selective: it returns all the glucose and protein, varying fractions of ions such as sodium and bicarbonate and about 40 per cent of the waste product urea. At the same time the cells of the tubule secrete into the filtrate a few more waste products, including potassium and uric acid. The reabsorption and secretion of the various materials are somehow regulated in accordance with the changing requirements of the body.

The artificial kidney does not look anything like a real kidney nor does it work like one. The narrow, intricately folded capillaries of the glomeruli provide an enormous filtering area that can be equaled only in a much larger man-made device. Moreover, the metabolic processes involved in filtration, reabsorption and secretion are too complex to attempt to duplicate.

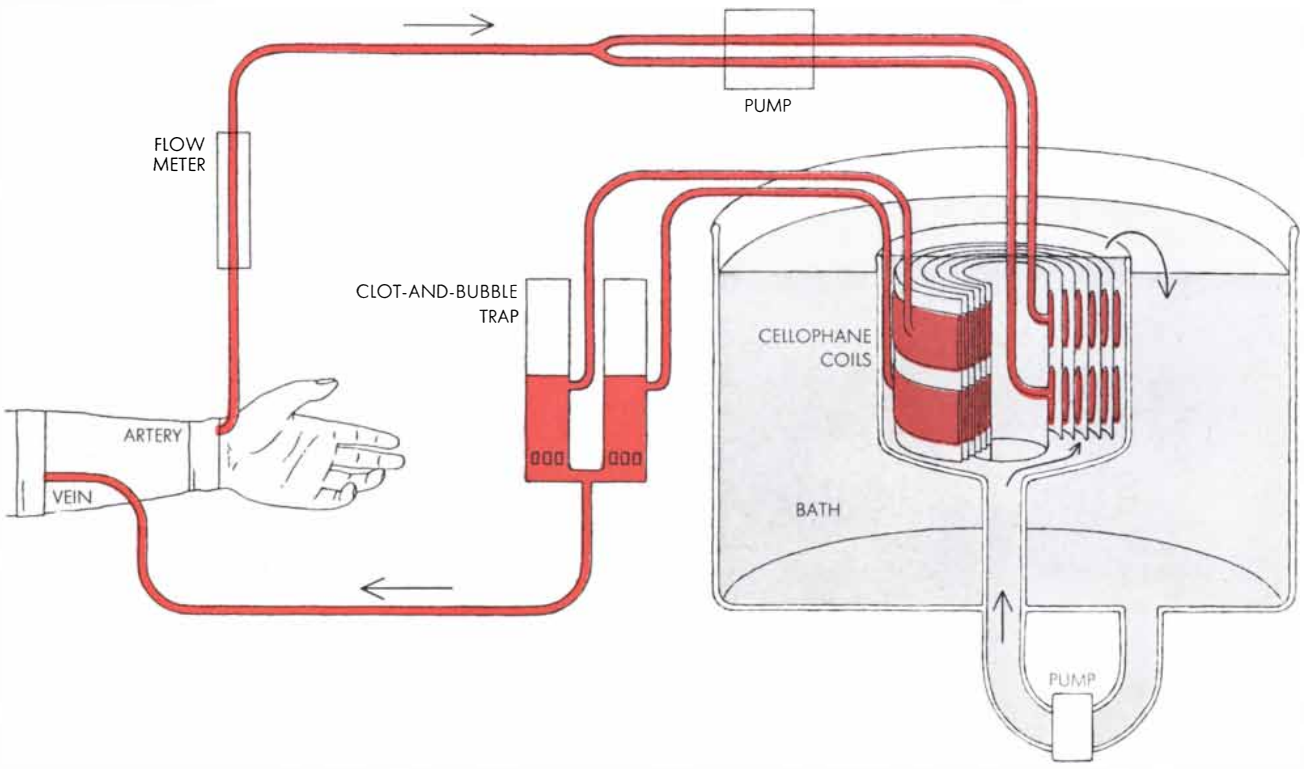
The basic element of the artificial kidney is a cellophane membrane—the same kind of cellophane, incidentally, that meat packers use for sausage casings. This material has pores of about the same diameter as the pores in the glomerular capillaries, so it can pass the same substances. Some artificial kidneys work partly by filtration, but in all of them substances are removed from the blood chiefly by the process called dialysis: when a porous membrane separates two solutions, atoms or molecules small enough to pass through the holes will migrate back and forth across the membrane but with a net transfer toward the lower concentration. In the artificial kidney, blood passes through a cellophane tube, or between cellophane sheets, immersed in a bath, or rinsing fluid. The direction and the rate of transfer of each constituent to which the cellophane is permeable depend on the relative concentration of that constituent in the blood and in the bath.

If, for example, the physician wants to lower his patient's potassium level, he makes the potassium concentration of the bath fluid less than that of the blood. Some potassium ions move each way, but the net movement is from blood to bath. The greater the difference in concentration, the faster the transfer of potassium from the patient's blood. By adding fresh rinsing fluid often enough the bath can be maintained at a permanently lower concentration and potassium can be continuously removed. If the bath contains no urea, an artificial kidney actually takes this waste product out of the blood faster than the natural organ can.

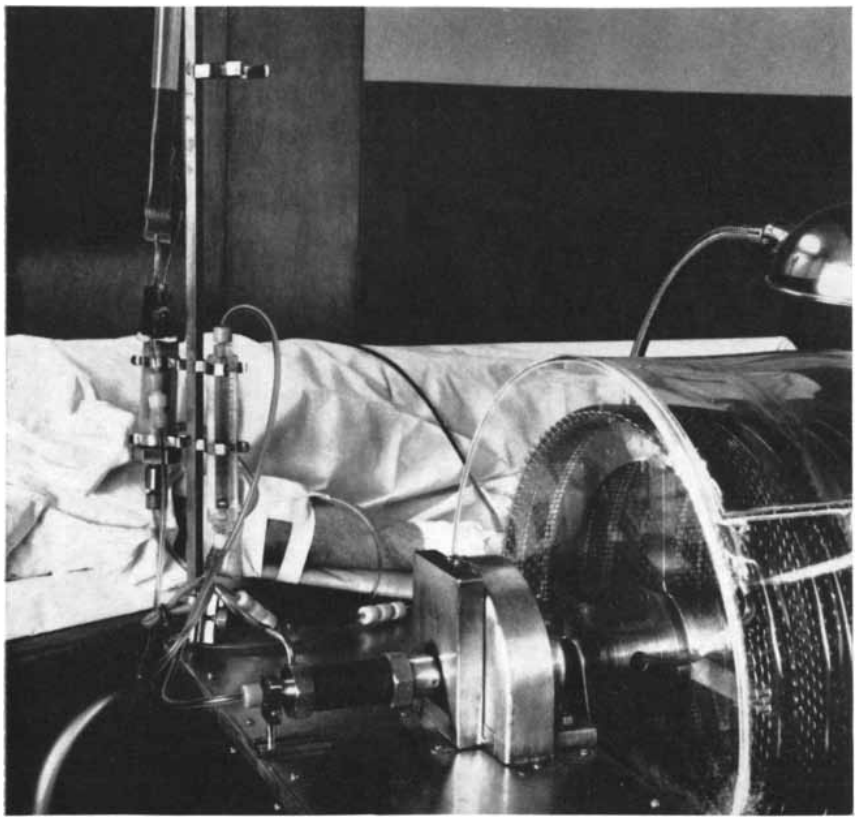
By altering the balance among filtration, reabsorption and secretion the natural kidney extracts more or less of any material from the blood. In the artificial kidney the net transfer can be in any amount and in either direction; substances can be added as well as removed. The movement of each substance is largely independent of the relative concentrations of other substances. Thus by adjusting the concentration of individual substances it is possible to remove potassium, say, at the same time that sodium is added to the blood, or to take



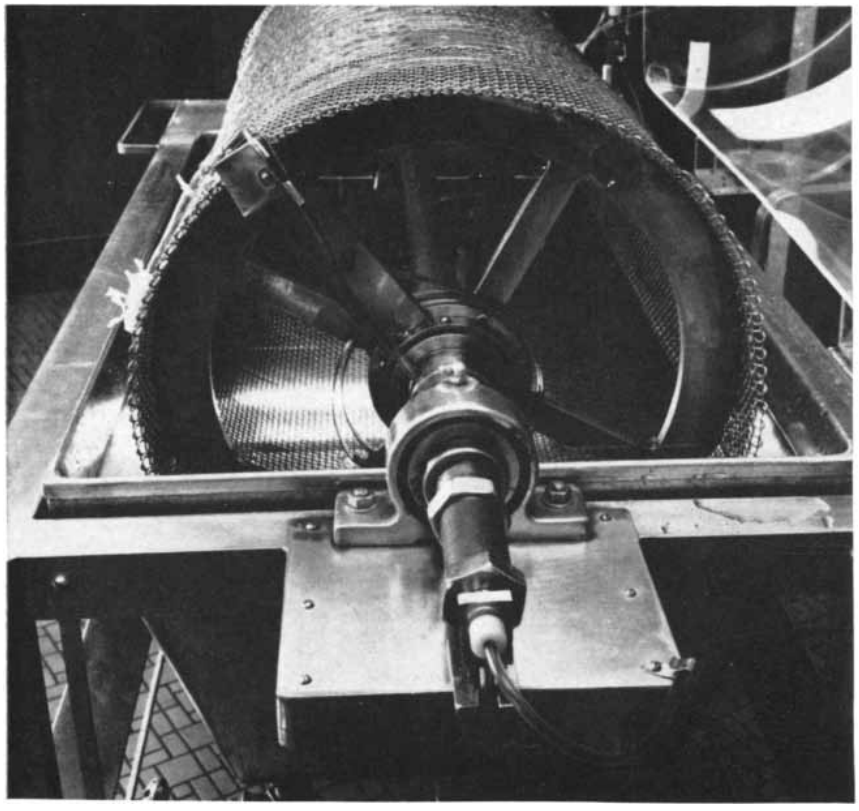
ROTATING-DRUM ARTIFICIAL KIDNEY is a modification of the one devised by Willem J. Kolff in 1945. The basic principle of the artificial kidney is dialysis, the tendency of substances in two solutions on opposite sides of a semipermeable membrane to migrate in the direction of lower concentration. By regulation of the composition of the dialyzing bath, various ions and molecules can be moved into and out of the blood. The dialyzing membrane in this case is ordinary cellophane sausage-casing. The blood is "screwed" along the tubing by gravity, forming a thin film on the wall of the cellophane that provides maximum exposure to the bath.



DISPOSABLE-COIL ARTIFICIAL KIDNEY designed by Kolff in 1956 is now available commercially. The blood is pumped in parallel through coils of cellophane tubing embedded in glass-fiber screens wrapped around a metal cylinder. The pump at the inflow end and the compression of the tubes by screening make it possible to keep the blood under pressure and so to filter as well as dialyze. This makes for more rapid removal of water from the blood. Relative motion between the cellophane and the bath fluid, obtained in the early Kolff model by rotation, is achieved here by continuous circulation of the solution through the inner container.



PATIENT'S BLOOD is drawn from an artery at the wrist. It passes through a graduated flow meter (*on right side of stand*) and thence into the machine. Blood leaving the artificial kidney at the opposite end is led back into the plastic bag (*top*), a trap to catch clots and air bubbles, and on to a pump (*on left of stand*) that impels it back into the patient's vein.



BLOOD ENTERS MACHINE through a rotating coupling (*foreground*). It then moves through the small plastic pipe to the cellophane dialyzing membrane wrapped on the drum.

out phosphate while adding bicarbonate.

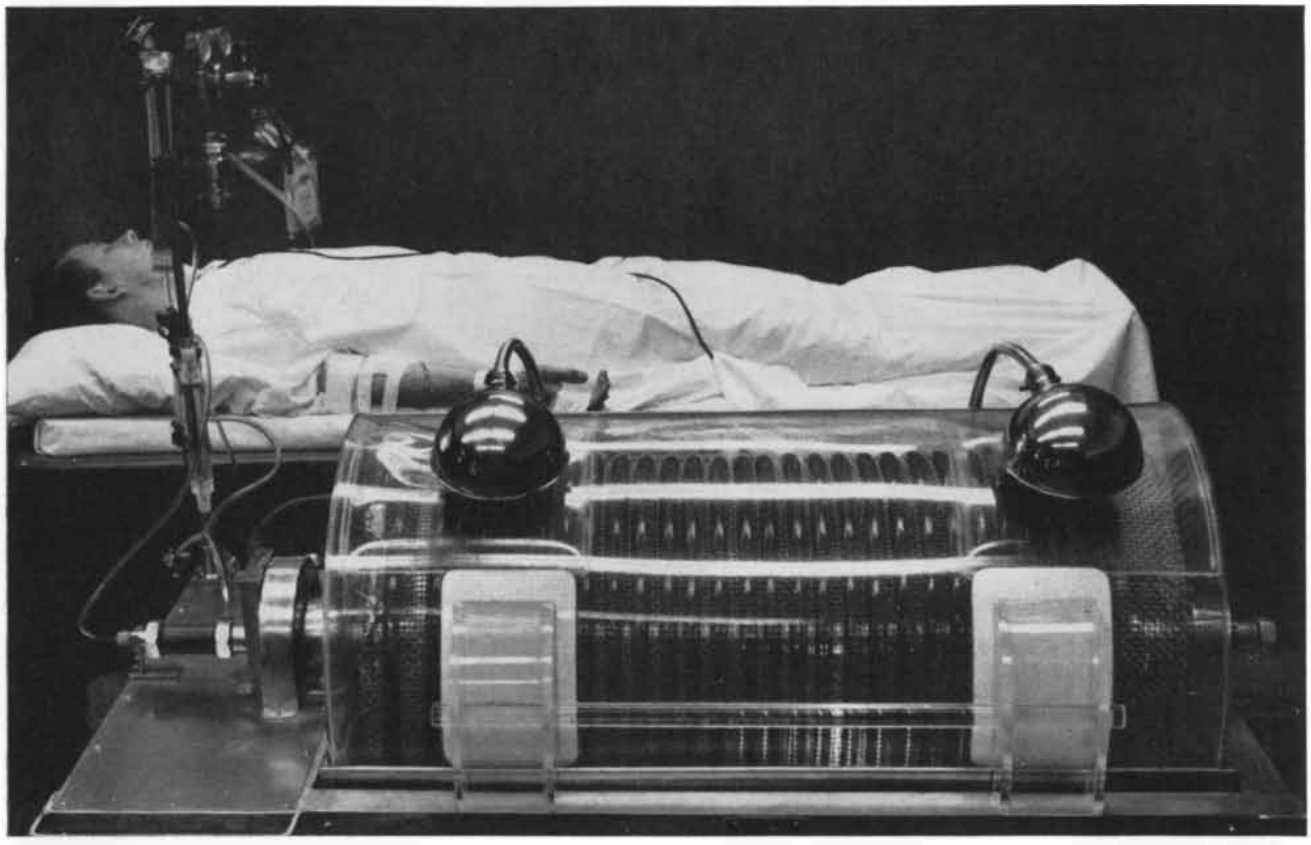
The possibilities of dialysis have been recognized for many years; long before the invention of cellophane, experimenters were trying to use animal membranes for this purpose. As early as 1877 a German physician, G. Wegner, injected fluid into the body cavity of animals and found that various substances moved from the blood across the peritoneal membrane into the fluid. In the mid-1920's another German worker, Hans Necheles, went a step further. He removed the peritoneal membrane from a sheep, placed it between supporting screens and made a dialyzing apparatus much like those of today. With this device he was able to remove from circulating blood a substance that stimulated secretion of gastric juices by the stomach.

The first successful application of an artificial membrane to living animals was made by John J. Abel, L. G. Rowntree and B. B. Turner of Johns Hopkins University in 1913. They passed the blood of dogs through a branching network of collodion tubes immersed in a bath and showed that toxic amounts of aspirin could be rinsed out of the blood. Their experiments, and their prediction that artificial kidneys (a term they used for the first time) would one day treat acute renal failure in humans, have been proved absolutely sound.

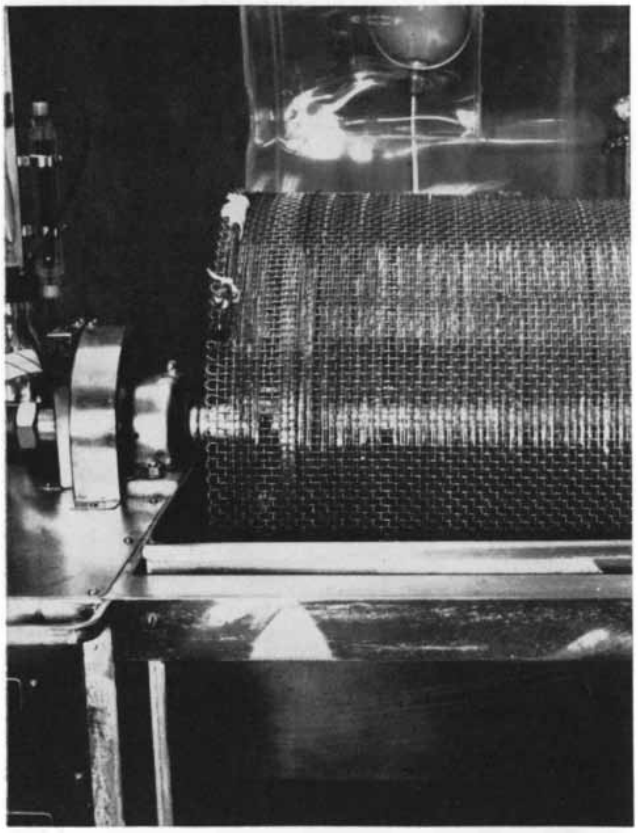
Not the least of the problems that these pioneers had to solve was that of preventing the blood from clotting while it flowed through the artificial vessels. They did not have modern anticoagulants, so Abel turned, ingeniously but laboriously, to the leech, which was known to secrete an anticlotting factor called hirudin as it sucked blood. The Johns Hopkins workers ground up the heads of thousands of leeches to get enough hirudin to keep the dogs' blood from clotting in the collodion tubing.

As an experiment Abel's attempt was eminently successful, but his apparatus and technique were hardly suited to the treatment of human patients. The practical artificial kidney awaited a more convenient and plentiful material for the membrane and a more readily available anticoagulant. Cellophane took care of the first problem; the second was solved by the discovery of heparin, which was isolated and then purified by Jay McLean and W. H. Howell and others at Johns Hopkins in the early 1930's.

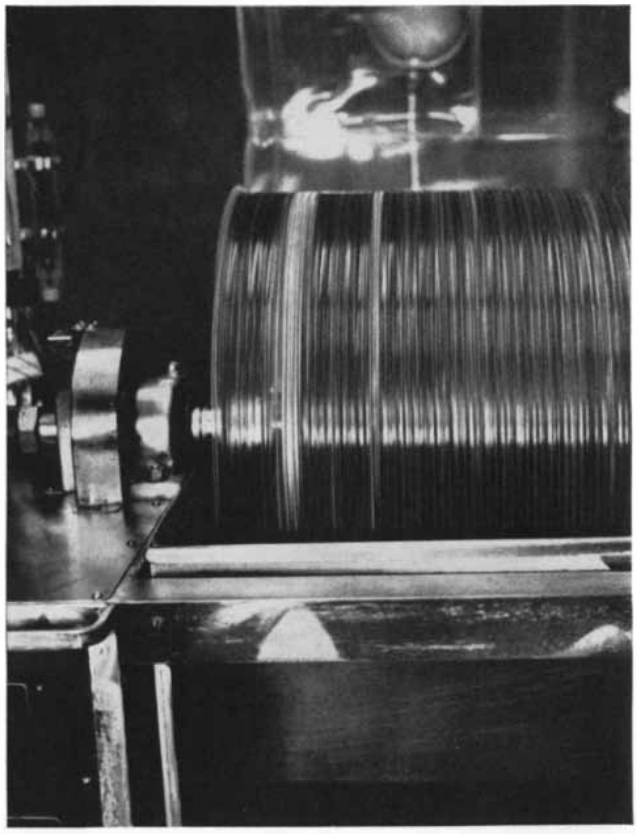
With these materials at hand, a Dutch physician, Willem J. Kolff, developed the prototype of the modern artificial kidney in 1945 and with it first treated



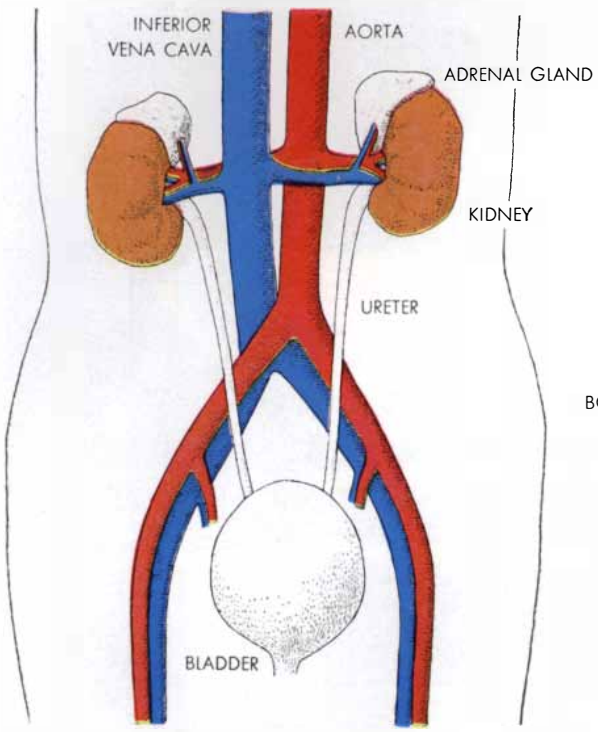
ARTIFICIAL KIDNEY is set up at the Peter Bent Brigham Hospital in Boston. Blood from the patient's artery enters the machine at left and moves through cellophane tubing wound on a rotating drum. The drum is immersed in a bath that "rinses" waste products from (and adds desired substances to) the blood, which is pumped back into a vein through a clot-bubble trap (*top left*).

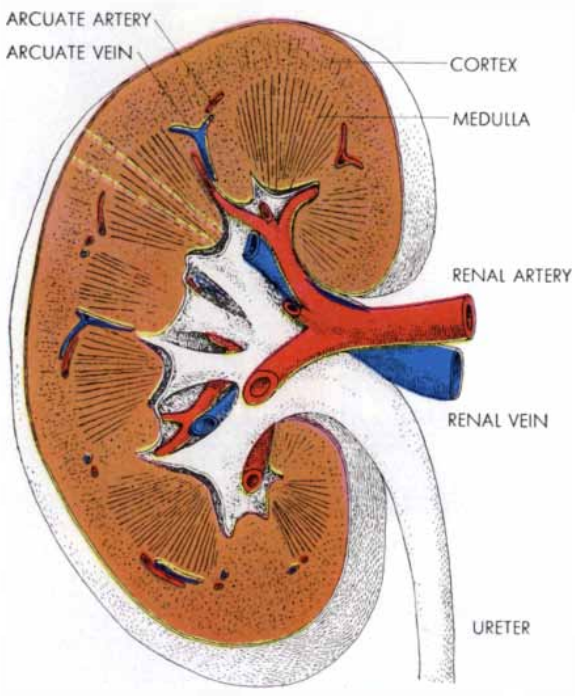


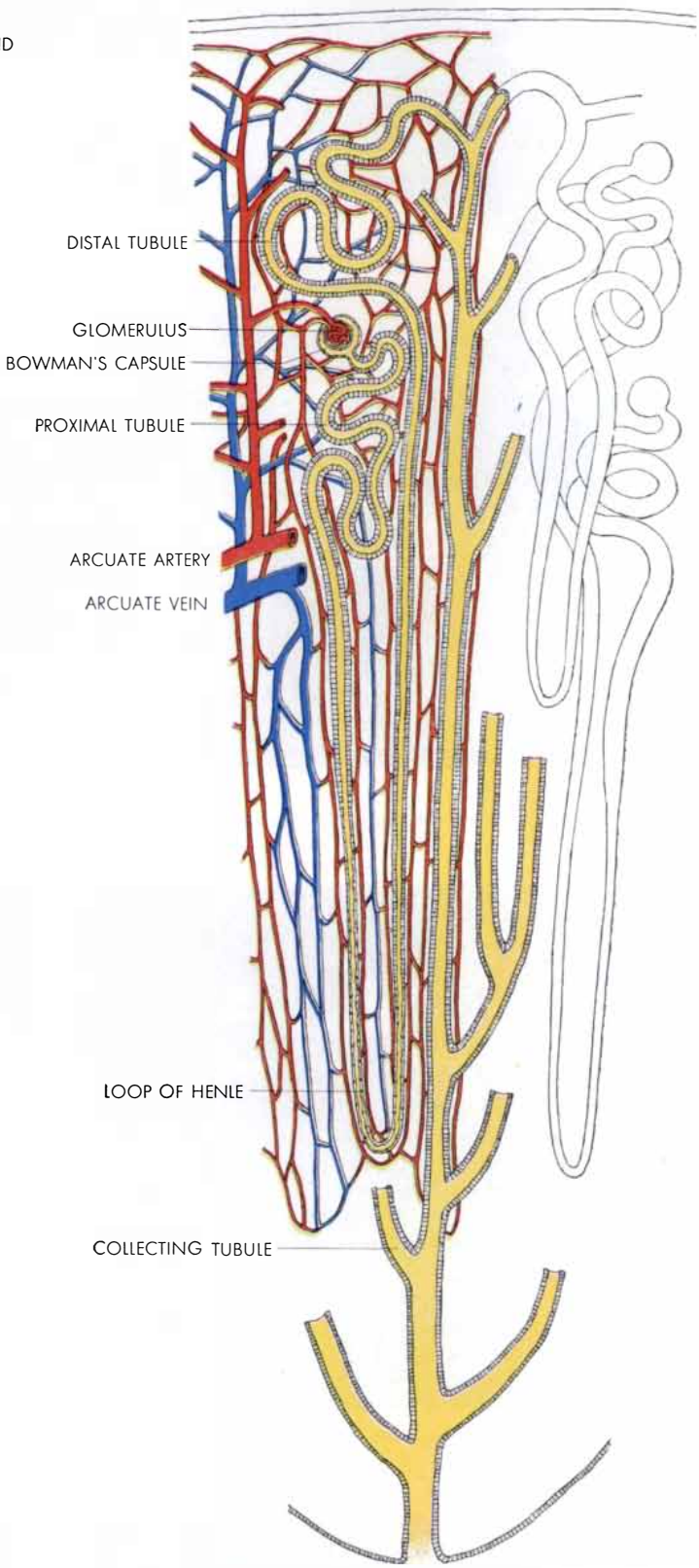
WIRE-MESH DRUM is wound with cellophane tubing, a membrane with pores that permit waste products in the blood to pass through.



DRUM ROTATES at about 25 revolutions per minute in the bath solution, and gravity carries the blood along through the tubing.







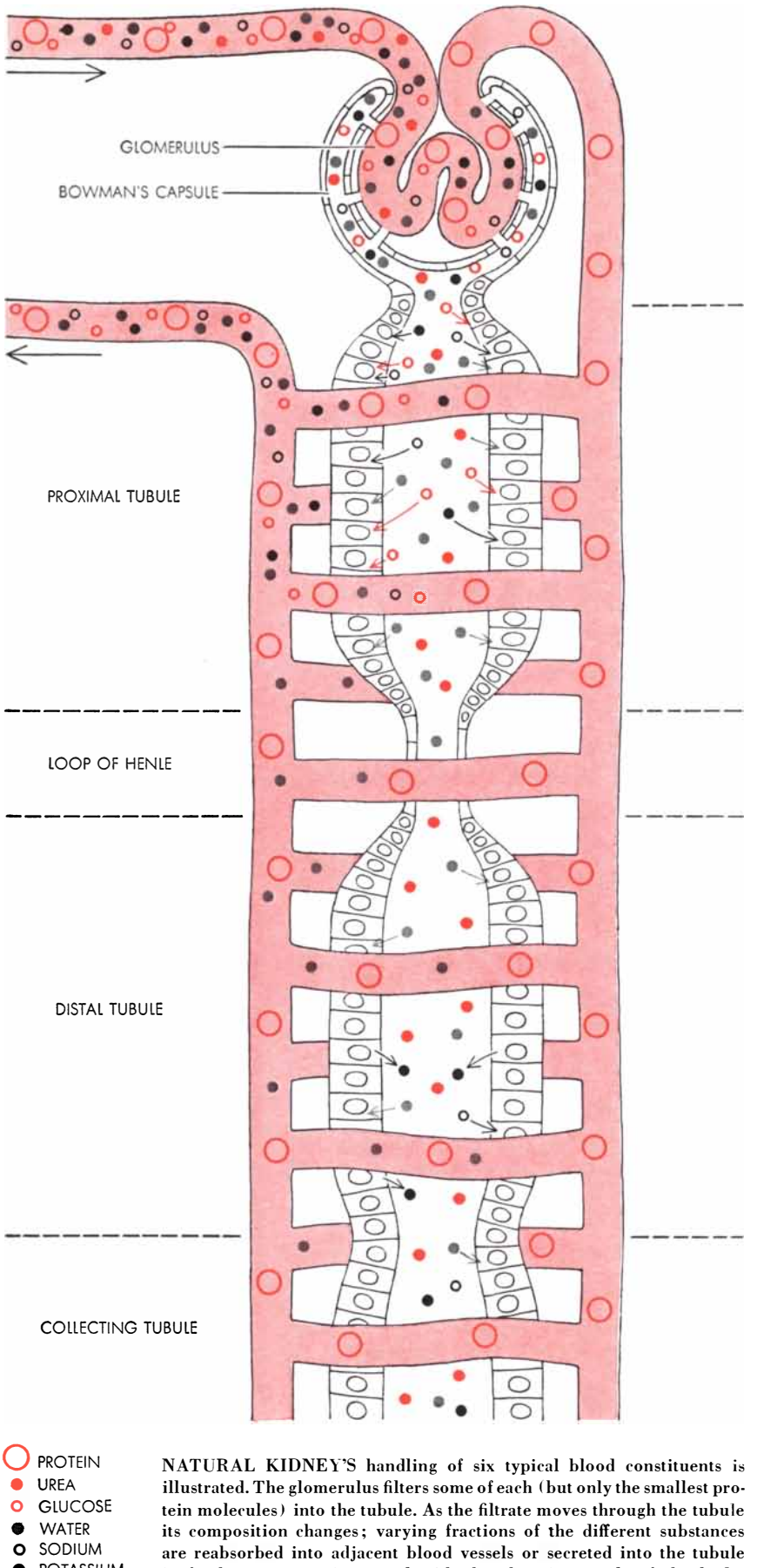
HUMAN KIDNEYS are paired organs, lying against the back of the abdominal cavity, that filter wastes and otherwise help regulate the composition of the blood. The urinary system (*top left*) includes the kidneys, the ureters and the bladder. The sectional view of the left kidney (*bottom left*) is seen from the back. The area outlined by the broken white line is enlarged (*right*) to show one nephron, the functional unit of the kidney, in detail. Blood is filtered at the glomerulus, a loop of capillaries. The filtrate moves through the tubule, where much of it is reabsorbed into adjacent blood vessels. The excess water and waste substances that remain constitute urine. Collecting ducts gather urine from several nephrons, two more of which are outlined in black (*far right*).

patients suffering from uremia, the toxic condition that results from kidney failure. Kolff's accomplishment was remarkable, particularly considering that he was working under great handicaps during the German occupation of the Netherlands. His device was clumsy but it worked. In 1947 our group at the Peter Bent Brigham Hospital in Boston began to use a modification of the Kolff kidney devised by Carl Walter, a surgeon-engineer at the hospital; this model remains the simplest and most effective of today's artificial kidneys. In it the blood passes through a cellophane tube wound around a wire-mesh drum. As the drum rotates, the blood is carried along the tubing through the dialyzing bath in which the drum is immersed. Only dialysis occurs; there is no filtration because the blood is not under pressure.

A number of other types of artificial kidney appeared after World War II. One developed by Nils Alwall of Sweden was the first to operate by filtration as well as dialysis. (Filtering provides the most convenient way of removing water.) It consisted of tubing wound spirally around a vertical drum, held in place by a surrounding metal screen. Supported by two rigid surfaces, the tubing could carry blood pumped under the pressure necessary to force liquid out through the membrane. In another design sheets of cellophane were arranged to form a multidecked sandwich with alternating layers of bath fluid and blood.

All the versions of the artificial kidney so far described had to be assembled by the doctors and nurses operating them. Now a standard model has become available. It is based on a device made in 1953 by W. Y. Inouye and Joseph Engelberg at the University of Pennsylvania School of Medicine; it consisted of alternate layers of cellophane and fine wire screening wound around a supporting structure and enclosed in an ordinary pressure cooker. Kolff, then working at the Cleveland Clinic, took up this idea and built an artificial kidney that is now manufactured commercially. Cellophane tubing, wound in a spiral between layers of Fiberglas screen around a metal core, is set in a tub that holds a circulating bath fluid. The cellophane-Fiberglas coil comes as a disposable unit, and the convenience of this machine, which filters as well as dialyzes, has made it possible for many more hospitals to provide artificial kidney therapy.

As Abel predicted in 1913, the artificial kidney has been applied with great



NATURAL KIDNEY'S handling of six typical blood constituents is illustrated. The glomerulus filters some of each (but only the smallest protein molecules) into the tubule. As the filtrate moves through the tubule its composition changes; varying fractions of the different substances are reabsorbed into adjacent blood vessels or secreted into the tubule in further amounts in accord with the changing needs of the body.

success in the treatment of acute kidney failure. A complete loss of kidney function can be caused by shock, infection, some forms of high blood pressure and many other conditions. Often the situation is temporary, and the kidney will eventually recover if the patient can survive the uremia that results when the kidneys shut down. It is in such cases that the artificial kidney has produced its most dramatic results. People dying of uremic poisoning are literally brought back to life by intermittent treatments with the artificial kidney.

Ideally these treatments should be repeated frequently so as to prevent rather than merely treat the effects of acute uremia. However, frequent dialyses have presented a surgical problem, because the tubes that carry the blood to and from the apparatus must be inserted repeatedly into the patient's artery and vein. A technique recently devised by Belding H. Scribner of the University of Washington circumvents this difficulty. He puts two lengths of plastic tubing into the blood vessels of the arm, one in an artery and the other in a vein, and leaves them there. Most of the time they are connected by a short, semicircular shunt. Blood flows from the artery to the vein through the shunt; in this way normal circulation is maintained, although it is partly short-circuited. When it is time for a treatment, the shunt is removed and the artificial kidney is connected to the two implanted tubes; the patient is simply "plugged in."

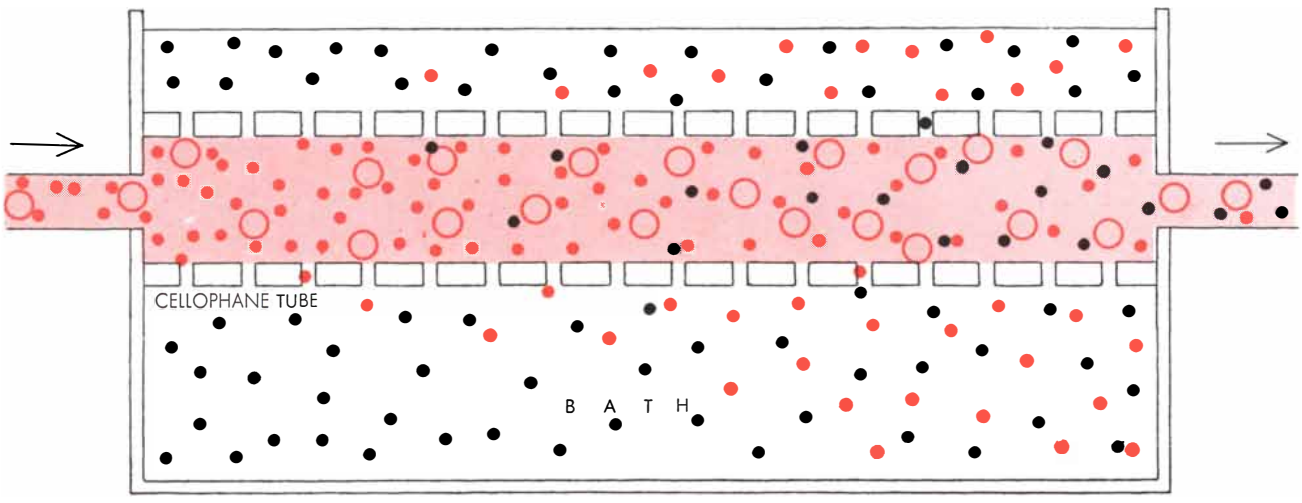
This convenient technique should prove extremely useful in acute renal failure. Making possible an indefinite period of therapy, it raises the hope of keeping people alive who have chronic renal failure. Whether or not the hope will be realized remains to be seen. Several cases have been reported in which the lives of patients suffering from chronic kidney disease were considerably prolonged, but there have been failures too. It should be remembered that the artificial kidney cannot take on all the functions of the natural organ, and in chronic cases this may be crucial.

Another practical difficulty in the operation of the artificial kidney has also yielded to a new technique. Patients critically ill with uremia often bleed from the gastrointestinal tract or from injuries; adding heparin to their blood may aggravate the hemorrhages or cause new ones. Using a method called regional heparinization, it is now possible to keep the anticoagulant out of the patient's body. Heparin is injected into the blood at the inflow end of the machine and neutralized at the outflow end before it enters the patient's vein. The neutralization is accomplished with protamine, which counteracts heparin.

Because of its selective ability to remove a wide variety of substances from the blood, the artificial kidney is valuable in many situations not involving impaired kidney function at all. In other words, it can supplement a healthy kidney. Poisons move through the circulatory system, and the artificial kidney is therefore an excellent tool with which to remove them. This application was foreshadowed by Abel's very first experiment in removing aspirin from the blood of dogs. Many cases of aspirin and barbiturate poisoning are now handled with the artificial kidney. There are two types of drug—bromides and thiocyanates—that the artificial kidney removes more effectively than the natural kidney does. In the natural organ these drugs are largely reabsorbed by the tubules after being filtered by the glomeruli. In dialysis, on the other hand, all the toxic ions that pass out of the blood into the bath stay there; hence the artificial kidney has been particularly successful in treating bromide or thiocyanate poisoning. Experiments have shown that dialysis also removes radioactive substances such as strontium 90 from the blood, preventing them from being deposited in bone or excreted by the natural kidney, where they can do severe damage.

Recent studies in Switzerland have raised a particularly interesting possibility. There is evidence that some substance circulating in the body fluids may play a role in schizophrenia; the Swiss investigators treated a number of schizophrenics with the artificial kidney and reported some remarkable improvements. The implication is that the hypothetical causative factor—whatever it may be—was removed from the patient's blood.

The ability of the artificial kidney to alter drastically the composition of the body fluids makes it a dangerous tool in the hands of inexperienced operators. Even when the total changes are within safe limits, the speed with which the machine can carry them out can cause trouble. Many ions diffuse rapidly between blood and bath fluid through cel-



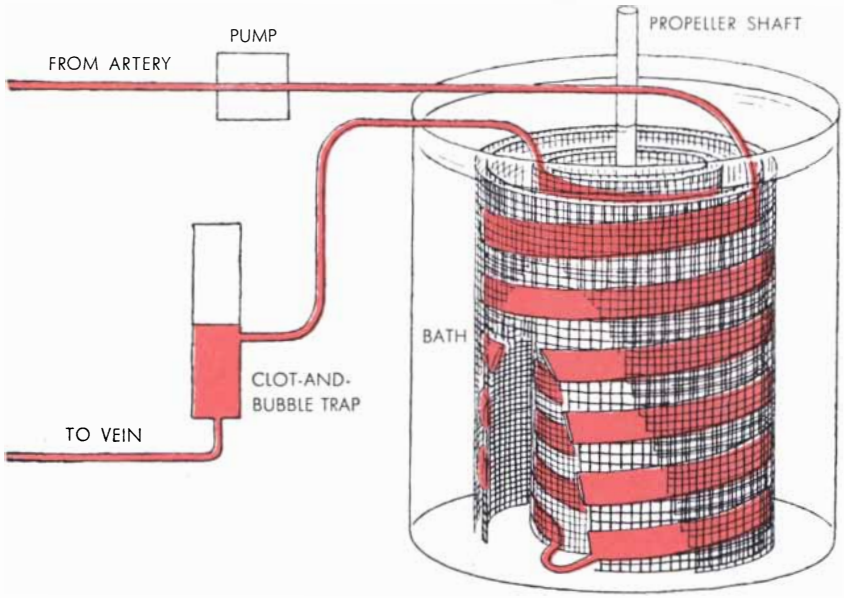
PRINCIPLE OF DIALYSIS by artificial kidney is illustrated for two of the many substances it can handle. In this hypothetical case the object is to remove urea from the blood and to add bicarbonate, so the fresh bath fluid contains no urea but a heavy concentration of bicarbonate ions. Dialysis, which tends to equalize concentrations, moves urea from the blood to the bath and bicarbonate into the blood.

lophane but move much more slowly between the cells of the body and the blood plasma. Dialysis can therefore move these ions in or out fast enough to upset the normal ratio between the concentrations of the ions in the cells and in the surrounding fluid.

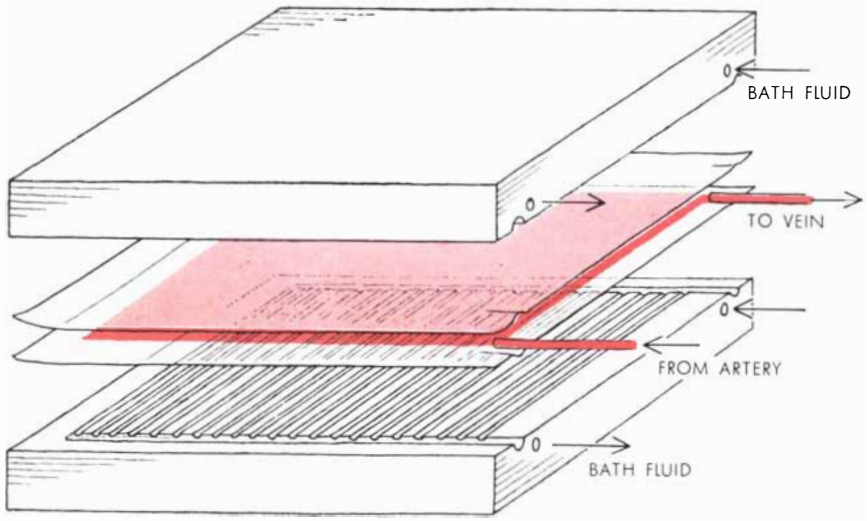
Bicarbonate is one such ion, and this gives rise to a surprising phenomenon. Excess acidity in the blood can be corrected by adding bicarbonate with the help of the artificial kidney. The body itself acts to correct acidosis by increasing the respiration rate and thereby excreting more carbon dioxide. The speed-up in breathing seems to be governed by excess acidity within the cells. If, in an attempt to correct acidity by dialysis, bicarbonate is added too rapidly, the bicarbonate level within the cell will lag behind. Respiratory movements then continue at the high rate called for by the intracellular acidity. The result is a sudden change in the patient from "metabolic acidosis" to "respiratory alkalosis."

Similarly, in patients with chronic uremia compensatory mechanisms have gradually developed within the cells over months or years, and rapid correction of abnormalities in the blood takes some time to be reflected in the cells. After a session on the artificial kidney there is the paradox of marked improvement in blood composition with little improvement in the patient; he is "chemically" well but clinically still sick. Then, in perhaps two or three days, with his blood chemistry actually regressing, he begins to look better and feel better.

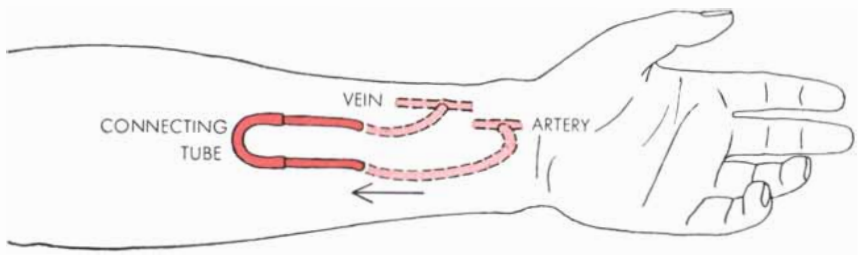
This is merely a sample of the information that is coming out of continuing work with the artificial kidney. We have learned, for example, that there is a regulatory mechanism controlling the concentration of such ions as calcium, magnesium and potassium inside and outside the cells. When the blood level of one of these ions is lowered to a certain concentration by dialysis, it stays there regardless of further treatment, maintained by ions moving out of the reserve within the cells. Now a high concentration of potassium in the extracellular fluid with respect to the intracellular level interferes with the impulses that regulate the heartbeat, and it may paralyze the heart. Treatment of this symptom through removal of potassium by dialysis is effective but may run into trouble for two reasons. For one thing, removing potassium from the blood plasma too rapidly can cause a second kind of problem, a disturbance in the rhythm



ALWALL'S KIDNEY was one of the first devices to include a pump at the inflow side and to compress the cellophane tubing between screens, making it possible to duplicate the filtering action of the normal kidney. A rotating propeller circulated the bath solution and, as in all such machines, a trap kept clots and air bubbles from entering the bloodstream.



SKEGGS-LEONARDS KIDNEY, unlike most others, does not use tubes for the dialyzing membrane. Instead the core of the machine is a "sandwich" made of two sheets of cellophane. The blood flows between them in a thin film, and the bath solution is circulated through grooves cut in panels on the outside of each membrane. A pump is used with this kind of artificial kidney, so it too is capable of filtration as well as dialysis of the blood.



SCRIBNER'S TECHNIQUE makes frequent dialyses of a patient feasible by avoiding the surgery otherwise required every time the blood vessels are connected to the machine. Plastic tubes are inserted under the skin of the patient's arm; one is implanted in an artery and the other in a vein. The tubes are connected by a semicircular shunt. This allows blood to flow uninterruptedly except during dialysis, when the shunt is removed and the tubes are hooked up to the artificial kidney. Some chronic patients have been helped by this device.

COMMERCIAL VERSION of the coil kidney is now used in many hospitals. The disposable coil is the white object in the inner container, through which bath fluid is circulated from the large tub. The pump at bottom right impels the blood through the machine.

of the heartbeat. Even if this does not happen, the more potassium ions are taken out of the blood, the more ions are released from the cells to the plasma. Then, when potassium builds up again in the plasma after dialysis, the ratio of extracellular to intracellular potassium is still further increased, and the original problem of heartbeat regulation is aggravated.

Some further examples will give an idea of the range of investigation made possible by the artificial kidney. One bears on the nature of uremia. The condition has been recognized for centuries; the term "uremia" ("urine in the blood") shows that its connection with kidney disorders was apparent long ago. But it is still not clear just which of the substances retained by the failing kidney are responsible for the symptoms. Urea, the major nitrogenous waste, has generally been held to be involved. Recently, however, we have treated uremic patients with an artificial kidney in which the bath fluid contained enough urea so that none was removed from the blood. The patients improved, indicating that their symptoms were not due to urea alone.

Robert I. Henkin, Pamela H. Byatt and Morton H. Maxwell at the University of California at Los Angeles School of Medicine have carried out a similar experiment at the cellular level. They grew human cells in tissue culture and then bathed the cells in blood serum from uremic patients; the growth of the cells was markedly inhibited. When they used serum from patients whose blood had been dialyzed, there was no such effect. Adding urea alone to the dialyzed serum inhibited cell growth only slightly. Apparently some factor other than urea that is removed by the artificial kidney is toxic to human cells. The problem now is to identify the factor.

Along a rather different line, the artificial kidney has thrown a new light on the action of an old drug, digitalis. Patients whose heart action is failing often accumulate excess body water. The condition is treated with diuretics, which increase the excretion of urine. Cardiologists have long known that this treatment tends to step up the effect of digitalis on the heart. We noted a similar phenomenon when patients who had been given digitalis developed signs of digitalis intoxication in the course of treatment with the artificial kidney. The symptoms turned out to be associated with the removal of potassium; the loss of potassium apparently enhances the power of digitalis already in the heart muscle. The electrocardiographic signs of digitalis intoxication could be produced by removing potassium even though the patient had taken no digitalis for four days and had a perfectly normal electrocardiogram just before the dialysis.

In such experiments as these the artificial kidney's ability to change the concentration of specific substances in the body fluids, while keeping the level of the others constant, makes it a powerful and flexible research tool. Used with care and imagination, it should continue to add to our knowledge not only of the human kidney but also of a wide variety of diseases and fundamental metabolic processes.

Kodak reports on:

high cards for the polypropylene game . . . x-ray film like tape . . . what can be done with a puree

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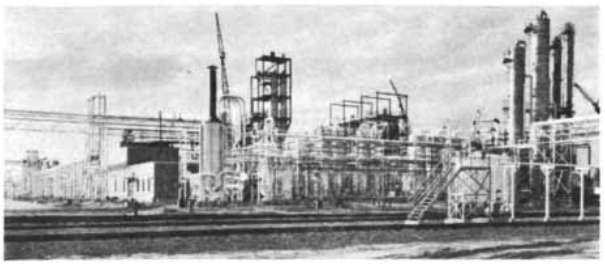

$[-CH(CH_3)CH_2-]_n$

This tidy little plant cost us a tidy little sum. It stands in Longview, Texas, receives propane by pipeline, and is now ready to turn it into 20 million pounds of polypropylene per annum.

We are not alone. Seven other large and reputable companies are known to be playing in the game against each other and us. If none of the players' announced plans go awry, 460 million pounds of polypropylene capacity will exist in the United States *next year*. Sober estimates of demand range from a pessimistic 300 million pounds to an optimistic 450 million pounds *by 1965*. All we players must therefore be very brave, hide our nervousness, and raise our glasses high in a toast to the memory of Senator John Sherman, who believed in the great public good that comes of free and untrammeled competition.

(Other nations have ambitious polypropylene plans of their own and are outproducing the U. S. in polypropylene right now in the aggregate. The peoples of the earth had better start making their artifacts out of polypropylene—and fast!)

As the game gets under way, we hold certain strong cards. Perhaps the other players will show you theirs, too. *Tenite Polypropylene*

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Why snip in the dark?

The "cultural lag" they talk about in sociology serves in simple ways to restrain technology from advancing too fast.

X-rays were discovered through their effect on the photographic emulsion. Photographic emulsion comes on photographic film. Photographic film is mostly used to take pictures by visible light. Visible light won't pass through paper. Paper therefore protects from light. The converse yields the principle that a sheet of film must be extracted from its paper protection before use. This principle seems sort of fundamental to photography. Though modern radiography employs a different kind of film and even omits a camera, the principle of transferring the film from its package to a separate exposure holder before use has been respectfully preserved (except by dentists who seem, in this respect at least, a little brighter than the rest of us).

The chains that bind have now been sundered. *Kodak Industrial X-ray Film* in sheets has been available for some little time now in a *Ready Pack* form, enclosed in individual lighttight packets. Now one can also buy a 200-foot roll of 70mm, 35mm, or 16mm x-ray film with a paper skin on it. One cuts off what one needs, seals the end with opaque tape, and strips off the paper just before processing.

You can get Kodak Industrial X-ray Film, Type AA *and* Type M *this way. (Type M is the one that trades speed for maximum resolution.) Eastman Kodak Company, X-ray Division, Rochester 4, N. Y., can supply the name of the nearest dealer.*

Light as air

Millions of Americans now facing a biological problem without significant precedent in all human history may well sit up and take notice of this picture. Theirs is the problem of avoiding more calories than their doctors say are good for them while enjoying the primal delight of good eating to which evolution has attuned the nervous system.

Both beakers contain the same quantity of applesauce. The one on the right contains only two additional ingredients: 1% of *Myverol Distilled Monoglycerides, Type 18-00* and 1000% of air. Both of these added ingredients are recognized by competent authorities to be as harmless as applesauce itself. One adds the monoglyceride, warms, and whips warm or cold. An ordinary kitchen mixer will do. If the result is a bit too airy for the common taste, one can either use more strongly flavored applesauce, freeze while mixing (as in making ice cream), or both. Even unfrozen, the fruit-fluff is every bit as stiff as it looks in the picture and stays so for several hours. If you want more time, you can dry it down to a powder, package it, ship it to a store, and let a customer whip it after reconstituting with hot water.

It doesn't have to be applesauce, either. We have made the idea work just as well with pears, bananas, peaches, tomato juice, grape juice, and sweet potatoes. We don't see why it wouldn't work with any other strained or pureed fruit or vegetables, or even with puree-like materials for purposes other than food.

We don't sell applesauce or any other purees. We don't even sell Myverol Distilled Monoglycerides in family-size quantities. We love to sell them, though, in processor-size quantities and love to talk to processors about them. The address is Distillation Products Industries, Rochester 3, N. Y. (Division of Eastman Kodak Company).

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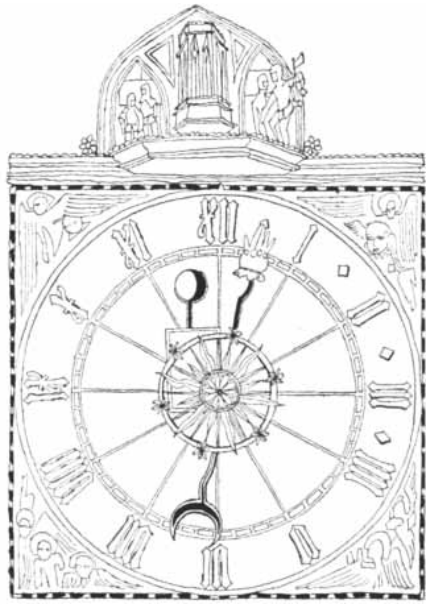
This is another advertisement where Eastman Kodak Company probes at random for mutual interests and occasionally a little revenue from those whose work has something to do with science



Genetic Messenger

The communication system that carries instructions from the genes to the protein assembly lines in the living cell has apparently been discovered. Recent papers in *Nature* from the California Institute of Technology and Harvard University report evidence that the job is performed by an unstable "messenger" form of ribonucleic acid (RNA).

In the past few years it has become almost certain that the blueprints for proteins are recorded in the genetic material proper: deoxyribonucleic acid (DNA). The actual templates on which the amino acid units of proteins are assembled consist of stable RNA and are located in small cellular particles known as ribosomes. (A third type of RNA—"transfer RNA"—brings the amino acid units to the ribosomes.)

The link between blueprint and template, however, is not clear. It has been generally supposed that each gene—*i.e.*, each complete coding sequence in the genetic material—acts as a template in making ribosomes that are specialized for the production of a particular protein. But recently this idea has run into a number of difficulties, chiefly the fact that RNA samples from different ribosomes seem remarkably alike and therefore are not adapted to the manufacture of widely different proteins. Accordingly François Jacob and Jacques Monod of the Pasteur Institute in Paris have suggested that ribosomes are general-purpose factory buildings, so to speak, which can house templates for various proteins. The templates are unstable molecules of RNA, made by the genes, and are used perhaps only once before disintegrating.

While visiting Cal Tech, Jacob, together with Sidney Brenner of the University of Cambridge and Matthew Meselson of Cal Tech, found direct support for this picture in experiments on the colon bacillus (*Escherichia coli*) and a virus that infects it. When *E. coli* cells are infected with virus, the cells stop making their normal protein and begin to manufacture virus protein. According to the old view, they would need new ribosomes to do this; on the messenger hypothesis, however, they would require only a new kind of unstable RNA.

Jacob and his colleagues grew *E. coli* in a medium containing heavy isotopes of carbon, nitrogen and phosphorus. Then they infected the bacteria with virus and transferred them to a "light" medium containing a radioactive tracer. Thus RNA formed by the uninfected cells before transfer would be "heavy," whereas RNA formed by the infected cells would be light and radioactively labeled.

Analysis showed that no new stable RNA or ribosomes formed after infection; the virus made use of pre-existing bacterial ribosomes. What was formed after infection was a new and unstable RNA. The new RNA was found, furthermore, to migrate to the ribosomes, which thereupon began manufacturing a new protein—virus protein.

At Harvard, François Gros and H. Hiatt, visiting from the Pasteur Institute, together with the Harvard workers Walter Gilbert, C. G. Kurland, R. W. Risebrough and James D. Watson, performed a similar trick with uninfected colon bacilli. They exposed growing cells to a brief labeling "pulse" (10 to 20 seconds long) in a medium containing radioactive precursors of RNA and found that the radioactivity was incorporated first in unstable RNA molecules and not in ribosomes.

Genes without Cells

For the first time genes have been made to carry out their specific function outside a living cell. The feat was performed by G. David Novelli, a biochemist at the Oak Ridge National Labora-

tory, who reported his experiments at a symposium in Cold Spring Harbor, N.Y.

Novelli worked with DNA extracted from the colon bacillus. In one set of experiments he induced the formation of an enzyme, beta-galactosidase, in his test tube system with DNA containing a gene for the production of this enzyme. In another he shut off production with DNA containing a gene that suppresses the enzyme synthesis.

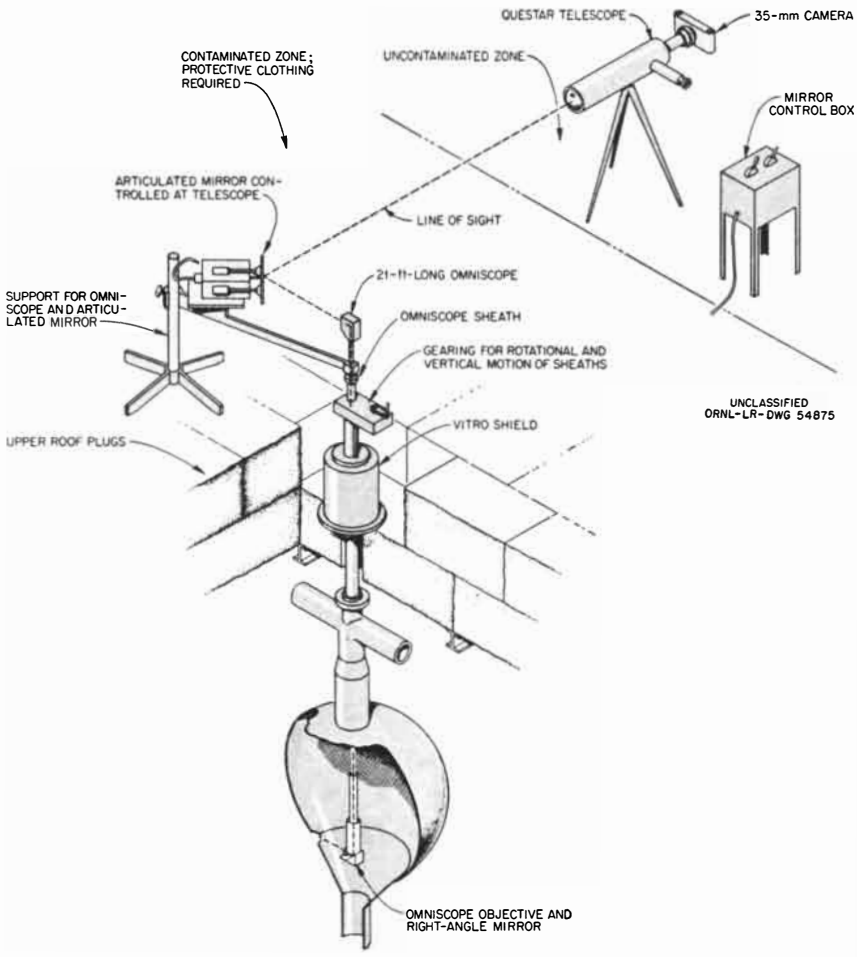
Many strains of the colon bacillus bear the gene for producing beta-galactosidase. Some also have a suppressor gene and form the enzyme only when treated with a suitable "inducer." Still other mutants lack the enzyme gene and cannot produce beta-galactosidase at all.

To demonstrate the action of the enzyme and suppressor genes in vitro, Novelli prepared a cell-free, DNA-free colon bacillus soup by breaking up the cells mechanically, centrifuging out the cellular debris and treating the remaining material with an enzyme that destroys DNA. (He took care to avoid damaging ribosomes, the particles in which proteins are formed in living cells.) He then added inducer compounds, amino acid building blocks for the enzyme, nucleotide building blocks for "messenger" RNA [*see "Genetic Messenger," above*] and compounds to provide energy.

This mixture proceeded to synthesize beta-galactosidase following the addition either of DNA extracted from bacterial strains that regularly synthesize the enzyme or of DNA from "inducible" strains that had been treated with inducer before being killed. The enzyme was also produced by fragments of the appropriate DNA molecules, although Novelli has not been able to determine how large a portion of the original molecules the fragments represent. DNA from nonproducing strains, on the other hand, made no enzyme. And DNA from suppressor strains that had not been pretreated with inducer promptly cut off enzyme production when they were added to preparations in which enzyme synthesis had been taking place.

Four Echoes from Venus

Three months ago the uncertainty in measurements of the mean distance from the earth to the sun—the astronomi-



This schematic diagram was sent to us by Oak Ridge National Laboratory at Oak Ridge, Tennessee, operated by Union Carbide Corporation, for the U. S. Atomic Energy Commission. It shows how the versatile Questar telescope, in the uncontaminated zone at top right, permitted metallurgists to work without protective clothing in comfort and safety while examining the interior of a radioactive core vessel twenty feet below the 5-foot-thick concrete shield. By means of a remotely controlled mirror, the operator could direct light rays from a 21-foot periscope, called an Omniscope, into the Questar, where visual or photographic images were formed at will. Inside the empty tank the radiation level sometimes reached 100,000 roentgens per hour, a small fraction of which would be lethal. With a 35-mm. camera attached to Questar's optical axis 5 x 7 prints were secured giving magnifications of 4 and 16x, while the standard Questar eyepieces allowed visual inspection at 4, 8, 16 and 32 diameters magnification. We are told that the metallurgists were highly pleased with Questar and optimistic about its possible use in other difficult applications. The examination proved the feasibility of powers to 60 diameters with improved lighting, that stereophotography is possible, and that mapping of the entire inner surface of the vessel may be done with a motion picture camera attached to Questar.

cal unit (A.U.)—was still about 50,000 miles [see "The Size of the Solar System," by James B. McGuire, Eugene R. Spangler and Lem Wong; SCIENTIFIC AMERICAN, April]. Thanks to powerful new radar sets, sensitive receivers and the inferior conjunction of Venus and earth on April 10 (which brought the two planets within 26.3 million miles of each other), the odds are now at least three to one that the A.U. has been established accurately to within 2,000 miles. It probably lies between 92,955,000 and 92,957,000 miles.

During May four teams of investigators in three countries—the United Kingdom, the U. S. and the U.S.S.R.—reported what happened when they sent radar signals toward Venus and precisely measured how long it took for echoes to return. Knowing that the signals traveled with the speed of light, they could calculate the distance to Venus and from this, using well-established astronomical relationships, they could determine the A.U.

Three groups—at the Jodrell Bank Observatory of the University of Manchester, at the Lincoln Laboratory of the Massachusetts Institute of Technology and at the Jet Propulsion Laboratory of the California Institute of Technology—got essentially the same answer. The Soviet value for the A.U., reported by V. Kotelnikov and I. Shklovsky, falls some 88,000 miles short of the other three. The four values in miles and their probable accuracy, as given by each group of workers, are as follows:

Manchester	92,956,600	± 3,000
Cal Tech	92,956,000	± 1,000
M.I.T.	92,955,400	± 1,000
U.S.S.R.	92,868,000	± 3,000

Although the Soviet value is inexplicably low, it is only 7,000 miles less than the first radar-echo values obtained by the Lincoln Laboratory and Jodrell Bank in 1958 and 1959. These two groups now assume that their previous results were in error. The new radar values are also 31,000 miles higher than the A.U. value obtained last year by tracking *Pioneer V* to a distance of 22 million miles in its orbit around the sun.

All four groups attempted to learn something about the rotation rate of Venus and the nature of its surface by analyzing the frequency spread of the returning radar signal. Again there was variance in results and inferences. The Soviet astronomers, who found a substantial spread in the signal, concluded that Venus rotates once every 11 days or less. The Jet Propulsion Laboratory

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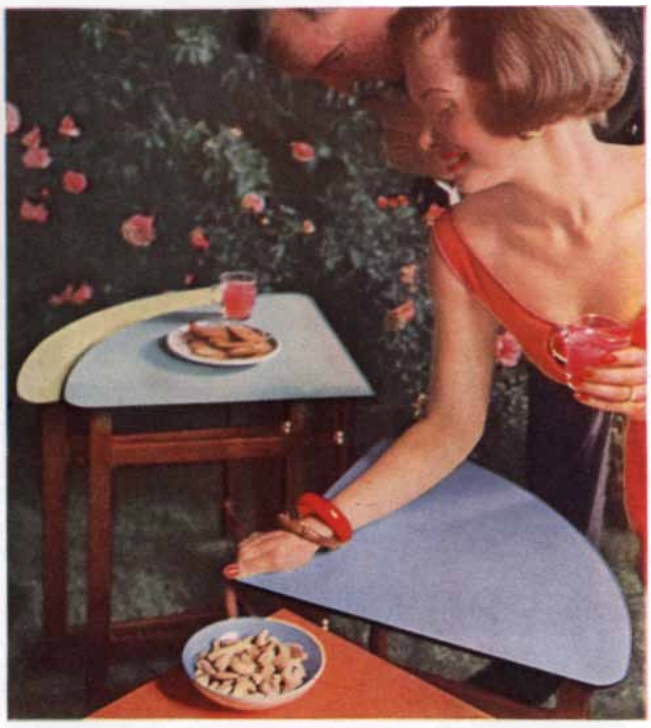

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workers found a spread of only 5 to 10 cycles and therefore concluded that one rotation may take a whole Venusian year, or 225 earth days. This rotation rate is tied to the assumption that Venus has a crater-marked surface like that of the moon. (If Venus were perfectly smooth, the reflection would appear to come from a point and no spread of signal would be detected.) The Lincoln Laboratory group found so little spread (less than one cycle per second) that they report "it is impossible to determine the planetary rotation." Fortunately there will be many more inferior conjunctions of earth and Venus before someone begins to pack for a trip to the small planet.

Too Many Drugs

In recent years 400 to 500 new drugs have been put on the market annually by the U. S. pharmaceutical industry. The number of prescriptions filled by druggists has risen from 182 million in 1939 to 712 million in 1959. More than 70 per cent of the money now spent on prescription drugs is spent for products less than 10 years old. But many of the new medicines, declares Mindel C. Sheps of the University of Pittsburgh, are being produced "in the same atmosphere that produces a rapid turnover in automobile models" and are being marketed without adequate evidence of value.

Writing in the *Journal of Public Health*, Sheps points out that the earliest trials of new drugs are usually arranged by the manufacturer. "Although some of these studies are of high quality, the scientific requirements for careful investigation of the clinical worthiness of a drug, including its superiority to existing products, have to compete with high-pressure marketing demands." The influence of these demands is illustrated by a quotation from the medical director of one pharmaceutical company: "The papers reporting the early studies stimulate interest in the product and give it its first promotional 'push,' but the studies themselves are really initiated to get scientific information. A second, and usually later, group of clinical trials serves promotional ends more directly. These trials are set up primarily to increase the medical profession's acceptance of the new drug and to gain its greater use. They seek to do this by increasing the number of papers published in journals or presented at medical meetings—all dealing with the new drug." Sheps asks: "When is the clinical value of the drug studied?"

Actually the number of new drug

products has grown so large that only a small proportion can be tested by physicians with the facilities and experience to conduct clinical trials. "A great part of the so-called clinical evaluation of new drugs," Sheps concludes, "is unscientific, lacks adequate provisions to eliminate bias, and cannot be objectively judged."

Spark Chamber

Progress in high-energy physics has followed closely on the development of its basic tools: accelerators, for making particles; and detectors, for observing what they do after they are created. In the past few months experimenters have been trying out a device that promises to be the best new detector to come along since the bubble chamber.

Called the spark chamber, it consists of a set of parallel conducting plates, set about half an inch apart in a vessel containing a gas such as neon. Alternate plates are connected to opposite sides of a generator, producing a potential of about 10,000 volts between each pair. When a charged particle passes through the array, it leaves a segmented trail of ionized gas atoms between the plates. Each segment acts as a nucleus for a localized spark that jumps from one plate to the next. By photographing the track of sparks from two perpendicular directions, the three-dimensional path followed by the particle can be reconstructed.

This arrangement has several advantages. It is simple. It operates at atmospheric pressure. Neither the gas nor the plate material need be highly purified, and the exact shape of the plates is not critical. A big detector with many heavy plates is not much harder to build than a small one.

A key feature of every detector is "resolution"—the ability to localize a particle in time and space. The spark trail is not so fine as those in cloud or bubble chambers; hence its space resolution is poorer. But the time resolution is thousands of times better. The spark chamber is sensitive only when there is high voltage on the plates, and voltage can be applied in pulses lasting only a ten-millionth of a second. Between pulses a small, steady voltage sweeps the gas clear of ions. Therefore only the particles passing through the chamber during the time of the pulse leave visible tracks. Auxiliary detectors can be arranged to set off a pulse only when some specific type of event takes place.

As more powerful accelerators are applied to the study of more unusual

events, the size, mass and time resolution of detectors become increasingly important. High-energy particles can traverse a large quantity of matter before exhausting their capacity to interact. In particular, a large and massive target is necessary if weakly interacting particles such as neutrinos are to have a reasonable probability of producing recognizable events within the confines of the detector. And the lower the time resolution, the more unwanted particle tracks accumulate to obscure the few significant ones.

The first working spark chamber was built in 1959 by S. Fukui and S. Miyamoto in Japan. Currently the Columbia University physicist Leon M. Lederman and his colleagues are assembling the biggest one yet—a 10-ton chamber made of 100 aluminum plates each four feet square and one inch thick. They plan to use the device this summer in conjunction with the 30-billion-electron-volt synchrotron at the Brookhaven National Laboratory in an experiment on high-energy neutrinos.

Operating under Pressure

Surgeons in Holland are performing experimental operations inside a steel tank under an air pressure three times normal atmospheric pressure. The object is to prolong the period during which heart operations can be carried out without the use of a heart-lung machine. At a pressure of three atmospheres red blood cells and blood plasma can hold about twice the usual quantity of oxygen. In a patient whose need for oxygen has been reduced by lowering his body temperature, this will supply sufficient oxygen to allow complete halting of the circulation for 10 minutes or more—time enough for many operations inside the heart.

Although the high pressure helps the patient, many doctors and nurses find it uncomfortable, and not all can tolerate it. Nevertheless, the Dutch workers feel that the technique for adding oxygen to the blood will prove helpful in treating impaired circulation in the brain and limbs, poisoning with toxic gases and other conditions as well as in cardiac surgery.

Cosmic Cloudburst

A record shower of cosmic ray particles has been recorded at Volcano Ranch, a New Mexico research station of the Massachusetts Institute of Technology. Containing between 20 and 40 billion charged particles, it must have

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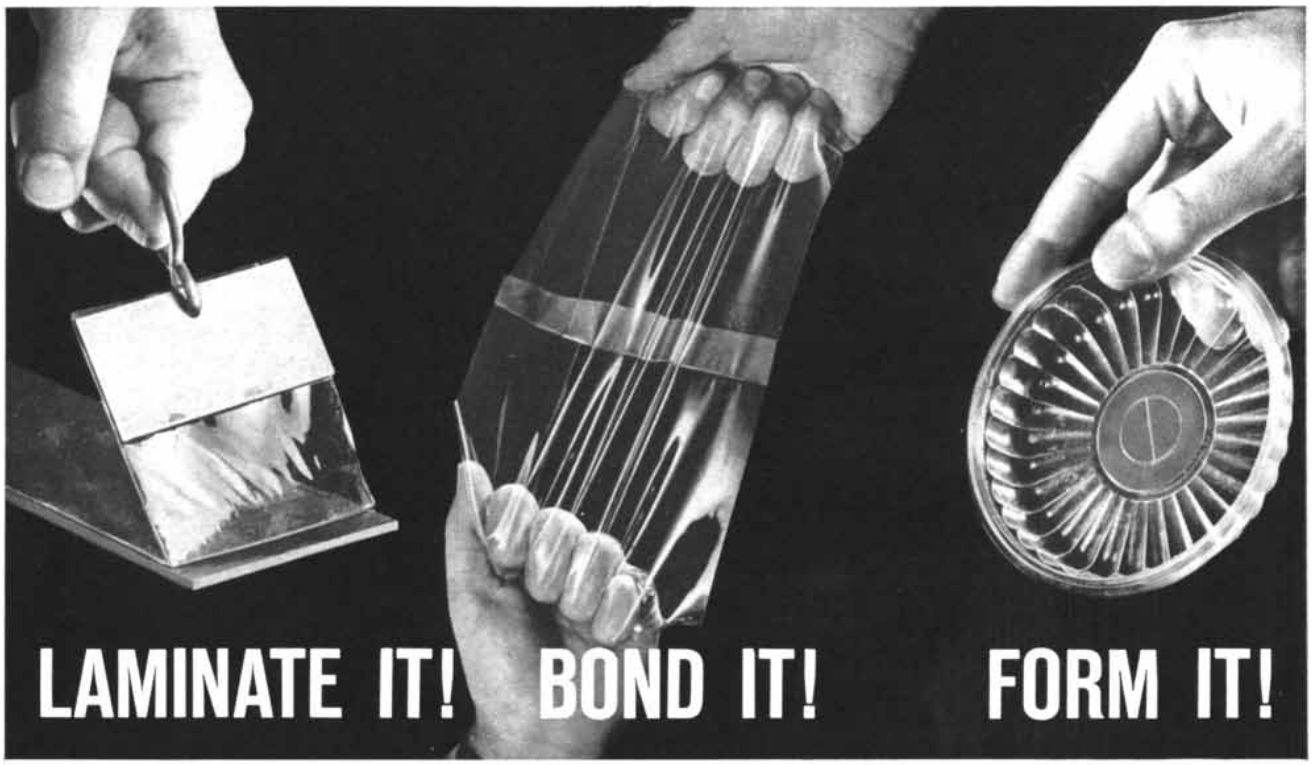

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been produced by a primary cosmic ray entering the atmosphere with an energy between 10 billion billion (10^{19}) and 100 billion billion (10^{20}) electron volts, says John Linsley, director of the station.

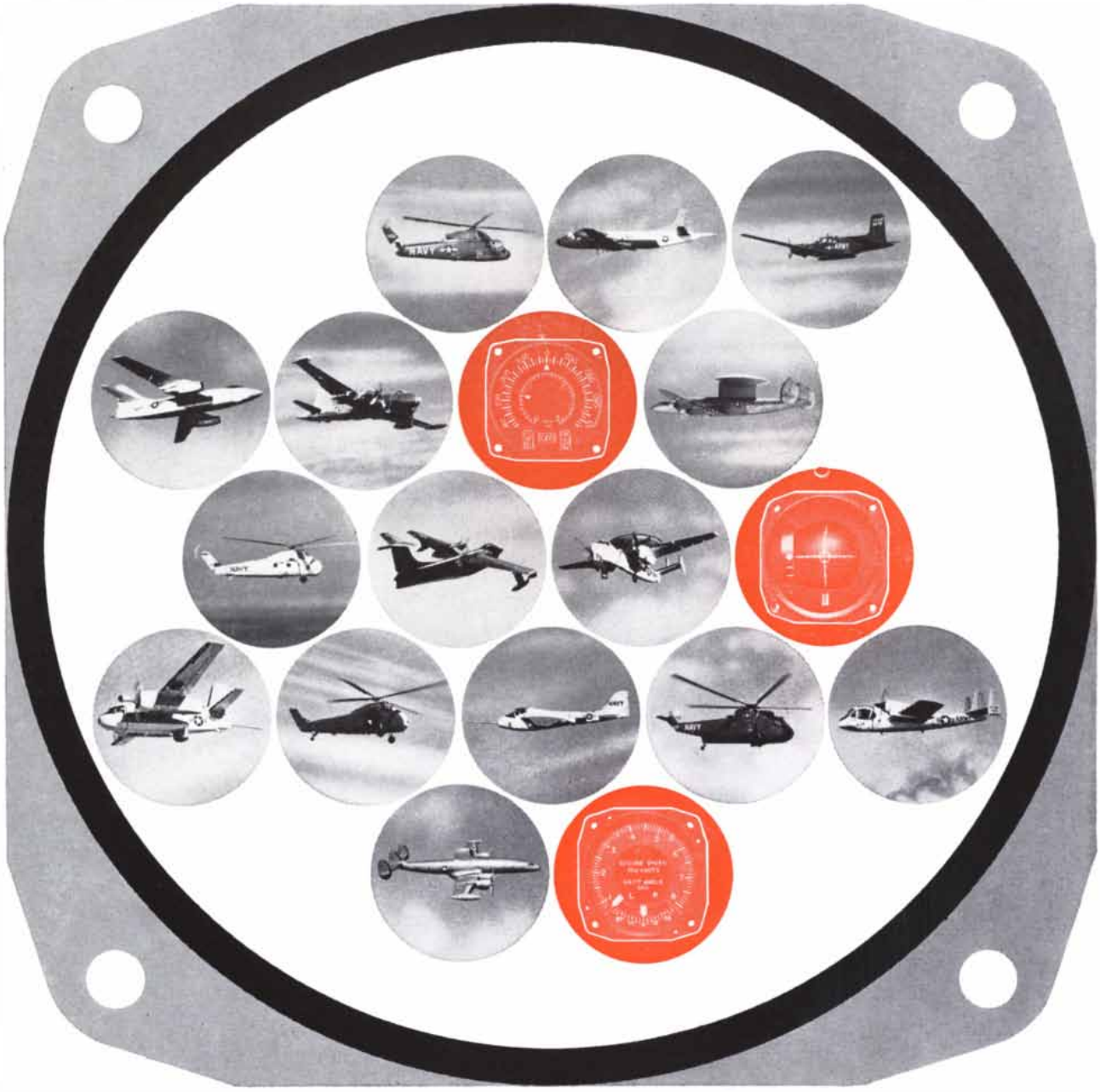
This shower represents the second known instance of a primary with energy above 10^{19} electron volts. The first one was recorded in December, 1959, also at Volcano Ranch. The second occurrence confirms the existence of cosmic rays in this energy range and supports the idea that they originate outside our galaxy. Current theories of the origin and acceleration of cosmic rays, and the current picture of the galaxy, can explain how a particle coming from somewhere within it could acquire an energy as high as 10^{19}. No mechanism conceivable at present, however, could give rise to particles of higher energy. Any particle arriving at the earth with greater energy must have started its journey somewhere outside the galaxy.

Snizard

The first living specimen of the Bornean earless monitor, an animal that bridges part of the evolutionary gap between lizards and snakes, has been found in Borneo. Four or five dead specimens had turned up in the 50 years since the first one was discovered, but the failure to encounter a live monitor convinced herpetologists that it was probably extinct.

Lanthanotus borneensis, to give the animal its Latin name, is among the closest living relatives of the mosasaurs, giant marine lizards that dominated the seas late in the age of dinosaurs 100 million years ago. Mosasaurs had skulls resembling those of living lizards but had the curved teeth and loose jaws of snakes. Both dinosaurs and mosasaurs died out in Cretaceous times. Small lizards descended from the mosasaurs successfully adapted to life on land; one group is thought to have evolved into modern snakes. No fossil remains have been found of lizards that look as if they had been about to enter snakedom, but zoologists suspect that these animals closely resembled *Lanthanotus*.

Essentially nothing is known of the character and habits of the Bornean earless monitor—not even if it is poisonous, like its cousin the Mexican beaded lizard, or the Gila monster. Authorities at the Sarawak Museum in Borneo are preoccupied merely with trying to keep it alive; it has refused to eat any of the fish fry, insects and worms offered it since capture.



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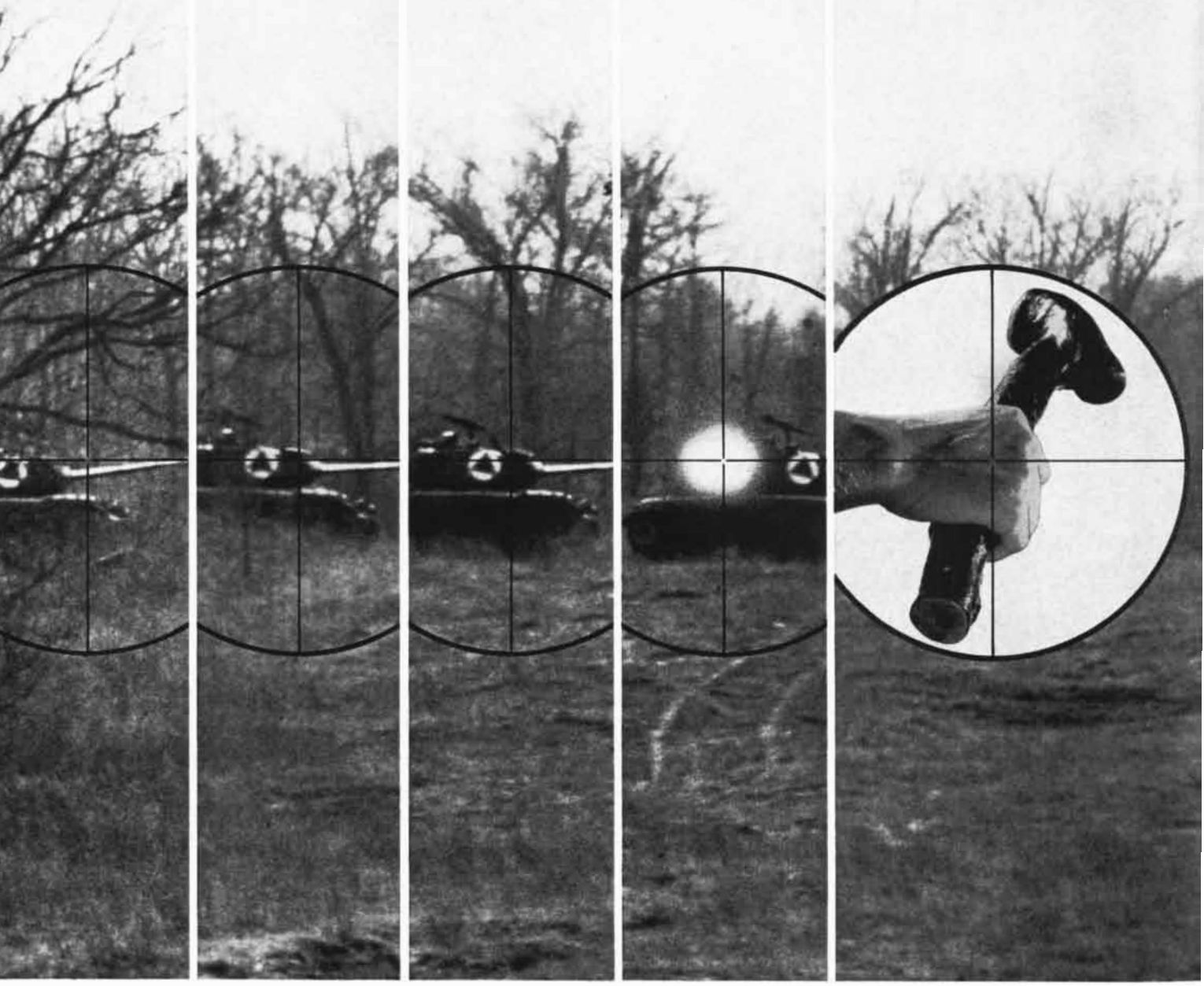

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WEATHER SATELLITES

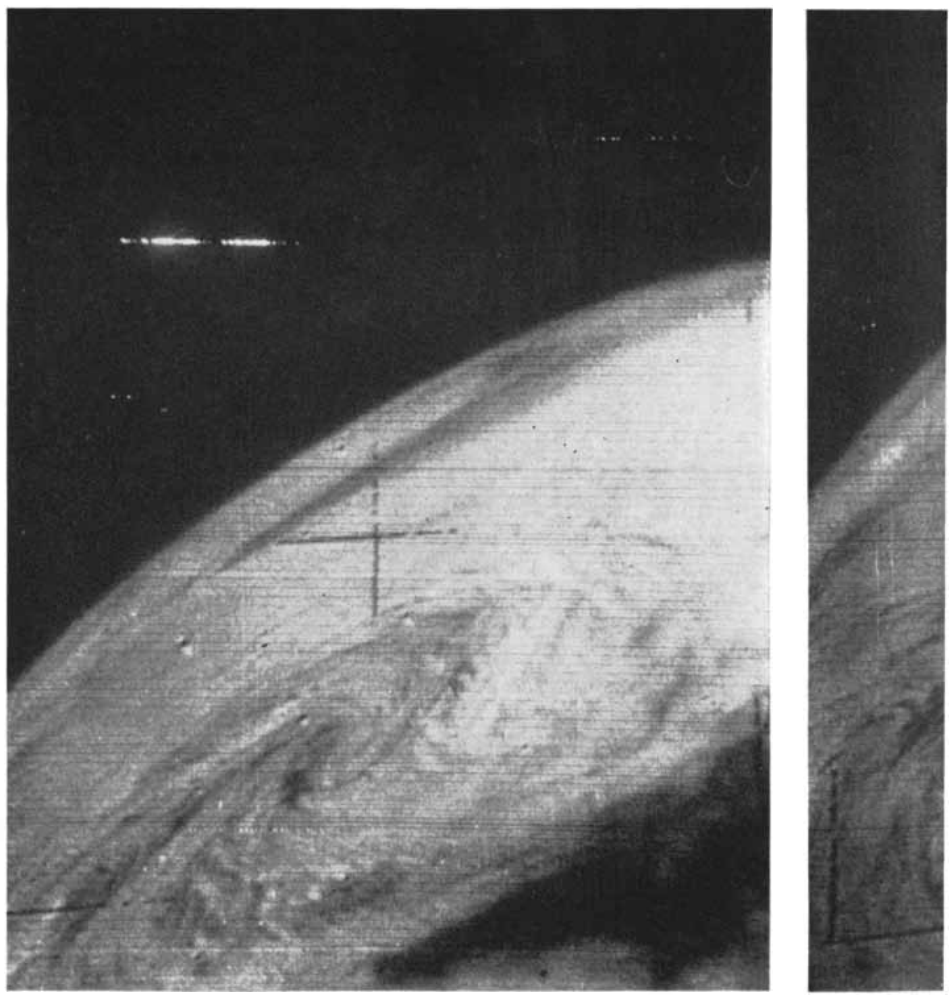
Tiros I and *Tiros II* have provided a broad view of the circulation of the atmosphere. Future satellites will gather even more useful information on this circulation and the earth's total heat budget

by Morris Neiburger and Harry Wexler

A little more than a year has passed since meteorologists saw for the first time the large-scale weather patterns they plot on their charts. The first view was provided by the weather satellite *Tiros I*, launched on April 1, 1960, which produced some 14,000 good pictures of the earth and its cloud cover during its 78 days of operation. *Tiros II*, launched last November, has returned about 24,000 useful pictures and is still operating as this article goes to press. In addition, *Tiros II* has been gathering—at the rate of some 2.5 million readings a day—the first comprehensive measurements of the visible and infrared radiation leaving the top of the earth's atmosphere. This radiation is made up partly of reflected sunlight and partly of infrared waves emitted by the earth's surface and the atmosphere.

How have these pictures and radiation measurements affected the science of meteorology and the practice of weather forecasting? Have they given rise to new concepts? Have they improved the accuracy of forecasts? This article will present some preliminary answers. The behavior of the atmosphere is so complex that it was not to be expected that a few months of satellite observation would suddenly clarify weather processes or lead to an immediate improvement in forecasts. Nevertheless, meteorologists who have been following the data received from *Tiros I* and *Tiros II* are convinced that weather satellites will have a revolutionary impact on their science.

Because of this conviction an enlarged series of weather satellites is being planned by the U. S. Weather Bureau in co-operation with the National Aeronautics and Space Administration. The series will include at least four more *Tiros* satellites, which utilize simple spin stabilization and are therefore said to be space-oriented; this means that their central axes tend to remain pointed in a fixed direction in space. The more advanced *Nimbus* series, to be placed in polar orbit, will be earth-oriented, meaning that they will keep their central axes pointed constantly toward the earth. The still more advanced *Aeros* series of weather satellites will circle the Equator at a distance of about 22,000 miles and at the same speed the earth is turning, thus permitting them to view the same area of the earth at all times. This series of space vehicles will cul-



INDIAN OCEAN CYCLONE, photographed by *Tiros I*, provides a majestic view of the vast expanses covered by ordinary weather processes. Not to be confused with a hurricane, which is much smaller and more violent, this storm has a diameter of almost 1,000 miles.

minate in a fully integrated system of weather satellites.

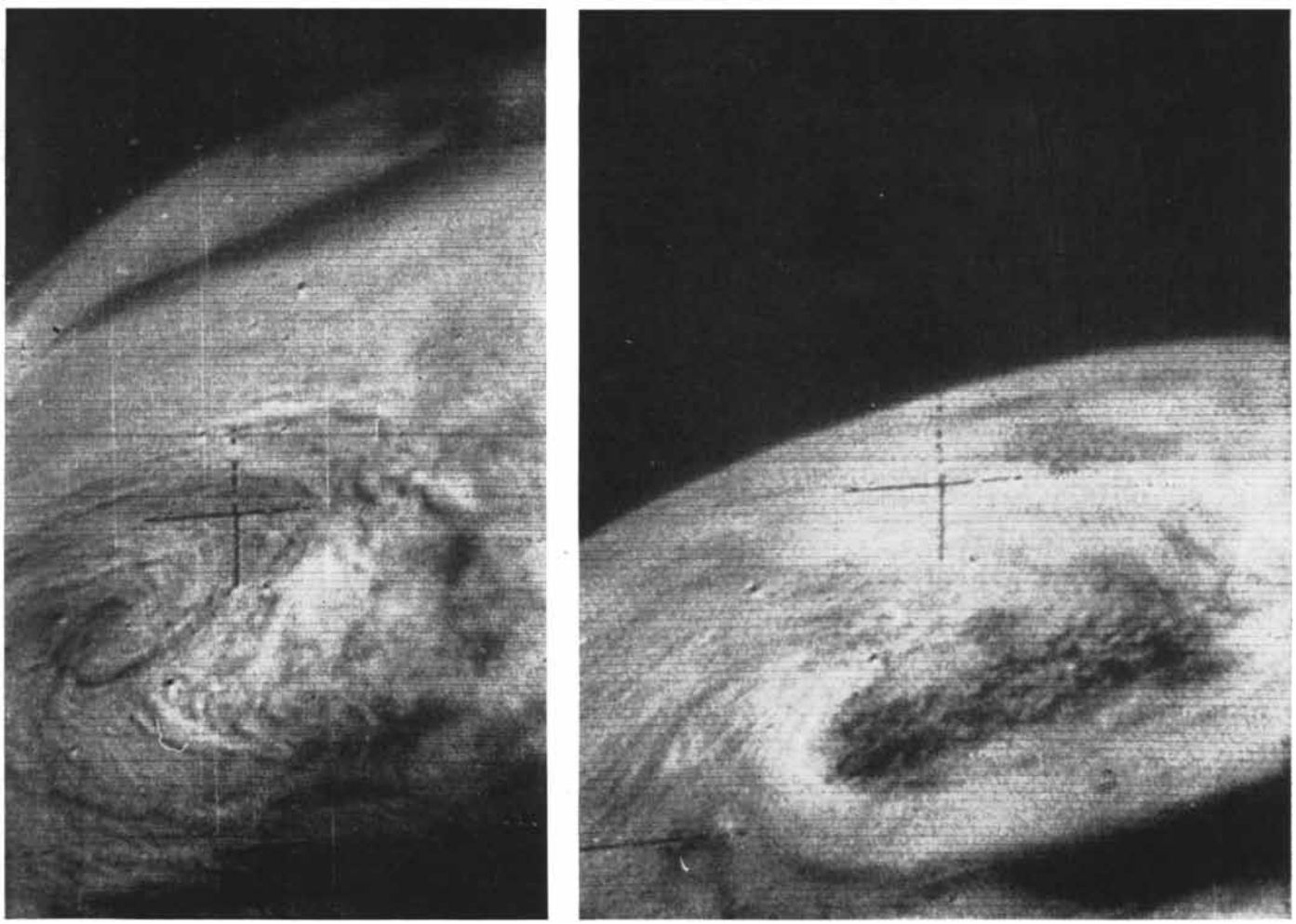
One can visualize an ideal weather service in which satellites automatically feed their global reports into electronic digital computers that process the data and produce weather forecasts without human intervention. One can look much further in time and imagine computer-controlled devices capable of modifying the predicted weather—if it is unfavorable—before it has a chance to develop.

A New View of Clouds

The most spectacular product of the first weather satellites has been the thousands of television pictures of clouds. Meteorologists were not sure in advance what could be learned from such pictures or how they could be used in weather forecasting. Each of the *Tiros* satellites carried aloft two cameras. One is provided with a wide-angle lens able to cover an area about 800 miles across if the lens is pointed straight down; the second camera has a narrow-angle lens covering an area 80 miles across. The resolving power of the wide-angle lens is about three miles; that of the narrow-angle lens, about .3 mile.

The first day's pictures from *Tiros I* disclosed two important features of the organization of cloud patterns, subsequently confirmed by many more examples. The first is that large-scale low-pressure areas, and their associated cyclonic wind patterns, are almost always accompanied by circular cloud patterns, up to 1,000 miles or more in diameter [*see illustrations on these two pages*]. These cloud patterns have a banded structure reminiscent of the smaller (and much more rapidly rotating) cloud patterns that occur in hurricanes. The second important type of pattern revealed by *Tiros I*, perhaps more surprising than the first, consists of an extensive area populated by many crescent-shaped or doughnut-shaped cloud cells, each some 30 to 50 miles in diameter [*see illustrations on page 83*]. The cells are too large to be seen whole from the ground and too small to be revealed by the widely spaced data that are plotted on conventional weather charts. Apparently the cloud cells are associated with large convection currents, which probably play an important role in transferring heat, water vapor and momentum from the ground and the ocean to the lower layers of the atmosphere.

The pictures from *Tiros I* show a number of other interesting features: spiral cloud bands of a tropical cyclone (the term used in the South Pacific for a hurricane or typhoon) north of new Zealand; cirrus streamers associated with a jet stream over the southern Andes; double-vortex clouds in cyclones that apparently have only one low-pressure center; cumulus-cloud "streets" (long parallel rows of puffy clouds) in the tropics; a single long, thin cloud about five miles wide and several hundred miles long (perhaps an airplane-con-



The first view (*left*) was taken April 30, 1960, on the satellite's 416th orbit of the earth; the next view (*middle*) was taken on the next pass, about 100 minutes later; the third view (*right*) was taken on the 429th pass, the next day. The photographs were made from an altitude of about 450 miles with the satellite's wide-angle television camera, which was pointed west-southwest.

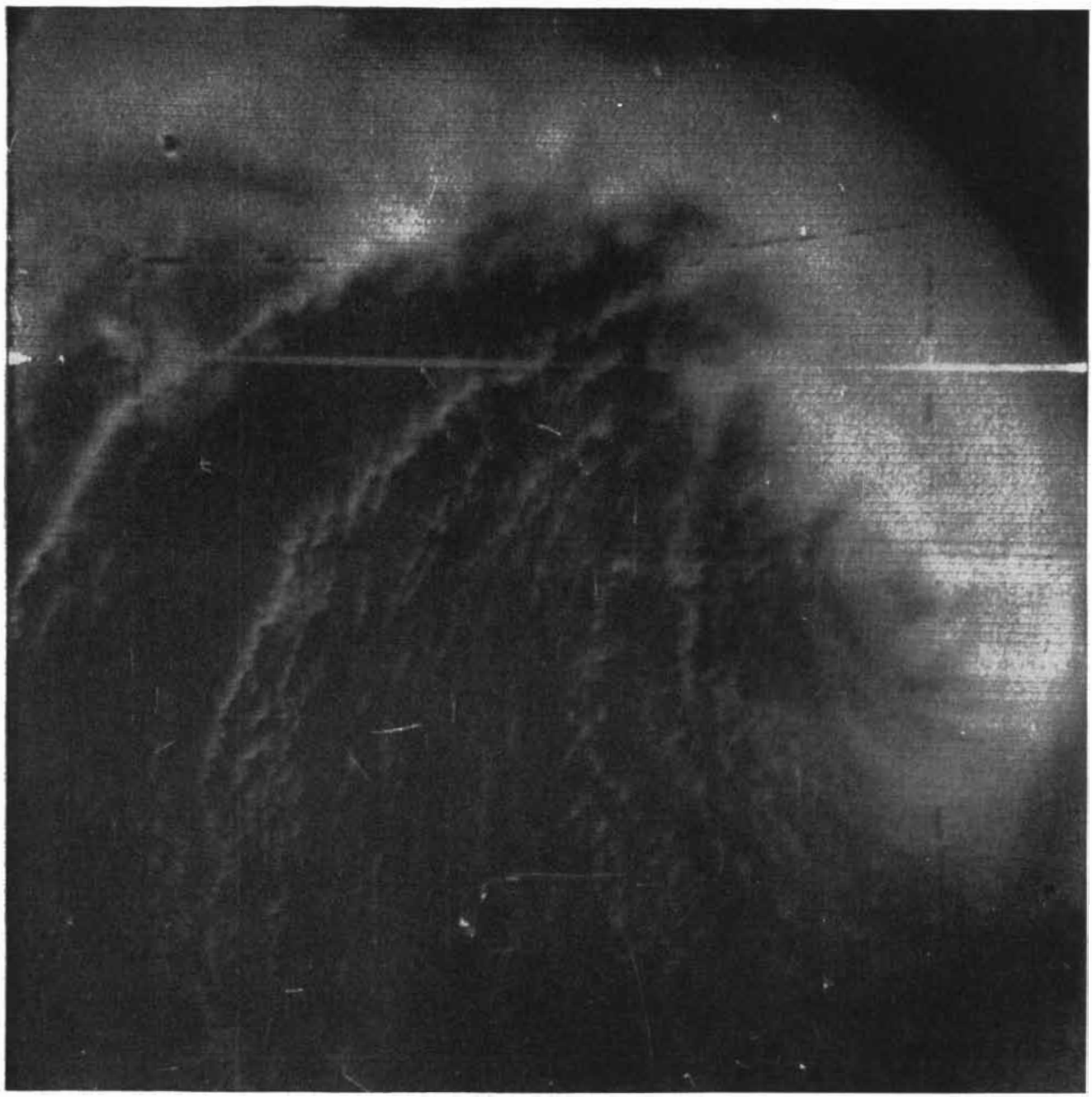
densation trail) east of Florida; a long, thin cloudless streak embedded in an otherwise unbroken cloud deck near Madagascar. The satellite picture of an isolated "square" (actually rhombic) cloud about 100 miles across raises the possibility that tornado-producing clouds may be distinguished from hundreds of ordinary thunderstorm-cloud formations [*see illustrations on pages 88 and 89*]. The pictures also show features of the earth's surface; for example, bright sand and darker rock areas in the North African deserts, a broken pattern of sea ice in the Gulf of St. Lawrence, snow fields in the Alps and in the Himalayas, and the sparkling reflection of the sun on water surfaces.

The *Tiros* pictures have been most immediately useful to weather forecasters in providing information in regions from which data is otherwise unavailable. For instance, there are areas of the Pacific larger than the U. S. in which no routine weather observations are made. Even where routine observations can be had the satellite pictures often reveal large-scale patterns that cannot be observed either from the ground or from aircraft.

Using data received from *Tiros II*, the National Meteorological Center in Suitland, Md., has been preparing "nephanalyses," which are graphic analyses of cloud distributions observed between 55 degrees North latitude and 55 degrees South. These analyses have been transmitted over the regular weather facsimile channels in time for use by forecasters in the U. S. and in several foreign countries.

Radiation Input and Output

Whereas the output of a camera is fascinating and almost immediately readable and applicable, it may not in the long run yield as much basic knowl-

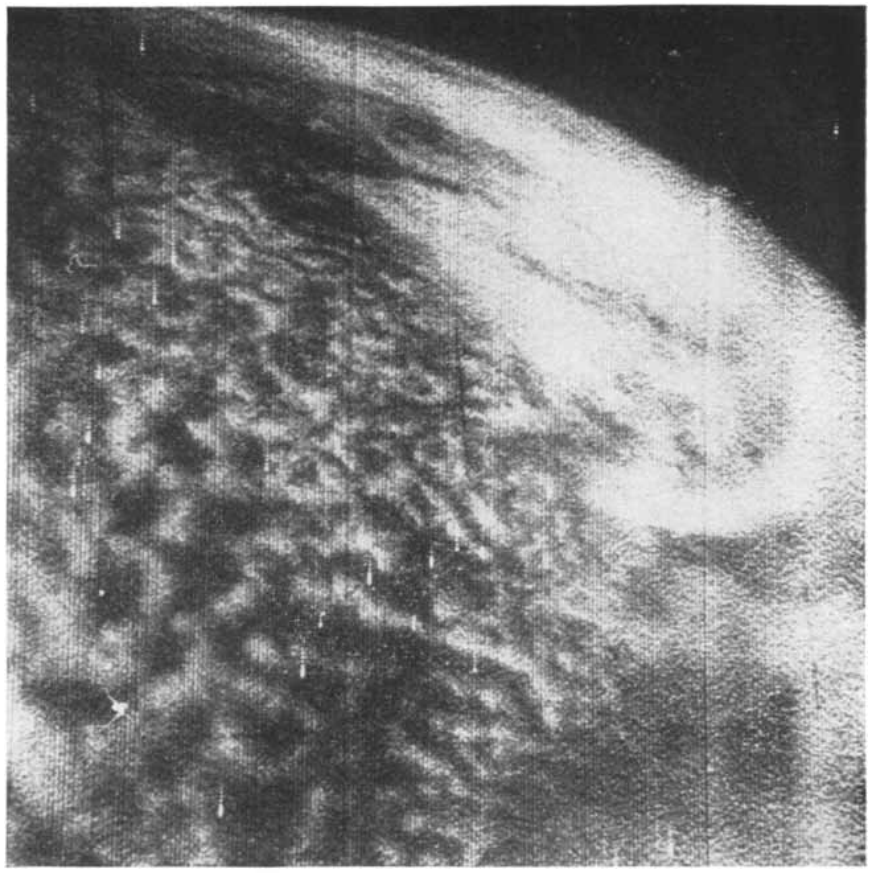


HURRICANE IN THE SOUTH PACIFIC was photographed by *Tiros I* on its 10th day in orbit: April 10, 1960. The big storm (commonly called a tropical cyclone when in the South Pacific) was 300 miles north of New Zealand. View is to the southwest.

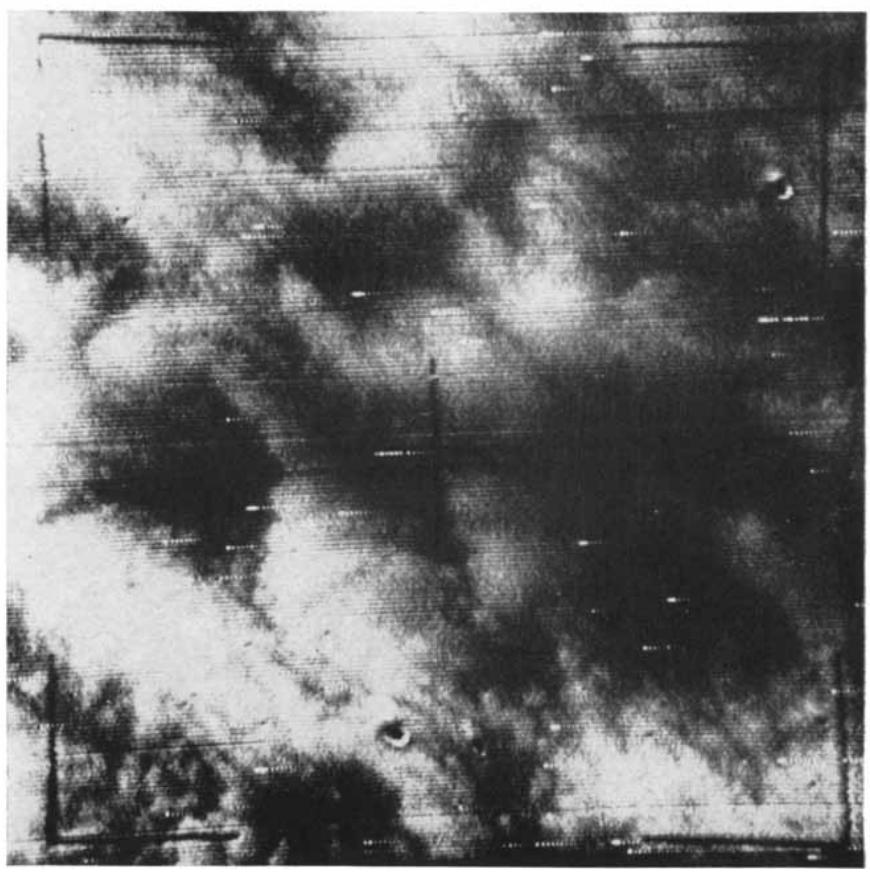
edge as many other instruments that a weather satellite can carry. A satellite can "look" down at the atmosphere in many ways; it can also "look" up, which may be just as important. With instruments pointed outward, toward the sun, satellites can for the first time measure continuously the amount and kinds of energy flowing from the sun to the earth's atmosphere.

The atmosphere is the thermodynamic fluid of an engine that ultimately derives practically all its energy from the sun. The response is by no means as immediate and direct as the response of an automobile engine to the change in fuel supply when the throttle is varied, yet it is clear that variations in solar energy must have some influence on the weather. How much influence—is the effect amplified or is it damped?—has not been determined in spite of years of investigation. The question has remained unresolved largely because no one has known exactly how much the input of solar energy varies in amount and character. The magnitude of these variations can now be established by satellites, which will be able to monitor the sun's electromagnetic radiation at various wavelengths and also the sun's corpuscular, or plasma, emissions. The best current estimates are that the total variation of solar electromagnetic radiation is less than .3 per cent; but it has been suggested that corpuscular emissions (chiefly barrages of high-energy protons) may at times augment the energy the earth normally receives from the sun by as much as 10 per cent in the latitudes where auroras most frequently occur. Although the corpuscular emissions are absorbed high in the atmosphere (almost always higher than 35 miles), it is conceivable that their indirect influence could subsequently be felt at lower levels. Tracing and testing possible influences would be much aided by a continuous record of the intensity of the emissions leaving the sun and reaching the outer limit of the atmosphere. If it is established that variations large enough to influence the lower atmosphere do occur, if the nature and consequences of this influence can be clearly understood and if there is sufficient time lag between the solar "cause" and the atmospheric "effect," the observation of solar energy of various kinds from space vehicles would give meteorologists an important new key to forecasting.

Even if the sun's output of energy were absolutely constant, this would not mean that the earth and its atmosphere absorb the incoming energy at a constant rate; a variable and unknown fraction of

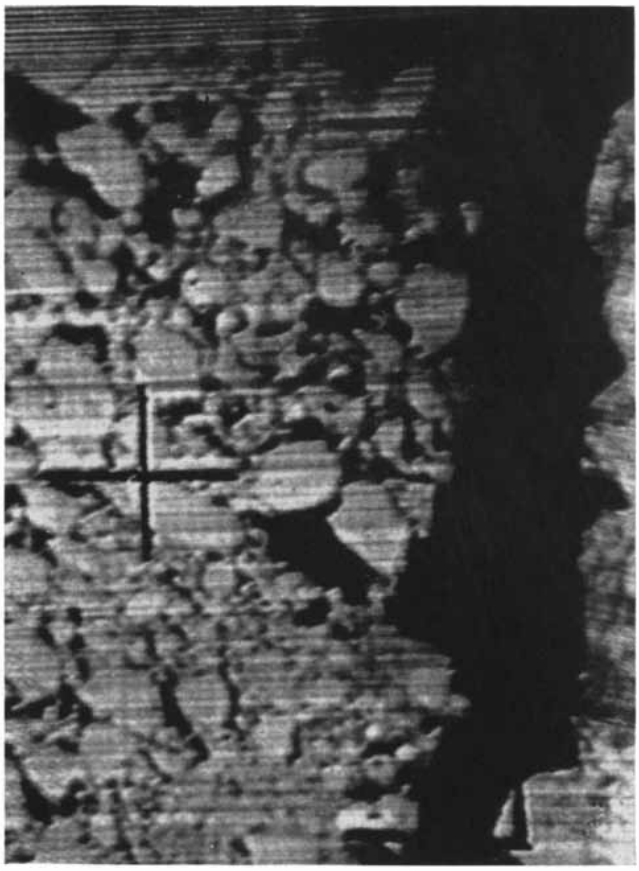


CLOUDS FORMED BY CONVECTION CELLS were photographed northeast of Bermuda by *Tiros I* on April 4, 1960. The individual crescent-shaped clouds are about 50 miles across.

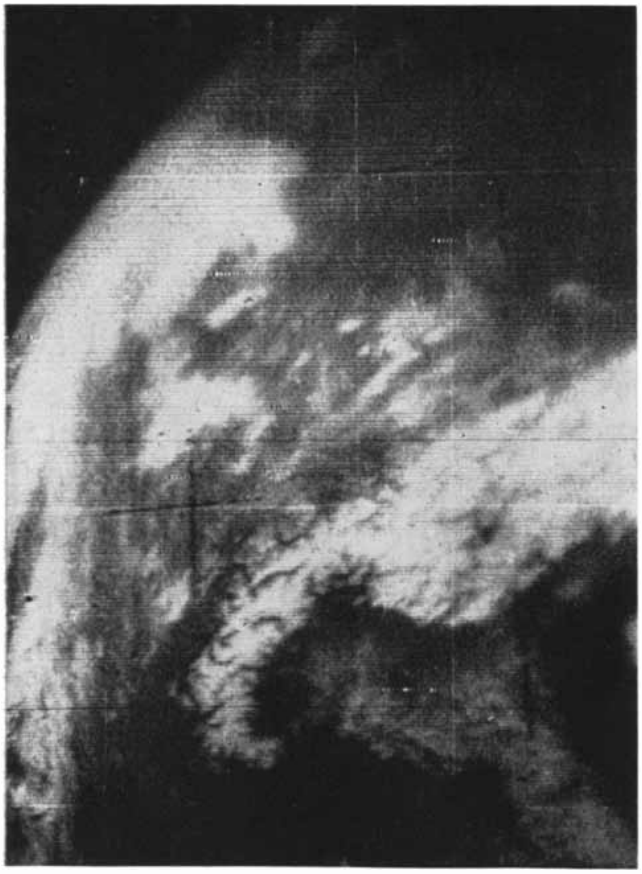


CLOSE-UP OF CELL CLOUDS was made with the narrow-angle camera at the same time as the wide-angle view at the top of page. The cloud pattern was new to meteorologists.

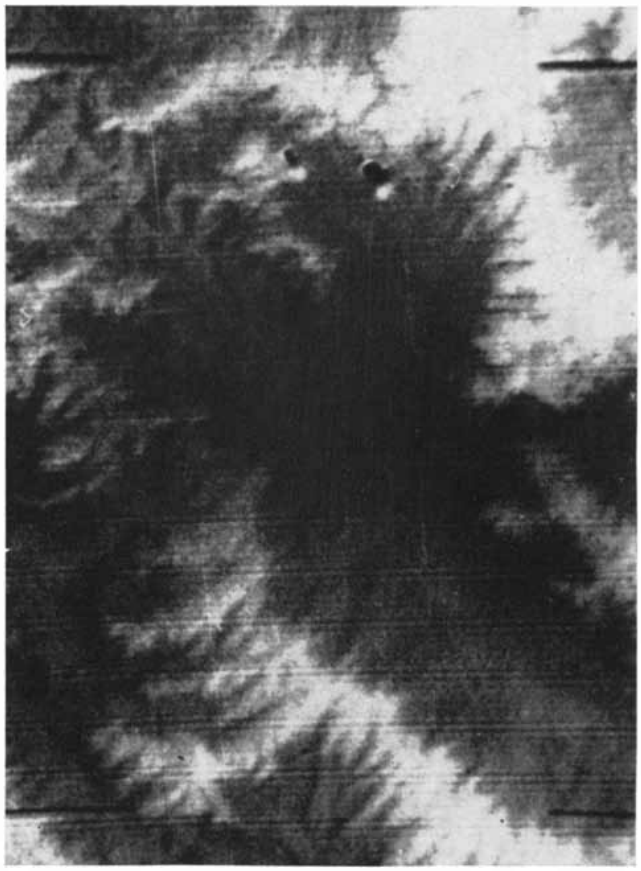
JET-STREAM CLOUDS, associated with high, fast-moving winds, were photographed over the Red Sea by *Tiros I* on April 4, 1960.



FIELD OF ICE FLOES extending to the edge of Newfoundland (*far right*) was photographed by *Tiros II* on March 23, 1961.



SNOW-COVERED ALPS, with the Italian peninsula projecting toward southeast, was photographed by *Tiros I* on April 2, 1960.

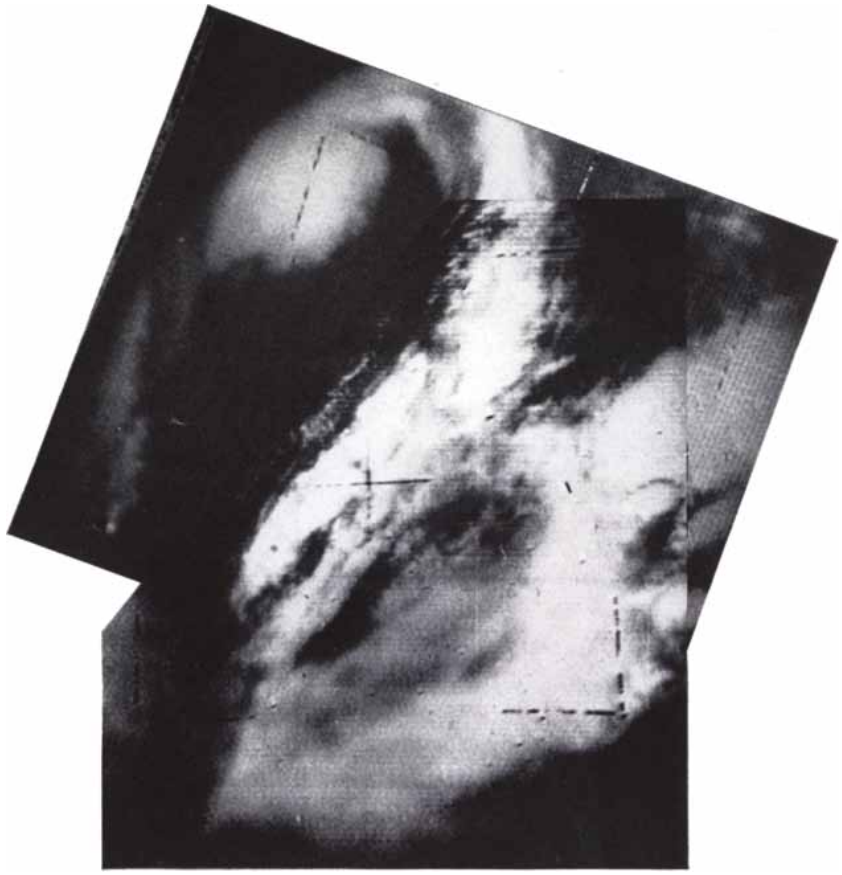


SNOW-COVERED HIMALAYAS appear in narrow-angle picture about 80 miles from top to bottom, made by *Tiros I* on May 13, 1960.

the arriving energy is reflected by the earth's surface (particularly the areas covered with snow), by clouds and by the dust and haze in the air. For example, the amount of solar energy reflected back into space by clouds depends both on the amount of the earth's surface blanketed and on the particular reflectivity of the clouds present. If we assume an average cloud reflectivity of 70 per cent, it is evident that a change of 5 per cent in the fraction of the earth's surface covered by clouds would produce a change of 3.5 per cent in the energy available to drive the atmospheric circulation. This, in turn, would be 10 times the present estimated maximum variation in the sun's output, and the variation would be entirely in that portion of the energy which penetrates to the lower layers of the atmosphere. Variations due to changes in the area covered by snow, and in the reflectivity of the snow (due to aging), may be of similar magnitude. Measurements from satellites of the radiation reflected back from the earth to space would thus provide valuable information concerning the energetics of the atmosphere.

Another variable in the energy budget of the atmosphere is the amount of infrared radiation leaving the earth and the atmosphere. Infrared waves are emitted by any body that is not at absolute zero; the warmer the body, the more infrared energy it radiates. Part of the infrared radiation emitted by the earth's surface and by clouds is absorbed by the water vapor, carbon dioxide and ozone in the atmosphere; these gases in turn radiate according to their own temperatures and at their own characteristic wavelengths. The net radiation flowing from the atmosphere into space depends, therefore, not only on the distribution of the temperature of the earth's surface and at the tops of clouds but also on the distribution of temperature, water vapor, carbon dioxide and ozone throughout the atmosphere. To estimate by conventional methods the energy lost to space would require a large program of observations, which at their best would not be very accurate; from a satellite such a measurement would be accurate as well as fairly simple.

In order to measure instantaneously the total output of both visible and infrared radiation from the entire earth, it would be desirable to have two satellites very high up, say 200,000 miles—one might be a station on the moon and the other could be on the opposite side of the earth. To measure the pattern of outgoing energy in detail, a number of satellites orbiting in the region between 300



LARGE CYCLONIC STORM was photographed over central U. S. with the wide-angle camera of *Tiros I* at 2:28 p.m. Central Standard Time of its first day in orbit: April 1, 1960. The satellite was over the Gulf of Mexico about 100 miles south of New Orleans; its cameras were aimed to the northwest. Southern edge of the round cloud (*top*) is over Oklahoma.

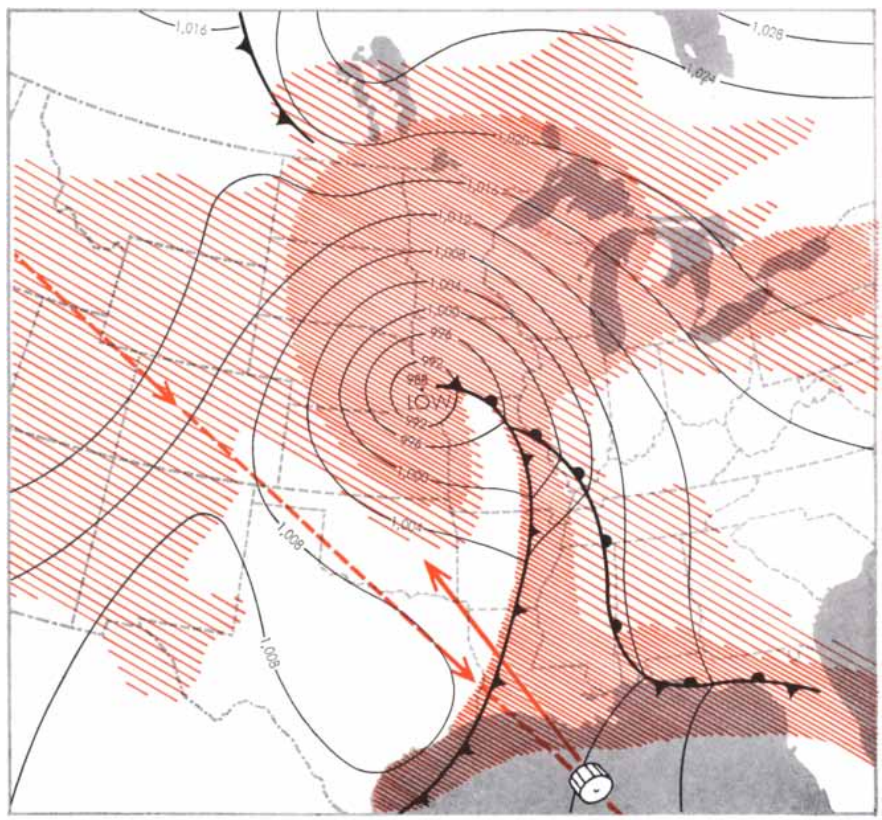
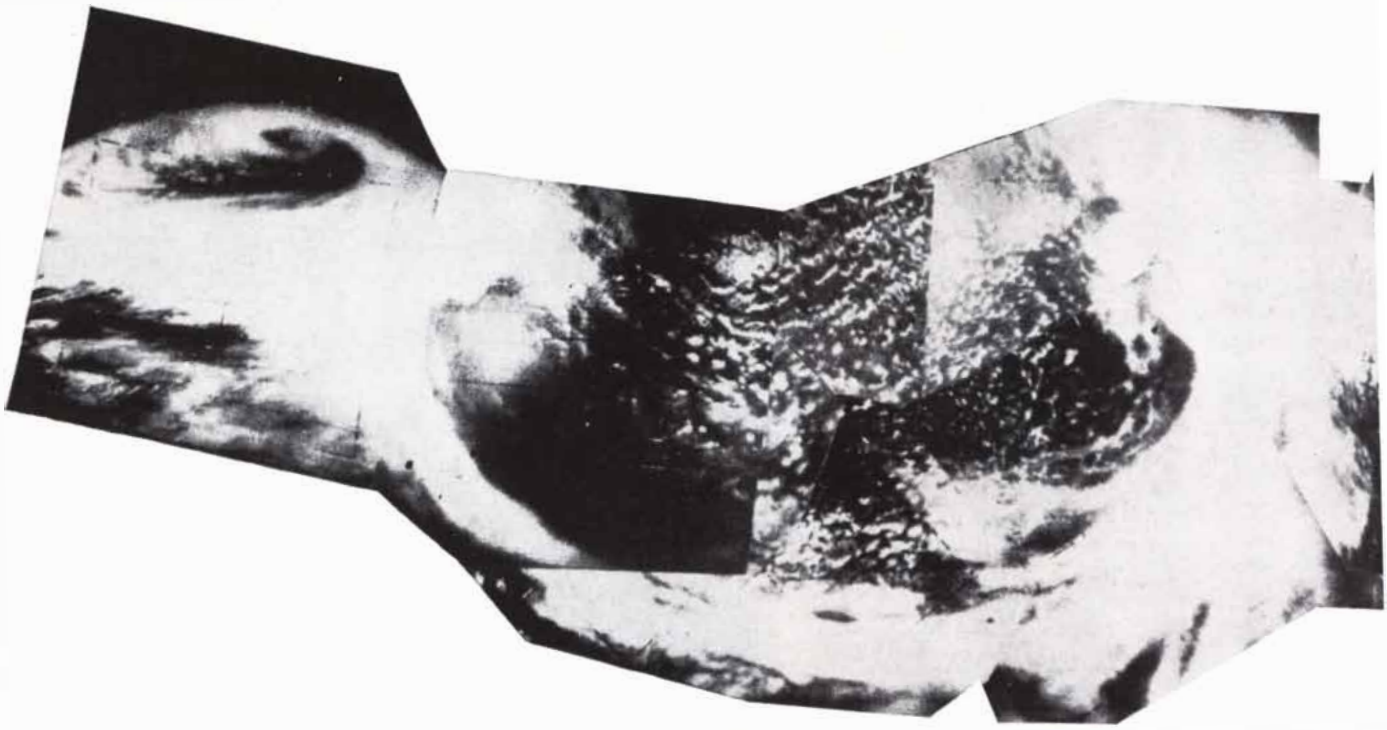


CHART OF CYCLONIC STORM, plotted from conventional meteorological readings taken on the afternoon of April 1, correlates well with the satellite pictures (*top of page*).



FAMILY OF STORM CLOUDS was photographed over the North Pacific, Canada and northwestern U. S. by *Tiros I* on May 20, 1960. The long-range connection between cloud systems emerged vividly when individual pictures were assembled in a montage. The clouds

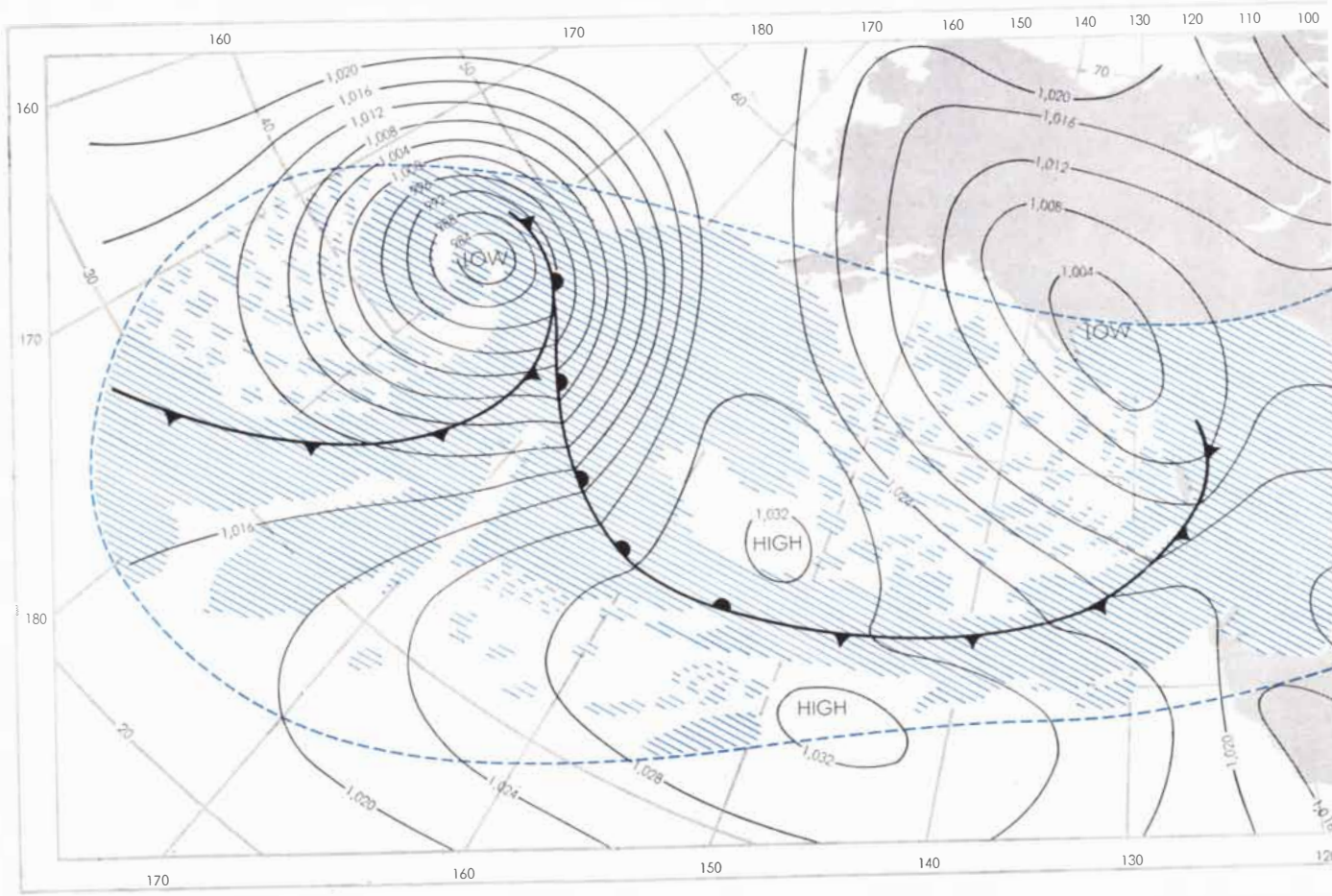
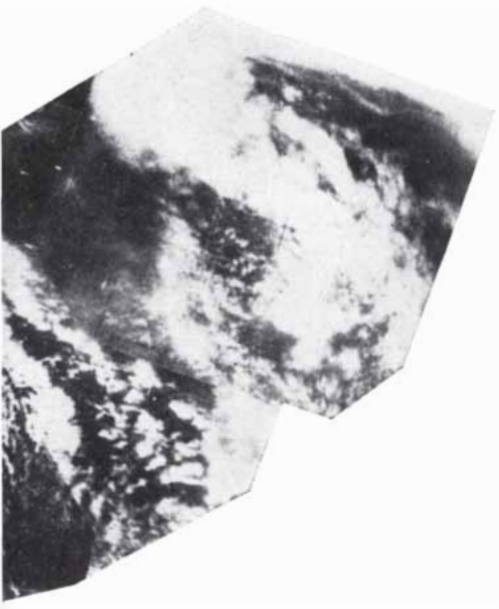
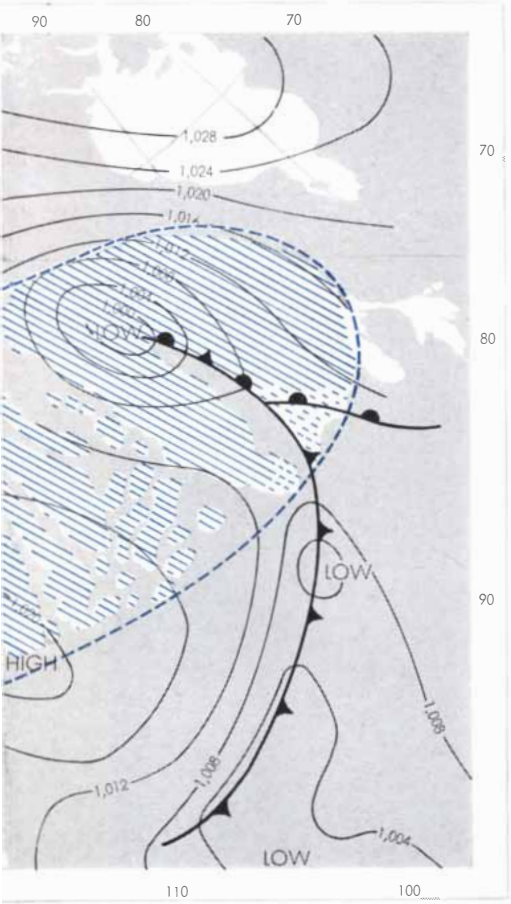


CHART OF PACIFIC STORM SYSTEM was made from standard meteorological readings covering the same period as that represented in the *Tiros I* photographs at the top of the page. The cloud patterns tend to follow the weather-front systems as they are conventionally plotted by meteorologists. The symbols on the black line at far left leading into the low-pressure area denote a cold



trace out in dramatic fashion the large-scale processes and motions of the atmosphere.



front. The symbols then change to indicate a warm front and finally revert to indicate a cold front reaching to U. S. coast.

and 3,000 miles would be best. The detailed measurements would identify places where energy outflow exceeds inflow and vice versa. Daily determination of this distribution of energy sources and sinks would enter into the computation of the atmospheric circulation, which must, after all, transfer energy from the places where it has accumulated to places where it is lost.

Preliminary measurements of the radiation budget of the earth and atmosphere were made by *Explorer VII* (1959 Iota), which was launched in October, 1959, as part of the program of the International Geophysical Year. This satellite was equipped with six elements for sensing radiation: three measured total energy at all wavelengths from various directions, one measured long-wave (infrared) radiation and two measured short-wave (solar) radiation [*see top illustration on page 90*].

More refined infrared measurements are being obtained by *Tiros II*. It carries a radiometer containing a cluster of five sensors, the optical axes of which are inclined 45 degrees to the spin axis of the satellite. Each sensor has a 5-degree field of view, covering an area of about 30 by 30 miles; the spin and movement of *Tiros II* along its orbit provide the scanning motion. The sensors respond to the following bands of wavelengths: (1) .2 to 5 microns, a broad band that measures the energy of reflected solar radiation; (2) .55 to .75 microns, a narrow band in the visible region that provides data that can be correlated with television images; (3) 8 to 12 microns, a band indicating the approximate temperature of either the earth's surface or the tops of clouds, whichever happens to be beneath the satellite; (4) 7 to 30 microns, a very broad band bracketing most of the terrestrial infrared radiation; and (5) 5.6 to 7 microns, a narrow water-vapor emission band that provides the average temperature of the highest layer of the atmosphere in which there is an appreciable amount of water vapor.

By April 1, 1961, more than 1,000 100-minute orbits of radiation data had been obtained from *Tiros II*. It will be mid-July before the data have been reduced and somewhat longer before they have been completely analyzed. In general, the surface temperatures that can be inferred from radiation measurements made at the band between 8 and 12 microns fall somewhat below temperatures recorded on the ground, but they seem to correlate well with the surface temperature and cloud patterns observed by other means [*see bottom illustration on page 90*].

Tiros II also carries a second radiometer designed to provide gross heat patterns over an area within the field of view of the wide-angle television camera. In this radiometer one detector coated white reflects most of the visible radiation but absorbs a broad spectrum of infrared energy. A second detector coated black absorbs both visible and invisible radiation. Readings from the two provide differential measurements needed to compute temperatures. Although the computed temperatures are lower than expected, they are in general agreement with the patterns seen on surface weather maps.

Weather satellites now being built or designed should be able to provide much other useful information. For example, the distribution of clouds at night, which shows up only in the infrared measurements of *Tiros II*, could be detected directly by ultrasensitive television cameras (operating on moon- or starlight) as well as by radar. Satellites equipped with radar could do a variety of jobs, depending on the wavelength of the signal. Some wavelengths would be reflected from the tops of clouds, providing a measure of cloud height; others would penetrate the clouds and be reflected back from raindrops or snowflakes, providing the vertical distribution of precipitating layers. Radar could also detect the "bright-band" echo caused by the melting of falling snowflakes and could thereby locate the height of the 32-degree-Fahrenheit isotherm wherever suitable conditions exist. Thunderstorms could be detected without radar simply by television observations of the lightning strokes themselves or by radio detection of their static discharges.

Advanced versions of *Nimbus*, the polar-orbiting, downward-looking weather satellite, will carry a special infrared spectrometer to measure radiation at wavelengths around 15 microns, where carbon dioxide has a strong absorption band. Precise measurements of this band should provide average temperatures, as well as temperature gradients, of the atmosphere wherever it is free from clouds. Later generations of satellites may be able to measure accurately the amount of water vapor, carbon dioxide and ozone in the atmosphere.

Precise information about barometric pressure and wind, both crucial in present methods of weather forecasting, are the hardest to obtain from vehicles outside the atmosphere. Even so, the problem is not hopeless. Clouds themselves may yield information about the wind and its vertical and horizontal gradients

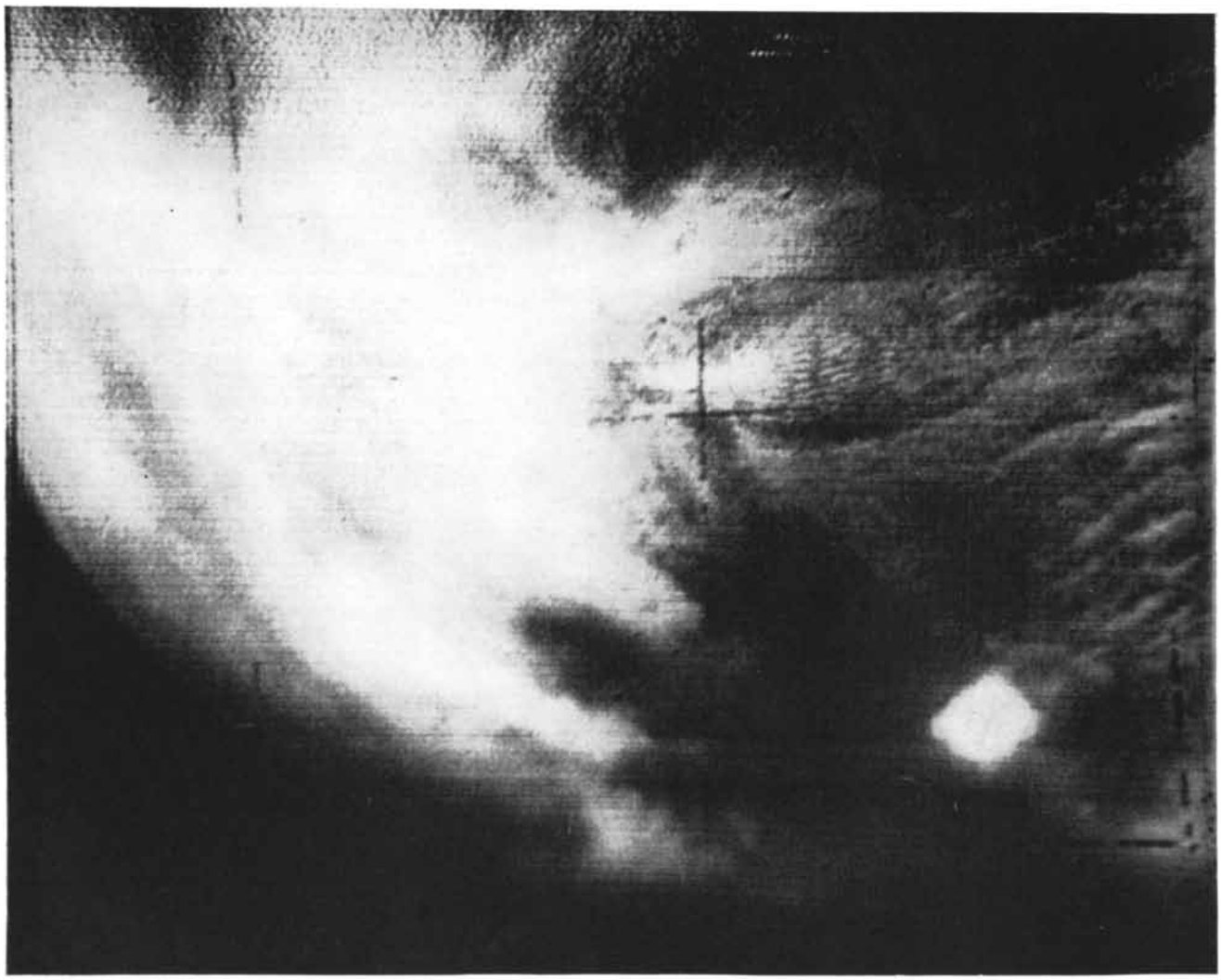
as our ability to interpret their patterns is increased. More accurate wind velocities and trajectories could be obtained by tracking hundreds of balloons set to float at predetermined heights. No one, however, has yet suggested a feasible method of determining barometric pressure from a satellite that would achieve the minimum desired accuracy of a few parts in a thousand.

No doubt with time new techniques will be developed for getting from satellites more complete and more precise measurements of the various quantities that are needed for weather forecasting. For the present it appears that the data from weather satellites will for the most part supplement observations made from the ground by filling in gaps in places where observations are not now available, by giving over-all patterns and details that elude even the densest ground networks and by providing important information about regional and over-all energy budgets of the atmosphere.

Techniques of Forecasting

Let us now look a little more closely at present weather forecasting procedures. These procedures are based on the assumption that future weather developments depend on the past and present behavior of the atmosphere. Over the past decade great advances have been made in numerical methods of forecasting, which have been made feasible by modern computers. In the numerical methods the motions of the air, as represented by the distribution of pressure at various levels, are inserted into mathematical equations that the computer solves to predict future patterns of wind and pressure. Formerly forecasters predicted the movement of the air and the development of pressure systems in part on the basis of past experience and in part by a crude qualitative application of the theory on which the mathematical equations are based. In both machine and nonmachine methods the atmosphere is treated as a self-contained, determinate system, in which the only disturbance from outside is the interaction of the atmosphere with the earth's surface.

At present weather forecasts are a composite of the results of the subjective procedures and the numerical methods using machines. The machine computations yield charts of the large-scale distribution of pressure and wind, which are used by the forecaster as a basis for his detailed prognosis. The detailed fore-

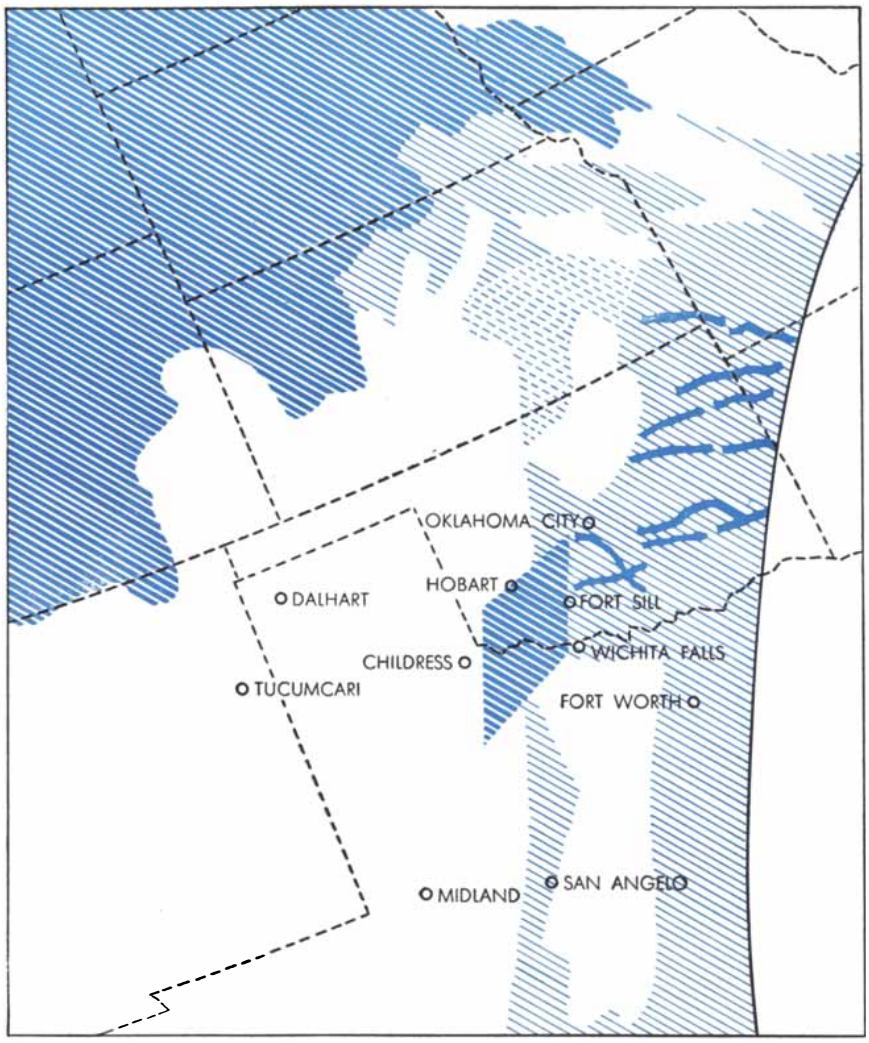


ISOLATED "SQUARE" CLOUD, about 100 miles across, turned up in a photograph of the southwestern U. S. taken by *Tiros I* at 2:00 p.m. C.S.T. on May 19, 1960. A rectified map of the picture shows the cloud to be rhombic (*right*). Two hours after the picture was taken five tornadoes struck between Fort Sill and Oklahoma City, a region northeast of the cloud. The cloud appears to be an

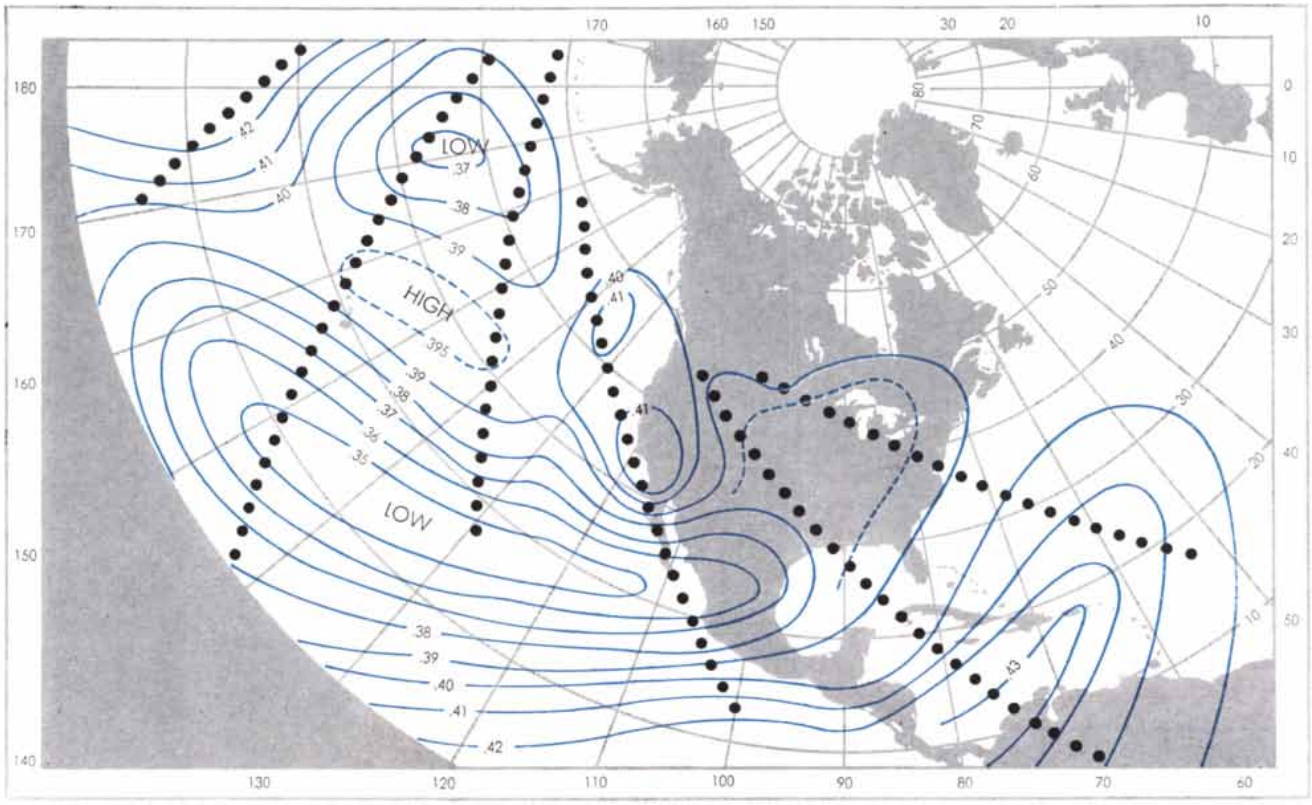
casts of temperature changes, clouds and precipitation come from his interpretation, by application of physical reasoning and previous experience, of the predicted pressure and wind patterns.

The first step in incorporating information from satellites will involve the interpretation of cloud data subjectively in terms of pressure and wind distribution, which then can be used in the conventional manner. Thus satellite pictures of the cloud system associated with a hurricane will enable the forecaster to estimate what stage a storm has reached in its development and the approximate speed and direction of the winds in various parts of it. These estimates, in turn, will help the forecaster predict the hurricane's speed and direction of travel. Similarly, the cloud patterns associated with fronts, with the cyclonic storms of high latitudes and with air masses of various sorts will help the forecaster to fill in the areas on his weather maps where data is otherwise unavailable. He can thereby learn of weather systems that may move into his forecast area or influence the behavior of those which actually move into it.

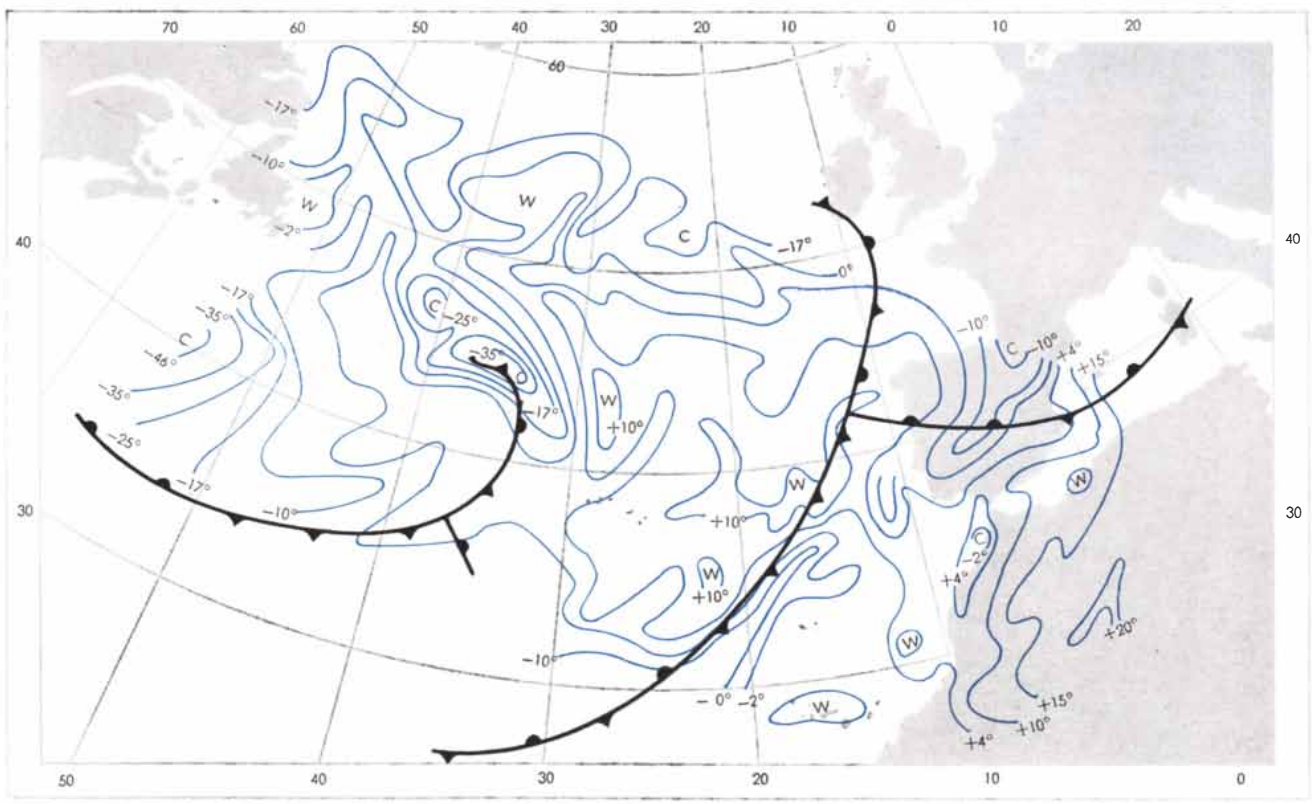
In the case of the numerical method any information at all—even intelligent guesses—over the areas where there are at present no observations will lead to considerable improvement in the forecasts; the prognostic equations are quite sensitive, and the forecast at any one



amalgamation of several "anvil-topped" cumulonimbus (thunderstorm) clouds in which tornadoes could have been embedded. On other occasions *Tiros I* photographed large isolated clouds, 100 to 200 miles across, that were associated with severe thunderstorms or tornadoes.



INFRARED RADIATION LOSS from the atmosphere and earth's surface was measured over the North Pacific and North America by *Explorer VII* in a series of passes (*dotted lines*) on December 2, 1959. The figures represent the heat loss in calories per square centimeter per minute, providing a clue to temperatures. Tops of clouds radiate less heat than warmer earth below.



APPROXIMATE TEMPERATURES, in degrees centigrade, were computed from radiation measurements made by *Tiros II* on November 25, 1960. The temperatures are for the earth's surface in cloudless areas and for cloud tops in areas of dense overcast. Such an overcast is indicated by cold regions (*C*) in western and middle Atlantic. Weather-front symbols are superimposed on the isotherms.

point is affected to some extent by the pressure distribution everywhere else.

At first the interpretation of satellite data will have to be subjective, but we can expect that methods will be quickly developed to carry out the process automatically by machine. A crude method might be to store in the memory of a suitable machine a library of cloud systems photographed by satellites and of the associated pressure distributions obtained by conventional means. As new satellite pictures are received, the machine would search out the cloud systems on file that resemble the new ones most closely and then fit the corresponding pressure distribution as well as possible into the distribution determined for other areas by actual observations of pressure. Still more refined methods are being developed in which the machine would use dynamical equations to seek out the horizontal wind field needed to produce the vertical velocities that must be present to produce the observed clouds.

The temperature data obtained from radiation measurements would give the subjective forecaster information about air-mass properties, which he could apply in forecasting temperature changes, pressure patterns, the probability of showers and the like. As the machine-forecasting methods become more sophisticated, temperature will play a more important role, and the availability of temperature data from areas where it would otherwise be unknown will also do much to raise the accuracy of forecasts.

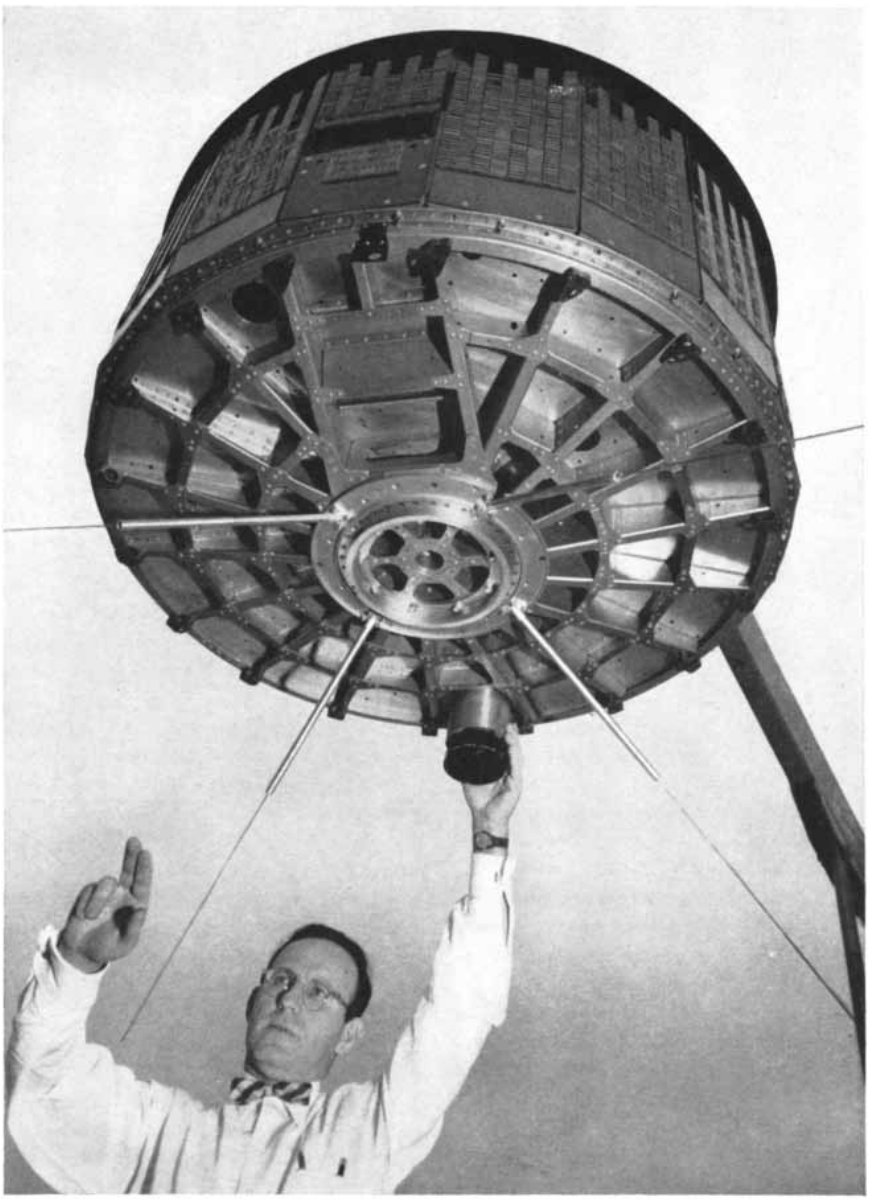
More important and more valuable, however, than any immediate improvement in the accuracy of weather forecasts is the great contribution that satellites can make to our basic understanding of weather processes. When we obtain data on the variations of the energy input into the atmospheric engine we will know to what extent the present forecasting methods—in which these energy variations are neglected—are valid. We will also be able to analyze in detail the effect of local energy surpluses or deficiencies. From these analytical studies we can expect to develop entirely new ways to use the radiation data provided by satellites in forecasting.

Weather Modification

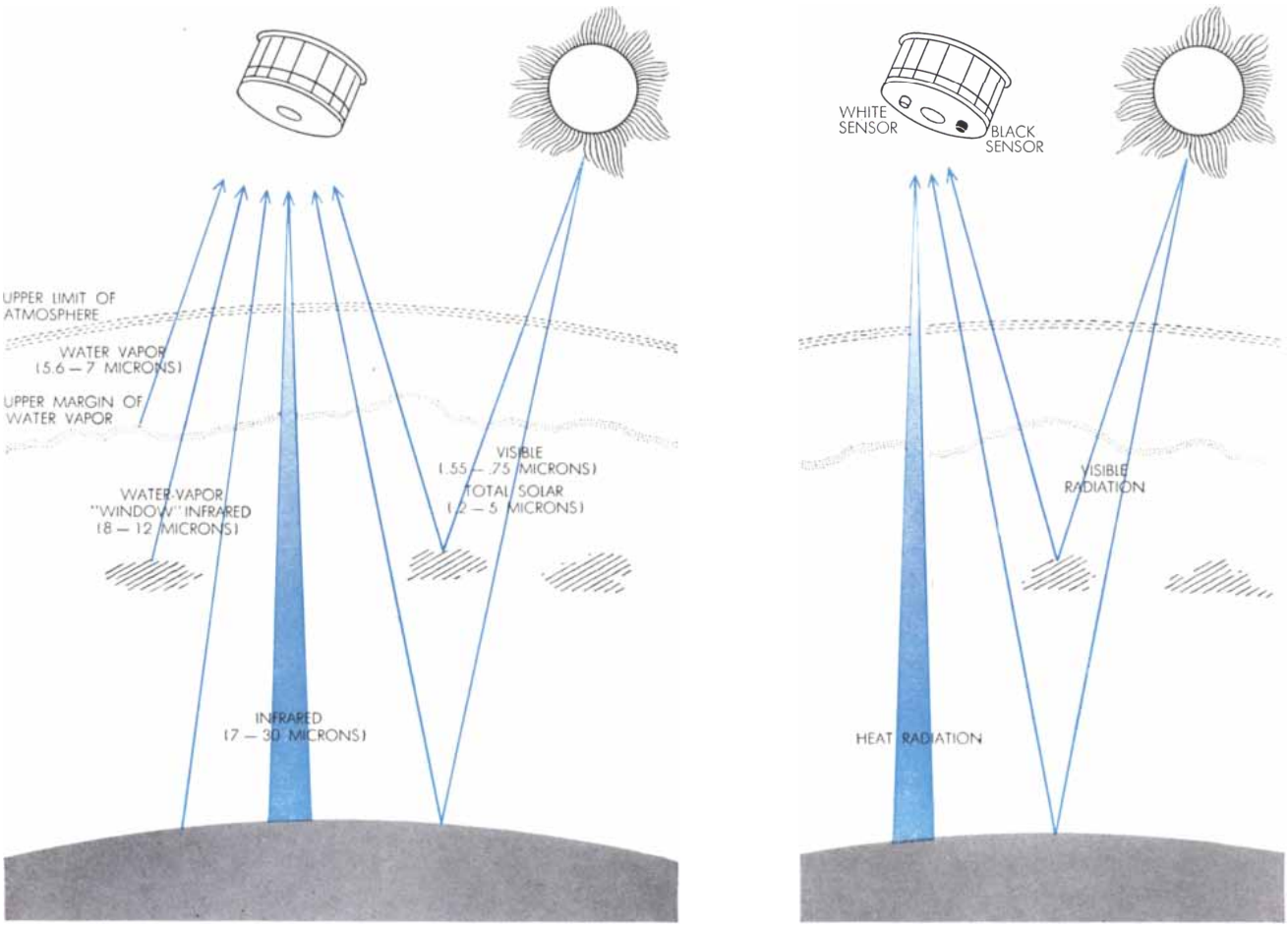
While there is much talk nowadays about weather control, we have only rudimentary knowledge of how to achieve it. Except for direct local modification of temperature (such as the heating of orchards to protect them from frost) and for cloud seeding, which under favorable circumstances has dissipated fog and clouds and may have influenced precipitation, there is no known way to affect the weather and climate of an area. Attempts to prevent hail and lightning and to influence the formation or movement of tropical storms have so far been unsuccessful. In view of such limited capabilities proposals for modifying the weather on a major scale require careful study and evaluation.

Space vehicles will contribute to weather modification primarily by increasing our knowledge of atmospheric processes, without which no intelligent control measures can be taken. Detailed observations from close-orbiting satellites should improve our understanding of the way storms form and develop, and could lead to discovery of means for stopping them at an early stage or altering their path. It has been suggested, for example, that the doughnut-shaped convection cells photographed by *Tiros I* and *Tiros II* are just about the right size to form the cloudless "eye" of a hurricane. Conceivably, when atmospheric conditions conspire, one cell out of hundreds will begin to grow, gather momentum and spawn a hurricane. If this conjecture is confirmed, the next step will be to discover what it is that triggers the growth of one particular cell and not others.

Only when satellites have provided



***TIROS I*, launched April 1, 1960, and still orbiting, is 42 inches across and weighs 270 pounds. Its name stands for "television and infrared observation satellite." Solar cells powered two television cameras, two tape recorders and other devices, together with a 1.9-watt transmitter. It transmitted some 14,000 usable cloud pictures to ground stations during 78 days of operating life. It was designed and built by the Radio Corporation of America.**



***TIROS* RADIATION DETECTORS provide five measurements in one instrument (*left*) and two measurements in a second instrument (*right*). The first instrument identifies the following: solar energy that is simply reflected (two channels between .2 and 5 microns), the total infrared radiation of the earth and atmosphere combined (7–30 microns), the infrared emitted mostly by the earth alone or by clouds (8–12 microns) and the emission from high-altitude water vapor (5.6–7 microns). The second instrument registers total visible and infrared radiation with a black sensing element and detects infrared alone with a white sensing element.**

an extensive series of measurements of incoming and outgoing radiation will it be possible to determine how variations in these quantities affect the atmospheric circulation and the weather. Such measurements may also help to tell us if we are inadvertently modifying the climate of the earth by burning fossil fuels, which increase the carbon dioxide content of the atmosphere. Carbon dioxide contributes to the "greenhouse effect" by allowing short-wave radiation to enter the atmosphere and preventing long-wave radiation from leaving.

Some investigators have appealed to the greenhouse effect to explain the slight but general rise in temperatures that have been recorded in the Northern Hemisphere since the end of the 19th century. In the same period there is evidence that the amount of water locked up in glaciers and in polar ice has been diminishing. If the temperature rise should persist, bringing a continued melting of ice, low-lying coastal areas will eventually be flooded by the rising sea level. If weather satellites should demonstrate over the years to come that the earth is indeed receiving more radiant energy than it is losing, one would want to search for countermeasures. One expedient would be to hasten the replacement of fossil fuels with nuclear fuels; another would be to create artificial clouds to reduce the amount of solar energy received by the earth. On the other hand, there is evidence that beginning about 1940, in spite of an unabated rise in fossil-fuel consumption, winters have become colder, so perhaps the carbon-dioxide hypothesis of climatic change has been overrated.

It may well be that another aspect of man's activities, the cloudlike condensation trails produced by high-flying aircraft, may exert a greater influence on climate. The world cloud cover is the most important component in determining the earth's albedo, or reflectivity, and it serves as a natural thermostat to keep the world temperature within narrow limits. Whenever the cloud cover increases, less solar radiation reaches the earth; as a result the earth cools, convection currents are damped and the cloud cover declines. Whenever the cloud cover decreases, more solar radiation reaches the earth's surface, heating it and causing more clouds to form. The average cloud cover over the earth is estimated to be close to 55 per cent; the average albedo of earth and clouds combined, 35 per cent. A one-percentage-point increase in cloud cover causes a .4-point increase in albedo, which, by reflecting more solar radiation back to space, means a decrease of the earth's temperature by .7 degree F. A system of weather satellites could keep track of variations of the world's cloud cover as a first step in deciding if man is having a noticeable effect on climate.

The quantities of mass and energy that are involved in weather processes are tremendous compared with most of the sources that man has had at his disposal for possible modification of them;

CM-122/DSM Signal Comparator

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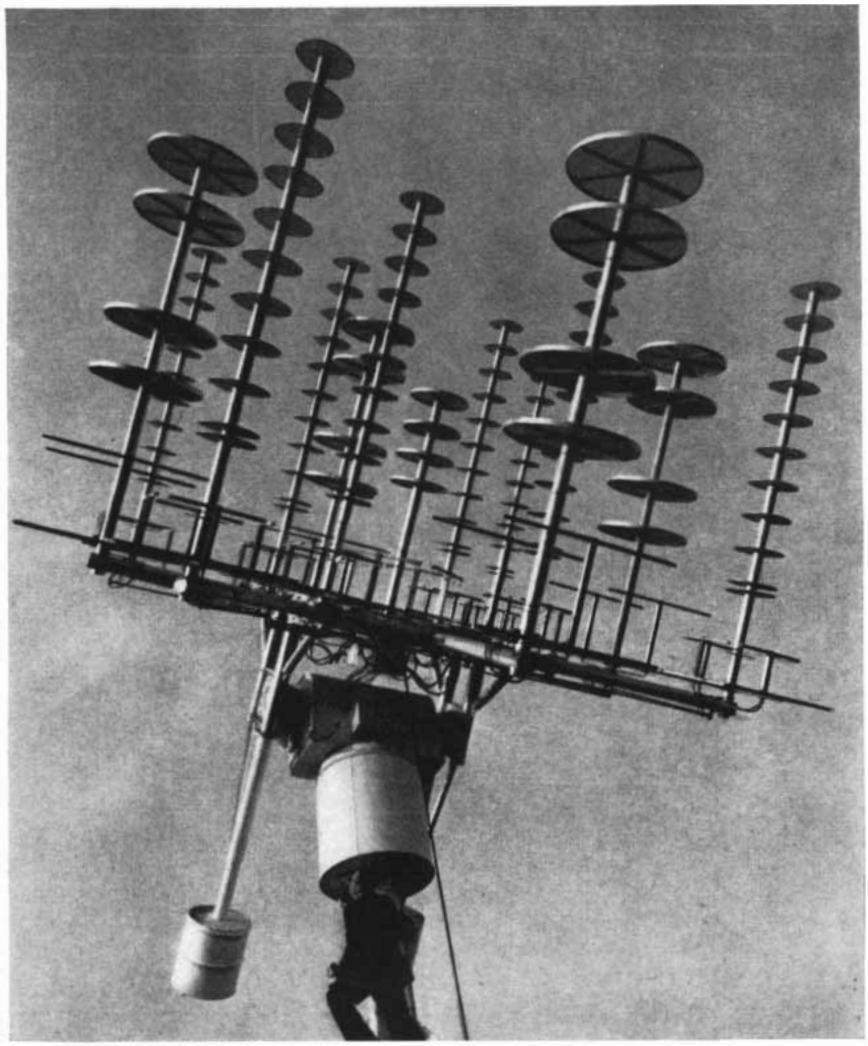
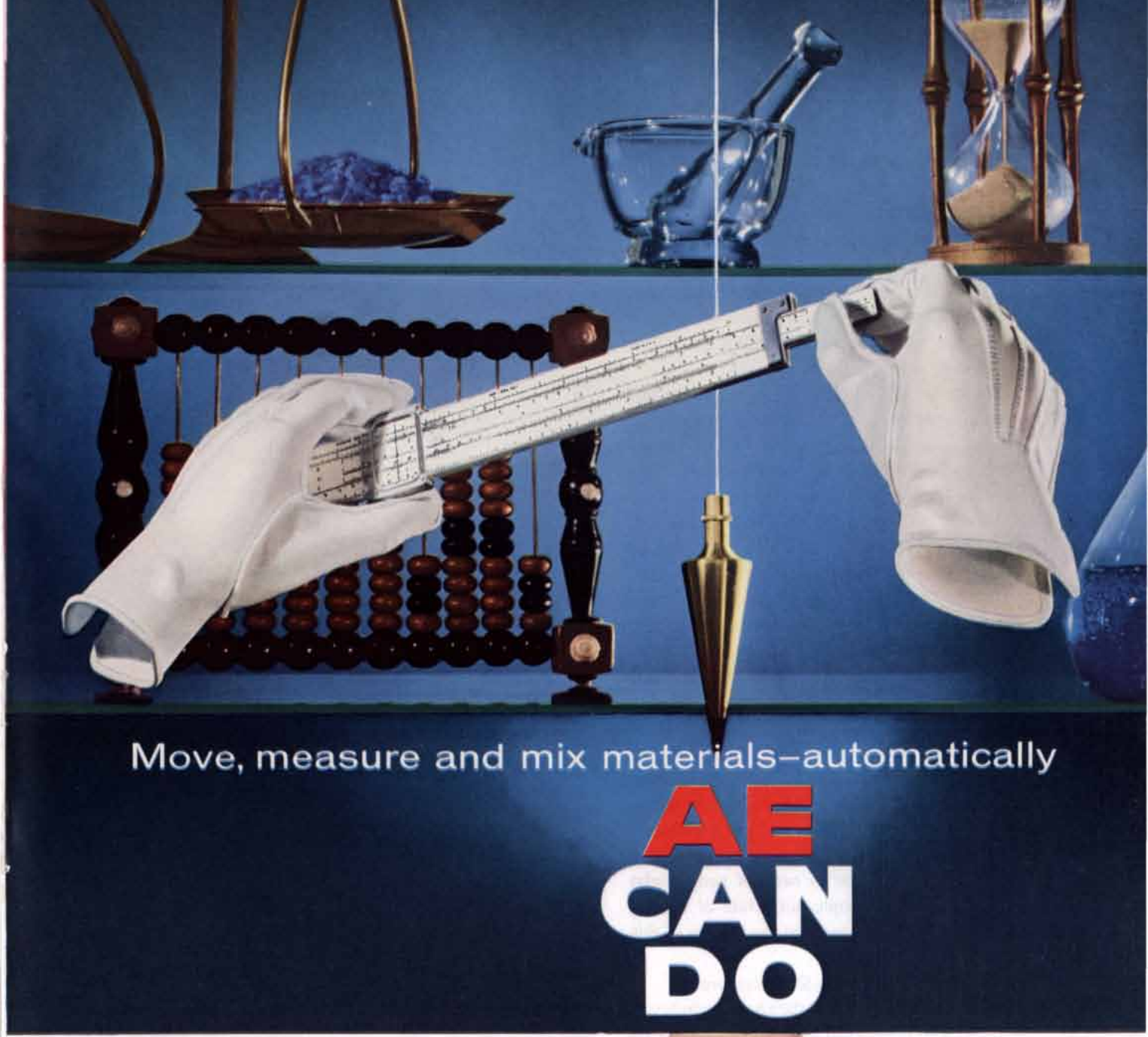


TRACKING ANTENNA at R.C.A. Space Center in Princeton, N.J., is designed to receive data from weather satellites. Most *Tiros I* data was actually received at Fort Monmouth, N.J., and Kaena Point in Hawaii; most *Tiros II* data, at Fort Monmouth and Point Mugu, Calif.

only a thermonuclear bomb involves energies of the same order of magnitude. Modification of the course of fully developed storms, if otherwise feasible, would require use of an energy source man is reluctant to use. It would be preferable from all standpoints, including the economic one, to achieve the desired changes with small expenditure of energy.

The best hope is that storms can be altered in an early stage of their development, when their future hangs in the balance and when a small impulse on one side would tip the scale away from an undesired development. That such unstable conditions exist at times is quite probable. Many Temperate Zone storms begin as small waves on the boundaries between air masses, and tropical storms often grow out of similarly small waves in the easterly trade winds. We have no way now of recognizing which small waves are unstable and which are not, nor do we know how to prevent or control the growth of the waves that are unstable. Because the network of observations is at present rather loose over much of the earth, it is seldom that a wave can be detected before it has begun to intensify into a storm. If satellite weather reconnaissance permits a more or less continuous watch for such atmospheric waves, it may be possible to perceive the conditions that make the waves unstable and to contrive ways to prevent or control the release of instability.

It is clear that we are far from the stage in which we will be able to press a button on the ground that will activate some exotic mechanism in a satellite able to dissipate a storm in one place or to make it rain in another. There is, however, every reason to expect that many new discoveries in meteorology will result from the use of satellites as global platforms from which to observe the energetic and restless atmosphere.



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The success of such programs can be measured in many ways. We see in them a means of encouraging an eternal spirit of curiosity. The world was never more in need of people who keep asking why. People not afraid of the big questions. Why can't we feed the hungry of this world? Why?

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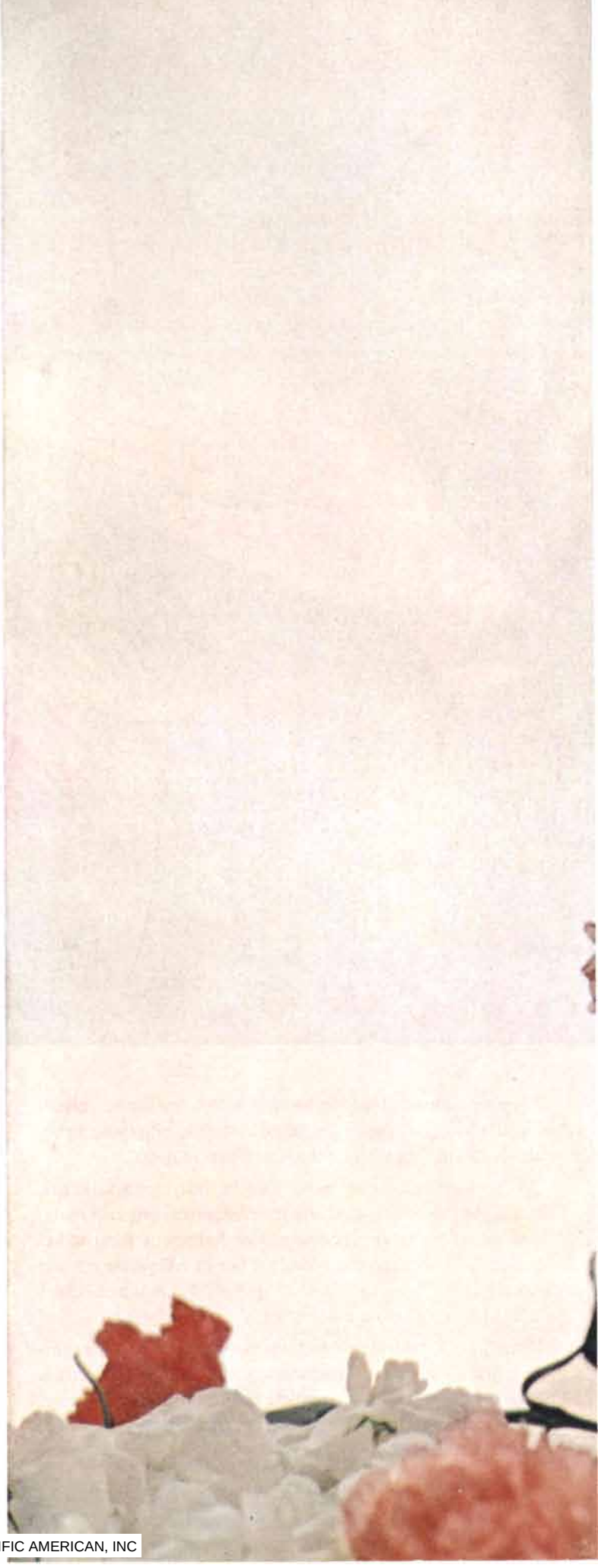


COLOR OF FROGS CHANGES RADICALLY when they receive certain hormones. The frog at left is lighter than normal after immersion in water containing melatonin, whereas frog at right is much darker than normal after an injection of melanocyte-stimulating hormone (MSH). Melanocytes are skin cells that make melanin, the principal pigment in the skin of man and many other animals.

SINGLE INFANT FROG, made abnormally light (*left*) by immersion in water containing melatonin, was injected with MSH. Over a period of several hours the frog became darker (*center*) and then black (*right*). Its normal color is approximately that of the center picture. The photographs on this page were made in the laboratory of the author at Yale University School of Medicine.

Hormones and Skin Color

The color of the skin of man and many other animals is established by cells containing the dark pigment melanin. Recent investigations indicate that these cells are strongly influenced by three hormones

by Aaron B. Lerner

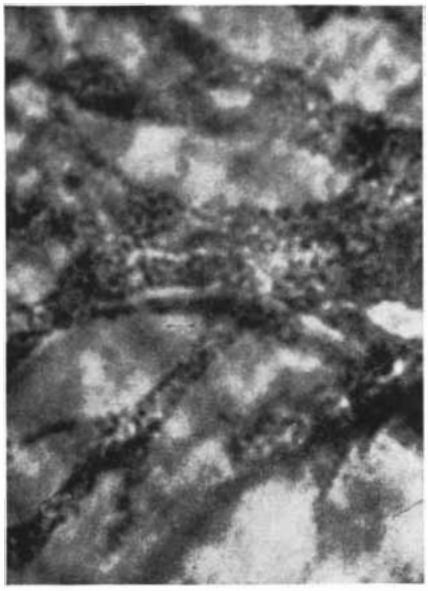
The color of human skin, hair and eyes comes principally from melanin, a brown-to-black pigment produced in skin cells known as melanocytes. People of different races have the same number of melanocytes sandwiched in a layer between the epidermis and the dermis, the outer and inner layers of the skin. Color differences among the races and among individuals and in parts of the body are due to differences in the quantity and the distribution of melanin in the skin. Melanin also imparts color to the skin and hair of many animals, and it is ejected in quantity in the "ink" with which the squid covers its retreat.

Within the past decade the study of the chemistry of skin color has led to the isolation of two previously unknown pituitary hormones and of the first hormone ever isolated from the pineal gland, a tiny body of unknown function that lies deep within the brain. The action of these hormones in the melanocytes underlies the rapid changes in skin color observed in certain animals; it also explains some changes and anomalies in the color of human skin. These findings derive a deeper significance from the fact that the melanocytes have their embryonic origin in nerve tissue. The color-regulating hormones may have even more important functions as members of the mysterious group of neurohormones, which mediate the interplay between the endocrine and nervous systems in the regulation of the body.

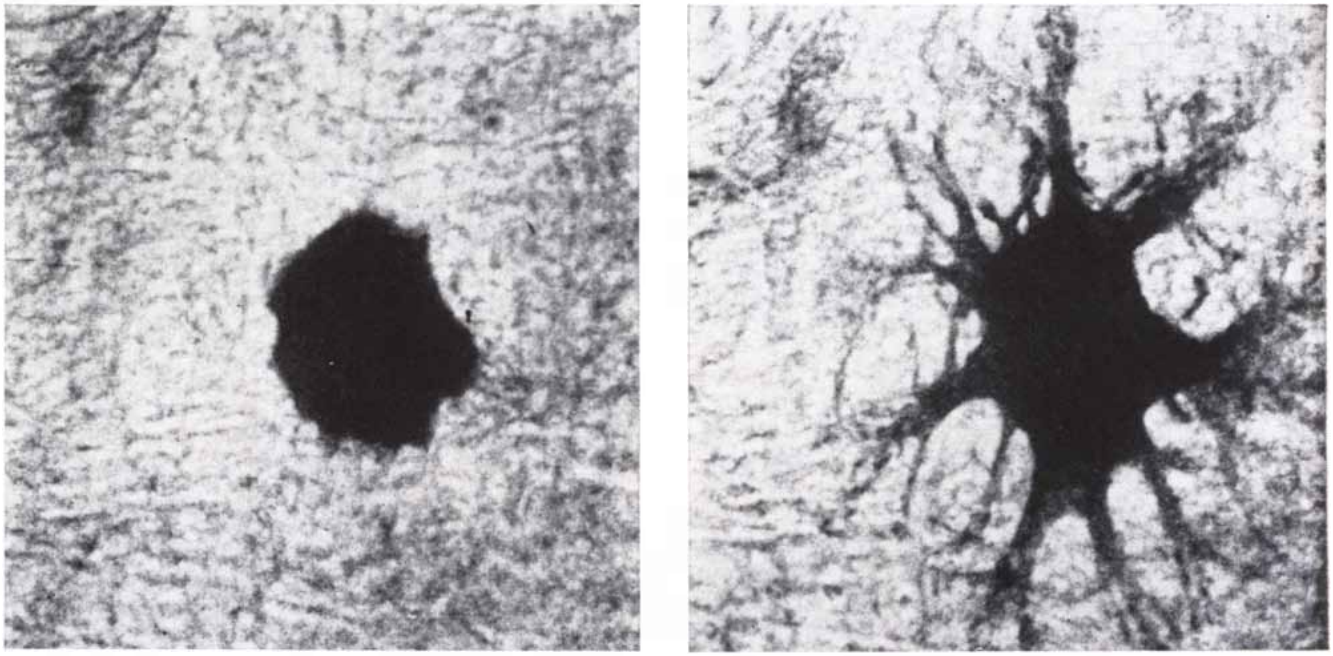
From nerve tissue in the human embryo melanocytes migrate by the third month of fetal life to permanent locations in the skin, eyes and covering of the brain. They retain the dendritic (branched) shape characteristic of nerve cells; in some of their chemical responses and in other characteristics, such as slow regeneration after damage, they continue to resemble nerve tissue. The face, neck, armpits and groin are richer in melanocytes and therefore are slightly darker than the rest of the body, whereas the palms, soles and thighs have fewer melanocytes and are lighter in color. Blue eyes and brown eyes have the same number of melanocytes but those in brown eyes contain more melanin; the light reflected from them gives the true color of the pigment. In blue eyes a smaller amount of nearly black pigment, which is located deep in the iris, appears blue because light of shorter wavelengths is scattered by tissue more than light of longer wavelengths. India ink injected deep into the skin produces a blue tattoo for the same reason.

Nevi, or moles, which are clusters of melanocytes, begin to appear on the body in the third year of life and increase slowly in number with age. Genetic and hormonal factors control the size and number of nevi in individuals. In rare instances excessive concentrations of melanocytes appear in some parts of the skin before birth, producing large or giant nevi. Ordinary freckles are caused not by an excess of melanocytes but simply by a higher concentration of melanin. In individuals with the appropriate genetic make-up, repeated exposure to sunlight causes freckles to appear beginning in about the sixth year.

The basis for present understanding of the chemistry of melanin was laid in the 1920's by the work of Bruno Bloch, professor of dermatology at the University of Zurich, and Henry S. Raper, professor of physiology at the University of Manchester. The formation of melanin starts with the oxidation of tyrosine, an amino acid that is found in many proteins. The enzyme tyrosinase catalyzes the reaction. In albinos, both human and animal, the tyrosinase for some reason does not function and the pigment cannot form. Albinos have the normal complement of melanocytes, but the enzyme defect leaves them virtually without melanin. Tyrosinase is one of several enzymes that require copper in order to function. Black-haired rats will grow gray hair when they are placed on a diet containing phenylthiourea, a compound that combines avidly with copper and leaves none for tyrosinase activity. In normal individuals tyrosinase exists in a partially inhibited state. X rays, alpha particles or radiant energy from the sun somehow, possibly by oxidation, remove inhibitors so that more pigment forms. Dark skin in human beings may never have served as camouflage, as it does in



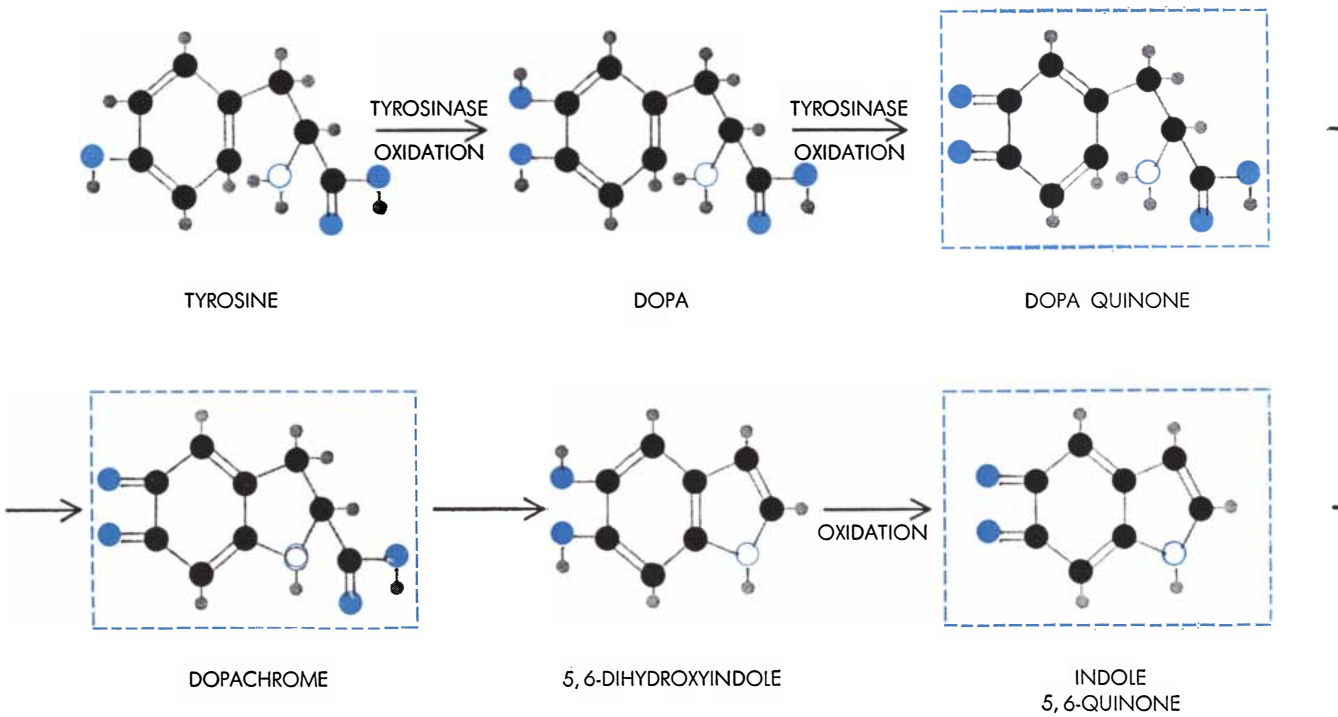
MELANIN GRANULES, the particles that make up pigment, are dispersed in the branches of a frog melanocyte. Enlargement in this photomicrograph is 720 diameters.



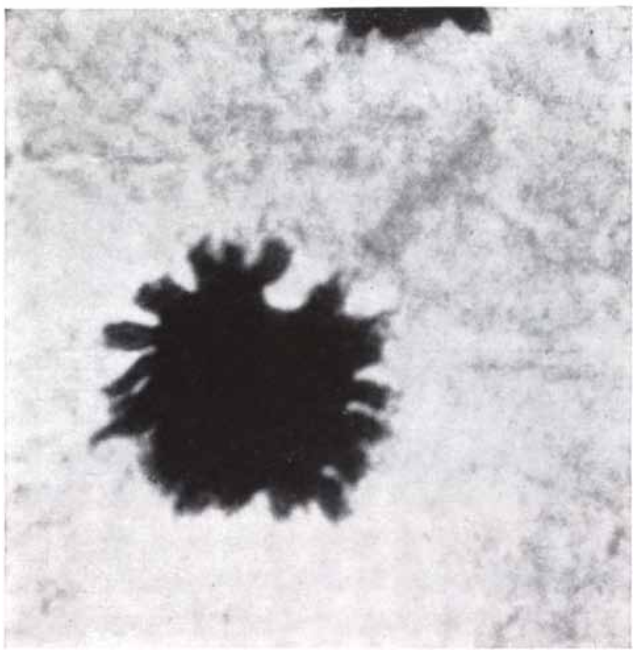
FROG MELANOCYTE with melanin granules clumped around the nucleus (*left*) becomes completely visible (*right*) after MSH is added, causing melanin granules to spread through all the branched processes of the cell. Granule dispersal makes frog's skin darken.

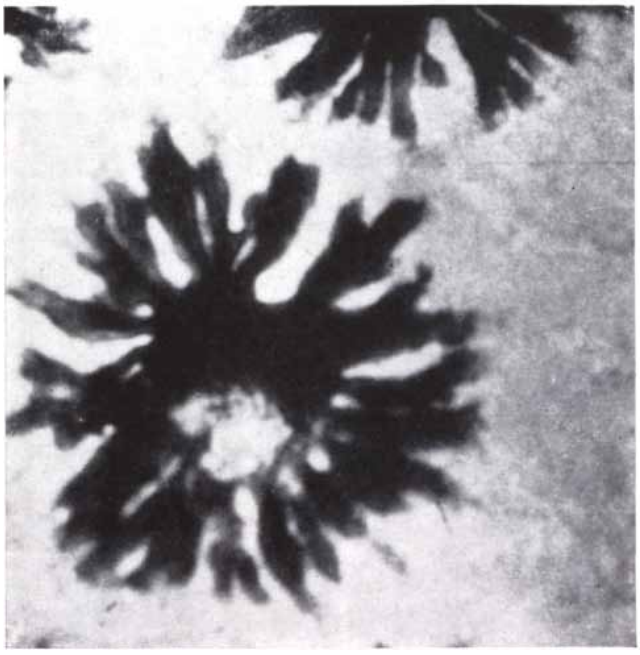
frogs and chameleons, but it does protect against burning by the sun. Melanocytes in the skin of darker races and of sunburned individuals secrete melanin into the outer layers of the skin, and the pigment, rather than the sensitive skin cells, absorbs much of the harmful radiation. A sun tan fades mostly by wearing away—the melanin moves along with epidermal cells to the surface of the skin, which consists of dead cells that slough off. In addition chemical reactions in the skin gradually destroy the pigment.

The oxidation of tyrosine, catalyzed by tyrosinase, produces the intermediate dihydroxyphenylalanine (dopa); it is an unusual intermediate in that it is necessary for the efficient function of the enzyme that produces it. Dopa reduces the copper ions in tyrosinase and makes the enzyme fully active. Once dopa forms, the enzyme quickly catalyzes the oxidation of tyrosine in the melanocyte. In succeeding reactions dopa yields, among other things, three active quinone compounds—dopa quinone, dopachrome and indole 5,6-quinone [*see illustration*



SYNTHESIS OF MELANIN in the melanocyte begins with the oxidation of the amino acid tyrosine, catalyzed by the enzyme tyrosinase, producing dihydroxyphenylalanine (dopa). The enzyme oxidizes dopa to dopa quinone. Further steps lead to dopa melanin,



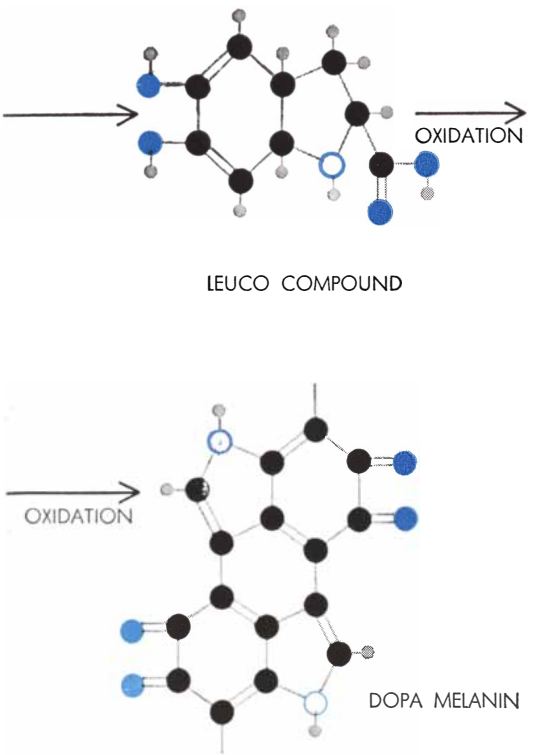


FISH MELANOCYTE shows same reactions as the frog melanocyte. Groove at upper right of nucleus area (*left*) can still be seen after granules have spread (*right*). Nucleus of cell is light after dispersal. Branches of other melanocytes are visible at the top.

below]. These substances combine readily with protein molecules, and the quinone-protein complexes oxidize to form melanin pigments. The differing routes of reaction would account in part for the different types of melanin that are found in the skin, hair and eyes of a given individual and in different species.

This much knowledge largely accounts for normal skin color and for nevi, freckles, sun tan and albinism. But it does not explain the darkening of the skin in pregnant women and in patients with Addison's disease or tumors of the pituitary gland. Nor does the chemistry of melanin account for the ability of tadpoles, frogs, chameleons, certain fishes and other animals to change color almost "at will." These processes are controlled by the newly discovered hormones; they involve not so much the amount of pigment or the concentration of melanocytes as the movement and distribution of melanin granules within the melanocytes.

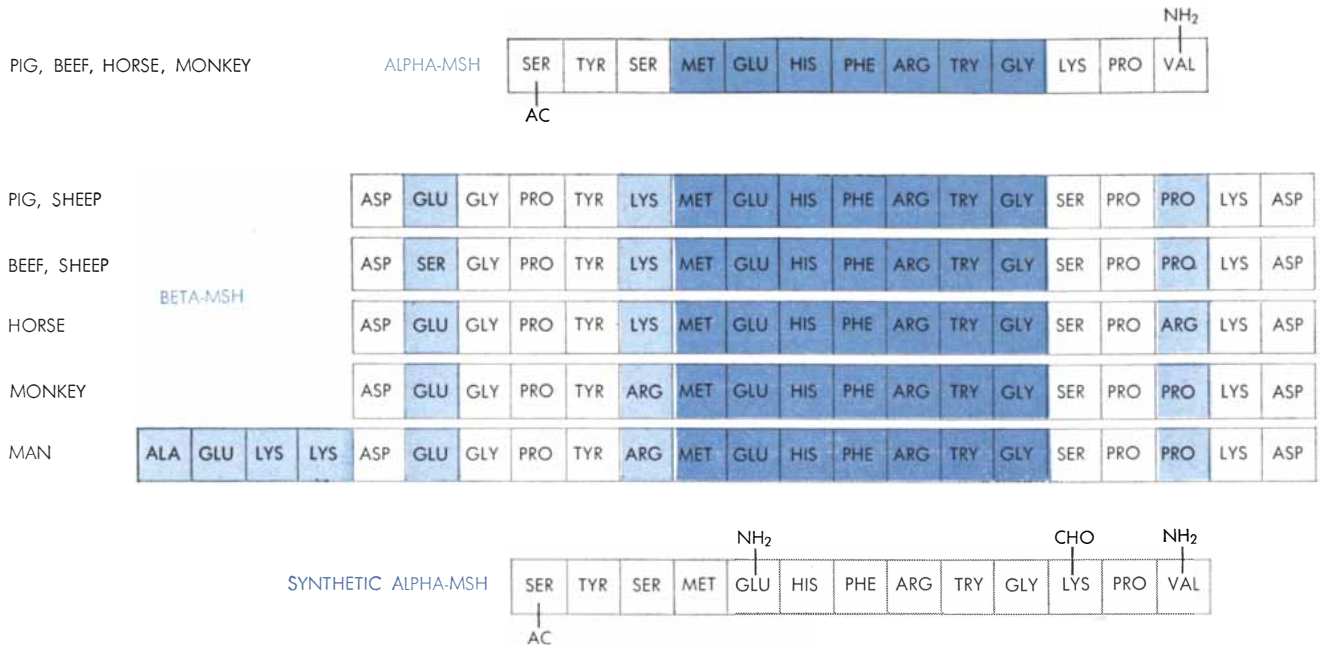
When a frog is in its light-colored phase, the pigment granules in its melanocytes are clumped together around the cell nuclei, leaving the rest of the cell translucent [*see illustration at top of opposite page*]. The animal can turn dark in from one to 60 minutes when the granules spread out from the nucleus through the rest of the melanocyte, making the cells opaque. The thin layer of pigment cells lying just under the epidermis then gives the entire skin a dark appearance. In the same way a large white tabletop with a small lump of coal in the center would be described as white; with the lump of coal ground to powder and spread uniformly on the surface, the table would appear black.



which forms long repeating units at sites of empty bonds, then combines with proteins to make melanin. The quinones (*in colored boxes*) also join with proteins to make pigments.

The search for the controlling hormones began 40 years ago when P. E. Smith at the University of California and Bennet M. Allen at the University of Kansas found that removal of the pituitary gland from tadpoles, frogs and certain other animals results in marked lightening of the skin. Conversely, it was shown that injection of pituitary extracts produces darkening. At about the same time the first clue to an active function of the pineal gland was discovered. When C. P. McCord and Floyd P. Allen, then at Parke, Davis & Co. in Detroit, added extracts from the pineal glands of cattle to the water in which tadpoles were swimming, the skin of the tadpoles became so transparent that their hearts and intestines were clearly visible. Further study revealed that these changes in pigmentation were caused by the clumping and dispersion of the melanin granules in the melanocytes under the influence of pituitary and pineal extracts.

At the University of Michigan Medical School in 1951 Teh H. Lee and I set out to isolate from the pituitary gland of pigs and cows the substance that makes frog skin darken. We had no idea of the nature of the substance—not even of the chemical family to which it might belong. We finally learned that it is a

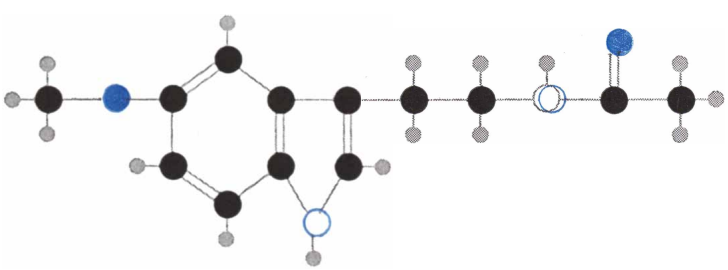


AMINO ACID SEQUENCE in alpha- and beta-MSH is the same in part of each molecule (*darker color*). Beta-MSH from different species varies at several positions in the sequence (*lighter color*). Synthetic alpha-MSH has same chain as natural alpha-MSH, except for two side groups, which do not interfere with its function. The names of the amino acids have been abbreviated in this diagram.

polypeptide (a chain of amino acid units). In 1955, when we were working at the University of Oregon Medical School, we isolated a potent darkener of frog skin, a substance that we named the melanocyte-stimulating hormone (MSH). Other laboratories had also been working on the problem; they had discovered a similar but less potent agent. The two substances were found to be different forms of the same hormone and were labeled alpha-MSH and beta-MSH. The isolation of alpha-MSH in our laboratory was facilitated by an assay procedure developed with the help of K. Shizume and later improved by M. Ruth Wright. Color changes in live pieces of frog skin serve in this assay to measure the concentration of MSH [*see bottom illustration on page 106 and illustrations on page 108*].

Investigations carried out largely by J. Ieuan Harris and H. B. F. Dixon at the University of Cambridge, Paul Roos at the University of Uppsala, C. H. Li and I. I. Geschwind at the University of California, and in our own laboratories at the Yale University School of Medicine brought the isolation and identification of alpha-MSH and beta-MSH from several animal species. Apparently every pituitary gland produces both forms. The pig, cow, horse, monkey and possibly man all produce the same alpha-MSH. The beta form, however, differs slightly from one species to another. A more familiar pituitary hormone, ACTH, can also darken frog skin, although not so efficiently as MSH. This is not surprising, because ACTH and both forms of MSH have some amino-acid sequences in common. Indeed, the entire 13-amino-acid sequence of alpha-MSH is the same as the first 13 amino acids of ACTH, which has a total of 39 amino acids. Recently Klaus H. Hofmann and his associates at the University of Pittsburgh and Roger Boissonnas and S. Guttmann of Sandoz, Ltd., in Switzerland performed the difficult task of synthesizing alpha-MSH. Just how MSH causes the melanin granules to disperse in the melanocyte is still unknown.

The hormone works in man as well as in frogs. Human subjects given large injections of MSH begin to darken within 24 hours. Daily doses lead to more darkening until the injections are discontinued. The skin returns to its normal color within three to five weeks after the last injection. The increased pigmentation is most pronounced in the face; nevi darken and new nevi seem to form. The skin of Negroes shows a more marked response to MSH than does the skin of whites, and in a shorter time. It remains to be determined if the darkening in human skin comes from the dispersion of melanin granules in the melanocytes, as is the case with frogs. The process is comparably distinct and rapid.



MOLECULE OF MELATONIN is diagramed. This hormone, the first to be discovered in the pineal gland, makes the skin of frogs and tadpoles become extremely light in color.

The discovery of the role played by this hormone in the coloration of human skin provides an explanation for the darkening of skin in pregnancy and in certain diseases. Ordinarily hydrocortisone produced in the cortex of the adrenal gland inhibits the release of MSH by the pituitary gland. In Addison's disease the outer layer, or cortex, of the adrenal gland is damaged or destroyed; as a result the pituitary releases an excess of MSH. The skin of individuals with some types of pituitary tumors becomes dark because the tumors

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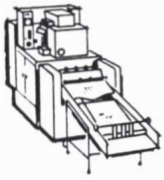

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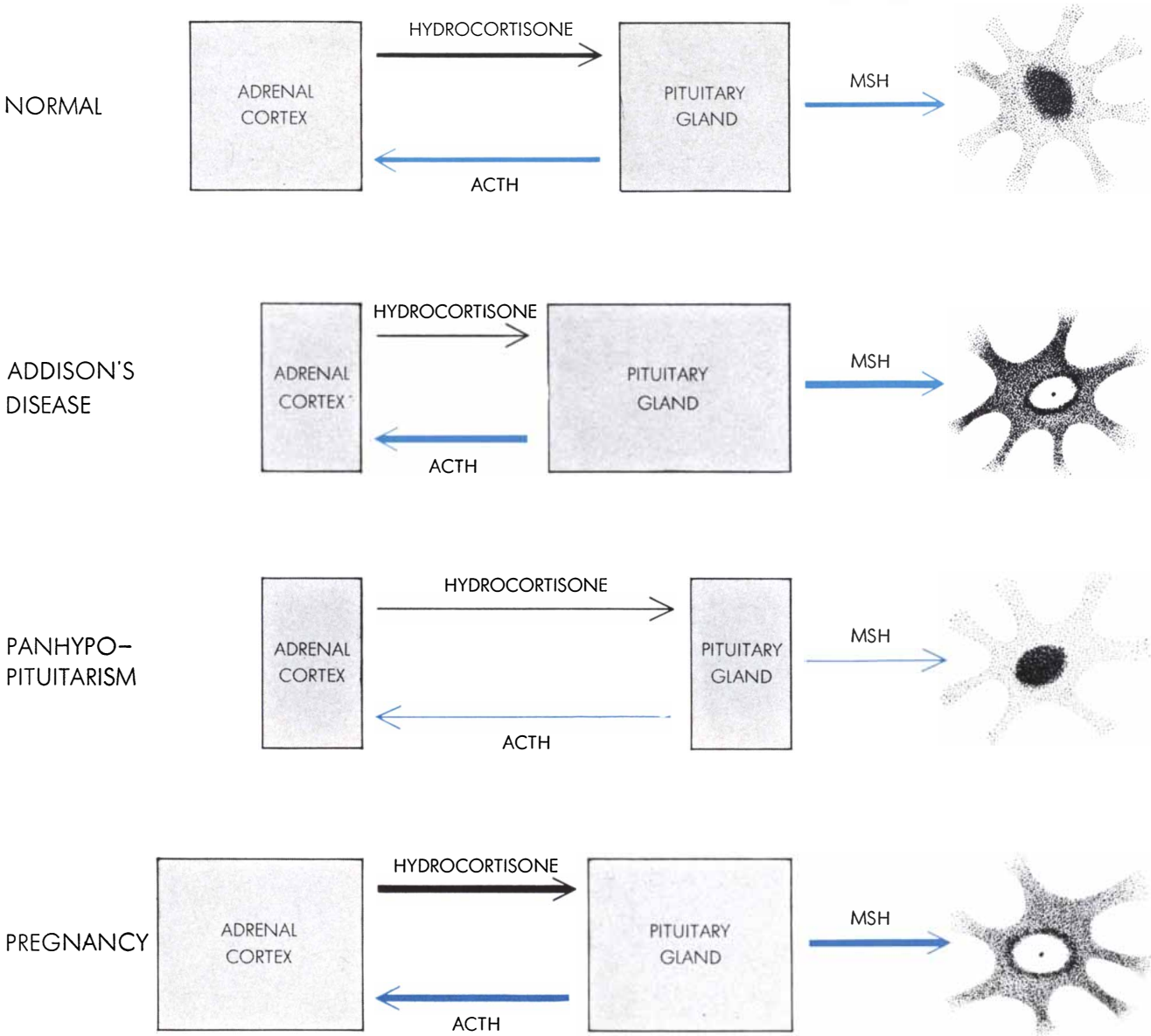
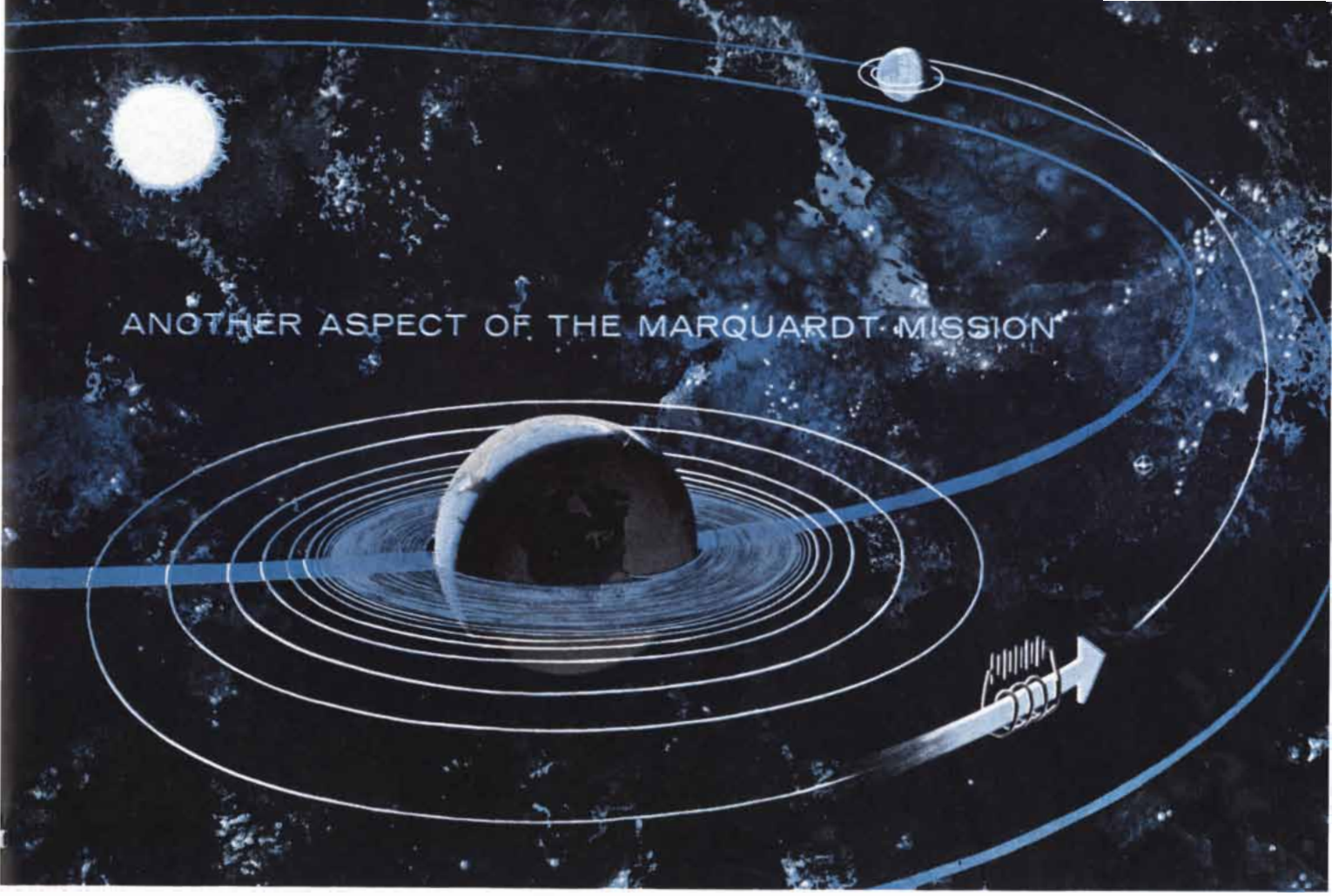
make large amounts of MSH. The darkening of the skin in pregnancy results in part from the normal enlargement of the pituitary attendant on pregnancy and the consequent release of extra MSH. Other hormones, such as progesterone, may play a role in the hyperpigmentation of pregnancy.

The isolation of MSH encouraged Y. Takahashi, James D. Case and me to undertake to isolate from the pineal glands of cattle the substance that causes tadpole and frog skin to become lighter. The possibility held special interest for us because we thought this compound might be involved in the human condition called vitiligo, which is characterized by the appearance of permanent, spreading white blotches in the skin. It had been postulated that an unknown hormone secreted by nerve endings in the skin might cause the condition by keeping nearby melanocytes light in color. So far, however, these hypothetical neurohormones have escaped detection and isolation. Since the pineal gland may be regarded as an active vestige of embryonic nerve tissue, we thought the factor that lightens frog skin might also be the vitiligo hormone.

Once again we did not know the nature of the compound we were seeking. It was some time before we realized that it is unstable in light and we therefore lost tiny but precious quantities of it. We used the frog-skin assay proce-



HORMONAL CONTROLS of skin color in health and disease are diagramed. In normal person, hydrocortisone from the adrenal cortex inhibits release of MSH by the pituitary. ACTH from the pituitary stimulates the adrenal cortex. The amount of MSH that results produces normal melanocyte color. In Addison's disease the adrenal cortex is damaged; inhibition of pituitary by hydrocortisone decreases and excess MSH darkens skin. The pituitary is damaged in panhypopituitarism and skin grows quite pale. During pregnancy the pituitary enlarges and, in spite of increased stimulation of adrenal cortex and increased inhibition by hydrocortisone, produces more MSH, darkening the skin. The rectangles of different sizes denote the functioning of the glands, not the changes in their actual size.



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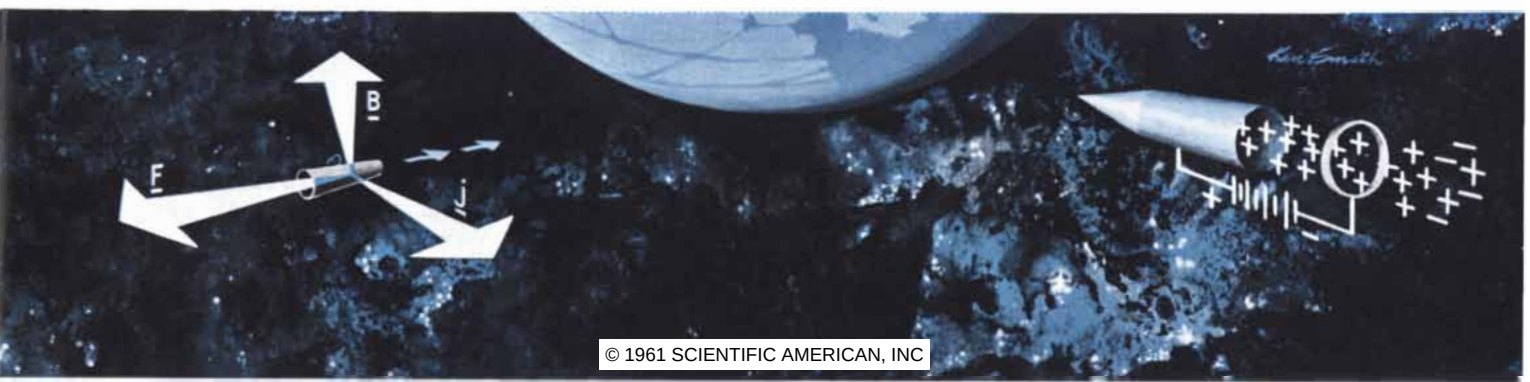
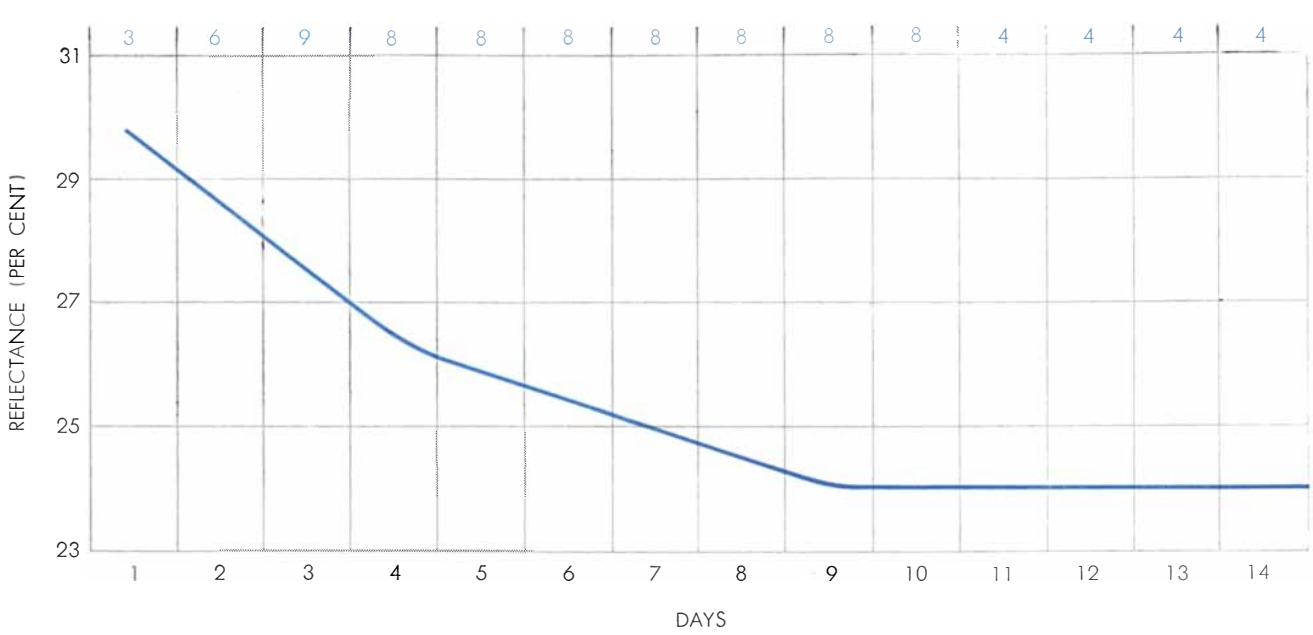
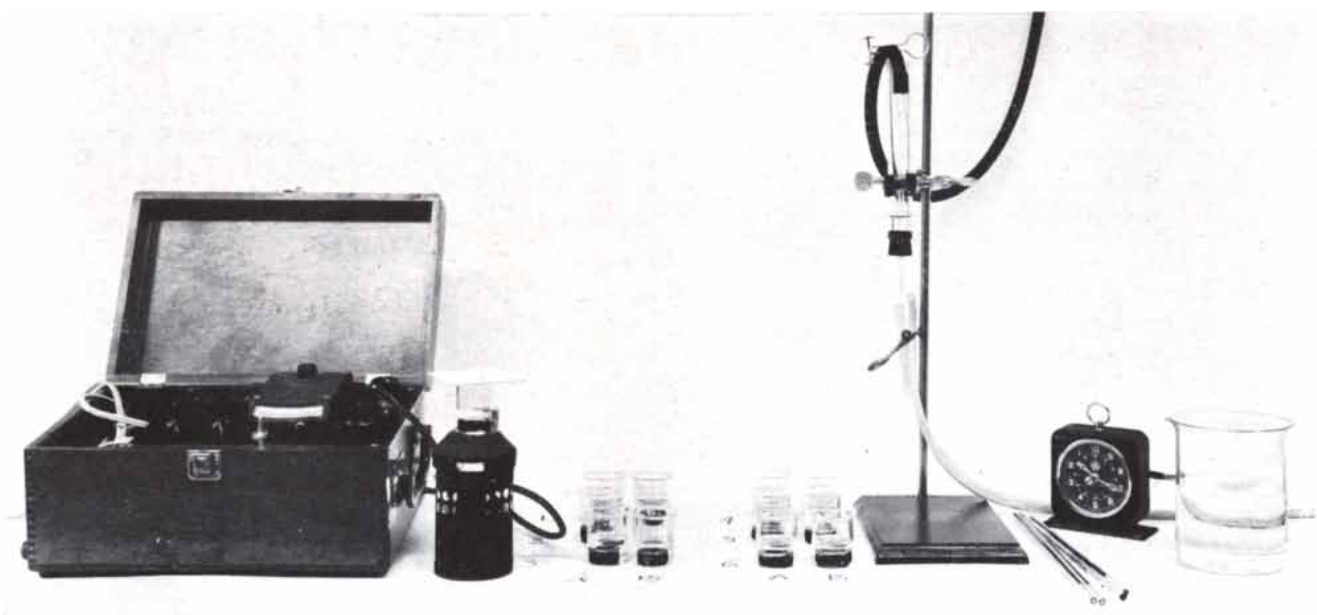


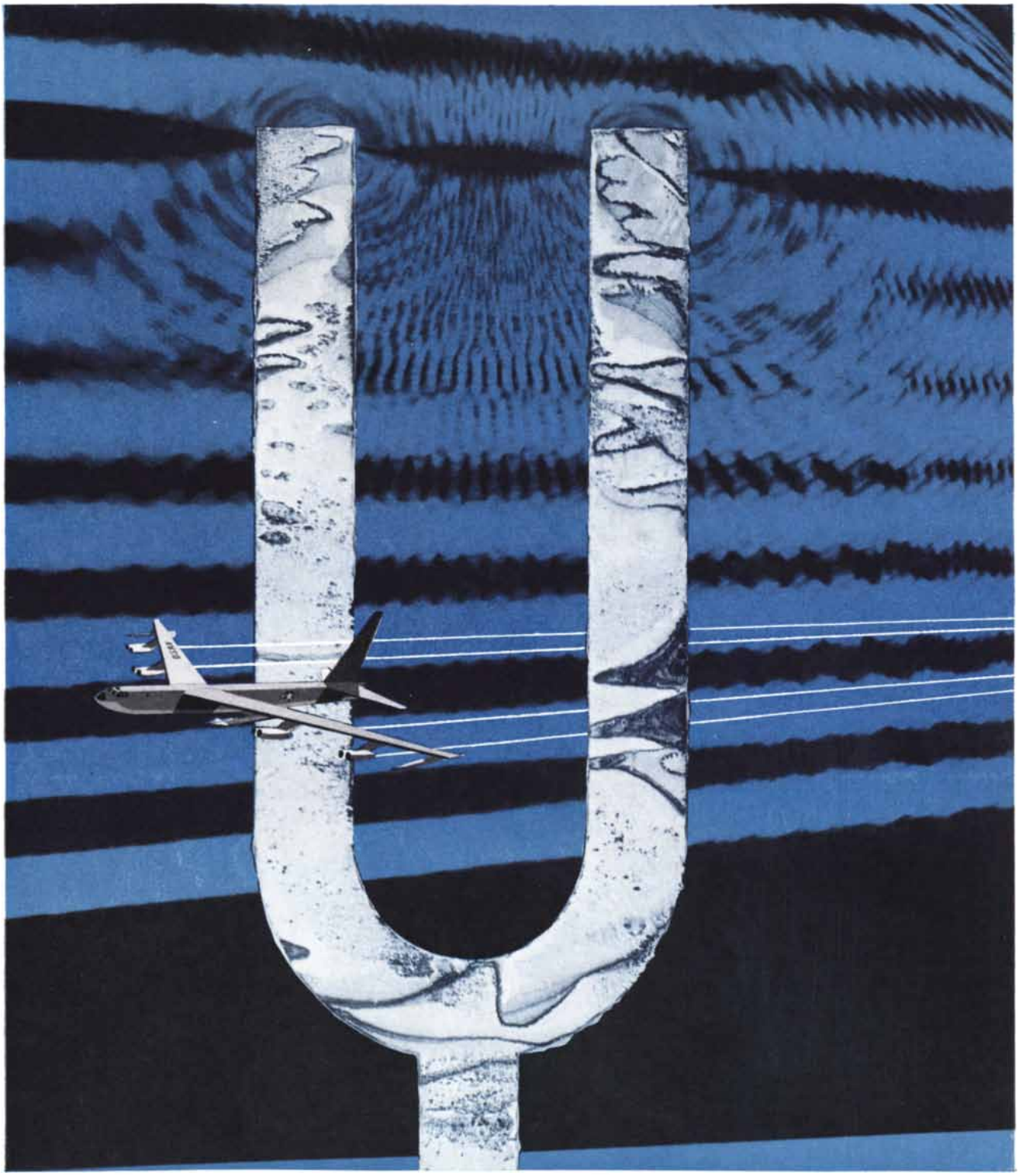


DARKENING OF HUMAN SKIN during administration of alpha-MSH is demonstrated by measuring per cent of light that the skin reflects. Daily doses of alpha-MSH, shown at top, caused skin of a Negro subject to reflect 6 per cent less light after nine days. The dark condition persists for several weeks after the experiment. Measurements of reflection of light were made on the forehead.

dure, but our work was complicated by the fact that we had to darken the skin to a known degree with MSH before we could test for the lightening factor. The pineal gland itself is minute and contains almost infinitesimal quantities of the substance. Taken fresh from a cow, the gland weighs only 200 milligrams (.007 ounce); with all its water removed, it weighs 40 milligrams (.0014 ounce). A large paper bag will hold 20,000 to 30,000 dried glands. Over nearly four years Armour & Co. furnished us with 200,000 glands. From this generous supply we were able to isolate at one time as much as 100 micrograms (.00000353 ounce) of the pure substance we were seeking. This was not enough to see with the naked eye, but with the help of R. V. Heinzelman and J. Szmuszkovicz of the Upjohn Company we were able to work out the molecular structure of the substance and to synthesize it. We named it melatonin. Oddly enough, like alpha-MSH, melatonin has an acetyl group attached to a nitrogen atom. Synthetic melatonin is now available for demonstrations of the lightening of tadpole skin. This neurohormone does not, however, make



LABORATORY EQUIPMENT that measures the depth of color of frog skin played a key role in the isolation of MSH and melatonin. In case at left is reflection meter with a galvanometer dial that registers the electric current produced when light hits a photoelectric cell. Black cylinder at right of the case is "search unit" containing a light and a photocell. A beaker with a sample of frog skin is on top of the unit. The 12 beakers in center hold samples of frog skin in solutions containing MSH or melatonin.



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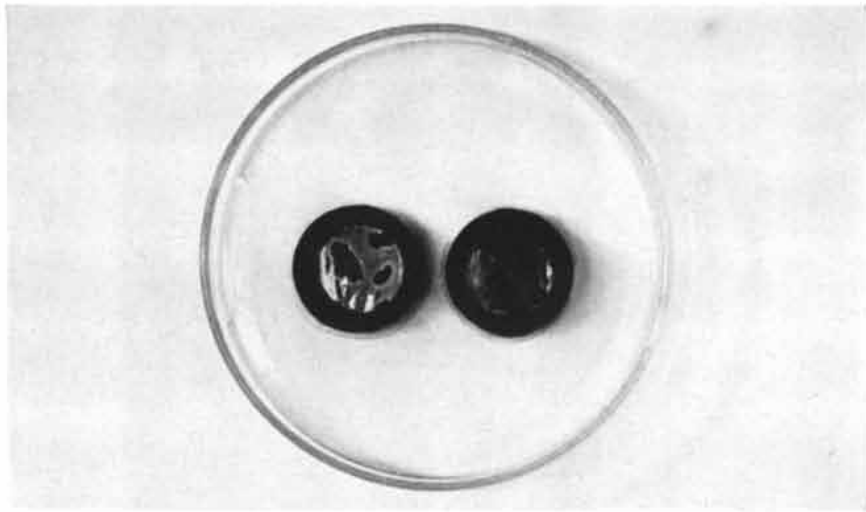
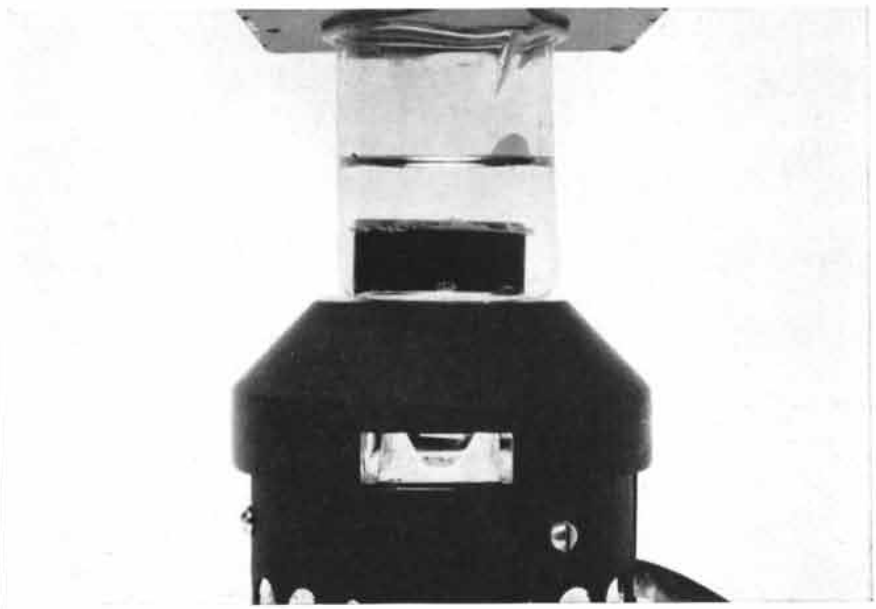
human melanocytes lighter in color and so does not cause vitiligo. Studies of the condition must begin anew.

Among the foremost problems in pigmentation research is the melanoma, the malignant tumor of melanocytes. Fortunately melanomas are not common; they are spectacularly malignant and are resistant to radiation therapy. Sometimes these tumors become so widespread and produce so many tyrosine-oxidation products that the entire body becomes dark. Injections of MSH have no effect on melanomas in animals other than to make them darker. While the hormone does stimulate melanocytes to darken, it seems to play no role in cancer. Studies with MSH and melatonin may nonetheless throw some light on malignant melanocytes.

The fact that melanocytes are nerve cells suggests that melatonin and MSH may act on the nervous system in ways as yet unknown. Indeed, the main physiological function of these hormones may not be the control of melanin granules, even though this phenomenon led to the isolation of the hormones. The investigation of skin color has thus opened the way to larger questions.



SAMPLES OF FROG SKIN for use in assay of hormones are mounted on small rings that resemble embroidery hoops. Melatonin has made one light; MSH has darkened the other.



SEARCH UNIT holds light source and a doughnut-shaped photocell that faces up and is shielded from light. Standing on unit is beaker holding frog skin mounted in ring and placed on top of hollow black cylinder. Skin is kept fresh in a salt solution. Light from source below reflects from skin into the photocell, which registers the intensity of the reflection, giving sensitive measurement of the extent of darkening or lightening of the skin. This reveals quantity of MSH or melatonin in a solution in which skin had been soaked.

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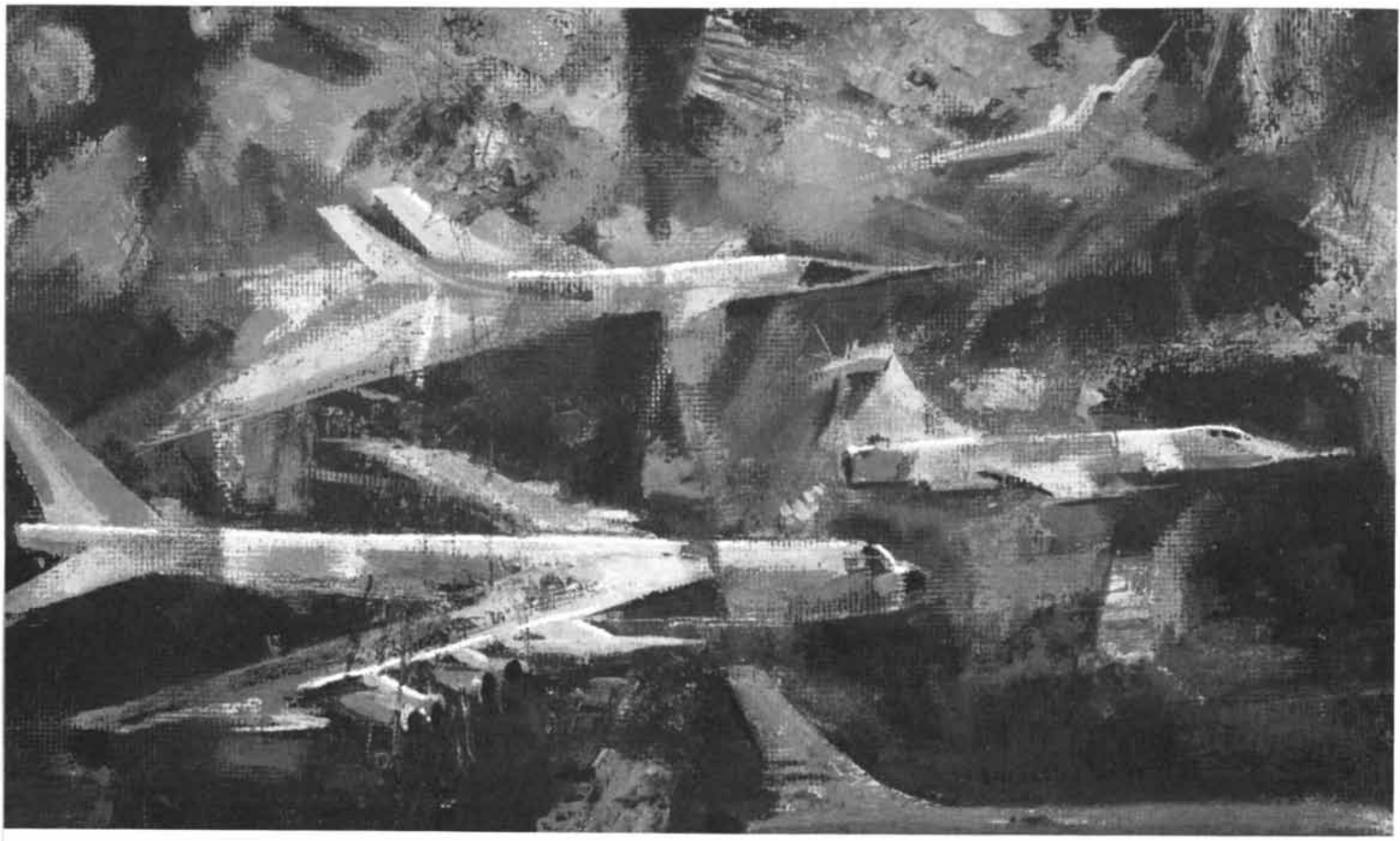

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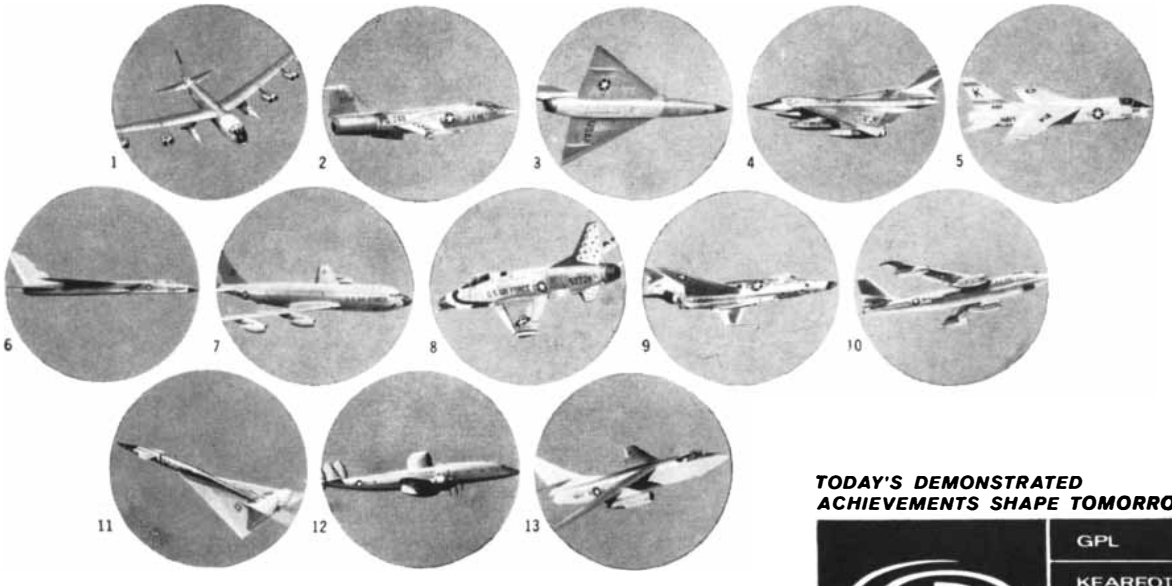

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New techniques for controlling the behavior of animals make it possible to measure their response to varying stimuli. In these experiments pigeons are trained to "tell" what they see

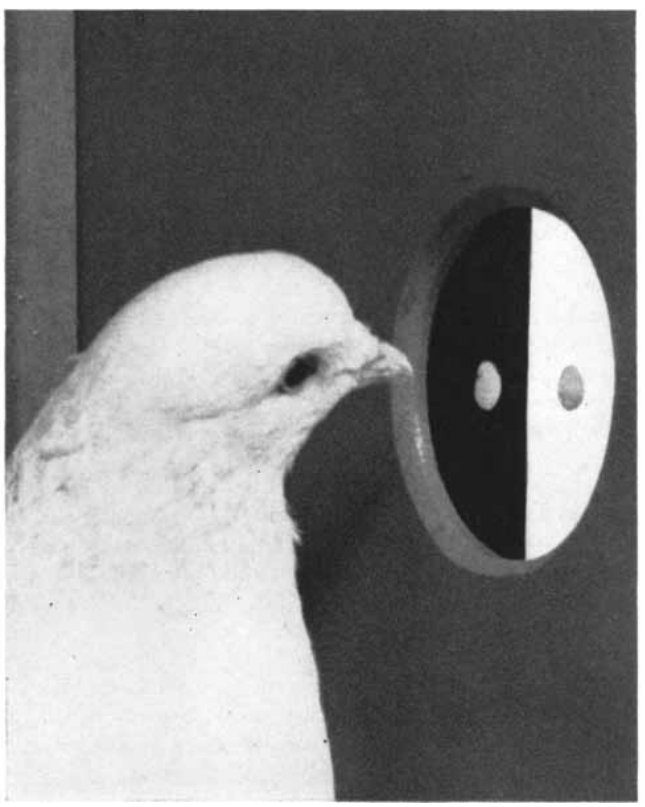
by Donald S. Blough

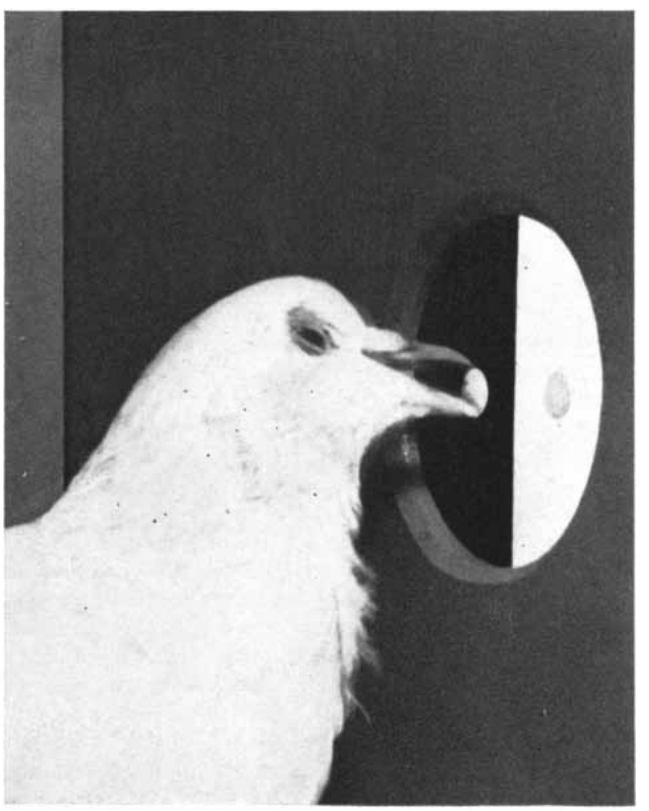
If you want to know what a man sees, you can ask him. How would you find out from a pigeon? This was a problem that Floyd Ratliff and I put to ourselves a few years ago when I was working in his laboratory at Harvard University.

We were specifically interested in the phenomenon of "brightness contrast": When two gray spots of equal brightness are displayed side by side, one against a white background and the other against a black background, the spot surrounded by white looks darker to most human subjects. To equalize the apparent brightness, the actual intensity of this spot must be made considerably greater than the intensity of the other. We wanted to know if one spot would seem brighter to pigeons too, and if so how much brighter.

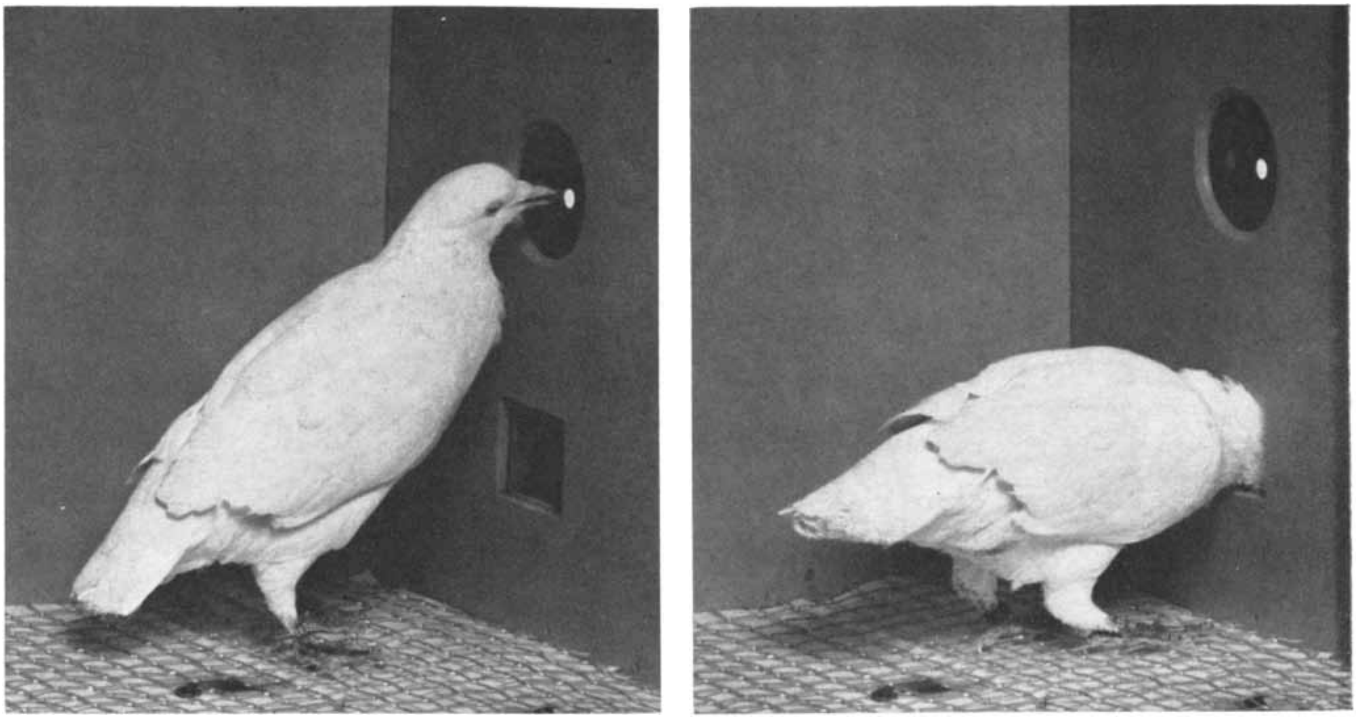
Such quantitative studies of perception belong to the branch of experimental psychology called psychophysics. Psychophysics was originated in 1850 by the German physicist and philosopher Gustav Theodor Fechner, who envisaged "an exact science of the functional relations... between the body and the mind." Although his best-known result—"Fechner's law" that the magnitude of a sensation is proportional to the logarithm of the intensity of the stimulus—now appears to be wrong, his general approach and ways of measuring have stood up well.

The terms "mind" and "sensation" have, to be sure, caused some difficulties in experimental psychology. Experimenters could rarely agree about what was going on in the minds of their subjects. Instead they turned to behavior,





PIGEON AT WORK in an experiment on "brightness contrast" is trained to peck at the brighter of two round spots. In this case the two are of equal intensity. But the dark background makes the left-hand spot seem brighter to the bird, which pecks accordingly.



PIGEON IN TRAINING stands in an experimental box. The bird faces two plastic panels, on each of which a spot of light of variable intensity is projected. Trained to peck at the panel with the brighter spot, the bird does so (*left*) and is rewarded with

which can be objectively specified and measured. When sensation is explicitly defined by behavior, an animal psychophysics comes within reach. But why reach for it? Why bother with animals when college sophomores are so readily available? There are several good reasons: Comparison of different species often helps in understanding psychological processes. Animals will work harder than sophomores. The investigator can control important variables, including upbringing and genetics; he can combine psychological with physiological studies. In spite of these advantages, most areas of psychophysics for a long time made little use of animals: their behavior was too hard to control precisely. Recently techniques affording the necessary precision have been developed, and animal work is beginning to make new headway.

For our first psychophysical experiment, on the brightness-contrast effect in animals, Ratliff and I chose the pigeon, partly because of its excellent vision. Moreover, just down the hall from our laboratory B. F. Skinner was already controlling the responses of pigeons to visual stimuli [see "How to Teach Animals," by B. F. Skinner; SCIENTIFIC AMERICAN, December, 1951]. We set out to apply Skinner's methods to teaching the birds how to tell us about the relative brightnesses of two spots of light—to teach them, as Ratliff liked to say, a sort of pigeon English.

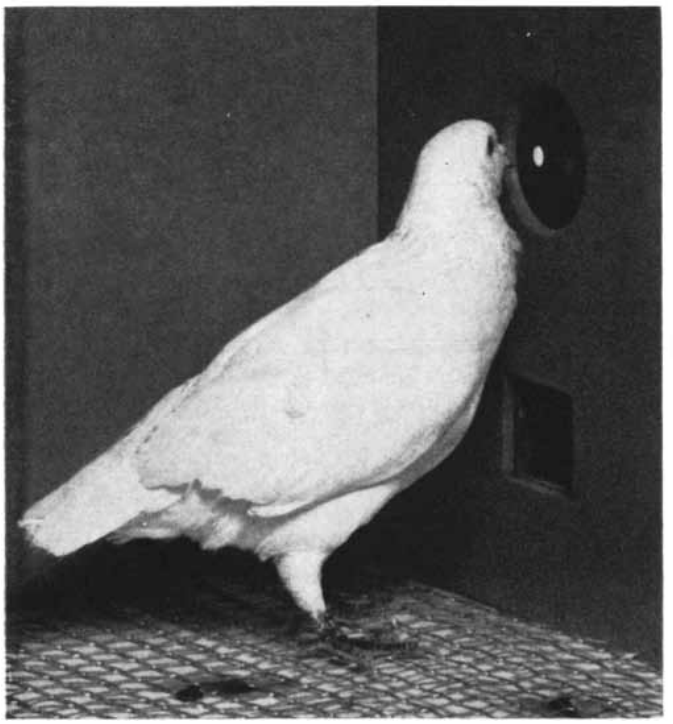
On the wall of a darkened training box we mounted a pair of white plastic panels. A hungry pigeon was put into the box facing the panels. A sharply defined spot of light was projected on the center of each panel; the surrounding area was dark. When the bird pecked at a panel, we rewarded it with a few seconds' access to a pan of grain. Once the pecking behavior had been established we varied the relative intensity of the spots, sometimes making the left-hand one brighter, sometimes the right-hand one. Now the bird was rewarded only for pecking at the brighter spot. Soon it was hammering away at the bright spot and avoiding the dimmer one. After a while we were able to cut the frequency of rewards substantially. Correct pecks produced food only at random intervals, but the pigeon kept pecking steadily even when three or four minutes passed between rewards.

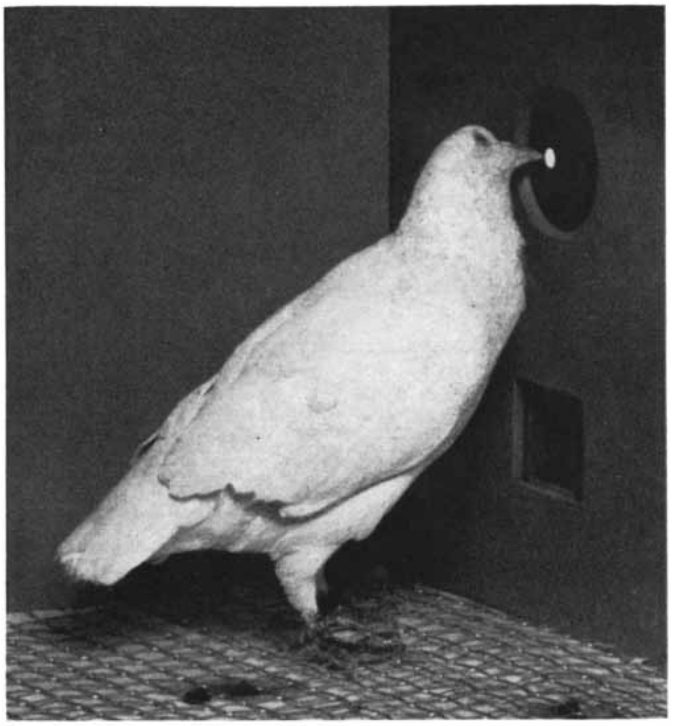
At this point we could have tried to go directly to the contrast situation. Instead we first incorporated an elegant method invented by Georg von Békésy, another neighbor in the department, to study auditory sensitivity in human beings. His subject listened to a soft, continuous tone and kept a telegraph key pressed down as long as he heard it. While the key was down it completed a circuit that gradually decreased the intensity of the tone. When the tone was no longer audible and the subject released the key, the tone automatically grew louder until it was heard again —whereupon the subject pressed the key, the tone faded and so on. The pen of a recorder, tracing out the fluctuations in intensity, "tracked" the subject's sensitivity on a moving piece of graph paper.

Békésy's tracking technique is efficient: the stimuli are never unnecessarily large or small. It provides a continuous record instead of a number of discrete points. Most important for animal experiments, tracking requires no talking by the subject.

To adapt Békésy's tracking method to our problem, we hooked up the target panels to a system of relays and motors that operated to change the relative intensity of the spots. A peck at a panel made its spot a little dimmer and the other spot a little brighter. The bird was still rewarded, although infrequently, for pecking at the brighter spot, so it stuck faithfully to the task. After a few pecks, however, the brighter spot became the dimmer one and the pigeon began to peck on the other panel, soon reversing the intensities again [*see photographs above*]. As the pigeon switched back and forth, the recording pen swung up and down across the point of apparently equal brightness, which was in this case the same as the point of objectively equal intensity.

Now we were ready to investigate brightness contrast. As the pigeon was tracking the equal-brightness point, we





grain (*second from left*). But each peck at a panel makes its spot less intense and the other one brighter; the pigeon notices the change and switches panels (*right*). Photographs do not show the actual box but an open model used for demonstration purposes.

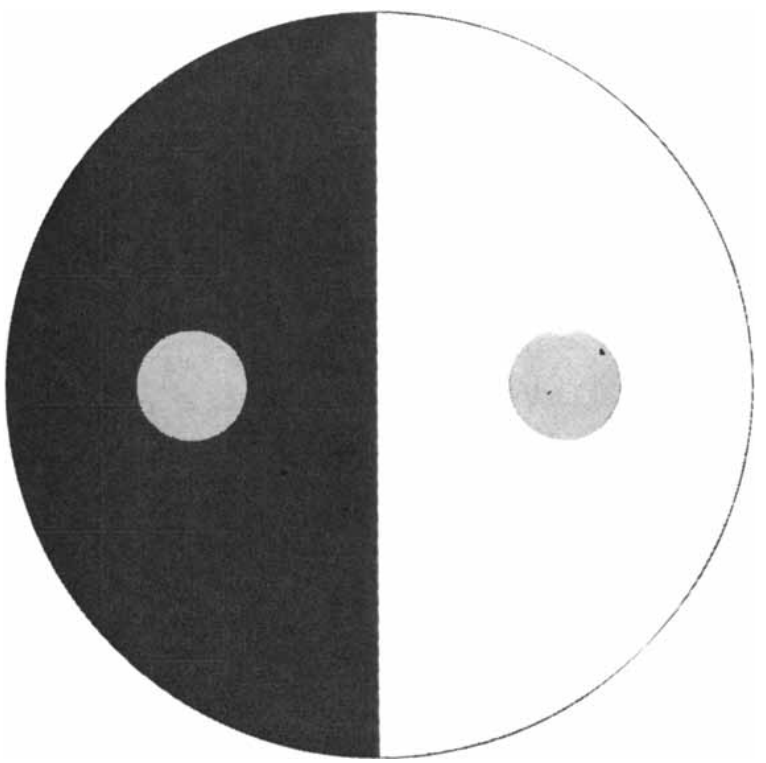
suddenly illuminated the area around the right-hand spot quite brightly, leaving the left-hand spot surrounded by darkness. Presenting this display to our pigeons, we asked them in effect to show by their pecking whether or not the left-hand spot looked brighter to them, as it did to us. Not knowing the answer, we no longer rewarded the birds; we could not tell them, they had to tell us.

Fortunately they would work for a time without food, being accustomed to intermittent rewards. Although somewhat taken aback by the bright surround, they continued to peck, attacking the left-hand panel—the one that appeared brighter to us. Each of the subjects quickly adjusted the intensities until the right-hand spot was much more intense than the left [*see illustration on next page*]. Then the subject proceeded to track around this point of inequality in the physical intensities. When the bright surround was turned off, the bird immediately returned the spots to their former equal intensities.

The results showed that tracking could be an extremely valuable technique in animal psychophysics, but the contrast experiment itself suffered from at least one serious flaw. Because the contrast situation was quite novel to the pigeons and rewards had to be cut off as soon as they encountered it, pecking slowed up drastically and stopped completely if the tests were repeated more than once or twice. I then became interested in a line of investigation in which this difficulty could be surmounted.

One of the basic psychophysical measures is the "absolute threshold," or smallest stimulus that can be detected. I decided to see if pigeons could be taught to track their visual thresholds in the same way that Békésy's human subjects had tracked their auditory thresholds.

For an experimental chamber my associates and I built a lightproof box with a single opening in one wall to admit the



BRIGHTNESS-CONTRAST effect is illustrated by the two gray spots in this illustration. They are of equal intensity, but the one on the white background looks darker than the other.

stimulus beam [*see illustration on page 120*]. To help the bird orient itself in total darkness we provided a partition with a hole for the subject's head. Standing with its head through the hole, a pigeon faced the stimulus spot a few inches away and brought its beak within reach of two response keys and a reward tray. The keys and light source were connected so that pecks on the bottom key (*A*) made the spot progressively fainter, whereas pecks on the top key (*B*) made it brighter. If the pigeon could learn to peck at key *A* as long as it could see the spot and at key *B* when the spot became too faint to see, it would drive the intensity up and down across its absolute threshold.

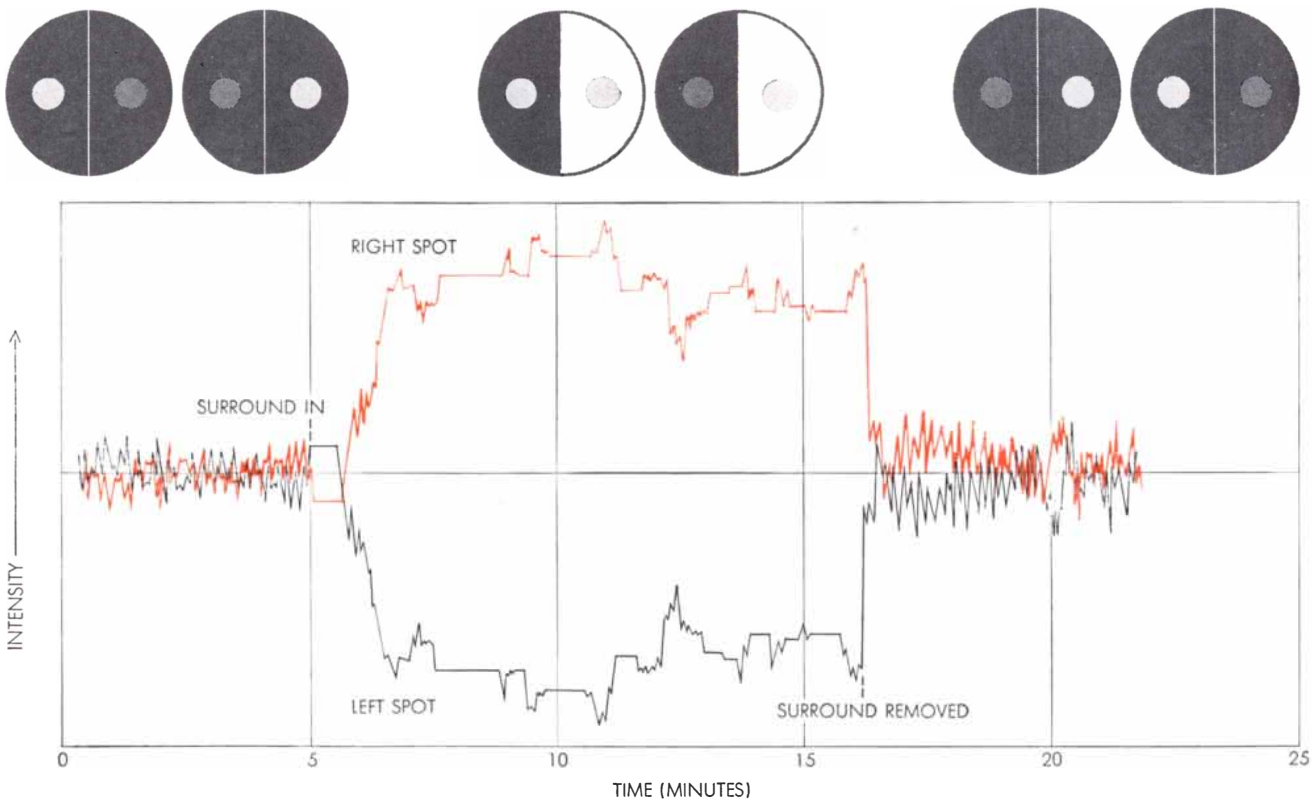
The tracking procedure was straightforward enough, but teaching pigeons to do it was not easy. First of all, they had to learn to work and eat in the dark instead of going to roost, as is their habit. We managed this by starting with an overhead light in the box and gradually dimming it during the course of several hours. They became surprisingly adept at finding grain in the dark; one of them consistently gained weight during the experiments.

A more serious problem was just when and how to present rewards. Essentially we wanted to reward key *A* pecks when the stimulus spot was visible and key *B* pecks when it was not. But we did not know when the stimulus was visible; indeed, that was the very thing we were trying to determine. We did know, however, that if the stimulus light was actually shut off, we could safely reward pecks on key *B* because the spot would then surely be invisible. As it turned out, this one certainty was all we needed to set up the bird's behavior on *both* keys. We inserted a shutter in the path of the light beam and closed it for intervals of time. During these times we provided a reward for pecks on key *B*. The disappearance of the spot came to signal the fact that food was available for key *B* pecks. According to a well-established principle of behavior, a stimulus that signals a reward in this way may itself be used as a reward—a "secondary" or "conditioned" reward. So we then applied this secondary reward—the disappearance of the stimulus spot—to keep the bird pecking at key *A*. That is, we closed the shutter in response to key *A* pecks; when the shutter was closed, key *B* pecks produced a reward. To anthropomorphize a bit, the bird pecked key *A* "to turn out the light" and key *B* "to get the food."

Constantly closing the shutter and feeding the bird, however, would make tracking of the threshold impossible. We therefore cut the number of rewards to a minimum. Pecks on key *A* closed the shutter only at random times, spaced an average of 20 seconds apart. When the shutter was closed, an average of nine pecks on key *B* (at a rate of perhaps five per second) was necessary to produce the food reward, and then the shutter reopened. Between the shutter closings tracking went on, pecks on key *A* making the stimulus dimmer and pecks on key *B* making it more intense.

Why did the bird ever shift from key *A* to key *B* during these intervals? Why didn't it keep pecking at *A* until it had obtained its secondary reward by closing the shutter? This is the basic point of the experiment: the bird could not tell the difference between the closing of the shutter and a simple drop in the intensity of the stimulus below threshold during tracking. The failure to discriminate between zero intensity and subthreshold intensities, in fact, defines the absolute threshold.

With practice, the pigeons did a beautiful job of tracking. Spurred on by an intermittent reward, they pecked away



PIGEON'S-EYE VIEW of brightness contrast is obtained by the tracking technique. When the backgrounds are the same, the bird keeps the intensities of the two spots about equal. But when the right-hand spot has a bright surround, it appears dimmer to the pigeon than the left-hand spot. To equalize the "brightness" the bird raises the actual intensity of the right-hand spot considerably.

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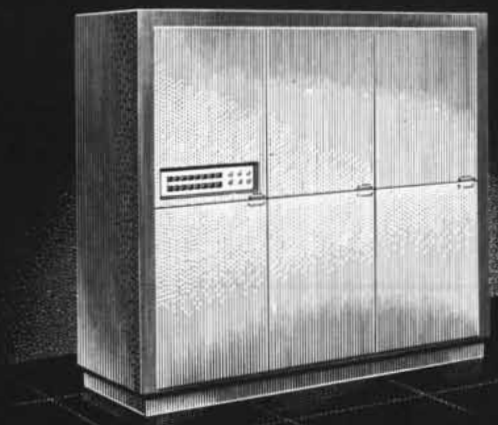

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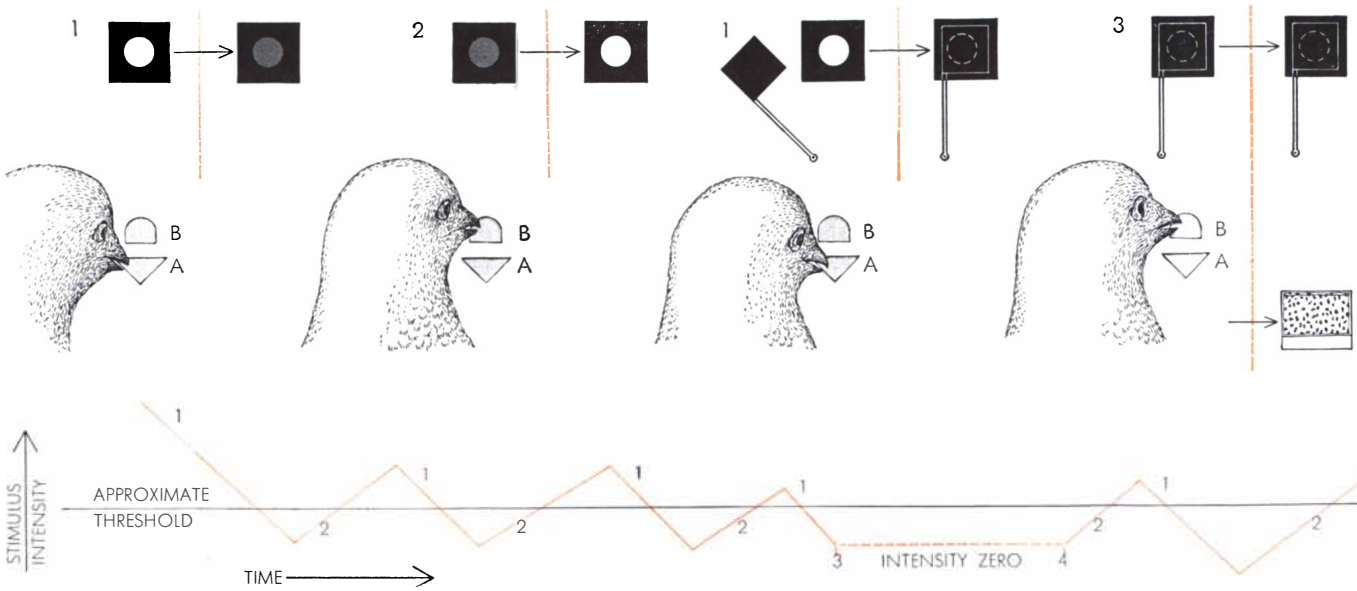
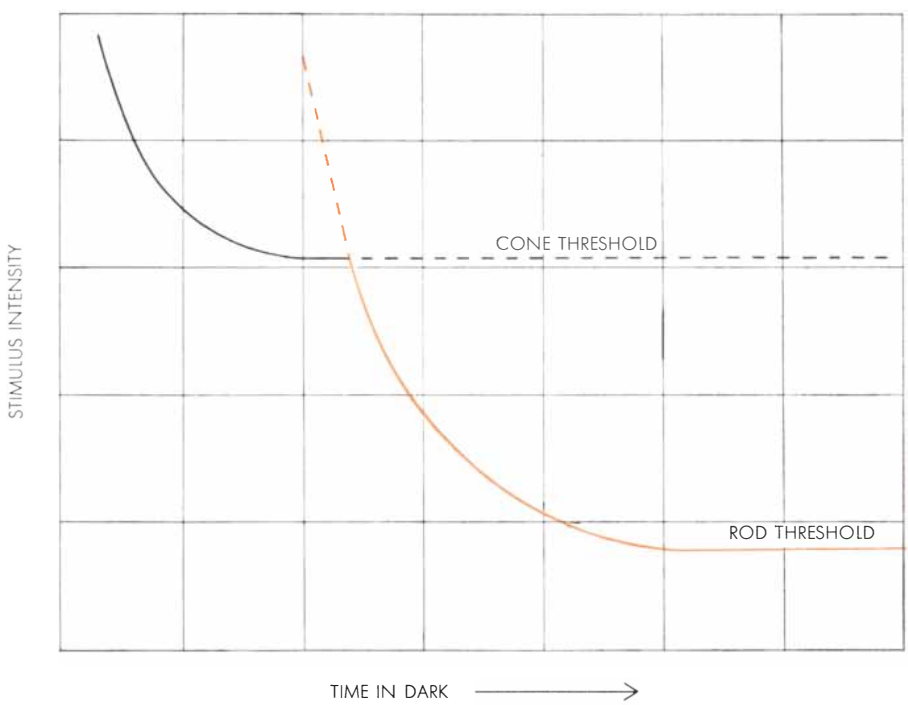


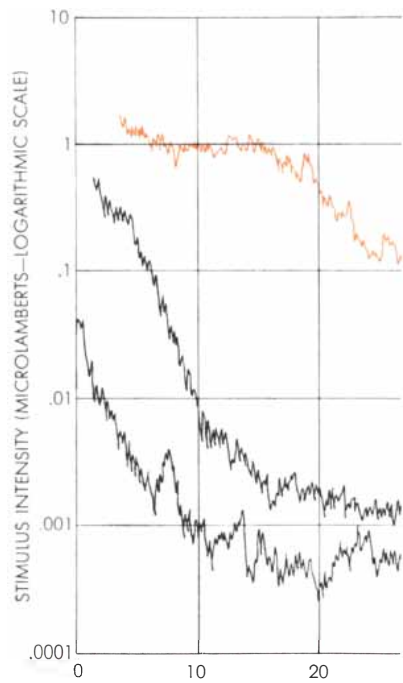
VISUAL THRESHOLD is determined by measuring the intensity of the dimmest light the pigeon can see. The bird is trained to peck key *A* when it can see the light, key *B* when it cannot. Most of the time key *A* pecks (1) drive the intensity down and pecks on key *B* raise it (2). A reward sequence is introduced at random intervals: as the bird pecks key *A* (1) a shutter closes (3), and pecks on

for hours with a patience we could only envy. They had their bad days, of course, but usually they seemed immune to the boredom and lapses of attention that plague human subjects and psychologists.

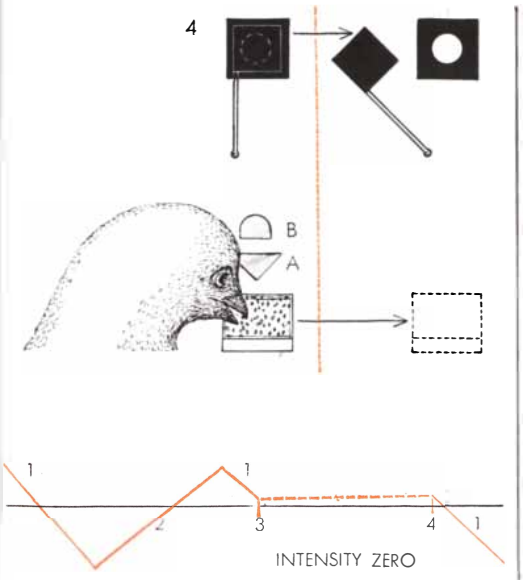
The first application of the pigeons' carefully cultivated threshold tracking ability was an experiment on dark adaptation, the process by which the eye increases its sensitivity in dim light. We are all familiar with the adjustment that takes place in a dark theater, for example, when we can see little at first but gradually make out more and more of the things around us. Dark adaptation is studied in the laboratory by tracing the visual threshold as it changes in the dark; the increasing sensitivity is represented by a decrease in the threshold.

The threshold curve for the dark adaptation of the human eye usually has a distinctive shape [*see chart at left below*]. During the subject's first few minutes in the dark his threshold falls rapidly, then the curve levels off for a while. Suddenly the threshold again drops precipitously and then it levels off gradually. The accepted explanation for this sequence is that the two seg-



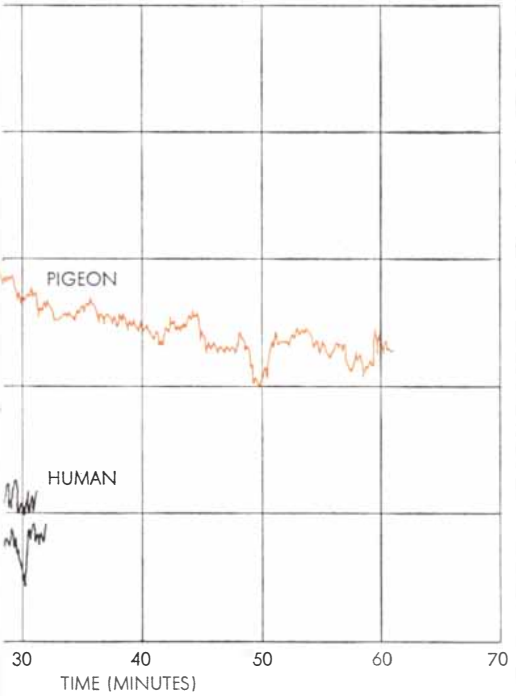


DARK ADAPTATION occurs in two stages, as shown by the chart at left. First the cone receptors in the retina reach maximum sensitivity, then the rods exceed them. The operative adaptation curve is shown by the solid lines. The chart at right compares dark adaptation in pigeons and man. The pigeon curve (*in color*) has a short cone segment and a long shallow rod segment. The lower human curve, made after the same pre-exposure as the pigeon curve (22 millilamberts), has no cone segment. Brighter pre-exposure

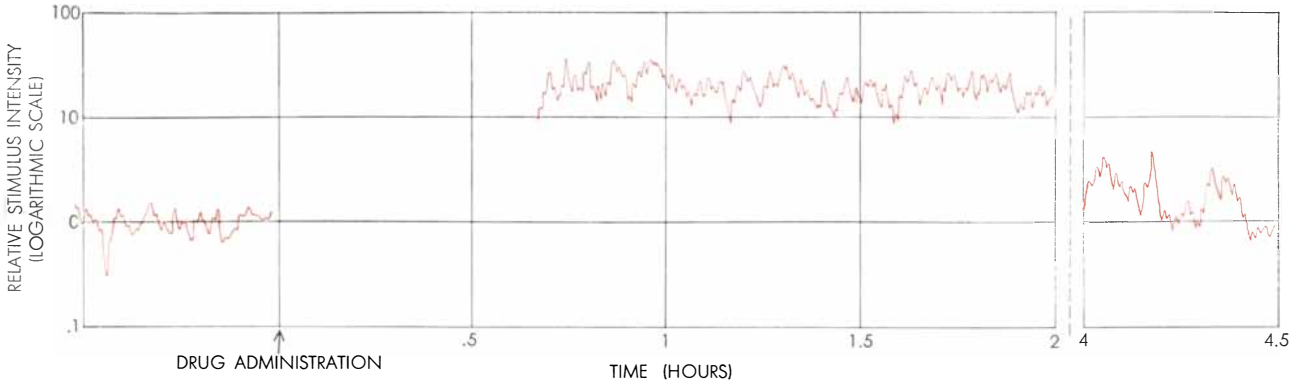


key *B* are rewarded by access to a pan of grain (4). Then the shutter reopens and the regular tracking procedure is resumed.

ments of the curve correspond to the two types of visual receptor in the retina—cones and rods. The cones are the less sensitive and carry the main burden of daytime and color vision. The rods, at their best much more sensitive than the cones, are specialized for night vision and do not distinguish colors. The first segment of the dark-adaptation curve apparently describes the activity of the



(343 millilamberts) brings out a short cone segment in the upper human curve. The curves reflect differences between pigeon and human retinal cells.



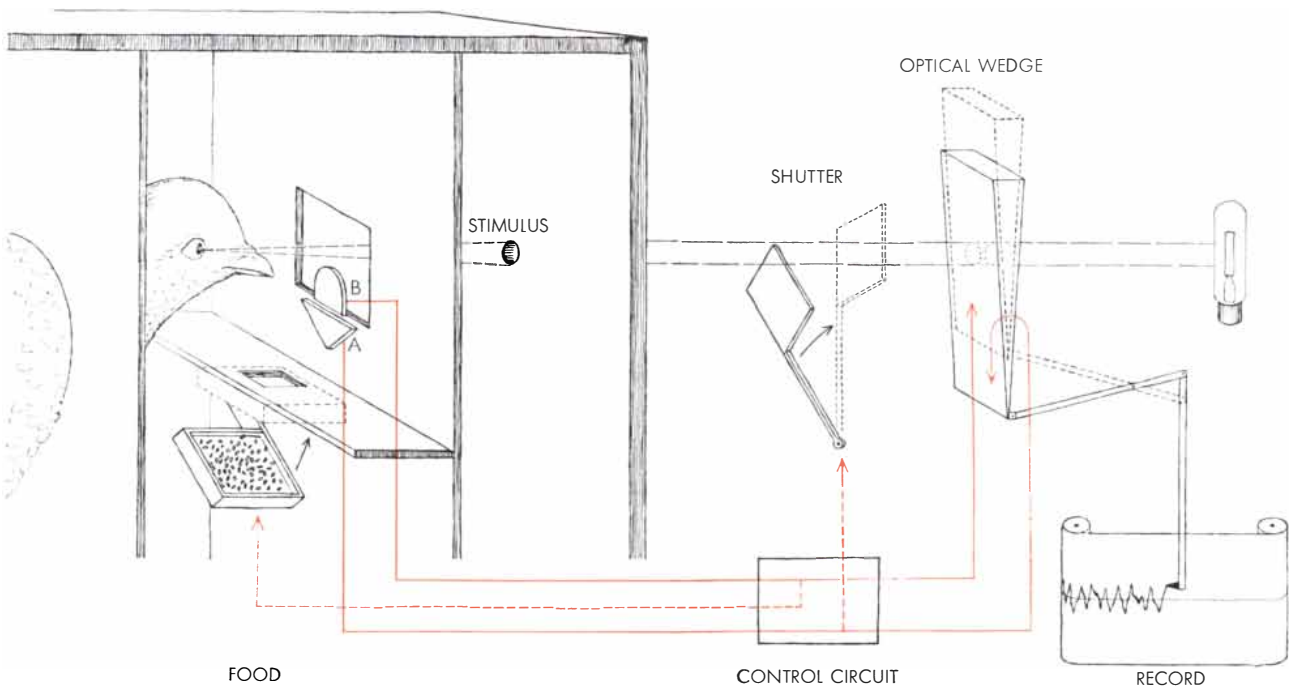
EFFECT OF A DRUG is measured by the tracking technique. The drug, lysergic acid diethylamide (LSD), reduces visual sensitivity. After tiny doses (300 millionths of a gram of LSD per kilogram of body weight in this case) the pigeons' threshold rose sharply.

cones, which quickly reach their maximum sensitivity. When the rods, adapting more slowly, exceed the cones in sensitivity, the second segment appears.

Counterparts of the human rods and cones are found in many species. Appropriately, nocturnal creatures such as the rat have many rods and few cones. Diurnal animals have many cones and may have no rods at all. Rods far outnumber the cones in the human eye; the pigeon, which is quite inactive at night, has fewer rods. This suggests that the pigeon's curve of dark adaptation may have a more prominent first segment and a shallower second segment than the curve for human beings has.

To measure adaptation in pigeons we put them for a time in a box with evenly illuminated white walls, then moved them to the experimental apparatus, where they tracked their visual thresholds as their eyes adapted to the darkness. After a 10-minute exposure to a brightness of 22 millilamberts (roughly the brightness of a piece of white paper in reading light) they produced a clearly segmented threshold curve. In one typical case the first, or cone, segment lasted 15 minutes and the second, or rod, segment took almost an hour to level off [*see illustration at bottom of pages 118 and 119*]. To get comparable data for the human eye I tested myself in as similar a way as possible—pressing telegraph keys, however, rather than pecking. My threshold curve dropped to a minimum in 15 minutes and showed no cone segment. Only by exposing myself to a much brighter light (343 millilamberts) could I hold off my rod adaptation enough to reveal a brief cone segment. My rod segment, on the other hand, fell farther than the pigeon's. All in all, the differences were about as expected.

The next series of experiments concerned the sensitivity of the pigeon's eye to different wavelengths of light. Measurements on the human eye had demonstrated that cones and rods have their maximum sensitivity in different regions of the spectrum: the cones are most sensitive to yellowish-green light with a wavelength near 555 millimicrons



EXPERIMENTAL SETUP for threshold tracking is illustrated schematically. The pigeon faces a stimulus light the intensity of which is decreased by pecks on key *A* and increased by pecks on key *B*. Once in a while key *A* pecks close the shutter, and key *B* pecks then bring access to the food reward. The full sequence of events in this procedure is shown by illustration on preceding two pages

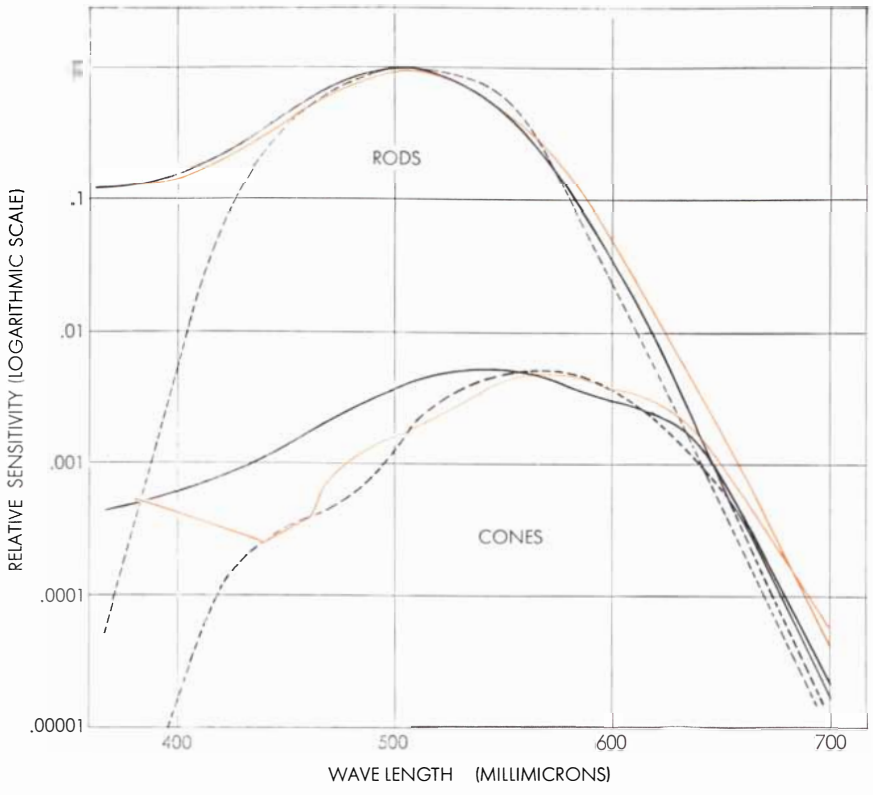
(millionths of a millimeter); the rods, to a blue-green light near 510 millimicrons.

To obtain comparable data for the pigeon we repeated the dark-adaptation tracking procedure, but instead of using white light we projected 15 different spectral colors with wavelengths spaced evenly across the visible range from 380 to 700 millimicrons. The first short, flat portion of each threshold curve represented the maximum sensitivity of the cones at that particular wavelength; the final flat section, the maximum sensitivity of the rods. Combining the values obtained from all the curves, we could plot the pigeon's spectral sensitivity for cones and rods. An average of the results for three test birds gave maximum rod and cone sensitivities at about the same wavelengths as with human subjects [*see top illustration on next page*].

A comparison of the complete sensitivity curves shows that pigeons are a good deal more sensitive than normal people in the short-wavelength, or violet, portion of the spectrum. This is apparently due to a filtering action of the lens in the human eye; the human lens, unlike the lens of the pigeon, has a yellowish cast and therefore absorbs much of the violet light. People who have had their lenses removed, usually because of cataracts, can see more violet (and even some ultraviolet) light. The sensitivity curve of such "aphakic" subjects matches the pigeon's curve rather closely.

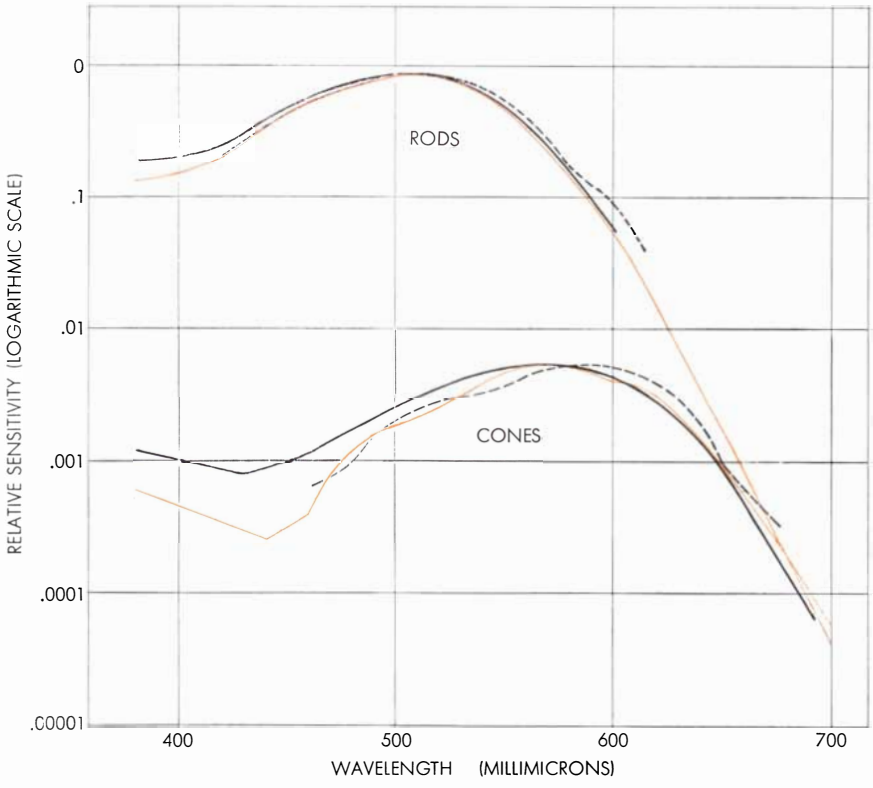
Spectral sensitivity can be measured in ways other than by our psychophysical technique, particularly in animals. At the Royal Caroline Medico-Surgical Institute in Stockholm, Ragnar Granit and K. O. Donner used an electrophysiological method. They inserted electrodes into the eyeballs of pigeons, exposed the birds to light of various wavelengths and recorded the electrical responses of cells closely connected to the receptor cells of the retina. Another approach has been to study the light-sensitive pigments in cones and rods. These pigments absorb more light at some wavelengths than at others, and their absorption curves are probably the ultimate basis for the spectral sensitivity of the eye. One such pigment—rhodopsin, or "visual purple"—is found in both human and pigeon rods. The characteristics of human cone pigments are not known with certainty, but a cone pigment called iodopsin has been extracted from the eyes of pigeons and other animals. George Wald of Harvard University has determined the absorption spectra of rhodopsin and iodopsin from the eyes of chickens.

Our tracking experiments provided a



PIGEON
APHAKIC HUMAN
NORMAL HUMAN

SPECTRAL SENSITIVITY of pigeons is compared with that of normal humans and of "aphakic" humans who lack the lens of the eye. The latter are more sensitive than normal to violet light, and their curves are similar to a pigeon's.



BEHAVIORAL METHOD
PHOTOCHEMICAL ABSORPTION
MICROELECTRODE METHOD

PIGEON COLOR SENSITIVITY is charted, based on three methods. Similar results were obtained from psychophysical tracking, retinal-pigment absorption and electric currents in optic-nerve cells.

unique opportunity to combine three types of data—psychophysical, electrophysiological and photochemical—for a single species. We plotted our pigeon curves again [*see bottom illustration on this page*] and this time matched to them, with peaks coinciding, the two other sets of curves: the electrical impulses recorded directly from the pigeon retina and Wald's absorption spectra for rhodopsin and iodopsin. The curves match surprisingly well, although there is a noticeable discrepancy in the short wavelengths between the curves for iodopsin and for psychophysical cone sensitivity. This probably results from the presence in the pigeon's cone receptors of tiny colored droplets of oil, which seem to act as color filters and absorb a good deal of light at short wavelengths.

At about the time that our birds finished pecking out their spectral-sensitivity curves, we heard some interesting reports about a new drug, lysergic acid diethylamide (LSD). This substance was attracting wide attention because in humans it could produce hallucinations and other symptoms of mental illness. In experiments on human subjects it had been found that minute doses of LSD somehow disrupt the visual system and reduce visual sensitivity. We decided to give the pigeons some LSD and see what happened.

After administration of the drug the birds sometimes stopped pecking for a time, but when they went back to work, they showed a marked decrease in sensitivity [*see illustration at top of page 120*]. A dose of only 100 millionths of a gram per kilogram of body weight was enough to raise the threshold an average of tenfold. In other words, the dimmest light the birds could see at the height of the drug's effect was about 10 times as intense as the dimmest they could see normally. Their sensitivity began to recover about four hours after receiving the drug, and by the next day it was normal. This striking, reversible effect of such tiny doses suggests that LSD could be a helpful tool in studying the transmission mechanisms of the visual system.

Tracking is, of course, adaptable to other animals. At Brown University, Allan Schrier and I are now adapting the method to test the visual capacities of monkeys; elsewhere several species of animal are tracking a variety of characteristics, both visual and auditory. Other powerful techniques are being developed. It seems clear that animal psychophysics will make a substantial contribution to psychological research.

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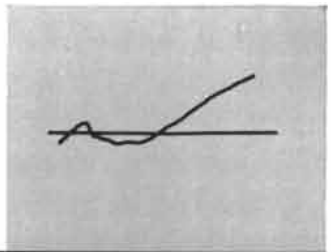

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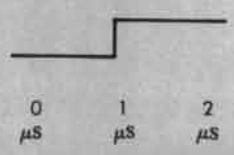

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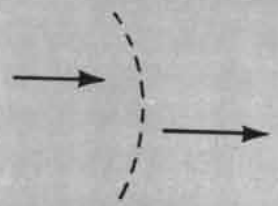

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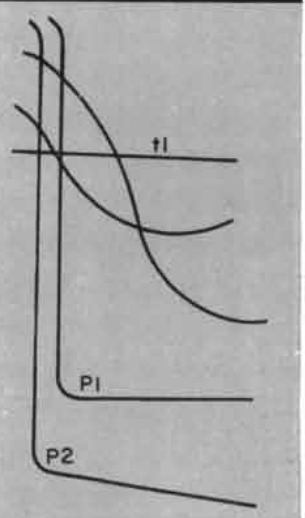

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All necessary control actions are initiated to bring process back to normal

PANIC-PROOF

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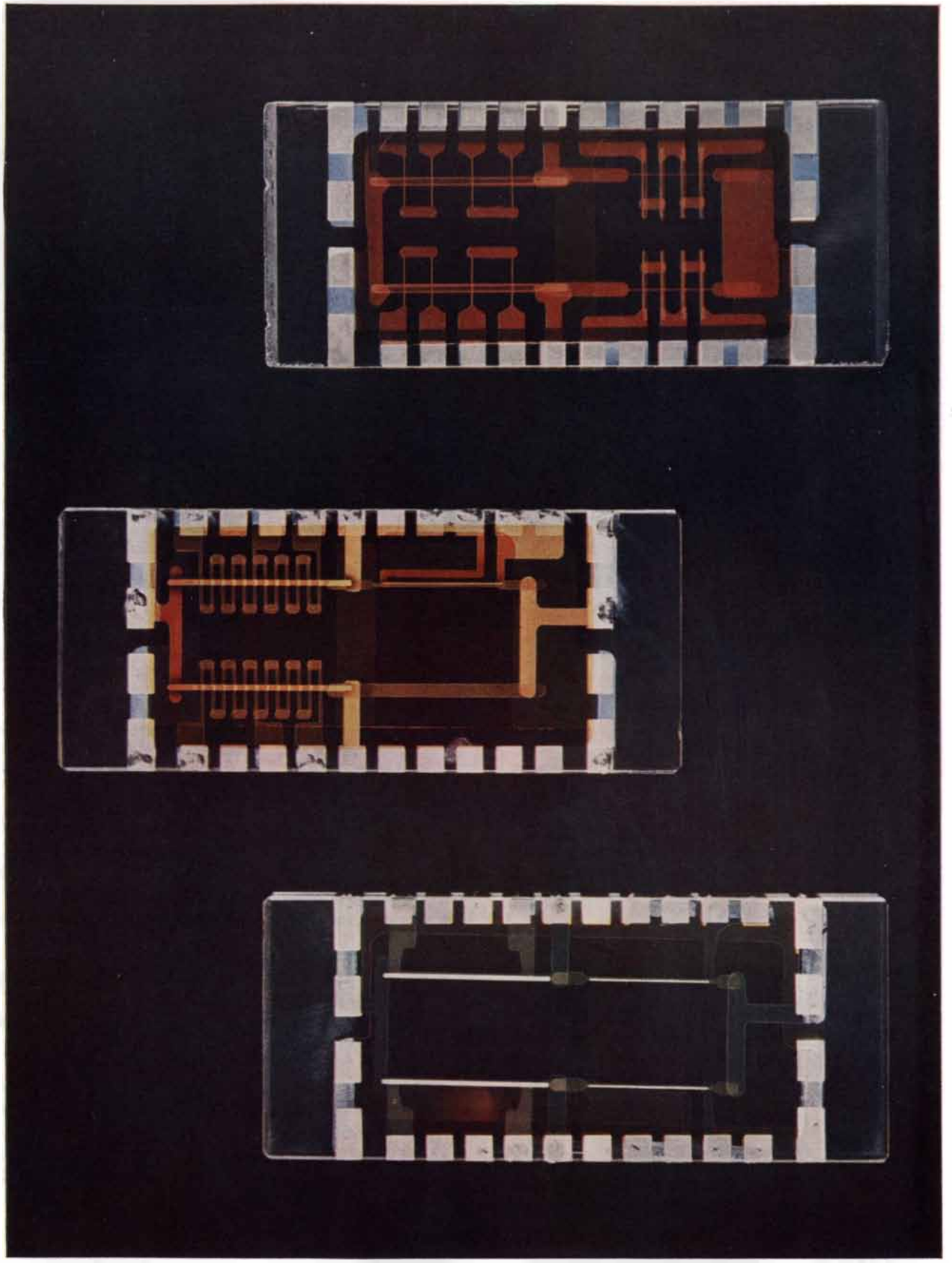


CRYOTRON CIRCUITS are made by condensing vapors of superconducting and insulating materials on glass plates. The colored bands in these photographs are films of lead and tin. Colors, like those in oil films, are produced by interference effects in the thin films. The three circuits are different versions of a switch, or "flip-flop," in which current is switched between upper and lower branches of the horizontal rectangular loops by the action of control films that cross the branches in upper two circuits and lie along them in bottom one. Top circuit switches in one microsecond; middle circuit, in .3 microsecond; bottom circuit, in .002 microsecond.

SUPERCONDUCTING COMPUTERS

The demand for computers of greater capacity calls for smaller and faster computer elements. One approach to the problem is to design elements that take advantage of the phenomenon of superconductivity

by William B. Ittner III and C. J. Kraus

The designer of computers sometimes feels like a mountain climber threatened by an avalanche of his own making. In this case it is an avalanche of numbers. Each advance in the art of high-speed computers has loosed a rush of numerical data and new problems from science, engineering and business. To take one example, solid-state physicists can now attack certain important questions concerning diffusion that they could not have touched a few years ago. To solve such problems, however, requires several months of continuous running time on a large computer. To keep pace with the mounting demand it will soon be necessary to have computers with hundreds—even thousands—of times the capacity of the huge machines now in existence. It is probably not an exaggeration to say that the present rate of scientific and technological progress will not be maintained unless such computers are developed.

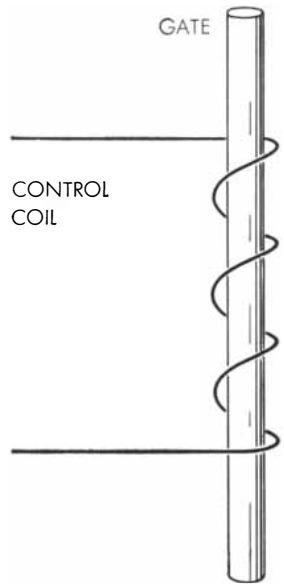
With refinements in design and in programing technique the basic elements in present computers can be made to perform substantially more efficiently than they do now, but not by a factor of hundreds or thousands. That will be accomplished only through radically new devices for carrying out the fundamental operations of digital computation. Workers in many laboratories are searching the broad field of solid-state electronics for such devices. This article will discuss the idea of superconductors as computer elements—an attractive possibility that the authors and others have been investigating for several years.

Although it is half a century since the Dutch physicist Heike Kamerlingh Onnes discovered superconductivity, the phenomenon is only now on the threshold of any practical exploitation [see "Applications of Superconductivity," by Theodore A. Buchhold; SCIENTIFIC AMERICAN, March, 1960]. The late Dudley Buck, a young electrical engineer at the Massachusetts Institute of Technology, first pointed out in 1956 that certain properties of superconductors make them well suited for use in computer circuits.

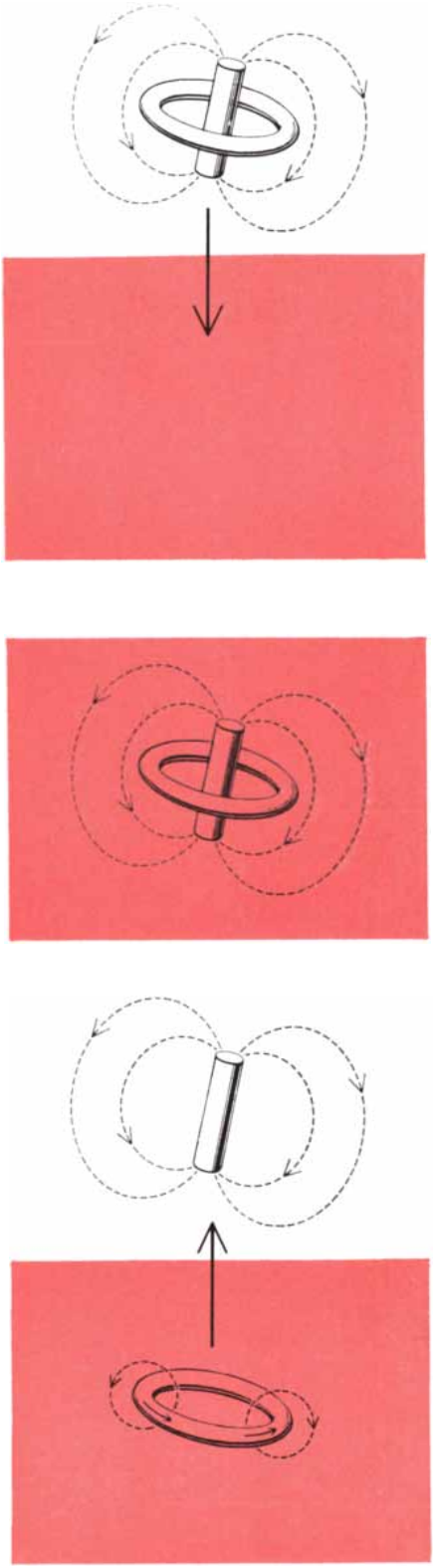
First of all, of course, there is the central fact of superconductivity: that the electrical resistance of many substances disappears completely at temperatures near absolute zero. The critical temperature at which this happens is different for each superconducting element and compound, varying from a fraction of a degree to about 20 degrees Kelvin (degrees centigrade above absolute zero). Secondly, the superconducting state is destroyed by a sufficiently strong magnetic field, either applied from the outside or generated by current in the conductor itself. The critical field strength for every material is greatest at zero degrees and decreases to zero at the so-called critical temperature [*see top illustration on page 128*].

As long ago as 1935 J. M. Casimir-Jonken and W. J. de Haas of the Kamerlingh Onnes Laboratory in Leiden built a simple switch based on this action. They wound a thin wire made of one superconducting material around a length of insulated, thicker wire made of another [*see illustration at right*]. The materials were chosen to make the critical field of the thin wire much greater than that of the thicker one. Hence the Dutch workers could design an arrangement in which a supercurrent through the winding produced a magnetic field strong enough to destroy the superconductivity of the central wire but not of the winding itself. They had made a relay: current in one circuit controlled the resistance of a second, switching it from zero to a finite value.

No one paid much attention to the device until Buck saw its possibilities. A digital computer is essentially an enormous switching network in which each element can have two positions corresponding to the binary digits 0 and 1. Superconducting switches, which Buck named cryotrons, offered several potential advantages, as will be shown later. In his version a winding ("cryotron control") of niobium switched a central wire ("cryotron gate") of tantalum. He adjusted the diameter and geometry of the wires so that the control current necessary to switch resistance into the gate was less than the current that the gate itself could carry without losing its superconductivity. Thus



ORIGINAL CRYOTRON consisted of a thin wire of niobium (*control coil*) wound around a thicker wire of tantalum (*gate*). Supercurrent flowing through control coil produced a magnetic field strong enough to destroy the superconductivity of the gate.



SUPERCONDUCTING LOOP maintains a constant magnetic field within itself, as demonstrated in a three-step experiment: (1) bar magnet is inserted in ring at room temperature (*top*); (2) combination is put into liquid helium (*color*) and ring becomes superconducting (*middle*); (3) magnet is withdrawn (*bottom*), inducing a supercurrent in the ring, which continues to flow indefinitely, creating a magnetic flux equal to that produced by the magnet.

the device had "gain": a smaller current controlled a larger one. This meant that the gate current of one unit could operate the control of a second, the gate current of which could serve in turn to control a third, and so on indefinitely. A network could be built entirely of cryotrons, without the need for auxiliary amplifiers.

Buck showed how to make a number of simple, typical computer circuits out of cryotrons. In most of them the elementary unit is not a single switch but a pair of switches, usually connected to form a loop [*see illustration on opposite page*]. The behavior of this fundamental circuit depends on another relation between superconductivity and magnetism: the magnetic flux, or total number of lines of force, passing through a superconducting loop can never change. To understand why it cannot, recall that whenever the flux through any closed conducting circuit is changed, for example by inserting or withdrawing a magnet, a current is induced. This current sets up a magnetic field of its own, oriented in such a way as to oppose the change. In a normal conductor some energy goes into overcoming electrical resistance, so that the induced field is always a little weaker than the inducing field. And as soon as the change in the inducing field stops, the current rapidly dies out.

In a superconductor, on the other hand, no energy is wasted by resistance, and the induced field essentially cancels the inducing one. Moreover, once a current is started it continues indefinitely. If a magnet is pushed into a superconducting ring, the resulting current produces a persistent field that cancels the field of the magnet. In short, no net flux can be inserted through the ring. Conversely, if the magnet is inserted before cooling the ring to the superconducting state, the field that is present at the time the material becomes superconducting is trapped. When the magnet is withdrawn, the induced current produces a flux of the same amount and direction as the flux that was originally provided by the magnet.

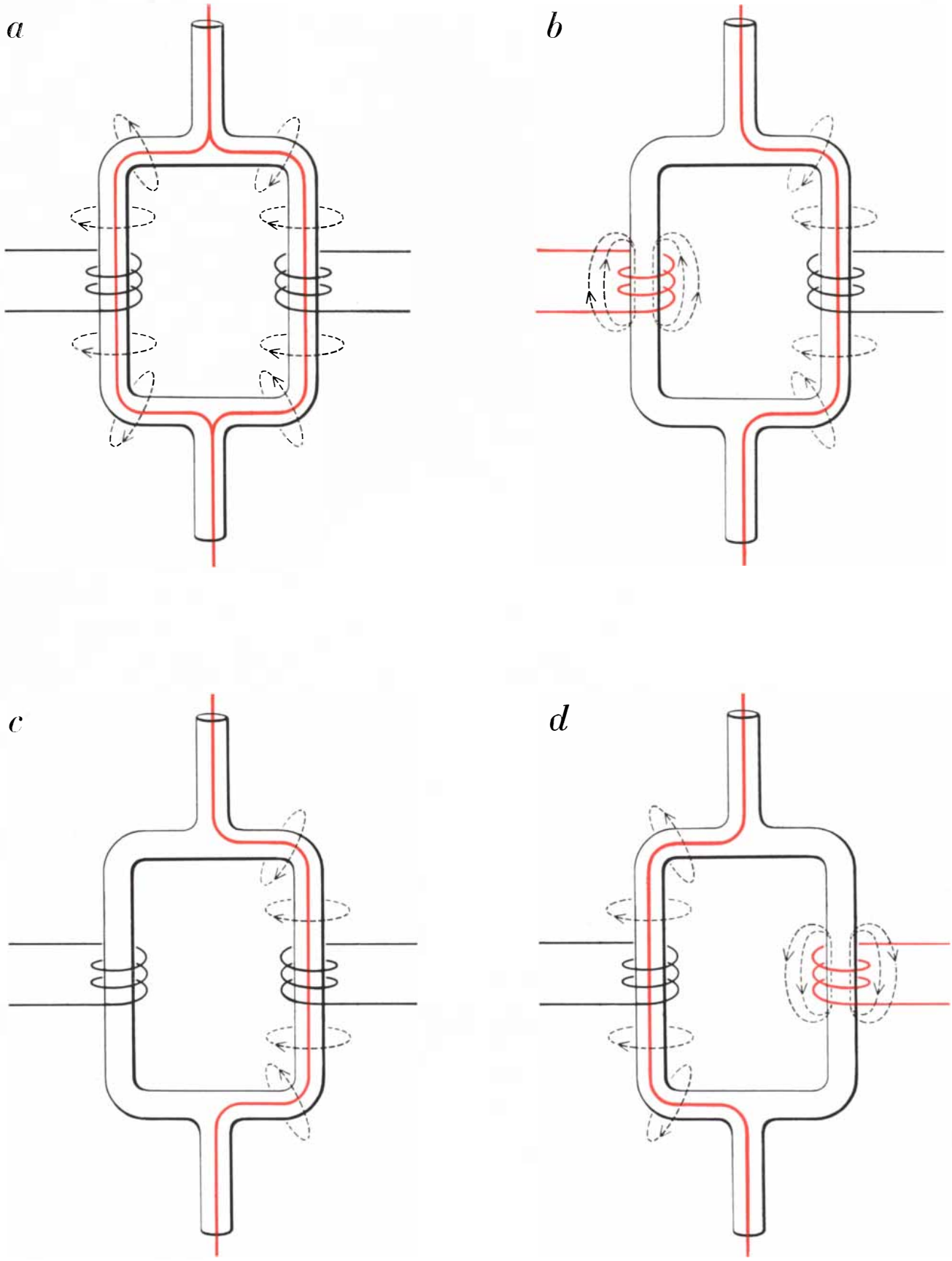
The last experiment, incidentally, was devised by Kamerlingh Onnes to determine if the resistance of a superconductor is really zero or simply too small to measure by ordinary means [*see illustration at left*]. He inserted a bar magnet into a ring, immersed the combination in a bath of liquid helium and then pulled out the magnet. Thereafter he tested the strength of the magnetic field around the ring from time to time and never detected any decrease. In 1955 Samuel C. Collins of M.I.T. performed a similar experiment, using the most sensitive instruments available. He kept it running for more than two years and he too could find no evidence of a drop in the current. For all practical purposes the resistance of a superconductor to the flow of direct current is indeed zero, and there is no theoretical reason to believe that any unmeasurably small resistance exists.

To return to the cryotron loop, consider its operation through a complete cycle. Originally there is no current through either of the parallel gates or through either control winding [*see illustration "a" on opposite page*]. All parts of the circuit are superconducting and the magnetic flux through the loop is zero. Now a current is sent through the line supplying the loop. Since the loop is symmetrical, the current must be divided equally between the two branches; in this way the field set up in the loop by one branch exactly cancels the field set up by the other, keeping the net flux equal to zero [*illustration "b"*]. Then a control current is allowed to flow through one of the cryotron control windings, say the left-hand one. The gate of the winding becomes resistive and the current that had been carried by the left side of the loop switches to the other side, which is still superconductive. With all the current flowing through the right-hand branch, there is now a net field through the loop [*illustration "c"*]. The flux has changed, but only because the superconductivity of the complete loop was destroyed.

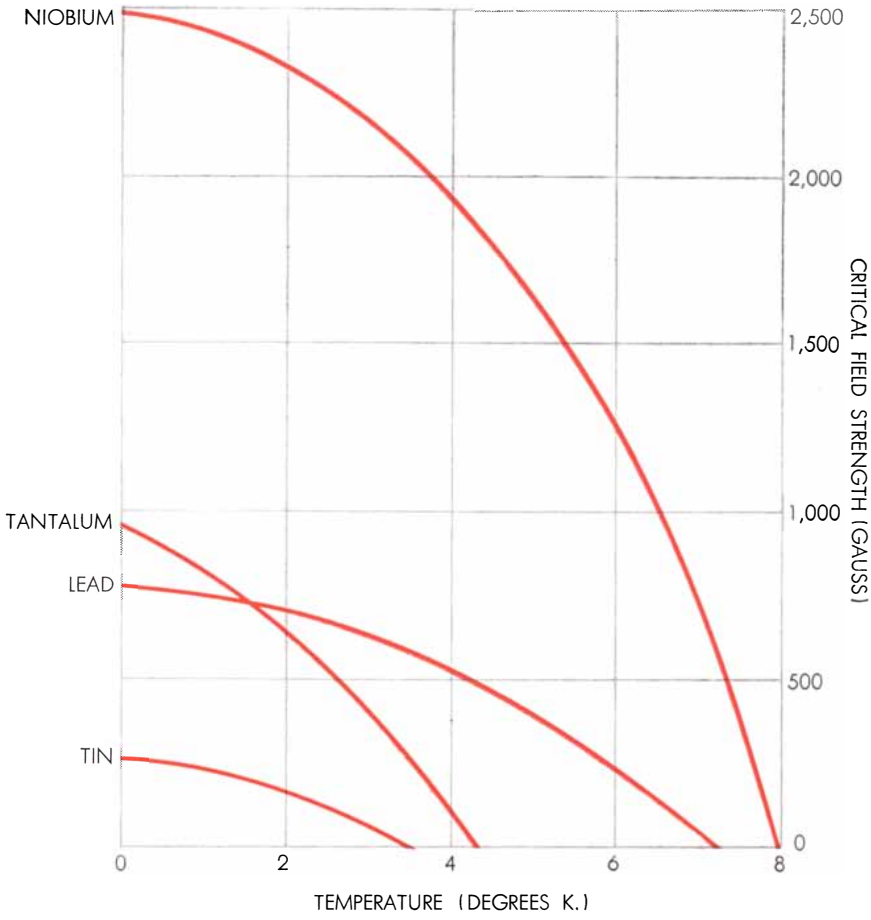
When the control current is turned off, the entire circuit again becomes superconducting, and the flux through the loop is trapped. This means that all the gate current must continue to flow through the right-hand side; if it were to divide in any way, the net flux would not remain constant. The only way to change the pattern is to actuate the right-hand control winding, switching resistance into this gate and thereby flipping the current to the left-hand side [*illustration "d"*].

The cryotron loop is a circuit element that has two stable conditions, and it can be switched repeatedly between one and the other. It therefore serves to register and to "remember" one binary unit ("bit") of information: current in one branch represents 0; current in the other branch, 1.

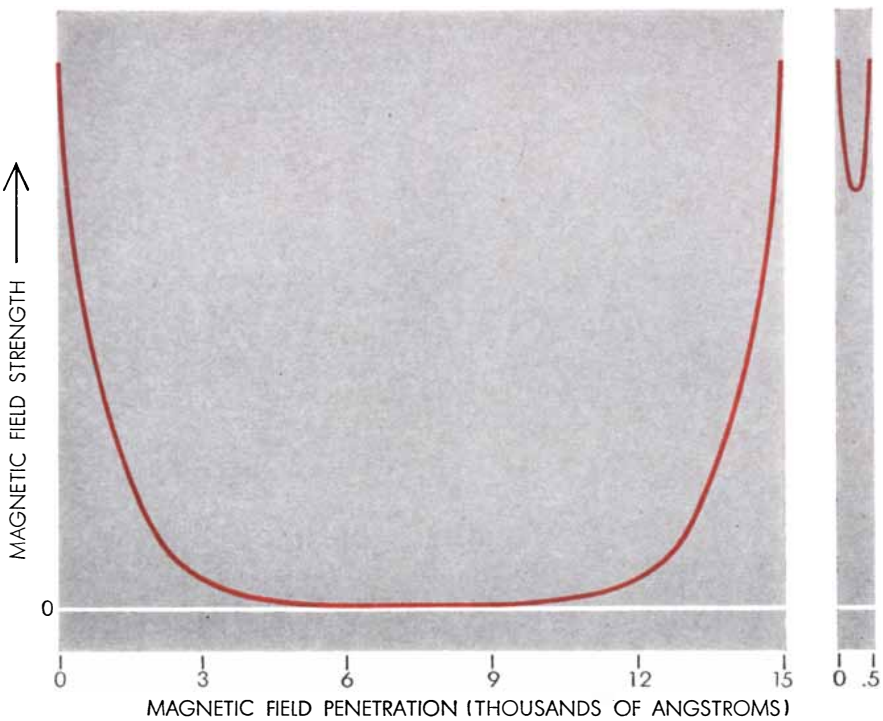
The foregoing description has glossed over one important point: When a gate becomes resistive, the current through it does not stop immediately. Instead it



CRYOTRON LOOP is the fundamental element in many computer circuits. Helices represent control coils; thick tube, the gate conductors; colored lines, electric current; broken lines, magnetic flux. In drawing *a* current divides between two gates so that flux from left-hand branch cancels flux from right-hand branch. In *b* a current through left-hand control puts resistance into its gate, switching all gate current to right. In *c* control current is removed, and left-hand gate becomes superconducting again. Gate current stays on the right, so that the net flux that now threads the loop does not change. In *d* current is switched to left-hand gate.



CRITICAL FIELD STRENGTH at which superconductivity is destroyed decreases as temperature increases. The curve of a material used in a cryotron control must lie above the curve of the gate material. In typical film cryotron control is lead and gate is tin.



MAGNETIC FIELD PENETRATES superconductors only a small distance below the surface. Shaded area at left represents, in cross section, a superconducting plate 15,000 angstrom units thick; the area at right represents a thin film 500 angstroms thick. Colored curves show the field strength at points inside compared with maximum value at the surface.

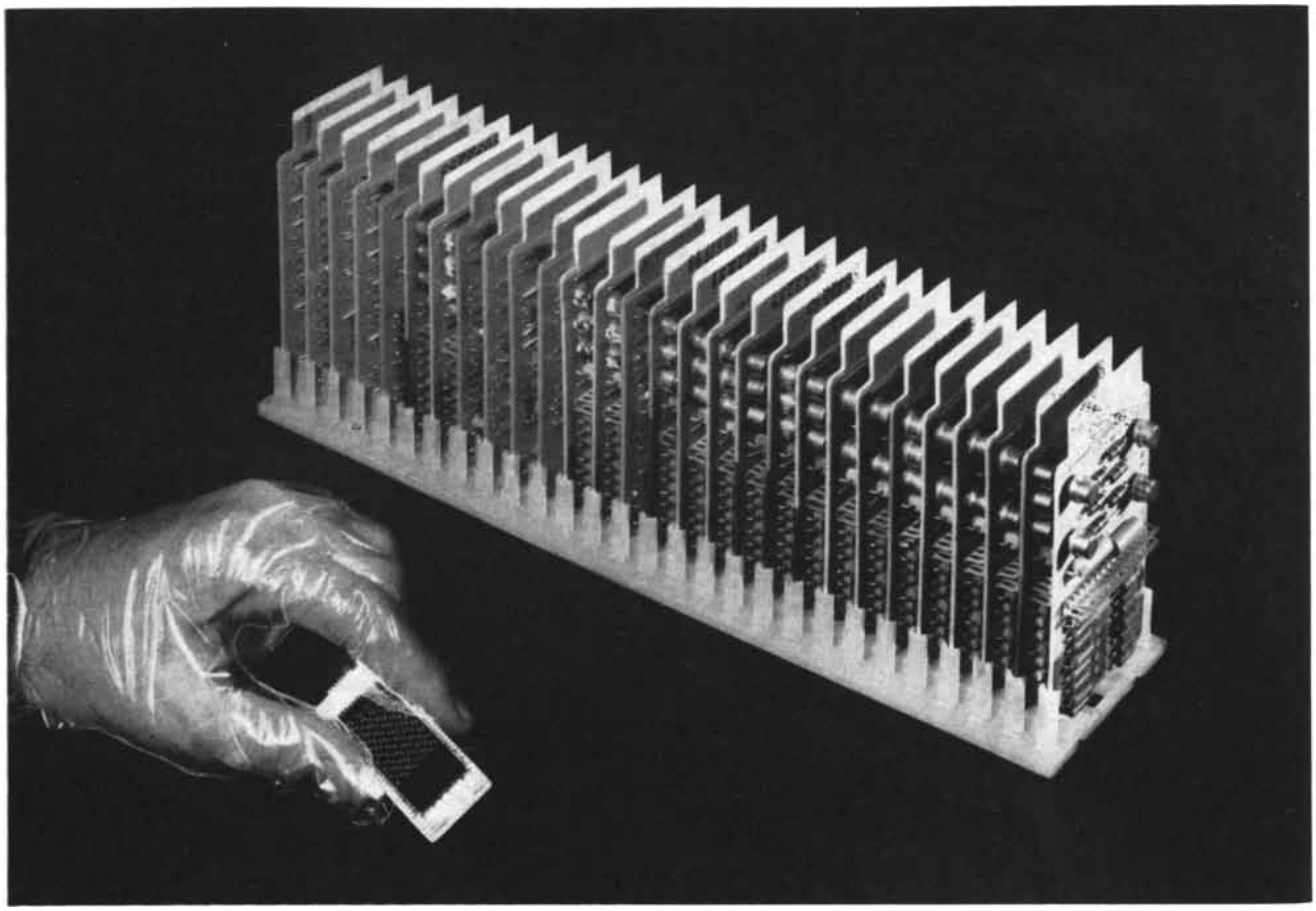
decays over a period of time determined by the amount of resistance in the gate and by the inductance of the circuit. Inductance, or self-induction, refers to the interaction of a conductor with the magnetic field of its own current. As in the case of induction by an external field, the interaction always opposes change: self-induced voltage pushes against a rising current but tends to prolong a dying one. In short, it furnishes a sort of electrical inertia.

Both resistance and inductance depend on the size of the conductor. The thicker a wire, the smaller its resistance; the greater its length, the greater its inductance. Therefore in general it takes longer to switch a large loop than a small one. Buck's original cryotron gate was about .25 millimeter in diameter, and his loop took several hundred microseconds to switch. The transistors in present computers do considerably better, and wire-wound cryotrons consequently have little practical interest.

To achieve shorter switching times cryotrons are now made of flat films only a few thousand angstrom units thick. (An angstrom unit is one ten-millionth of a millimeter.) These films have hundreds of times the resistance of bulk wires. Moreover, their inductance can be substantially reduced by mounting them over superconducting base plates. The effects combine to give current transfer times of the order of a billionth of a second, which is quite good by the standards of present commercial computer technology.

The reason that a base plate decreases inductance is to be found in another aspect of the magnetic effects discussed earlier. Whenever the lines of force of an external field impinge on a conductor, eddy currents start to flow near the surface, producing, as always, a field that opposes or cancels the outside field. In a normal conductor the currents quickly dissipate, and the external field penetrates the material. In superconductors the eddy currents keep on flowing, permanently barring the penetration of the field beyond a depth of about 500 angstrom units [*see bottom illustration at left*]. The surface is in effect a reflector of magnetic fields.

Placing such a reflector near a superconducting ribbon that is carrying a current confines the field surrounding the ribbon into the narrow gap between the surfaces. As a result of this compression the total flux that is produced by a given current decreases, with a corresponding decrease in the self-induction of the circuit.



CRYOTRON MEMORY CIRCUIT (*in hand*) **is compared with transistor circuit performing similar switching functions. Glass plate on which the superconducting films are deposited is 2⅜ inches long, 1 inch wide and .04 inch thick. It contains 135 cryotrons.**

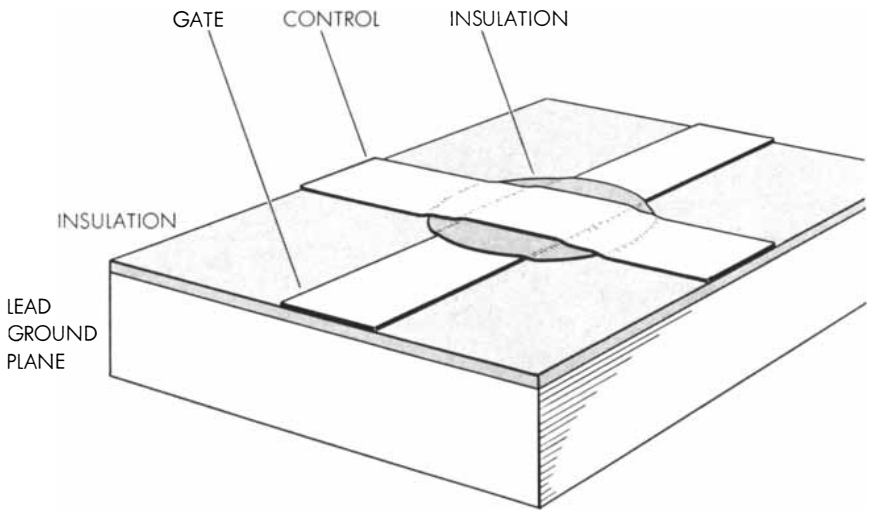
A film cryotron, then, is a three-decker sandwich, with three superconducting layers—base plate, gate and control—surrounding two layers of insulation [*see illustration at bottom right*]. Instead of coiling around the gate the control simply crosses it at right angles. Gain is obtained by proper choice of width for control and gate. The narrower a strip, the stronger the field set up around it by a given current. Therefore a small current in a narrow control film can switch resistance into a wider gate that carries a larger current.

What are the advantages of cryotrons? First, their switching time, in small loops, is short. In this essential respect, however, they do not excel a number of other elements currently under development.

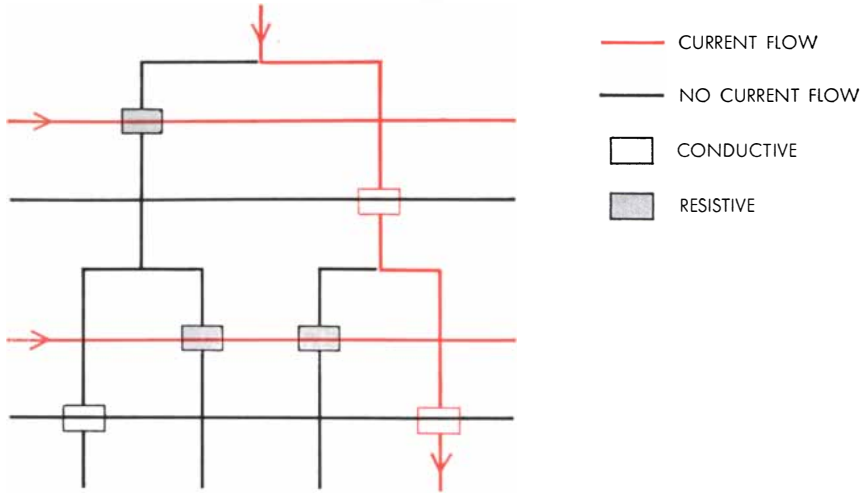
Second, they consume only tiny quantities of energy. A cryotron loop in either of its superconducting equilibrium conditions dissipates no power at all. Only during the very short interval when dying current continues to flow through a resistive gate is any energy consumed. The amount is so small that a network of a million cryotron loops, each being switched 10 million times a second, would require about one watt of power!

Third, strip cryotrons are small. The upper circuit shown on the cover of this issue of SCIENTIFIC AMERICAN is a plate 2⅜ inches long, 1 inch wide and .04 inch thick. It contains 135 separate cryotrons. Hence it is physically possible to put a very large number of cryotrons in a small space. Because of their relatively low power dissipation this can be done without causing overheating.

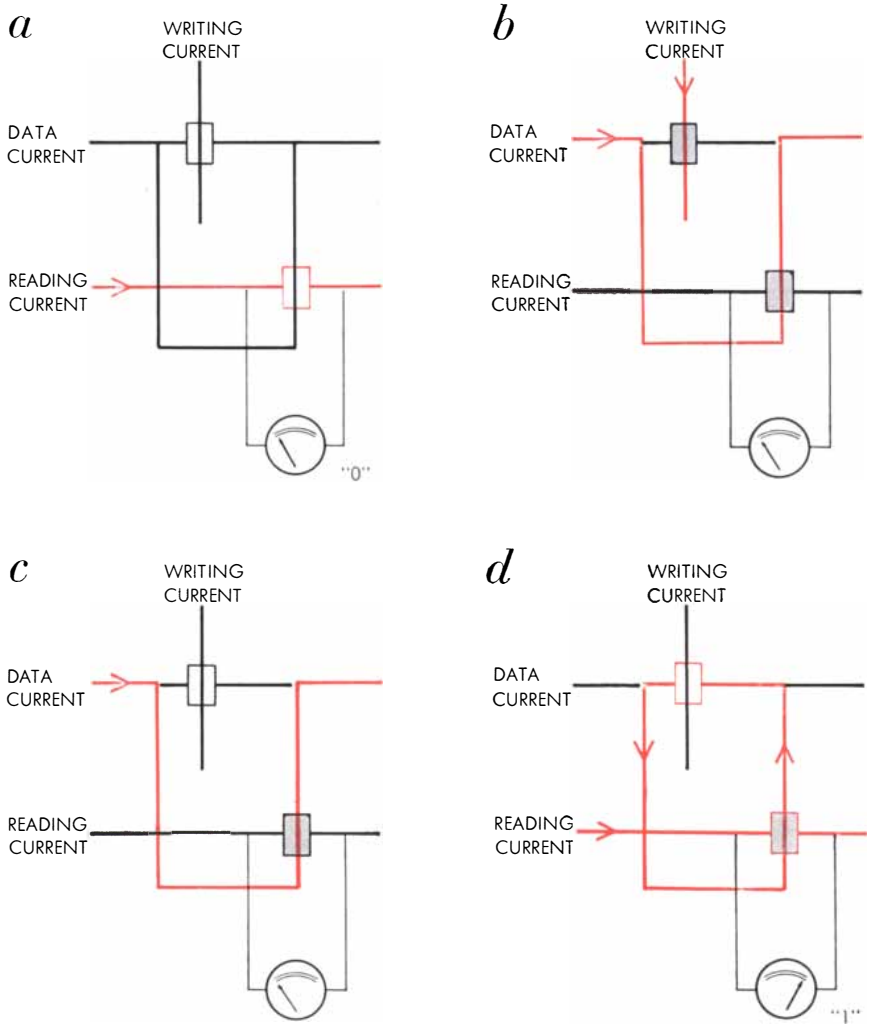
As computers grow larger and switches become faster there will be an increasing premium on compactness: the time



FILM CRYOTRON consists of a pair of superconducting strips that cross at right angles and are insulated from each other and from a thicker superconducting ground plane. Usually the control film and ground plane are lead, the gate film is tin and insulation is silicon monoxide.



CRYOTRON "DECODER," essentially a branching network of switches, is an example of a superconducting computer circuit. Black lines represent superconducting wires carrying no current, colored lines represent wires carrying current. Superconducting gates are shown as white rectangles, resistive gates as gray rectangles. By directing current through one or another of the pairs of horizontal wires, vertical current switches to any of four branches.



MEMORY LOOP stores digital information. When lower gate (*rectangle*) is superconducting (*a*), reading current produces no voltage drop and voltmeter reads "0." To write a "1" current is sent through data and writing branches (*b*). Upper gate is resistive and data current takes lower path. Removing writing and data currents successively (*c* and *d*) traps current in loop, makes lower gate resistive and causes a voltage drop recorded as "1."

consumed in sending signals from one part of the computer to another will soon become greater than the time spent in performing calculations. (An electrical pulse travels about one foot along a wire in a billionth of a second.) Eventually the distance between different sections of a computer will set the limit on overall speed.

It should also be noted that the small space occupied by cryotron networks tends to offset their chief drawback—the necessity of keeping them immersed in liquid helium. To be sure, the refrigerating equipment is bulky and requires considerable power to run. But, as has been pointed out, reducing the size of the computer proper will probably justify spending considerable space and energy on the container.

So far as we know no one has actually built a superconducting computer. In the laboratory of the International Business Machines Corporation a variety of subsidiary circuits such as counters, memories and decoders have been built and tested. As always happens in a research program, a number of unexpected problems have turned up, but the cryotron principle still appears very promising for computers. Meanwhile continuing investigations of thin films are yielding some new insights into the superconducting state itself.

Bulk samples of superconducting materials behave as though they were impervious to magnetic fields. The few hundred angstroms to which the field actually penetrates represent a negligible part of the total volume of the specimen. This is not the case with thin films. Here the depth of penetration may be a substantial fraction of the thickness. Moreover, when a film becomes very thin, its superconducting efficiency decreases, as will be explained shortly. As a consequence the field penetration is greater at any given depth in thin films than it is in bulk materials [*see bottom illustration on page 128*].

The greater the degree of penetration, the smaller the current that can be carried without destroying superconductivity. A calculation of the energy of the superconducting state leads to the seemingly paradoxical result that the deeper the penetration of the field, the *larger* the external field required to produce resistance in a superconductor. Both effects act in the same direction, to decrease the gain of a cryotron as the film becomes thinner: the gate current decreases, whereas the amount of the necessary control current increases. From a practical point of view this sets

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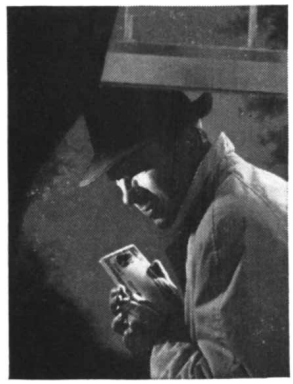

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a limit to the thinness of the film in cryotrons. It also affords an experimental method for investigating some fundamental concepts in the theory of superconductivity.

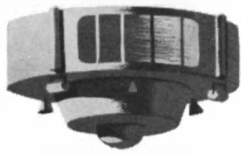
The first successful attempt at a theoretical description of the superconducting state was made in 1935 by Fritz and Heinz London. Their theory predicted that magnetic fields would penetrate superconductors for short distances only. Recent experiments demonstrated, however, that the actual depth of penetration differs substantially from the values that the London theory calls for.

The year 1957 saw a major breakthrough in the understanding of superconductivity when John Bardeen, Leon R. Cooper and J. Robert Schrieffer of the University of Illinois published a detailed quantum-mechanical theory of the superconducting state. Very roughly, the BCS theory, as it has come to be known, embodies the fact that certain electrons in the atoms of crystalline solids interact not only directly through electrostatic repulsion but also indirectly through the vibrations of the crystal lattice. The latter interaction may, under certain circumstances, produce an attractive force between electrons. In materials that become superconducting the attractive force exceeds the repulsive force below the critical temperature.

In this view the superconducting state is one in which the electrons are condensed into a special, low-energy state, separated by an energy gap from the states that can be occupied by normal electrons. The width of the gap and the fraction of all the electrons in the low-energy state are interrelated quantities, and both vary with temperature. The gap and the number of superconducting electrons are a maximum at absolute zero and decrease with increasing temperature until they disappear at the critical temperature.

The depth to which a magnetic field penetrates a superconductor is also known to vary with temperature. The BCS theory shows that it depends on the percentage of electrons in the superconducting state and therefore also on the energy gap. In general, the penetration is least at absolute zero and becomes infinite at the critical temperature. Since the gain of a cryotron depends on the penetration depth, a study of the variation of gain with temperature provides indirect information about the width of the superconducting energy gap and direct information about the depth of penetration of the field.

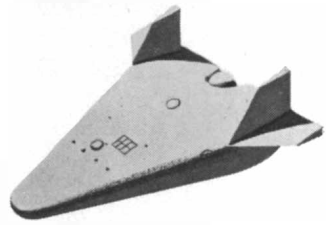
These experiments also serve to illuminate another feature of the BCS



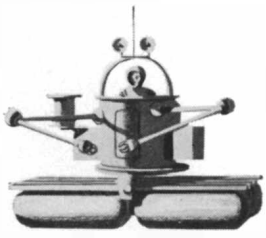
Lunar VTOL Vehicle. A rocket-propelled craft designed to collect lunar ore specimens.

Nuclear Space Ship. An unconventional design by Douglas with living quarters around the ring at the bottom. On landing, it would ease down, ring first.

Nuclear Space Ship. A Douglas design for a space ship with crew quarters and control rooms in the nose, nuclear reactor in the rear.



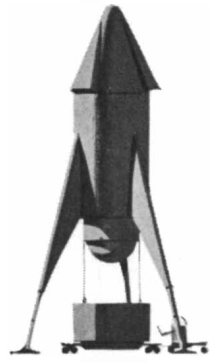
Supply and Escape Vehicle. A compact re-entry vehicle to supply orbiting space stations or to return crews to earth.



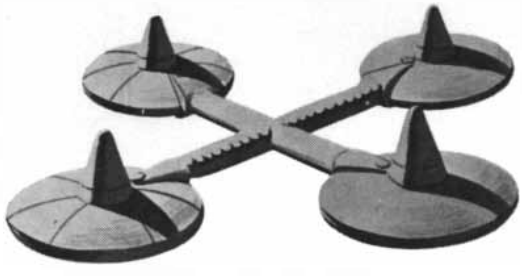
Lunar Service Vehicle. Travels like a "swamp buggy" on inflated rollers. Mechanical arms provided to handle outside chores.

Nuclear Space Ship. A future, medium-thrust, nuclear-electric space ship for one-year interplanetary round trips (Martian and Venusian).

Douglas Thor. Designed as a military IRBM, this dependable missile is the workhorse of the Space Age.

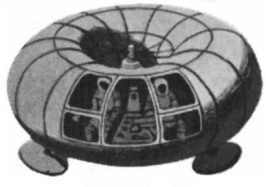


Lunar Cargo Handlers. Would load lunar ore samples into containers to be towed back to earth by rockets.



Space Observatory. Sections of this Douglas-designed space station would be sent into space in rockets and be joined together in orbit.

Saturn. First U.S. vehicle designed to put tons of payload into orbit . . . or onto the moon. Douglas-built second stage is as tall as a 4-story building.



Lunarmobile. Donut-shaped exploration vehicle to use rocket power in space and tractor treads on the moon's surface.

Eleven ways to outwit the law of gravity

When the Space Age dawned, Douglas was ready with specific proposals for space equipment either completed or in advanced stages of development. (Some appear above.)

These Douglas proposals were based on *realistic* estimates of the capabilities of men and materials. They are the valued dividends of the company's considerable experience, gained from the design and production of 30,000 missiles and rockets. These include the Douglas *Thor,* an IRBM which has been totally successful in 86% of its tactical and space firings over the past two years.

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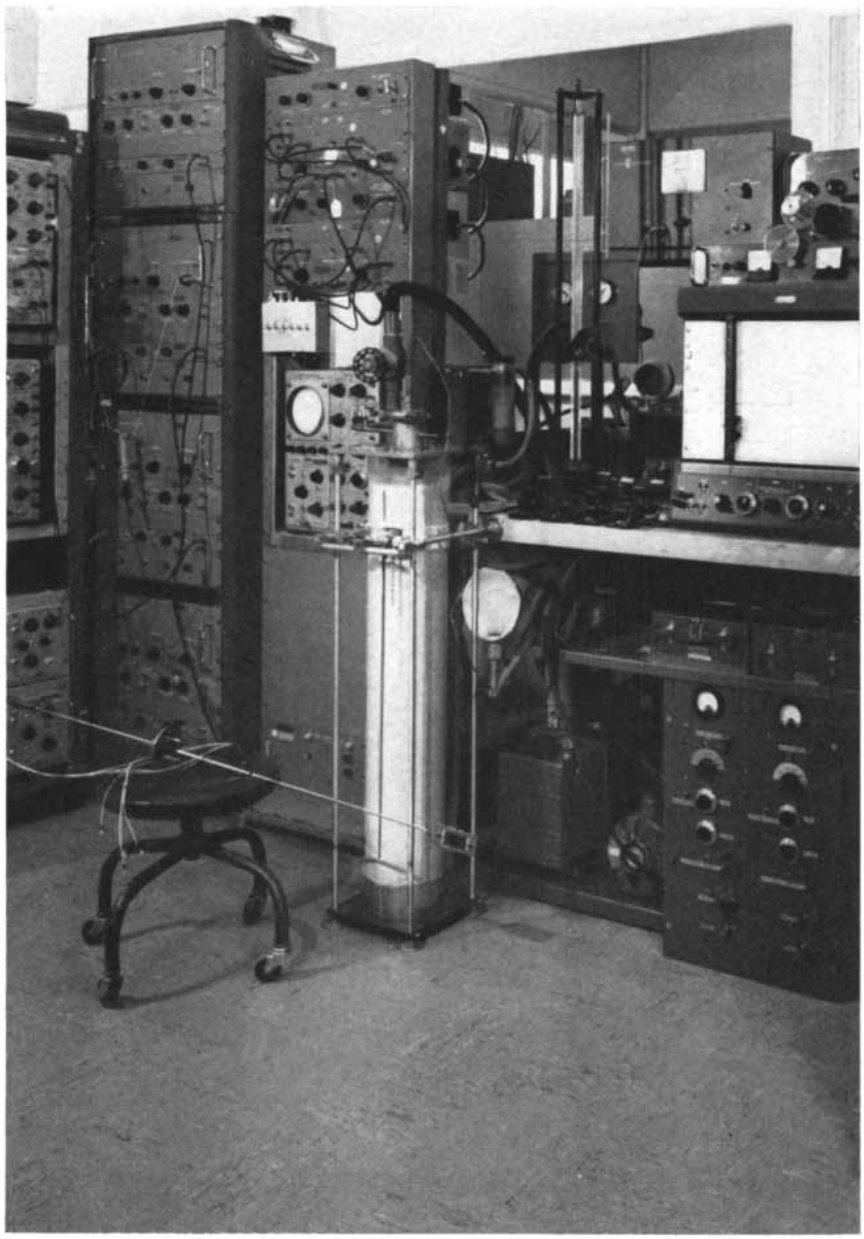
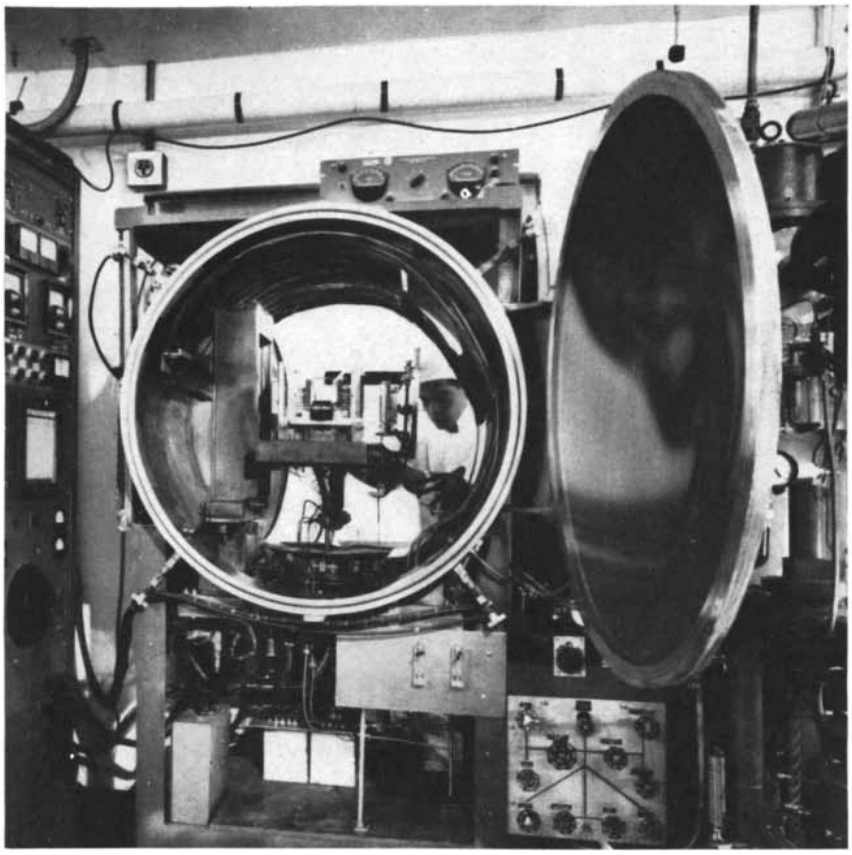
theory: its "nonlocal" character. The London theory sought to relate the supercurrent at a specified point in a superconductor to the magnetic field at that point. Bardeen and his colleagues have taken into account the fact that the current at any point depends on the field throughout the body of the superconductor. In other words, superconductivity is a long-range phenomenon, brought about by interactions between electrons over a fairly long distance—about 2,500 angstroms. This distance is called the range of coherence.

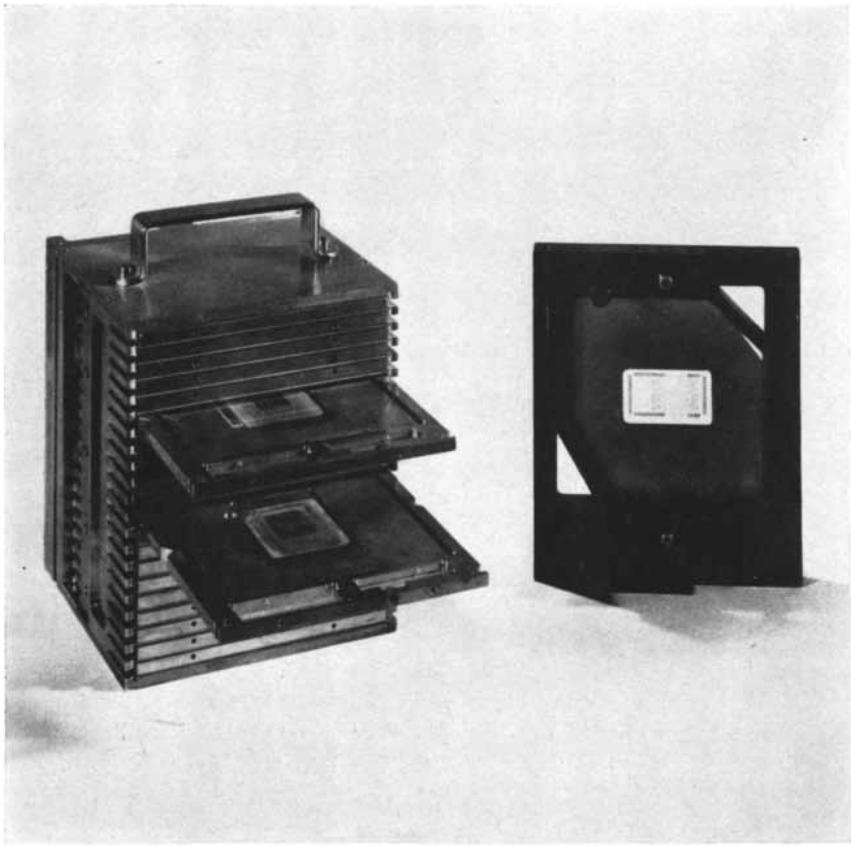
In films with a thickness equal to or less than the range of coherence, the normal long-range interactions are distorted. As might be expected, the patterns of supercurrent and magnetic field within such a film differ from the values predicted by a local theory. Measurements on thin superconducting films accordingly provide information on the nature of the long-range interaction in various materials.

Finally, we should mention some of the problems involved in fabricating superconducting films with a thickness comparable to the wavelength of light. In our laboratory these films are made by evaporating the appropriate substances in a high vacuum and letting them condense on plates of glass or other materials. (Lead and tin are normally used as conductors because of their low boiling points, and silicon monoxide as



LIQUID-HELIUM BATH required to cool cryotron circuits is contained in vertical cylinder (*center*). Rod on stool is used to hold sample (*at right-hand end*) in helium bath.





FILM CRYOTRONS ARE MADE in the vacuum chamber shown in top picture. Various stencils to be used in fabrication are stacked in cartridge at left in bottom picture. Drawers are pulled out in proper sequence automatically, moving stencils in front of glass plate on which films are formed. Master stencil at right in bottom picture is used for registry.

an insulator.) The cryotron circuits shown on the cover and on page 124 were built by evaporating vapors in successive layers through stencils.

In principle it should be possible to produce sandwiches of many layers that would function as part or all of a computing circuit. There are still a number of practical difficulties to be overcome, and these have stimulated considerable activity in the fields of vacuum technology and thin-film physics.

For example, all vacuums at present attainable contain some residual gas that may react with freshly deposited metal surfaces. Gaseous impurities trapped in a thin superconducting film influence the electronic configurations in the metal, thereby interfering with long-range interactions. Films thus contaminated have properties different from those of bulk materials. With the help of advanced experimental vacuum techniques superconducting films have been manufactured in vacuums with pressures of the order of a billionth of a millimeter. These films behave like bulk specimens of pure metal. Adding small amounts of individual gases to the high vacuum system has demonstrated that only a few residual gases, principally oxygen, have much effect on the characteristics of thin-film cryotrons. It is possible to remove most of the oxygen from a mixture of gases by chemical means and thus to produce good cryotrons in ordinary commercial vacuum systems.

Another stumbling block has led to a better understanding of the way in which thin films are formed. To perform satisfactorily a cryotron gate must be a very fine-grained film of uniform thickness. Unfortunately the edges of a film deposited through a stencil ordinarily taper off quite gradually. Because the critical field of a thin superconducting film depends sensitively on its thickness, the tapering edges are undesirable. By adjusting the temperature of the base on which the films are deposited, the mobility of the atoms in the depositing film can be controlled so as to produce rounded edges. Under these conditions, however, the material tends to condense in very large grains. This difficulty in turn is solved by coating the base with monolayers of material that serve to nucleate the depositing film in a fine-grained structure.

It is too early to predict what role superconductivity will play in the development of computer systems. But the results so far, in addition to their fundamental interest, unquestionably justify an intensive effort to develop superconducting computers.

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Air-conditioned Termite Nests

Some African termites build nests that are brilliantly designed to maintain the temperature and humidity within the nest while permitting oxygen to flow into it and carbon dioxide to flow out

by Martin Lüscher

Termites live in critical dependence on the temperature and humidity of their immediate surroundings. An entire colony of the tree-dwelling termite of Africa (*Nasutitermes arboreus*) will perish in half a day's exposure to dry air; single individuals die in five hours. The few termite species that live in temperate regions are active only during the warm months of the year; in winter the termites stay motionless in their galleries unless the overheating of a building they inhabit encourages them to renewed activity. Not even in the tropics, where most termite species live, do these insects find high humidity and warm temperatures in the day-after-day constancy that their existence requires. Termites survive only because their elaborate social organization enables them to build nests in which they establish the microclimate suited to their needs. They live their entire existence in the closed environment of the nest and the tunnels that connect it to sources of food and water; only the reproductive forms of termite venture forth to found new colonies.

As air-conditioning engineers, termites maintain the warmth and humidity of their microclimates in various ways and with varying degrees of success, subject always to the satisfaction of a third and equally compelling need: termites, like other animals, must breathe. Their tissues take in oxygen from the atmosphere within the nest and give off carbon dioxide. The exchange of oxygen and carbon dioxide between the interior of the nest and the world outside must take place by diffusion through the wall of the nest. A thick wall that provides good insulation does not permit good ventilation; what is more, the nearly saturated air within the nest causes the pores in thick walls to fill with water, virtually cutting off the movement of air. In general, temperature control can be achieved only at the expense of gas exchange and vice versa. The way in which these conflicting claims are compromised ultimately determines the size of termite colonies and limits the distribution of the various termite species.

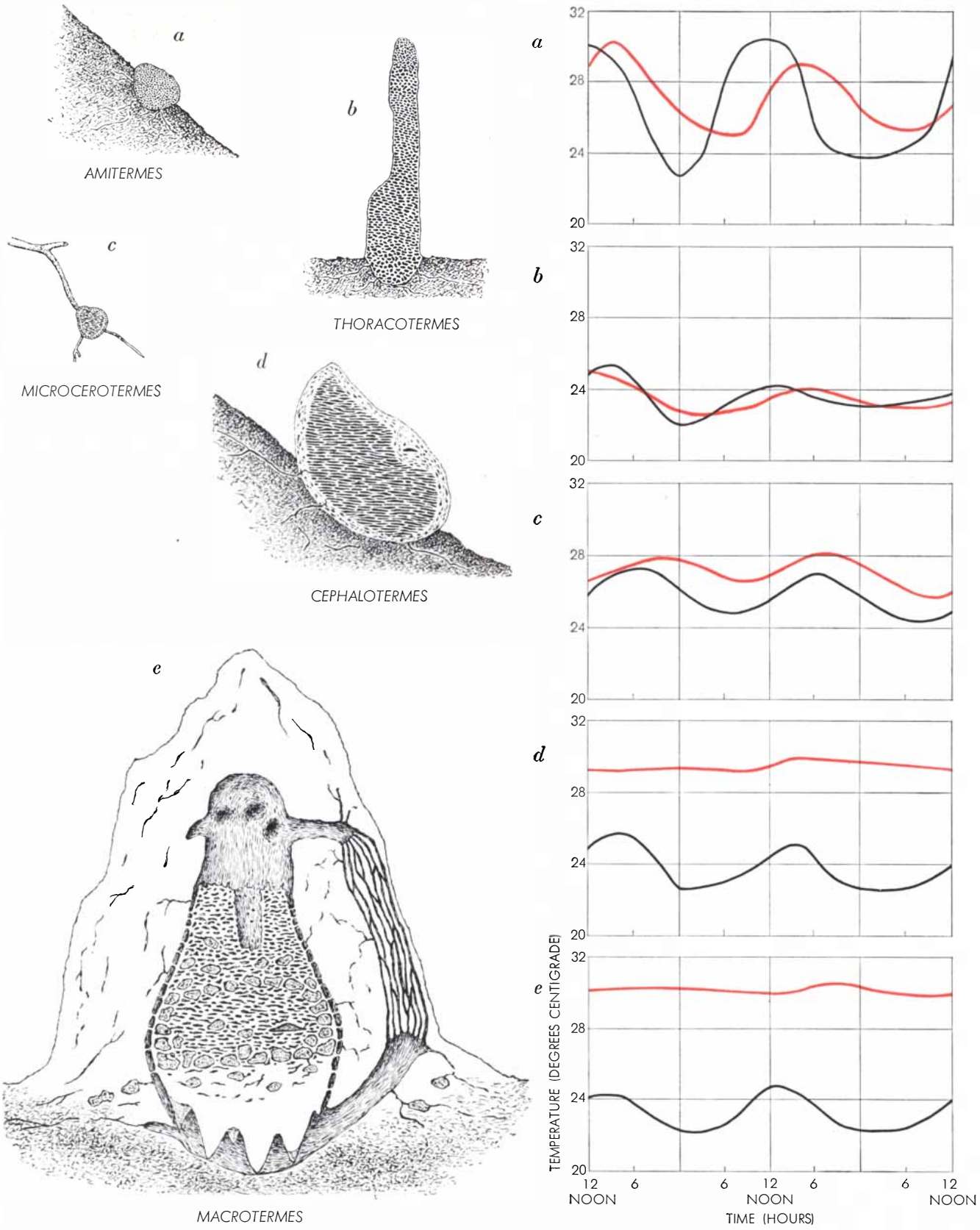
A few advanced mound-building termites native to Africa have managed to obtain good ventilation through thick walls. These insects are able to establish their closely regulated microclimate in most of the habitats offered by the large continent of Africa and are the most widespread of all tropical termites. Only a few animals have achieved wider distribution; all of them (with the exception of the domesticated or parasitic animals that live with man) are social animals. Man is one of them; he long ago learned to clothe himself and heat his dwellings. Recently he has acquired more refined control over his microclimate, learning to cool it and regulate its humidity. Almost as ubiquitous as man is the honeybee *Apis mellifera* and its relatives. The honeybee makes its own microclimate and holds the temperature of the hive relatively constant in spite of variations in the environment. For the time being, at least, no termite species can rival the honeybee in geographic distribution.

In 1953, with the help of Urs Rahm, I conducted in the Ivory Coast of Africa a study of the microclimates in the nests of five termite species. We drilled holes in the nests with a special hollow borer that took gas samples the moment we breached a cavity wall. At the same locations we made measurements of the temperature and humidity over extended periods. These observations and careful study and dissection of the nest structures have given us a new appreciation of the technology of air conditioning as evolved by the termites long before man first evolved.

The humidity inside the nest usually ranged between 98 and 99 per cent; we never found it below 96.2 per cent. Part of the moisture that is so essential (apparently termites dry out easily, either because the outer layer of their waxy cuticle is poorly developed or because they constantly scrape it off in their tunnels) results from the metabolic processes of the members of the colony. In some nests additional moisture is furnished by fungi, which the termites cultivate in spherical combs of wood particles, thus rendering the wood more digestible for themselves. In addition, some termites make tunnels to water outside the nest. Pierre-Paul Grassé and Charles Noirot of the University of Paris have found that certain desert termites go as deep as 130 feet in the sandy soil to reach water, which they somehow carry back into the nest. With water soaking the nest, evaporation keeps the air close to the saturation point even when the temperature rises.

Temperature does not yield easily to such close regulation, and the temperature in the nests of most termite species tends to vary with that of the atmosphere. Some species build thin-walled nests in the open under the sun, where the temperature rises and falls throughout the day and night. Others construct mounds only deep in the shade of tropical forests, where the temperature normally remains fairly uniform. The mounds of a few species have walls of moderate thickness; within such mounds, and in those with thick walls, the temperature stays constant and considerably higher than the temperature outside. The metabolic heat of the ter-

NEST OF *THORACOTERMES*, one of the five termite species studied by the author in the Ivory Coast of Africa, is built like a column. It is always deep in the shade of the forest. Two devices for measuring temperature and humidity, installed by the author, are clearly visible after nest is cut open (*right*). Irregular compartments make up the interior. This nest is nearly five feet tall.



NESTS OF FIVE TERMITE SPECIES are drawn to scale in cross section. The *Macrotermes* mound is 10 feet high. Curves at right show temperature inside each mound (*color*) and outside the mound (*black*) over a period of two days. Temperature in mounds of *Macrotermes* and *Cephalotermes* hardly varies; in *Amitermes* nest it changes, after a delay, with the exterior temperature.

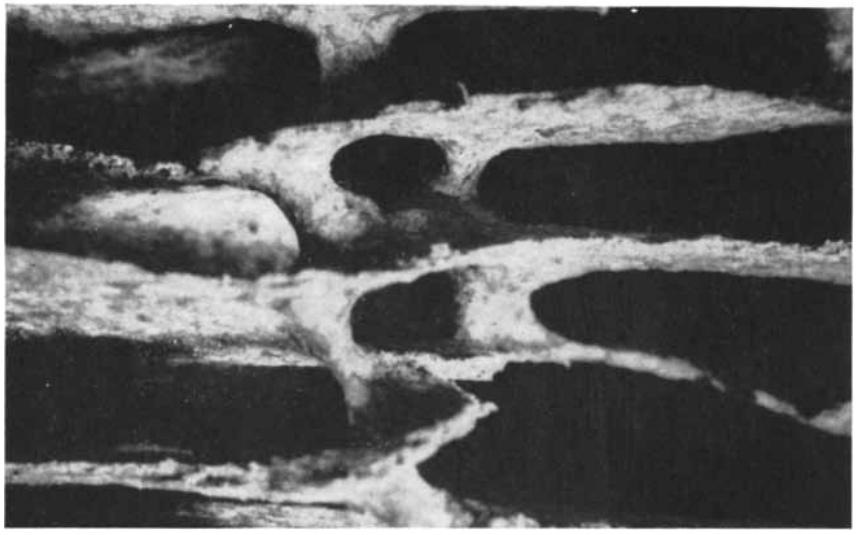
mites supplies the extra warmth. Where the termites cultivate fungi, the heat of fermentation in the fungus combs supplies still more warmth. It has been found that tropical termites do best at 30 degrees centigrade (86 degrees Fahrenheit); the corresponding temperature for Temperate Zone species is 26 degrees C. (79 degrees F.). At lower temperatures the growth and development of individuals and colonies slows down and eventually stops.

The third important variable in the microclimate of the nest—the supply of oxygen—not only varies inversely with improvement in insulation but also is limited by simple geometry. The larger the nest and the population inside, the smaller is the relative surface area available for exchange of respiratory gases. The occurrence of mounds more than three feet in height all over tropical Africa is a measure of the ingenuity of at least some species of termite.

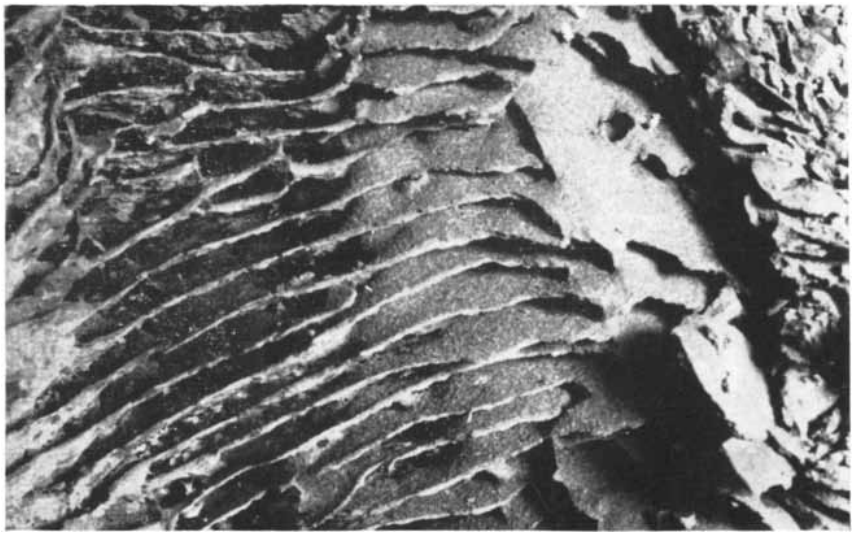
The most primitive species we studied in the Ivory Coast, *Amitermes evuncifer* and *Thoracotermes macrothorax*, build thin-walled nests containing irregular cavities connected by narrow passages. The relatively soft building material consists of humus mixed with the saliva of the worker termites. *Amitermes* is the hardier of the two; it builds its more or less spherical mounds both in the shade and in the open. The nest we investigated lay on a slope directly exposed to the sun. *Thoracotermes* always builds its columnar nest in the shade of a forest. The temperature in the nests of these two species is only .1 to .5 degree C. above that of the surrounding atmosphere, and it fluctuates, with a short time lag, as the environmental temperature changes. Moreover, the nest of *Amitermes* does not efficiently exchange respiratory gases. The spherical shape of the nest gives it a small surface-to-volume ratio and, though the wall of the nest is thin, the atmosphere inside it contains a high concentration of carbon dioxide. The columnar mound of *Thoracotermes* provides a larger surface for gas exchange.

The species *Microcerotermes edentatus* builds a small, spherical, thin-walled nest in a tree. The nest consists of wood particles glued together with saliva and excrement to form a material rather like hard cardboard. Neat horizontal layers characterize the interior. The queen occupies a special compartment that is protected by being near the center of the nest. The nest we investigated had a volume of only four

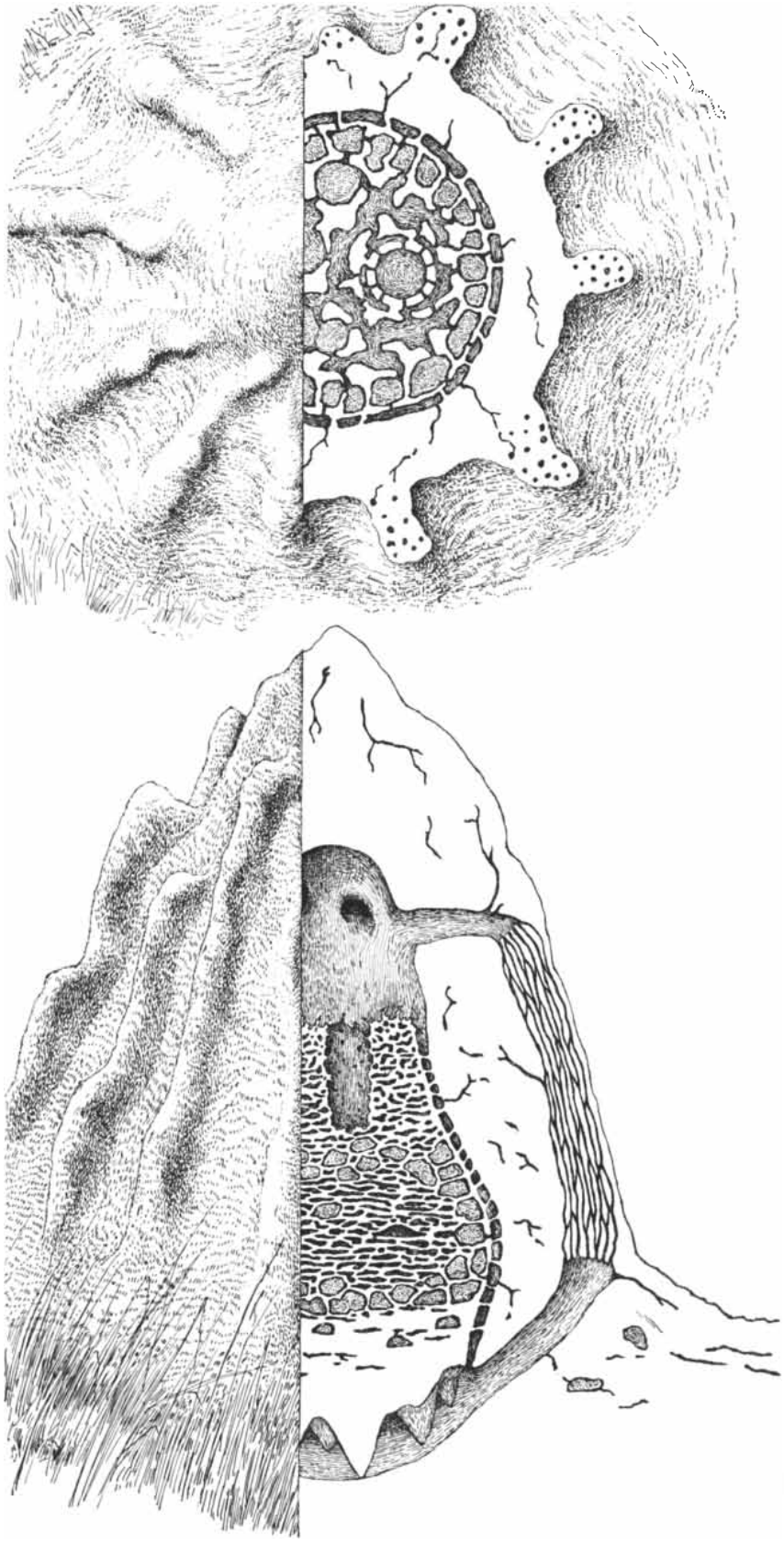
CLOSE-UP OF INTERIOR of *Thoracotermes* nest shows details of structure and some soldier termites. Soft building material consists of humus mixed with saliva of termites.



NEST OF *MICROCEROTERMES* is arranged in horizontal compartments. The building material is wood particles glued together with saliva and excrement to make a hard board.



NEST OF *CEPHALOTERMES* is built of the same material as that of *Microcerotermes*. Its interior also consists of compartments arranged in numerous horizontal layers.



GIANT MOUND OF *MACROTERMES* is revealed in cross sections as a complex structure. Rising from the cellar are pillars that support the foundation of the nest proper. Large compartment in nest, just to right of center, is occupied by the queen. Brood chambers and fungus combs surround it. The hole visible in the back of the attic, above the nest, leads into an exterior ridge of the mound wall. Air channels in such a ridge are seen at right. At top is a partial horizontal cross section of the mound, made at the level of the queen cell.

liters (a liter is approximately equal to a quart); it was too small for us to obtain a good gas sample. The temperature within rises and falls with the outside temperature but averages about 1.5 degrees above it. The thin walls and small size of the nest should ensure excellent ventilation.

Cephalotermes rectangularis constructs cone-shaped mounds that stand on the forest floor, often leaning against a tree. Like *Microcerotermes*, it manufactures a building material resembling hard cardboard, but the wall of the nest is two to three inches thick. Horizontal layers fill the interior; the queen lives in an enlarged compartment in the wall of the nest. The combination of a shady location and a thick wall keeps the inside temperature warmer and more stable than the surrounding air, but gas exchange is somewhat less efficient than in the mound of *Thoracotermes*.

By far the most advanced of the species we studied was *Macrotermes natalensis*. Its enormous pinnacled mounds, with curious ridges running like veins down their outer walls, are familiar to anyone who has traveled through equatorial Africa. The mounds sometimes reach a height of 16 feet and can have a diameter of 16 feet at the base. *Macrotermes* builds its mounds in the forest and in the open over much of the continent. The architecture of the mounds is far from uniform and can be quite different in various parts of Africa.

In the Ivory Coast the mounds of *Macrotermes* have walls 16 to 23 inches thick. The termites bring up particles of the African lateritic soil from below the humus layer and mix it with their saliva to make a hard cement. The nest proper stands within the mound on a firm foundation supported by pillars that rise from the floor of the "cellar," three feet below ground level. Above the nest is another hollow space—the "attic." Horizontal brood chambers surround the queen's cell in the center, and fungus combs form a spherical layer around the brood cells. Still another layer of small cells separates the combs from the wall of the mound.

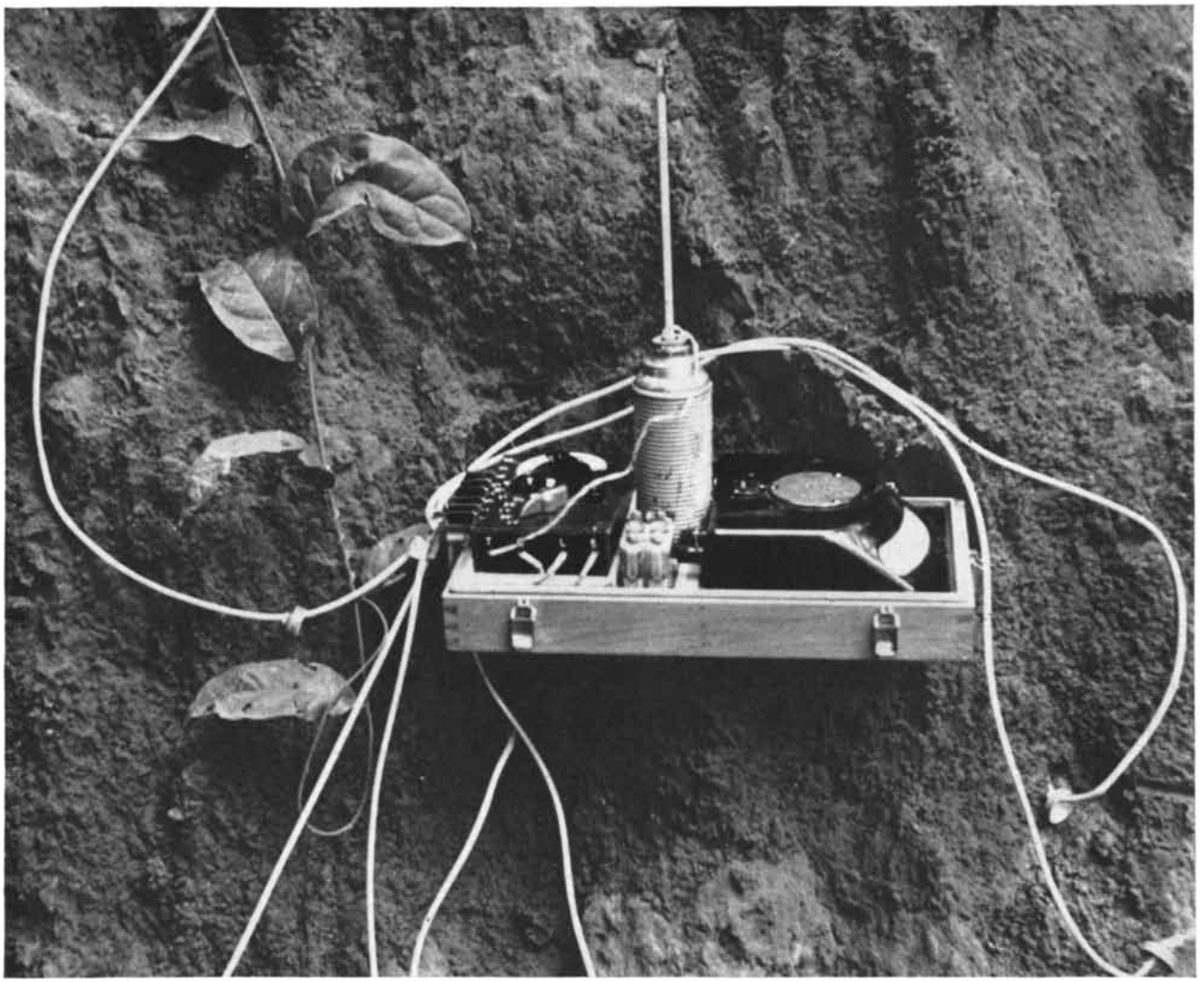
The metabolism of the colony and of the fungi warms the air inside the nest and contributes moisture to its high humidity. Water brought up from the soil irrigates the interior of the nest and brings the air to the saturation point. The thick, dense wall of the mound securely insulates the microclimate from variations in the temperature and humidity of the atmosphere outside. But what about ventilation? Even in the dry

state the wall of the mound would be an effective barrier to the diffusion of air. The saturated air within the mound, however, fills the pores of the wall with water. Since the respiratory gases diffuse 10,000 times more slowly through water than through air, ventilation would appear to be shut off completely. Yet the mound of *Macrotermes* houses the largest termite city of all.

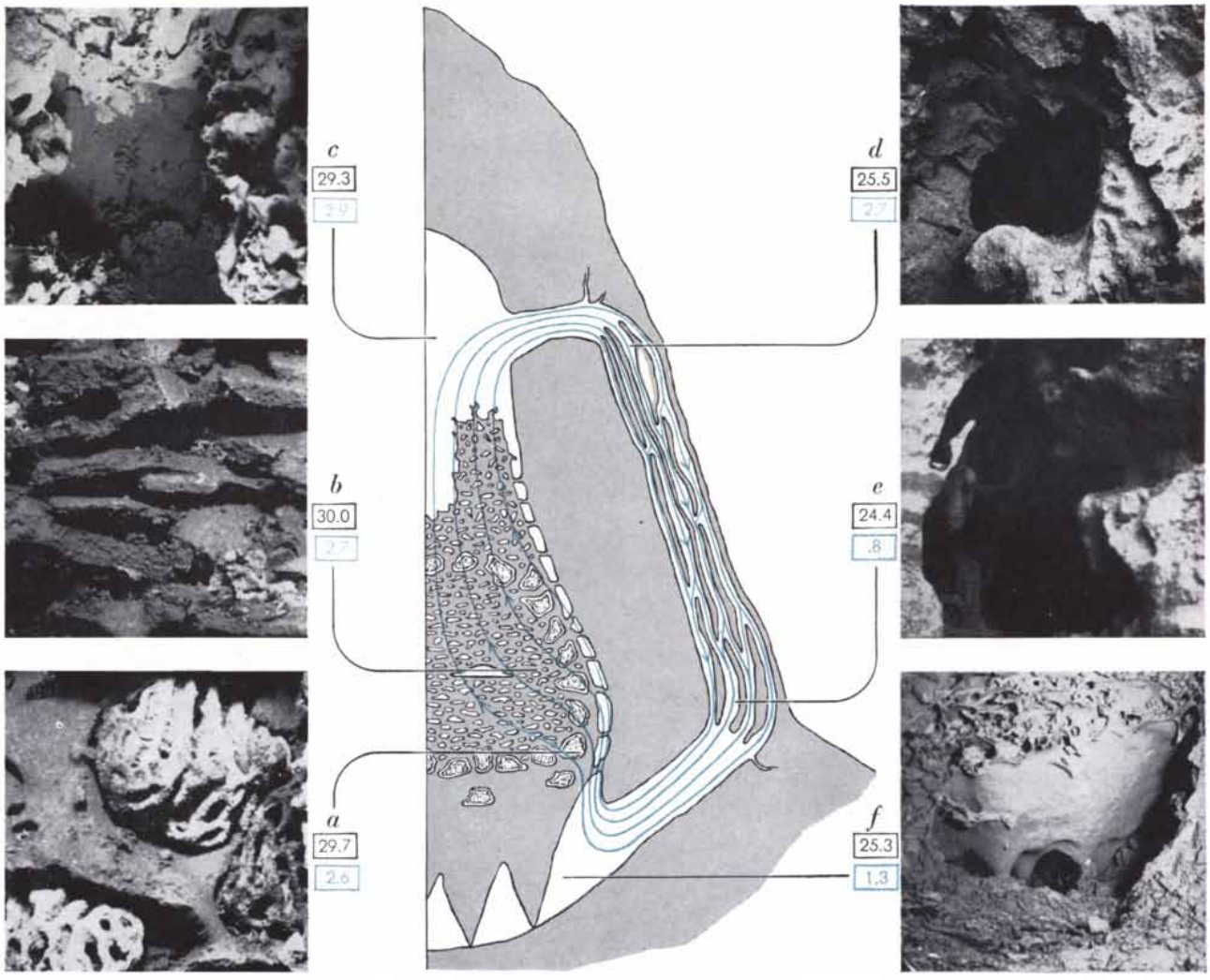
A medium-sized nest contains two million individuals that need at least 240 liters of oxygen, or 1,200 liters of air, a day. If the nest were hermetically sealed, the air in it would not last 12 hours. Nonetheless, our measurements showed a carbon dioxide content of only 2.7 per cent in the center of the nest, rather high compared with the other species but remarkably low under the circumstances. Study of the mound of *Macrotermes* revealed the function of the ridges on the surface of the mound and disclosed the simple but ingenious mechanism that accomplishes the respiratory change.

Each ridge serves as a conduit carrying half a dozen or more narrow channels that link the air chambers in the cellar and the attic [*see illustration on next page*]. The mass of termites and the fungi in the nest proper keep the interior of the mound considerably warmer than the outside, where the ridges are. Our measurements of the temperature and analyses of the gas concentrations in various parts of the nest showed that convection currents circulate the air from the nest upward to the attic. There the air passes into the narrow channels in the external ridges and runs downward through the ridges to the cellar. The air flowing in the upper ends of the ridges contains more carbon dioxide than the air flowing in the lower ends, and a correspondingly higher percentage of oxygen is found in the lower ends of the ridges than in the upper ends. By the time the air flows into the cellar it carries a new supply of oxygen. In good weather the ridges and the narrow air-circulation channels inside them stay completely dry. Gases diffuse easily across the ridge material because the diffusion distance is short, and the protrusion of the ridges from the mound wall greatly enlarges the surface available for gas exchange. The ridges can therefore be considered the lungs of the termite society.

When it rains, the ridges are soaked and their respiratory efficiency is impaired. Most of the water runs down between the ridges, however, and they always dry quickly. We do not know what happens when continuous rain keeps the ridges wet for prolonged periods. The termites may move the narrow channels in the ridges quite near the



EXPERIMENTAL EQUIPMENT attached to mound of *Macrotermes* measures and records temperature and humidity at different locations within the structure. The gas samples were taken through a hollow borer used to drill the necessary holes in wall.



AIR IS CIRCULATED (*colored arrows*) **ingeniously in mound of** *Macrotermes*. **This was shown by measurements of temperature and carbon dioxide at the following locations:** (*a*) **in fungus combs at bottom of nest proper,** (*b*) **in brood chambers,** (*c*) **in the attic,** (*d*) **in upper part of a ridge channel,** (*e*) **in lower part of a ridge channel and** (*f*) **in cellar. The locations are shown in the photographs. Black figures in boxes are temperatures in degrees centigrade; colored figures give percentage of carbon dioxide at each location. Curves at bottom of page show how temperature** (*black*) **and carbon dioxide content** (*color*) **of air changes during circulation. These changes take place due to diffusion of gases and the radiation of heat through the thin, dry walls of the ridges.**

surface, thereby securing the necessary gas exchange, or they may even perforate the surface. It seems that no one has ever observed termite mounds closely during heavy rains, probably because most research workers, including the author, prefer to travel in Africa during the dry season.

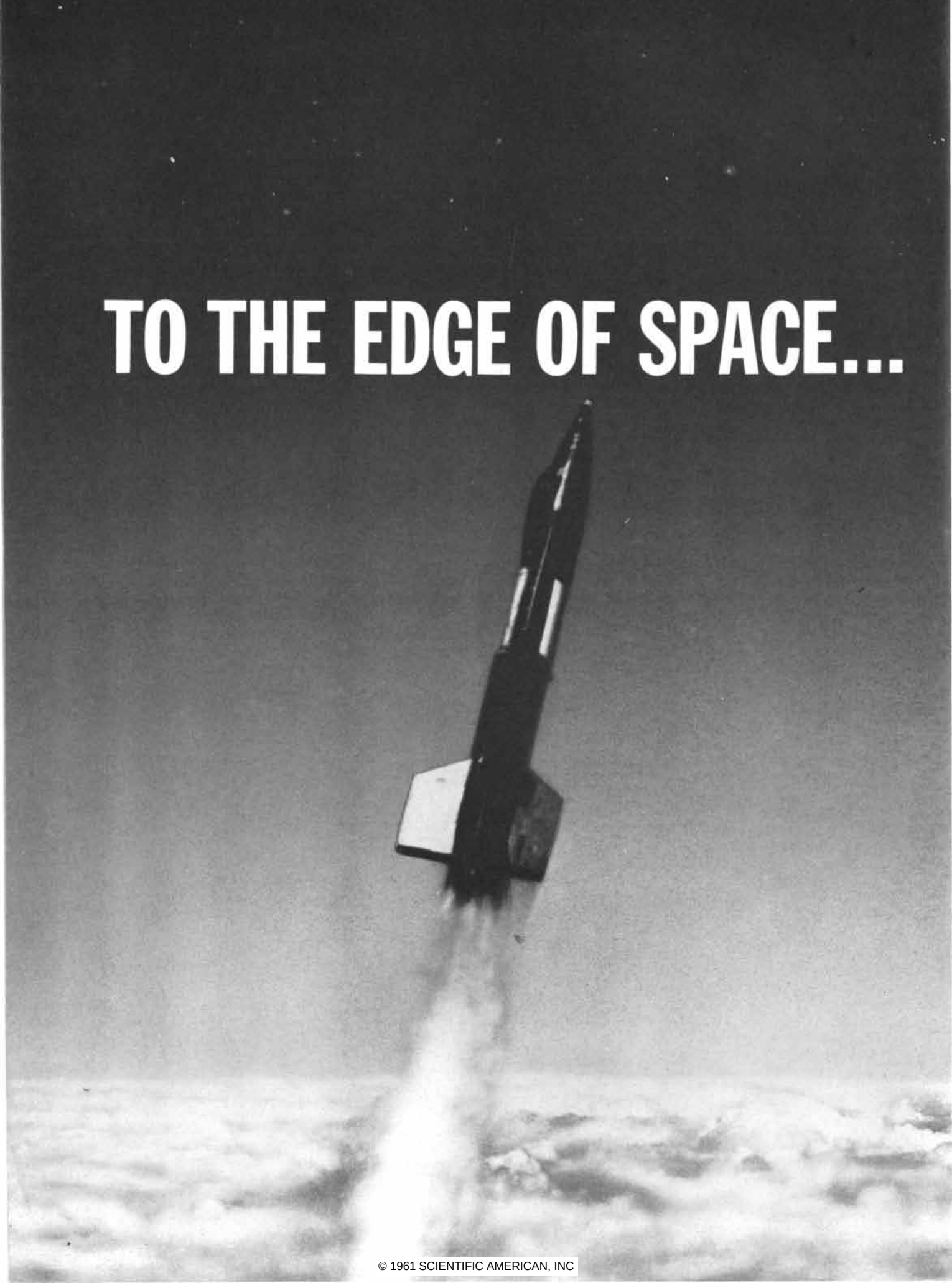
The ridges may also hold the explanation of how *Macrotermes* keeps the interior temperature of its mounds so remarkably constant. It may be that colony members are steadily at work in the ridges, closing and opening the air-circulation channels and so regulating the flow of air through them. There would be nothing extraordinary in this; although the mound is an elaborate architectural masterpiece, it is not the finished, stable structure it seems to be when we open it. In reality we can see only a phase of a dynamic process, because the termites are always at work pulling down some parts, rebuilding others, enlarging the mound and remodeling every detail. The structure remains the same from day to day only in principle. With termites working all the time throughout the mound, some of them are no doubt at work in the channels of the ridges. They may close up some channels when the nest begins to cool and open new channels when the temperature rises. Unfortunately it is not possible to see exactly what is happening; invasion of the mound disturbs the termites and radically modifies their behavior.

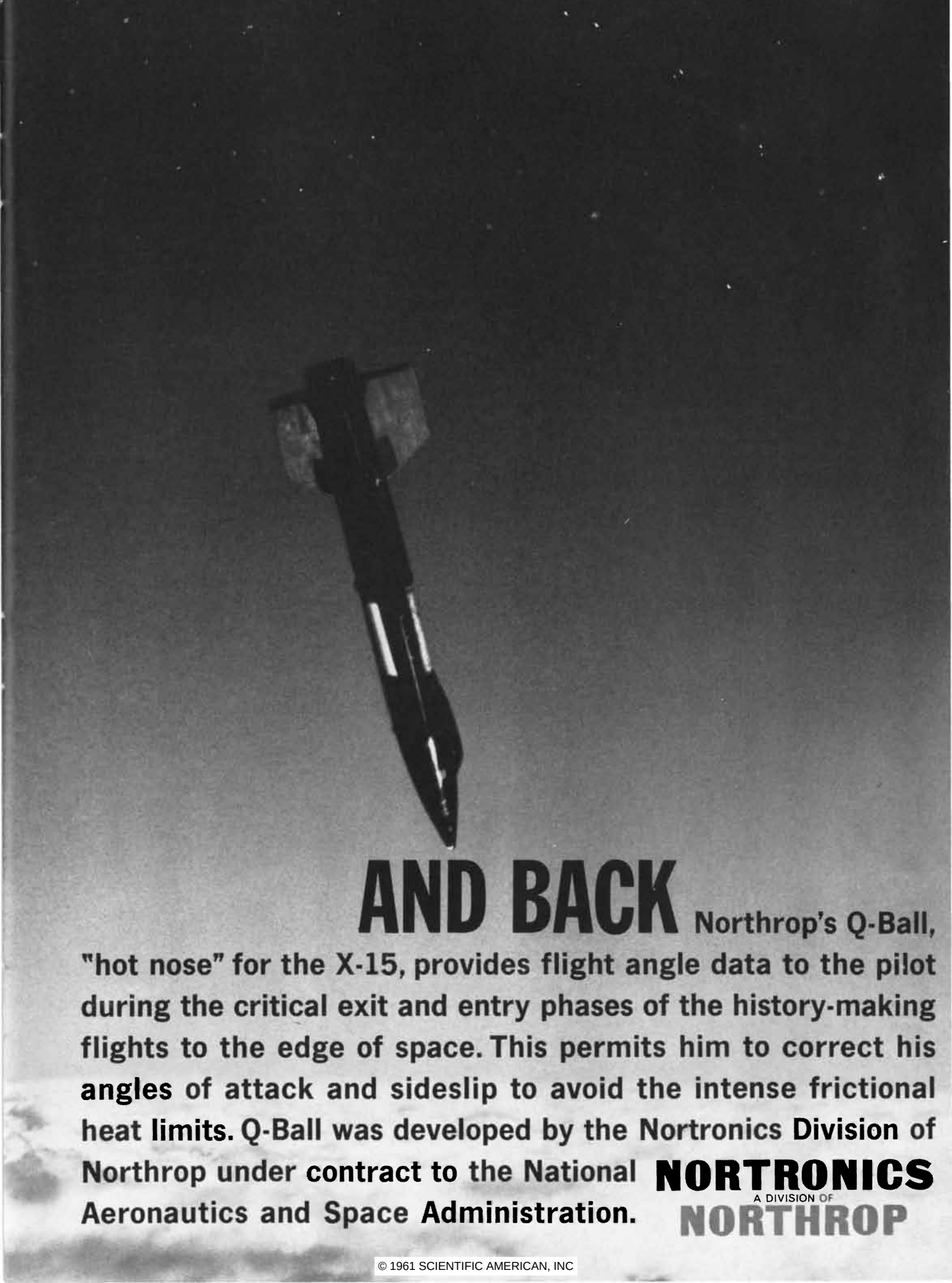
In view of the fact that termites tend to be dried out by air currents, it was puzzling to learn that air circulates continuously in the mound. It can be shown, however, that the circulation is slow. Since the oxygen concentration increases about 10 per cent each time the air passes through the ridge channels, simple arithmetic indicates that the air must go through the channels about 10 times in 24 hours to supply the 240 liters of oxygen needed in a day. This circulation produces an air speed of about two millimeters per second in the ridges (approximately the speed of a moving snail) and only .15 millimeter per second in the nest cavities. Such an air speed is considerably slower than that experienced by a termite walking through still air; hence it is unlikely that the "breeze" disturbs the termites.

The feat of air conditioning has made *Macrotermes* and some other species remarkably independent of the outside temperature and humidity. It is no wonder, then, that *Macrotermes* has the widest distribution of all African termites. Such independence is achieved, however, only after the nest has reached a certain size. New *Macrotermes* colonies pass through a "solitary" phase in which a king and queen go out alone to start a brood. For some time the colony is so small that it cannot build a nest large enough to control the temperature. Therefore new colonies must depend on the tropical climate for heat, and this probably explains why these termites have not spread over North Africa and Europe. If evolution ever permits *Macrotermes* to form "worker swarms" as bees do, or bud large, complete colonies from the original mound as some species of termite already do, no climatic barrier will be strong enough to hold it back.

***MACROTERMES* WORKER, with "beaded" antennae, is seen in lower half of photograph taking an egg from its queen. All the photographs were made by the author in Africa.**

TO THE EDGE OF SPACE...





AND BACK

Northrop's Q-Ball, "hot nose" for the X-15, provides flight angle data to the pilot during the critical exit and entry phases of the history-making flights to the edge of space. This permits him to correct his angles of attack and sideslip to avoid the intense frictional heat limits. Q-Ball was developed by the Nortronics Division of Northrop under contract to the National Aeronautics and Space Administration.

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MATHEMATICAL GAMES

Some diverting mathematical board games, and the answers to last month's problems

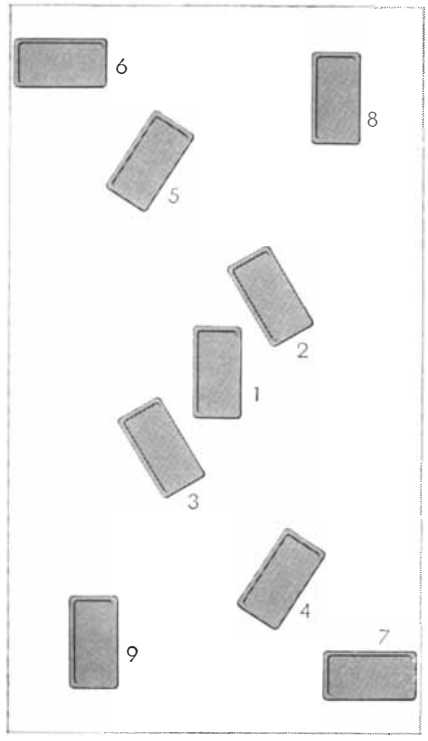
by Martin Gardner

Mathematical board games such as ticktacktoe, checkers, chess and go are contests between two players that (1) must end after a finite number of moves, (2) have no random elements introduced by devices such as dice and cards, (3) are played in such a way that both players see all the moves. If a game is of this type and each player plays "rationally"—that is, according to his best strategy—then the outcome is predetermined. It will be either a draw or a certain win for the player who makes the first move or the player who makes the second move. This month we shall first consider two simple games for which winning strategies are known, then a popular board game for which a winning strategy has just been discovered and a class of board games not yet analyzed.

Many simple games in which pieces are placed on or removed from a board lend themselves to what is called a symmetry strategy. A classic example is the game in which two players take turns placing a domino anywhere on a rectangular board. Each domino must be put down flat, within the border of the rectangle and without moving a previously placed piece. There are enough dominoes to cover the board completely when the pieces are packed side by side. The player who puts down the last domino wins. The game cannot end in a draw, so if both sides play rationally, who is sure to win? The answer is the player who puts down the first domino. His strategy is to place the first domino exactly at the center of the board [*see illustration on this page*] and thereafter to match his opponent's plays by playing symmetrically opposite as shown. It is obvious that whenever the second player finds an open spot, there will always be an open spot to pair with it.

The same strategy applies to any type of flat piece that retains the same shape when it is given a rotation of 180 degrees. For example, the strategy will work if the pieces are Greek crosses; it will not work if they have the shape, say, of the letter T. Will it work if cigars are used as pieces? Yes, but because of the difference in shape between the ends the first cigar must be balanced upright on its flat end! It is easy to invent new games of this sort, in which pieces of different shapes are alternately placed on variously patterned boards according to prescribed rules. In some cases a symmetry strategy provides a win for the first or second player; in other cases no such strategies are possible.

A different type of symmetry play wins the following game. Any number of coins are arranged in a circle on the table, each coin touching two of its neighbors. Players alternately remove either one coin or two touching coins. The player who takes the last coin wins.



A domino board game

Known to rout hawks a hundred times his size, the hummingbird is a creature of courage. But when he takes this risk, it is with a distinct advantage. His powers of flight are matched by none.

We admire his style. And we share the philosophy. Knowing that our own capabilities are highly distinctive, we too believe that they are a thing to be used with boldness. Two years ago, Fairchild pioneered commercial production of diffused silicon Mesa transistors. They became the industry's most widely copied types. But we developed direct replacements — silicon PLANAR transistors (PLANAR diodes too were developed) — another step forward. Our newly introduced PLANAR EPITAXIAL devices and MICROLOGIC elements continue the progress.

We have many ambitious programs ahead. If you like our approach and have a relevant background, we would like to hear from you.

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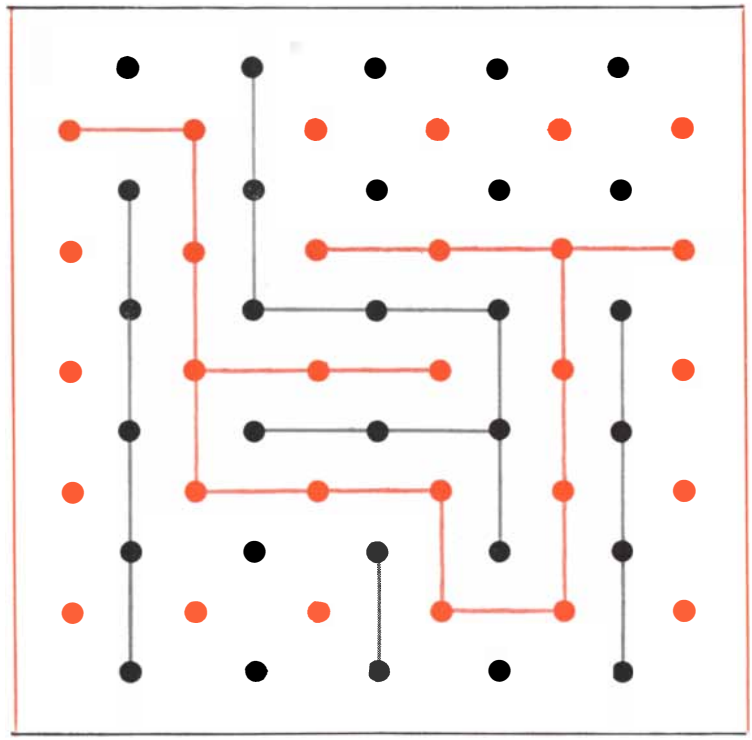
Photo from the book "HUMMINGBIRDS" by C. H. Greenewalt; © American Museum of Natural History

In this case it is the player who makes the second move who can always win. After the player who makes the first move has taken away one or two coins, the remaining coins form a curved chain with two ends. If this chain contains an odd number of coins, the player who makes the second move takes the center coin. If it contains an even number, he takes the two center coins. In both cases he leaves two separate chains of equal length. From this point on, whatever his opponent takes from one chain, he duplicates the move by taking one or two coins from the other chain.

Both this and the preceding strategy are examples of what game theorists sometimes call a pairing strategy: a strategy in which the plays are arranged (not necessarily in symmetrical fashion) in pairs. The optimal strategy consists of playing one member of the pair whenever the opponent plays the other member. A striking example of a pairing strategy is provided by the topological game of Bridg-it, placed on the market last year and now a popular game with children. The reader may remember that Bridg-it was introduced by this department in October, 1958, as "the game of Gale"; it was devised by David Gale, a mathematician at Brown University.

A Bridg-it board is shown in the illustration at the bottom of this page. If it is played on paper, one player uses a black pencil for drawing a straight line to connect any pair of adjacent black spots, horizontally or vertically but not diagonally. The other player uses a red pencil for similarly joining pairs of red spots. Players take turns drawing lines. No line can cross another. The winner is the first player to form a connected path joining the two opposite sides of the board that are his color. (The commercial Bridg-it board has raised spots and small colored plastic bridges that are placed between spots.) For many years a proof has been known that there is a winning strategy for the player who makes the first move, but not until early this year was an actual strategy discovered.

It was Oliver Gross, a games expert in the mathematics department of the Rand Corporation, who cracked the game. When I learned of his discovery, I wrote immediately for details, expecting to receive a long, involved analysis that might prove too technical for this department. To my astonishment the explanation consisted of nothing more than the diagram reproduced on page 152 and the following two sentences: Make the first play as indicated by the gray line at lower left in the diagram. Thereafter whenever your opponent's play crosses the end of a dotted line, play by crossing the other end of the same line. This ingenious pairing strategy guarantees a



A finished game of Bridg-it. Red has won

ANNOUNCING AN ISSUE OF **SCIENTIFIC AMERICAN** DEVOTED TO THE TOPIC OF

THE LIVING CELL

TO BE PUBLISHED IN SEPTEMBER, 1961

win for the first player, though not necessarily in the fewest moves. Gross describes his strategy as "democratic" in the sense that "it plays stupidly against a stupid opponent, shrewdly against a shrewd one, but wins regardless." This is not the only pairing strategy that Gross discovered, but he picked this one because of its regularity and the ease with which it can be extended to a Bridg-it board of any size.

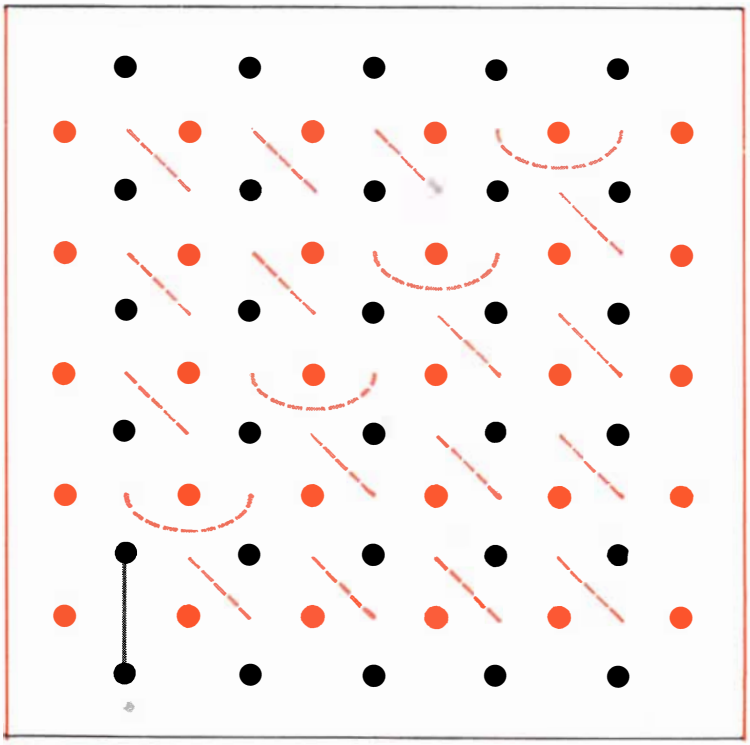
Note that in the diagram no plays are indicated along the edges of the board. Such plays are allowed by the rules of Bridg-it (in fact, plays of this type are shown on the cover of the box), but there is no point in making such a move, because it can contribute nothing to winning the game. If in the course of playing the winning strategy your opponent throws away a play by making an edge move, you can counter with an edge move of your own. Or, if you prefer, you can play *anywhere* on the board. If at some point later in the game this random move is demanded by the strategy, you simply play somewhere else. Having an extra play on the board is sometimes an asset, never a liability. Of course, now that a winning strategy for the first player is known, Bridg-it ceases to be of interest except to players who have not yet heard the news.

Many board games with relatively simple rules have defied all attempts at mathematical analysis. An example is provided by the family of games that derives from halma, a game widely played in England late in the 19th century. "The normal English way," wrote George Bernard Shaw in 1898, is "to sit in separate families in separate rooms in separate houses, each person silently occupied with a book, a paper, or a game of halma. . . ." (This quotation is given in *The New Complete Hoyle*, by Albert H. Morehead, Richard L. Frey and Geoffrey Mott-Smith.)

The original halma (the name is a Greek word for "leap") was played on a checkerboard with 16 squares to a side, but the basic mode of play was soon extended to other boards of varying size and shape. The game known today as Chinese checkers is one of the many later varieties of halma. I shall explain here only a simplified version, which can be played on the familiar eight-by-eight checkerboard and which leads to an entertaining solitaire puzzle that is still unsolved.

The game begins with the checkers in the standard starting position for a checker game. Moves are the same as in checkers, with these exceptions:

1. No jumped pieces are removed.
2. A checker may jump men of either color.



Oliver Gross's pairing strategy for winning at Bridg-it

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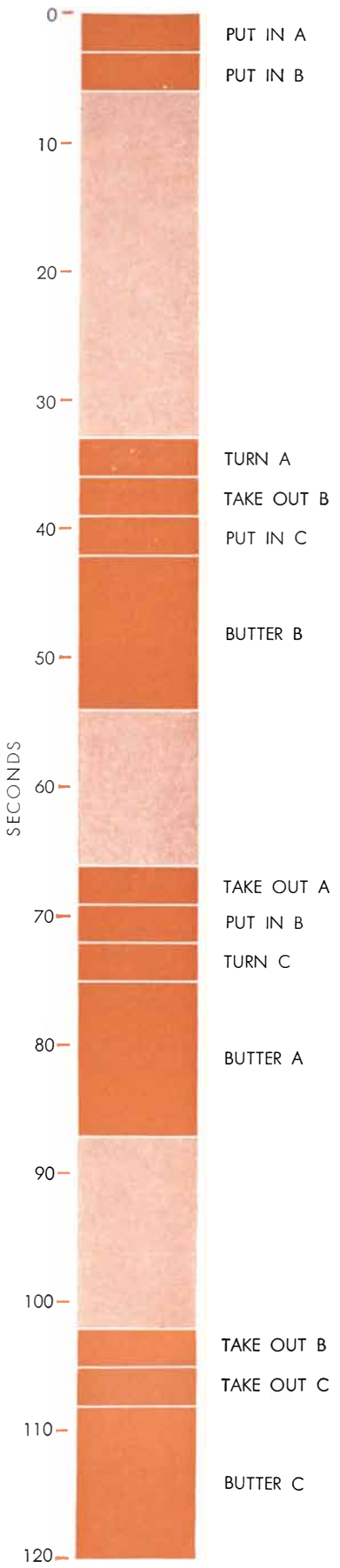

Solution to the toaster puzzle

3. Backward moves and jumps are permitted.

A chain of unbroken jumps may be made over men of both colors, but one is not allowed to combine jumps with a nonjump move. The object of the game for each player is to occupy his opponent's starting position. The first to do so is the winner. A player also wins if the game reaches a situation in which his opponent is unable to move.

Some notion of how difficult it is to analyze games of the halma type can be had by working on the following puzzle, first called to my attention by Octave Levenspiel. Arrange 12 checkers in the usual starting positions on the black squares of the first three rows of checkerboard. The rest of the board is empty. In how few halma plays can you transport these men to the three rows on the opposite side of the board? A "play" is defined as either a diagonal checker move, forward or back, to a neighboring black square; or a jump over one or more men. An unbroken jump may include forward and backward leaps and is counted as a single play. As in halma, it is not compulsory to jump when jumps are available, and a series of unbroken jumps may be terminated wherever desired even though more jumps are possible.

Although this problem is familiar to many puzzlists throughout the world, it has not to my knowledge ever received a final answer. May I call on readers of this department for help? If the reader will send me the shortest solution he can obtain, I shall discuss in the October issue the best solutions received. It will not be possible to acknowledge these letters, but I shall appreciate getting them, and it will be instructive to see how short a record can be achieved. The problem is quite easy to solve in 30 moves, so there is no point in writing unless you do better than that. For convenience in recording a solution, number the black squares, left to right and top to bottom, from 1 to 32.

Here are the solutions to the short problems given last month:

1.

The dime and penny puzzle can be solved in four moves as follows. Coins are numbered from left to right.

1. Move 3,4 to the right of 5 but separated from 5 by a gap equal to the width of two coins.

2. Move 1,2 to the right of 3,4, with coins 4 and 1 touching.

3. Move 4,1 to the gap between 5 and 3.

4. Move 5,4 to the gap between 3 and 2.

2.

Three slices of bread—A, B, C,—can be toasted and buttered on the old-fashioned toaster in two minutes. The illustration on this page shows the way to do it.

3.

The illustration at the top of page 156 shows how the 6-by-10 rectangle, formed with the 12 pentominoes, can be cut into two parts and the parts refitted to make the 7-by-9 rectangle with three interior holes. The illustration at the bottom of page 156 shows the only two possible patterns for the 6-by-10 rectangle in which all 12 pieces touch the border. The first of these patterns is also remarkable in that it can be divided (like the rectangle in the preceding pentomino problem) into two congruent halves.

4.

A man goes up a mountain one day, down it another day. Is there a spot along the path that he occupies at the same time of day on both trips? This problem was called to my attention by psychologist Ray Hyman of the General Electric Company, who in turn found it in a monograph entitled "On Problem-Solving," by the German Gestalt psychologist Karl Duncker. Duncker writes of being unable to solve it and of observing with satisfaction that others to whom he put the problem had the same difficulty. There are several ways to go about it, he continues, "but probably none is . . . more drastically evident than the following. Let ascent and descent be divided between *two* persons on the same day. They must *meet*. Ergo. . . . With this, from an unclear dim condition not easily surveyable, the situation has suddenly been brought into full daylight."

5.

A. If OODDF is the square root of WONDERFUL, what number does it represent? O cannot be greater than 2 because this would give a square of 10 digits. It cannot be 1 because there is no way that a number, beginning with 11, can have a square in which the second digit is 1. Therefore O must be 2.

F, the last digit in the square root, cannot be 1, 5 or 6 because in each case this would make the *same* digit the final

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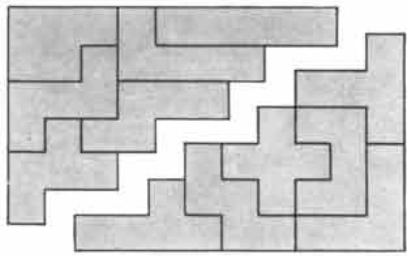
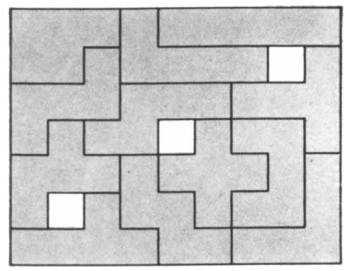




A 6-by-10 rectangle made up of pentominoes is refitted into a 7-by-9 one with three holes

digit of WONDERFUL. With this in mind, we find that there are 30 different possible combinations of digits for OODDF: 22334, 22337 and so on.

We can eliminate more than half of these by using a dodge based on the concept of the digital root. The sum of the nine digits of WONDERFUL (we were told zero was excluded) is 45, and this in turn sums to 9, the digital root of the original number. The square root of WONDERFUL must have a digital root that, when squared, gives a number with a digital root of 9. The only digital roots meeting this requirement are 3, 6 and 9; therefore OODDF must have a digital root of 3, 6 or 9. This eliminates all but 11 possibilities, of which only 22887 has a square (523814769) that fits the code word WONDERFUL.

B. The timesaving insight in this problem is the realization that if the nine digits are placed on a 3-by-3 matrix to form a rookwise connected chain from 1 to 9, the odd digits must occupy the central and four corner cells. This is easily seen by coloring the nine cells like a checkerboard, the center cell black. Since there is one more black cell than white, the path must begin and end on black cells, and all even digits will fall on white cells.

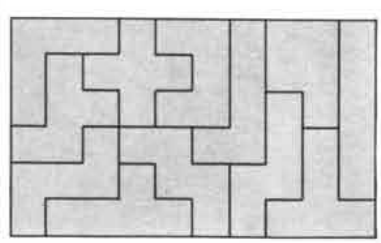
There are 24 different ways in which the four even digits can be arranged on the white cells. Eight of these, in which 2 is opposite 4, can be eliminated immediately because they do not permit a complete path of digits in serial order. The remaining 16 patterns can be quickly checked, keeping in mind that the sum of the two upper digits on the left must be less than 10 and the sum of the two upper digits on the right must be more than 10. The second assertion holds because the two upper digits in the middle are even and odd, yet their sum is an even digit. This could happen only if 1 is carried over from the sum of the right column. The only way to form the path so that the bottom row of the square is the sum of the first and second rows is shown on page 158.

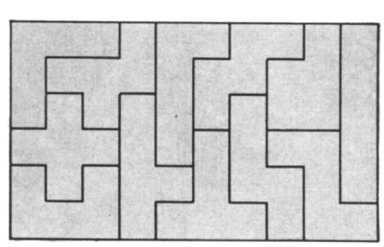
6.

Immanuel Kant calculated the exact time of his arrival home as follows. He had wound his clock before leaving, so a glance at its face told him the amount of time that had elapsed during his absence. From this he subtracted the length of time spent with Schmidt (having checked Schmidt's hallway clock when he arrived and again when he left). This gave him the total time spent in walking. Since he returned along the same route, at the same speed, he halved the total walking time to obtain the length of time it took him to walk home. This added to the time of his departure from Schmidt's house gave him the time of his arrival home.

7.

The young lady is older than 20, younger than 30. Her most likely age is 29, the next most likely is 28 and so on





All the pentominoes in these 6-by-10 rectangles touch the border of the rectangle

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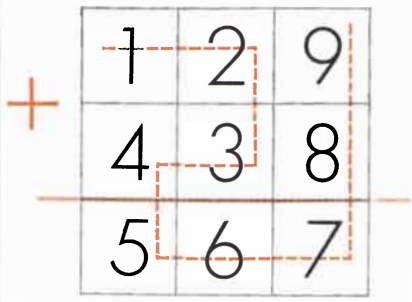

Solution to the chain-of-digits problem

down to 21, the least likely. If the mathematician wishes to guess her age in as few yes or no questions as possible, his best first question is "Are you 29?" If she says no, he adopts the usual strategy of binary division on the remaining eight ages, obtaining the answer in three more questions.

Seth Zimmerman of Dartmouth College gives the general solution in his article "An Optimal Search Procedure," in *The American Mathematical Monthly* for October, 1959. Only the procedure, not the proof, will be given here.

The first step is to list the possible elements (in this case nine different ages) from left to right in increasing order of probability. (If two or more elements have the same probability they are placed side by side in any order.)

21, 22, 23, 24, 25, 26, 27, 28, 29

The elements are grouped by pairs, beginning at the left:

(21, 22) (23, 24) (25, 26) (27, 28)
(29)

These parenthetically enclosed sets are now treated as five single elements and once more grouped into pairs, beginning at the left:

[(21, 22) (23, 24)]
[(25, 26) (27, 28)]
[(29)]

The three bracketed sets are handled the same way, making two final elements:

([(21, 22) (23, 24)]
[(25, 26) (27, 28)])
([(29)])

The best strategy for minimizing the number of questions is to take these di-

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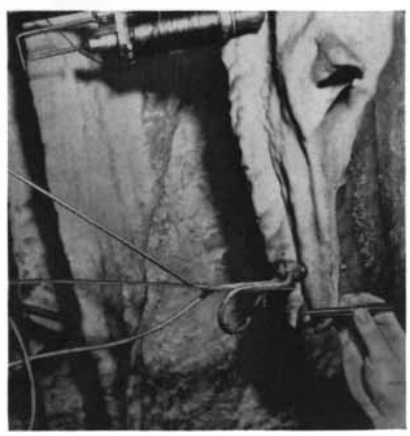

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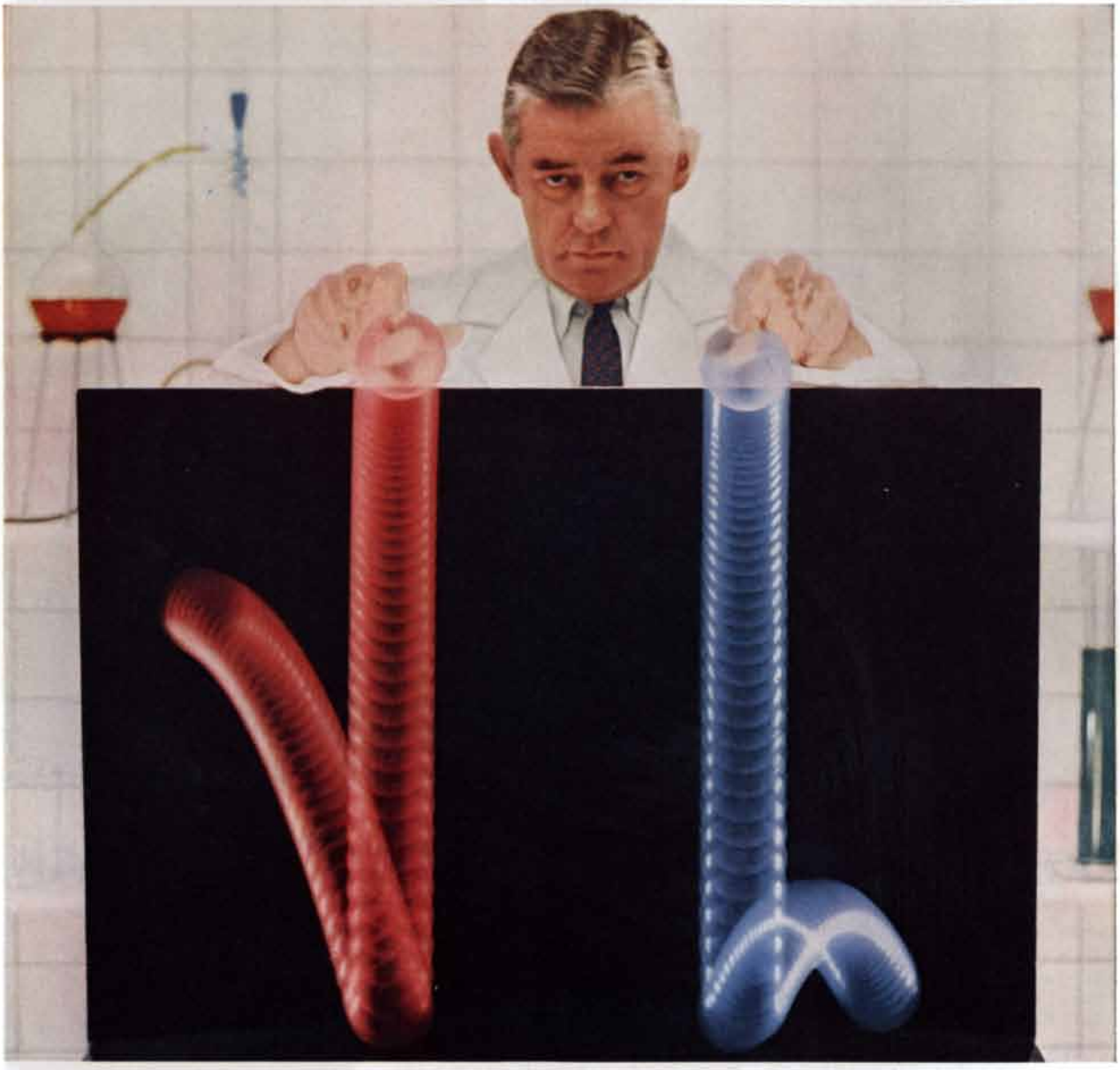

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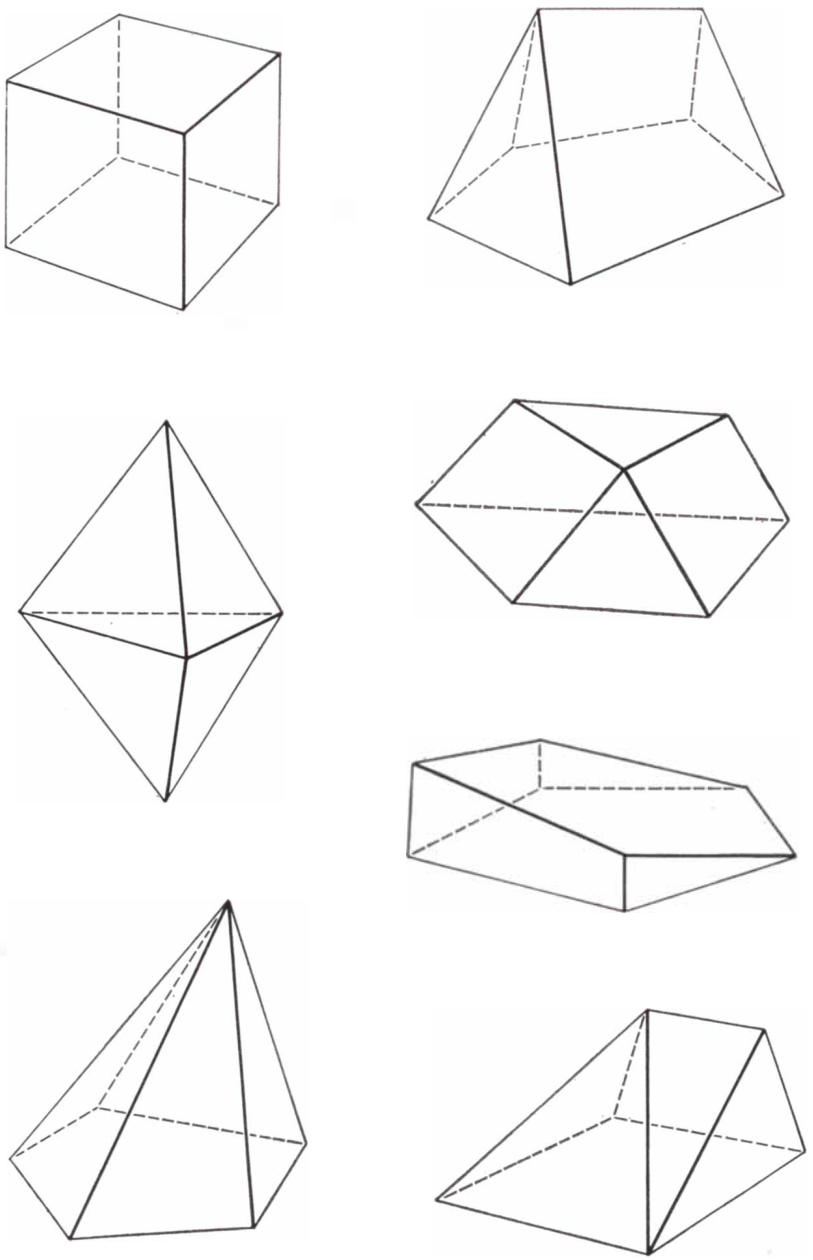
visions in reverse order. The first question, therefore, is whether or not the girl is 29. If not, three more guesses are required. In the case of nine elements, it does not matter how the eight are divided for the last three questions provided that they are halved at each division, because the optimal strategy provides no way of pinpointing the correct age in less than three more questions.

8.

In the chess problem white can avoid checkmating black only by moving his rook four squares to the west. This checks the black king, but black is now free to capture the checking bishop with his rook.

9.

The seven fundamentally different varieties of hexahedron (six-sided polyhedron) are shown in the illustration on this page. I know of no simple way to prove that seven is the maximum number. For those who are interested, there are 34 varieties of seven-sided polyhedron and 257 varieties of eight-sided polyhedron. Beyond this, the problem of determining the number of varieties of an n-sided solid becomes enormously difficult.



The seven varieties of hexahedron

THE AMATEUR SCIENTIST

An amateur uses paper chromatography to separate the constituents of mixtures

Conducted by C. L. Stong

Although almost everyone has taken a chemistry course in high school and chemistry sets are easy to obtain, few serious amateurs think of taking up analytical chemistry. Interesting experiments in this field seem to require too much study, too much equipment and too much mess. Curiously, one of the most advanced analytical techniques—paper chromatography—is well within reach of the amateur. With modest effort and expense the amateur can use paper chromatography to perform many diverting and meaningful analyses.

To demonstrate the power and simplicity of paper chromatography, cut a strip about an inch wide and four inches long from the clean margin of a newspaper. Place a dot of blue-black ink in the center of the strip about half an inch from one end and suspend the paper so that the edge of the inked end barely dips into a small container of water. Capillary attraction will draw water into the fibers of the paper and wash the ink up the strip. Bands of color will soon appear behind the migrating boundary of the water: red, yellow and green, perhaps, depending on the dyes in the ink. By the time the water reaches the top of the paper the colors will have been concentrated along the strip in the form of irregular but distinct bands. If the strip is examined under an ultraviolet lamp, fluorescent bands may also be seen. The separation of these dyes by the traditional methods of analytical chemistry would be a formidable undertaking for the average amateur, particularly if the sample weighed only a few micrograms, as it did in this case.

Because of its effectiveness and its economy of material and labor, paper chromatography has within the past 15 years come into wide use for the separation of organic substances such as amino acids. It is also useful, as the simple experiment with ink indicates, for the separation of inorganic substances. The technique was first described in 1944 by the British investigators Raphael Consden, A. H. Gordon and A. J. P. Martin, who had been using a glass column filled with silica gel to separate amino acids. In looking for an improvement on this chromatographic technique the British experimenters hit on the idea of substituting paper for the column of silica gel and, by a stroke of luck, made the first experiment with Whatman No. 1 filter paper. The amino acids promptly separated into distinct bands. Few papers have since been discovered that work as well.

The original paper chromatogram was made by the so-called descending method. A small spot of the mixture to be analyzed was applied near one edge of the sheet. This edge was placed in a trough of solvent and held in place by a weight; the rest of the sheet was draped over a horizontal rod as shown in the illustration on the opposite page. After being taken up from the trough, the solvent migrated down the sheet. To prevent evaporation from the paper, Consden, Gordon and Martin enclosed the apparatus in a length of drainpipe. The bottom of the pipe rested in a pan of solvent, which saturated the atmosphere surrounding the paper. The top of the pipe was covered with a sheet of glass. The experimenters found that their solvent migrated down the paper at the rate of about one inch per hour.

Subsequent investigation showed that the process could be speeded up substantially by making the solvent migrate up the paper instead of down. This is known as the ascending technique. The solvent normally rises between three and 30 inches per hour, depending on the temperature and the properties of the solvent. The ascending technique is widely used for analyzing substances that separate readily on strips not more than 12 inches in length. The most difficult separations are made by the descending technique on strips up to four feet long. A typical amateur setup for the ascending technique is shown in the illustration on page 164.

Other variations include the "elliptical" technique, which calls for a disk of filter paper in which a V-shaped cut is made; the top of the V is at the center of the disk and the bottom is near the edge. The bottom of the V is bent down so that it can be dipped into a shallow container of solvent. A dot of the sample to be analyzed is applied to the bend in the paper at the top of the V. The disk is then placed as a lid on the container of solvent and is covered by another container to enclose the paper in a saturated atmosphere. Solvent drawn into the bottom of the V migrates through the disk radially and bands form as a series of ellipses. The separations are considerably more distinct than those of the strip methods, as is suggested in the illustration on page 166.

Still sharper bands are produced by another variation known as the circular technique. Again a disk of paper is used, but here the paper is sandwiched between two sheets of quarter-inch plate glass. A spot of the mixture to be analyzed is applied to the center of the paper. After the sample has dried, the paper is placed flat on the bottom sheet of glass. The covering glass has a small hole in the center; the hole is centered over the specimen. (For a method of drilling glass see "The Amateur Scientist" for April, 1956.) Solvent is then applied through the hole to the sample by a pipette, as illustrated on page 168. A convenient stand for supporting the pipette can be made by twisting the ends of three wires around a metal rod the diameter of the pipette, soldering the twisted portion lightly and spreading the wires to form legs.

The list of substances that can be analyzed by paper chromatography is steadily growing, as is the list of solvents. Some of both are described by David Plaut, a student at Goshen College in Goshen, Ind. "The experiments I have made," he writes, "require six test tubes of 20-millileter capacity with rubber stoppers, a one-milliliter pipette graduated in units of .01 milliliter, a roll of

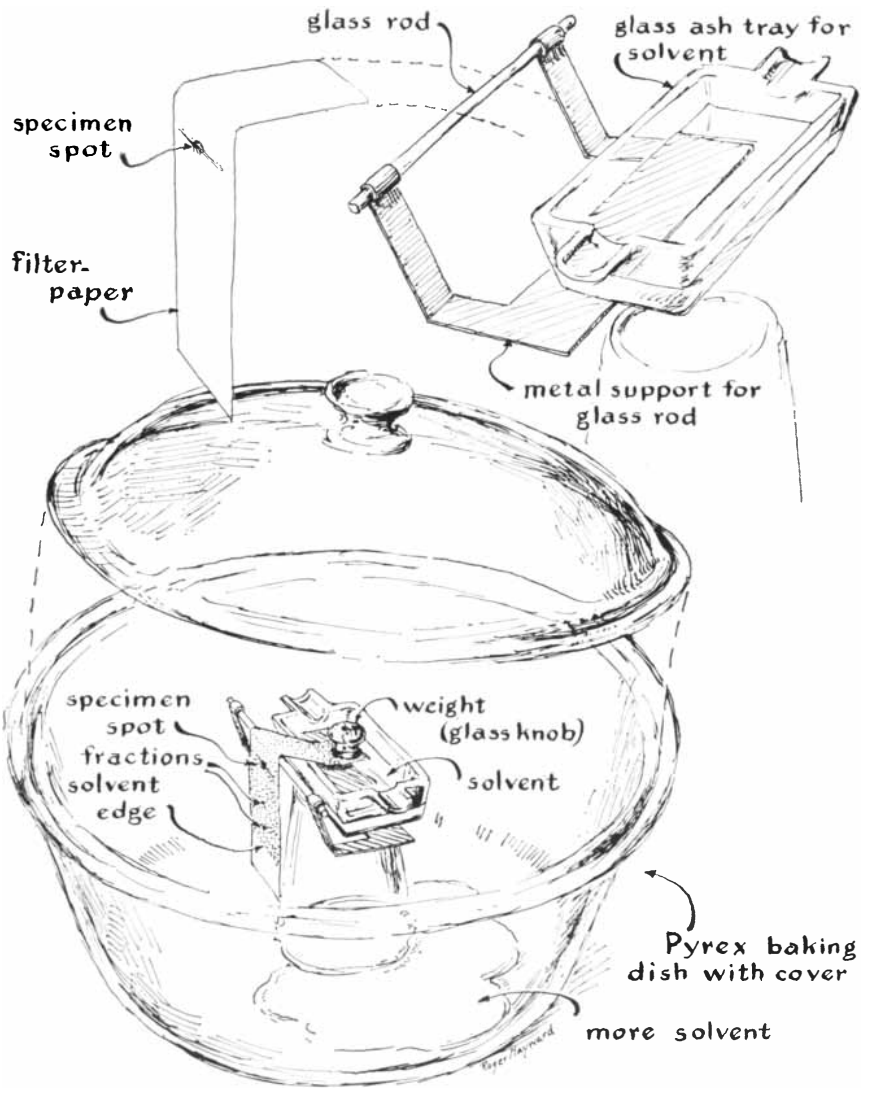
Whatman No. 1 chromatographic paper half an inch wide, a pair of rubber gloves, tweezers, a 250-milliliter flask and a micropipette.

"The micropipette can be made from a four-inch length of glass tubing with an inside diameter of about two millimeters. Heat the middle of the tube in a gas flame until it softens, then quickly draw the ends apart. Make a shallow nick in the glass at the closed end with a fine file and break off the tip so that the opening is as narrow as possible. Fire-polish the broken end by returning it to the flame for a moment, but be careful not to overheat the end and close it off.

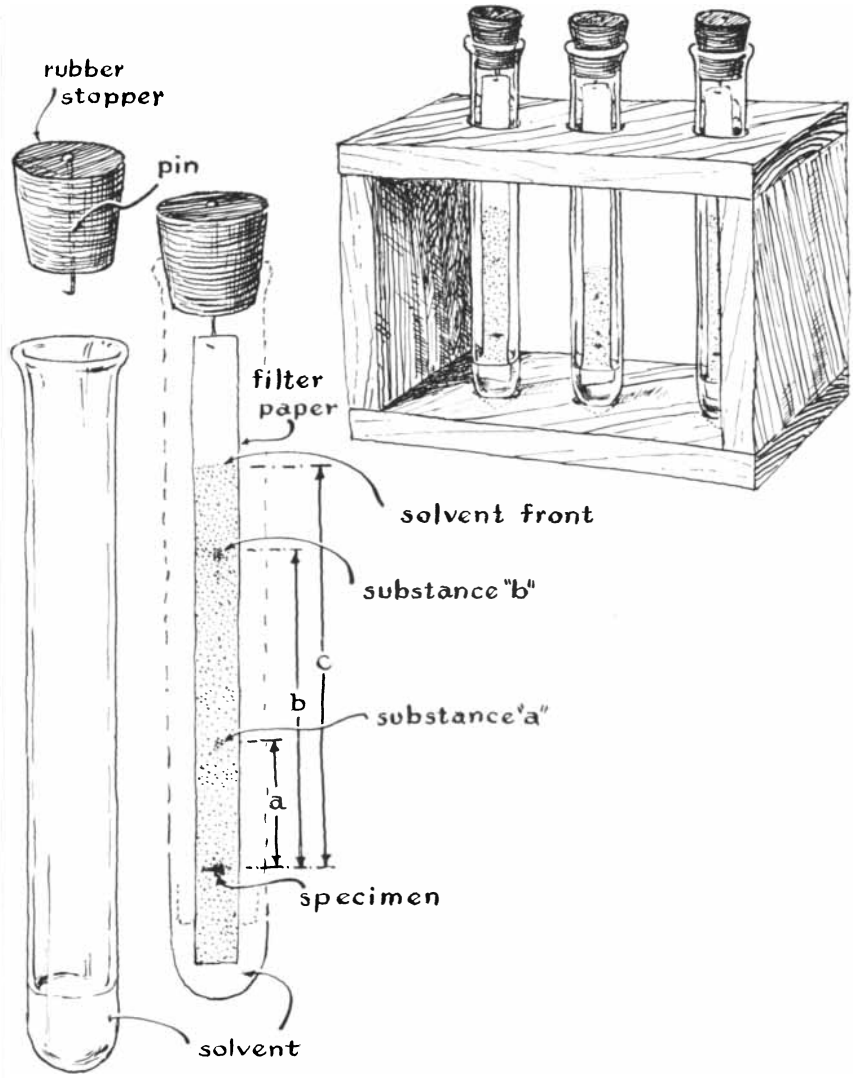
"The reagents include food coloring (from the grocer); 88 per cent carbolic acid; 70 per cent isopropyl alcohol; distilled water, which can be bought in minimum quantities from druggists; small quantities of amino acids, including aspartic acid, glutamic acid, glycine and tyrosine; 10 milliliters of .25 per cent Ninhydrin in butanol; 20 milliliters of ethyl ether, and like amounts of acetone and aqueous ammonia. These substances and Whatman paper (in strips, sheets or disks) can be ordered through druggists from chemical supply houses such as the Fisher Scientific Company, 633 Greenwich Street, New York 14. The amino acids are also available from Nutritional Biochemicals Corporation, 21010 Miles Avenue, Cleveland 28. The latter firm also markets a kit of 22 assorted amino acids (one gram of each) for $11.50. Finally, 10-milliliter quantities are required of molar solutions of mercuric nitrate, silver nitrate and lead nitrate and 50 milliliters of .25 molar potassium chromate. These concentrations are made by adding to 10-milliliter quantities of water 3.33 grams of mercuric nitrate, 1.7 grams of silver nitrate and 3.31 grams of lead nitrate, and to 50 milliliters of water 2.5 grams of potassium chromate.

"The separation of a mixture of food colors makes an interesting first experiment. Push common pins through three of the rubber stoppers and bend the points into short hooks, as shown in the accompanying illustration [*next page*]. Cut strips of filter paper of such length that when the strips are suspended by the stopper hooks inside the test tubes, the lower corners of the paper will just touch the rounded glass bottom. Mix a few drops of each food color in a clean container, pipette a drop of the mixture onto the center of the strips about half an inch from the bottom end and allow the strips to dry outside the test tubes. While the specimens are drying, pipette one milliliter of isopropyl alcohol into the test tubes. When the spots have dried, place a second drop at each of the spots and allow them to dry. Then hook the strips to the stoppers, lower them into the test tubes and push the stoppers down until the bottom edge of the paper makes contact with the alcohol. As the solvent front moves up the strip, bands of only red, yellow and green are likely to appear. Other food colors are usually made by combining these three.

"Colorless substances can be analyzed by making chromatograms in the same way and then coloring the bands chemically. The technique can be demonstrated by making a qualitative analysis for ions of silver, mercury and lead. Spot a strip, as in the previous experiment, with silver nitrate solution and develop the chromatogram with a solvent of distilled water. When the solvent front has migrated to within half an inch of the top, remove the strip from the test tube and dry for a few minutes. This chromatogram will show no color. To make the band visible dip the strip into a test tube containing potassium chromate, remove and wash gently in distilled water. A bright orange band will appear at the top, indicating the presence of silver chromate. Now pass the strip over an open vessel containing ammonia. The color will disappear. The silver forms the colorless, soluble silver-ammonia complex. Repeat the experiment using the nitrates of mercury and lead. Lead will give rise to a vivid yellow color and the mercury will appear black. When you have learned to develop and identify these colorless substances, mix a small quantity of all three and repeat the experiment. (Be sure to wash the pipette thoroughly after handling each substance to avoid contaminating the stock solutions.) The bands indicating mercury and silver will stand out clearly on the developed chromatogram. The



An amateur's apparatus for making paper chromatograms by the "descending" method



An apparatus for making paper chromatograms by the "ascending" method

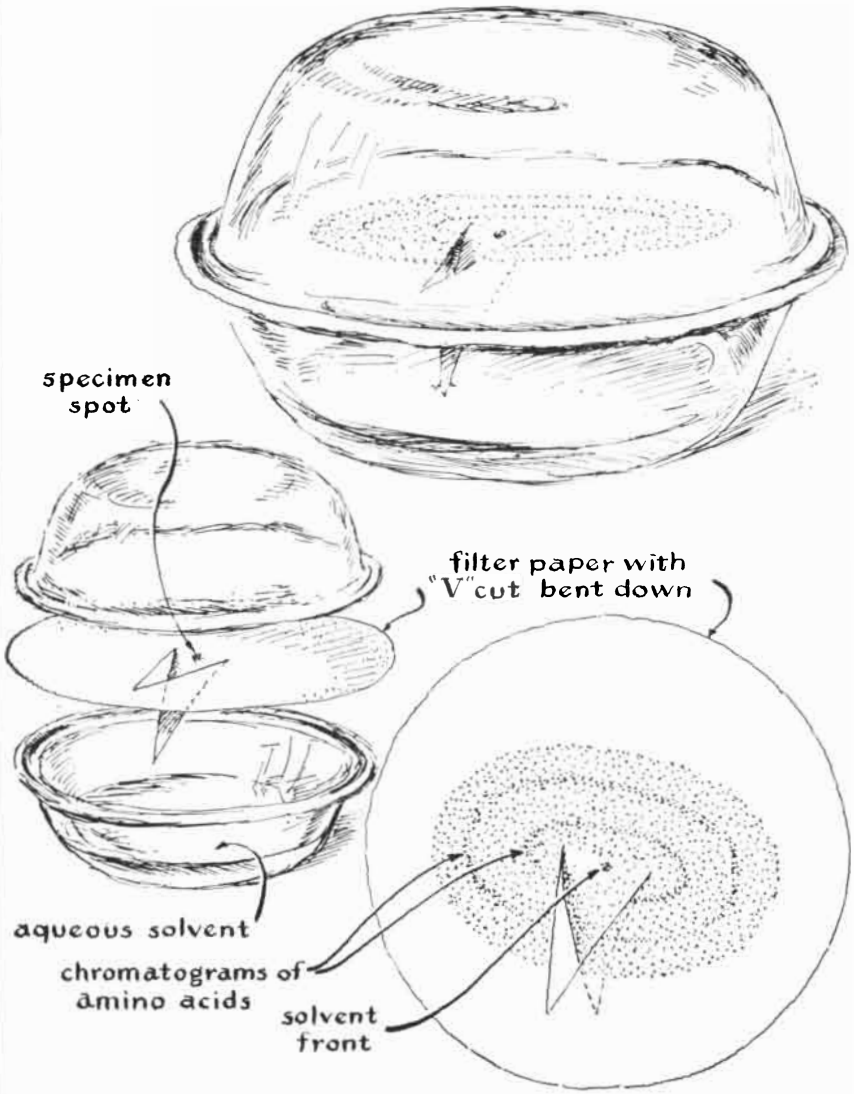
orange band of the silver chromate may, however, mask the yellow band of lead. But when the strip is passed over the ammonia, the orange will fade and reveal the yellow.

"Chromatograms of most organic substances are colorless, but those of plant pigments such as the chlorophylls, xanthophylls and carotenes are exceptions. To make a chromatographic analysis of plant pigments grind a few spinach leaves in a mortar or beaker until they are pulpy, add 10 milliliters of acetone and continue grinding until the solution turns deep green. Pour off the liquid, add three milliliters of acetone and repeat the grinding. Again pour off, combine the liquids and place a drop on a strip of filter paper as in the previous experiments. Dry, place a second drop at the same spot and dry again. Repeat until the spot becomes distinctly green. Then transfer the strip to a test tube containing enough ethyl ether to immerse the lower edge of the strip. (Remember that ether is highly flammable. Do not work with it near an open flame.) The developed chromatogram will show a band of chlorophyll at the top, then a band of xanthophylls and a gray band, which may contain a mixture of decomposed chlorophylls and orange or yellow carotene. Almost any mixture of plant pigments can be analyzed on paper by ethyl ether, from those in tomato catchup to those from the leaves of trees. It is interesting to run a series of experiments on tree leaves from spring to fall and tabulate the variations in pigment content.

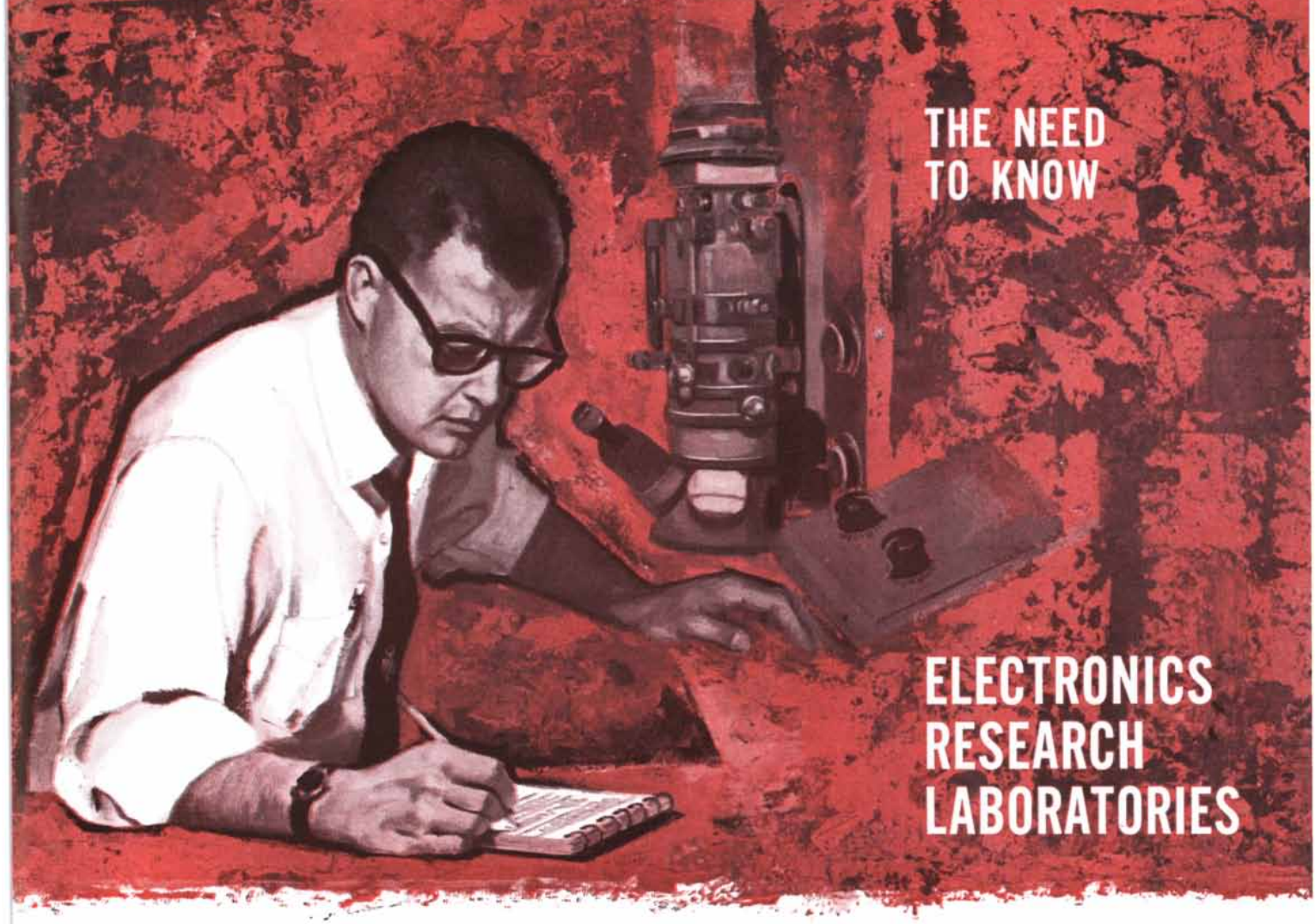
"By running a series of chromatograms on a given mixture it can be shown that each constituent of the mixture migrates at a characteristic rate with respect to the rate at which the solvent front advances. The substance with the highest migration rate is concentrated in a band closest to the solvent front; a substance that migrates slower will concentrate farther away from the front. In the case

of the amino acids the migration rates are normally measured and used as approximate guides for identifying the acids. The rates, called R_f values, are equal to the quotient of the distance that a substance moves from the starting point on the paper divided by the distance that the solvent moves from the same starting point. For example, a substance that migrates three inches from the starting point while the solvent front advances six inches has an R_f value of .5 for the particular run. Thus the R_f value of substance *a* shown in the accompanying illustration [*page 164*] is $R_f = a/c$; of substance *b*, $R_f = b/c$. Identification of the amino acids would be easy if all experimenters always found the same R_f value for each substance. Some of the variables that prevent exact agreement are (1) the kind of paper used for the chromatogram; (2) the orientation of the paper fibers; (3) the length of the strip; (4) the composition of the solvent; (5) the technique used for making the chromatograms, *i.e.*, ascending, descending, elliptical or circular; (6) the initial distance of the solvent from the starting line; (7) the concentration of the mixture being analyzed; (8) the amount and kind of impurities present in both solvent and solute; and (9) temperature. In spite of the fact that each of these variables can influence the R_f values, agreement between the results observed by various experimenters often turns out to be surprisingly close for the reason that some of the variables do not influence the migration rate appreciably. Moreover, a bias introduced in one direction by a major variable may be offset by the opposite bias of one or more other variables. As a consequence R_f values are useful clues to the identity of individual amino acids.

"An introductory experiment that demonstrates the use of R_f values can be



An apparatus for making paper chromatograms by the "elliptical" method



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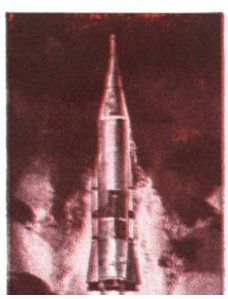

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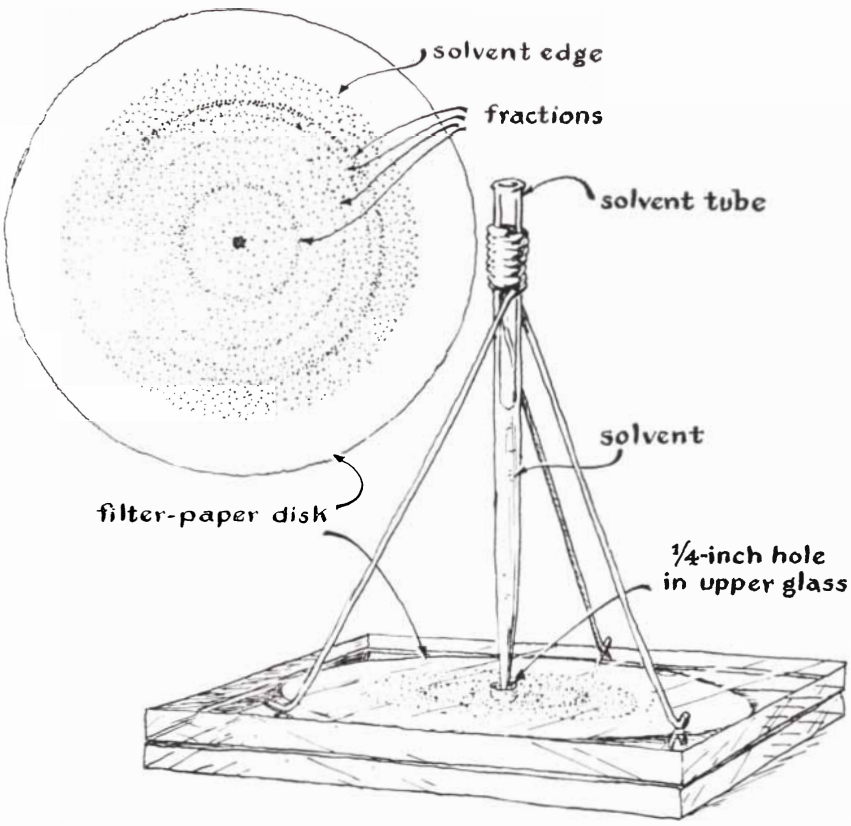
based on a mixture of aspartic acid, glycine, glutamic acid and tyrosine. These readily available substances differ substantially in R_f values and so are easy to identify. Rubber gloves should be worn to avoid contaminating the chromatogram. (Amino acids are colorless, therefore the chromatogram must be sprayed with a staining chemical such as Ninhydrin to develop color, and Ninhydrin develops fingerprints beautifully.) A good solvent for amino acids is phenol saturated with water. Add one part of water to four parts of phenol and mix well. Let the mixture stand for about 20 minutes. If the solution separates into two layers, the phenol is saturated. If there is no separation, add water, shake and allow to stand. Repeat until two layers appear. Saturated phenol settles as the bottom layer. An alternate solvent consists of a mixture of butanol, acetic acid and water in the proportion of eight to one to eight by volume. This mixture also forms two layers on standing. Again the bottom layer is the solvent. Although butanol so prepared is the solvent most widely used to analyze amino acids, the mixture gradually deteriorates and should not be kept more than a week or two.

"After preparing one of these solvents, dissolve a few crystals of one of the amino acids in two milliliters of water. (Five-milliliter vials with screw caps are convenient for storing stock solutions of amino acids.) Incidentally, the experiment will gain in interest if the acids are analyzed in accurately measured amounts. If possible, weigh the crystals, add them to a measured volume of water and apply to the chromatographic strip with a calibrated micropipette.

"It is always useful in chromatography experiments to draw a pencil line across the strip at the point where the specimen is applied, say an inch from one end. The line is essential when R_f values are to be determined. Apply a spot of any amino acid to the middle of the starting line and allow it to dry. Add solvent to the test tube, taking care that no drops cling to the walls of the tube, suspend the strip by the hooked pin and insert it in the tube. When the solvent has migrated to within half an inch of the top of the strip, remove and dry. Drying may require an hour or more at room temperature but may be speeded by baking the strip in a warm oven at 150 to 175 degrees Fahrenheit.

"Spray the dried chromatogram with Ninhydrin and, if desired, dry in the oven for 10 minutes. The band of acid will appear as a bluish spot somewhere along the strip. If all goes well, the spot



An apparatus for making paper chromatograms by the "circular" method

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should be about the same shape and size as the spot applied to the starting line. If the acid is impure, the phenol unsaturated or the solvent contaminated, the spot may have a tail. Chromatograms of a single pure amino acid normally show one spot. Do not be surprised, however, if a number of spots appear. These unexpected 'ghosts' are usually monoethyl esters of the acid under test, but they may also indicate the presence of other acids.

"Make a series of runs on a selected acid. When sufficient experience has been gained so that results are consistent, compute the R_f value of the acid. Then determine and tabulate the R_f values of the remaining acids. Compare your tabulations with the following typical values for acids in the concentrations specified above when developed at 72 degrees F. by saturated phenol on Whatman No. 1 chromatographic paper: aspartic acid, .14; glycine, .4; glutamic acid, .24; and tyrosine, .59. Finally, mix two or more of the acids and develop a composite chromatogram.

"If a full kit of 22 acids has been bought, determine the R_f value of each. A variety of common substances can then be analyzed. Some brands of canned soup will show glutamic acid, for example, as will Accent, the commercial preparation used for intensifying the flavor of foods. Aspartic acid will be found in green tea; soy sauce will yield a galaxy of acids. There is little point in attempting to analyze milk or urine by the strip technique because the many amino acids present in these fluids appear on the chromatogram as a meaningless pattern of overlapping spots.

"All the techniques of paper chromatography discussed so far share a basic limitation. Two or more substances analyzed under identical conditions may have the same or very nearly the same R_f values and migrate at substantially the same rate; and therefore they will concentrate as overlapping bands. For reliable identification by any of these techniques, the migration rates must differ by 10 per cent or more. How, then, can materials rich in many amino acids be analyzed?

"The problem is solved by altering one of the factors that exert a substantial influence on migration rate, such as the solvent. After being developed by one solvent the chromatogram can be turned 90 degrees and developed again by another solvent. This is known as the two-dimensional technique. A sheet of paper (usually 15 inches square or larger) is substituted for the strip. The mixture is applied to a corner of the sheet about an

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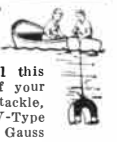

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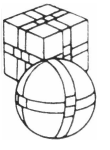

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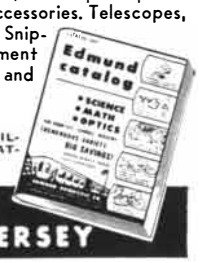

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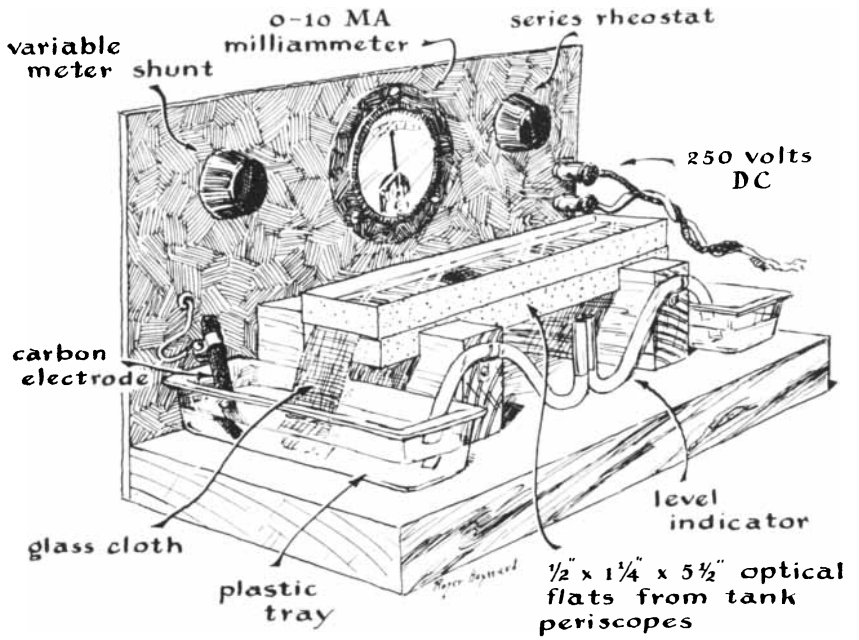

An amateur's version of an electrophoresis apparatus

inch from the edges. With the spot at the bottom, the sheet is suspended so that its bottom edge makes contact with a trough of solvent. The entire assembly is enclosed in an airtight housing. When the solvent front has migrated to within an inch of the top, the sheet is removed, dried and rotated 90 degrees, with the chromatogram at the bottom and parallel with the trough. The bottom edge is now immersed in a different solvent and developed again. The sheet is removed, dried and sprayed with Ninhydrin. The amino acids should appear as separate spots distributed over a large area of the paper. Each acid or fraction is now characterized by a pair of R_f values, one for each of the solvents. In fact, the two-dimensional chromatogram may be considered a graph of the mixture, with each fraction plotted according to its R_f values."

Frank A. Sheldon of Magnolia, N.J., submits his version of an apparatus for separating mixtures by the electrophoresis method. As explained in this department for August, 1955, electrophoresis resembles chromatography in certain respects. Whereas chromatography is based on differences in the strength with which various substances are adsorbed in a medium such as paper, electrophoresis takes advantage of the fact that many substances exist as ions in solution, have a characteristic electric charge and migrate at a characteristic rate in an electric field. Albumins and some organic dyes, for example, are ionized in a .3 molar solution of sodium carbonate (approximately one ounce of baking soda per pint of water).

Sheldon's apparatus consists of a strip of glass-fiber cloth about an inch wide and 10 inches long sandwiched between a pair of glass plates arranged so that the ends of the cloth dip into glass containers of solution [*see illustration on this page*]. Direct current from a 250-volt source is connected to the solution by carbon electrodes in the containers. Current through the glass cloth (on the order of 10 milliamperes) is controlled by a rheostat in series with one of the leads and is measured by a 0–10 milliammeter. Current values greater than 10 milliamperes can be measured by connecting a 0–100,000-ohm rheostat across the terminals of the meter and calibrating the meter for intermediate settings of the rheostat against a meter designed for higher currents. Siphon manometers made of transparent plastic tubing indicate the relative level of solution in the containers. They must be at the same level or gravity will cause solution to migrate through the glass cloth from the upper to the lower container and induce an unwanted chromatographic effect. The optically flat glass plates are from a surplus tank periscope.

To make an electrophoresis analysis Sheldon first dips the glass cloth in solution, blots it thoroughly, applies a spot of the mixture to be analyzed to the center of the cloth, assembles the apparatus as shown and switches on the current. With a current of 10 milliamperes spots of food coloring migrate at a maximum rate of four millimeters per minute.

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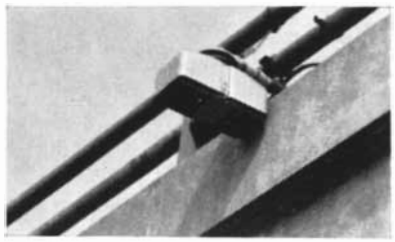

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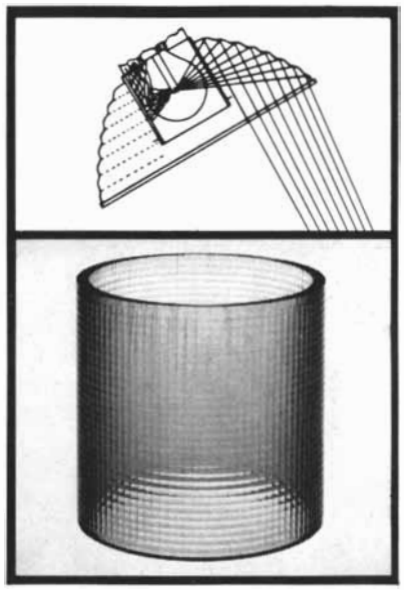

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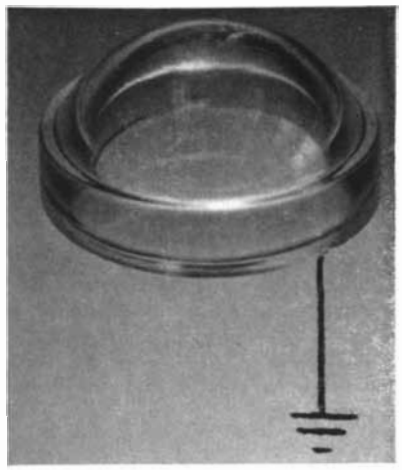

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BOOKS

Lewis Mumford's new work about the culture of cities

by Henry S. Churchill

THE CITY IN HISTORY, by Lewis Mumford. Harcourt, Brace & World, Inc. ($11.50).

The city is man's greatest artifact and the most enduring record of his fleeting passage. From its ruins, from its remnant monuments, from temples, cathedrals and the pattern of streets, from its neon lights, its wastelands of parking lots and the perpetuity of its slums, the curious historian, anthropologist, artist or novelist, of whatever bent of mind, can reconstruct whatever kind of world he wishes. This is the ambivalence of the past: for the present it becomes justification or denial and for the future it can spell hope or despair.

Out of the past Lewis Mumford has chosen to show how the city has failed, how at every critical turn in history it has betrayed man's trust. *The City in History* is not really about cities and people but about an anthropomorphic conception called The City, which Mumford treats as a biological and social entity in which people lead vicarious lives. The City is the victim of evil and diabolic forces that have taken possession of it: spirits, thrones and powers, kings, tyrants, scientists, hucksters, the halt in good will, the lame in brain, the blind to vision.

Mumford is the true reformer, the essential pessimist to whom the good exists always and only as potential. He describes himself rightly as a generalist, and he is a very erudite one, whose scope of knowledge is broad and whose power of synthesis is strong. To this he adds a moral fervor that has brought him homage as a philosopher both at home and abroad; indeed, he is a sort of popular Cassandra. His philosophy of the Ugly Civilization offers the reader a happy relief from Freudian guilt, a relief that in simpler and grander days was called catharsis. His horrid accusations and dismal threnodies—all true, of course, but only part of a many-faceted truth—make the conscious subconscious of the intellectuals shiver and rejoice.

So much for background, which is necessary because this extraordinary book is on two levels: a level of learned and interesting exposition and information about cities as makers of a social order, and a level of moral conclusions often derived from only a partial view of what a city is physically and what people were and are.

Mumford says of Venice: "When we admire the surviving outward form, we must not forget the persistence of the inner trauma—the trauma of civilization itself, the association of mastery and slavery, of power and human sacrifice." This is juxtaposition of a kind that constantly recurs in his book. Speaking of Hellenistic disillusionment and the development of the Eleusinian mysteries as a reaction against urban repressions, he writes: "All this began far earlier than the sixth century B.C., for the emptiness of civilization that had no other goals than its own existence had become visible, as I have pointed out, long before: Vanity of vanities, all is vanity under the sun." And again, speaking of the present, he says that "the prime need of the city today is for an intensification of collective self-knowledge . . . such a knowledge as is achieved by a neurotic patient in facing a long-buried infantile trauma that has stood in the way of his normal growth and integration."

It is to the analysis of this trauma, which has deepened from ziggurat to automation, that *The City in History* is devoted. It begins in the flickering light of prehistory, with the formation of the city around ancient abodes of the gods or places of sacrifice or sources of spiritual power, ruled by priest-kings who became temporal tyrants. This is the basic trauma; then we come, after a long time, into history and the recorded past of Mohenjo-Daro and Sumer, the long morning of the river valleys and at last to the Greek polis. For Mumford, as for so many others, this is high noon: the closest the city ever got to fulfilling its function of making people whole. In Athens every seventh man was a freeman, a citizen, a member of the leisure class; bearing arms in defense of the city, listening to the wisdom of the greatest collection of sages the world has known, dwelling under the rock that bore the most pellucid and exquisite expressions of man's abstract essence, the product of "exorbitant pride and shocking moral callousness." This was the world of Plato and Aristotle. Mumford discusses Plato's ideal city at length and rejects it—as he later rejects Thomas More's Utopia—for its totalitarian rigor, its boredom, its inhuman categories. One might add that all utopias are inhuman; it is of their essence that all inhabitants must conform, lest the form vanish.

As for Aristotle, Mumford writes that his ideal "was not a rationally abstract form to be arbitrarily imposed on the community: it was rather a form already potential in the very nature of the species, needing only to be brought out and developed." It might be added that the age-old distinction between Plato and Aristotle applies to Le Corbusier and Frank Lloyd Wright, to La Ville Radieuse and Broadacre City. Mumford also draws an interesting parallel between Plato and St. Benedict. The influence of the Benedictines was probably the greatest force in architecture, and even in city planning, during the Middle Ages. The fact that the monasteries were as rigidly authoritarian as any utopia is something Mumford glosses over because of St. Benedict's humanitarianism. There was, however, a real difference here: one became a monk or not, as one chose, and so submission was also a matter of choice.

What we know of the Greeks today, what we see on the Acropolis, is residual. The high moment passed: "The monuments of Greek art, which we now prize, were valid expressions of this life at its loftiest moments. But in part they were likewise material substitutes for a spirit that, *had it known the secret of its own perpetuation*, might have made an even more valuable contribution both to urbanism and to human development." The italics are mine; the perpetuation is

the Parthenon, the perpetuation is that it is still Greek thought, Greek art and Greek wisdom we use as touchstones for our own accomplishment.

The forces that brought an end to Athens and to Greece were not all internal, as Mumford implies. There are world forces that at times are inevitable and that small virtue, however morally indomitable, cannot resist. Such a force was the rise of Rome, and it is bending history to morality to avoid the issues of the economic and material drives that made Rome what it was. In spite of its crassness, and because of its materialism, Rome brought into the world an order that it had not known before and that paved the way for a vaster and more complex world than had ever been thought of by the polis. Rome was much more, much more, than Mumford's rancid picture of its lack of sanitation, its horrible tenements, its degraded butcheries; the symbol of Rome is not the Cloaca Maxima. Granted that the gentle reader who learned about Rome from Horace was not familiar with the seamy side of the city and would need to be enlightened, it is even more likely that today those who read Petronius and Catullus are not familiar with that other image of Rome as the Eternal City. If any city in history deserves the fullest and most complete description and, in the direct meaning of the word, comprehension, it is Rome.

Rome "fell," of course, tenements and all, leaving an image of law and order so strong that every element of the Western world still reflects it. This applies to the physical image as well as to the legal and political; the baroque city is deeply indebted to the great Roman architect Vitruvius. Everywhere, even in Byzantium (which does not appear in *The City in History*), the physical characteristics of the Roman urbs made themselves felt. We are learning more and more about how this influence was carried through the Dark Ages, a period that, as we learn more about it, becomes less dark, more full of people and their goings and comings; of the business of life, which does not stop; of birth, growth and death, of architecture, poetry and song. The Western world did not become a vacuum, and some form of urban life throve continuously: Lutetia, Nîmes, Aachen, London, Saragossa—even Rome itself.

Out of it emerged in 12th- and 13th-century France a flowering similar, in the unity of its thought and the quality of its life, to the great years of Greece. Though the center and highest achievement of this flowering was in the Île-de-France, it encompassed more than France: the Gothic vision of the spirit ranged from Ireland to Spain, from Syria across the Black Sea and up the Russian rivers to Scandinavia. Everywhere along the routes of conquest and trade new cities appeared. A new economic life stirred, political unrest grew and, as trade routes changed, economics changed with the change in the business ability as well as the ideals of rulers. Cities changed too. Mumford, with his emphasis on the moral and metaphysical, will not admit these outside forces. He not only denigrates the almost undeniable evidence of these influences given by the historian Henri Pirenne but also rejects as of minor consequence the effect of the coming of gunpowder on the actual form of cities.

The Middle Ages, as Mumford well points out, was an era of awakening social consciousness among civic leaders. In the ancient world social responsibility was at best a fringe benefit; in Rome it was totally absent. If Christianity was responsible for the Inquisition, it was also responsible for responsibility; if the Church was obliged to save the heretic willy-nilly from Hell's fire, there was also the responsibility of giving help to the faithful here on earth. Mumford points out that the guilds, in protecting their own, were basically fraternal organizations with their roots in the Eleusinian mysteries and older traditions; however, he overlooks the fact that the feudal relationship of lord and peasant was far different from the relationship of master and slave in that *noblesse oblige* was not just a slogan. Out of this social conscience came new civic needs: hospitals, almshouses, housing for the aged, communal halls, guildhalls—all new and formative functions around which the burghers could center their loyalty and from which they could make common cause against the enemy, whether king, bishop, lord or foreigner. It was now that the university made its formal appearance, "and as the cloister and library of the monastery might be called a passive university, so the university might be termed an active cloister." The physical forms tended to blend too, as Padua and Oxford, the old Sorbonne and others still testify. They provided a place for quiet and meditation, a place, as Mumford says, for "the practice of abstention and prayerful withdrawal." This we now lack; not only do our cities not have such places but apparently our homes do not either: "Today, the degradation of the inner life is symbolized by the fact that the only place sacred from intrusion is the private toilet."

Yet that puts us ahead of the Palazzo Massimi and Versailles, of Blenheim, the Winter Palace and the Escorial. Presumably this accounts for the fact that the 13th century, which had cloisters and sanitation, produced Thomas Aquinas; that the 18th century, which had neither cloisters nor sanitation, produced Voltaire; and that we, who have only sanitation, produce Norman Vincent Peale.

This is not irrelevant, for Mumford believes that the development of The City is closely related to the sexual and fecal habits of the indwellers. That the sanitation of the good old days was deplorable there is no doubt, as anyone who has visited an "underdeveloped" city knows. It takes corporate wealth, organization and industrialization to create sanitary services; our sanitary and deplorable metropolises are the result. There is, it seems, no silver lining without a dark cloud. As for sex and The City, they seem to go on together and to be always new and wonderful for those who can sing songs—in Greek, in pig Latin, in today's vernaculars.

The Middle Ages waned, the walls of The City became earthworks, "boulevarts." The mental walls changed too. Horizons widened across the ocean sea. Still, the basic trauma and schizophrenia remained; nothing changed.

Something must have changed, if only the surface of things. The transition from the medieval city to the baroque city is succinctly and brilliantly set forth in "The New Urban Complex," a section of Mumford's chapter "The Structure of the Baroque Power." "Baroque" is used here not in the restricted sense of an architectural style, nor even in the wider sense as the end period of the Renaissance, but in the now generally accepted sense of a period of political absolutism that was distinguished by a characteristic way of living, which is summed up thus: "Beneath the superficial polish of baroque upper-class manners there is the constant threat of an ugly, coercive discipline. These two qualities thread through every aspect of baroque life, even its luxury and folly." The effect on The City was profound; as in the Hellenistic city, principles of order had not become the means of ordering life, but "life had become an instrument of order."

"As soon as baroque order became widespread, uniform, and absolute, when neither contrast nor evasion was possible, its weaknesses lay revealed. Clarification gave place to regimentation, openness to emptiness, greatness to grandiosity." Baroque life, as might be expected, displayed similar defects: "Power and pleasure, a dry abstract or-

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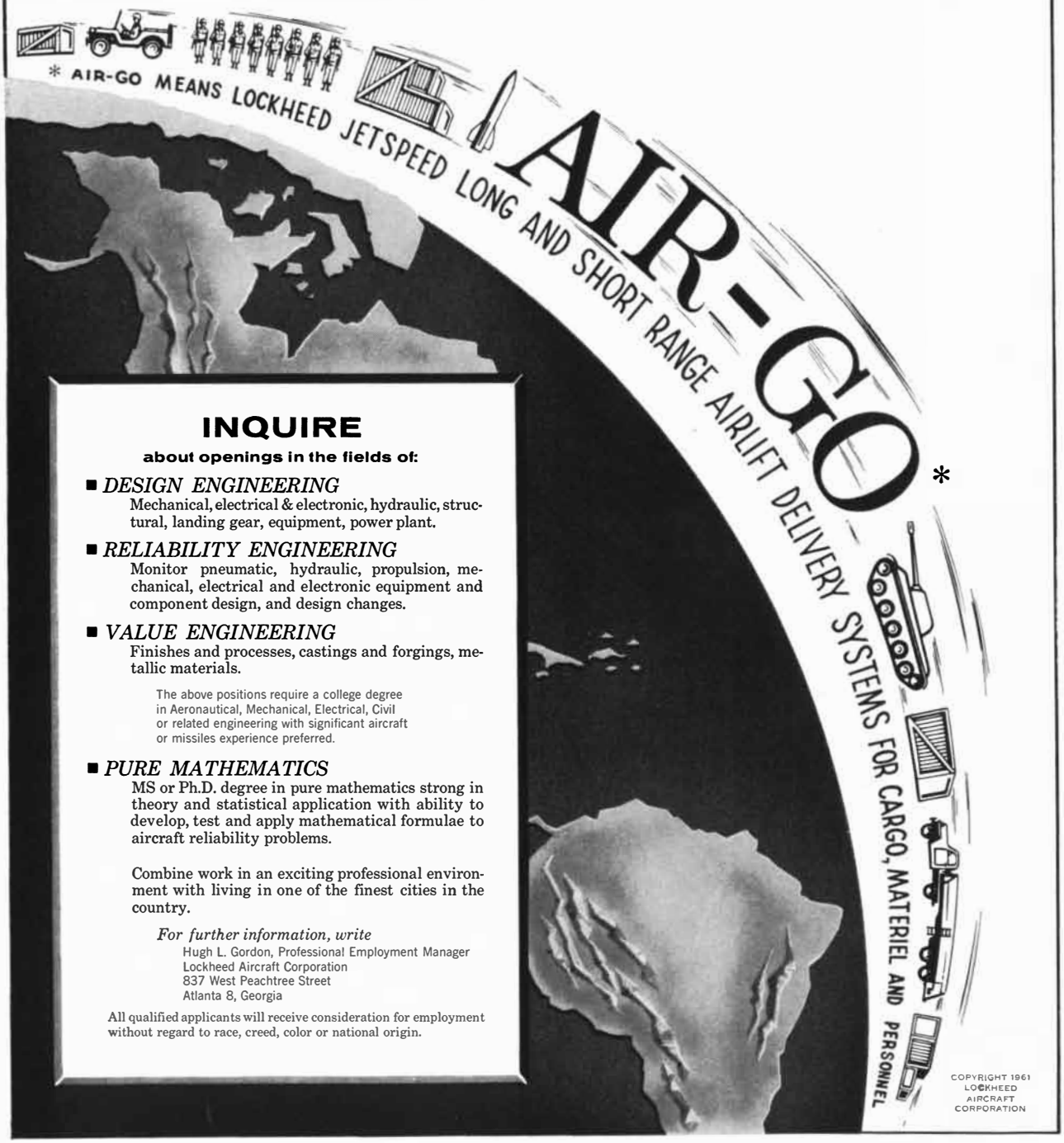

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der and an effulgent sensuality, were the two poles of this life. Mars and Venus were the presiding deities, until Vulcan finally cast his cunning iron net of utilitarianism over their concupiscent forms." This is just, as well as sharp, even if it omits the counterpoising swell of respect for humanity that began with Montaigne, the passion of Rembrandt, the voice of Donne. Mumford's treatment of the 18th century and the eventual merging of its basic principles of city life and civic organization into the "eotechnic" phase of early industrialism is excellent. The role of mechanization and capitalist mercantilism is developed, and the shift from the ownership of land to the ownership of the means of production is well brought out as a new source of centralized power and abuse. The theme provides him with the necessary material for demonstrating that 19th- and 20th-century cities are the culmination of the ancient trauma, now not only schizophrenic but paranoiac as well. If we are to be saved from ourselves, our entire civilization must become other than it is.

Indeed, the indictment Mumford makes of the 19th century, the "paleotechnic" period, is complete and damning. He continues the tirades of Friedrich Engels and multiplies the angles of wretchedness. In a brilliant summation he writes: "At the very moment that cities were multiplying in numbers and increasing in size all through Western civilization, the nature and the purpose of the city had been completely forgotten: forms for social life that the most intelligent no longer understood, the most ignorant were prepared to build. Or rather, the ignorant were completely unprepared, but that did not prevent their building."

Then, as Henry Adams foretold in his astonishing little essay "The Rule of Phase in History," the dynamo took over. The suffix "lithic" became obsolete; the age of stone—of masonry—came to an end. It is this transition that we find it so difficult to adapt to in our cities and our lives and that Mumford sees only as schizophrenia. In pointing out the consequences of our moral laxity his voice becomes clear and compelling; the moral issues are clear; there is a clear and present danger. He sets down the fateful choices we can make, must make, are making, and shows where our continued abuse of technical skill, our social blindness and our political ineptness may eventually lead us.

Like so many others, Mumford has concerned himself almost exclusively with the "great" cities: Rome, Paris, London, New York. They are the pacemakers, but the smaller cities are the conservers of values. It is the changes they undergo that give the tone of civilization as a whole; they are places like Cleveland and Liverpool and Toulouse, which are making haste slowly. There are still other towns that are changing hardly at all, serving as anchors, towns like Slippery Rock, Chipping Brownstone and Brive-la-Gaillarde. What these provincial cities and towns mean in the history of cities is not to be found in *The City in History;* their meaning is expressed in Balzac and Stendhal and Hardy and Mark Twain—to start early in the last century and to note that the novelist as social commentator, up to this very moment, is a more valuable guide for understanding the city than all the data of the sociologists.

The provincial cities are of course the nuclei of the new metropolitan regions and it is their development and "renewal" that will bring back some measure of balance to an urban scene that is dislocated by the fixation on New York. We are, I am convinced, on the threshold of urban coagulation rather than urban dissolution. Here Mumford's discussion of the basic theories of Ebenezer Howard and of Britain's New Towns is something that every city planner should read and ponder. Let him not be confused by the exterior forms imposed by Le Corbusier, the needs of the automobile and the vistas of the high-rise building. Let him look, rather, at the New Towns themselves, at the new groupings going up all over the Continent and at the content and the ideal of what we are trying to do here at home. It will be seen that Howard's humane theories have been as fully expressed as those of the baroque architect Leon Battista Alberti, which are the source of Le Corbusier's Procrustean city designs. An unlikely marriage, Howard and Le Corbusier, but it may turn out to be a happy one.

We are doing much more that is experimental, and even more that is not experimental, but it is still based mostly on the kind of ignorance that Mumford deplores. Yet I believe it is wrong, in the long view, to be too disdainful of the Levittowns and Park Forests, of suburbia and urban sprawl. These are, paradoxically, all direct evidence against Mumford's bitter onslaught on our "market civilization," its conformity, its disregard of "life." The so-called flight from the city is a revolt against these very things. Never mind that it has often been a case of out of the frying pan into the fire. The motive for leaving was, I repeat, revolt, an effort on the part of hundreds of thousands to find human values for themselves and a desperate hope of "something better for the children." I think that, in spite of the sociologists' worries about suburban uniformity, a vast majority of those who moved found a good part of what they wanted. As has often been noted, most nonconformists want company for their nonconformity.

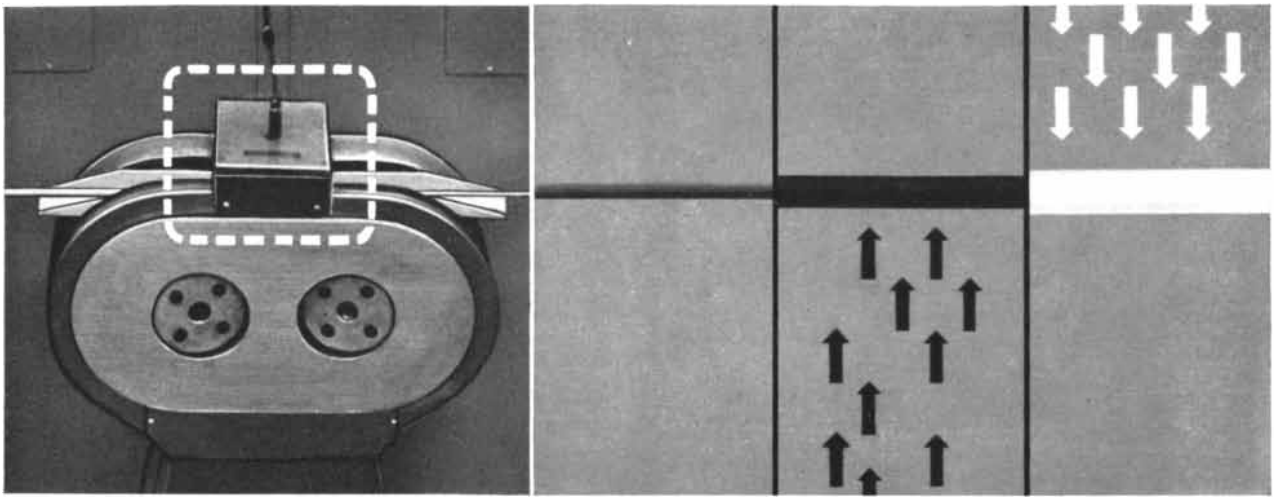
This is not to deny that a huge amount of what was and is being built is potential, and often immediate, slum. Here is an advantage in our accustomed use of wood and shoddy synthetics. When the time comes, they will be easier to get rid of than city tenements, thatch-roofed hovels in the Cotswolds or the "picturesque" slums of stone-built France.

My guess is that the next phase, in 30 years or so, will be that of "suburban redivision" or "sprawl elimination." There will then occur the process of "polynucleation," to use one of Mumford's felicitous terms, on a base of much sounder knowledge than we have now of the relationship between social well-being and physical environment. We are already seeking patterns for the city of tomorrow. Never before has there been such an effort to achieve "collective self-knowledge." Never before has there been so much study of the city—social, political, economic, demographic, geographic, anthropological. It may even be that there is too much of this, that there is too great an accumulation of immediately obsolete data being processed, too many pointless studies.

I think our task today is to combine the order and clarity of the baroque city with freedom for the growth of life. It is no easy task. We have so little to go on. It is hard to translate order and humanism into the physical terms of a dimly perceived social and business organization based on telecommunication. This much we can grope for as an immediate future. Beyond that we cannot even grope, so fast is the pace of technical change and social evolution.

I cannot accept Mumford's pessimism; he takes Madison Avenue too seriously. There has never been a time, even in Athens, when there has been such an outpouring of creative activity, when life has been so full for so many. In the arts, to be sure, this does not hold. The arts have at least temporarily taken second place to what is loosely called "science." It is in this area of creativity that the Western world has been so amazingly prolific: in medicine, physics, chemistry, biology, mathematics, even in such tangential fields as anthropology and archaeology. To assume that these contributions, made by hundreds upon hun-

Where one head is better than two!



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. . . and 0.010" PVC outer jacketing—in one operation.

Western Electric engineers devise a unique extrusion line that simultaneously insulates and jackets copper conductor wire with two dissimilar plastics

One of Western Electric's many jobs as manufacturing and supply unit of the Bell Telephone System is to produce rugged rural wire for sparsely populated localities and for prompt restoration of service in areas hit by storms, fires, or floods. Since the demand for this wire has been steadily increasing, Western Electric engineers sought a way to make it faster, better, and at lower cost.

Previously, two separate extrusion lines were used to sheathe the copper conductor with dissimilar plastic materials. One line applied a black layer of polyethylene insulation; the other applied an outer colored jacket of polyvinyl chloride (PVC) for extra protection and color coding (polyethylene used for color coding purposes will not "weather" satisfactorily).

In coming up with *one* production line to do both coating jobs, Western Electric's engineers had to overcome many manufacturing and engineering obstacles. Since the operating temperatures of the two plastics differ by approximately 100° F, special water cooling and thermocouples had to be provided for the extrusion screws to control these temperatures and to guard against scorching certain PVC compounds which are heat-sensitive. And plastic pressures of approximately 5000 lbs./sq. in. and 2500 lbs./sq. in. for the polyethylene and PVC, respectively, were needed for the operation.

The engineers at Western Electric's Baltimore Works solved these problems by designing and building a unique, *single* extruding head (containing an ingenious set of extrusion dies)—and associated equipment—which simultaneously applies polyethylene and polyvinyl chloride compounds on the copper conductor at the rate of 1600 feet per minute and at precisely the correct temperatures and pressures.

Over-all results to date of the multicoat, common-head extrusion line are: a higher quality, more uniform product... half as much operating space required... about 40% saving in investment costs as against conventional equipment... and substantial operating economies such as reduced scrap, lower maintenance, and a more effective utilization of labor. Furthermore, the simultaneous extrusion process is already being applied by Western Electric to the manufacture of other types of double-coated wire needed in ever-increasing quantities by the Bell System.

One more example of how Western Electric's creative engineering is contributing to America's rapid progress in communications.

Western Electric

MANUFACTURING AND SUPPLY UNIT OF THE BELL SYSTEM

BELL SYSTEM

dreds of gifted people, are not such vital manifestations of the human spirit, of the full living of life, as were the works of art and the craftsmanship of other periods is to completely misapprehend the meaning of culture. That only the artist or the craftsman or the tiller of the soil can be a whole man is hardly reasonable.

We are making colossal mistakes, to be sure. It will not be easy to get rid of Los Angeles, either as a visible or an invisible city. Nevertheless, as the failures of today become understood, the successes of tomorrow are assured. Mumford points a way: "The city should be an organ of love; and the best economy of cities is the care and culture of men."

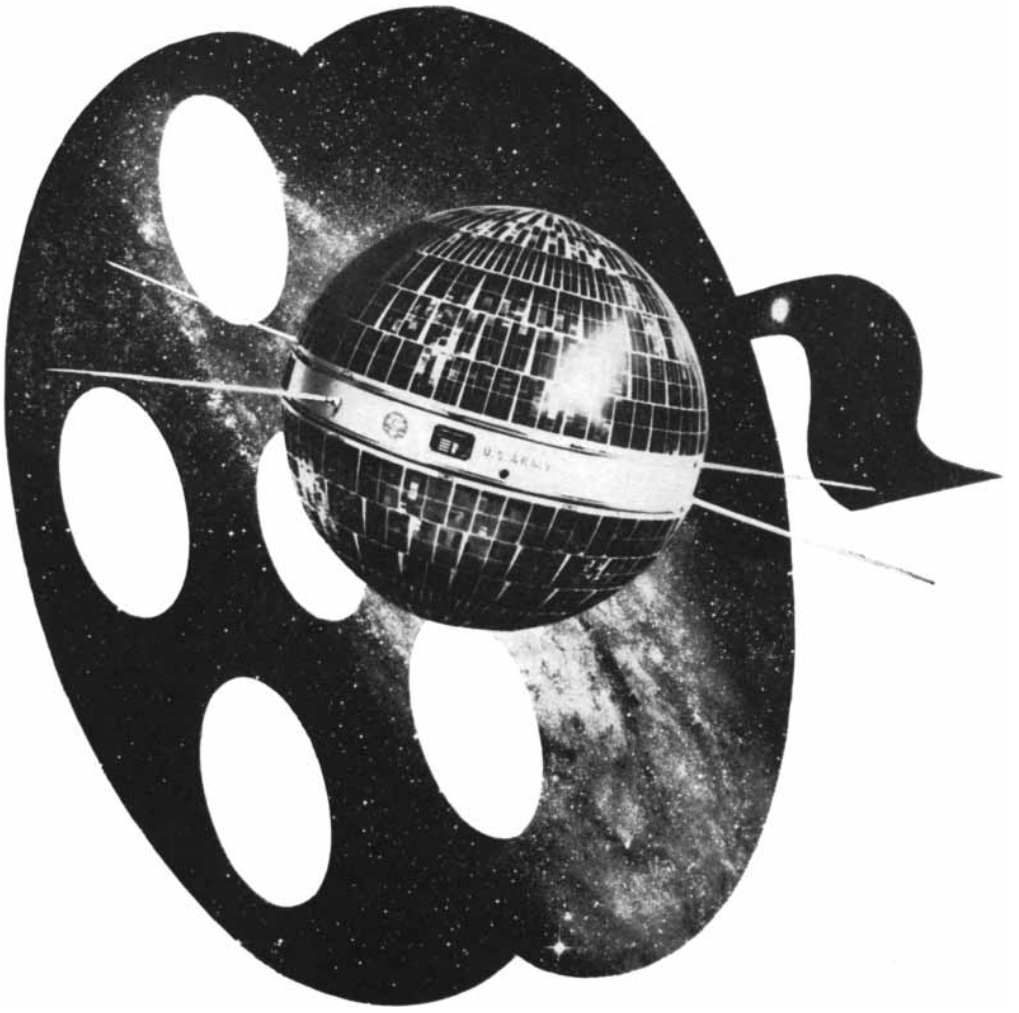
Short Reviews

EINSTEIN ON PEACE, edited by Otto Nathan and Heinz Norden. Simon and Schuster, Inc. ($8.50). Einstein, first among the scientists of his generation, was a good, courageous and wise man. Much has been said about the simplicity and directness of his approach, to both the problems of nature and of society. He had his visions, but these were only moments of a lifetime. No less important was his modest way of piercing to the heart of complex things and his quiet confidence in the trueness of his insights. In the preface to this volume Bertrand Russell reminds us that when A. S. Eddington undertook to verify the general theory of relativity by observing the solar eclipse of 1919, Einstein was much less interested in the result than Eddington was. This recalls the story about a lady who told James Whistler that she had seen Battersea Bridge looking just as it did in one of his pictures, to which Whistler replied: "Ah, Nature's coming on!" Einstein saw his predictions about the physical world confirmed; he also lived to see confirmed his profound misgivings about peace and the fate of mankind. The cause of peace was always close to his heart. He had the warmest human sympathy, the highest regard for individual liberty. He was suspicious of nations and hated war. From 1914 until his death in 1955 he declared his beliefs and fought for them with his gentle persuasiveness. In this book are gathered his many utterances on peace: addresses, letters and other writings. He communicated with the mighty, with famous men, with plain men; always in the same tone, always with respect, always with firmness, and sometimes with a touch of humor or irony which gave emphasis to his position and refreshed the mind. One cannot help wondering whether, if he had had an opportunity to do it over again, he would have written his famous letter to President Roosevelt that led to the making of the atomic bomb. On April 11, 1955, the Israeli ambassador, Abba Eban, called on Einstein in Princeton to discuss with him an address for television and radio Einstein had offered to make to celebrate the anniversary of Israel's independence. Within the next few days Einstein had begun to draft this address, but he was fatally stricken before he could complete more than a page of it. The very last paragraph he wrote deserves to be quoted: "In essence, the conflict that exists today is no more than an old-style struggle for power, once again presented to mankind in semi-religious trappings. The difference is that, this time, the development of atomic power has imbued the struggle with a ghostly character; for both parties know and admit that, should the quarrel deteriorate into actual war, mankind is doomed. Despite this knowledge, statesmen in responsible positions on both sides continue to employ the well-known technique of seeking to intimidate and demoralize the opponent by marshaling superior military strength. They do so even though such a policy entails the risk of war and doom. Not one statesman in a position of responsibility has dared to pursue the only course that holds out any promise of peace, the course of supranational security, since for a statesman to follow such a course would be tantamount to political suicide. Political passions, once they have been fanned into flame, exact their victims. . . ." The last sentence was unfinished, as was the work itself to which he had devoted so much of his life.

AN OUTLINE OF EUROPEAN ARCHITECTURE, by Nikolaus Pevsner. Penguin Books, Inc. ($30). This is the sixth edition of a work by a foremost historian of architecture which covers the subject from the Temple of Neptune in Paestum (*ca.* 560 B.C.) to Roehampton, a British housing development completed in 1959. The *Outline* began modestly in 1943 as a Pelican Book of 159 pages with 32 pages of illustrations, costing ninepence. In this dress it thrived, fattened, passed through five paper-backed editions, was widely read and highly praised. Now in its "Jubilee Edition," it is a splendid thing, as traceable to its origins as an oak to an acorn and almost as different. It is handsomely bound, securely boxed, beautifully illustrated with more than 600 plates of the highest photographic quality, and its price (neither unreasonable nor inconsiderable) is now more than 150 times that of the nine-penny ancestor. Thus the buyers are bound to be fewer than the buyers of the earlier editions, but whoever does buy will be delighted. This remains by far the best summary of its kind: a skillful matching of text and pictures, a lucid, thoughtful and lively sweep of the building art, of changes in style and taste, of historical and social influences expressed in churches, railroad stations, palaces, town halls, theaters, libraries, entrance halls, office buildings, private homes, schools, spires, mosques, castles, city walls, choirs, sacristies, roofs, towers, domes, hospitals, courtyards, cloisters, decorations, tombs, chapels, altars, windows, porches, columns—in short, a panorama of examples of "spatial expression," though not of the bicycle shed or the humble cottage.

ADAPTIVE CONTROL PROCESSES: A GUIDED TOUR, by Richard Bellman. Princeton University Press ($6.50). A series of lectures which attempt a unified approach to control theory and seek to provide a technique for making various problems amenable to machine solution. Feedback control, dynamical systems, decision processes and dynamic programing, boundary-value problems, sequential machines and the synthesis of logical systems, uncertainty and random processes, adaptive processes, stochastic control processes, theory of games and pursuit processes, communication theory—all are within the author's net. Bellman is more than a good mathematician; he has humor, verve and style, all of which, unlikely as it may seem, he applies to these topics.

JANE'S ALL THE WORLD'S AIRCRAFT: 1960–1961, compiled and edited by John W. R. Taylor. McGraw-Hill Book Company, Inc. ($35). The airplane may be dying but its studbook gets bigger. The parent group, to be sure, is becoming extinct, but the offspring are more varied than ever, competing fiercely for survival and adapting to swiftly changing conditions. Among the newer forms are an aircraft that will cruise for hours at three times the speed of sound, aerial nuclear-power plants, vehicles in which astronauts will be sent to orbit the earth at 18,000 miles per hour and a British airliner which will be able to carry 212 passengers across half the world in a day. Serving the older spirit, when men simply dreamed of flying and touching the clouds, are a British man-powered airplane with a total weight of 74 pounds, an Ilyin ornithopter with a three-horse-



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power piston engine and an ornithopter designed by Herman Rybnikov that has flapping wings resembling those of an insect. These craft can fly, are noncarnivorous and would have pleased Leonardo da Vinci.

JANE'S FIGHTING SHIPS: 1960–1961, compiled and edited by Raymond V. B. Blackman. McGraw-Hill Book Company, Inc. ($35). The 63rd edition of this standard work keeps up with the happy state of the world. Ship data, reference tables, specialized notes have been revised and amplified to take cognizance of new species and modified old species; 470 new illustrations are included, making a grand total of more than 2,500 photographs and scale drawings. A battleship isn't a battleship any more, nor a cruiser a cruiser nor a destroyer a destroyer. Guided-missile platforms are the thing. Killing is still the purpose but now there are attack ships, command ships, assault ships, support ships, "deterrent" ships, commando ships, task ships, antisubmarine-warfare ships, amphibious-warfare ships, early-warning ships, antiaircraft ships, aircraft-direction ships, amphibious-force flagships, submarines, submersibles of other categories, and so on and on. This is not the world of *Water Babies*, but it is very real.

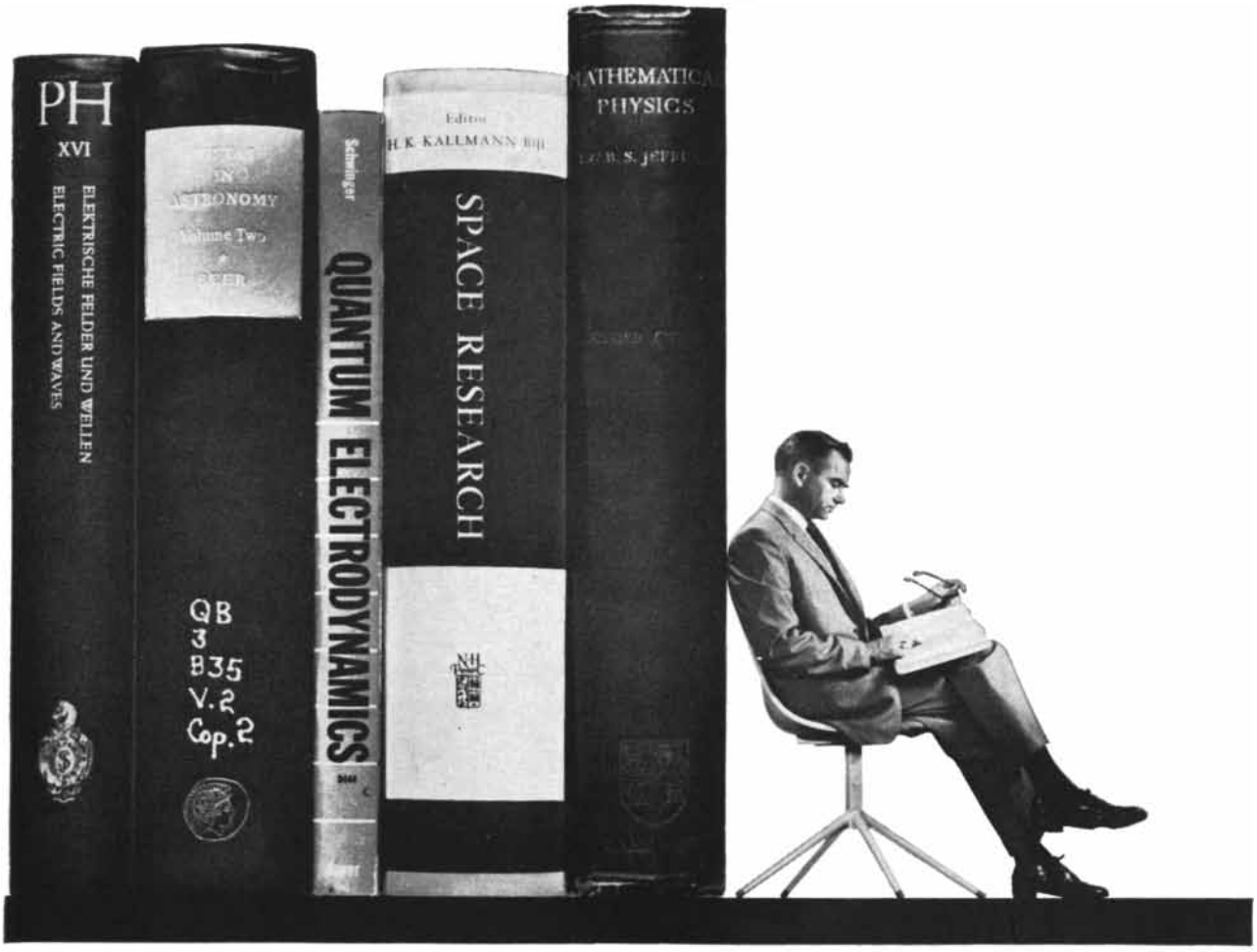
THE ENCYCLOPEDIA OF SEXUAL BEHAVIOR, edited by Albert Ellis and Albert Abarbanel. Hawthorn Books, Inc. ($30). A sane and civilized work, many articles of which are of compelling interest. It covers important aspects of the biology, physiology and anatomy of sex; it deals with emotional, psychological, historical and anthropological questions. There are, among others, articles on abortion, sexual abstinence and the sex life of Africans; on censorship, aphrodisiacs, coitus, divorce, frigidity, music and sex, marriage laws and impotence; on illegitimacy, orgasm, homosexuality, sexual dynamics in contemporary dance, perversions, transvestitism, venereal disease, sex and literature, extramarital sex relations, eugenics, the menstrual cycle, jealousy, psychoanalysis, prostitution, the art of loving, the sense of smell and sex, sex in the U.S.S.R. The articles, even those on the most controversial issues, are marked by honesty and refreshing candor in a field whose literature is often marred either by absurd euphemisms, hypocritical respectability or prurience. While the encyclopedia has its shortcomings, it is by far the best available survey of its kind, and many professionals and specialists in different fields, as well as plain readers, will be properly grateful that such a book exists to guide and enlighten them.

PHYSICS AND ARCHAEOLOGY, by M. J. Aitken. Interscience Publishers, Inc. ($6). A description of some of the ways physics has been applied to archaeology: magnetic location, resistivity surveying, mine detectors, radiocarbon dating, magnetic dating, analysis of materials by spectrometry. To cite one interesting example: the sensitive proton magnetometer will pick up the magnetism of baked clay and other burned structures which are apt to be found on many archaeological sites. The book discusses the equipment itself, the way it is used and the results which have been obtained. Illustrations.

A SHORT HISTORY OF TECHNOLOGY, by T. K. Derry and Trevor I. Williams. Oxford University Press ($8.50). An attractively illustrated survey for the general reader and students covering the development of technology from the earliest times to 1900. Williams was one of the editors of the well-known five-volume *History of Technology* (reviewed in these columns as the volumes appeared), and this book is admittedly based upon the larger work; it is not, however, an abridgement. It is, rather, a work designed for a different audience and with greater emphasis on the relation in each period of technology to contemporary historical circumstances. A useful book, but it is a pity no attempt was made even to summarize the main events after 1900.

THE CELL: BIOCHEMISTRY, PHYSIOLOGY, MORPHOLOGY, edited by Jean Brachet and Alfred E. Mirsky. Academic Press Inc. ($38). These two volumes dealing with specialized cells complete a five-volume treatise of up-to-date knowledge in the many active fields of cell research. Among the topics treated in the final installments are viruses, the organization of bacteria, protozoa, intracellular parasitism and symbiosis, the neuron, the structure of photoreceptors, muscle cells, gland cells, kidney cells, blood cells, pigment cells, bone and cartilage, cancer cells. Illustrations and extensive references to the literature.

MATHEMATICAL HANDBOOK FOR SCIENTISTS AND ENGINEERS, by Granino A. Korn and Theresa M. Korn. McGraw-Hill Book Company, Inc. ($20). A reference collection of mathematical definitions, theorems and formulas for the use of scientists, engineers



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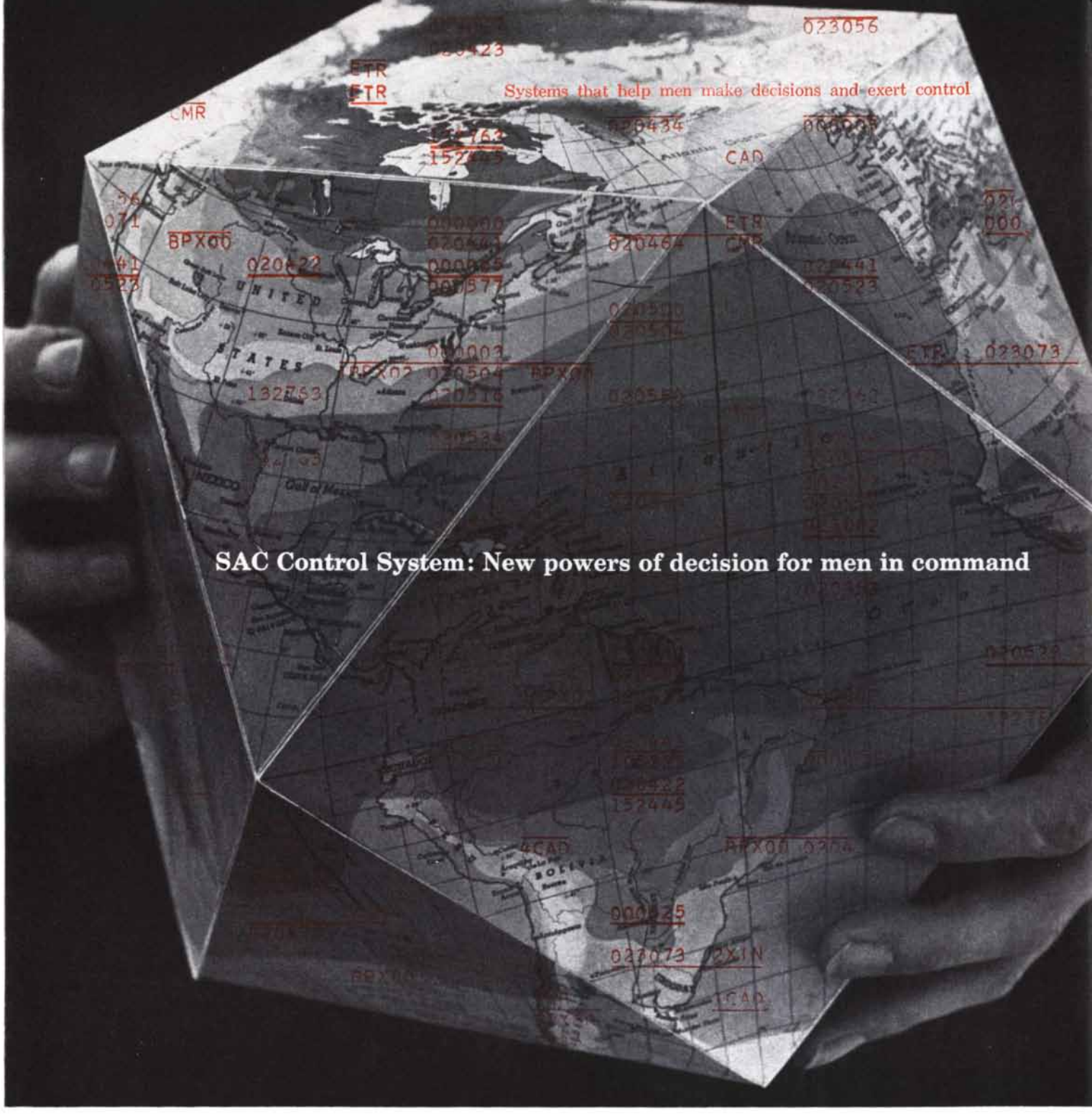

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The globe shown is the Dymaxion projection by R. Buckminster Fuller. It depicts the spherical world as a flat surface with a minimum of distortion.

and students. The material is so arranged that each chapter can also be used as a rapid review text (though no proofs are given) of a given mathematical subject. Illustrations, references and bibliographies.

Notes

THE FUTURE OF MAN, by P. B. Medawar. Basic Books, Inc. ($3). The 1959 Reith Lectures (presented by the British Broadcasting Corporation) by a brilliant British zoologist, mainly concerning the effect on man of evolutionary forces interacting with his own actions: intelligent, stupid, humane, destructive. Very palatable and illuminating.

THE WANDERING SCHOLARS, by Helen Waddell. Anchor Books ($1.45). A paper-backed reissue of the sixth edition of Helen Waddell's lovely book which describes the life and art of the lyric poets of the Latin Middle Ages and presents a full selection, in the original and in translation, of the heritage of Latin song they left behind.

THIS IS THE AMERICAN EARTH, by Ansel Adams and Nancy Newhall. Sierra Club ($15). A series of magnificent Adams photographs—landscapes, wildlife, mountains, cities, rivers, lakes, waterfalls—together with a somewhat purplish plea by Nancy Newhall, formerly of the Museum of Modern Art, on behalf of conservation. Regardless of the text, this is a stunning volume.

THE READER'S ADVISER AND BOOKMAN'S MANUAL, edited by Hester R. Hoffman. R. R. Bowker Company ($15). The ninth edition of a guide to fiction, biographies, dictionaries, encyclopedias, bibles, classics, drama, poetry, science, philosophy and travel history. A serviceable book but, so far as its science coverage is concerned, one that is full of blind spots.

SOURCES OF CHINESE TRADITION, compiled by Wm. Theodore de Bary, Wing-tsit Chan and Burton Watson. Columbia University Press ($7.50). As an introduction to the background of contemporary civilization in China, the authors present translations from Chinese sources illustrating Chinese thought since earliest times.

THE ROTATION OF THE EARTH, by Walter H. Munk and Gordon J. F. MacDonald. Cambridge University Press ($13.50). A geophysical essay which examines the nature and causes of cer-

tain observed irregularities in the rotation of the earth, irregularities which are a nuisance to the astronomer but which the geophysicist turns into an asset.

TURNING POINTS IN PHYSICS, by R. J. Blin-Stoyle and others. Harper Torchbooks ($1.45). This book, consisting of lectures given at Oxford in 1958, was reviewed in these columns two years ago. A few of the lectures, for example the one by K. Mendelssohn, are of uncommon merit, and it is agreeable to have this volume available in an inexpensive reprint.

IDENTITY AND ANXIETY, edited by Maurice Stein, Arthur J. Vidich and David Manning White. The Free Press of Glencoe, Illinois ($7.50). Who we are and what we are and how modern Western society confuses our answers to these questions is the subject of this collection of writings by sundry students, among them Erik Erikson, C. Wright Mills, I. A. Richards, Karl Jaspers and Frieda Fromm-Reichman. A disturbing and interesting book.

PUL ELIYA, by E. R. Leach. Cambridge University Press ($8). A study of land tenure and kinship in a village in the north central provinces of Ceylon, an area where habitation is possible only with the help of elaborate irrigation systems which have been in use since ancient times.

ANATOMY OF THE MONOCOTYLEDONS: GRAMINEAE, by C. R. Metcalfe. Oxford University Press ($13.45). This volume devoted to the grasses covers more than 400 species and presents information on general morphology and anatomy as well as the significance of histological details in grass classification.

MATHEMATICS, QUEEN AND SERVANT OF SCIENCE, by E. T. Bell. McGraw-Hill Book Company, Inc. ($2.50). An inexpensive reissue of Bell's lively account of major developments in pure and applied mathematics. A most readable book, as was everything that came from the pen of the late professor of mathematics at the California Institute of Technology.

ÉMILE DURKHEIM: 1858–1917, edited by Kurt H. Wolff. Ohio State University Press ($7.50). A collection of essays about the greatest of French sociologists, describing his contributions to a variety of disciplines. Also included are translations of several of Durkheim's essays previously unpublished.

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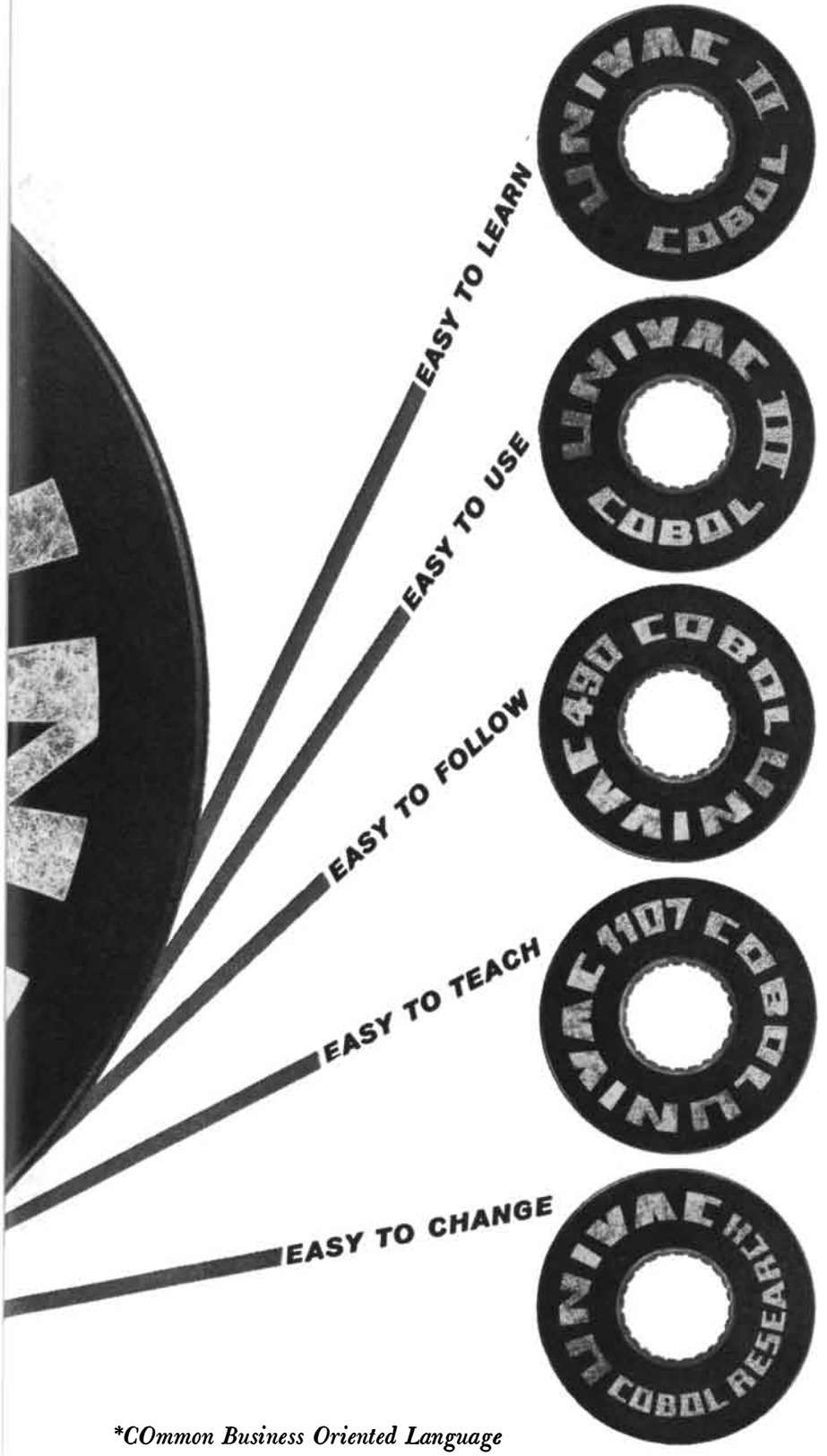
A DECADE OF PROGRESS IN ENGLISH-LANGUAGE COMPILERS



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From March 10 to May 10, 1961, JPL's Deep Space Instrumentation Facility at Goldstone, California, conducted an important radar bounce experiment directed at the planet Venus and hundreds of hours of scientific data were collected. The results obtained helped establish the United States as the leader in the new science of planetary radar astronomy.

Prior to this experiment, the Astronomical Unit (AU) contained an uncertainty factor of 60,000 miles which JPL scientists have now been able to reduce to 1,000 miles—possibly 100 miles—as one of the results of this effort.

Establishing a more accurate value for the AU will enable JPL to measure the exact distance to Venus prior to the launching of the first U.S. Venus probe.

One of the most important conclusions to be drawn from this successful experiment is the knowledge that we can now design a planetary radar observatory capable of almost continuous surveillance of Venus, Mars, Mercury and Jupiter. Therefore, March 10, 1961 marks the beginning of a new era in space technology and exploration.

This scientific accomplishment is only one of the many research programs in progress at JPL under its space exploration responsibility to NASA. These extensive investigations into the science and technology of the space environment offer real and stimulating incentives to uninhibited scientists and engineers with searching minds. JPL needs such men, who look forward to rewarding careers in this uncharted field.

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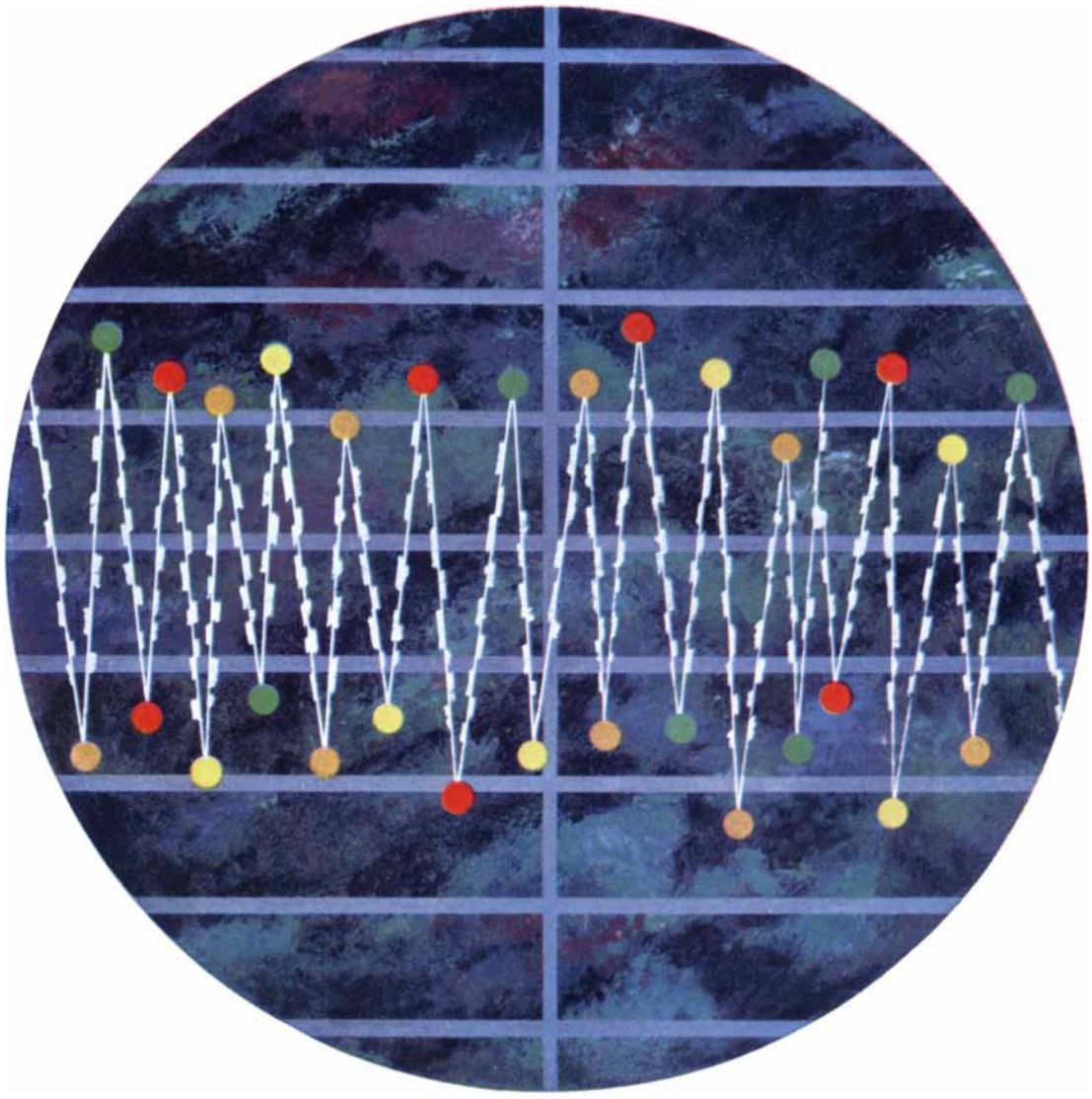

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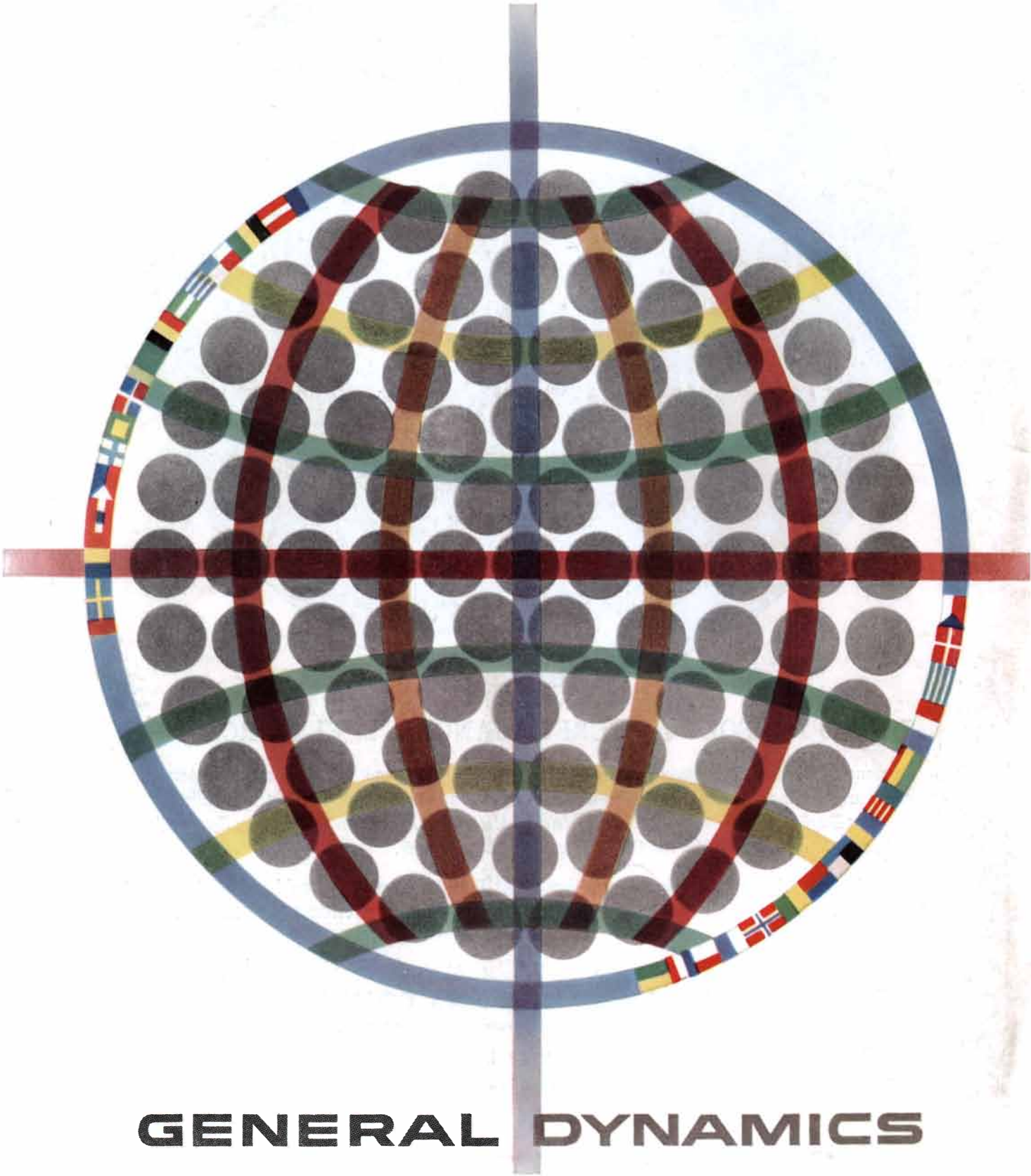

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