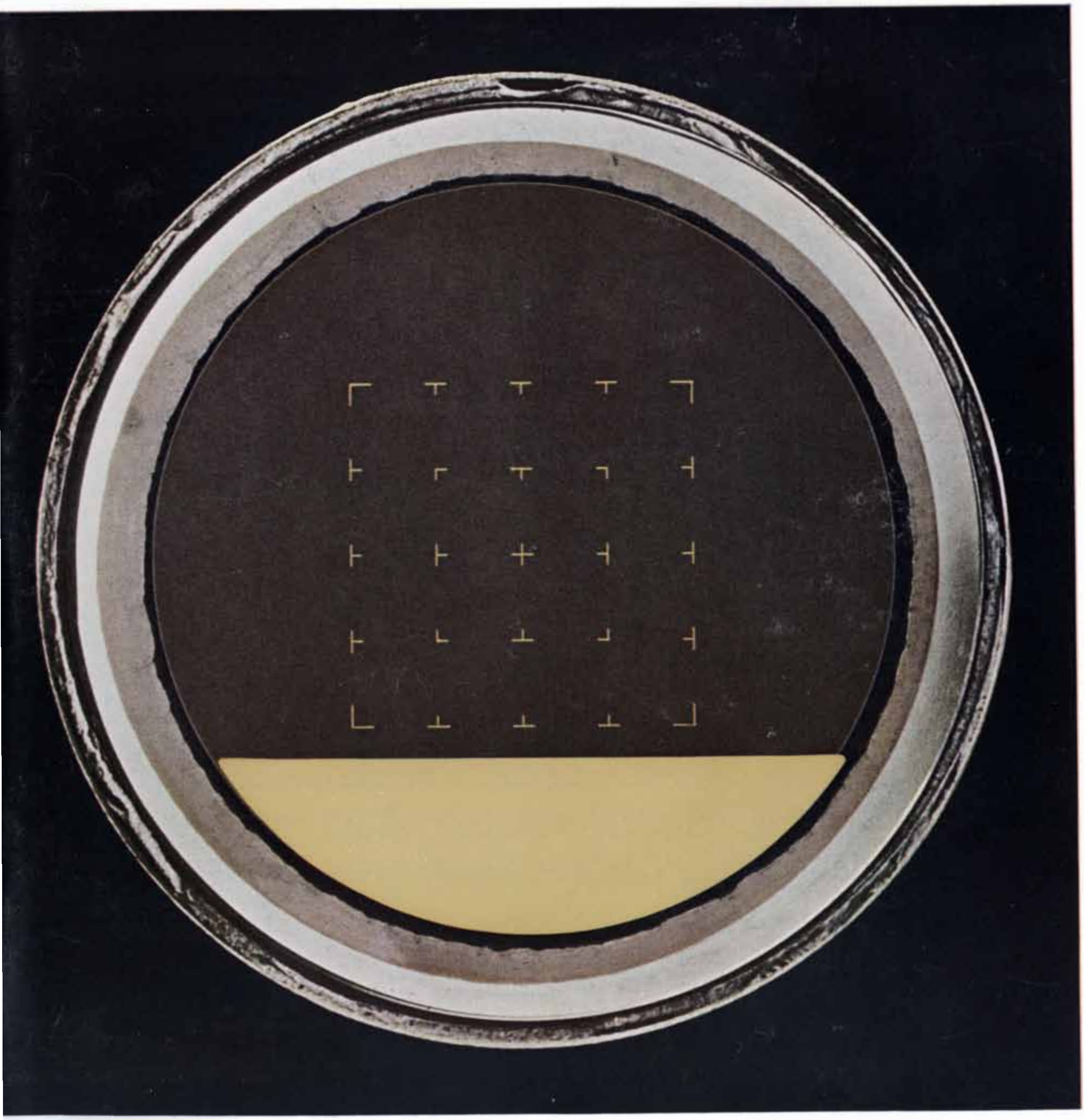
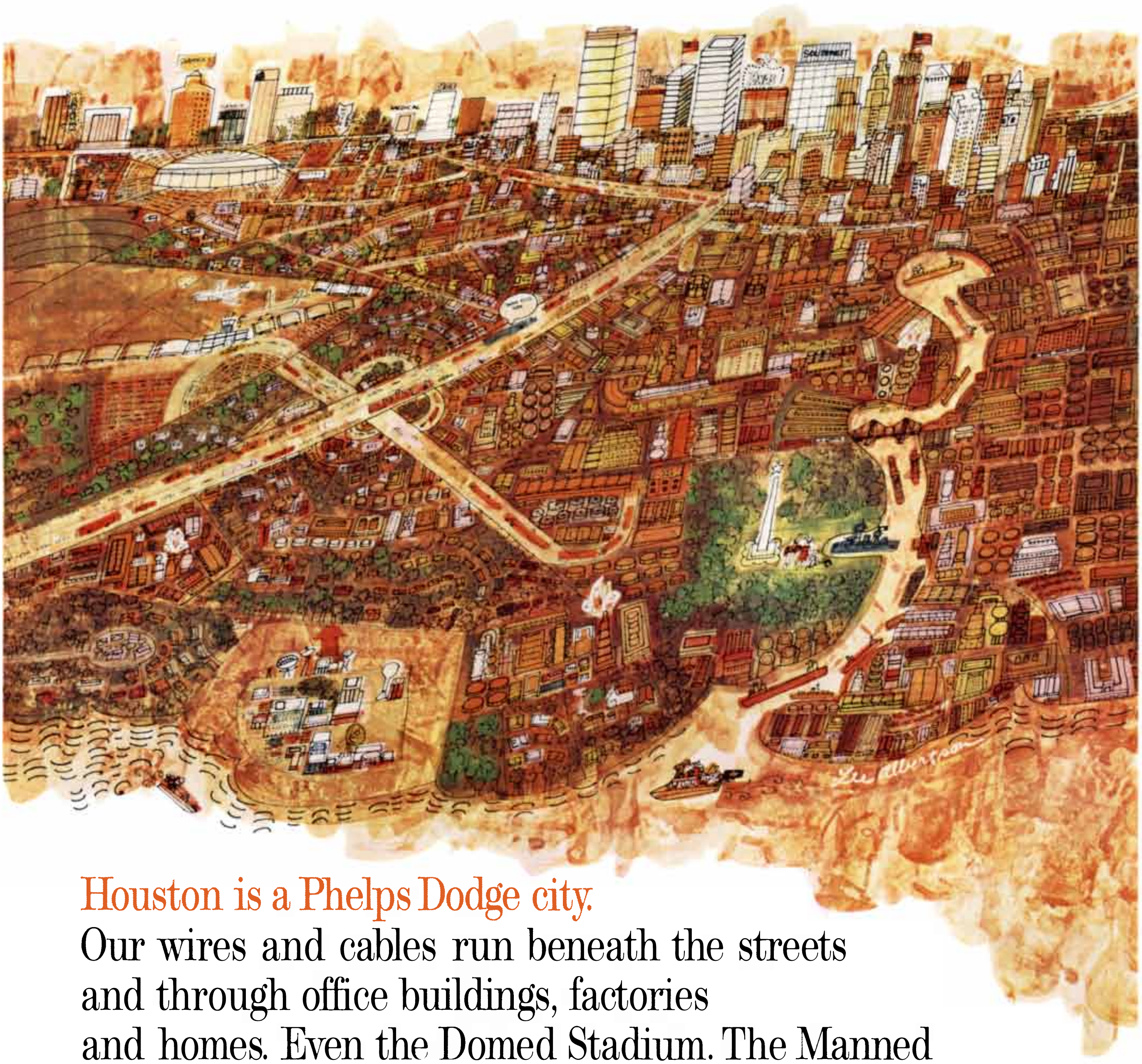
SCIENTIFIC AMERICAN



LUNAR TELEVISION TUBE

SIXTY CENTS

January 1966



RECENT findings

RESEARCH LABORATORIES

Ford

MEASURING HUMAN JUDGMENT

A variety of psychophysical techniques assist Ford Motor Company scientists as they quantify human judgments

A prime problem in the measurement of subjective judgments is the simple fact that human experience tends to resist the basic rules of measurement. Techniques developed by Ford Motor Company researchers aim to establish a scale of measurement for "greater than" or "less than" judgments with successive points not only in increasing numerical order and equally stepped on the subjective continuum but, ideally, on a ratio scale (a scale with a true zero).

In one procedure the subject adjusts a known stimulus to equal the sensation of a test stimulus. Sound, for example, is matched to whole-body vibrations simulating automobile ride motion. Figure 1 shows the average of repeated trials of this experiment in which subjects sit on a vibrating platform and adjust the volume of a noise generator until noise loudness seems to match the sensation produced by the vibrations. In effect, the vibration is being calibrated by a known subsidiary function. Although the settings scatter widely, a sufficient statistical clustering occurs to allow significant magnitude scaling.

Successful estimates of sensation magnitude, when dealing with intensity-type stimuli such as noise, light and vibration, led Ford scientists to expand their efforts in an attempt to quantify preferences in the same way.

Figure 2 shows the results of a special test in which seven different automobile steering systems were compared, a pair at a time. Each test driver expressed his degree of preference on a ratio scale. The scale value of 1.50 represents an appeal which, on the average, is about 50% stronger than that of any other steering system lying on the 0.99 contour. The solid circles represent the seven experimental steering systems which were tried, arranged in a hexagonal "response surface" experiment design. Studies such as these assist Ford Motor Company's research scientists in applying scientific principles to product improvements.

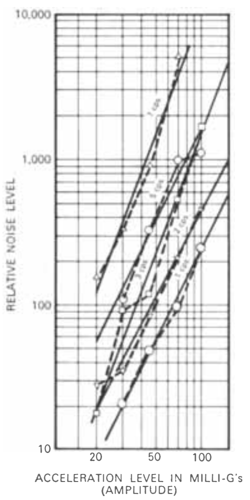


Figure 1 RIDE VIBRATION

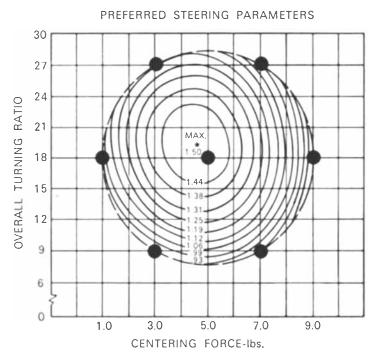


Figure 2 MEASURES STEERING

Figure 1. Data obtained from tests matching vibration sensation to sound loudness result in a reasonably straight-line function plotted on log-log coordinates. It is known, (from the work of S.S. Stevens and others) that loudness of noise is a power function of input level as follows:

Loudness $= gP^{0.6}$ (where g = proportionality constant, P = sound pressure level.)

The slopes of the curves can then be used to solve for the exponent of similar hypothesized power functions relating "feel" sensation to vibratory input acceleration (A) because the subject has adjusted the two to match subjectively as follows:

Loudness $=$ "Feel" $= gP^{0.6} = cA^n$

In this case it was found that the value of n tended to be about unity.

Figure 2. A contour map showing preferences for steering systems in the two-parameter space has been obtained. The procedure is to obtain the least-squares solution for the coefficients in the following quadratic model relating the vehicle parameters to human judgment.

Rel. Pref. $= a + bX_1 + cX_2 + dX_1^2 + eX_2^2 + fX_1X_2$

It is an inevitable consequence of human judgment that large differences among people will exist, and that we cannot count on strong consistency in the same person from time to time. Even though the figure shows a pronounced and meaningful relation between human judgment and vehicle parameters, only half or less of the total variances in the judgments could be accounted for by the least-squares fit.

PROBING DEEPER TO SERVE BETTER

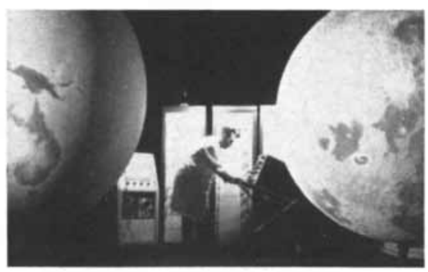
Ford

FIRST MINUTEMAN II firing from an underground silo at Vandenberg AFB was a complete success. Minuteman II's nose cone splashed on target, some 5,000 miles down the Western Test Range. U.S. Air Force's most advanced ICBM, Minuteman II has increased range, improved guidance, more flexible targeting and larger payload. Minuteman missiles can remain on alert in underground silos for long periods with minimum maintenance. As Minuteman weapon system integrator, Boeing continues its responsibilities for assembly, installation, test, launch control and ground support equipment for new Minuteman II.

Capability has many faces at Boeing

LUNAR HOT SPOTS. Boeing scientists, using data they gathered during moon scans, are developing thermal map showing temperature peaks and plateaus of moon surface, as one of many aids in selecting best moon landing spot.

SST. Model of Boeing supersonic jet, which could cross the U.S. coast to coast in two hours. Boeing's variable-sweep wing design provides ideal shape for fast cruise and slow landings.



SIMULATOR in new Boeing Space Center uses earth and moon globes with TV and computer systems to simulate space flight. Pilots "fly" space missions, orbital re-entry and controlled landings on earth and moon. The Space Center is most advanced in private industry.

BOEING

Space Technology • Missiles • Military Aircraft Systems • 707, 720, 727, 737 Jetliners • Systems Management • Helicopters • Marine Vehicles • Gas Turbine Engines • Also, Boeing Scientific Research Laboratories

Established 1845 **SCIENTIFIC AMERICAN** January 1966 Volume 214 Number 1

ARTICLES

DEPARTMENTS

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THE COVER

The photograph on the cover shows the faceplate of a Vidicon tube with the pattern of reticles that has become a familiar sight on television photographs of the moon taken by the Ranger series of spacecraft (see "The Ranger Missions to the Moon," page 52). Similar Vidicon tubes were also in the television cameras carried by *Mariner IV* on its successful voyage to Mars. The reticles define a square that is .4 inch on a side. They provide precise reference points for photoanalysis and for rectifying photographs if they have become distorted during transmission. The Vidicon tubes are similar to those used in ordinary television cameras. An optical image is focused on the face of the tube and is scanned from inside the tube by an electron beam. The Vidicon tube on the cover and those on the successful Ranger flights were manufactured by the Radio Corporation of America.

THE ILLUSTRATIONS

Cover photograph by Paul Weller

Page	Source
20–21	Hatti Sauer (*top*), Sol Mednick (*bottom*)
22	James Egleson
23	James Egleson (*top*), Hatti Sauer (*bottom*)
24	Hatti Sauer
25	James Egleson (*top and middle*), Hatti Sauer (*bottom*)
26–27	James Egleson
28–29	Jack Scott, Smithsonian Institution
30	Jo Ann Beechel
31–32	Jack Scott, Smithsonian Institution
33	John Langley Howard (*top*); Jack Scott, Smithsonian Institution (*bottom*)
34–35	John Langley Howard
36	John Cairns, Cold Spring Harbor Laboratory of Quantitative Biology
37–39	Joan Starwood
40–41	John Cairns, Cold Spring Harbor Laboratory of Quantitative Biology (*left*); Joan Starwood (*right*)
42–44	Joan Starwood
52–53	Mount Wilson Observatory (*left*); Jet Propulsion Laboratory, California Institute of Technology (*right*)
54	Jo Ann Beechel
55–57	Eric Mose
58–59	U.S. Air Force and Joan Starwood
60	Jet Propulsion Laboratory, California Institute of Technology
61	Eric Mose
62	Jet Propulsion Laboratory, California Institute of Technology
63	Jet Propulsion Laboratory, California Institute of Technology (*top*); Eric Mose (*bottom*)
64	Jet Propulsion Laboratory, California Institute of Technology
65	Jet Propulsion Laboratory, California Institute of Technology (*top and middle*); Jo Ann Beechel (*bottom*)
66	Jet Propulsion Laboratory, California Institute of Technology
67	Jet Propulsion Laboratory, California Institute of Technology (*top*); Jet Propulsion Laboratory, California Institute of Technology, and Joan Starwood (*bottom*)
71–78	Thomas Prentiss
83	Bunji Tagawa
84–90	Dan Todd
95–100	Bunji Tagawa
105–110	Irving Geis
112–114	Jo Ann Beechel
116	A. C. Lonert
117	A. C. Lonert (*top*), Roger Hayward (*bottom*)
118	Roger Hayward
119	A. C. Lonert

LETTERS

Sirs:

The note "The Moonlike Planet" ["Science and the Citizen," SCIENTIFIC AMERICAN, September, 1965] relates Clyde W. Tombaugh's prophetic description of the Martian surface, quoting his views as published in *The Astronomical Journal* for October, 1950: "The lack of water erosion on Mars would permit the surface to retain a visible record of major events that happened during the planet's entire separate existence, similar to the moon." This is the same conclusion drawn by the *Mariner IV* investigators 15 years later.

It is unfortunate that the note did not quote further from *The Astronomical Journal*, because Tombaugh goes on to say: "The round 'oases' are depicted as sites of impact craters caused by the collisions of small asteroids. Great dust clouds on Mars are observed occasionally. They indicate some wind erosion, which if extended over long geologic ages would mitigate the abrupt slopes of the craters." Thus the crater-covered surface of Mars, which has so amazed some of the Mariner investigators, had long ago been inferred by an observational astronomer.

It should be pointed out that Tombaugh's conclusions were drawn from an application of geological principles to the results of his many visual observations of Mars, dating back to 1928. Thus his predictions were based on a careful evaluation of observational data and not on mere speculation.

BRADFORD A. SMITH

Director, Observatory
New Mexico State University
University Park, N.M.

Sirs:

I strongly disagree with some statements made by Martin Gardner in the "Mathematical Games" section of your August [1965] issue.

It is quite fashionable to relegate the Martian canals to illusions. The people who subscribe to such a view have little or no experience in actually looking at planetary detail. There are several observing parameters necessary to see the delicate subdivisions in Saturn's rings, the intricate "festoons" on Jupiter, canals and oases on Mars and minute clefts and craters on the moon.

Gardner writes: "Although some astronomers enthusiastically confirmed [Percival] Lowell's observations of Martian canals, others with better telescopes and better eyes could see no canals at all." The latter part of this statement is incorrect. The Hartmann tests and the optical performance of the 24-inch Lowell and 36-inch Lick refractors show that these telescopes are of extraordinary optical quality. I have spent several hundred hours observing the moon and the planets with the Lowell 24-inch refractor. Only during the rarest moments of freedom from our own atmospheric turbulence are the finest recorded details visible. I would estimate that such quality seeing exists for less than a hundredth of 1 percent of the time one spends looking through the eyepiece. Now, what are the chances of an astronomer's seeing very fine planetary detail if he takes a look at a planet for a few minutes before beginning his stellar program of observing for the night?

The late Dr. Robert Trumpler of the Lick Observatory was doubtful of the canals on Mars in his younger days. Then he decided to observe Mars carefully throughout the 1924 opposition. He saw and recorded a great number of canals, as attested by his maps of Mars. Dr. E. C. Slipher also had keen eyes and saw well.

You learn to see fine planetary de-

Scientific American, January, 1966; Vol. 214, No. 1. Published monthly by Scientific American, Inc., 415 Madison Avenue, New York, N.Y. 10017; Gerard Piel, president; Dennis Flanagan, vice-president; Donald H. Miller, Jr., vice-president and treasurer.

Editorial correspondence should be addressed to The Editors, SCIENTIFIC AMERICAN, 415 Madison Avenue, New York, N.Y. 10017. Manuscripts are submitted at the author's risk and will not be returned unless accompanied by postage.

Advertising correspondence should be addressed to Martin M. Davidson, Advertising Manager, SCIENTIFIC AMERICAN, 415 Madison Avenue, New York, N.Y. 10017.

Subscription correspondence should be addressed to Jerome L. Feldman, Circulation Manager, SCIENTIFIC AMERICAN, 415 Madison Avenue, New York, N.Y. 10017.

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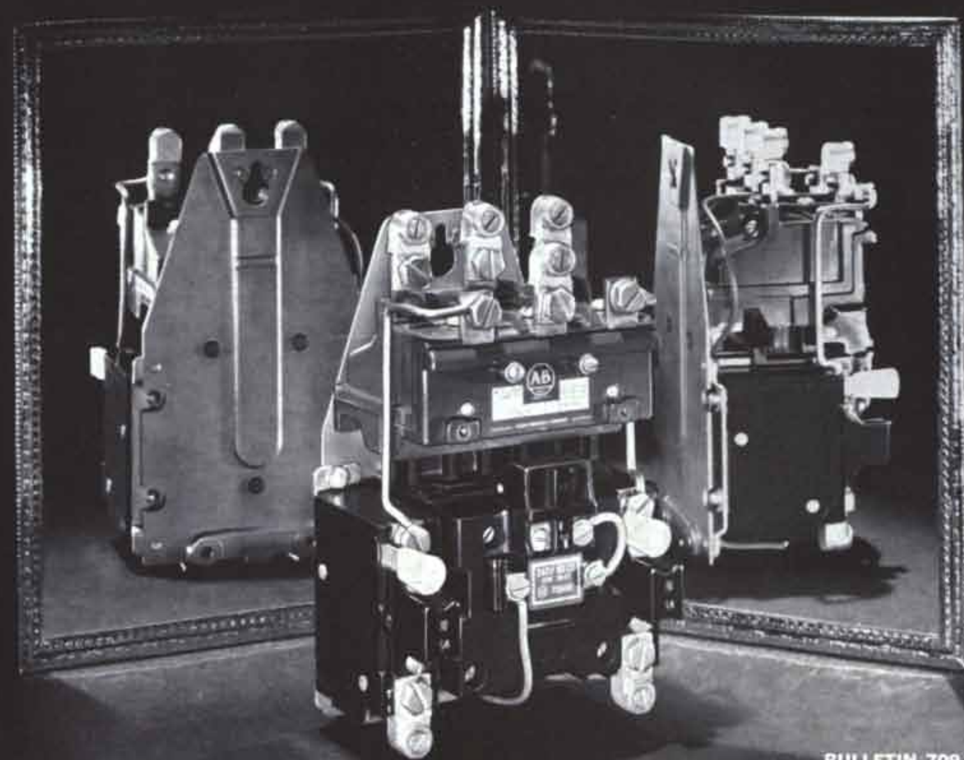

BULLETIN 709 Series K Size 2 motor starter rated 15 hp, 240 v; 25 hp, 480-600 v.

the lines are simple and clean—the mark of a "quality" starter

■ Consequently, Allen-Bradley Series K motors add a mark of "quality" to the machines which they operate. There's an industrial beauty to the control itself, as well as the enclosure, that carries a "family likeness" through the entire Series K line. Becoming acquainted with one starter automatically gives you an intimate knowledge of the entire line, including contactors, reversing switches, multi-speed starters, combination starters, etc.

Of course, a "quality performance" matches the starter's "quality look." All Series K starters use the justly famous Allen-Bradley solenoid design having only one moving part—so simple and so rugged, nothing can go wrong. This is your guarantee for many "extra" millions of trouble free operations. The failure-free record of the pressure molded coil makes possible our offer to exchange at "no cost" any such coil that fails in service while being operated at its nameplate specifications. Note also, that the weld-resistant cadmium oxide silver contacts will never need a moment's service attention.

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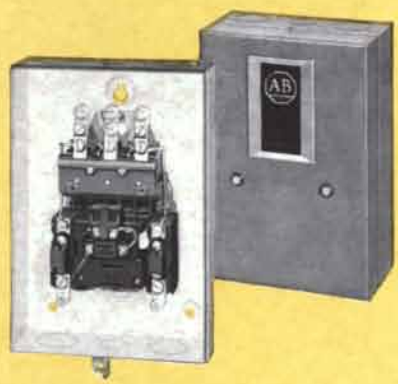

This shows the Bulletin 709 Series K Size 2 motor starter in a NEMA Type 1 enclosure. All Series K general and special purpose enclosures have the same attractive appearance—it reflects the true quality of the control. And the Allen-Bradley white interiors cut down on the installation time.

ALLEN-BRADLEY

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QUALITY MOTOR CONTROL

tail by much looking through a good telescope, not by sitting in an armchair in a warm office. A person with normal eyesight can see canals when the seeing is extraordinarily good, provided that the optical parameters of the telescope are proper. Anyone who uses a large aperture with too low a magnifying power obtains a dazzlingly brilliant image. This drowns out delicate dark detail because of the fierce irradiation from the overbrilliant surrounding area on the planet's disk.

In all probability the canals are likely to be discontinuous dark patches in an alignment. My studies of Mars indicate that the canals are crustal faults and are discontinuous where dust has covered up portions of them. The boundaries of the angular maria are exactly aligned with canals that proceed across the Martian deserts for hundreds of miles to dark spots called "oases," which are probably large impact craters (see *The Astronomical Journal,* October, 1950, page 184).

There are certainly portions of canals visible on some of the *Mariner IV* pictures. You cannot measure truth by popular vote, because only a few learn the difficult techniques of seeing fine planetary detail from much patience and experience. The stronger canals of Mars are also recorded on photographs. One does not solve a scientific phenomenon by wishing it out of existence.

CLYDE W. TOMBAUGH

Observatory
New Mexico State University
University Park, N.M.

Sirs:

The controversy among astronomers, between the small minority who report seeing straight lines on Mars and the majority who have been unable to see them, has been a bitter one that is not yet laid to rest. "The only possible explanation of the differences," wrote the eminent British astronomer H. Spencer Jones in his *Life on Other Worlds,* "is that the observation of these faint elusive details is subject to complex personal differences. . . . Subconscious interpretation of what is faintly glimpsed may be very different for two different persons. The eye of one may tend to bridge the gap between faint details and to draw a marking as a uniform, straight, continuous line unless he can clearly see that there are irregularities, bends and discontinuities in it. Another may only draw it in this way when he can see beyond the possibility of doubt that it is uniform, straight and continuous." Jones cites an experiment in which dots, shady patches and short lines were randomly drawn on a sheet of paper, and a class of children was asked to draw what it saw. Many of the children, particularly those in back seats, connected the prominent features with straight lines.

One of the strongest indications that Giovanni Schiaparelli and Percival Lowell, the first two astronomers to map the Martian "canals," were victims of optical illusions is that both men reported an unaccountable "doubling" of canals. Over a period of days, or even hours, certain canals were mysteriously and temporarily transformed into two parallel lines. Lowell reported seeing hundreds of such instances, although it was pointed out at the time that the distances on Mars, between pairs of parallel lines, were much too small for the resolving power of the lenses he was using.

Dr. Tombaugh's more moderate view, that there are linear structures on Mars and that they are crustal faults connecting impact craters, is similar to one advanced by Alfred Russel Wallace in a fascinating and perhaps prophetic little book called *Is Mars Inhabitable?* (London, 1907). Wallace disagreed with Lowell's belief that the canals were the work of intelligent beings—indeed, he concluded that Mars was not only uninhabited but also "absolutely uninhabitable"—although he did not question the existence of a canal network. He argued that Mars had been so heavily pelted by meteors that its surface became molten. As the planet cooled, meteors continued to fall, causing more craters that became weak spots in the crust. As the crust continued to cool and shrink, it cracked along straight lines that joined these large impact craters.

In the next few years we may learn exactly to what extent linear features exist on the Martian surface, although the controversy could drone on as a cloudy semantic quarrel over whether certain features should be called "linear." In my opinion the word "canal" should be reserved for the long, sharply defined, extremely straight threadlike lines mapped by Schiaparelli, Lowell, Trumpler and others and not applied to the broad, hazy, irregular markings that show on some photographs.

MARTIN GARDNER

Hastings-on-Hudson, N.Y.

1. Advanced osmometers developed by Hewlett-Packard have introduced speed, convenience and accuracy to open areas of measurement previously unexplored because of the time earlier techniques required.

2. Scientists examine an electron capture detector cell from an F&M Scientific Division Model 402 High-Efficiency Gas Chromatograph, widely used for the analysis of a variety of samples in chemical research investigations.

3. Extremely useful in the chemical laboratory is the Hewlett-Packard DY-2801A Quartz Thermometer, here shown measuring the temperature difference between the ice-point and triple-point of water.

4. This chromatogram shows the separation of the predominately C_3 cut of the hydrocarbon gas fraction on special column installed in an F&M Series 810 Chromatograph.

5. A sample of a substance to be analyzed is injected in an F&M Series 810 Research Gas Chromatograph.

6. Application areas where gas chromatography is finding ever-growing applications include analysis of lunar soil and planetary atmospheres, pesticide contamination control important in such areas as food processing, and the analysis of constituents of vehicular exhaust.


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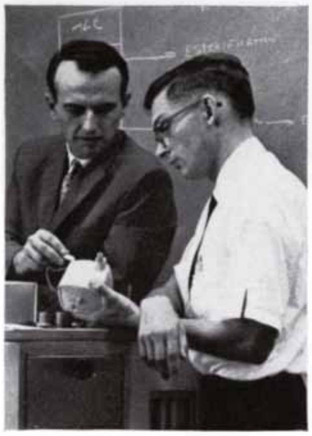
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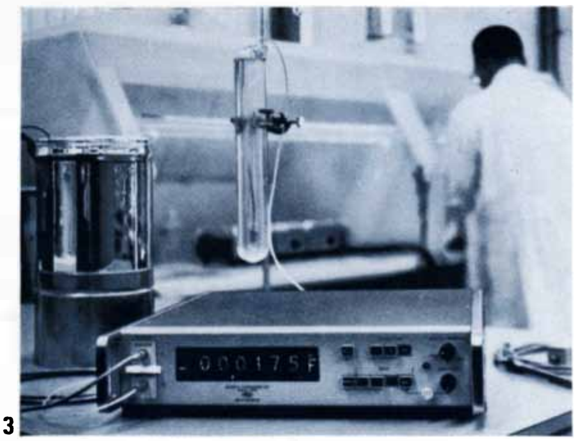
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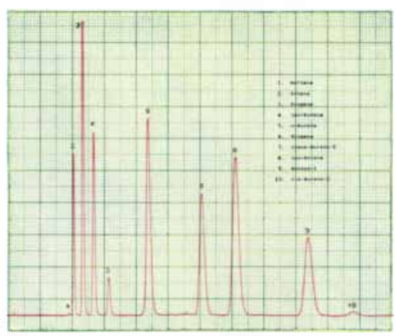
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6

When the Chemist Turns to Hewlett-Packard

50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

JANUARY, 1916: "A cursory view of the military situation in Europe, as seen from the outside of the so-called 'iron ring' that the Allies have attempted to maintain around the Central Powers, would seem to justify the assertion of the German Chancellor, von Hollweg, that Germany is everywhere victorious. She holds Belgium and one of the richest sections of France in the West; Poland is hers, and recently, with the aid of Bulgaria, she has overrun Serbia and opened up a rail connection with Constantinople. The question of German success, however, is indissolubly bound up with the question of German aims, and thanks to the explicit teachings of her military writers we know exactly what the military aims of Germany were when the Kaiser let loose the dogs of war in the summer of 1914. Judged solely by the test of what Germany set out to do, she has failed. The German lines in France are holding, it is true, but the Anglo-French drive in September gave every reason to believe that when another million of the British troops have been thrown into France and the requisite supplies of ammunition have been stored back of the Allied position, it will be found possible to break through the German line on a front wide enough to cause a retirement of the whole front to new positions. Failing that, the war on the Western front must settle down to one of attrition, and judging by the acknowledged Prussian losses to date of 2,250,000 men, and the monthly losses on all fronts estimated by the best military authorities at 300,000, the decisive issue must surely come before the close of 1917."

"At the recent meeting of the Experimental and Academical Brewery in Berlin, Prof. Delbrück made a startling announcement. It had been, he said, the constant endeavor of those attached to that establishment, from the outbreak of hostilities, to utilize yeast not only as a producer of albumen but also for yielding fat. Now, a pupil of the Institute of Fermentation Industries, Herr Schrettkensager, had sent a package from the trenches, the contents of which turned out to be a dried mass of fungus. On examining this under the microscope Prof. Lindner found each individual cell of it to be filled with a drop of gelatine. The fatty yeast so long sought had at last been discovered."

"It is announced by the officials of an American aeroplane manufacturing company that orders have been placed by the Allied governments for 11 huge battle-planes of the most modern design. Each aeroplane will weigh in the neighborhood of 30,000 pounds, and the framework will be entirely of steel. It is said that the wing spread is to be 180 feet, while the length of the aeroplane from tail to propellers will be 104 feet. The framework will be constructed on the cantilever truss principle, ensuring great strength with a minimum weight. Twin bodies will be used, each body carrying an engine of 800 horsepower. It is planned to arm the machines with four guns, two fore and two aft, of a caliber of between 1½ and two inches and capable of firing 20 to 40 rounds per minute. Each airship will carry a number of bombs of any size up to 14 inches in diameter. The specifications call for a speed of 85 miles per hour and a crew of six men."

Scientific American.

JANUARY, 1866: "The observations of the eclipses of Jupiter's first satellite and those of the phenomena of aberration lead directly, although with a different degree of approximation, to the determination of the time light occupies to run over the mean distance of the sun from the earth. As this length is run over by the light in eight minutes 18 seconds, or in 498 seconds, we conclude that the velocity of light is 191,391 miles in one second. However, for some years several circumstances have conspired to make us believe that the determination of 8.57 seconds given as the value of the sun's parallax is too small and that the parallax ought to be augmented by a quantity not less than the thirtieth of its value, which would elevate it to about 8.9 seconds. From this increase in parallax results a diminution in the earth's distance from the sun and consequently in the distance gone over in eight minutes 18 seconds by the light; the velocity of light will therefore be reduced to a little less than 186,420 miles in a second. The next transit of Venus, which will happen in 1874, cannot fail to set at rest all doubts which may yet remain on this point."

"M. Duchemin proposes to construct Ampère's electric boat upon a sufficiently large scale and to use it as a warning buoy on shoals, etc. He proposes to float, by means of cork, a carbon cylinder within a hollow cylinder of zinc, the connecting wire to be made to strike a bell in the usual way."

"Some years ago M. Gaudin found that by heating iron tolerably free from carbon with a small quantity of boron to a very high temperature, he obtained a product which could not be forged but which possessed extraordinary hardness. He has now found that an equally hard metal can be obtained by adding to ordinary cast iron, phosphate of iron and peroxide of manganese—he does not mention in what proportions. The product cannot be forged, but it casts easily and is therefore readily applicable to the construction of such machines, or parts of machines, as require in their material extreme hardness rather than tenacity. The metal so produced is, moreover, singularly sonorous, and M. Gaudin accordingly proposes it as a material for bells. He finds that a still harder metal is produced by the addition of tungsten—again he omits to say in what amount—to ordinary cast iron. He states that this tungsten iron surpasses everything previously known as a material for tools for cutting rocks, and that crystals of it will cut glass as readily as diamond."

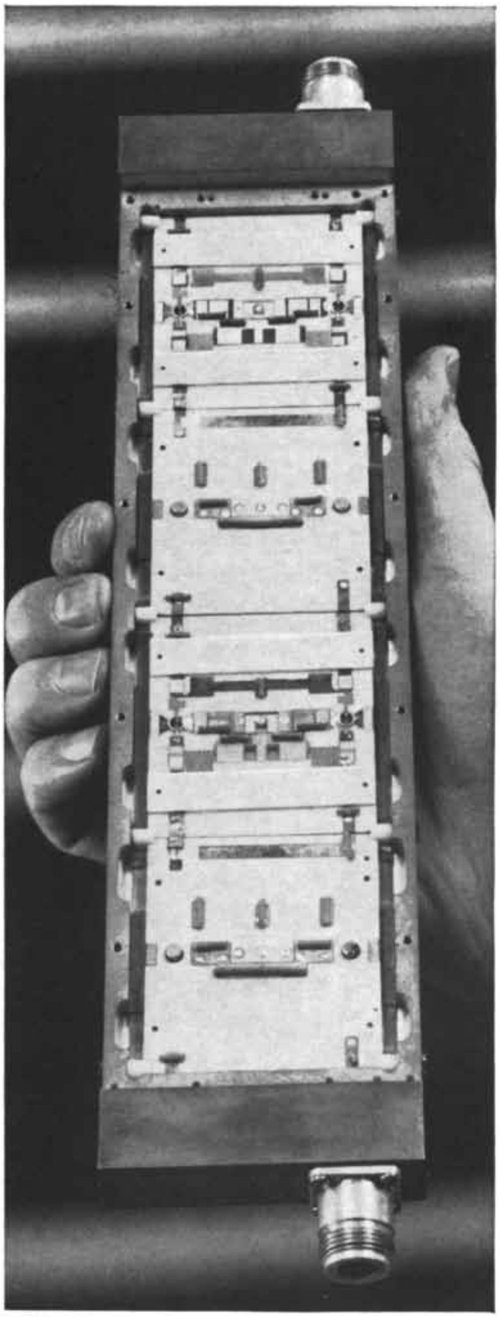
"The arrangements of the directors of the Atlantic Telegraph Company as to new capital are now completed, and several hundred miles of the cord are finished. The *Great Eastern* is chartered to go to sea in June, 1866, for the double purpose of laying an entirely new cable and of raising the broken end of the 1,100 miles of cable laid last year, so as to splice additional cable to it and thus, if successful, furnish to the public a second means of communication. This 1,100 miles of submerged cable is ascertained to be in the most perfect order by tests taken at the time it broke and still continued daily. The buoys at the end of it are washed away, but this is of no consequence, as they were intended only for a temporary purpose, the spot for grapneling having been laid down by solar observations, so that a good navigator can at any time sail to within half a mile of the broken cable."

Report from
BELL LABORATORIES

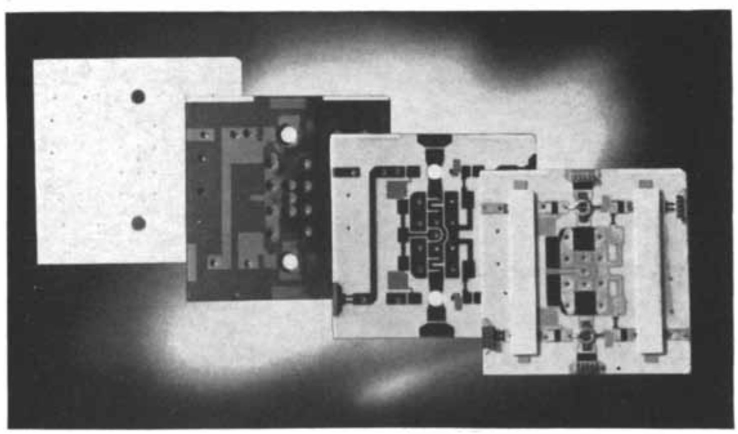
Integrated circuits at microwave frequencies

Engineers at Bell Telephone Laboratories have developed integrated circuits for use as amplifiers in the microwave range. Thin-film tantalum techniques are used to provide the precise, stable resistors, capacitors and transmission-line components required at microwave frequencies. Improved transistors provide up to 10 db of gain per stage and noise figures as low as 3 db.

A "balanced" design, using a power-splitting directional coupler, makes possible wideband, stable gain characteristics without the need for tuning adjustments. Up to the highest frequency for which these amplifiers are now usable—4 gigacycles—the electrical performance characteristics are equal or superior to those of low-noise traveling-wave tubes. In addition, they have the other advantages of solid-state circuitry, such as long life and reliability.



Laboratory model of a four-stage microwave amplifier which can provide up to 40-db gain and noise figures as low as 3 db in the 1- to 2-gigacycle frequency range. Similar amplifiers have been developed to operate at frequencies from 0.5 to 4 gigacycles with bandwidths of 1000 mc.



Thin-film techniques are used in the integrated microwave amplifier. Starting from bare ceramic substrates of about 2 x 2 inches (left), partially finished circuits are shown during the multi-step fabrication process. Circuit at right, complete with transistors, comprises one stage of amplifier. "Balanced" design with electrically similar transistors gives precise wideband amplification in the low-microwave-frequency range.

Bell Telephone Laboratories
Research and Development Unit of the Bell System

THE AUTHORS

STEWART E. MILLER ("Communication by Laser") is director of the Guided Wave Research Laboratory of the Bell Telephone Laboratories. He joined the Bell Laboratories in 1941 after receiving bachelor's and master's degrees in electrical engineering at the Massachusetts Institute of Technology. For eight years he did research on development of coaxial-cable carrier systems and on radar. Then he joined the radio research department, where he worked at first on components for microwave radio systems. In his present position he heads a group investigating communication techniques for wave regions ranging from the optical portion of the electromagnetic spectrum through waves of millimeter length.

BETTY J. MEGGERS and CLIFFORD EVANS ("A Transpacific Contact in 3000 B.C.") are united both in matrimony and in professional activity, being respectively research associate and curator in the division of cultural anthropology at the Smithsonian Institution. They met at Columbia University, where they received doctoral degrees in anthropology. Since 1948, when they made the first of several field trips to South America, they have concentrated on the lowland areas of that continent. "Traveling as a married couple," they write, "contributes to a friendly reception from local inhabitants, who view a man alone with suspicion." The authors have found that work in the little-known parts of South America "has brought not only basic information on the development and dissemination of prehistoric cultures on the continent but also unexpected discoveries such as the evidence of transpacific contact described in the present article."

JOHN CAIRNS ("The Bacterial Chromosome") is director of the Cold Spring Harbor Laboratory of Quantitative Biology. He was born in England and obtained a medical degree at the University of Oxford. For several years he did research in Australia on the multiplication of influenza virus and vaccinia virus. Later he worked on the visualization of DNA molecules by autoradiography, a project he describes in part in the present article. Cairns writes that since assuming his present position he has found himself "mainly occupied with fiscal problems," although he has done some work "on the effect of breaking the bacterial chromosome on the replication of the chromosome."

H. M. SCHURMEIER, R. L. HEACOCK and A. E. WOLFE ("The Ranger Missions to the Moon") are at the Jet Propulsion Laboratory of the California Institute of Technology working on the Voyager project, which has the objective of landing an instrumented space vehicle on Mars. They were also involved in the Ranger project, which was supervised by the Jet Propulsion Laboratory for the National Aeronautics and Space Administration. Schurmeier took degrees in mechanical and aeronautical engineering at Cal Tech and joined the Jet Propulsion Laboratory in 1949. Heacock, who joined the laboratory in 1953, received bachelor's and master's degrees in electrical engineering at Cal Tech. Wolfe also is a graduate of that institution and has been involved in some phase of rocketry for almost 20 years. He has been at the Jet Propulsion Laboratory since 1952.

JOSEPH ARDITTI ("Orchids") is instructor in botany and cell physiology at the University of Southern California. He was 12 years old when the Soviet army advanced into Bulgaria, where he was born; he and his parents left that country for Palestine. Arditti later served two and a half years in the Israeli army. On his discharge in 1954 he emigrated to the U.S., arriving with $50 as his total wealth. While working at a commercial orchid farm in California, first as a laborer and then as chief grower, he attended the University of California at Los Angeles, receiving a degree in floriculture in 1959. Last year he obtained a Ph.D. in plant physiology at the University of Southern California.

RICHARD WOLFGANG ("Chemistry at High Velocities") is professor of chemistry at Yale University. Born in Germany, he was educated in England and the U.S. As a candidate for a doctor's degree at the University of Chicago, he worked under Willard F. Libby and was involved in the discovery of tritium in nature. After obtaining his Ph.D. in 1951 he spent some time at the Brookhaven National Laboratory and Florida State University before going to Yale. Wolfgang worked initially on the mechanisms of nuclear reactions. "This led me to wonder," he writes, "why some of the techniques and, more particularly, modes of thinking could not be applied to chemical reactions." That interest led to his work on "hot" atoms, involving the field of chemical reactions that occur above the energies obtainable by thermal methods. He is also interested in the chemistry of atoms of very high chemical potential, such as atomic nitrogen and atomic carbon.

LAURENCE IRVING ("Adaptations to Cold") is director of the Institute of Arctic Biology and professor of zoophysiology at the University of Alaska. A graduate of Bowdoin College, he received a master's degree at Harvard University in 1917 and a Ph.D. at Stanford University in 1924. He has worked in Alaska since 1947, going there after more than 20 years of teaching, mostly at Swarthmore College. "I have long been inclined to study the physiological adaptations that enable men and animals to succeed in extreme natural conditions," he writes. "It turned out that the natural physiological reactions of arctic animals to cold were of dimensions large enough to demonstrate general principles of adaptation to various temperatures that we had been unable to ascertain in mild climates and by the use of domesticated animals."

MARVIN SHINBROT ("Fixed-Point Theorems") is associate professor of mathematics and engineering science at Northwestern University. He worked as a research scientist with the National Advisory Committee for Aeronautics and with the Lockheed Aircraft Corporation for several years after receiving a master's degree in 1949 at Syracuse University, where he also did his undergraduate work. Obtaining a Ph.D. at Stanford University in 1960, he began a teaching career that took him to the University of Chicago and the University of California at Berkeley before he went to Northwestern this past fall. He writes: "I am now working on the Navier-Stokes equations, which govern the motion of a viscous fluid. In addition I am writing a book on 'the general method of Wiener and Hopf.' This is a method for, among other things, solving boundary-value problems where two different types of boundary data are given on two parts of the boundary."

HOWARD E. EVANS, who in this issue reviews *The Natural History of Flies,* by Harold Oldroyd, and *A Catalog of the Diptera of America North of Mexico,* under the direction of Alan Stone, Curtis W. Sabrosky, Willis W. Wirth, Richard H. Foote and Jack R. Coulson, is curator of insects at the Museum of Comparative Zoology of Harvard University.

Variable Sweep Wings: A report from General Dynamics

A major step forward in aircraft design:

This week, several pilots redesigned their airplanes in flight. Shortly after takeoff, each pilot moved a trombone-shaped slide in his cockpit and folded back the wings of his plane.

The ability to do this made the F-111's they were flying the first aircraft that can (1) operate from short landing fields, *and* (2) fly economically for long subsonic cruise ranges or ferry itself across an ocean, *and* (3) strike supersonically at treetop height *or* dash at two-and-a-half times the speed of sound at an altitude of 12 miles.

The key is its variable sweep wing. Today the first eight developmental F-111's, built by General Dynamics, are daily demonstrating the feasibility of a movable wing—a development that finally makes a truly multipurpose airplane practical.

The matter of flight envelope:

Every aircraft has a specific "envelope" —a set of limitations, or boundaries, of speed and altitude, within which it can operate effectively. The final design of a plane depends upon which of several possible purposes is most important.

A long wing extended straight out is best for short takeoff and landing, long range and endurance, or high load-carrying characteristics. For the high lift demanded, a large amount of wing surface is needed.

But as speed increases, less lift is needed from the wings. In fact, at high speeds, large wings increase resistance from the air. Such an airplane can be pushed to supersonic speed by brute power, but not efficiently.

This resistance is commonly called drag, and one way to reduce it has been to sweep the wing back. For instance, the modern passenger jet, whose wings are partially swept back, can fly efficiently for long distances just below the speed of sound. But the swept wing provides less lift, and such aircraft need long runways, sometimes up to two miles long, and special braking devices.

Very high speeds—faster than sound —can best be reached with a very small wing, sometimes in a triangle or delta shape. But the still lower lift can require even longer runways, and additional braking devices such as drogue parachutes. The very small wing offers considerably less fuel efficiency for long-range, subsonic flight.

Three aircraft in one:

A wing whose position can be changed by a pilot *in flight* gives a single airplane the special talents of all three types. With the wing fully extended, the aircraft has high lift for short takeoff or landing or high-load capacity. With the wings partially swept, efficient long-range subsonic flight becomes practical. Pulling the wings all the way back to their smallest exposed area provides supersonic dash, without having sacrificed either high lift or cruise economy.

Previous—and impractical—attempts to achieve variable wing geometry go all the way back to 1911. The chief problem: an undesirable relationship between center of gravity and center of lift as the wings moved would cause an airplane to nose up and down sharply—become longitudinally unstable.

How it operates:

Not until 1960 did the National Aeronautics and Space Administration conceive the answer to this instability—simultaneously sweeping both wings around separate pivot points which were moved out on the wing root rather

Top: The F-111 with its wings extended straight out for high lift at takeoff.
Bottom: Wings being swept back to allow F-111 to reach supersonic speeds.

than having a single pivot in the center of the fuselage. The concept has been refined and developed by General Dynamics through more than 22,000 hours of wind tunnel testing, and more than 25 million man-hours of design and development.

The F-111's variable wing can be moved in flight from its fully extended position (technically with 16° of sweep measured at the leading edge) to a full sweep of 72.5°, with the wings tucked back against (and much of them actually inside) the fuselage for a narrow delta shape. The position of the wings can be set and held at any position between these two extremes, with the pilot himself deciding what wing setting is best for maximum performance in a given set of circumstances. He can normally lever the wings from one extreme to the other in about twenty seconds.

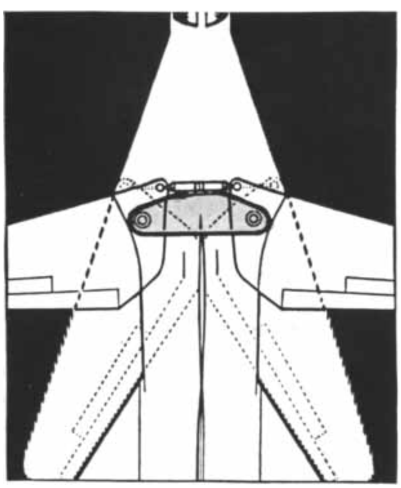
The precision of design is so exact and the wing so balanced that negligible elevator trim is needed to compensate for full sweep of the wing.

Heart of the system:

The heart of the F-111's variable sweep system is a 14-foot steel yoke across the fuselage (see drawing below).

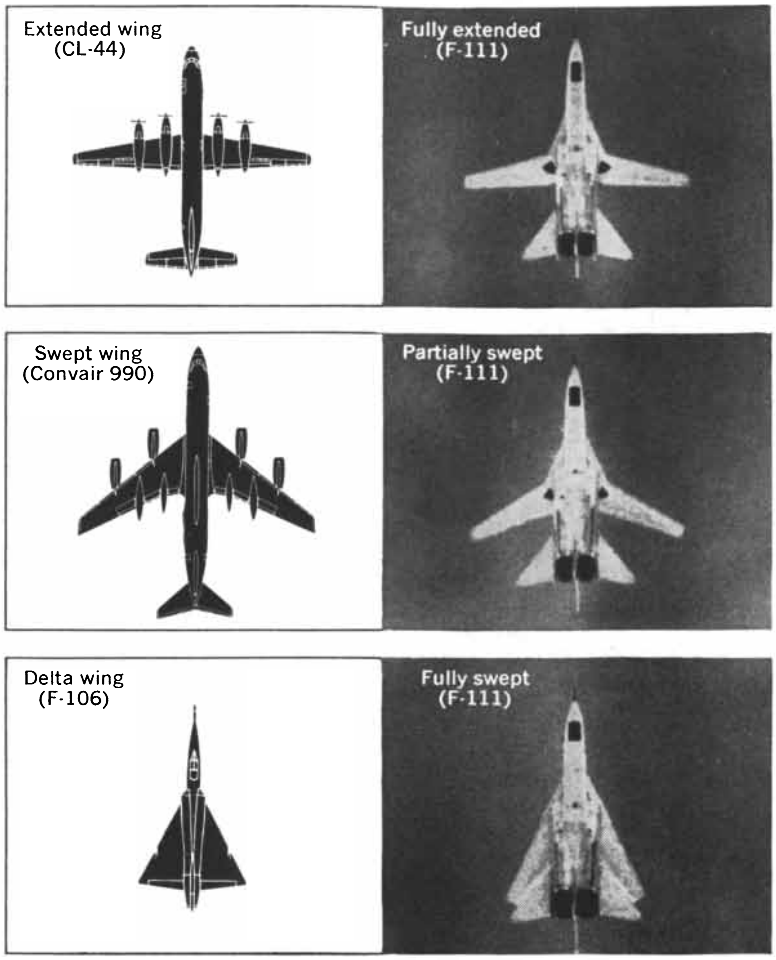
The movable portions of each wing are fastened to the yoke by 8½-inch diameter high-strength steel pivot pins. Forward of the yoke hydraulically powered actuators, responding to the pilot's control selection, move the wings from one position to another.

For additional high lift at takeoff and landing, full span slats and flaps are incorporated into the wing. The wing itself is ingeniously tapered so that much of its area when fully extended is highly cambered—that is, with a relatively thick curve for greater lift—and thin at the area remaining exposed when wings are swept back for high-speed flight.



How the wing works. A 14-foot steel yoke, with its 8½-inch diameter pins, on which the wings pivot, is the heart of the variable sweep winged F-111. The yoke and pins support the whole plane in flight. A jackscrew just forward of the yoke actuates the wings during sweep.

How wing configuration determines flight envelope



Left, top to bottom: Drawings of planes flying today. Extended wing of transport provides relatively short takeoff and landing with heavy loads. Swept wing of passenger liner provides less lift, but allows the plane to fly efficiently just below the speed of sound. Small delta wing of military fighter reduces air resistance (drag) and allows the plane to fly at supersonic speeds.

Right, top to bottom: Photos of the F-111 show how the variable sweep wing gives it the advantages of the extended wing, swept wing and delta wing—all in one plane.

The future for the sweep wing:

Since the Wright Brothers' first breakthrough in the art of manned flight, there have been relatively few major advances in the basic art of airplane building. One was the introduction of light aluminum structures, another the introduction of the turbine—better known as the jet—engine for propulsion.

The variable sweep wing represents a similar major step forward. For any category of aircraft—military, commercial or private—where the combination of very high-speed flight, long economic cruise and high lift for easy takeoff and landing is desired, the variable sweep wing sets the new standard. Even space ships may ultimately incorporate some form of variable geometric wing to make them more maneuverable within different atmospheres.

General Dynamics is a company of scientists, engineers and skilled workers whose interests cover every major field of technology, and who produce for defense and industry: aircraft; marine, space and missile systems; tactical support equipment; nuclear, electronic and communication systems; and machinery, minerals and gases.

GENERAL DYNAMICS

Established 1845 **SCIENTIFIC AMERICAN** January 1966 Volume 214 Number 1

Communication by Laser

The unique properties of the light produced by lasers open the way to the eventual exploitation of light waves for the long-distance transmission of electrical signals

by Stewart E. Miller

The announcement in 1960 that a working model of a laser had been achieved was greeted with enthusiasm by workers in many fields, but none were more sanguine about the prospects of the new device than investigators interested in the problem of long-distance communication. The basis for their enthusiasm was the simple fact that the capacity of a communication channel is proportional to the width of its band of frequencies; thus a communication system utilizing electromagnetic waves in the visible region of the spectrum, where enormously wide bands of frequencies are available, should in principle be capable of carrying many times the amount of information carried by lower-frequency radio-wave systems.

The chief obstacle to the exploitation of light for communication before 1960 was the lack of a source that could produce light waves that were both coherent (in step) and monochromatic (with a single frequency). Since the light produced by a laser is both coherent and monochromatic, it was felt at the time that the laser was the answer to a communication engineer's prayer. Although a practical, working system of long-distance communication by laser has yet to be built, the initial enthusiasm has not waned. Today there are probably more physicists and engineers working on the problem of adapting the laser for use in communication than on any other single project in the field of laser applications. At the Bell Telephone Laboratories many workers, including the author, are engaged in exploring the potential of the laser for communication. In this article I shall attempt to explain some of the advantages of a laser communication system and also some of the problems that remain to be solved before such a system can become an actuality.

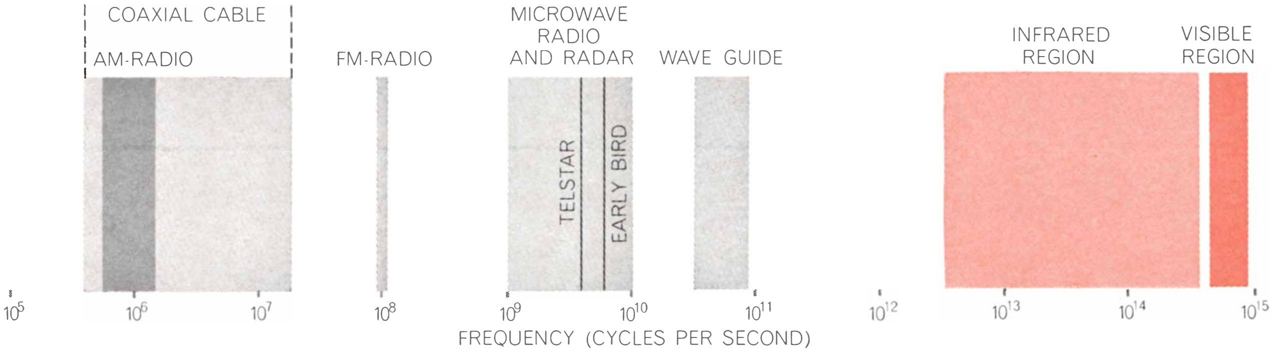
There are available at present four proved electrical techniques for transmitting a large volume of messages over a long distance. The oldest of these is the coaxial-cable system, which still carries a large proportion of the communication traffic between cities in the U.S. The standard coaxial cable consists of a copper tube three-eighths of an inch in diameter with a single copper-wire conductor in the center; the cables are generally gathered in bundles of eight to 20. Depending on the amount of communication traffic to be carried, amplifying equipment must be located every two to four miles along the cable. Coaxial cables normally carry radio waves with wavelengths of from 600 to 15 meters and with frequencies of from 500,000 to 20 million cycles per second.

The largest share of the intercity communication traffic in the U.S. today is transmitted through the air by means of microwave-radio relay towers, spaced some 20 to 30 miles apart. This system employs beams of microwave radiation, mainly in the frequency band between one billion and 10 billion cycles per second.

A third long-distance transmission technique, called wave guide, has been perfected in recent years but is not yet in widespread use. In wave guide a single hollow tube about two inches in diameter is used to transmit millimeter waves with frequencies of from 30 billion to 90 billion cycles per second. Eventually—if and when the need arises—a wave guide system would be able to handle appreciably more communication traffic than any other system currently available.

The fourth and newest long-distance electrical communication technique involves the use of artificial earth satellites. Broad-band communication by satellite—operating within the microwave-radio band—was first achieved experimentally between the U.S. and Europe with the Bell System's *Telstar* satellite and has now been introduced commercially by the Communication Satellite Corporation's *Early Bird.*

At the heart of every one of these long-distance communication systems is the principle called multiplexing—the simultaneous transmission of many different messages over the same pathway. A channel for transmitting an individual human voice, for example, requires a frequency band extending from 200 to 4,000 cycles per second. The information contained in this frequency



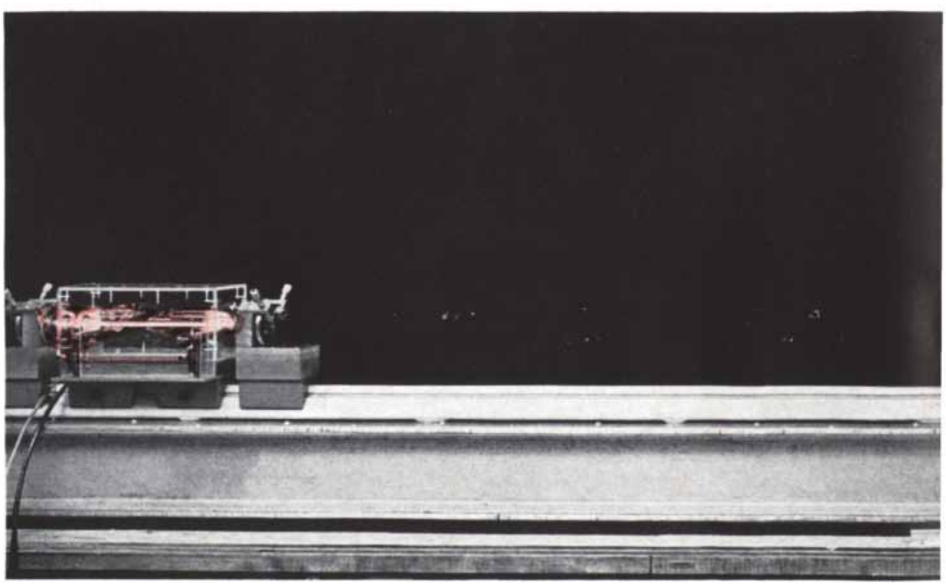
FREQUENCY BANDS in which several of the major electrical communication systems operate are shown in gray in this drawing of a section of the electromagnetic spectrum. Since the capacity of a communication channel is proportional to the width of its band of frequencies, an intercity communication system utilizing electromagnetic waves in the visible region of the spectrum (*extreme right*) should in principle be capable of carrying many times the amount of information carried by the lower-frequency radio-wave systems.

band, however, can be transmitted just as well in the band from 100,200 to 104,000 cycles per second—or for that matter in any other band that is 3,800 cycles per second wide. The act of transferring a signal from one frequency band to another is called modulation. In order to perform the function of modulation without adding noise, or interference, to the signal, an intercity communication system requires an oscillator capable of producing a carrier wave with a very narrow spectral width. This single-frequency carrier wave is then successively modulated by a large number of voice channels to create a new, composite signal wave [*see illustration on page 24*]. For example, 1,000 telephone channels, each with a nominal bandwidth of 3,800 cycles per second, can be transferred to a single signal wave that contains the band of frequencies extending from the frequency of the original carrier wave to that of the carrier wave plus 3.8 million cycles per second (1,000 times 3,800). Similarly, a second set of 1,000 telephone channels can be transferred to a second carrier wave to form another broad signal wave, and so on. Special electrical networks then combine several of these broad energy bands for simultaneous transmission over a single intercity pathway. At the other end of the line a similar network separates the single signal into its component broad bands, and these in turn are subdivided by means of a demodulation process into individual telephone signals.

The aim of the whole multiplexing process is economy; it is cheaper to transmit a single broad-band signal wave on a single coaxial cable, say, than it is to transmit many narrow-band signal waves on many coaxial cables. For this reason all the currently available intercity transmission techniques employ some variation of the multiplexing process.

It should not be difficult at this point to see what is attractive to communication engineers about the visible portion of the electromagnetic spectrum. Since an individual communication channel requires the same bandwidth regardless of the region of the spectrum in which it is located, the higher-frequency regions, which have far more room for communication channels, have a much greater potential capacity than the lower frequencies. The frequency in the center of the visible region of the spectrum is about 100,000 times greater than the frequency of the six-centimeter waves used in the microwave-radio relay system; thus the theoretical communication capacity of a typical light wave is about 100,000 times greater than that of a typical microwave. This fact has long been recognized by communication engineers, and attempts to exploit the vast potential of light for communication were made at the Bell Laboratories before 1950. After a brief period of exploration this work was deferred; to understand why, it is necessary to review briefly how carrier waves are produced by a conventional radio communication system and by light sources other than lasers.

Power for radio communication is produced by electrical circuits, each of which is made up of a number of passive tuning elements (coils and parallel-plate capacitors) in combination with an



LASER BEAM produced by a helium-neon gas laser (*left*) is focused by means of a "gas lens" (*center*) in this photograph made in the author's laboratory at the Bell Telephone Laboratories in Holmdel, N.J. As the beam emerges from the lens it decreases to minimum before expanding. The photograph was made in three stages. First the optical bench on which the various components are mounted was fully illuminated and exposed. Then the

active element (either a vacuum tube or a transistor) and a source of current. The active element serves as a kind of valve for transforming the current into one that pulsates at a frequency determined by the number of turns in the coils or the number of plates in the capacitors. A circuit of this type is called an oscillator.

Almost all of a radio oscillator's power is concentrated at a single frequency, which can be adjusted at will by changing the arrangement of the coils or the capacitors. When the output current from such an oscillator is fed into a suitably designed horn, the energy is radiated in the form of a beam that spreads at an angle roughly equal to the wavelength of the radiation divided by the diameter of the horn's aperture [*see illustration on next page*]. Because all the energy originates in circuits that are small compared with the length of the typical radio wave and because the energy is usually radiated from a horn with a wide aperture, the wave fronts of the beam are essentially plane, or flat, at the mouth of the horn and gradually assume a spherical shape as the beam progresses away from the horn.

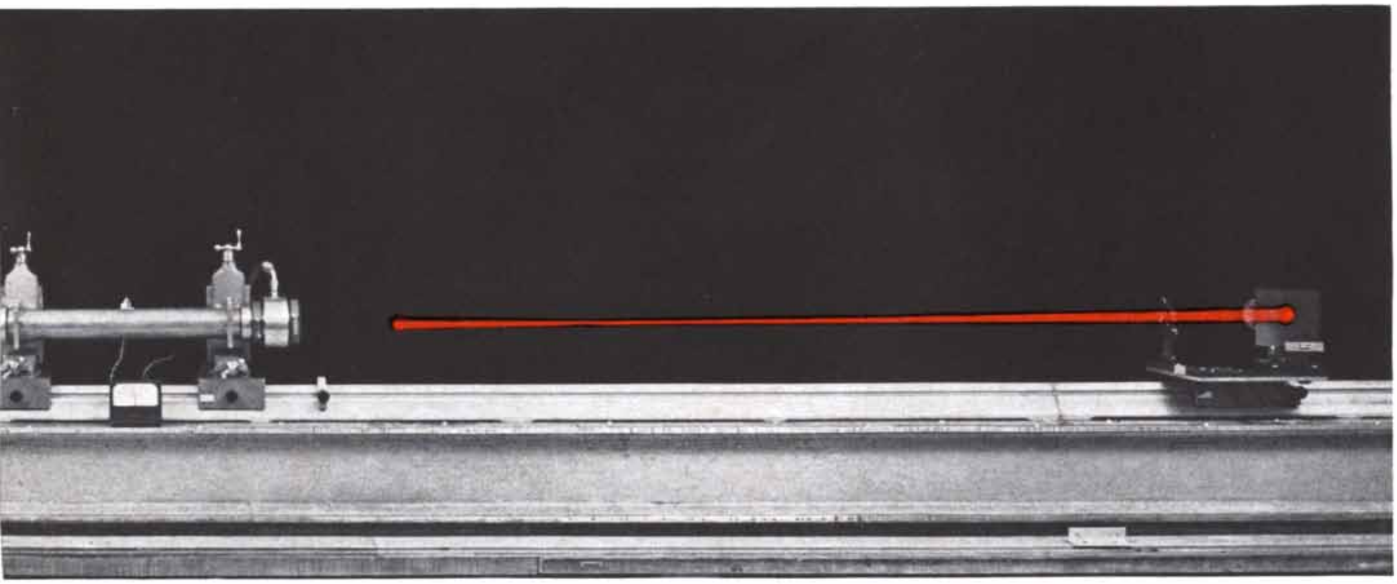
Now consider how light is produced by an ordinary incandescent, or hot-wire, electric lamp [*see illustration at top of page 23*]. A current passing through the fine wire heats it to a high temperature, whereupon it emits electromagnetic energy in the form of visible light. The light from the hot wire radiates in all directions; more precisely, each point on the wire radiates in all directions. This is an important difference between a radio oscillator and a hot-wire light source, and before the advent of the laser it was one of the main drawbacks to the use of light waves for communication. When one attempts to focus the light output from a hot-wire lamp into a beam, several undesirable effects ensue. First, only part of the radiation from the wire falls on the focusing lens; second, and more important, each radiating point produces a beam whose angle with respect to the axis of the main beam is proportional to the distance of that particular radiating point from the center of the wire. In order to make this angle as small as possible, "point sources"—for example carbon arcs—are used in searchlights and other lamps in which a narrow beam is essential. Even with a point source, however, the resulting beam spreads at an angle equal to the wavelength of the light divided by the diameter of the source. Obviously a point light source can supply only a small amount of power compared with a source that is not so restricted in size.

Another important difference between a hot-wire light source and a radio-wave source is the range of frequencies at which a given source radiates. The emission frequency of a hot-wire source varies with temperature; moreover, a hot-wire radiator spreads its power over a very broad spectral band—in sharp contrast to a radio oscillator, which radiates steadily at a single frequency.

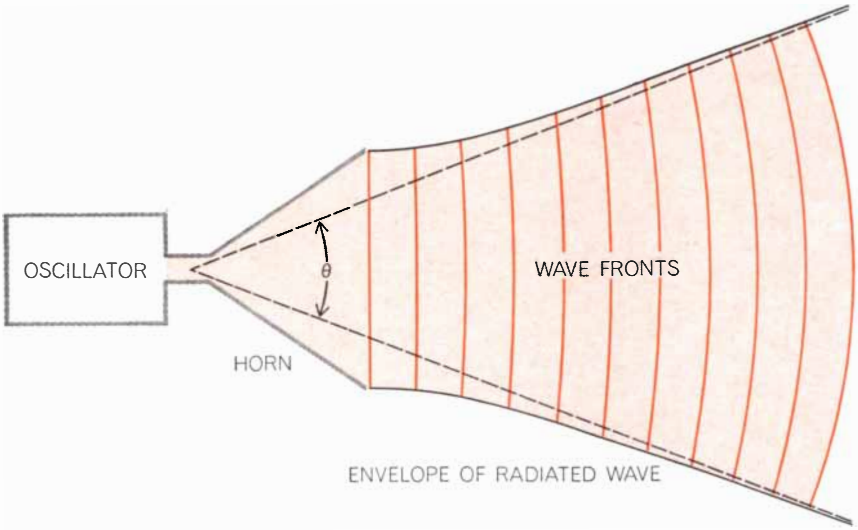
The inadequacy of a hot-wire light source as an oscillator for producing single-frequency carrier waves ultimately led to the deferral of early research on the exploitation of light for communication. Invariably the wide-band emissions from a series of hot-wire oscillators would overlap and cause mutual interference. In addition, within any given channel interference would occur among various individual voice signals. An attempt to avoid these problems could be made by selecting with a filter only the energy within a narrow band; although this would produce a more nearly monochromatic source, it would utilize only a tiny fraction of the original power of the lamp. The loss of efficiency involved in this step would make the whole procedure impractical.

The invention of the laser in the late 1950's by Arthur L. Schawlow and Charles H. Townes provided a way out of this dilemma. The principle on which the laser—as well as its parent, the maser—is based can be traced back as far as 1917, when Albert Einstein showed that "stimulated," or controlled, radiation could be obtained from an atom under certain conditions. (The term "laser" is an acronym for "light amplification by stimulated emission of radiation"; "maser" is an acronym for "microwave amplification by stimulated emission of radiation.")

In order to grasp the novelty of the



room lights were turned out and the laser itself was activated and exposed. Finally the laser was masked and a portion of the laser beam was photographed in color with the aid of a special device mounted on a sled on the optical bench (*right*). The device contains an ordinary glass lens for focusing the beam on a circular mirror, which in turn rotates the beam through an angle of 90 degrees toward the camera; the beam then strikes a translucent surface, where it is recorded as a circular image on the photographic film. When the sled is pushed along the optical bench, these successive circular images form a continuous image of the beam on the film.



RADIO WAVES obtained from a radio oscillator (*left*) in the form of a pulsating current can be fed into a suitably designed horn (*center*), from which they are radiated into space in the form of a beam that spreads at an angle (θ) roughly equal to the wavelength of the radiation divided by the diameter of the horn's aperture. The wave fronts of the beam are essentially plane at the mouth of the horn and assume a spherical shape as the beam progresses away from the horn. The angle θ has been exaggerated here; normally it is less than 10 degrees.

concept of stimulated emission, let us first examine a little more closely how light is produced by an ordinary incandescent lamp and by a fluorescent lamp. In both cases radiation is the result of a change in the orbital arrangement of electrons in a molecule or around an atomic nucleus. According to the rules of quantum mechanics there are discrete orbital arrangements that a given set of electrons can assume; certain of these arrangements have more energy than others. When an electron drops from a configuration of higher energy to one of lower energy, the surplus energy appears as radiation, partly electromagnetic and partly acoustic, or vibrational. Since the possible energy levels are discrete, the electromagnetic radiation from any one type of change in electronic configuration always has the same frequency. In a hot solid, however, many different electronic configurations are possible, and the differences in energy among the permitted states are slightly different from one another. As a consequence light is emitted at many different frequencies. Further complications in the electromagnetic spectrum of an emitting hot wire are introduced by acoustic interactions, which will not be discussed here.

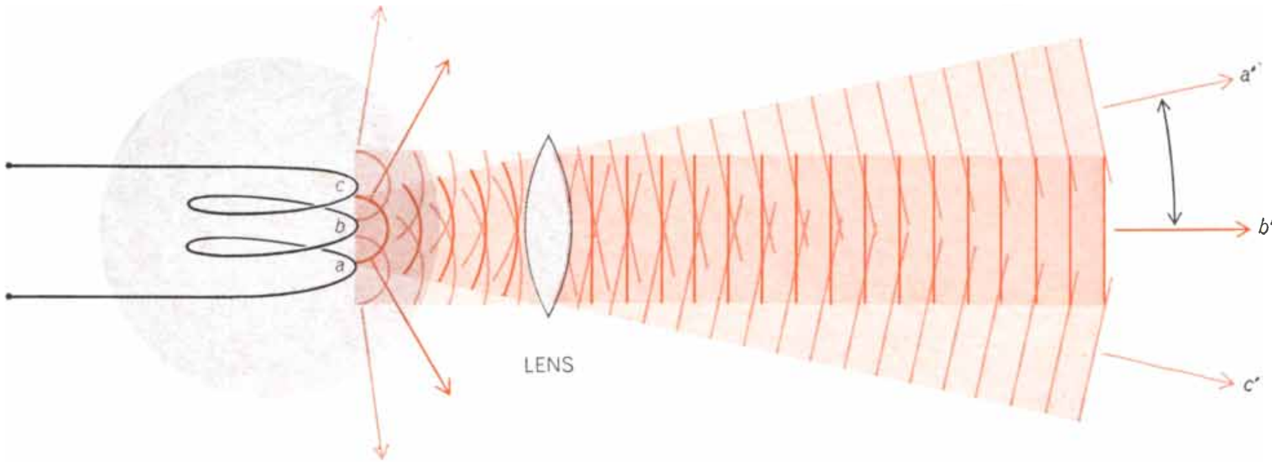
In a fluorescent lamp an electric current is passed through a gas rather than through a solid, but the radiative mechanism is essentially the same as in a hot-wire lamp. Electrons are raised from a lower energy state to a higher one, and when they fall back to the lower state, their surplus energy is emitted as light. The situation is somewhat simplified in the case of a fluorescent lamp by the fact that acoustic interactions are negligible, and the frequency of the emitted light is related directly to the changes in the electronic energy levels. Moreover, a few types of energy change may tend to predominate, giving fluorescent tubes used in advertising signs their characteristic colors: yellow for sodium vapor, violet for mercury vapor and so on. Although the bandwidth is narrow enough to appear as a definite color, it is still very broad—on the order of 500 billion cycles per second for a sodium-vapor lamp.

The crucial difference between these conventional light sources and a laser lies in the extent to which the emission of surplus energy can be controlled. Einstein showed that when an atom or a molecule has somehow had its energy status raised, the release of this stored energy can be controlled by subjecting the atom or molecule to a small electromagnetic field of the proper frequency. (In contrast, the emissions of a hot-wire or fluorescent radiator occur spontaneously.) The controlled release of energy by the foregoing technique is called stimulated emission; the weak field doing the stimulating is enhanced by the energy of the stimulated radiation. In order to ensure that the stimulated emission is dominant, heat radiation must be kept to a minimum.

The number of possible frequencies emitted by a laser can also be restricted by selectively feeding power into a few specific changes in the electronic configuration of the emitting atoms. This situation is too complicated to explain in detail here, but in general it means that an emitting atom in a laser behaves ideally when it is suspended relatively far from its neighboring atoms. This isolation occurs naturally in a gas; it can also be achieved in a solid by mixing the emitting atoms or molecules very dilutely in a substance that is both transparent to the stimulated emission and passive in the frequency range of the emission, that is, in a solid in which no energy-level differences exist in the vicinity of the one responsible for the stimulated emission. By introducing energy that is specifically capable of raising the energy status of the isolated atoms only, the stimulated emission is kept to a narrow spectral band.

In a gas laser, such as the helium-neon laser shown in the top illustration on page 25, a steady electric discharge is maintained through the gas mixture. In the region of the discharge electrons associated with the neon atoms are raised to higher energy levels, from which they may drop spontaneously to lower energy levels with only a few discrete energy differences. One such energy difference accounts for the emission of red light with a wavelength of 6,328 angstrom units and a frequency of 473 trillion cycles per second. By sending a weak electromagnetic wave at exactly 473 trillion cycles per second through the laser tube one can stimulate emission from the excited neon atoms: the weak input wave will emerge as a more energetic output wave with the same frequency. Input energy at any other frequency will not stimulate this emission and will pass through the laser essentially unchanged. Moreover, if the input wave has plane wave fronts, so will the amplified output wave have them. The latter property, which is called spatial coherence, is in contrast to the series of broad, spherical wave fronts produced by the spontaneous, uncorrelated emissions of a hot-wire source.

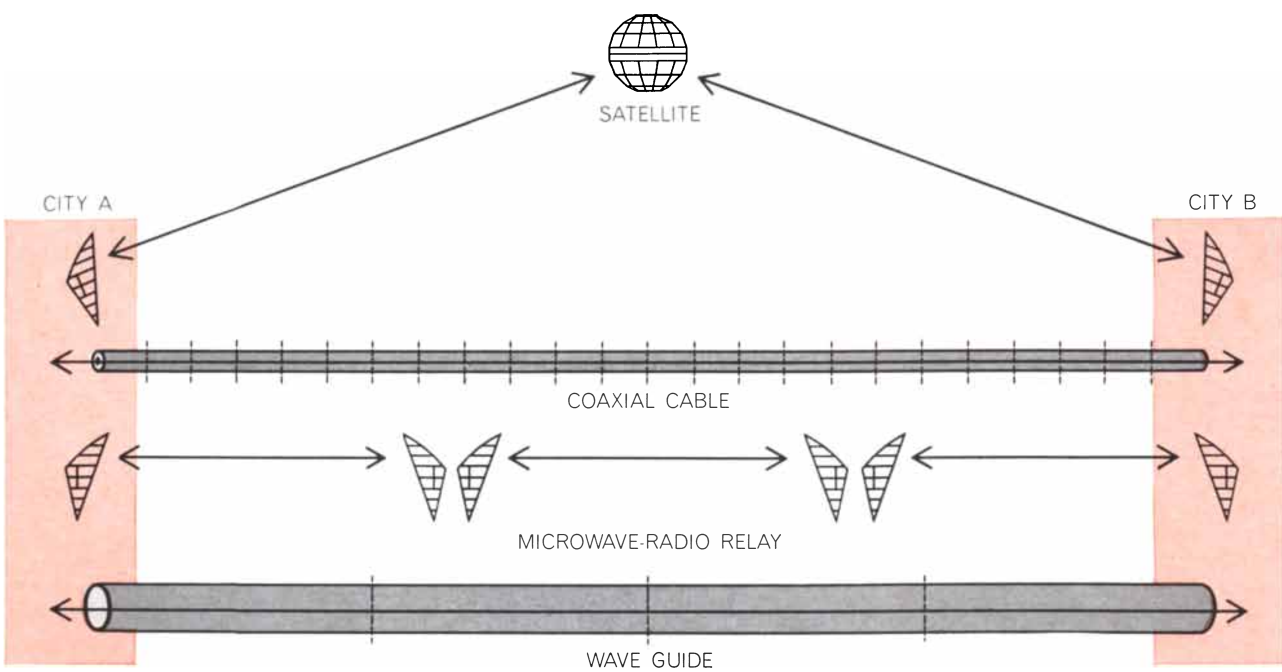
A laser can be made to act as an electrical oscillator by adding two reflectors at the ends of the tube to form a resonant cavity [*see middle illustration on page 25*]. The light oscillating back and forth between the two mirrors at 473 trillion cycles per second is built up by additional stimulated emissions until it uses up all the excited electrons; some of the energy in the cavity is then re-



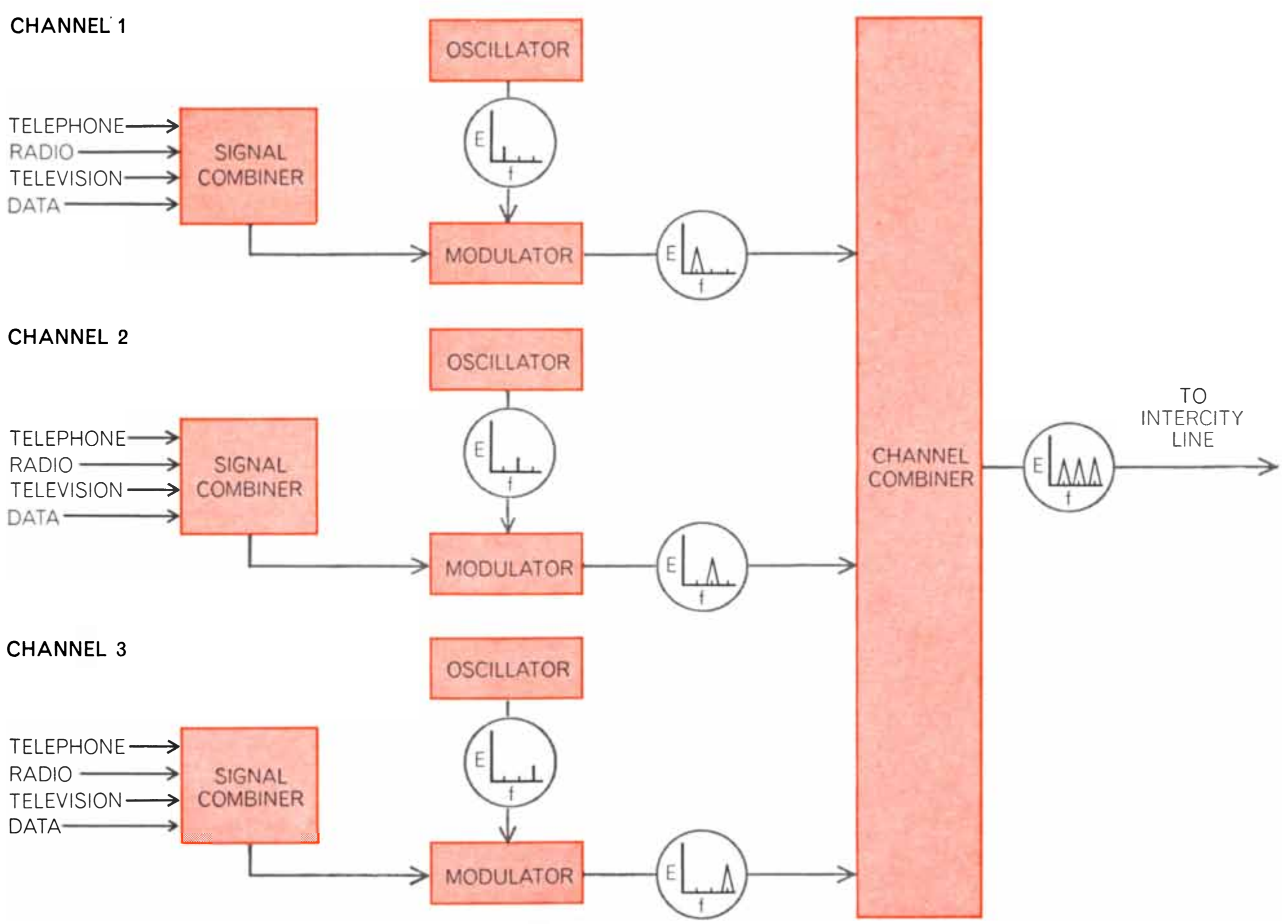
INCOHERENT LIGHT WAVES obtained from an ordinary incandescent, or hot-wire, electric lamp (*left*) radiate in all directions; stated more precisely, each point on the wire radiates in all directions. When one attempts to focus the light output from a hot-wire lamp into a beam, only part of the radiation from the wire falls on the focusing lens. Moreover, each radiating point produces a beam whose angle with respect to the axis of the main beam (*bb'*) is proportional to the distance of that particular radiating point from the center of the wire. These two drawbacks—and the fact that a hot-wire radiator spreads its power over a very broad spectral band—make the incandescent lamp unsuitable for use in a long-distance communication system based on light waves.

leased through one of the end mirrors, which is partially transparent. The output of such a laser is concentrated at a single frequency, with a maximum deviation from the fundamental frequency of only a few thousand cycles per second. As in the case of the laser amplifier, the output of this laser oscillator is spatially coherent.

The two properties of monochromaticity and spatial coherence make the laser a potentially useful oscillator for intercity communication systems. What is more, the spatial coherence of a laser beam makes possible highly directional transmission unattainable by conventional radio techniques. A plane-wave laser source radiates a beam that is almost constant in width for a distance equal to the diameter of the source squared divided by four times the wavelength of the radiation [*see top illustration on page 26*]. Beyond this distance the beam gradually expands to form a cone, the angle of which is equal to the wavelength of the radiation divided by the diameter of the source. In other words, the spreading of a laser beam and a radio-wave beam is identical. Because of the vast differ-



FOUR ELECTRICAL TECHNIQUES for transmitting a large volume of messages over a long distance are available at present. The newest technique involves the use of artificial earth satellites (*top*). The coaxial-cable system (*second from top*) still carries a large proportion of the communication traffic between cities in the U.S. The largest share of the intercity traffic in the U.S. is transmitted through the air by means of microwave-radio relay systems (*second from bottom*), with amplifying stations spaced some 20 to 30 miles apart. The wave guide technique (*bottom*), which has recently been perfected, will be able to carry more communication traffic than any other system currently available. Amplifiers (*short broken lines*) are spaced two to four miles apart in the coaxial-cable system and 10 to 15 miles apart in the wave guide system. Microwave-radio relay horns are actually 10 to 15 feet in diameter.



MULTIPLEXING—a process for simultaneously transmitting many different messages over the same pathway—is employed in every long-distance electrical communication system. A single-frequency "carrier" wave produced by some kind of oscillator is successively modulated by a large number of individual signals to form a new, composite signal wave. This process is repeated for many different channels, using carrier waves of different frequencies. Special electrical networks then combine several of these broad energy bands for simultaneous transmission over a single intercity pathway. In each circled graph *E* stands for energy and *f* for frequency.

ence in wavelength, however, the practical implications of these formulas are quite different for the two radiations.

For example, in the case of a microwave-radio relay system the width of the antenna horn is typically 10 feet and the wavelength of the radiation is 7.5 centimeters. Applying the first formula yields 100 feet as the maximum distance over which the width of the beam remains constant. This means that a receiver with a 10-foot horn must be within 100 feet of the transmitter to receive most of the original beam. The normal practice in a microwave-radio relay system is to space the transmitter and the receiver 20 to 30 miles apart, with the result that the received power is about a hundred-thousandth of the transmitted power.

In the case of the laser, on the other hand, the beam width might be two inches and the wavelength of the beam on the order of 6,300 angstroms. This yields a maximum distance without beam expansion of about three-fifths of a mile; thus a two-inch lens three-fifths of a mile from the laser would collect most of the transmitted power. For longer distances a series of two-inch lenses spaced three-fifths of a mile apart could be used to confine the beam and guide it to the receiver [*see second illustration from top on page 26*]. The power loss at each lens due to beam expansion could in principle be made as small as one part in 100,000, or even less by making the lens spacing 20 to 40 percent less than the maximum distance before beam expansion. Extremely long total distances would appear to be attainable before the net received power would drop to a hundred-thousandth of the transmitted power, as is the case in microwave-radio relay systems.

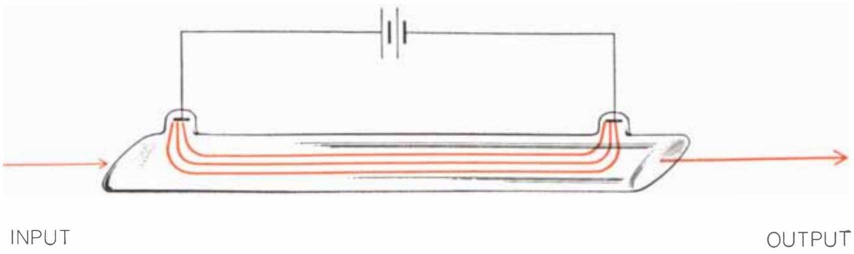
We have seen that the two basic properties of a laser beam—monochromaticity and spatial coherence—make it perfectly suited for use in a long-distance communication system. Nonetheless, many ticklish problems remain to be solved before this potential can be effectively exploited. I shall now describe briefly the status of current research aimed toward solving these problems.

In order to build an efficient laser communication system, a large number of lasers are required to serve as oscillators. Their frequencies should be spaced far enough apart to avoid overlap when their modulated outputs are combined on an intercity line. On the other hand, too large a spacing between frequencies is undesirable, because this would waste valuable frequency space that could be used to carry communication traffic. Obtaining a properly spaced series of frequencies is by no means an easy task; laser frequencies are determined by discrete energy-level differences in the emitting atoms or molecules, and these are essentially fixed for a given material. A search is under way for an appropriate set of frequencies and for some rule by which such frequencies can be predicted. This research involves not only various gaseous mixtures but also solid laser materials, the emitting atoms of which are suspended as very dilute impurities in a transparent "host" solid.

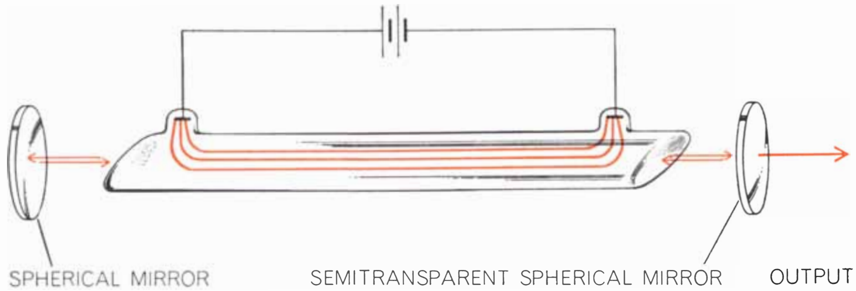
Another problem arises from the fact that a given molecule may have more than one emission frequency. The helium-neon mixture mentioned earlier, for example, can emit at 261 trillion and 88.5 trillion cycles per second as well as at 473 trillion cycles per second. Since only one frequency is desired from each laser, techniques must be found for isolating a single emission frequency. Much remains to be done in this area, but so far laser outputs ranging from a few thousandths of a watt to millions of watts have been achieved, and hundreds of different laser frequencies have been observed. Recently at the Bell Laboratories a laser-like source with a continuously variable frequency was conceived and demonstrated; this device uses ambient-temperature control to vary the natural emission frequency through a 5 percent range in the vicinity of 300 trillion cycles per second.

The actual long-distance transmission of a laser beam is another challenge to which much current research is devoted. Although very low point-to-point transmission losses could be obtained in the near vacuum of outer space by using a highly directional beam, the earth's atmosphere is hostile to electromagnetic waves in the visible region. Rain, snow and fog can cause heavy power losses. When high reliability is a requirement of a particular transmission system, an unshielded atmospheric path does not seem feasible, but in special cases in which intermittent communication is acceptable unshielded pathways may suffice. Studies are under way to determine if an infrared laser would be more suitable for transmission through the atmosphere.

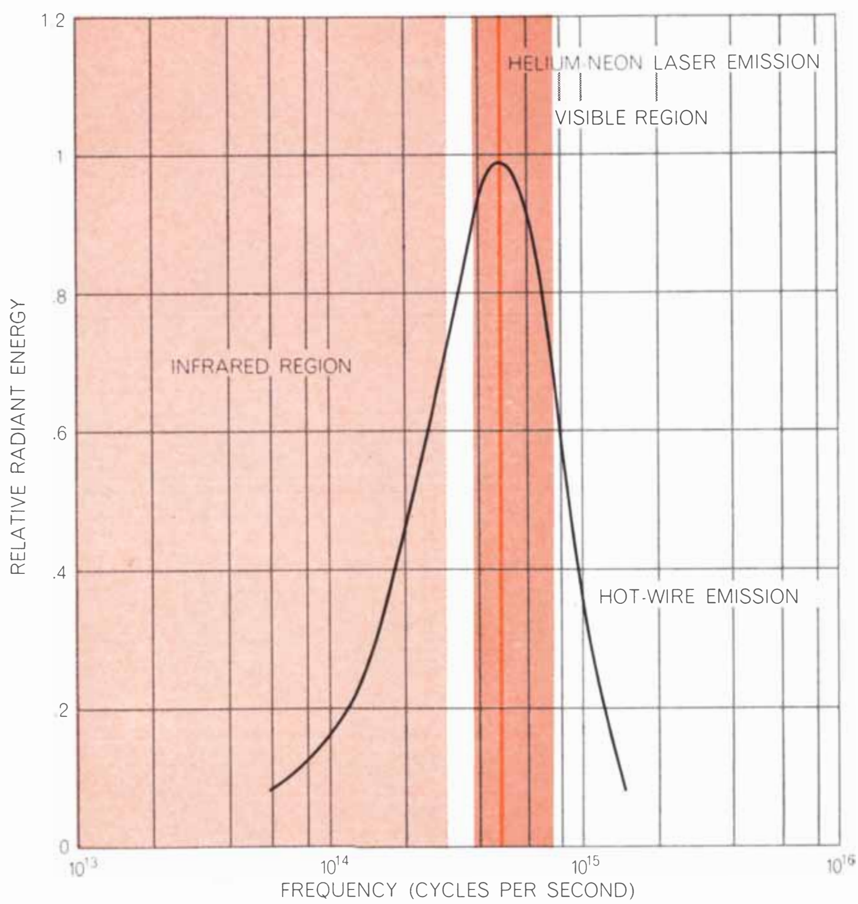
Guided laser transmission can be shielded from the atmosphere by putting the lenses in an airtight pipe, possibly underground. Here one has several options. The lenses can be spaced 300 feet or more apart and still contain the beam within a tube one inch in diameter. When this is done, high-quality optical lenses appear suitable for focusing, but some additional provision must be made to allow the beam to follow the curving path demanded by hills and horizontal turns. The laser beam will not follow a curved sequence of lenses for such large lens spacings. New techniques have been conceived for sensing the beam's position and, by means of a feedback mechanism, prop-



GAS LASER normally acts as an amplifier. A weak input wave stimulates emission from the excited gas atoms and emerges as a more energetic output wave with the same frequency.



LASER ACTS AS OSCILLATOR when one adds two reflectors at the ends of the tube to form a resonant cavity. The light oscillating back and forth between the two mirrors is built up by stimulated emissions before it is released through one of the mirrors (*right*).

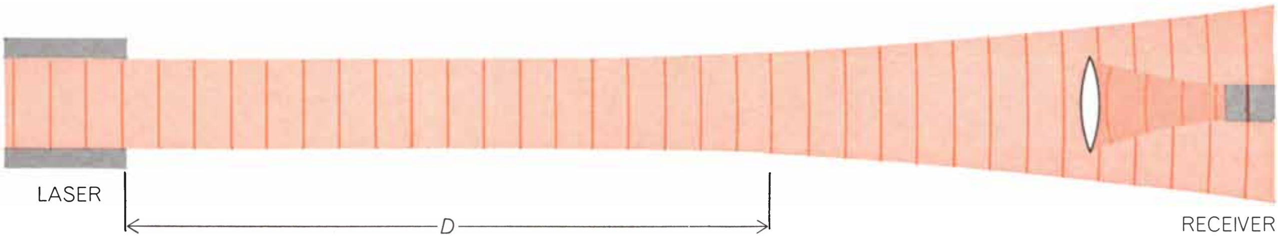


LASER EMISSION (*vertical colored line*) is concentrated at a single frequency, with a deviation from the fundamental frequency of only a few thousand cycles per second. In contrast, the emission from a hot-wire lamp (*black curve*) is spread over a broad spectral band.

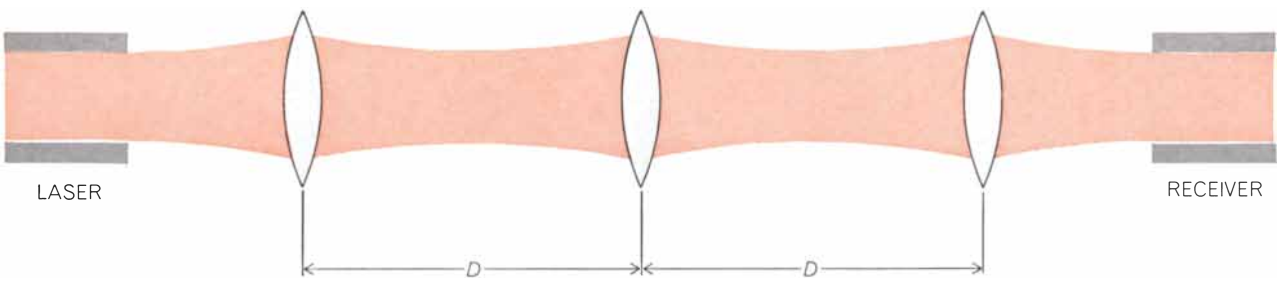
erly directing the beam around the curve.

Alternatively, the lenses can be brought close together; quarter-inch lenses spaced a few feet apart will allow a beam to follow curves typical, say, of a modern superhighway. In this case the lenses must have a very low power loss, as there would be more than 1,000 lenses per mile. The best quartz optical lenses have far too much loss for this purpose, as a result of surface roughness and reflection from the interface between the quartz and the air.

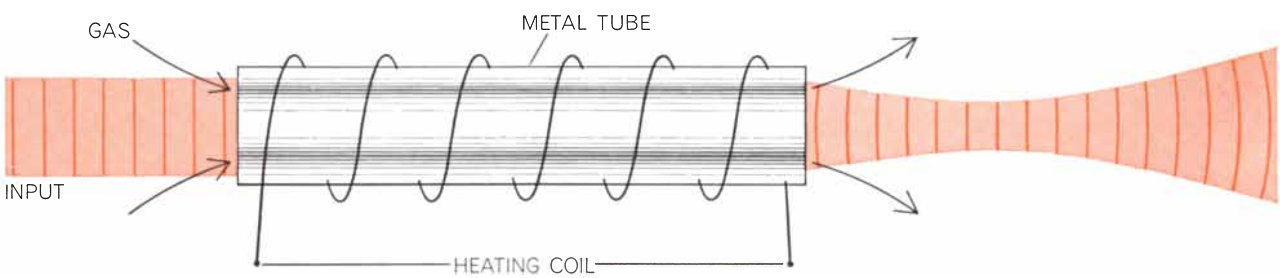
In order to overcome these difficulties a new type of lens, called a gas lens, has been invented by Dwight W. Berreman of the Bell Laboratories and improved by some of his colleagues. In one model a gas—for example carbon dioxide—is passed through a heated



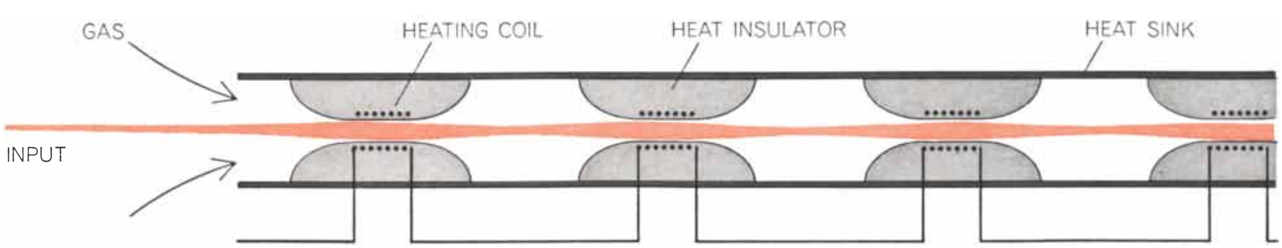
SPATIAL COHERENCE of a laser beam makes possible highly directional transmission. A plane-wave laser source radiates a beam that is almost constant in width for a distance (D) equal to the diameter of the source squared divided by four times the wavelength of the radiation. Beyond this distance the beam gradually expands to form a cone. The expansion of the beam is greatly exaggerated here; in actuality D would be about three-fifths of a mile for a two-inch beam with a wavelength of some 6,300 angstrom units.



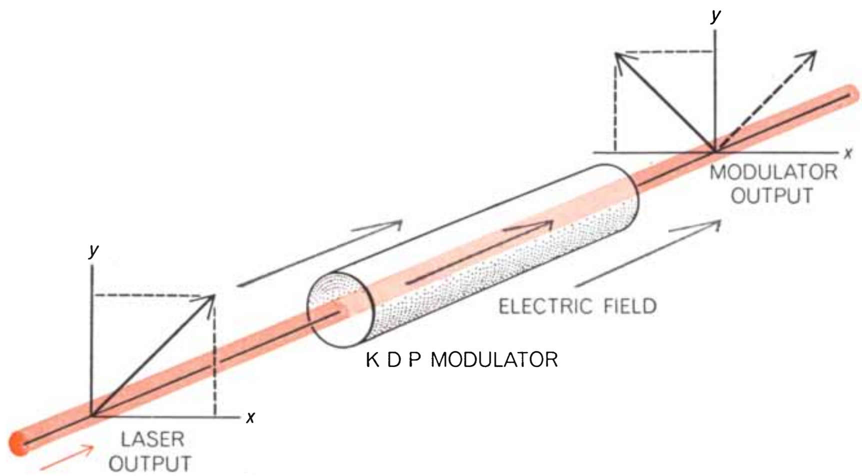
SERIES OF LENSES spaced at the distance D apart could be used to confine the laser beam and guide it to the receiver. The power loss at each lens due to beam expansion could in principle be made as small as one part in 100,000 or even less by making the lens spacing 20 to 40 percent less than D. Again the beam expansion has been greatly exaggerated and the horizontal scale compressed.



PRINCIPLE OF GAS LENS was invented by Dwight W. Berreman of the Bell Laboratories. A gas—for example carbon dioxide—is passed through a heated tube. Because the gas travels faster in the center of the tube, it is cooler there than near the wall. The cooler gas in the center is denser and hence a converging lens is formed. The great advantage of the gas lens is that there are no surfaces in the path of the laser beam, and the lens losses are limited to a very slight scattering of the light by the gas molecules. A gas lens is free from turbulence effects because the velocity of the gas is very low (about five miles per hour).



GAS-LENS WAVE GUIDE is one of several types already built by workers at the Bell Laboratories. Gas-lens wave guides must be built to meet extremely stringent tolerances, and further work will be needed to determine if the necessary accuracy can be achieved at a reasonable cost. The gas lens shown in the photograph on pages 20 and 21 uses air as the focusing medium.



MODULATION OF LASER BEAM is based on variations in the refractive index of some substance in synchronism with the broad-band radio wave produced by combining many individual telephone, television and radio signals. In this particular modulator the laser output passes through a solid cylinder of potassium dihydrogen phosphate (KDP), which is placed in an electric field that is proportional to the signal wave. The index of refraction of the cylinder along the *x* axis differs from that along the *y* axis by an amount proportional to this applied electric field. As a result the laser beam emerges from the far end of the modulator polarized at right angles with respect to the polarization of the input wave.

tube. Because the gas travels faster in the center of the tube, it is cooler there than near the wall. The cooler gas in the center is denser and hence a converging lens is formed [*see third illustration from top on opposite page*]. Several different types of gas-lens wave guides have already been built. The great advantage of the gas lens is that there are no surfaces in the path of the light beam, and the lens losses are limited only to a very slight scattering of the light by the gas molecules. The light-guidance problem is much further from solution than this might suggest, however. A gas lens is free from turbulence effects because the velocity of the gas is low (about five miles per hour), but some aberrations appear nonetheless. A gas-lens wave guide must be built to meet extremely stringent tolerances, and further work will be needed to determine if the necessary accuracy can be achieved at a reasonable cost.

An essential component of any long-distance communication system is a modulator. In order to modulate the light output of a laser the light waves must be capable of being varied in synchronism with the broad-band radio wave produced by combining many individual telephone, television and radio signals. All the optical modulators devised so far have been based on variations in the refractive index of some substance in synchronism with the signal wave. In one of these devices [*see illustration on this page*] the laser output passes through a solid cylinder of potassium dihydrogen phosphate, which is placed in an electric field proportional to the signal wave. The index of refraction of the cylinder along the vertical axis differs from that along the horizontal axis by an amount proportional to this applied electric field. As a result the laser beam emerges from the far end of the modulator polarized at right angles with respect to the polarization of the input wave. In addition the amplitude of the modulator output wave varies according to the strength of the applied electric field.

Laser modulators of this type are operable but at present too inefficient to be entirely satisfactory. Similar devices based on modulation of the refractive index in semiconductor junctions are being examined.

Research is also being directed toward finding a suitable light detector for use at the receiving end of a laser-communication path. Vacuum tubes containing surfaces from which electrons are emitted in response to an impinging light beam—outgrowths of the familiar photomultiplier tube—have been perfected and in the visible region of the spectrum are reasonably efficient. Their efficiency falls, however, at infrared frequencies. Another detector consists of a semiconductor junction that responds to light by releasing electrons into a low-frequency circuit in proportion to the energy of the impinging light wave.

A major part of the research effort devoted to finding better detectors, modulators and lasers involves new materials. Metallurgists, chemists and physicists are challenged to develop an understanding of the behavior of various materials and to devise techniques for deriving both purer materials and materials with carefully controlled traces of known "impurities" in otherwise pure and well-ordered crystals. Before the advent of the laser the need to study many of these properties of materials did not exist. Besides providing the need, the laser has provided a new capability for studying materials in ways not possible before. The essentially monochromatic nature of the laser output has made possible revealing spectroscopic studies of energy levels in a wide variety of substances.

In spite of the many advantages of the laser in long-distance communication, the economic competition from the present systems can be expected to be severe. The test of commercial success is not merely the feasibility of communicating in the visible region of the spectrum. A combination of coaxial-cable, microwave-radio and wave guide systems can provide the equivalent of a single super-broad-band system. Such a composite system could provide the foreseeable communication needs of the world for many years to come and has the main advantage of diversification: less risk of losing the entire communication system as the result of an accident. In addition, any new system must not only do the job at a lower cost than existing systems but also anticipate various improvements in the existing systems. The transistor and other solid-state devices have revolutionized the existing communication systems in the past 10 years, and the laser must now compete in an era in which vacuum tubes with two-year life-spans have been replaced by solid-state devices with 20-year life-spans.

The laser, however, can also be expected to partake of the solid-state revolution. Solid-state lasers already exist, and although they have not had the spectral purity of gas lasers, this situation appears to be changing. The overriding trend in the history of electrical communication has been toward ever larger bandwidths and ever higher frequencies, because the use of wide-band systems has proved to be more economical than parallel narrow-band systems designed to achieve the same total communication capacity. Judging by this trend, we would expect the laser to play an important role in the communication systems of the future.

A Transpacific Contact in 3000 B.C.

Archaeological evidence strongly indicates that pottery found in Ecuador, the oldest known in the New World, was introduced there by fishermen who had drifted from Japan

by Betty J. Meggers and Clifford Evans

Although the time of man's first arrival in the New World from the Old World is still uncertain, authorities agree that the principal route was across the Bering Strait from Siberia to Alaska. Perhaps as early as 40,000 years ago, and surely by 13,000 B.C., groups of hunters and gatherers began to populate North America. As the millenniums passed, they spread throughout the hemisphere and gradually developed different ways of life. In some places, such as Mexico and Peru, the process of cultural evolution and differentiation culminated in civilizations that rivaled—and in the view of some Spaniards were superior to—the civilization of 16th-century Europe.

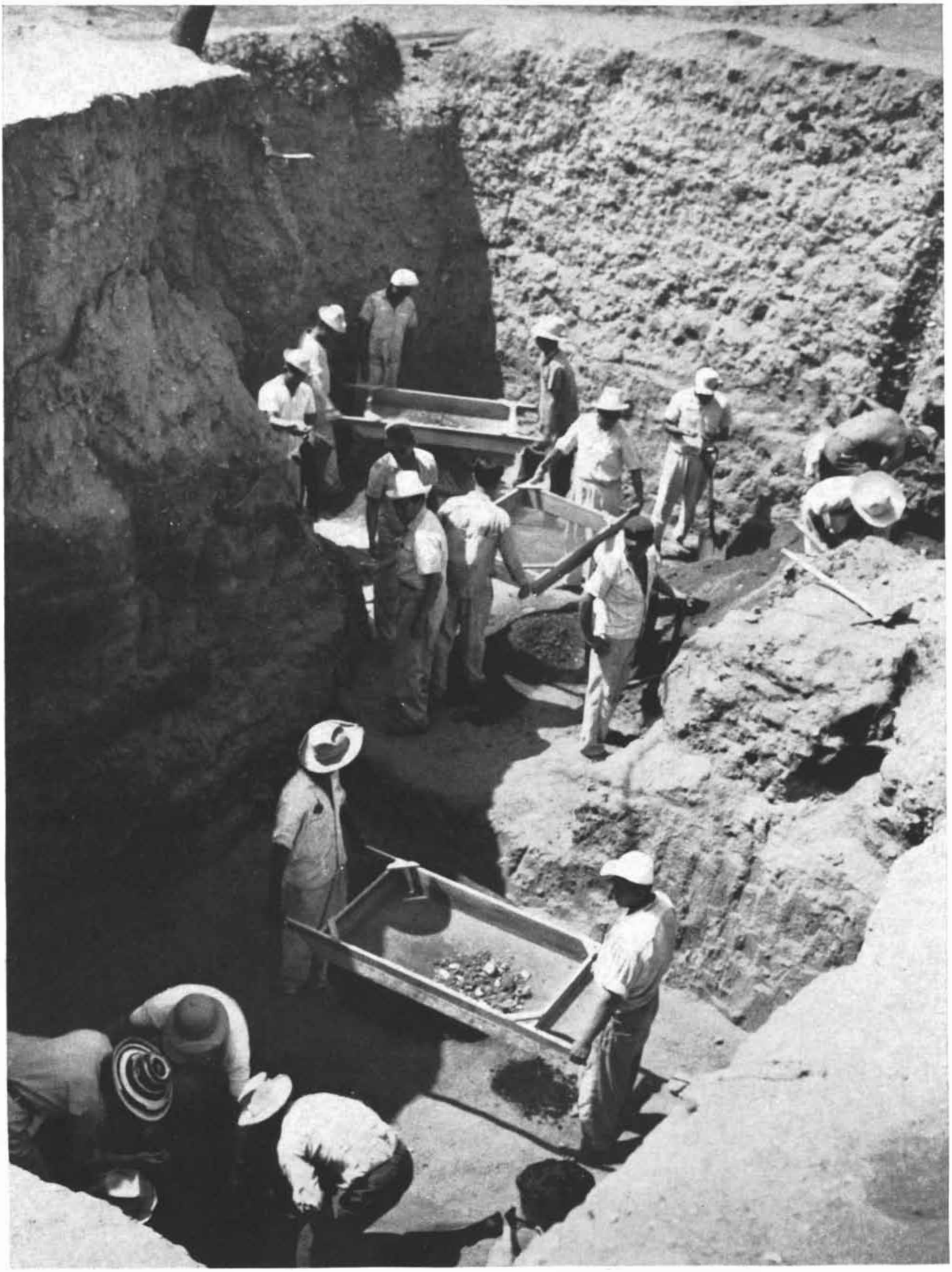
As these New World civilizations have become better known archaeologically, striking parallels have been observed with the architecture, religious practices and art styles of Asia. It has been suggested that these parallels are evidence of unrecorded "discoveries" of America long before Columbus. Most professional archaeologists have remained unconvinced because the possibility of an independent origin of the parallel traits could not be eliminated. Recent archaeological investigations on the coast of Ecuador, however, have brought to light facts that can lead to only one conclusion: a boatload of inadvertent voyagers from Japan strayed ashore in the New World some 4,500 years before Cortes reached Mexico.

There are two principal ways in which similar culture traits can come into existence in widely separated parts of the world. One is convergence, a process by which traits that were initially different come to resemble one another independently. The other is diffusion, or "borrowing," a process by which a trait is passed from a donor culture to a recipient one. Since borrowed traits are often modified during their transfer, it may be difficult to tell which of the two processes is responsible for any particular similarity.

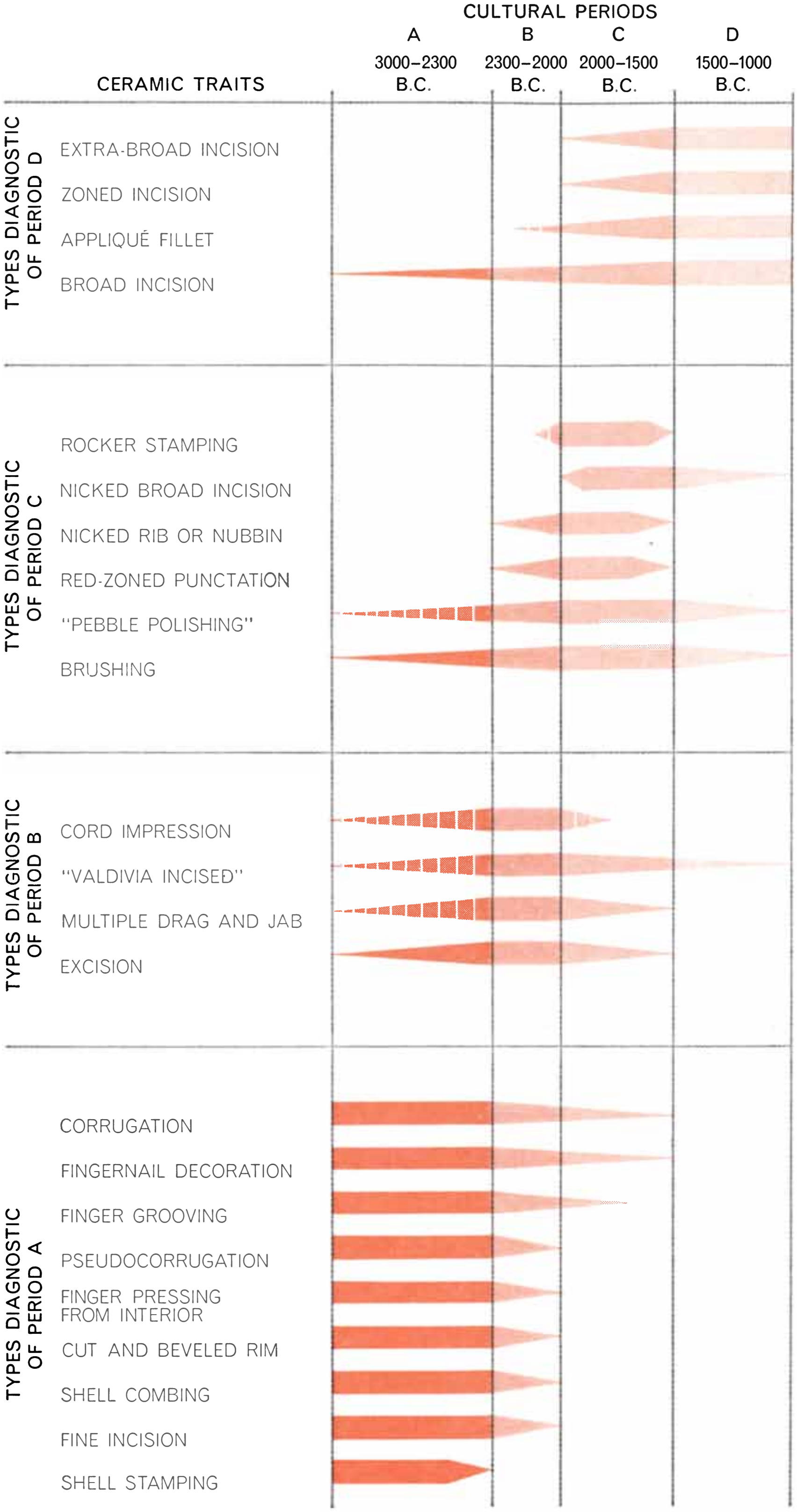
Borrowing rather than convergence becomes the preferable explanation only if three criteria can be met. First, the trait or complex of traits in question must be shown to be older in the donor culture than in the recipient culture, or at least as old. Second, the antecedents of the trait or complex of traits should be traceable in the donor culture; conversely, the parallel item in the recipient culture should appear full-blown, with no observable antecedents. Third, the physical form of the trait should be unrelated to its function; this operates to rule out parallels that arise because of limitations set by the material from which an object is made or by the use to which it is put.

The first two criteria have not been satisfied for most of the culture traits that have been cited as evidence for contacts across the Pacific. Even though the areas of high culture in Mexico and South America are among the best-known parts of the New World, large sections remain almost untouched by archaeologists; the situation in most of Asia and the adjacent Pacific islands is no better. When more work has been done, other conclusions may be as surprising as the one we propose here: The knowledge of how to make pottery was first brought to Ecuador—where the earliest pottery so far discovered in the

FIRST CLUE to cultural contact between Asia and the New World 5,000 years ago was provided by fragments of a pottery vessel from the lowest level of a Valdivia culture site in Ecuador. They display a rim decorated with a "castellation," or peak; this decoration was uncommon elsewhere in the world at that time except on the Jomon pottery of Japan.



DEPTH OF DEPOSIT at a site near Valdivia, a village on the coast of Ecuador, is evident in this stratigraphic section that reached sterile soil at the bottom of the cut. Pairs of workers with wire screens are sifting pottery fragments and other bits of human handiwork from the accumulated debris of the earliest level of the Valdivia culture, in which Jomon-like pottery was unearthed.



VARIETY OF TECHNIQUES used to decorate the earliest Valdivia pottery suggests that the craft was imported rather than invented locally. Each bar's length shows the duration of the ceramic trait it represents; tapering at the left indicates a trait's inception, at right its extinction. Broken tone implies uncertainty. Nine traits are typical of Period *A* pottery, and three of the four traits typical of Period *B* may first have appeared in Period *A*. Some of the parallels between this pottery and Jomon ware are illustrated on the opposite page.

New World has been found—by fishermen who had drifted there from Japan, more than 8,000 nautical miles away.

This conclusion was drawn only after a long period of fieldwork, classification and analysis. Rather than merely summarize the evidence on which the conclusion is based, we should like to review the chain of events that led to it. The starting point was the discovery of a series of seashell deposits along the coast of the Ecuadorian province of Guayas. An astute amateur archaeologist, Emilio Estrada, excavated one of these middens in the fall of 1956 and found that it contained heavily eroded fragments of pottery. He immediately recognized that the techniques of decoration resembled those used to ornament Guañape pottery—the earliest known on the coast of Peru—which dates back to about 2000 B.C. On the basis of this similarity Estrada proposed that the newly discovered Ecuadorian pottery belonged to the same early period as its Peruvian counterpart.

Estrada went on to investigate similar middens and found one with a deeper refuse deposit and better-preserved pottery near the modern fishing village of Valdivia. This name he gave to the culture that produced the pottery. Excavations at the Valdivia site since 1956 have provided material for carbon-14 analysis that extends the date of origin for the Valdivia culture back to about 3000 B.C., which makes it even older than Estrada had originally thought.

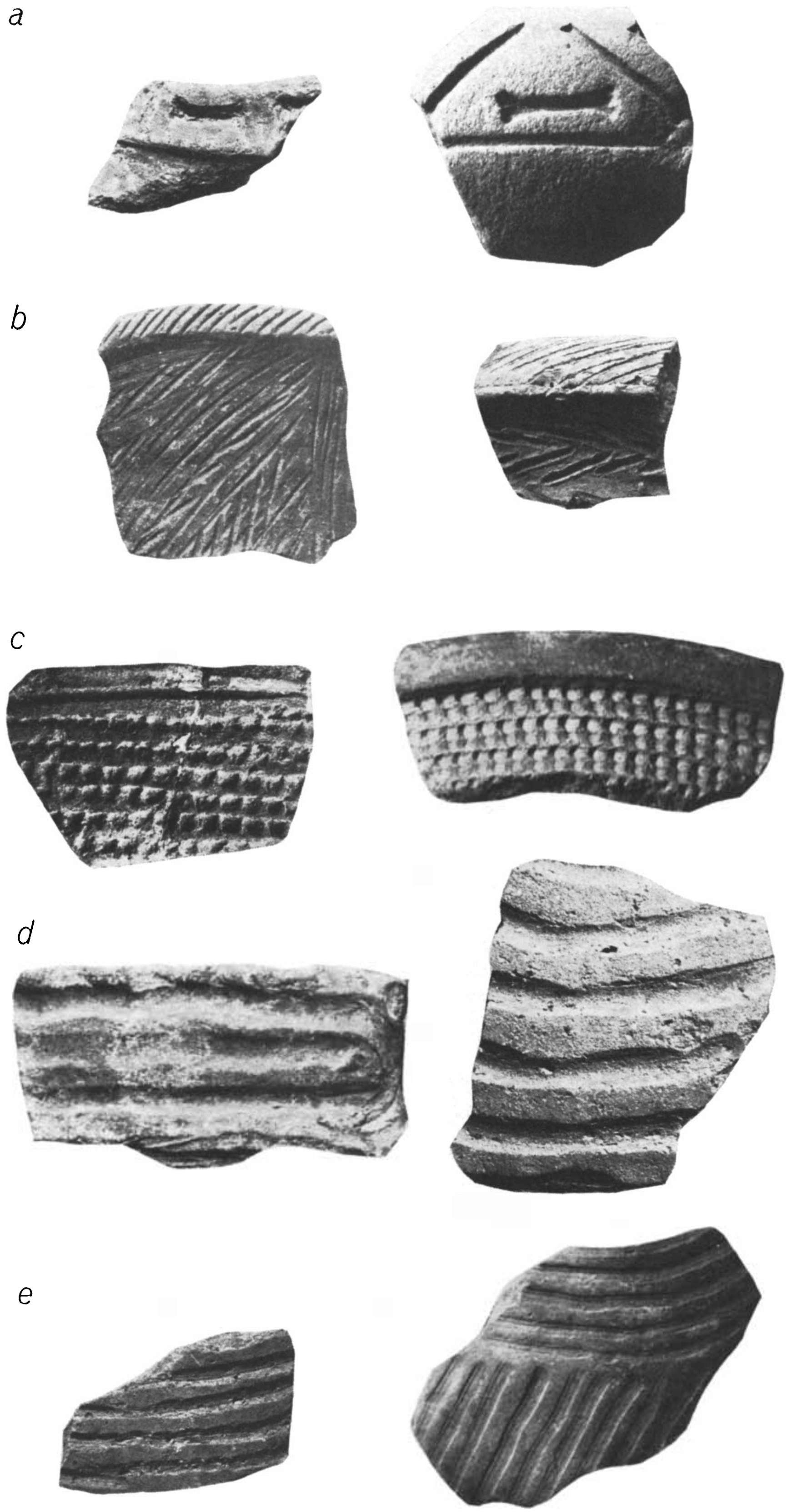
The antiquity of the Valdivia sites is reflected in their location on the margins of ocean inlets, which today are barren salt flats. Between 3000 and 1500 B.C. these flats were probably covered with, or ringed by, mangrove trees and were submerged by the sea either permanently or at high tide; such mangrove swamps still persist farther to the south along the Ecuadorian coast. The margins of these inlets were favored places of residence for the Valdivians because mollusks, crustaceans and fish, which were among their principal foodstuffs, were at hand. The people also ate deepwater species of fish, a fact that implies a knowledge of boating. The presence of deer bones in the refuse indicates that the Valdivians also practiced hunting.

No plant remains have been found in Valdivia sites, but both the habits of modern hunting-and-gathering peoples and archaeological evidence from Peru, where the dry climate helps to preserve perishable materials, make it a safe guess that the Valdivians did not neglect the edible wild plants of their region. They may even have taken some of the initial steps toward the domestication of plants, as did their contemporaries in Mexico and Peru. In general, however, their adaptation to a shore environment was so complete that it may have been their undoing. About 1500 B.C. the inlets began to dry up and the food supply to which the Valdivians were accustomed began to dwindle. The people retreated south and east toward the mouth of the Guayas River, but the new environment was less favorable and the Valdivia culture appears to have gradually become extinct.

A typical site of the Valdivia culture contains an abundance of mollusk shells, fair quantities of broken pottery and smaller amounts of bone and stone. There is little direct evidence of house construction, but fragments of burnt clay bearing the impression of twigs suggest that the Valdivians built huts with wattle-and-daub walls.

Although stone projectile points were manufactured by earlier peoples and are found frequently in the highlands of Ecuador, the Valdivians did not employ them. Stone tools for cutting, chopping and scraping were shaped only to the extent necessary to produce a working edge. Pebbles were converted into sinkers by cutting shallow notches at the sides to prevent the line from slipping off. Shell fishhooks were made with the aid of small sandstone saws and reamers. The fishhooks are small and almost circular, with a narrow gap separating the point from the shank. Tools made of bone are the scarcest of all; they consist chiefly of awls made of fishbone and punches fashioned from deer antler. In short, the surviving components of the Valdivians' tool kit are far from distinctive.

Quite the opposite is true of the pottery, which displays a variety of decorative techniques and vessel shapes that seems incongruous in the oldest pottery of the New World. For all its elaboration in shape and decoration, Valdivia pottery exhibits its primitive character by the thickness of the vessel walls and the imperfect symmetry of rim and body contours. The vessels were built up from coils of clay that sometimes were left visible on jar necks as an ornamental effect. The surface of most of the vessels was smoothed and often polished to a high gloss; about a fifth of them were given a red "slip."



PARALLELS between Jomon and Valdivia decoration techniques and design motifs are evident in these matching pottery fragments. In each example the Japanese pottery is at left and the Ecuadorian at right. At *a* the technique is excision and the motif is a "dog bone." At *b* the vessel rims are incised with parallel lines and the necks are decorated with zigzag incising. At *c* a multiple-edged tool has been alternately dragged and jabbed. At *d* fingers were used to form grooves. At *e* a tool has left fine lines at the bottom of each incision.

Numerous methods of decoration were employed, including incision, punctation, scraping, grooving, rocker-stamping, excision and appliqué. Decorative variety was increased by combining these methods with different kinds of surface finish; for example, incised designs were added to unpolished, polished or red-slipped surfaces. In addition, two kinds of decoration, such as incision and punctation, were sometimes applied to the same vessel. These combinations gave rise to a wide range of decorative effects.

One of the tasks facing the archaeologist is to reduce such variations to general categories that can be used to study change over a period of time and to compare one pottery complex with another. When Valdivia pottery is classified in this way, differences in the popularity of several of the decorated types become evident [*see illustration on page 30*].

Such differences provide a basis for dividing the history of the Valdivia culture into four periods. Most important for investigation of the origin of Valdivia pottery are the nine types of decoration characteristic of Period *A*. Typical early shapes include large, shallow, thick-walled bowls with slightly constricted mouths and round jars with thickened rims that were often ornamented by pressing the fingers on the lower edge of the rim. Other features characteristic of Period *A* are vessels with four small, closely spaced "feet," and others with rims that are undulating or "castellated" (formed into several peaks).

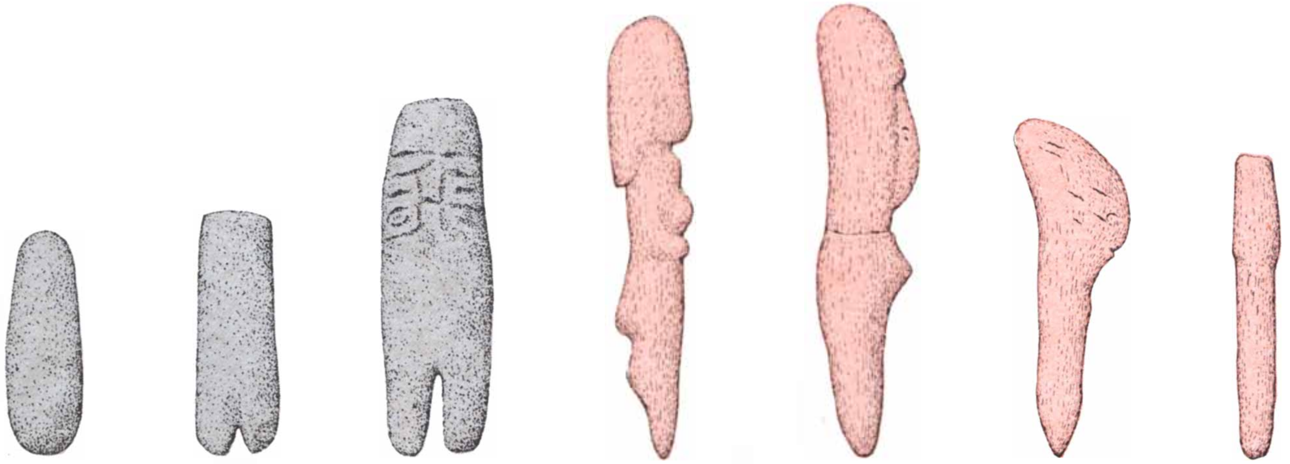
Figurines are another distinctive element of the Valdivia culture. Those of Period *A* were made of stone, but about the beginning of Period *B* pottery became the preferred material. The earliest figurines were nothing more than thin slabs of soft stone either selected for the symmetry of their natural form or worked into a rectangular outline; they are identifiable as figurines because of their early position in an evolutionary continuum that culminates in figurines with recognizable human characteristics.

The style changes completely with the introduction of pottery figurines at the beginning of Period *B*. The earliest of these, known as the Valdivia type, is realistic and often carefully made [*see illustration below*]. During Period *C* the realism gradually disappears, although the types known as San Pablo and Buena Vista retain traces of their ancestry. By Period *D* figurines have lost their popularity; the few examples of the type that is known as Punta Arenas are a far cry from the careful creations of Period *B*.

The abundance of fragments of figurines in the Valdivia sites suggests that the figurines were put to some common use. Two facts are relevant to inferences on this point. First, although many of the figurines represent females, the lack of emphasis on pregnancy or genitals makes it unlikely that they were fertility images. Second, the seemingly casual manner in which they were discarded suggests that their value was transitory. Today Indians in northern Colombia and Panama make for healing ceremonies wooden figurines that are similarly short-lived and unemphatic with respect to sex; new ones are carved for each ceremony and are then thrown away. Since they are made of wood, they soon disappear. The Valdivia figurines, made of durable materials, simply broke into fragments.

A survey of the characteristics of other early New World archaeological

POTTERY FIGURINES are first found at the end of Period *A* in Valdivia sites, or about 2350 B.C. They are more realistic than the stone figurines that precede them or the other pottery figurines that come after them (*see illustration at top of opposite page*). The majority are female and show great variability in the way the hair is dressed. Four of the figurines are shown from front and rear



RISE AND DECLINE of realism in the style of the figurines unearthed at Valdivia cover a span of almost 2,000 years. Stone figurines of Period *A* began as flat slabs, then developed a basal notch to represent legs and next included anthropomorphic facial features on one side of the top (*front views at left*). The figurines of pottery that followed were, first, the realistic Valdivia type (*center and illustration at bottom of these two pages*). Next came the increasingly stylized San Pablo and Buena Vista types. During the last 400 years of Valdivia culture the pottery figurines degenerated into the featureless Punta Arenas type (*shown in profile view at far right*).

complexes serves to highlight the uniqueness of Valdivia pottery. Complexes such as the Monagrillo in Panama (2100 B.C.), the Puerto Hormiga in Colombia (3000 to 2500 B.C.) and the Guañape in Peru (2000 to 1000 B.C.) all have pottery characterized by a limited number of vessel shapes and fewer techniques of decoration. Furthermore, the carbon-14 dates for these complexes (with the possible exception of the Puerto Hormiga complex) are later than the earliest Valdivia dates, which means that none of these cultures could have been the source from which pottery-making was introduced to the coast of Ecuador. Still another alternative—the possibility that Valdivia pottery was a local invention—appears improbable because of the variety this pottery exhibits from the very start; such variety is understandable only as the culmination of a long period of development.

The clue that finally led to the most

alternately. They exhibit a grooved parting of the hair (*far left*), a braid front and back, with the crown of the head half-bare (*left*), a long bob with the sides tucked under a straight center hank at the back of the head (*right*) and a long bob with cross-bindings at front and rear that look like a hairnet (*far right*). Other variations are buns on each side of the head and purely geometric incisions.

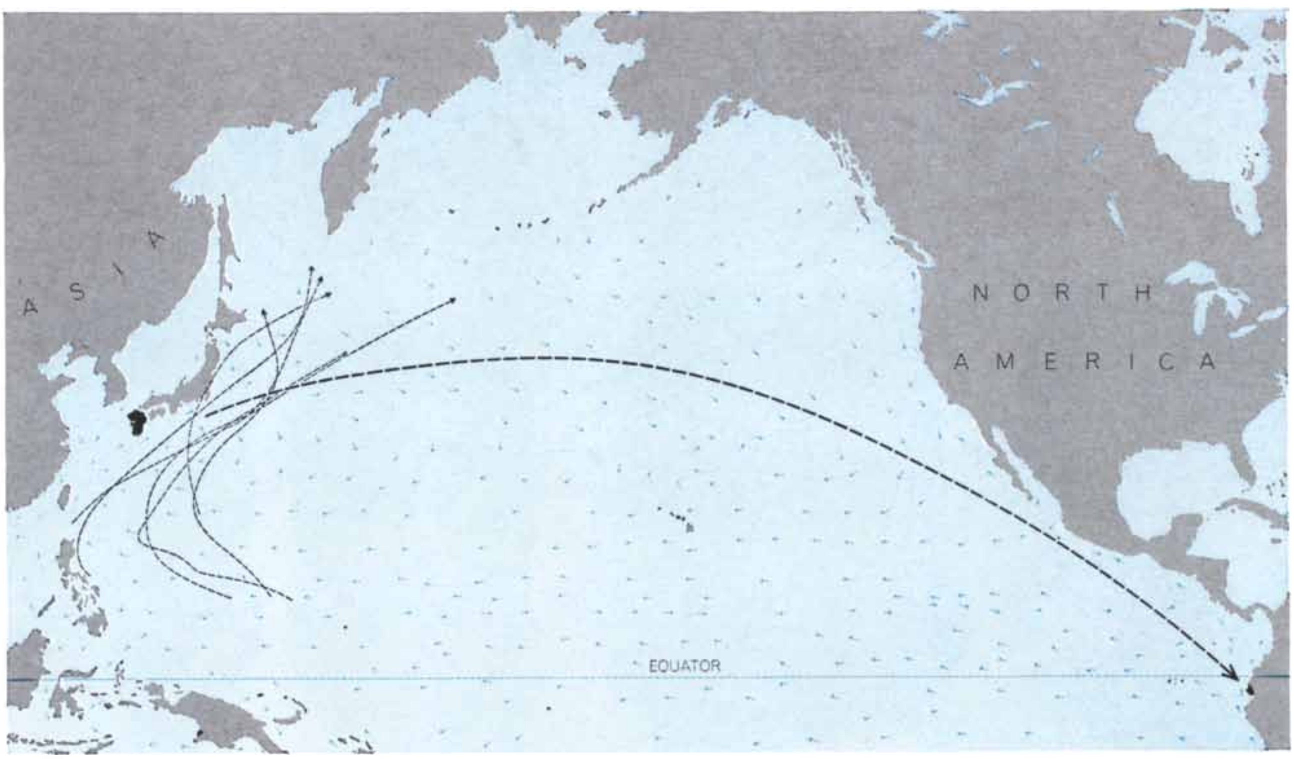
probable origin of Valdivia pottery did not come to light until 1961, when the last shovelfuls of debris were being removed from the deepest part of the large stratified deposit Estrada had excavated at the Valdivia site. This clue was a fragment of a red-slipped and incised vessel with a unique type of rim: when the vessel was whole, the rim rose in a series of castellations [*see illustration on page 28*]. At a time as early as Valdivia Period *A* this form of rim is rare anywhere in the world except Japan. There it commonly occurs on pottery of the prehistoric Jomon period.

When we followed this clue by examining other characteristics of Jomon pottery, we discovered a large number of other similarities with Valdivia pottery, both in decorative technique and motif and in vessel shape. In fact, almost all the initial Valdivia characteristics could be identified in the Early Jomon and Middle Jomon pottery of Japan. Not only are techniques of decoration duplicated; the design elements and patterns are often nearly identical [*see illustration on page 31*].

In making a comparison of this kind it is desirable to demonstrate, if possible, that the traits in question not only occur together in the recipient culture but also form a complex in the donor culture. Often the facts are not available, either because not enough work has been done or because the approaches to classification in the two regions are so different that the materials cannot easily be compared. Until archaeology reaches the level of standardized concepts and procedures attained by the physical and biological sciences, this lack of comparability between results of investigations in different parts of the world will continue to be a problem. Here the difficulty was partly overcome by a National Science Foundation grant that enabled us to visit Japan and examine pottery from a number of Jomon sites on the islands of Honshu and Kyushu. This examination proved that a majority of the decorative techniques and motifs characterizing early Valdivia pottery are also present in pottery from sites in Kyushu dating from the period of transition between Early Jomon and Middle Jomon, or about 3000 B.C.

Three sites are outstanding in possessing almost all the relevant Valdivia traits: Ataka and Sobata near the modern town of Kumamoto in central Kyushu and Izumi on the western coast of Kyushu. Like the Valdivia sites, they consist of shell, bone and stone refuse mingled with fragments of pottery. The evidence suggests that the Jomon people of 3000 B.C. lived a life similar in many respects to the life of the coastal inhabitants of Ecuador and Peru in the same period. Much of their food came from the sea; it included mollusks and crustaceans gathered from tidal flats and deepwater fish caught with hooks by fishermen in canoes offshore. The stone, bone and shell implements are generally equivalent in function to those found in the Valdivia sites, although some of them are different in form.

The context in which pottery is found on Kyushu about 3000 B.C. is thus very similar to the context in which it suddenly appears on the coast of Ecuador at about the same time. An important difference is apparent, however, when the antecedents of the Jomon complex are considered. Valdivia pottery is the oldest so far discovered in South America; the Early Middle Jomon pottery of Japan, on the other hand, is indicated by carbon-14 dates to be the product of several millenniums of evolution in pottery-making. The earliest known pottery in Japan, which is more than 9,000 years old, is simple both in decoration and in vessel shape. The contents of a long series of progressively more recent sites serve to document the changes in decoration and vessel form that culminate in the Jomon pottery complex that



PROBABLE ROUTE from Kyushu to Ecuador is a product of the pattern of prevailing currents (*colored arrows*) and the assumption that a typhoon carried a party of Jomon fishermen so far to the northeast (*black arrows show sample storm tracks*) that a return to Japan was impossible. Thereafter the winds and currents favored continued drifting eastward along a great-circle course to Ecuador.

flourished about 3000 B.C. and possessed the elements that make their sudden appearance on the coast of Ecuador at that time. Hence the Jomon sites on Kyushu satisfy two contextual criteria: equal or greater antiquity and well-established antecedents. The third criterion—absence of functional limitation—is also fulfilled, since the techniques of decoration and variations in rim and base form of these vessels are not dictated by the use to which they were put.

Enough is known about the pattern of subsistence during the Jomon period to hazard a reconstruction of the way in which Jomon-like pottery came to be introduced to Ecuador. Since the Jomon people engaged in deep-sea fishing, we may suppose that a group set out on what was meant to be a routine fishing trip. As they moved away from the southern shore of Kyushu they would have entered waters with some of the strongest currents in the entire Pacific Ocean. These currents move northeastward along the coast of Japan at 24 to 32 nautical miles per day—a speed that under normal circumstances would not have made it impossible for the fishermen to get home. South of Japan, however, is the region where typhoons develop, and the path of these storms often follows the northeast direction of the strong ocean currents.

Such a storm could have caught a boatload of fishermen and swept them far to the northeast. After the wind had died down the force of the current could have been so strong that the fishermen would not have been able to return to Japan. In such circumstances the fishermen would probably have settled down to await whatever end might be in store for them.

Those of us who belong to land-oriented cultures may find it difficult to believe that such involuntary voyagers could survive a few weeks at sea, let alone the months required to reach Ecuador. In possessing this attitude we reflect a background of several millenniums of civilized life, during which we have lost our ability to survive when thrown on our own resources in an unfamiliar environment. In contrast, the peoples of Micronesia are brought up even today to regard the sea as a source of food and an avenue of communication; they are not afraid to set out on long voyages, nor do they become panic-stricken if they lose their way. Although they do not always survive, their chances of doing so are relatively good. It seems likely that the prehistoric Jomon fishermen, like the modern Micronesians, knew how to keep themselves provided with food and water and were accustomed to spending days at sea exposed to sun, wind and rain.

Currents that move five to 10 nautical miles per day prevail along the Jomon fishermen's probable transpacific route, which curves far to the north of Hawaii and then southeastward along the coast of North America until it reaches the latitude of Baja California. There some currents bear to the west, out into the Pacific [*see illustration on opposite page*]. Here chance could have turned a drifting boat away from land, but evidently the Jomon fishermen continued southward.

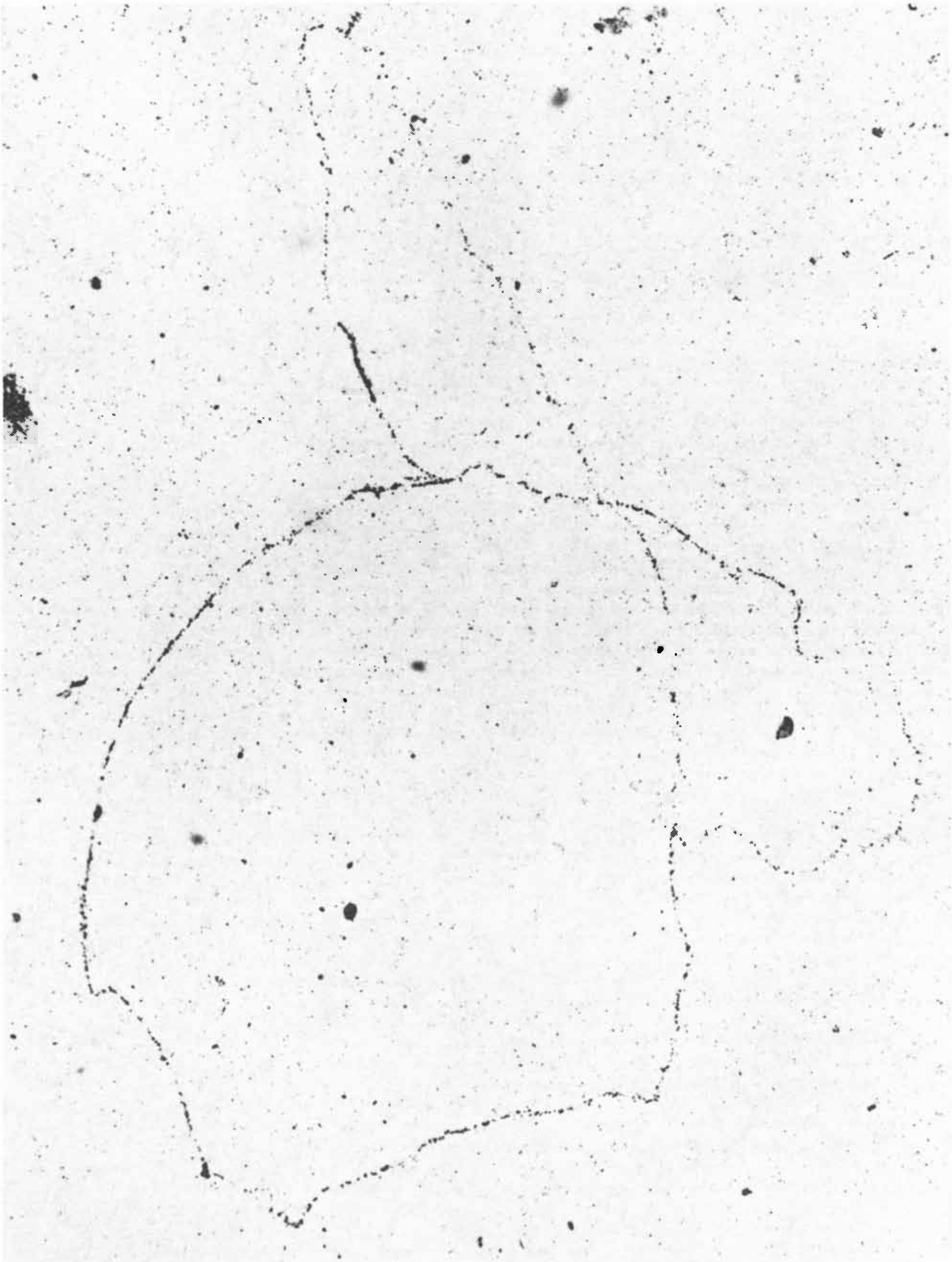
From a geographical standpoint Ecuador is a predictable landfall: its coast projects farther to the west than any other part of South America except the adjacent coast of Peru. It is also the point where ocean currents from north and south meet, join forces and form the equatorial current moving west. This pattern of currents would carry a drifting craft westward if it did not first reach the coast of Ecuador. Such may well have been the fate of similar voyagers in earlier or later times. The Jomon fishermen who introduced pottery to the coastal Ecuadorians were more fortunate. At landfall they had traveled more than 8,000 nautical miles. As a great-circle route this is the shortest distance between Kyushu and Ecuador, but it is still an epic voyage.

There may have been a physical resemblance between the Jomon fishermen and the people they met ashore. The modern Japanese, whose appearance is quite different from that of South American Indians, are comparatively recent arrivals from the Asiatic mainland and do not represent the physical type prevalent among the islands' inhabitants during Jomon times. Communication between the newcomers and the local people must have been restricted at first by the absence of a common language; patterns of social behavior and religious belief doubtless differed in general or in detail. More important than these differences was the fact that the Jomon people and the indigenous population represented an approximately equal level of cultural development; adjustment should not have been difficult.

One further difference that must have struck the newcomers was the absence of pottery in Ecuador. They began to instruct the Valdivians, who were such apt students that their pottery soon equaled and perhaps surpassed that of distant Kyushu. The newcomers may have brought about modifications in other aspects of the Valdivia culture. If so, the traces have been obliterated by the destructive action of nature and man during succeeding millenniums.

COAST OF ECUADOR, from Cabo San Lorenzo to La Puntilla, is the most westerly part of South America except for the portion of Peru between the Gulf of Guayaquil and Punta Negra. This position makes the region a logical transpacific landfall.

If our reconstruction of the origin of Valdivia pottery is correct, the question remains of whether or not this transpacific contact—and others that may later have resulted in the introduction of different technologies, art styles and patterns of behavior—significantly modified the direction of indigenous cultural development in the New World. Were transpacific influences from the high cultures of Asia fundamentally responsible for the development of civilization in the New World, or were their effects superficial, like the frosting on a cake? Two decades ago most archaeologists accepted the idea that civilization followed a parallel but independent course of development in the Old World and the New. Now we are not so sure. The origins of many major features of New World culture—for example metallurgy, mathematics and writing—are still unknown. Until it can be shown that these arts have local antecedents or that, like Valdivia pottery, they are transplants from the Old World cultural stream, no final answer can be given.



AUTORADIOGRAPH shows a duplicating chromosome from the bacterium *Escherichia coli* enlarged about 480 diameters. The DNA of the chromosome is visible because for two generations it incorporated a radioactive precursor, tritiated thymine. The thymine reveals its presence as a line of dark grains in the photographic emulsion. (Scattered grains are from background radiation.) The diagram on the opposite page shows how the picture is interpreted as demonstrating the manner of DNA duplication.

THE BACTERIAL CHROMOSOME

When bacterial DNA is labeled with radioactive atoms, it takes its own picture. Autoradiographs reveal that the bacterial chromosome is a single very long DNA molecule and show how it is duplicated

by John Cairns

The information inherited by living things from their forebears is inscribed in their deoxyribonucleic acid (DNA). It is written there in a decipherable code in which the "letters" are the four subunits of DNA, the nucleotide bases. It is ordered in functional units—the genes—and thence translated by way of ribonucleic acid (RNA) into sequences of amino acids that determine the properties of proteins. The proteins are, in the final analysis, the executors of each organism's inheritance.

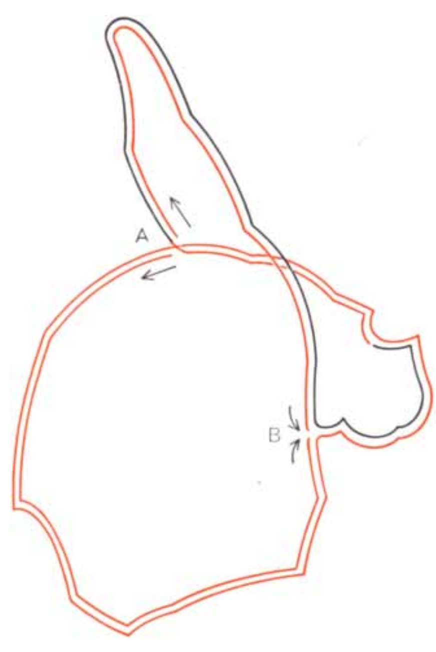
The central event in the passage of genetic information from one generation to the next is the duplication of DNA. This cannot be a casual process. The complement of DNA in a single bacterium, for example, amounts to some six million nucleotide bases; this is the bacterium's "inheritance." Clearly life's security of tenure derives in large measure from the precision with which DNA can be duplicated, and the manner of this duplication is therefore a matter of surpassing interest. This article deals with a single set of experiments on the duplication of DNA, the antecedents to them and some of the speculations they have provoked.

When James D. Watson and Francis H. C. Crick developed their two-strand model for the structure of DNA, they saw that it contained within it the seeds of a system for self-duplication. The two strands, or polynucleotide chains, were apparently related physically to each other by a strict system of *complementary* base pairing. Wherever the nucleotide base adenine occurred in one chain, thymine was present in the other; similarly, guanine was always paired with cytosine. These rules meant that the sequence of bases in each chain inexorably stipulated the sequence in the other; each chain, on its own, could generate the entire sequence of base pairs. Watson and Crick therefore suggested that accurate duplication of DNA could occur if the chains separated and each then acted as a template on which a new complementary chain was laid down. This form of duplication was later called "semiconservative" because it supposed that although the individual parental chains were conserved during duplication (in that they were not thrown away), their association ended as part of the act of duplication.

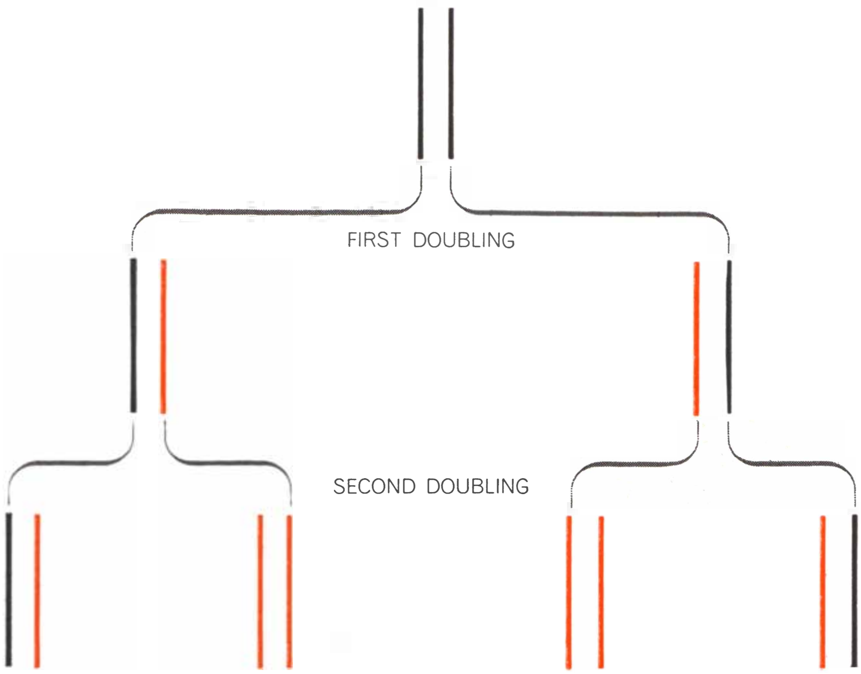
The prediction of semiconservative replication soon received precise experimental support. Matthew S. Meselson and Franklin W. Stahl, working at the California Institute of Technology, were able to show that each molecule of DNA in the bacterium *Escherichia coli* is composed of equal parts of newly synthesized DNA and of old DNA that was present in the previous generation [*see top illustration on next page*]. They realized they had not proved that the two parts of each molecule were in fact two chains of the DNA duplex, because they had not established that the molecules they were working with consisted of only two chains. Later experiments, including some to be described in this article, showed that what they were observing was indeed the separation of the two chains during duplication.

The Meselson-Stahl experiment dealt with the end result of DNA duplication. It gave no hint about the mechanism that separates the chains and then supervises the synthesis of the new chains. Soon, however, Arthur Kornberg and his colleagues at Washington University isolated an enzyme from *E. coli* that, if all the necessary precursors were provided, could synthesize in the test tube chains that were complementary in base sequence to any DNA offered as a template. It was clear, then, that polynucleotide chains could indeed act as templates for the production of complementary chains and that this kind of reaction could be the normal process of duplication, since the enzymes for carrying it out were present in the living cell.

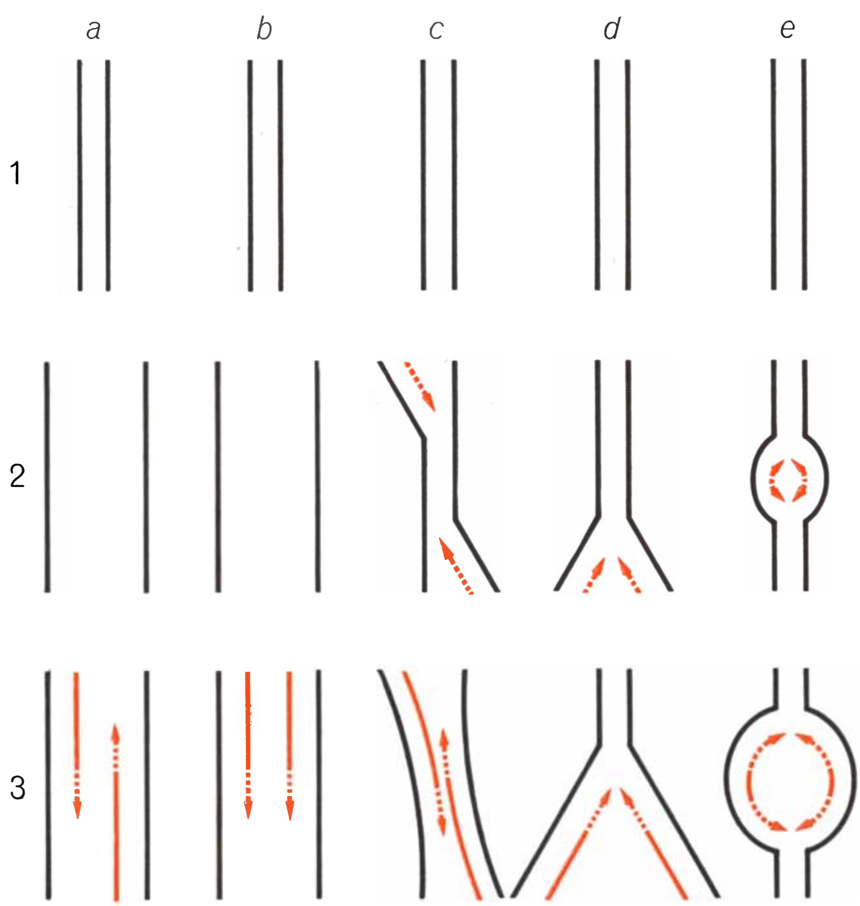
Such, then, was the general background of the experiments I undertook



INTERPRETATION of autoradiograph on opposite page is based on the varying density of the line of grains. Excluding artifacts, dense segments represent doubly labeled DNA duplexes (*two colored lines*), faint segments singly labeled DNA (*color and black*). The parent chromosome, labeled in one strand and part of another, began to duplicate at *A*; new labeled strands have been laid down in two loops as far as *B*.



SEMICONSERVATIVE DUPLICATION was confirmed by the Meselson-Stahl experiment, which showed that each DNA molecule is composed of two parts: one that is present in the parent molecule, the other comprising new material synthesized when the parent molecule is duplicated. If radioactive labeling begins with the first doubling, the unlabeled (*black*) and labeled (*colored*) nucleotide chains of DNA form two-chain duplexes as shown here.



DUPLICATION could proceed in various ways (*a–e*). In these examples parental chains are shown as black lines and new chains as colored lines. The arrows show the direction of growth of the new chains, the newest parts of which are denoted by broken-line segments.

beginning in 1962 at the Australian National University. My object was simply (and literally) to look at molecules of DNA that had been caught in the act of duplication, in order to find out which of the possible forms of semiconservative replication takes place in the living cell: how the chains of parent DNA are arranged and how the new chains are laid down [*see bottom illustration on this page*].

Various factors dictated that the experiments should be conducted with *E. coli*. For one thing, this bacterium was known from genetic studies to have only one chromosome; that is, its DNA is contained in a single functional unit in which all the genetic markers are arrayed in sequence. For another thing, the duplication of its chromosome was known to occupy virtually the entire cycle of cell division, so that one could be sure that every cell in a rapidly multiplying culture would contain replicating DNA.

Although nothing was known about the number of DNA molecules in the *E. coli* chromosome (or in any other complex chromósome, for that matter), the dispersal of the bacterium's DNA among its descendants had been shown to be semiconservative. For this and other reasons it seemed likely that the bacterial chromosome would turn out to be a single very large molecule. All the DNA previously isolated from bacteria had, to be sure, proved to be in molecules much smaller than the total chromosome, but a reason for this was suggested by studies by A. D. Hershey of the Carnegie Institution Department of Genetics at Cold Spring Harbor, N.Y. He had pointed out that the giant molecules of DNA that make up the genetic complement of certain bacterial viruses had been missed by earlier workers simply because they are so large that they are exceedingly fragile. Perhaps the same thing was true of the bacterial chromosome.

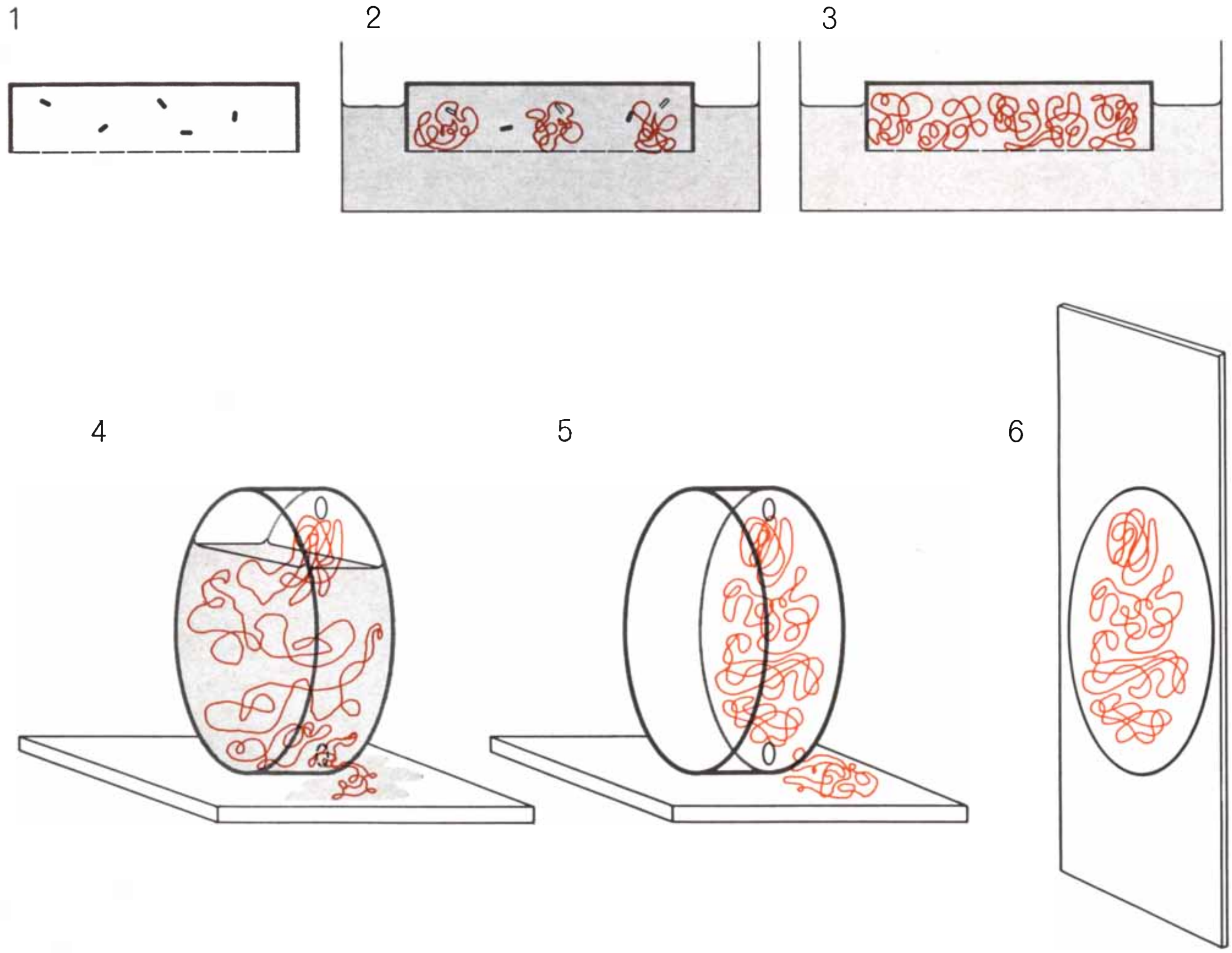
If so, the procedure for inspecting the replicating DNA of bacteria would have to be designed to cater for an exceptionally fragile molecule, since the bacterial chromosome contains some 20 times more DNA than the largest bacterial virus. It would have to be a case of looking but not touching. This was not as onerous a restriction as it may sound. The problem was, after all, a topographical one, involving delineation of strands of parent DNA and newly synthesized DNA. There was no need for manipulation, only for visualization.

Although electron microscopy is the

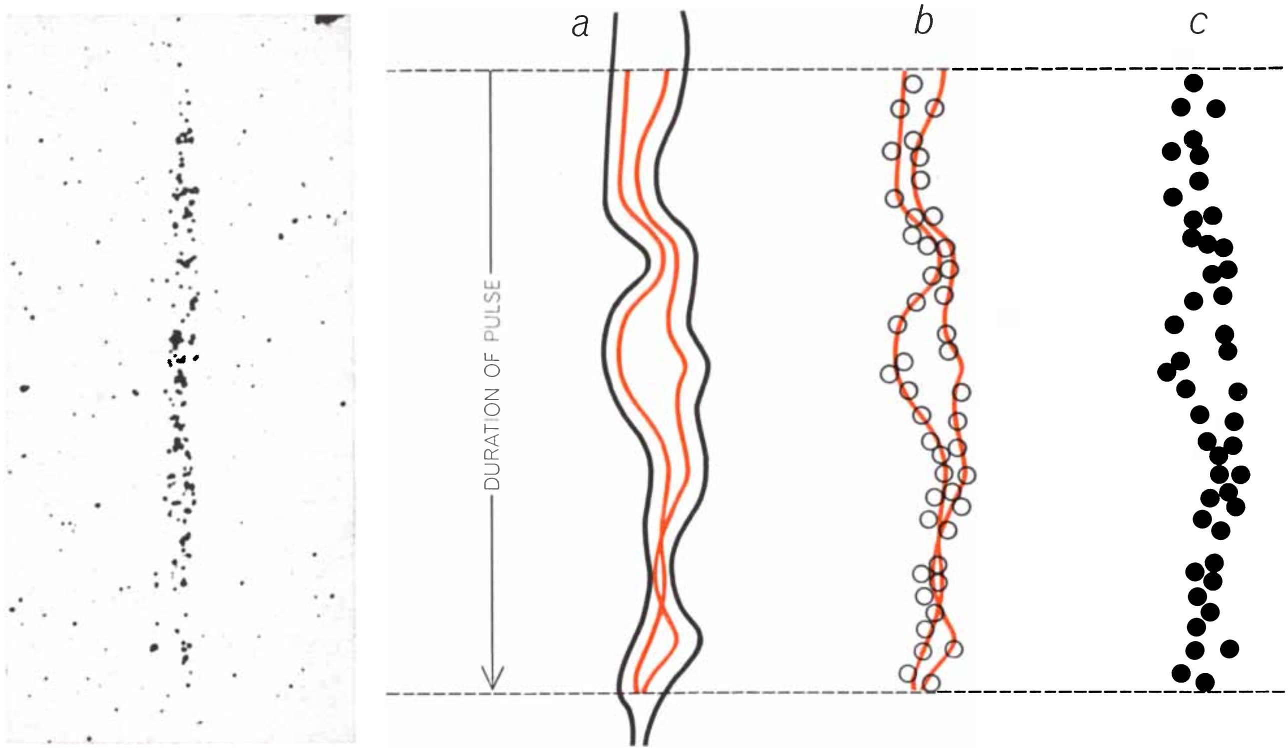
obvious way to get a look at a large molecule, I chose autoradiography in this instance because it offered certain peculiar advantages (which will become apparent) and because it had already proved to be the easier, albeit less accurate, technique for displaying large DNA molecules. Autoradiography capitalizes on the fact that electrons emitted by the decay of a radioactive isotope produce images on certain kinds of photographic emulsion. It is possible, for example, to locate the destination within a cell of a particular species of molecule by labeling such molecules with a radioactive atom, feeding them to the cell and then placing the cell in contact with an emulsion; a developed grain in the emulsion reveals the presence of a labeled molecule [see "Autobiographies of Cells," by Renato Baserga and Walter E. Kisieleski; SCIENTIFIC AMERICAN, August, 1963].

It happens that the base thymine, which is solely a precursor of DNA, is susceptible to very heavy labeling with tritium, the radioactive isotope of hydrogen. Replicating DNA incorporates the labeled thymine and thus becomes visible in autoradiographs. I had been able to extend the technique to demonstrating the form of individual DNA molecules extracted from bacterial viruses. This was possible because, in spite of the poor resolving power of autoradiography (compared with electron microscopy), molecules of DNA are so extremely long in relation to the resolving power that they appear as a linear array of grains. The method grossly exaggerates the apparent width of the DNA, but this is not a serious fault in the kind of study I was undertaking.

The general design of the experiments called for extracting labeled DNA from bacteria as gently as possible and then mounting it—without breaking the DNA molecules—for autoradiography. What I did was kill bacteria that had been fed tritiated thymine for various periods and put them, along with the enzyme lysozyme and an excess of unlabeled DNA, into a small capsule closed on one side by a semipermeable membrane. The enzyme, together with a detergent diffused into the chamber, induced the bacteria to break open and discharge their DNA. After the detergent, the enzyme and low-molecular-weight cellular debris had been diffused out of the chamber, the chamber was drained, leaving some of the DNA deposited on the membrane [*see illustration below*]. Once dry, the membrane was coated with a photographic emulsion sensitive to electrons emitted by the tritium and was left for two months. I hoped by this procedure to avoid subjecting the DNA to appreciable turbulence and so to find



AUTORADIOGRAPHY EXPERIMENT begins with bacteria whose DNA has been labeled with radioactive thymine. The bacteria and an enzyme are placed in a small chamber closed by a semipermeable membrane (*1*). Detergent diffused into the chamber causes the bacteria to discharge their contents (*2*). The detergent and cellular debris are washed away by saline solution diffused through the chamber (*3*). The membrane is then punctured. The saline drains out slowly (*4*), leaving some unbroken DNA molecules (*color*) clinging to the membrane (*5*). The membrane, with DNA, is placed on a microscope slide and coated with emulsion (*6*).



DNA synthesized in *E. coli* fed radioactive thymine for three minutes is visible in an autoradiograph, enlarged 1,200 diameters, as an array of heavy black grains (*left*). The events leading to the autoradiograph are shown at right. The region of the DNA chains synthesized during the "pulse-labeling" is radioactive and is shown in color (*a*). The radioactivity affects silver grains in the photographic emulsion (*b*). The developed grains appear in the autoradiograph (*c*), approximately delineating the new chains of DNA.

some molecules that—however big—had not been broken and see their form. Inasmuch as *E. coli* synthesizes DNA during its entire division cycle, some of the extracted DNA should be caught in the act of replication. (Since there was an excess of unlabeled DNA present, any tendency for DNA to produce artificial aggregates would not produce a spurious increase in the size of the labeled molecules or an alteration in their form.)

It is the peculiar virtue of autoradiography that one sees only what has been labeled; for this reason the technique can yield information on the history as well as the form of a labeled structure. The easiest way to determine which of the schemes of replication was correct was to look at bacterial DNA that had been allowed to duplicate for only a short time in the presence of labeled thymine. Only the most recently made DNA would be visible (corresponding to the broken-line segments in the bottom illustration on page 38), and so it should be possible to determine if the two daughter molecules were being made at the same point or in different regions of the parent molecule. A picture obtained after labeling bacteria for three minutes, or a tenth of a generation-time [*at left in illustration above*], makes it clear that two labeled structures are being made in the same place. This place is presumably a particular region of a larger (unseen) parent molecule [*see diagrams at right in illustration above*].

The autoradiograph also shows that at least 80 microns (80 thousandths of a millimeter) of the DNA has been duplicated in three minutes. Since duplication occupies the entire generation-time (which was about 30 minutes in these experiments), it follows that the process seen in the autoradiograph could traverse at least 10 × 80 microns, or about a millimeter, of DNA between one cell division and the next. This is roughly the total length of the DNA in the bacterial chromosome. The autoradiograph therefore suggests that the entire chromosome may be duplicated at a single locus that can move fast enough to traverse the total length of the DNA in each generation.

Finally, the autoradiograph gives evidence on the semiconservative aspect of duplication. Two structures are being synthesized. It is possible to estimate how heavily each structure is labeled (in terms of grains produced per micron of length) by counting the number of exposed grains and dividing by the length. Then the density of labeling can be compared with that of virus DNA labeled similarly but uniformly, that is, in both of its polynucleotide chains. It turns out that each of the two new structures seen in the picture must be a single polynucleotide chain. If, therefore, the picture is showing the synthesis of two daughter molecules from one parent molecule, it follows that each daughter molecule must be made up of one new (labeled) chain and one old (unlabeled) chain—just as Watson and Crick predicted.

The "pulse-labeling" experiment just described yielded information on the isolated regions of bacterial DNA actually engaged in duplication. To learn if the entire chromosome is a single molecule and how the process of duplication proceeds it was necessary to look at DNA that had been labeled with tritiated thymine for several generations. Moreover, it was necessary to find, in the jumble of chromosomes extracted from *E. coli,* autoradiographs of unbroken chromosomes that were disentangled enough to be seen as a whole. Rather than retrace all the steps that led, after many months, to satisfactory pictures of the entire bacterial chromosome in one piece, it is simpler to present two sample autoradiographs and explain how they can be interpreted and what they reveal.

The autoradiographs on page 36 and at the right show bacterial chromosomes in the process of duplication. All that is visible is labeled, or "hot," DNA; any unlabeled, or "cold," chain is unseen. A stretch of DNA duplex labeled in only one chain ("hot-cold") makes a faint trace of black grains. A duplex that is doubly labeled ("hot-hot") shows as a heavier trace. The autoradiographs therefore indicate, as shown in the diagrams that accompany them, the extent to which new, labeled polynucleotide chains have been laid down along labeled or unlabeled parent chains. Such data make it possible to construct a bacterial family history showing the process of duplication over several generations [*see illustration on next page*].

The significant conclusions are these:

1. The chromosome of *E. coli* apparently contains a single molecule of DNA roughly a millimeter in length and with a calculated molecular weight of about two billion. This is by far the largest molecule known to occur in a biological system.

2. The molecule contains two polynucleotide chains, which separate at the time of duplication.

3. The molecule is duplicated at a single locus that traverses the entire length of the molecule. At this point both new chains are being made: two chains are becoming four. This locus has come to be called the replicating "fork" because that is what it looks like.

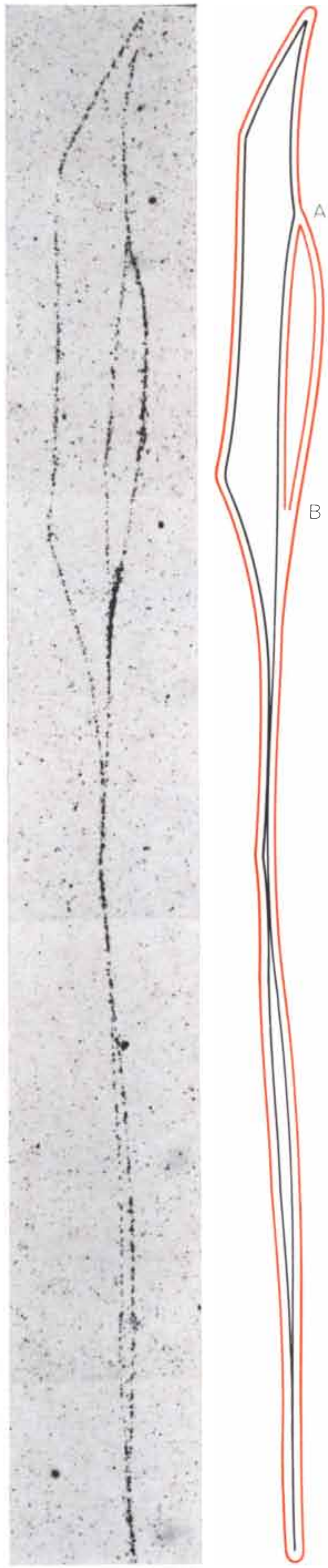
4. Replicating chromosomes are not *Y*-shaped, as would be the case for a linear structure [*see "d" in bottom illustration on page 38*]. Instead the three ends of the *Y* are joined: the ends of the daughter molecules are joined to each other and to the far end of the parent molecule. In other words, the chromosome is circular while it is being duplicated.

It is hard to conceive of the behavior of a molecule that is about 1,000 times larger than the largest protein and that exists, moreover, coiled inside a cell several hundred times shorter than itself. Apart from this general problem of comprehension, there are two special difficulties inherent in the process of DNA duplication outlined here. Both have their origin in details of the structure of DNA that I have not yet discussed.

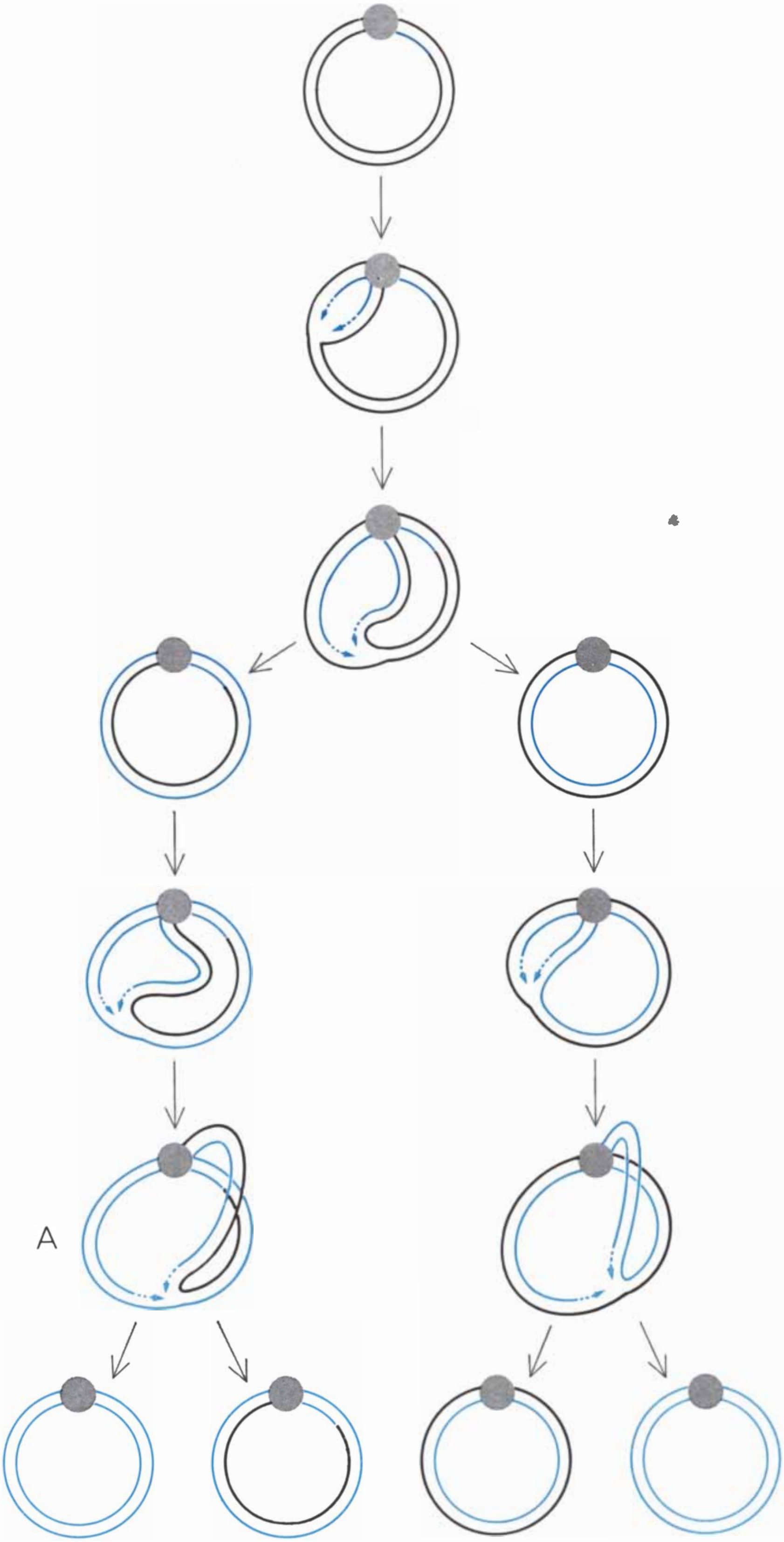
The first difficulty arises from the opposite polarities of the two polynucleotide chains [*see illustration on page 43*]. The deoxyribose-phosphate backbone of one chain of the DNA duplex has the sequence $–O–C_3–C_4–C_5–O–P–O–C_3–C_4–C_5–O–P–$... (The C_3, C_4 and C_5 are the three carbon atoms of the deoxyribose that contribute to the backbone.) The other chain has the sequence $–P–O–C_5–C_4–C_3–O–P–O–C_5–C_4–C_3–O–$...

If both chains are having their complements laid down at a single locus moving in one particular direction, it follows that one of these new chains must grow by repeated addition to the C_3 of the preceding nucleotide's deoxyribose and the other must grow by addition to a C_5. One would expect that two different enzymes should be needed for these two quite different kinds of polymerization. As yet, however, only the reaction that adds to chains ending in C_3 has been demonstrated in such experiments as Kornberg's. This fact had seemed to support a mode of replication in which the two strands grew in opposite directions [*see "a" and "c" in bottom illustration on page 38*]. If the single-locus scheme is correct, the problem of opposite polarities remains to be explained.

The second difficulty, like the first, is related to the structure of DNA. For the sake of simplicity I have been representing the DNA duplex as a pair of chains lying parallel to each other. In actuality the two chains are wound helically around a common axis, with one complete turn for every 10 base pairs, or 34 angstrom units of length (34 ten-millionths of a millimeter). It would seem, therefore, that separation of the chains at the time of duplication, like separation of the strands of an ordinary rope, must involve rotation of the parent molecule with respect to the two daughter molecules. Moreover, this rotation must be very rapid. A fast-multiplying bacterium can divide every 20 minutes;



COMPLETE CHROMOSOME is seen in this autoradiograph, enlarged about 370 diameters. Like the chromosome represented on pages 36 and 37, this one is circular, although it happens to have landed on the membrane in a more compressed shape and some segments are tangled. Whereas the first chromosome was more than halfway through the duplication process, this one is only about one-sixth duplicated (*from A to B*).



BACTERIAL DNA MOLECULE apparently replicates as in this schematic diagram. The two chains of the circular molecule are represented as concentric circles, joined at a "swivel" (*gray spot*). Labeled DNA is shown in color; part of one chain of the parent molecule is labeled, as are two generations of newly synthesized DNA. Duplication starts at the swivel and, in these drawings, proceeds counterclockwise. The arrowheads mark the replicating "fork": the point at which DNA is being synthesized in each chromosome. The drawing marked *A* is a schematic rendering of the chromosome in the autoradiograph on page 36.

during this time it has to duplicate—and consequently to unwind—about a millimeter of DNA, or some 300,000 turns. This implies an average unwinding rate of 15,000 revolutions per minute.

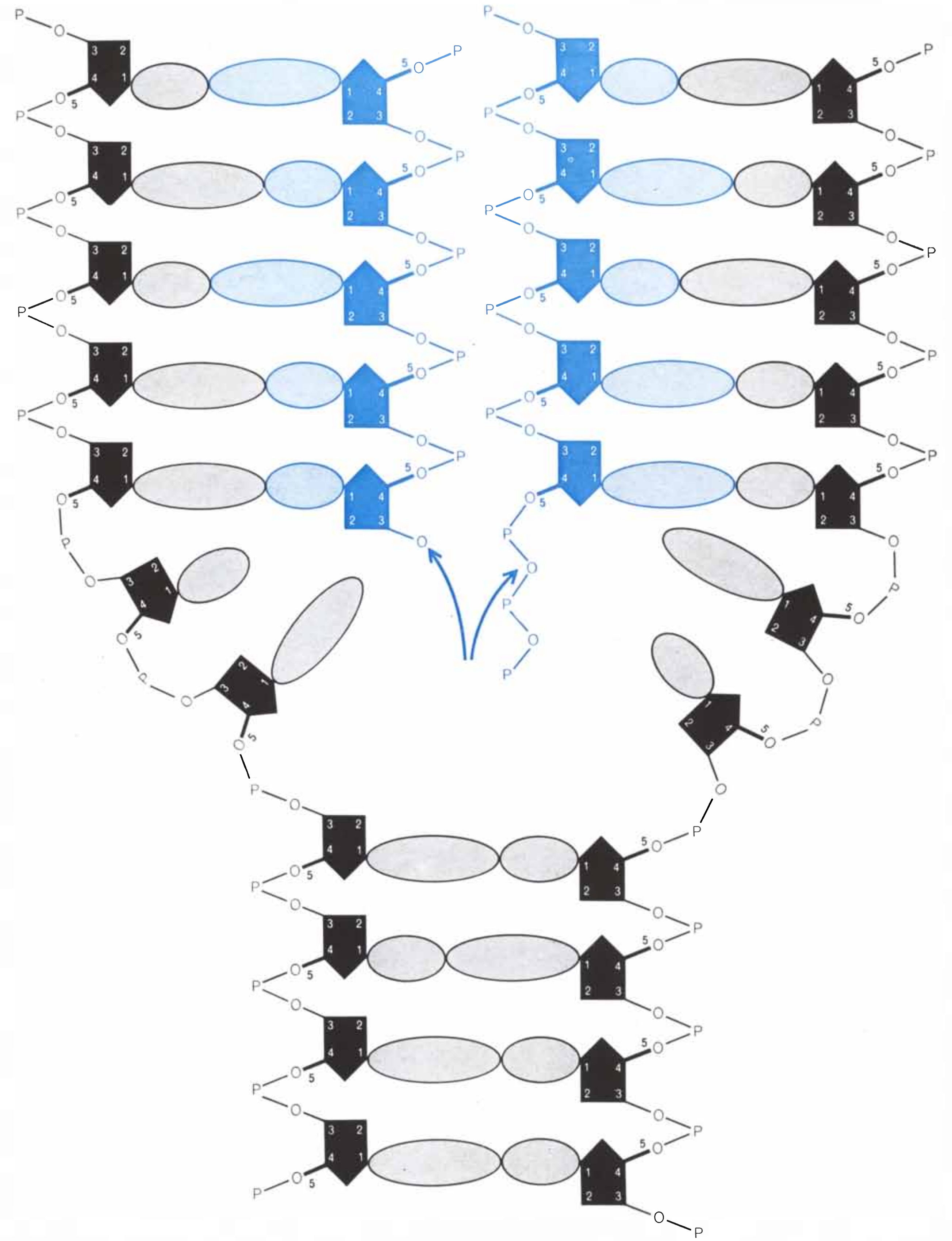
At first sight it merely adds to the difficulty to find that the chromosome is circular while all of this is going on. Obviously a firmly closed circle—whether a molecule or a rope—cannot be unwound. This complication is worth worrying about because there is increasing evidence that the chromosome of *E. coli* is not exceptional in its circularity. The DNA of numerous viruses has been shown either to be circular or to become circular just before replication begins. For all we know, circularity may therefore be the rule rather than the exception.

There are several possible explanations for this apparent impasse, only one of which strikes me as plausible.

First, one should consider the possibility that there is no impasse—that in the living cell the DNA is two-stranded but not helical, perhaps being kept that way precisely by being in the form of a circle. (If a double helix cannot be unwound when it is firmly linked into a circle, neither can relational coils ever be introduced into a pair of uncoiled circles.) This hypothesis, however, requires a most improbable structure for two-strand DNA, one that has not been observed. And it does not really avoid the unwinding problem because there would still have to be some mechanism for making nonhelical circles out of the helical rods of DNA found in certain virus particles.

Second, one could avoid the unwinding problem by postulating that at least one of the parental chains is repeatedly broken and reunited during replication, so that the two chains can be separated over short sections without rotation of the entire molecule. One rather sentimental objection to this hypothesis (which was proposed some time ago) is that it is hard to imagine such cavalier and hazardous treatment being meted out to such an important molecule, and one so conspicuous for its stability. A second objection is that it does not explain circularity.

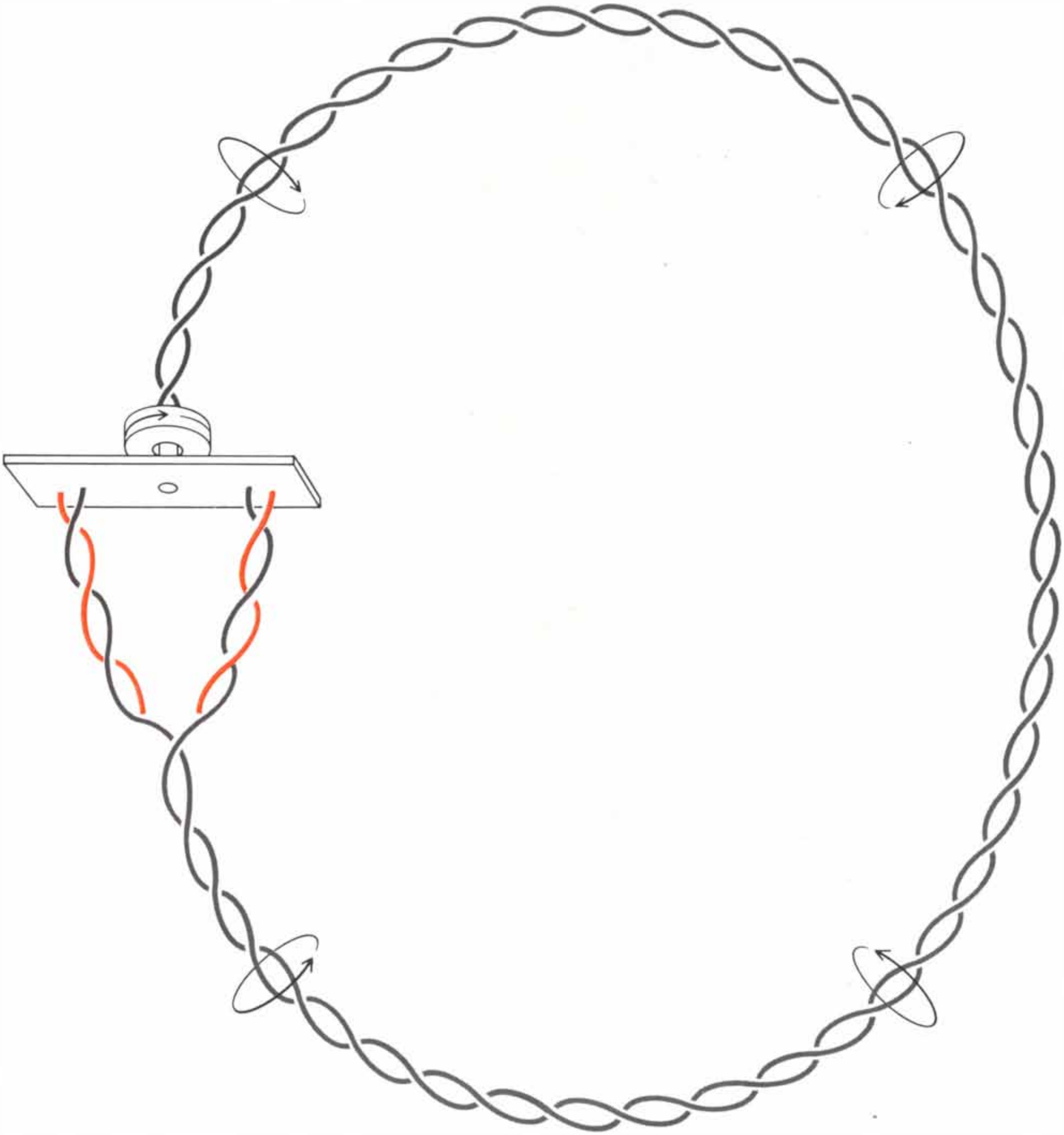
The most satisfactory solution to the unwinding problem would be to find some reason why the ends of the chromosome actually *must* be joined together. This is the case if one postulates that there is an active mechanism for unwinding the DNA, distinct from the mechanism that copies the unwound



OPPOSITE POLARITIES of the two parental chains of the DNA duplex result in opposite polarities and different directions of growth in the two new chains (*color*) being laid down as complements of the old ones during duplication. Note that the numbered carbon atoms (*1 to 5*) in the deoxyribose rings (*solid black*) are in different positions in the two parental chains and therefore in the two new chains. As the replicating fork moves downward, the new chain that is complementary to the left parental chain must grow by addition to a C_3, the other new chain by addition to a C_5, as shown by the arrows. The elliptical shapes are the four bases.

chains. Now, any active unwinding mechanism must rotate the parent molecule with respect to the two new molecules—must hold the latter fast, in other words, just as the far end of a rope must be held if it is to be unwound. A little thought will show that this can be most surely accomplished by a machine attached, directly or through some common "ground," to the parent molecule and to the two daughters [*see illustration below*]. Every turn taken by such a machine would inevitably unwind the parent molecule one turn.

Although other kinds of unwinding machine can be imagined (one could be situated, for example, at the replicating fork), a practical advantage of this particular hypothesis is that it accounts for circularity. It also makes the surprising—and testable—prediction that any irreparable break in the parent molecule will instantly stop DNA synthesis, no matter how far the break is from the replicating fork. If this prediction is fulfilled, and the unwinding machine acquires the respectability that at present it lacks, we may find ourselves dealing with the first example in nature of something equivalent to a wheel.



POSSIBLE MECHANISM for unwinding the DNA double helix is a swivel-like machine to which the end of the parent molecule and also the ends of the two daughter molecules are joined. The torque imparted by this machine is considered to be transmitted along the parent molecule, producing unwinding at the replicating fork. If this is correct, chromosome breakage should halt duplication.

Kodak advertises:

the mating game, audiovisual style . . . an odd chemical in a plain bottle . . . seeing to 30μ, unafraid of sweat and dew . . . expected improvements in photography

The chief starts it off crisply

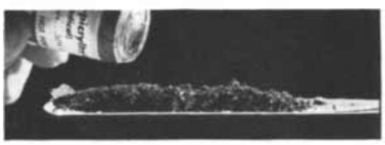
Orders are now being accepted by camera shops and audio-visual dealers for a little device of ours priced at less than $30 that mates any decent stereo tape machine to a KODAK CAROUSEL Projector. It permits a field man to fill more of the happily heavy demand for presentations of his observations without neglect of his obligations at home base.

The chief's voice is heard from the tape. When he makes the recording, every time he pushes the "forward" button of the CAROUSEL Projector a signal is recorded on the unused one of the two stereo audio channels. In playback the beep is never heard but serves merely to change the slide.

Carefully prepared among all the comforts of home, with opportunity for revision, polishing, and editing, his presentation is succinct and finishes in plenty of time to allow a good, stimulating question period. This question period is handled by the junior colleague who brought the tape, the recorder, and the CAROUSEL Slide Tray of 80 slides. (The hosts will probably provide the CAROUSEL Projector. It is becoming sort of standard lecture equipment.) The junior colleague needs the practice of standing up before an audience to defend and promote the line of research. Being junior, he is doubtless more intimately familiar with the details than the chief. With his mentor present only in canned form, he will feel less inhibited.

KODAK CAROUSEL *Sound Synchronizer we designate the little gadget. It works with the* CAROUSEL *700, 800, or AV-900 Projector.*

See the free radical



We are prepared to sell 5 grams of *2,2-Diphenyl-1-picrylhydrazyl* in a plain, non-cryogenic bottle for $14.35. If you like you can imagine the weirdly unpaired electrons glittering at you. When the great organic chemist Gomberg first proposed the concept of a stable free radical to explain some strange results in 1900, skeptics squelched him. A generation later the far more stable free radical we picture above had been made and had been shown to exist mainly as the monomeric radical whether in solid state or in solution.

EASTMAN *7703 probably isn't the oddest of all the thousands of* EASTMAN *Organic Chemicals that can be ordered from Distillation Products Industries, Rochester, N. Y. 14603 (Division of Eastman Kodak Company). Let's hope your library has all four supplements in its copy of List No. 43.*

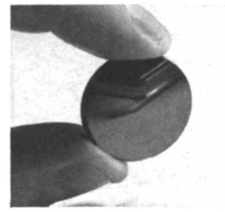
Another successful marriage from the periodic table

Cadmium telluride now becomes an engineering material.

Some imaginative combinations of elements are sought out for what they will do and others for what they won't do. Cadmium telluride won't interact with photons hardly at all from 2 to 30μ in wavelength. Much the same can be said of that more familiar compound sodium chloride, but sodium chloride is far less tenacious of the solid state. Incompatible is usefulness in seasoning watermelon and supporting life with usefulness for constructing durable optical parts that pass thermal radiation.

Similarly transparent are several other alkali halides and similarly vulnerable to dew and sweat. One halide, thallium bromide-iodide ("KRS-5"), that has had to do for far-infrared transmission, is less soluble than the others but still plenty soluble by comparison with CdTe and prone to cold flow under mere gravity, an optically disconcerting effect.

We have learned how to put cadmium telluride into a form which is neither an amorphous glass (no cold flow) nor a crystal (hence no cleavage planes for splitting) but an interlocked mass of crystals that takes and keeps a beautiful optical polish and looks about as transparent as coal.*



CdTe is the sixth compound to which we have successfully applied our proud art of creating polycrystalline optical materials. It will become known as KODAK IRTRAN 6 Material. By comparison with all the other IRTRAN materials, we'd have to call it soft, but it is not as soft as any of the known alternatives for its wavelength range. For low thermal expansion it trounces them severely.

Special Products Sales, Eastman Kodak Company, Rochester, N.Y. 14650 (phone 716-325-2000, ext. 5166) handles all IRTRAN *business.*

Beneath the frosting

The new cadmium telluride and the old tame free radical make fine frosting for a substantial, tummy-filling cake we have managed to bake in 1965 by the old-fashioned recipe of giving the public what they expect of us. What they expect of us is unflagging progress in making photography more painless. On TV and in the popular press we can deal only with the fun side. Here is some unfunny news of possible value to you:

EASTMAN TRI-X Reversal Film has been modified to become the 16mm film of choice when bright lights shining at the camera threaten to mess up the photography with their haloes. Furthermore, the Manufacturing Approval Card for the revision, a company-confidential document that would be worthless unless candid, calls the graininess improvement "impressive." No sacrifice has been made in speed. *Details from our Motion Picture & Education Markets Division.*

EASTMAN 4-X Panchromatic Negative Film cashes in on the other side of the coin from certain recent discoveries of ours concerning speed/grain ratio. With little or no sacrifice in graininess from movie films now in general use, it makes possible properly exposed 16mm or 35mm motion-picture photography in environments so dim that most exposure meters don't work reliably. *Details from our Motion Picture & Education Markets Division.*

KODAK EKTACHROME MS Film can now be obtained with super-strong ESTAR Base for rough duty, as in high-speed cameras. This color film for data-gathering can have its effective exposure index adjusted in processing *after* exposure, since engineers cannot always control light levels as precisely as can the cinematographers of the entertainment industry. *Details from our Instrumentation Products Group.*

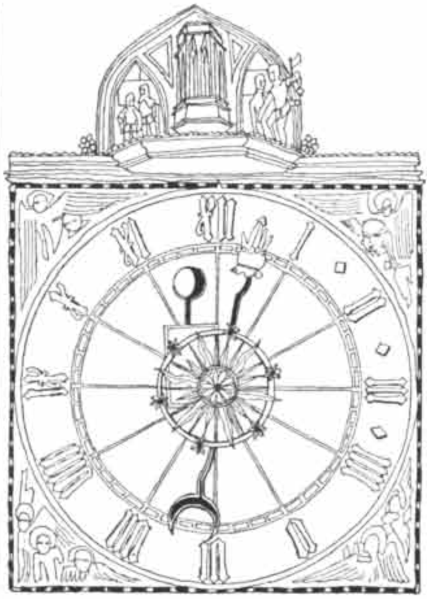
No product name yet but various arrangements are being worked out to supply unusual sensitized goods to groups now engaged in projects for direct recording of electron beams. To the surprise of some engineers, a 100-megacycle carrier turns out to be not beyond photographic recording with a pencil of electrons when no phosphor or lens intervenes. *Inquiries of more than merely casual motivation are welcomed by our Special Applications Group.*

It's all Eastman Kodak Company, Rochester, N.Y. 14650.

*At 850mμ the curtain due to absorption by electrons starts to lift, is all the way up by 2μ, stays all the way up until lattice vibration starts absorbing photons at 28μ, and doesn't fully cut off the show before 30μ. About the only loss over that long span is the 2-surface reflection loss of 35%. If this is too much, the high index permits relief by coating. The high index also suggests use of the material for "immersing" detectors, where it contributes to collecting power.

Prices subject to change without notice.

SCIENCE AND



The Anti-Ballistic-Missile Ban

A citizens' panel has recommended that the U.S. and the U.S.S.R. agree to a moratorium of at least three years on the deployment of antimissile missiles in an effort to avoid escalation of the nuclear-arms race. The moratorium suggestion was one in a long series of proposals made by a disarmament panel to the White House Conference on International Cooperation at the end of November. The chairman of the panel was Jerome B. Wiesner of the Massachusetts Institute of Technology, former science adviser to President Kennedy.

Anti-ballistic-missile (ABM) systems have been in development for some years, both in this country and in the U.S.S.R. The technological problems and the costs are formidable, and successive U.S. administrations have refused to move into production and deployment of the Army's Nike Zeus system in spite of strong pressure from the Army and from some members of Congress. In 1963, according to *The New York Times,* the Senate met in secret session (for the first time since World War II) to consider authorizing an ABM system but voted against it 58 to 16. Research and development have continued, however; at a cost of some $2 billion advanced radars and computers have been developed to cope with the task of distinguishing incoming warheads from decoys, tracking them and guiding the new Nike-X and Sprint nuclear antimissile missiles to intercept them. Last summer the Joint Chiefs of Staff unanimously recommended proceeding with at least a limited ABM system; it would cost about $8 billion and, it is maintained by the Joint Chiefs, offer adequate protection against a missile threat from China if not from the U.S.S.R. A complete ABM defense, it has been estimated, would cost some $20 billion. An integral part of any ABM defense would be a nationwide system of fallout shelters.

The Wiesner report urged a moratorium "on new deployment (but not on the unverifiable research and development) of systems for ballistic-missile defense." Even if a limited system were said to be directed toward the Chinese threat only, according to the panel, any antimissile program would almost surely lead both the U.S. and the U.S.S.R. to increase their strategic-weapons programs in an effort to maintain their "deterrent" power. Maintaining that the time is not "appropriate" for a U.S. decision to deploy an ABM system, the panel first questioned the basic military value of the system, quoting Defense Secretary Robert S. McNamara's statement that "there are many technical problems still to be solved" in addition to problems of how to fit an antimissile system into an overall defense against nuclear attack. A moratorium would provide time, moreover, for consideration of important political aspects of ABM deployment. The panel listed some of them: Could undesired effects on the deterrent forces of the two superpowers be avoided? Should ABM systems be emplaced in Europe? Should they be made available to allies? Would deployment play into the hands of China by disrupting Soviet-U.S. relations and progress in arms control? Does the Chinese threat really require immediate action? The panel concluded that inauguration of ABM production would seriously upset the tenuous détente between the U.S. and the U.S.S.R. and make efforts to freeze or reduce the level of strategic delivery systems impossible.

Apart from the ABM moratorium the panel's most striking recommendations called for talks between the U.S. and China on arms control, a nonaggression treaty between NATO and the Warsaw Pact organization, a zone of U.S. and Soviet arms limitation in the Bering Strait area and a series of efforts to pre-

THE CITIZEN

vent nuclear proliferation. These would include a comprehensive, verifiable test-ban treaty; an end to production of weapons-grade fissionable material by the U.S., the U.S.S.R. and the United Kingdom; a treaty prohibiting the transfer of nuclear weapons by nuclear powers to other countries, supplemented by pledges to defend nonnuclear countries against nuclear attack.

In this connection the panel recommended that Western security arrangements should "not result in the creation of new nuclear forces." One of the reiterated objectives of U.S. policy has been the creation of some kind of "multilateral force" to give NATO allies a greater share in nuclear weapons. West Germany's access to nuclear arms in such a force has been cited by the U.S.S.R. as an obstacle to any nonproliferation treaty. During November it was revealed—first by Congressman Chet Holifield, chairman of the Joint Congressional Committee on Atomic Energy—that for at least six years the U.S. has made nuclear warheads available to its allies in Europe, including West Germany. The Department of Defense acknowledged that some of these weapons are actually mounted in allied aircraft but insisted that they remain under U.S. control through "permissive action links" ranging from U.S. sentries guarding the planes to U.S.-operated electronic controls that arm the warheads.

The General Assembly of the United Nations meanwhile took several actions with regard to arms control. The General Assembly voted 93 to 0 for a resolution instructing its Disarmament Committee, which meets in Geneva, to prepare a treaty to bar the spread of nuclear weapons. The General Assembly also passed, 112 to 0, a resolution calling for "a world disarmament conference not later than 1967," to which all countries would be invited—including China.

Jupiter as a Star

Recent studies of the infrared radiation from Jupiter, the largest body in the solar system apart from the sun, indicate that it radiates about two and a half times more heat than it receives from the sun. The discovery of this self-generated flow of energy inspired Gerard P. Kuiper, director of the University of Arizona's Lunar and Planetary Laboratory, where the observations were made, to remark that "Jupiter in a sense is a small star rather than a very large planet."

To survey Jupiter, Frank J. Low coupled a liquid-helium-cooled germanium bolometer to the university's newly completed 61-inch telescope at Catalina Station near Tucson. The germanium bolometer, which Low invented in 1960 and has refined since then, is sensitive to infrared radiation at wavelengths ranging from one micron up to one millimeter; the Jupiter observations showed the planet's temperature to be 130 degrees Kelvin, or 25 degrees in excess of the temperature to be expected from solar heating alone. This is far from hot (130 degrees K. is 143 degrees below zero centigrade), and there is no evidence that Jupiter's energy output is due to thermonuclear processes that illuminate the bodies that are usually regarded as stars. Nonetheless, if Kuiper's view that the planet is a small star is taken literally, the sun, like most other stars, is a member of a binary system.

The Hologram and the Computer

One of the most serious deficiencies of modern computers is their inability to "read" printed or handwritten instructions made up of characters that have many variants. Now a British investigator, Dennis Gabor of the Imperial College of Science and Technology, has come forward with a new proposal for mechanical character recognition. The new system is based on the technique of holography, or photography by wave-front reconstruction, invented by Gabor 17 years ago and recently advanced by the invention of the laser (see "Photography by Laser," by Emmett N. Leith and Juris Upatnieks; SCIENTIFIC AMERICAN, June, 1965).

In a recent article in *Nature* Gabor describes how the hologram principle can be adapted to serve as the basis for a mechanical translation, or coding, device. Ordinarily a hologram is produced by allowing two sets of light waves that are coherent, or in step, to fall simultaneously on a photographic plate, one set of waves from an illuminated object *A* and the other from a light source *B*. (In the recent systems *B* is usually a laser.) The two light waves are recorded as an interference pattern on the plate. Later the plate can be illuminated by *B* alone and it will produce an image that is an exact three-dimensional representation of *A*. In effect the original wave fronts reflected by *A* in the first stage of the process are reconstructed.

Gabor proposes to alter this sequence of events as follows: Let *A* be a character—for example a printed or handwritten letter or numeral—that can be read by a human being but not by a machine, and let *B* be a combination of point light sources that form a code word that can be read by a machine. A hologram is produced by combining *A* and *B*. Now when *A* or a character sufficiently similar to it is presented to the hologram with the original illumination, the code word *B* will appear.

Because many images can be stored on a single hologram by changing the angles of the impinging light waves, this technique can be used to record a large number of characters and their variants. Gabor concludes that "there is good reason to believe that a single hologram may discriminate between all the numerals and the letters of the alphabet, each with 30 variants."

Celestial Maser?

Radio astronomers at the Massachusetts Institute of Technology and its associated Lincoln Laboratory have reported finding celestial radio emission that is narrower in bandwidth and more strongly polarized than any previously observed. The source of the emission is designated W3, one of a number of "H II" regions that are strong emitters of radio energy. Such regions consist of a cloud of ionized hydrogen that has been excited by a hot star.

Some of the H II regions have recently been found to contain hydrogen combined with oxygen in the form of hydroxyl (OH) radicals, highly reactive molecules that consist of one atom of oxygen and one atom of hydrogen. These radicals reveal their presence by emitting or absorbing radio energy at characteristic frequencies. Absorption of radio energy by hydroxyl radicals was first reported in 1963 by radio astronomers at the Lincoln Laboratory (see "Hydroxyl Radicals in Space," by Brian J. Robinson; SCIENTIFIC AMERICAN, July, 1965).

Late last year Harold F. Weaver, D. R. W. Williams, Nannielou H. Dieter and W. T. Lum of the University of California at Berkeley reported hydroxyl emission at a frequency of 1,665 megacycles per second from W3 and several other H II regions. Because the emission had certain puzzling features they concluded that not all of it could be due to the hydroxyl radical and so postulated the existence of an unidentified emission line they called mysterium. A new study of W3 has now been made at the Lincoln Laboratory by S. Weinreb, M. L. Meeks and J. C. Carter of the laboratory staff and Alan H. Barrett and A. E. E. Rogers of M.I.T. These workers, reporting in *Nature*, have concluded that the mysterium line is simply the 1,665-megacycle emission of hydroxyl radicals, but of hydroxyl radicals in an unusual state of excitation. They found that some of the emission is linearly polarized by as much as 38 percent and that some of the emission features have a line width as narrow as one kilocycle. This is the first polarized spectral line to be detected by radio astronomers, and the line is narrower than any other radio emission line by a factor of two. The narrowness of the line is surprising because the gas in an H II region is assumed to be hot and turbulent, the effect of which should be to broaden emission lines.

Several mechanisms might account for the polarization. For example, radiation will emerge polarized if it is produced in the presence of a magnetic field (the Zeeman effect). The observed polarization, however, would require fields 100 to 1,000 times stronger than those that are thought to be present. The Lincoln Laboratory–M.I.T. workers now suspect that only some form of maser action can account for both the polarization and the extreme narrowness of line width. In a maser a majority of the particles in a medium (which can be a gas) are raised to a particular state of excitation; when they are stimulated to drop to some particular lower state, they emit radiation consisting of a very narrow band of frequencies.

Homo erectus in Europe

Homo erectus, the immediate precursor of modern man, has been represented only by fossils found in China (Peking man, formerly known as *Sinanthropus*), in Java (Java man, formerly known as *Pithecanthropus*) and in Africa. Now for the first time fossils of *H. erectus* have been found in Europe.

The fossils were uncovered in a quarry near Vértesszöllös, some 30 miles west of Budapest, by M. Kretzoi and L. Vértes of the Hungarian National Museum. In 1963 Kretzoi and Vértes had excavated a deeply buried hearth used by Lower Paleolithic hunters; it contained pebble tools similar to those from the caves at Choukoutien in northern China, where the remains of Peking

Unique aerospace fuel cell introduces a new louvered thermal control system

lightweight, modular design provides highly flexible power systems for unmanned satellites

Each of these shuttered aerospace fuel-cell modules weighs just 30 pounds and occupies less than a half cubic foot; yet each can deliver 200 watts at 26 volts dc. These modules are designed to operate between 22.0 and 29.5 volts dc.

Developed by Allis-Chalmers for the Air Force, these 200 watt aerospace modules feature a weight-saving thermal control system, utilizing self-actuated shutters. They regulate module emissivity to meet the requirements of any environment from 20°F to 160°F: operating parameters readily achieved by simply selecting a radiation shield of suitable reflectivity.

The building block concept permits ideal answers to many different space-power requirements. Space and weight are trimmed because no coolant, man were found. In addition to the distinctive stone tools, the hearth site contained the split and burned bones of deer, bear, wild ox, horse and dog but—on first examination—no human remains.

During the 1964 season the two investigators washed out and sieved several hundred pounds of the muddy matrix that contained the hearth floor; the washed material was taken to the National Museum for further study. Kretzoi and Vértes now announce in *Nature* that the washings contained one intact canine tooth and two fragmentary molars that unmistakably belong to *Homo erectus.*

Electronic Typesetting

A method for "setting" type electronically and photographically at the rate of 150 letters a second, or about 1,800 words a minute, has been developed by Max Mathews of the Bell Telephone Laboratories. Unlike other phototypesetting methods, Mathews' method is able to dispense with a master file of type faces, which are usually stored on glass or film. Instead the faces are stored in digital form within the memory of a computer. To change from one type face to another, or to switch to completely different characters used in other languages, one simply changes the set of computer instructions. At present the system produces printed text whose quality approaches that of a typewriter. There is no reason why the quality cannot be improved to match that of type in newspapers and books.

In Mathews' method the typesetting machine is a cathode-ray tube, similar to a television tube, that generates tiny letters segment by segment, or patch by patch, according to a stored program. Each letter is only about a quarter of the size of a letter made by a typewriter and each patch appears only fleetingly as the moving electron beam races along, producing an entire line of type. Before creating the line the computer figures out in advance the spacing between letters and words so that the finished line will exactly fill the column. The electron beam fills in the patches of each character by moving in a tight zigzag pattern. The shape of each patch is determined by eight coordinates that specify its position and contours. Mathews was assisted in devising a computer program by Henry McDonald and Carol Lochbaum.

The images created on the screen of the cathode-ray tube are photographed to provide about 60 lines of type on a single sheet of film. The film then serves as copy for producing an etched plate that can be used for printing in the conventional fashion.

Nature's Morticians

How does it happen that the carcass of an animal that dies in a natural environment is rapidly reduced to bones? According to Jerry A. Payne of the Oak Ridge National Laboratory, it happens partly because a small army of insects and their larvae feeds on the carcass and partly because bacteria and digestive juices are brought to the carcass by the insects. Payne describes in *Ecology* a series of experiments he conducted at Clemson College with the bodies of baby pigs that were born dead or were accidentally crushed by their mothers. "A total of 522 species," he writes, "representing three phyla, nine classes, 31 orders, 151 families and 359 genera were collected and identified from the five stages of pig-carrion decomposition." Of the 522 species, 422 were insects.

Payne exposed the bodies, which were preserved by freezing until the start of an experiment, in a wooded environment under two conditions: one in which insects had free access to the carcass and one in which they were mostly excluded from it. He found in the first condition that sarcophagids (flesh-eating flies) arrived within five minutes and that "each stage of decomposition was characterized by a particular group of organisms." Many of the insects laid eggs, which soon became larvae that contributed to the cleaning activity by feeding on parts of the carcass. "By the eighth day only dry skin, cartilage and bones remained," Payne writes; continued activity by various insects during the next two weeks or so reduced the remains to "hair, bits of skin, bones and teeth."

In contrast, "the decomposition and disintegration of pigs free from insects was very different." Carcasses proceeded through bloating and dehydration stages over a period of several days, arriving at a mummified condition that lasted as long as two months. "Body form was still well defined after three months," when the experiments, which were conducted during two summers, ended. Payne concluded that insects, attracted to carrion by odor, not only feed on it but also "undoubtedly hasten liquefaction and disintegration by dissemination of bacteria, by the digestive juices they secrete and by the mechanical processes of tunneling and burrowing through the carcasses."

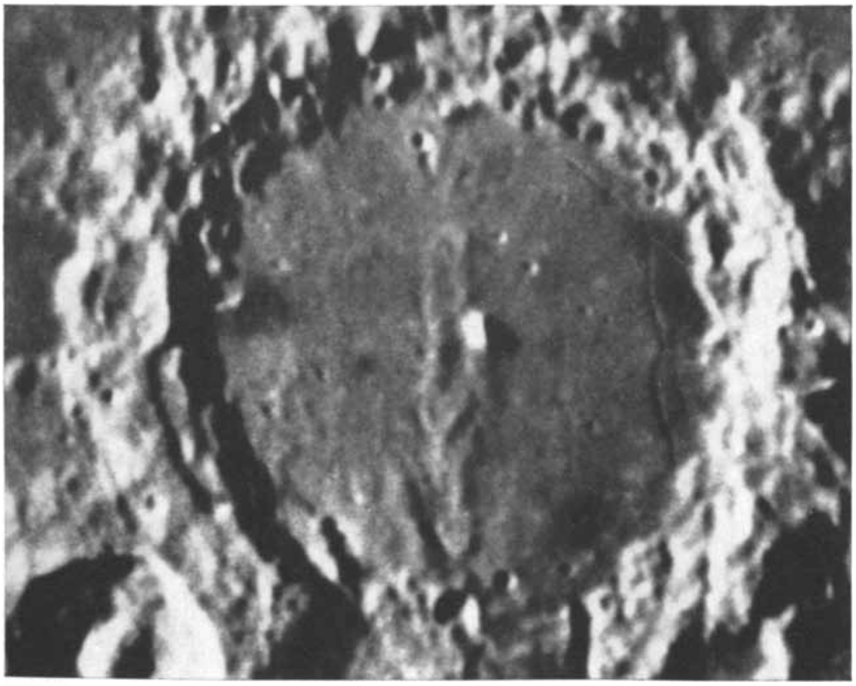
The Ranger Missions to the Moon

Nine months after Ranger IX provided live television close-ups of the moon, the entire program of Ranger launchings is assessed

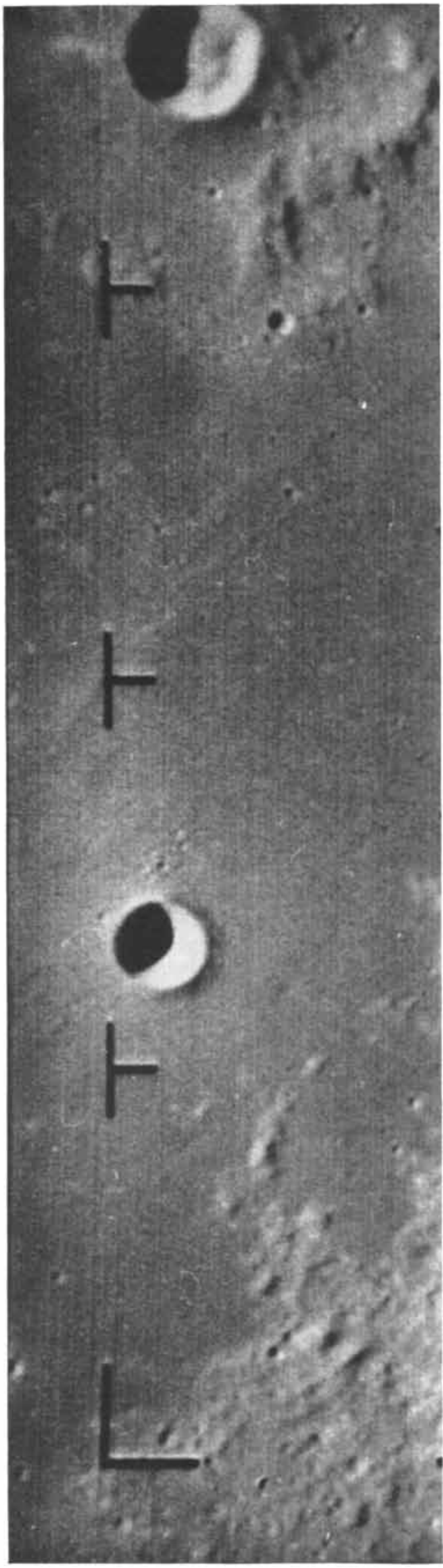
by H. M. Schurmeier, R. L. Heacock and A. E. Wolfe

Shortly before 6:00 A.M. Pacific Standard Time last March 24, people in the U.S. saw their first live television from space when cameras aboard *Ranger IX* began sending back pictures of the moon. For the next 15 minutes the images on the television screen carried the viewer closer and closer to the floor of the crater Alphonsus; finally at 6:08 A.M. the screen went blank, signaling that the spacecraft had completed its mission, adding one more small crater to the millions already on the lunar surface.

Between August, 1961, and March, 1965, a total of nine Ranger spacecraft were launched from Cape Kennedy. Of seven aimed at the moon, five reached the lunar surface, with the last three providing more than 17,000 photographs. The large majority of these pictures are more detailed than any ever made from the earth and will keep students of lunar geography and geology busy for years to come. Although the Ranger program was initially beset with trouble, the final flights demonstrated that the program and the vehicle design



TELESCOPIC VIEW OF ALPHONSUS, the target of *Ranger IX*, was made at the Mount Wilson Observatory. The photograph represents about the clearest view of the moon obtainable from the earth. Compare its detail with that in the *Ranger IX* photograph at the right.



***RANGER IX* VIEW OF ALPHONSUS was made from an altitude of 416 kilometers (258 miles) while the spacecraft was travel-**

ing at about 5,600 miles per hour. About 165 seconds after the picture was taken *Ranger IX* crashed near the prominent crater that interrupts a rill that can be seen radiating toward the upper right of the picture from the large central peak. *Ranger IX* had missed the aiming point by only three miles. Other views of Alphonsus taken by *Ranger IX* as it continued its plunge appear on pages 66 and 67.

		LAUNCH DATE	WEIGHT (POUNDS)	FLIGHT DATA	RESULTS
BLOCK I	I	August 23, 1961	675	Earth orbit	Failed to reach deep space orbit. Reentered atmosphere August 30, 1961.
	II	November 18, 1961	675	Earth orbit	Failed to reach deep space orbit. Reentered atmosphere November18, 1961.
BLOCK II	III	January 26, 1962	727	Solar orbit	Missed moon by 22,862 miles.
	IV	April 23, 1962	730	Reached moon in 64 hours	Landed on back side of moon, 140.5°W, 15.5°S. Experiments unsuccessful owing to timer failure.
	V	October 18, 1962	755	Solar orbit	Missed moon by 450 miles.
BLOCK III	VI	January 30, 1964	804	Reached moon in 65.6 hours	Landed in Sea of Tranquillity. Television cameras failed to function.
	VII	July 28, 1964	806	Reached moon in 68.6 hours	Landed at site renamed Mare Cognitum. Returned 4,308 photographs.
	VIII	February 17, 1965	809	Reached moon in 64.9 hours	Landed in Sea of Tranquillity, 2.59°N, 24.77°E. Returned 7,137 photographs.
	IX	March 21, 1965	809	Reached moon in 64.5 hours	Landed in crater Alphonsus, 12.91°S, 2.38°W. Returned 5,814 photographs.

OUTCOME OF NINE RANGER FLIGHTS appears in this condensed log. The Block I flights were intended to test new concepts of launching, navigation and attitude control. The Block II missions sought to hard-land an instrument package on the moon. The Block III flights were designed to photograph likely landing places for future spacecraft.

were soundly conceived. The purpose of the final series of flights was to provide information for planning the unmanned and manned lunar missions that lie ahead; this objective was accomplished.

The Ranger project originated in design studies conducted in 1959 at the Jet Propulsion Laboratory, which was operated by the California Institute of Technology on behalf of the Army Ballistic Missile Agency. In 1960 the newly created National Aeronautics and Space Administration authorized the Jet Propulsion Laboratory to proceed with the project. It was clear from the outset that four major new technologies would have to be developed before lunar and planetary missions could be accomplished.

First and perhaps foremost was the development of accurate navigation and guidance systems that would enable a spacecraft to be directed to a specific target on or near the moon or the planets. Second, it was necessary to develop a spacecraft that would maintain a stable attitude during flight and that would assume new orientations on command from the earth. Attitude stabilization was important for several reasons. It would enable the solar cells that generated power for the spacecraft's equipment to operate at maximum efficiency, it would allow the use of a high-gain directional antenna for maximum efficiency in communication and make it possible to aim instruments and cameras in specific directions. In addition, the ability to orient the spacecraft on command was indispensable for mid-course guidance and for terminal maneuvers near the moon or the planets.

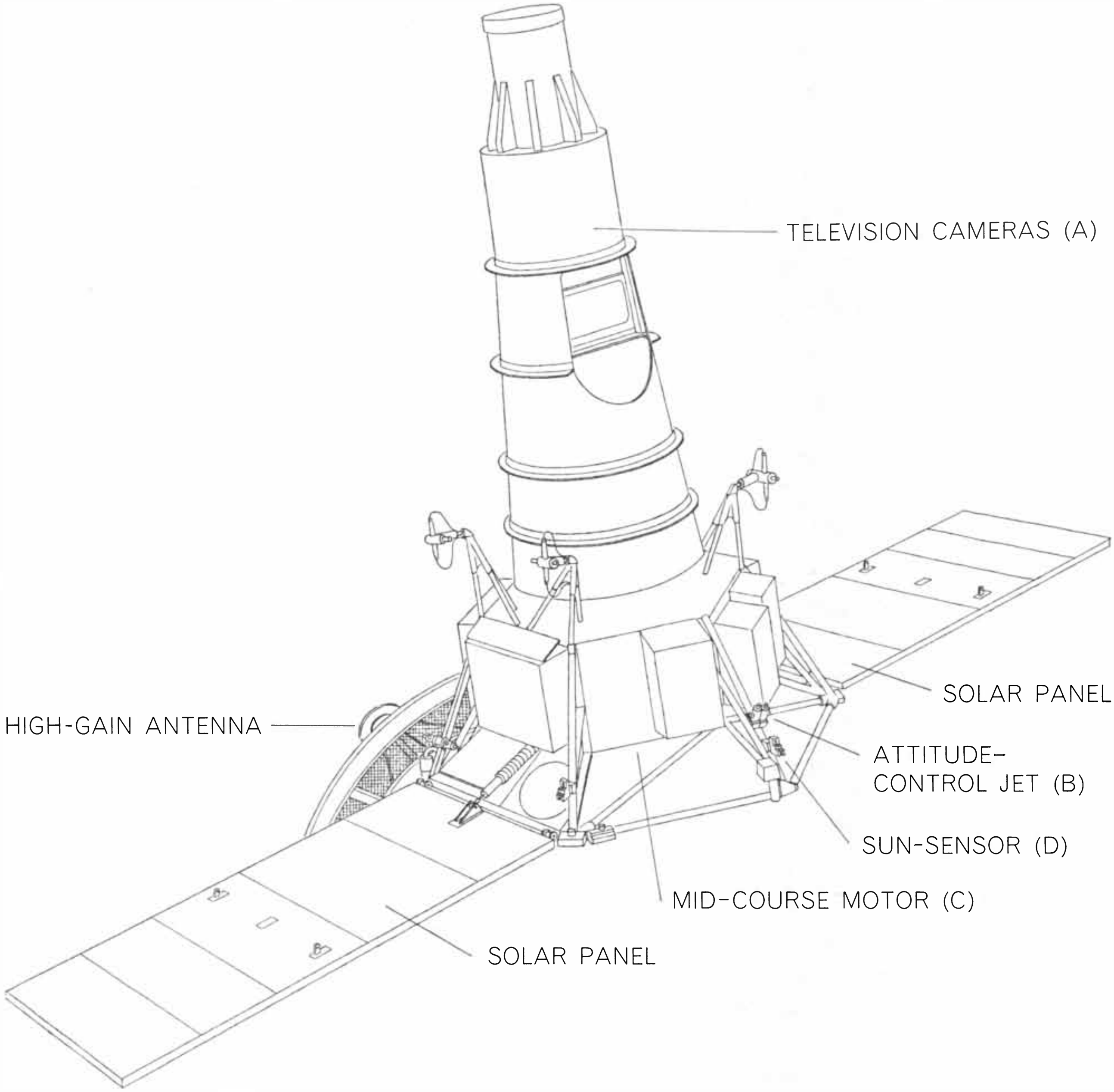
The third of the new technologies that had to be developed was a special launching method that would compensate for the fact that the launching site, being geographically fixed, was not optimal. The launching technique also had to provide a practical launching interval so that the takeoff would not require split-second timing. The required flexibility had to be achieved, moreover, without incurring a serious weight penalty.

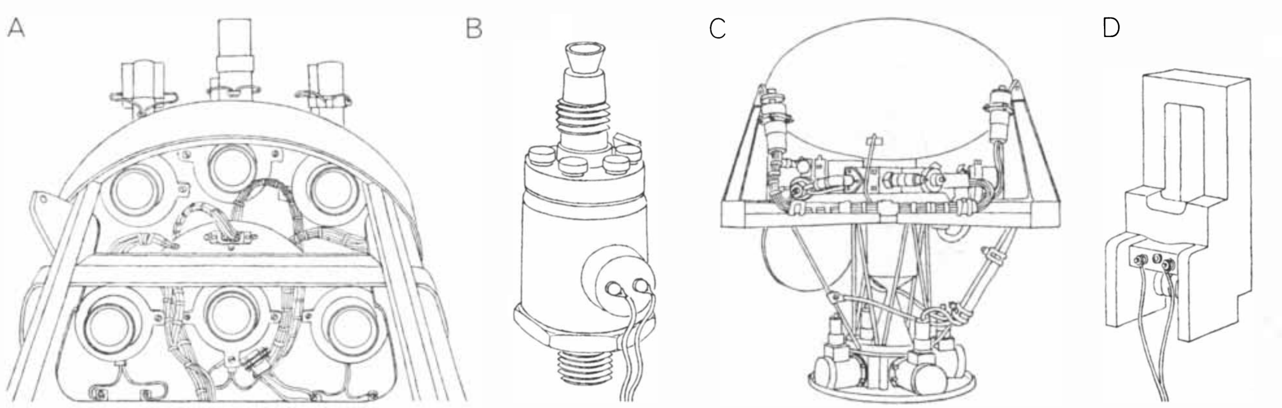
Finally, there was the novel problem of finding ways to sterilize complex technical apparatus destined to be landed on the moon or the planets. Later the demanding sterilization requirements were dropped when it was concluded that terrestrial organisms would not propagate on the moon and therefore would be confined to the area of impact on the lunar surface. The sterilization program has been continued, however, in anticipation of landings on planets where extraterrestrial life might conceivably be found. Except for sterilization, all the new technologies were developed and demonstrated.

The initial Ranger program consisted of five flights divided into two blocks. Block I consisted of two flights in the second half of 1961 to demonstrate two of the new technologies: the "parking orbit" technique that compensated for the nonoptimal location of the launching site, and the performance of an attitude-stabilized spacecraft. The launch vehicle for all the Ranger flights was a modified Atlas rocket combined with a second-stage Agena rocket. Because the Agena failed to perform properly on both Block I flights, the spacecraft were not launched successfully from their parking orbits and only a few simple checks of their performance could be made.

The three Block II missions had the primary goal of placing a small instrumented capsule on the surface of the moon. These missions required the full technological capability planned for the Ranger (including sterilization) plus a retro-rocket system to reduce the terminal velocity of the capsule. There was no intention, however, of achieving a soft landing; the capsule was designed to survive a substantial impact. Because of various failures in the launch-vehicle guidance system and in the spacecraft itself, a lunar landing was not accomplished. Nevertheless, the three flights demonstrated that a spacecraft could be launched from a parking orbit, that the attitude of the craft could be stabilized and that the communication system functioned successfully. Unfortunately the three things were not all achieved on the same flight.

In 1961, after President Kennedy had declared that landing a man on the moon was an urgent national goal, four more Ranger missions, known collectively as Block III, were added to the Ranger program. The objective of the Block III flights was to obtain high-resolution photographs of selected areas of the lunar surface. Lessons learned in the Block I and II flights were applied in the new effort to increase the probability of success. These lessons involved not only changes in the spacecraft and launch vehicle but also a variety of





LAST FOUR RANGERS, the Block III versions, were equipped with six television cameras. The entire spacecraft, which weighed about 800 pounds, was 12 feet high and 15 feet across with the solar panels extended. The solar panels had a total area of 25 square feet, contained 9,792 solar cells and generated 150 watts of power. Detailed diagrams show the arrangement of the six television cameras (*A*), the nitrogen jets that control the attitude of the spacecraft during flight (*B*), the mid-course-correction motor (*C*) and the sun-sensor (*D*). The mid-course motor weighs only 46 pounds and can provide a thrust of 50 pounds. Note that the television cameras are aimed more or less toward the rear of the spacecraft, along a line that forms an angle of 38 degrees with the craft's central axis.

changes in ground-support facilities and methods.

In January, 1964, after a year's delay, the first Block III flight, *Ranger VI*, was launched. Everything appeared to be working perfectly until a few minutes before impact, when the expected television signals failed to arrive. It was discovered later that the television subsystem had been critically damaged when it had accidentally got turned on before the spacecraft had attained its parking orbit. Because the craft at the time was in a region where high voltages could ionize the rarefied gases in the surrounding atmosphere, electric arcing occurred in the television subsystem, burning out the high-voltage circuits that supplied power for the television transmitters. Design changes were made in succeeding Rangers to ensure that the accident would not happen again.

Six months later, on July 31, 1964, the Ranger team was rewarded for its long and patient effort when *Ranger VII* transmitted back to earth 4,308 excellent photographs, giving the world its first close look at the moon's surface. The equally successful *Ranger VIII* and *Ranger IX* followed in February and March of 1965, bringing the program to a close.

Spacecraft Design

Let us examine more closely some of the ingredients that went into the final success of the Ranger program. We shall describe the spacecraft itself, the television subsystem, the testing and calibration procedures and the flight program.

Readers with a long memory may recall that the early instrumented space probes, such as the Explorer and Pioneer satellites, had no attitude control beyond spin stabilization. A spin-stabilized satellite tends to remain pointing in a fixed direction in space as it travels around the earth or out into the solar system. The complete attitude stabilization built into the Rangers—and into the similarly designed Mariners that flew to Venus and Mars—represented a major step in space technology.

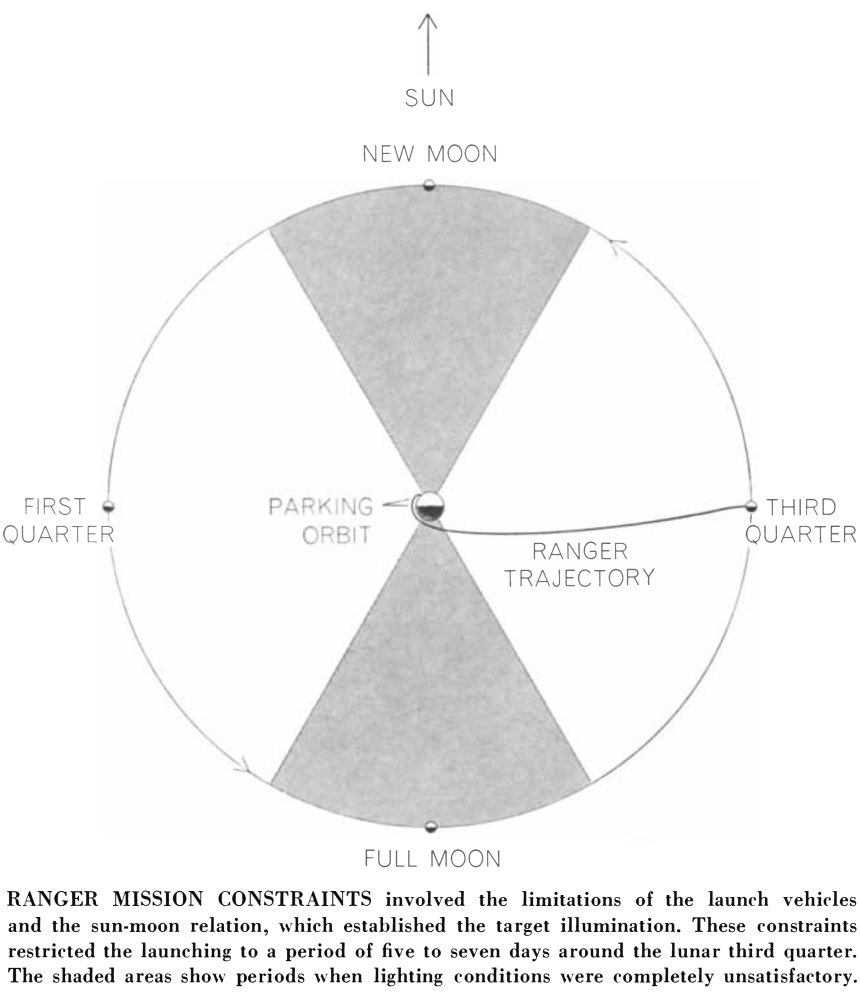
The attitude of these craft was controlled by jets of nitrogen. The jets were fired in bursts in response to changes in pointing angle detected by instruments of two basic types: sensors fixed on the sun and the earth that detected errors in position, and gyroscopes that detected angular motion about the axes of the spacecraft. In the Ranger flights the central axis of the spacecraft was pointed at the sun and held there by the sun-sensor. The purpose of this orientation was to keep the 9,792 solar cells, mounted on 25 square feet of panel surface, facing the sun. The solar cells supplied a minimum of 150 watts of power and were supplemented by silver-zinc batteries.

The earth-sensor had the job of keeping the high-gain antenna pointed at the earth; this it did by controlling the spacecraft attitude around the roll axis and the position of the antenna hinge. The earth-sensor contained three photomultiplier tubes whose sensitivity was adjusted to minimize the probability of its locking on any object dimmer than the earth.

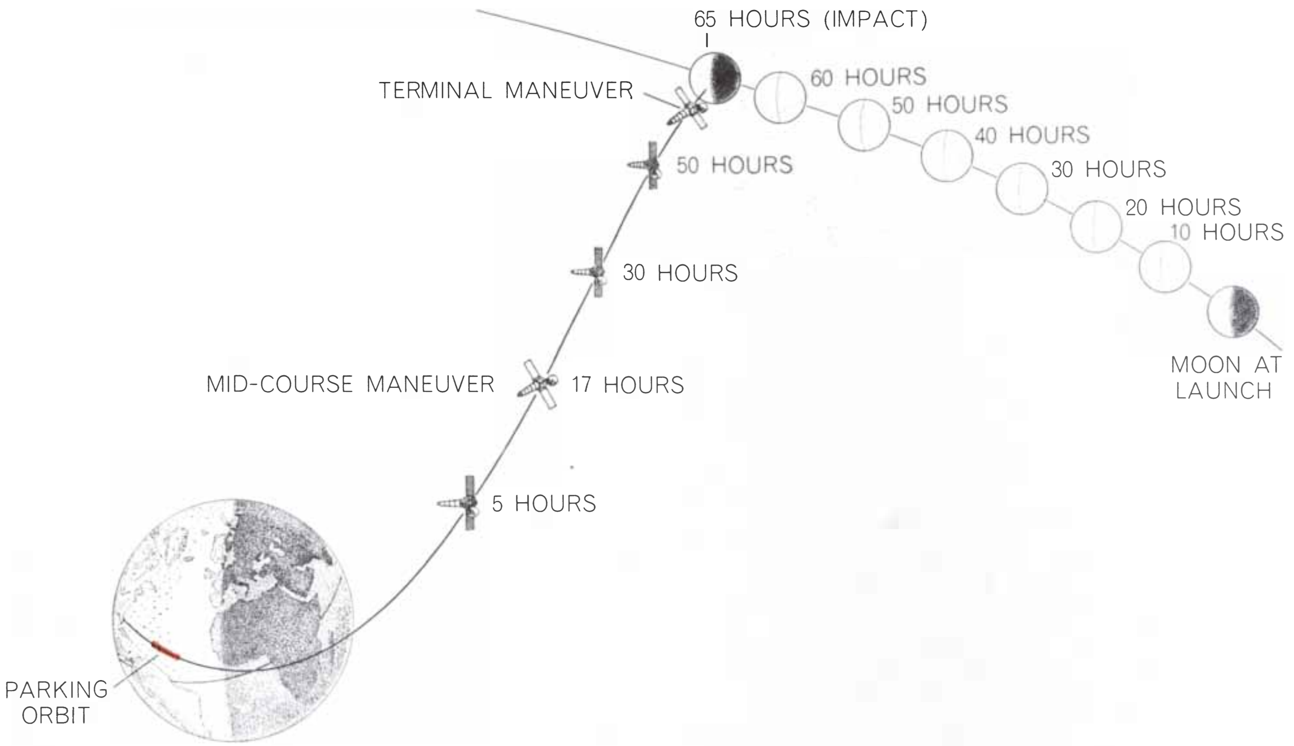
In addition to attitude-stabilization jets the Rangers carried a small rocket motor that would allow a mid-course correction in the flight trajectory. The success of such a correction obviously depended on the spacecraft's being aimed in a carefully selected direction before the rocket motor was fired. The rocket motor weighed only 46 pounds and provided a thrust of 50 pounds, using a liquid monopropellant. With this motor it was possible to correct for errors in initial aiming that otherwise could have caused the Ranger to miss the moon by thousands of miles.

The radio link from the Ranger to the earth was provided by a three-watt transmitter. In the early stages of the flight and during mid-course maneuvers the transmitter output was sent out through a low-gain omnidirectional antenna. Once the earth-sensor had locked on the earth, however, the transmitter output was transferred to the high-gain antenna. The transmitter had an important function beyond the simple transmission of data: it worked in conjunction with the spacecraft receiver to provide extremely accurate information about the Ranger's velocity away from the earth. The velocity could be computed by measuring the extent to which signals were shifted in frequency, as a result of the Doppler effect, after making a round trip from the earth to the spacecraft and back.

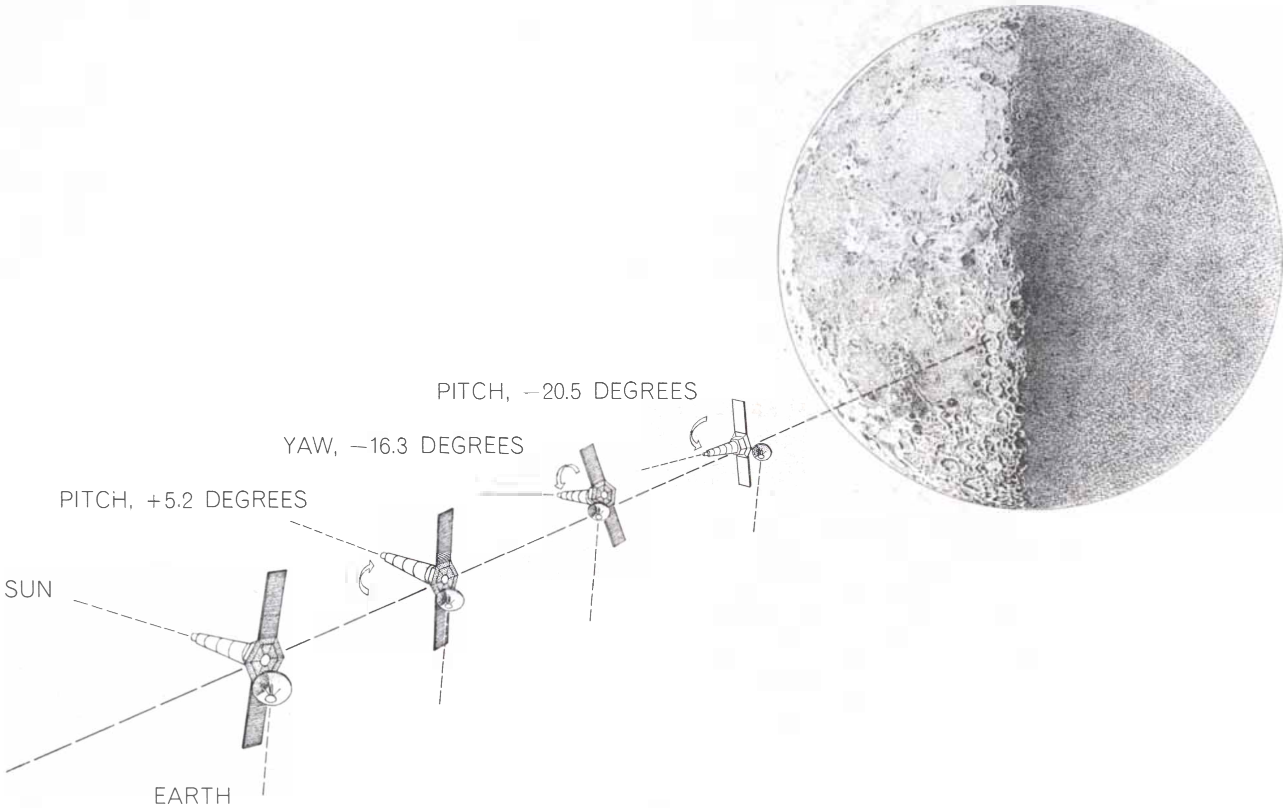
Two general types of command were relayed from the earth to the spacecraft. The first were "proportional" commands to specify the angles through which the craft was to be turned during mid-course and terminal maneuvers and to indicate the velocity to be im-



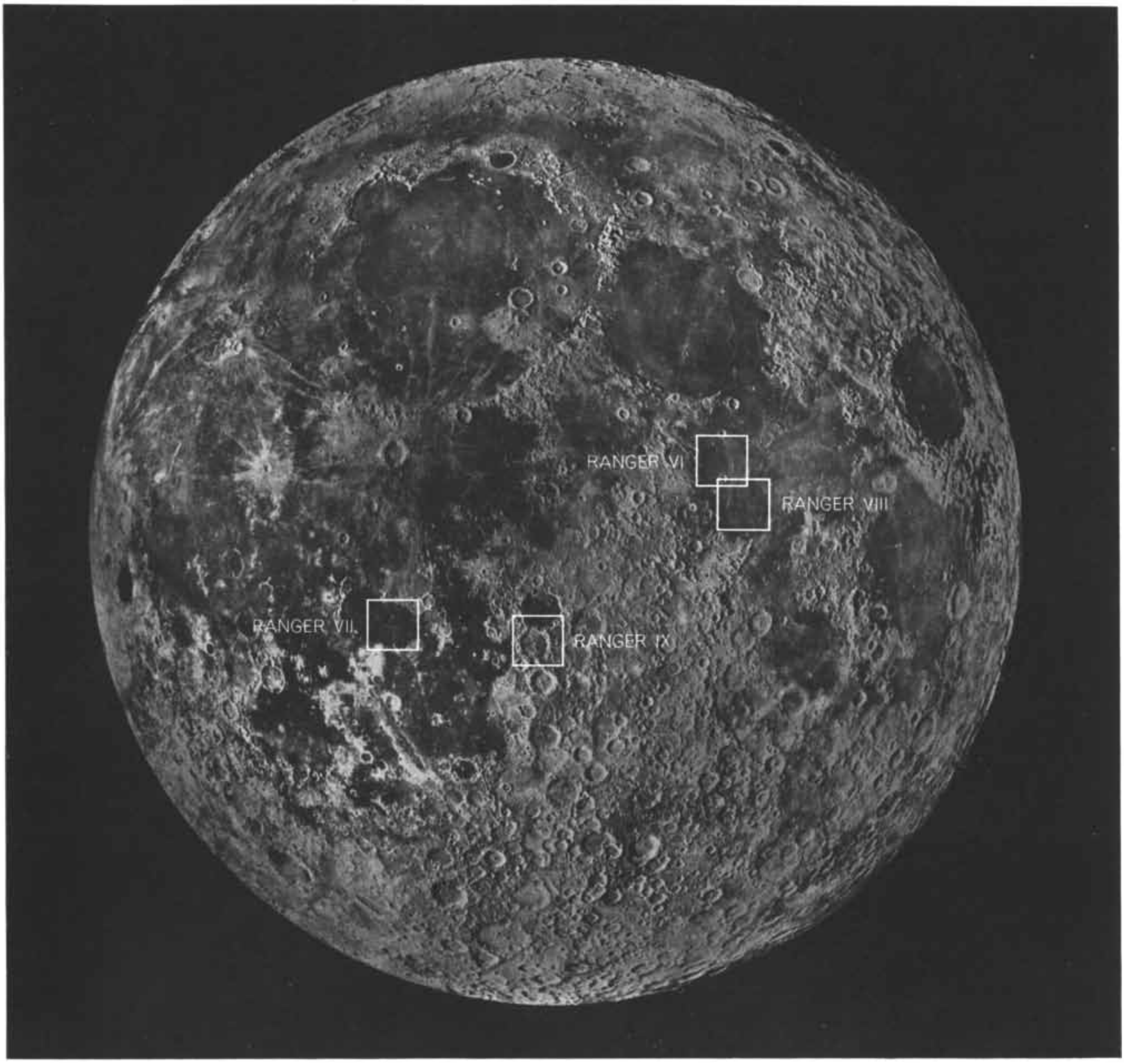
RANGER MISSION CONSTRAINTS involved the limitations of the launch vehicles and the sun-moon relation, which established the target illumination. These constraints restricted the launching to a period of five to seven days around the lunar third quarter. The shaded areas show periods when lighting conditions were completely unsatisfactory.



RANGER FLIGHT PATH covered slightly more than 240,000 miles in about 65 hours. With the help of an Atlas first stage the Agena second stage carried its Ranger payload into a "parking orbit." When the Agena and Ranger, still coupled, had coasted to a point approximately opposite to where the moon would be at the time of encounter, the Agena engine was reignited to give the Ranger its final push into space. Approximately 17 hours later the Ranger's flight trajectory was refined by means of a mid-course maneuver.



RANGER TERMINAL MANEUVER was available to aim the cameras in a direction that would provide the best coverage. The diagram shows the three turns used to align the cameras of *Ranger IX*. The maneuver was not used in other Ranger Block III missions.



RANGER MARKSMANSHIP is depicted in this composite photograph of the moon and in the targets (*right*) that compare the impact points with the aiming points. *Ranger VII* and *Ranger IX* landed within 10 miles of the bull's-eye; two other Rangers land-

parted by the mid-course motor. Such commands were stored until they were needed. The second type of command involved the initiation of an action such as the start of a mid-course-maneuver sequence or the turning on of the television cameras.

Commands were authorized by the Space Flight Operations Director only after extensive and continuous analysis of telemetry data and trajectory computations. Telemetry and trajectory information was gathered by three stations, part of the Deep Space Network, located at Goldstone in California, Woomera in Australia and Johannesburg in South Africa.

If everything aboard the Ranger functioned as designed and if all commands were correct, the spacecraft would reach a point some 1,200 miles from the lunar surface, speeding toward its designated target at 5,600 miles per hour. Here the television subsystem, produced by the Radio Corporation of America, would have to be switched on and, in the few remaining minutes before impact, gather the several thousand photographs that would justify the entire mission.

The Television System

A serious problem that had to be solved early in the development program was how to prevent the high terminal velocity of the spacecraft from blurring the photographic images. One obvious step was to aim the cameras in the general direction the spacecraft would be traveling; this precluded taking oblique views of the lunar surface. The second method of minimizing blur was to place a high-speed shutter behind the lens of each television camera [*see bottom illustration on page 63*]. Shutter speeds of 1/200th and 1/500th of a second were finally selected. In an ordinary television camera the optical image is focused on the face of the Vidicon, or image tube, continuously, and an electronic beam scans the image from inside the tube at a fixed scanning rate.

The use of a shutter required the de-

RANGER VI

RANGER VII

RANGER VIII

RANGER IX

ed within 20 miles. A fifth Ranger, *Ranger IV*, landed on the far side of the moon.

velopment of a special Vidicon that had a fast response and high sensitivity and that could retain an image while it was being read out for transmission to earth. There would have been no point, of course, in tape-recording the images—the Ranger would be destroyed before the tape could be played back. Once an image had been read out, the Vidicon's photosensitive surface had to be electrically erased before the shutter was opened for the next exposure.

The photographic quality attainable with Vidicon camera systems is limited by a number of factors, the principal one being the number of scanning lines per frame. U.S. commercial television employs 525 scanning lines per frame, but as viewed on home receivers under typical conditions the effective resolution is between 200 and 250 lines per frame. The Rangers carried two basic camera systems built around six cameras of two different focal lengths: three cameras of 25 millimeters and three of 76 mm. (The focal length of a typical 35-mm. camera is 50 mm.) Two of the six cameras read out pictures .44 inch square with 1,152 lines per frame; the pictures had an effective resolution, when received on the earth, of 800 lines. The other four cameras did not scan the entire image on the Vidicon tube but read out pictures .11 inch square with 300 lines per frame and an effective resolution of 200 lines. The purpose of using partial-scan cameras was to achieve more pictures per second: five frames per second instead of one frame every 2.6 seconds for the full-scan cameras. In 2.6 seconds the Ranger, in its final moments, would travel four miles. This meant that the last complete pictures to be taken before impact would come from the faster-operating cameras; these final pictures would contain the most detailed information about the lunar surface. The two full-scan cameras were designated F_A and F_B; the four partial-scan cameras were designated P_1, P_2, P_3 and P_4.

The television system, including its associated ground equipment, was carefully calibrated to allow full extraction of the information that would be contained in the lunar photographs. For this purpose engineers at the Jet Propulsion Laboratory carefully examined the total "transfer function" of the system, which specifies how much the image is degraded by all the steps from the time it first appears on the face of the Vidicon tube until it is received back on the earth. The transfer function includes such things as losses due to geometrical distortions and noise at each link in the communication chain. The calibration data were subsequently used in a digital computer for automatic correction and processing of the photographs. Computer methods have been developed to compensate for nonuniformity in light-transfer characteristics, for nonrandom noise, for geometrical distortion, for contrast-v.-resolution losses and to generate contour maps.

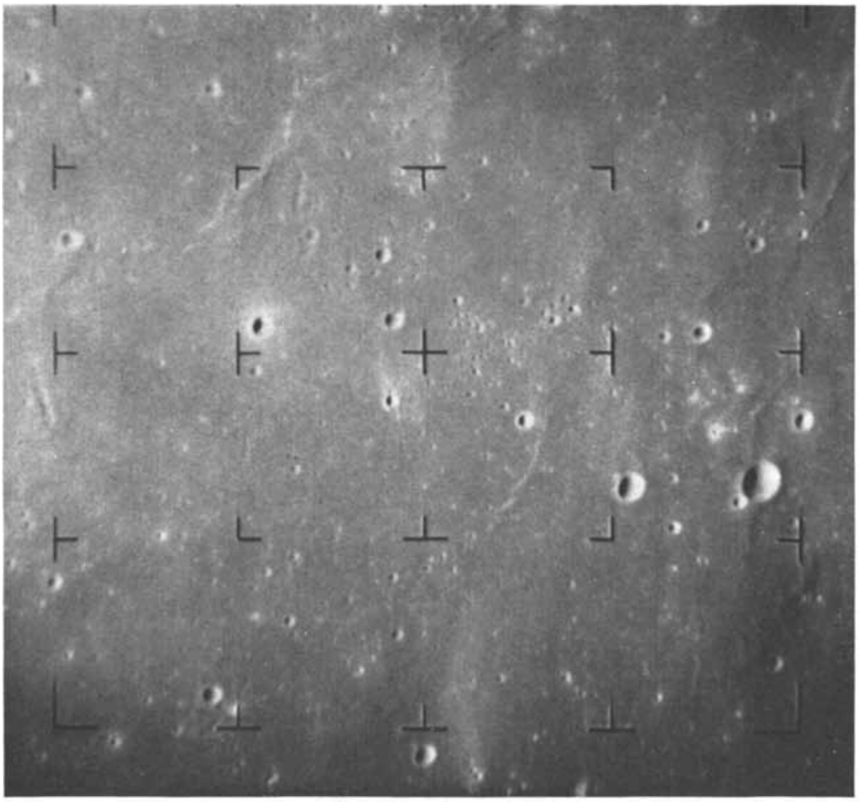
The calibrations of the television subsystems were only part of the total calibration and testing effort devoted to each of the subsystems and finally to the fully assembled spacecraft. The subsystems had to be exhaustively tested under a variety of conditions that reproduced or exceeded in intensity those to be encountered throughout the flight: the tremendous vibration of takeoff, the vacuum of outer space and sudden changes in temperature. A complete test spacecraft was subjected to similar qualification testing before any of the flight spacecraft were assembled.

The flight Rangers were subjected to a similar test program, with the exception that the test levels were equal to rather than in excess of those expected in actual flight. In addition engineers subjected the spacecraft repeatedly to all the flight sequences and maneuvers it would be asked to perform, exhaustively checking the various backup and redundancy features that had been incorporated in its design. All told each flight Ranger was subjected to between 500 and 800 hours of testing prior to launching. Ultimately, of course, there are certain crucial conditions that cannot be simulated in the laboratory, such as zero gravity and the full spectrum and intensity of solar radiation. Nevertheless, the successes of the Block III Rangers, of *Mariner II*, which traveled to Venus, and of *Mariner IV*, which photographed Mars, demonstrate what can be achieved by experienced and dedicated engineers before the countdown for a mission begins.

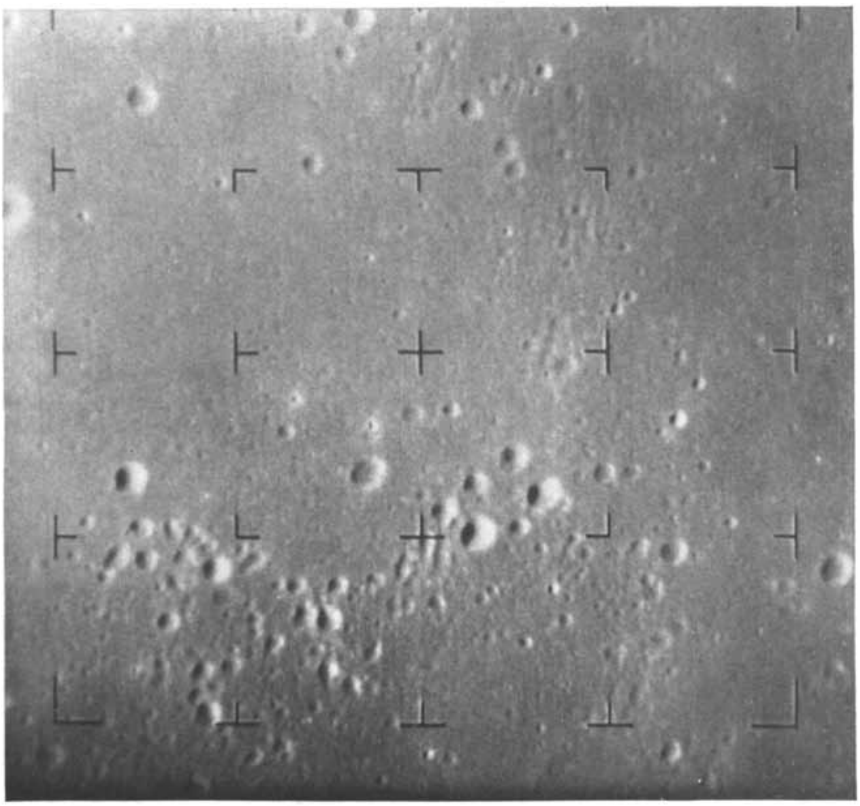
The Flights

The ideal launching time for a Ranger photographic mission to the moon fell during a period of five to seven days near the lunar third quarter [*see illustration on page 56*]. This period was dictated by two constraints. The first involved limitations in the complexity of trajectory that could be executed by the Atlas-Agena launch vehicle, even from a parking orbit, together with limitations in the amount of mid-course maneuvering that could be performed by the Ranger itself. The second constraint was even more compelling. If one wanted to photograph a certain area of the moon under conditions that would present the desired mixture of light and shadow, one had to wait until the sun and moon were in the proper position.

One might think that it would make no difference whether the sun cast shadows to the left or to the right on the lunar surface, and that the first quarter would therefore be just as suitable for photographic purposes as the third quarter. Actually the angle at which the camera views the surface enters into the equation, and one finds that the amount of light reflected from the lunar surface falls off rapidly as the angle



MARE COGNITUM, "the sea that has become known," was photographed at an altitude of 92 miles by the F_A camera (one of two full-frame cameras) aboard *Ranger VII*. The area shown is more than 40 miles wide. The cluster of small craters just to the right of the center reticle were made by material ejected from the large craters Tycho and Copernicus.



CLOSER VIEW OF MARE COGNITUM, taken about 26 miles above the surface by the F_A camera of *Ranger VII*, shows an enlarged view of the cluster of craters to the right of center in the picture at the top of the page. The area shown in this picture is about 12 miles wide.

between the camera-viewing direction and the illumination direction is increased. Because of constraints on the angle of the Ranger's approach, the third quarter is found to yield three times more light for photography than the first quarter.

Let us now follow one of the Rangers on its trip to the moon. The launching is scheduled to take place during an interval that varies in length from one to two and a half hours—a period that specifies how long the "launch window" remains open on a particular day, taking into account all the mission constraints. It is the parking-orbit technique that provides a window whose duration is measured in hours rather than in minutes. Depending on the exact time of lift-off, the length of the parking orbit can vary from several hundred miles to several thousand miles. The Agena second stage and its Ranger payload coast around the earth in the parking orbit to a point nearly opposite to where the moon will be at encounter [*see top illustration on page* 57]. At that point the Agena rocket is reignited to accelerate the Ranger to "escape" velocity, the velocity needed to free the two objects from the earth's gravity.

When the Agena rocket is shut off for the second time, the Agena and Ranger should be on a reasonably accurate trajectory toward the desired lunar target. The Agena and the spacecraft are then separated, whereupon the Agena executes a 180-degree turn and fires a small rocket that acts as a retro-rocket to ensure that the Agena will not hit the moon or interfere with the Ranger.

One hour after lift-off the spacecraft begins a series of operations that unfolds the solar-cell panels and orients the central axis of the spacecraft toward the sun. About two and a half hours later the earth-sensor is turned on to begin the earth-acquisition sequence. The antenna carrying the earth-sensor is preset to the proper hinge angle so that it will trace out a cone intersecting the earth as the gas jets roll the spacecraft slowly about its sun-oriented central axis. When the earth appears in the sensor's field of view, other gas jets stop the roll and the sensor system locks on the earth. The time has now come for the tracking station in South Africa to send out a signal transferring the spacecraft transmitter output from the omnidirectional antenna to the high-gain antenna. This places the Ranger in the "cruise mode," in which it is locked on the sun and the earth and functioning on solar power.

The three tracking stations of the

Deep Space Net now measure the angles at which their large antennas must be pointed to receive the telemetry signals at maximum strength. These angles are combined with measurements of the Doppler shift in the returned signal (which establishes the spacecraft's radial velocity) to determine the craft's trajectory. After the Ranger has been in flight for about 10 hours, the trajectory determinations should allow the impact point to be computed with an accuracy of plus or minus 30 kilometers.

When the Ranger has been en route for about 17 hours and has traveled nearly halfway to the moon, the tracking stations have refined the trajectory data sufficiently to permit execution of the mid-course correction maneuver. A computer determines the required change in velocity and the direction in which the craft is to be pointed when the mid-course rocket engine is fired. Appropriate commands are then issued to the spacecraft.

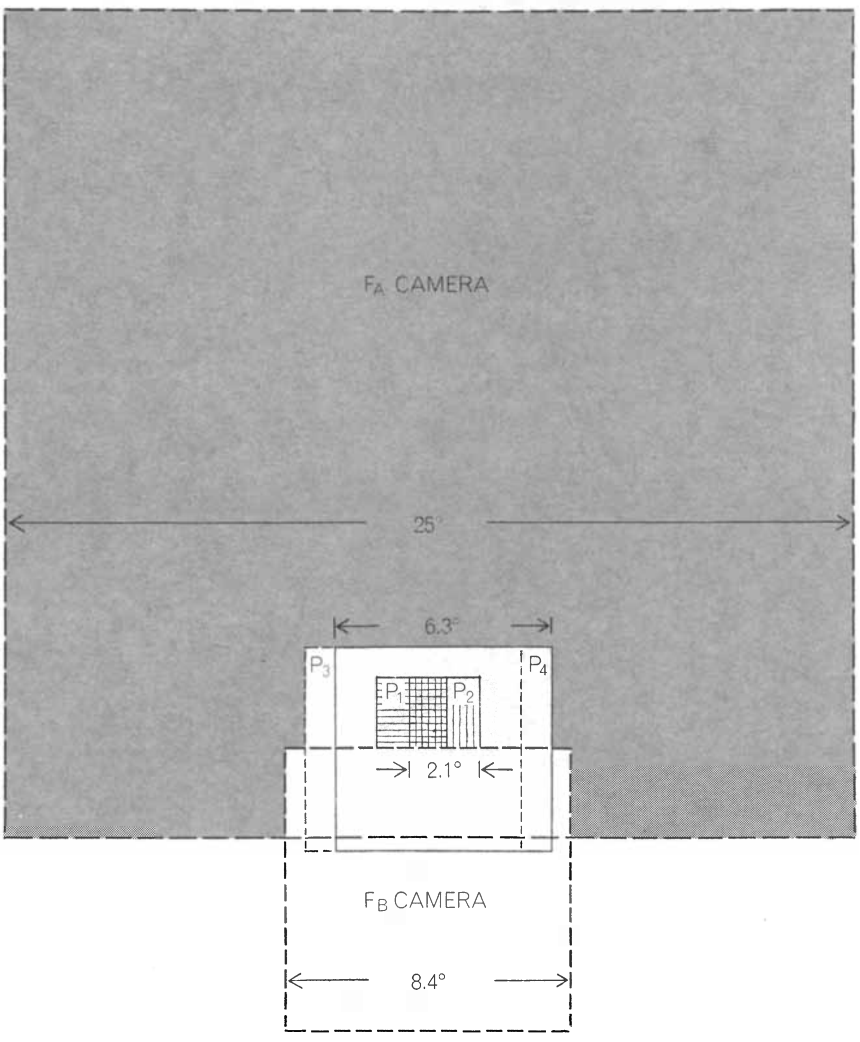
The desired orientation is accomplished by gas jets that rotate the Ranger at a constant rate around two of its axes in sequence; first it is turned around its roll axis and then around its pitch axis. The duration of the two turns determines the final pointing direction. The duration of firing of the mid-course rocket engine is transmitted as a command that represents the desired output, in pulses, of an accelerometer aboard the spacecraft. The frequency of the pulses is proportional to the acceleration imparted by the mid-course engine. The engine is turned on; when the required number of pulses has been counted, the required velocity has been obtained and the engine is shut off.

On the last four Ranger flights the mid-course engine was fired for periods that ranged from 31 to 67 seconds, producing velocity increments that varied from 55 to 125 feet per second. *Ranger IX* was placed on such an accurate trajectory by the launch vehicles that the mid-course maneuver could be delayed until the 39th hour of the flight, when the spacecraft was 176,864 miles from the earth and only 77,048 miles from the moon. This delay made possible an improvement in the tracking data and resulted in an impact only five kilometers (three miles) from the aiming point. The next most accurate mission, *Ranger VII*, had missed the bull's-eye by 15 kilometers [*see illustration on pages 58 and 59*].

After the mid-course maneuver the spacecraft is returned to the cruise mode and tracking data is accumulated to determine the new trajectory. The geometry of approach is then studied to see how the terminal orientation maneuver should be carried out to obtain the most useful set of photographs. The maneuver sequence is initiated about an hour before impact and consists of three sequential turns to align the central axis of the camera cluster along the desired direction [*see bottom illustration on page 57*]. Depending on the alignment selected, one can obtain pictures that overlap in various ways and depict larger or smaller areas of the lunar surface. Thus if the cameras are pointed along the line of flight, less area will be photographed than if they are pointed slightly off to one side. As it turned out, a terminal maneuver was performed only with *Ranger IX*.

The preflight plans called for the television cameras to be switched on about 15 minutes before impact. The Ranger trajectories were selected and timed so that the television signals could be collected with the 85-foot receiving antennas at Goldstone. After reception the signals were amplified and recorded in two ways: directly on magnetic tape and by making 35-mm. photographs of the pictures as they appeared on a television-like screen. The Goldstone station was equipped with two completely separate systems to provide 100 percent redundancy in the reception and recording of the Ranger photographs. The photographic data from the three successful missions required about 350 feet of photographic film and 70,000 feet of magnetic tape. The *Ranger VII, VIII* and *IX* flights respectively produced 4,308, 7,137 and 5,814 photographs.

In selecting the areas to be photographed by the Rangers, the Jet Propulsion Laboratory had the advice of four experts in lunar topography and

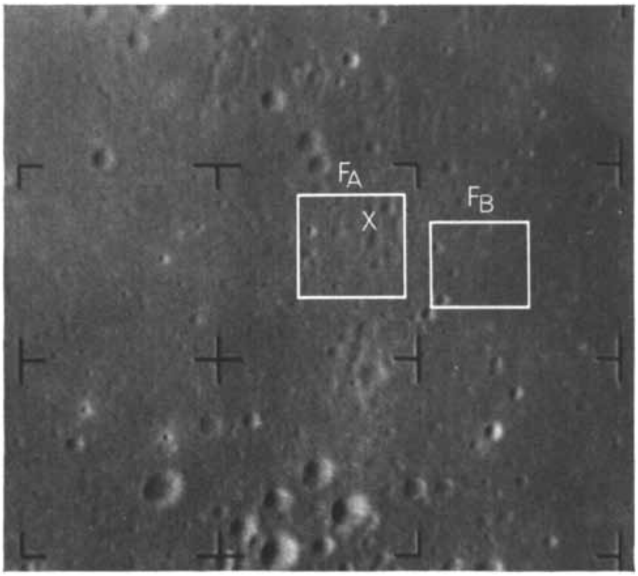


CAMERA FIELDS OF VIEW provided photographs that overlapped as shown. The F_A, P_3 and P_4 cameras had lenses with a focal length of 25 millimeters; the F_B, P_1 and P_2 cameras had lenses with a focal length of 76 mm. The two focal lengths provided fields comparable to those obtainable with a 35-mm. camera equipped with lenses of 90-mm. and 280-mm. focal length. The standard lens used in such a camera has a focal length of 50 mm.

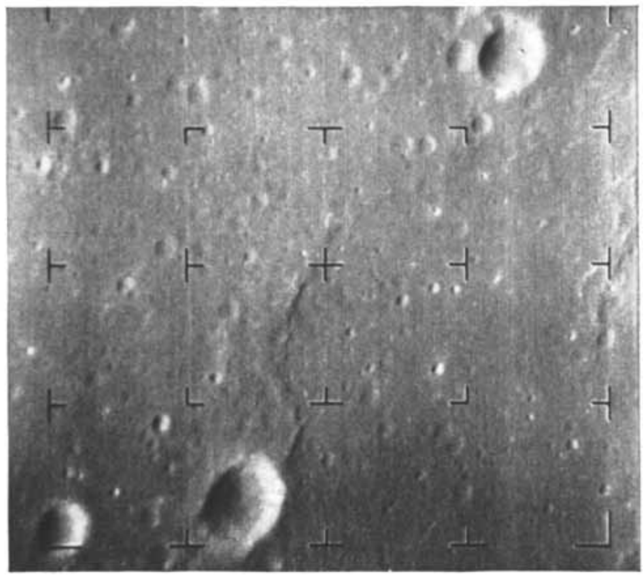
geology: Gerard P. Kuiper and Ewen A. Whitaker of the University of Arizona, Eugene M. Shoemaker of the U.S. Geological Survey and Harold C. Urey of the University of California at San Diego. These four, plus one of the authors (Heacock), constituted the "experimenter team" that selected the impact areas for each favorable launching day, taking into account mission constraints and lunar illumination.

In accordance with the primary objective of the Ranger program, the first targets were chosen in order to learn more about lunar areas that seemed most promising for landing both unmanned and manned vehicles. As might be expected, the experimenter team was anxious to obtain a close look at the maria ("seas"), which present such a smooth appearance when viewed through terrestrial telescopes.

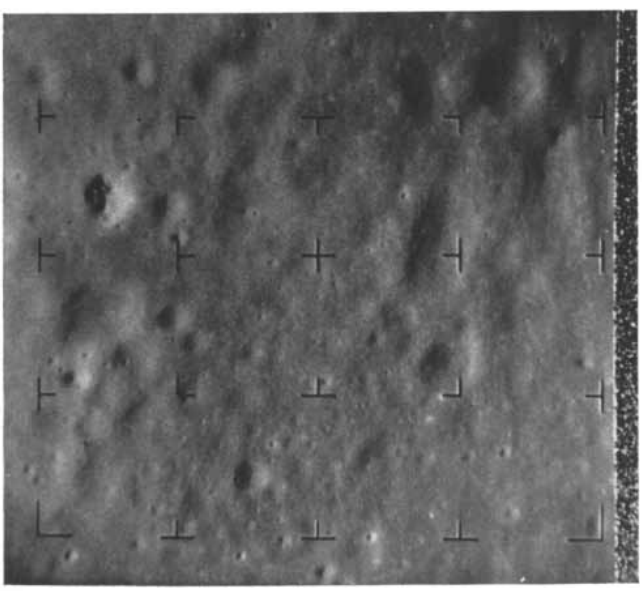
It is believed that the lunar maria were formed when magma, or molten rock, welled up into large crater basins and flooded lowland areas [see "The Geology of the Moon," by Eugene M. Shoemaker; SCIENTIFIC AMERICAN, December, 1964]. All the flooding did not occur at the same time, and some of it may have been triggered by the impact of large bodies. The maria have been classified into two major types: "blue" and "red," signifying slight spectral differences in their reflectivity. One hoped that the Ranger photographs might supply information for further classification of the maria and perhaps shed light on their origin and history.

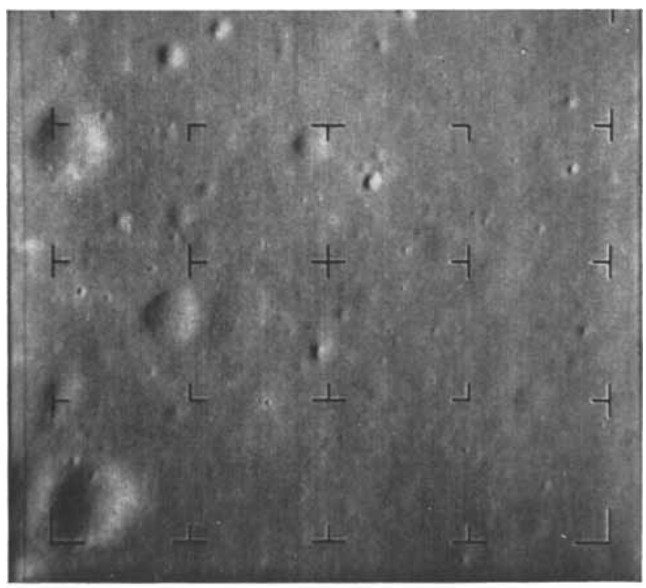


LOCATION OF FINAL PICTURES taken with the F_A and F_B cameras (*see photographs below*) and the impact point of *Ranger VII* are shown in this photograph, which is a duplicate of the one at the bottom of page 60. The point of impact is marked with an *X*.



"WRINKLE RIDGE" in Mare Cognitum appears in this photograph made by the *Ranger VII* F_B camera at an altitude of about 36 miles. The picture shows an area about eight miles wide; the largest crater measures about a mile across and is about 800 feet deep.





LAST *RANGER VII* PHOTOGRAPHS taken with the full-frame television cameras are the F_A view at the left and the F_B view at the right. The area shown in each photograph is about two miles wide; the location of each area is plotted in the picture at the upper left on this page. The F_A photograph shows a surface roughened by rays that can be traced to the crater Tycho. The neighboring area shown in the F_B picture is ray-free, indicating that it had escaped bombardment by material ejected from Tycho.

The target for the unsuccessful *Ranger VI* mission was on the western edge of the blue Mare Tranquillitatis. When the failure of that flight resulted in a five-month delay in the launching of *Ranger VII*, the available targets were shifted to the west. The target selected for *Ranger VII* was a relatively uncluttered red mare area on a line between the large "rayed" craters Copernicus and Tycho.

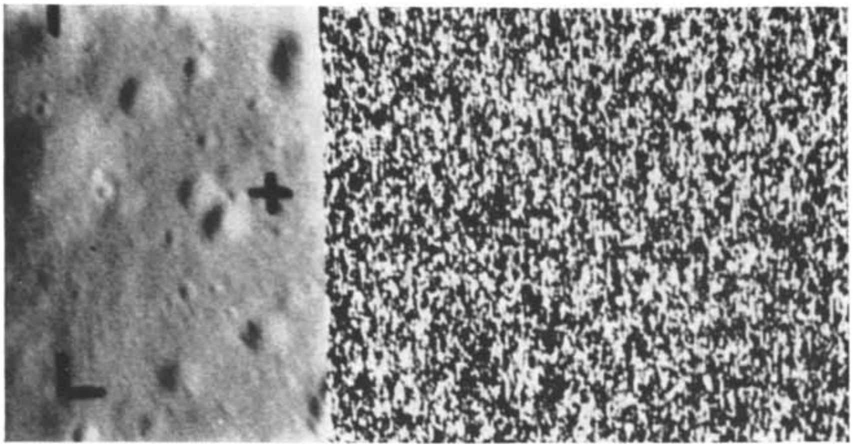
Because of the difficulties with *Ranger VI*, the laboratory staff—particularly the Ranger team—followed the flight of *Ranger VII* with mounting tension. When the time came for the television cameras to begin operating, the suspense became almost unbearable. With the news that the cameras were working, a great cheer went up in the small auditorium where staff members and their friends were gathered. Even then, because the last few pictures were so important, the tension continued until the recording staff reported that the final photographs had been received. In honor of the achievement the International Astronomical Union renamed the area of impact of *Ranger VII* "Mare Cognitum"—the sea that has become known.

The moon's apparent brilliance to the unaided eye is misleading. The actual surface has an albedo (reflection coefficient) that ranges from .05 to .18, which is about the reflectivity of dark slate. It has been established in laboratory experiments that the dark and fairly colorless appearance of the moon can be duplicated by bombarding samples of terrestrial rock and soil with protons; evidently the moon's drab appearance is the result of bombardment by protons from the sun.

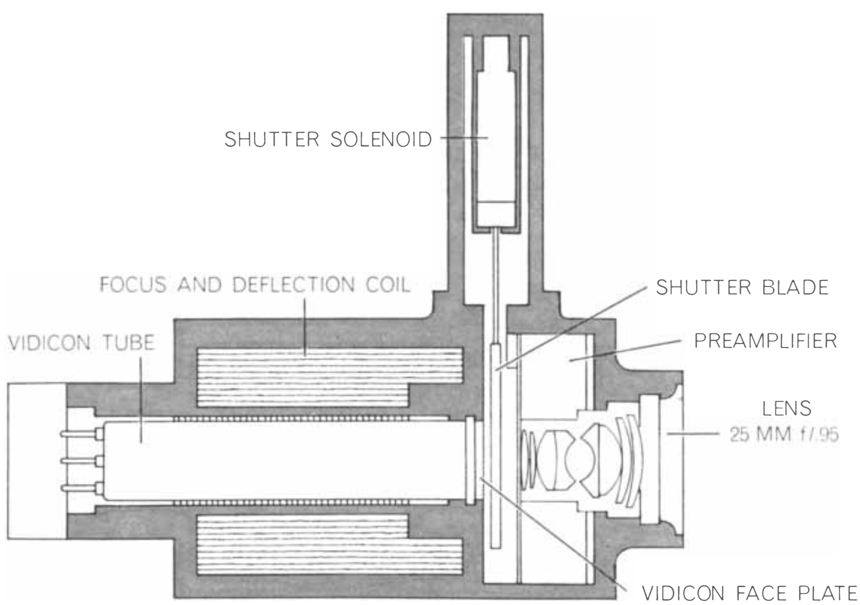
Lacking an atmosphere and a magnetic field, the moon is totally exposed to bombardment by protons, meteorites and micrometeorites. It had been estimated that the meteorite bombardment had produced a layer of rubble that varied in depth from half a meter to more than 80 meters. It was further assumed that the uppermost layer had been hammered into a fine powder by micrometeorites. Evidence that the lunar surface is indeed porous to an average depth of a meter or so had been obtained by various analytical techniques: study of light polarization, infrared measurements of the surface cooling rate and analysis of radar reflections.

Under the best conditions the smallest details of the lunar surface that can be photographed from the earth are about 400 meters across. The resolution achieved by *Ranger VII* just before impact improved on this resolution by a factor of more than 1,000. The last *Ranger VII* photograph covers an area approximately 34 by 48 meters and shows craters that are smaller than a meter in diameter [*see illustration above*]. The observed surface degradation from meteorite bombardment was greater than expected. On the other hand, the depth of rubble indicated by the photographs was slightly less than predicted.

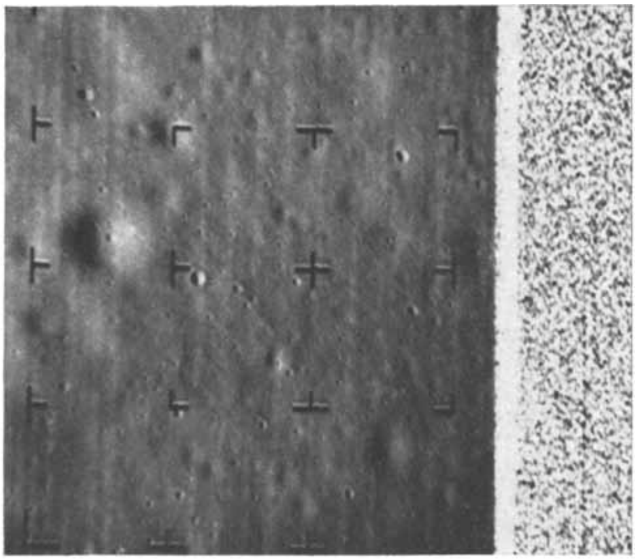
The area shown at the top of page 60, an F_A photograph taken from an altitude of about 150 kilometers, shows several of the crater rays from Tycho and Copernicus. One can see clearly that these rays have been formed by particles ejected from the large craters by the primary impact. Whitaker has suggested that the large ray craters were formed by collisions with comets. Gas contained in the comet would propel large particles over considerable distances and would create a wind pattern that could explain the observed ray geometries. The bottom illustration

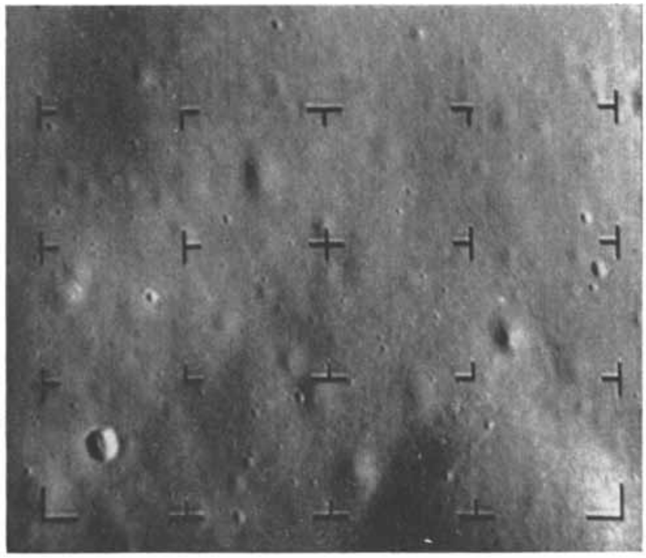


FINAL *RANGER VII* PHOTOGRAPH was taken by the P_3 camera .19 second before impact. Only a portion of the picture was scanned before the crash ended transmission; the random pattern at the right is electronic noise in the receiver at Goldstone in California. The picture shows an area about 105 by 150 feet and reveals no hazards to a soft landing.



RANGER TELEVISION CAMERA, unlike a conventional television camera, incorporated a focal-plane shutter. The optical image formed on the face of the Vidicon tube was retained while the image was scanned from behind and was subsequently erased. This sectional view shows one of the *P*, or partial-frame, cameras, that had an *f*/.95 lens with a 25-mm. focal length. The partial-frame cameras scanned an area only .11 inch square on the face of the Vidicon. The full-frame (*F*) cameras scanned an area with four times the width (.44 inch).





SEA OF TRANQUILLITY, a "blue" mare, was photographed by the next Ranger, *Ranger VIII*. These last two pictures made by the F_A and F_B cameras (*left and right*) show that the surface of Mare Tranquillitatis is very much like that of Mare Cognitum, photographed by *Ranger VII*. The shallow crater in the lower right corner of the F_B picture, which is about 3,000 feet across, contains several positive-relief features in its side wall. The shadows are long because the sun is only about 15 degrees above the horizon.

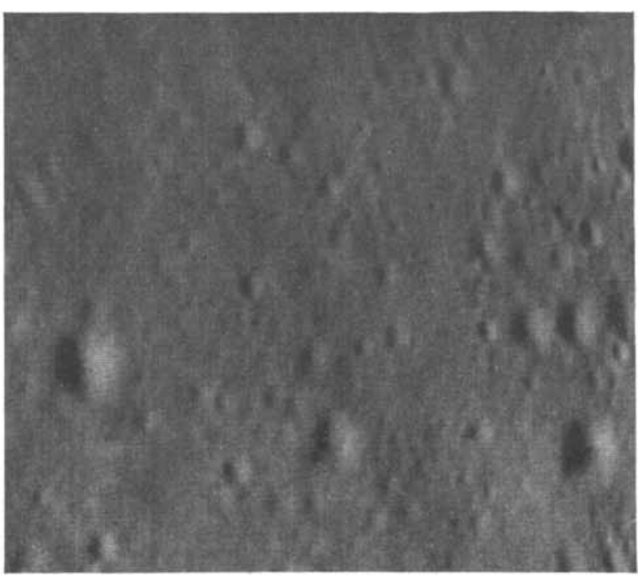
on page 60, also an F_A exposure, is an enlarged view of the cluster of craters visible at the right in the preceding picture.

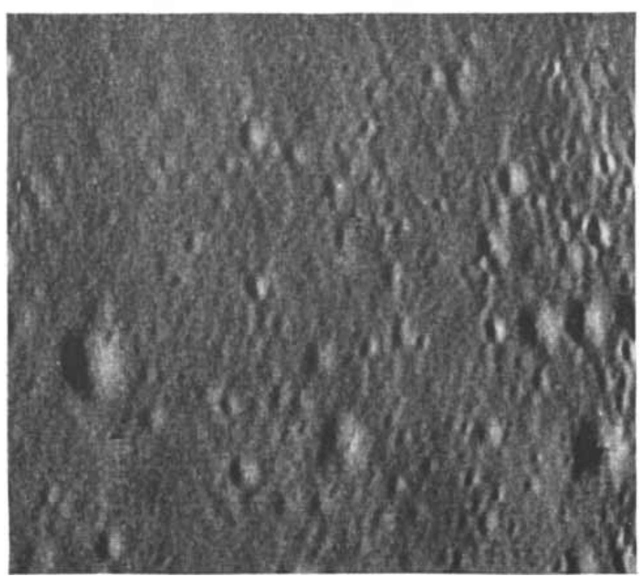
Additional photographs of the same region taken still later with the F_A and F_B cameras appear at the bottom of page 62. The photographs show adjacent areas, each about three kilometers across. The F_A photograph shows a surface covered with faint rays produced by secondary and tertiary impacts. The adjacent area directly to the east in the F_B photograph is free of rays and therefore much smoother.

The picture at the upper right on page 62, an F_B photograph taken from an altitude of about 60 kilometers, is of interest because it shows the interaction of a "wrinkle ridge" with a fairly large crater. Such ridges had been thought to mark the boundaries of magma flow. Now it seems that they are pressure ridges resulting from thermal contraction.

The launching of the next Ranger—*Ranger VIII*—was delayed until February, 1965, to allow the launching of other spacecraft, including the Mars vehicle *Mariner IV*. Because *Ranger VII* had reported on the topography of red maria, the experimenters decided that *Ranger VIII* should sample the blue maria. The region chosen was in Mare Tranquillitatis, southeast of the point originally selected for *Ranger VI*.

The mission went off successfully and a good approach was made without need for a terminal maneuver. The last F_A and F_B photographs made by *Ranger VIII*, shown above, are similar in scale and resolution to the corresponding photographs made by *Ranger VII*. The last usable photograph, taken by the P_3 camera, is shown below in two





LAST USABLE *RANGER VIII* PICTURE, taken about .45 second before impact by the P_3 camera, is shown in two versions generated by computer from data stored on magnetic tape. The comparison shows how the computer can restore missing contrast.

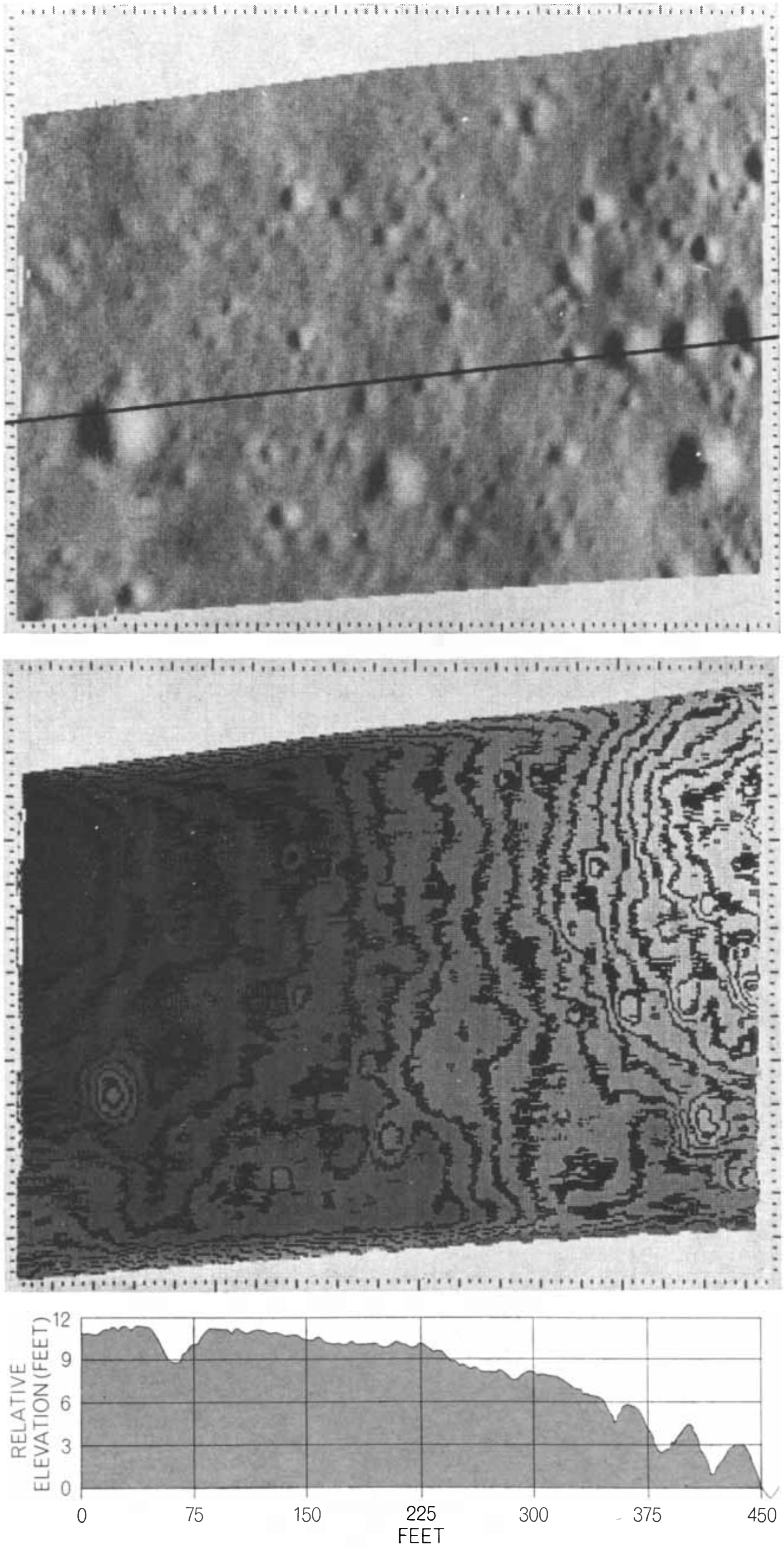
forms. The picture was taken about half a second before impact from an altitude of about 740 meters. The area shown in the picture is roughly 90 by 120 meters, revealing craters with a diameter of about 1.5 meters.

The two versions of the photograph were generated by a digital computer from data recorded on magnetic tape. The photograph at the right in the pair has been enhanced by the computer to compensate partially for the characteristic loss of contrast when the television system is working near the limits of resolution. After enhancement the photograph more closely represents the lunar surface as the eye would see it. The apparent roughness is due to the many small craters near the limits of resolution. One must assume that still smaller craters exist down to a point where some other surface texture begins to predominate. The illustrations on this page show (1) the same area after rectification by a computer, (2) a computer-generated contour map of the area and (3) an elevation profile located near the middle of the area.

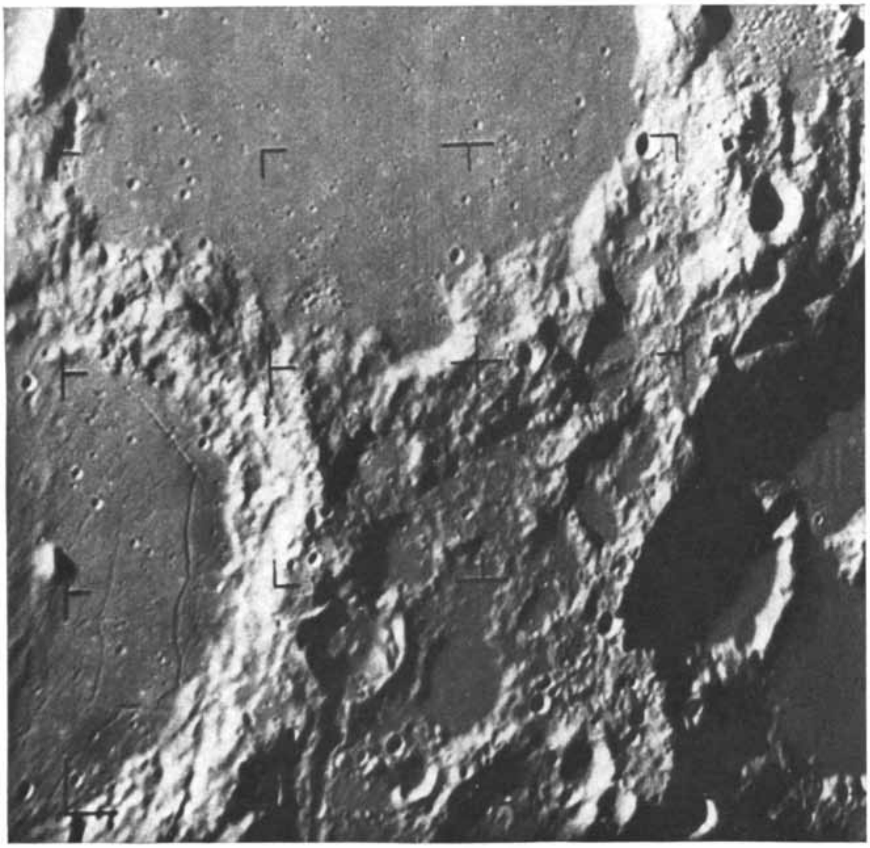
A View of the Highlands

The success of *Ranger VII* and *Ranger VIII* in revealing the small-scale topography of red and blue maria, and the similarity of the two topographies, prompted the experimenters to consider other kinds of target for *Ranger IX*. The prime contenders for this last Ranger mission were any one of several types of highland terrain or specific targets of special scientific interest. The experimenters finally selected the crater Alphonsus, partly because some observers had reported evidence for the emission of gases near the central peak and partly because it contained unique "dark-haloed" craters and an extensive system of rills, or narrow valleys. This selection required that the first and second launching days out of a possible sequence of seven in a given period be dropped so that the sun would cast long shadows and make it possible to detect slopes of low angles. The *Ranger IX* target was to the northeast of the central peak of Alphonsus; a small terminal maneuver was required to photograph the central peak as well as the dark-haloed craters and the rills. The maneuver was executed successfully and *Ranger IX* provided the most spectacular photographs of the entire series.

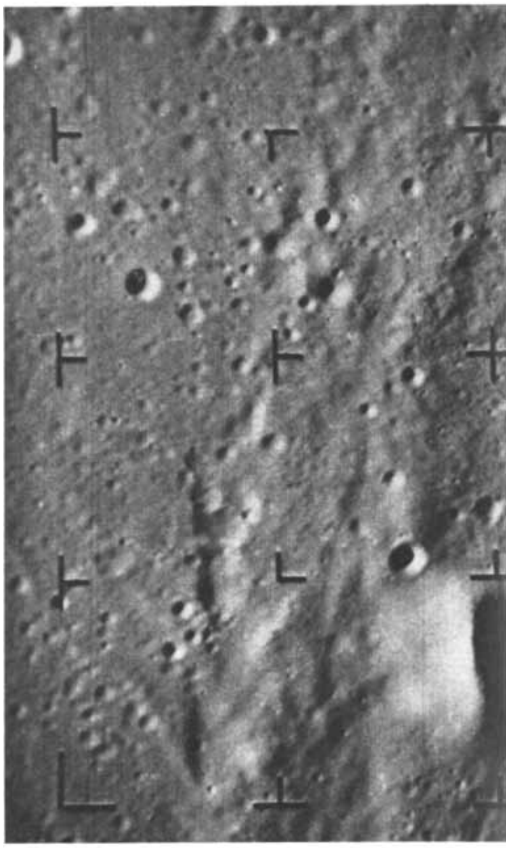
Some of the most striking *Ranger IX* pictures appear on pages 52 and 53 and at the top of the next two pages. The



FURTHER COMPUTER PROCESSING of the last P_3 photograph shown at the bottom of the opposite page yields a rectified picture (*top*), a contour map (*middle*) and an elevation profile (*bottom*). The area shown is about 450 feet wide, as measured after rectification. The contour map is shaded to show that the surface slopes gently from left to right. The smallest craters are about five feet across and a foot deep. Note that the vertical scale is exaggerated by a factor of 10. The picture was taken from an altitude of about 2,400 feet.



RANGER IX PHOTOGRAPH was taken from an altitude of 1,257 kilometers (780 miles) by the F_B camera about six minutes before the F_A camera took the photograph on pages 52 and 53. It shows three large craters: Alphonsus (*left*), Ptolemaeus (*top*) and Albategnius (*right*). Judging from the number of small craters in each, Albategnius may be the youngest.



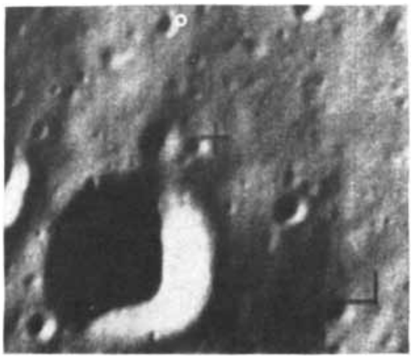
PEAK IN ALPHONSUS shows up vividly in this *Ranger IX* picture taken by the F_A camera at an altitude of about 58 miles. It had been speculated that the peak might

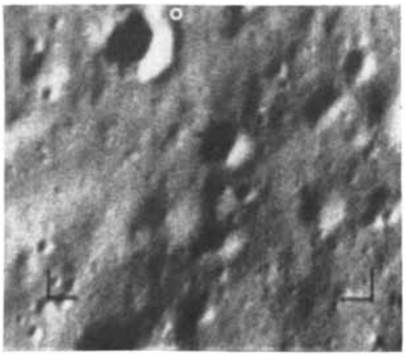
picture on pages 52 and 53 provides an excellent comparison of the effects of meteorite bombardment on mare areas and on highland ones. The lower density of craters on Mare Nubium, at the left in the photograph, provides evidence that its surface is substantially younger than that of the adjacent highlands and that it was probably formed by the flow of magma across a lowland region.

The middle picture of the three at the top of these two pages offers a close-up of the central peak in Alphonsus from an altitude of 93 kilometers. The peak, which is about 3,500 feet high, seems to be perfectly smooth and devoid of any source for venting gas. The smoothness of the peak was a surprise to everyone.

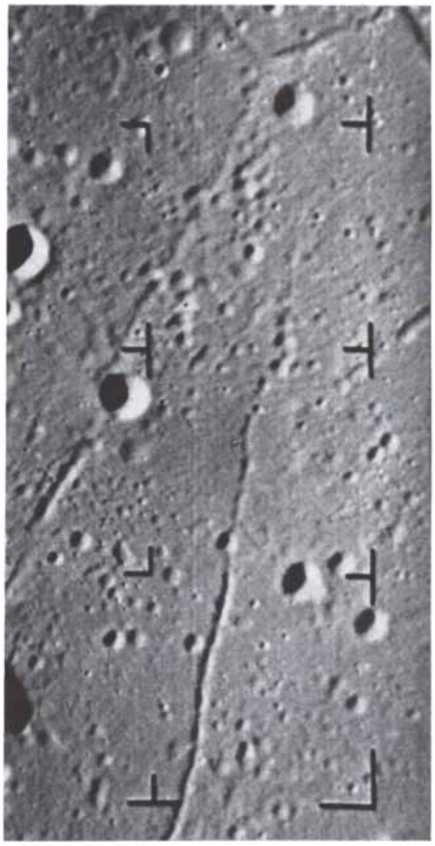
The picture at the right in the set of three at the top of these two pages shows the same kind of smoothness in the highland region that forms the wall of Alphonsus. The smoothness has been produced by meteorite bombardment over hundreds of millions, if not billions, of years. To the right of center in this picture one can see a basin that has collected debris eroded from the surrounding peaks; the basin is pocked with craters and has the same appearance as the floor of Alphonsus.

Several of the largest craters grouped

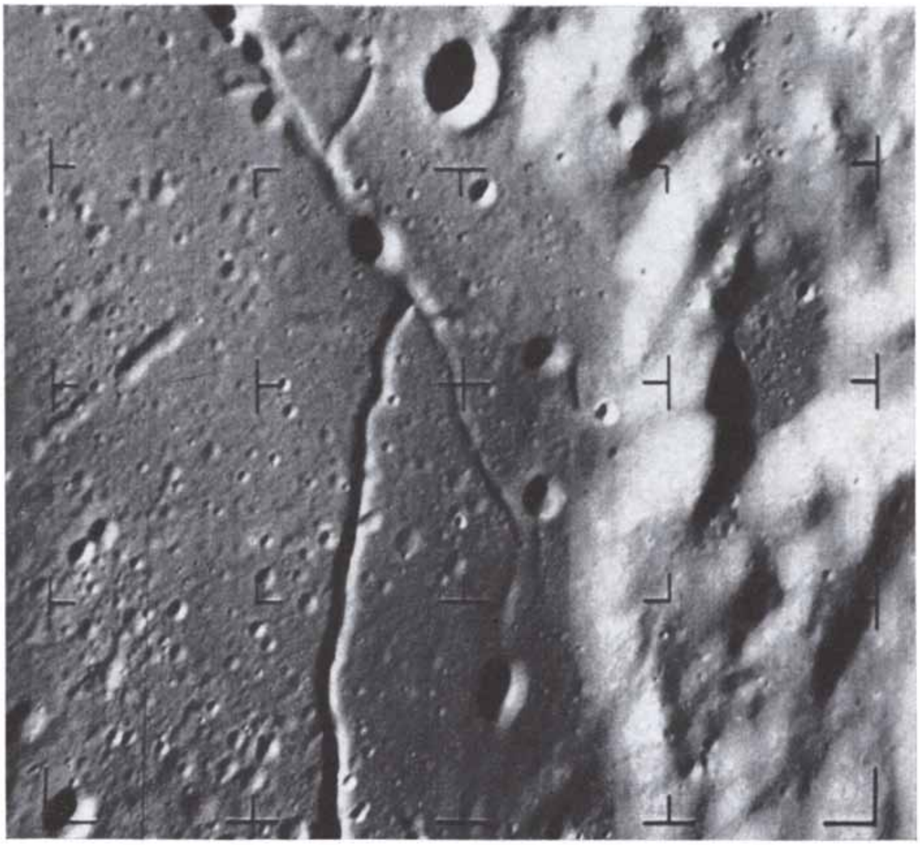




LAST *RANGER IX* PICTURES made with the P_1 camera were taken from altitudes of 5.16, 3.13 and 1.09 kilometers. The white circle at the top of each picture marks the impact point next to a crater that is about 25 feet in diameter. *Ranger IX* probably produced another crater of the same size. Note the tiny pimple-like feature at the lower right corner of the last picture (*right*). Typical of several such features, it is about a foot high and the closest thing to a rock to be seen in any of the Ranger pictures.



contain a fissure through which gases could be vented, but none is visible. The low angle of illumination (10.4 degrees) accentuates surface features.



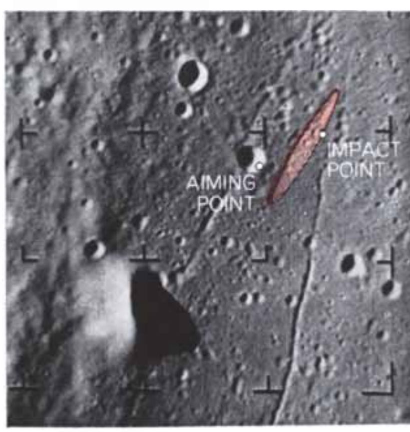
"DARK-HALOED" CRATERS can be studied in this F_B close-up of Alphonsus. Two of the largest have deposited material from the moon's interior in the rills on which they are centered, indicating they were produced by subsurface activity rather than by meteorites. A debris cache, pocked with craters, can be seen between the two *T*-shaped reticles at the right side of the picture.

in a vertical array in the center of the picture are typical dark-haloed craters. They are of particular interest because it can now be seen that they were almost surely produced by subsurface activity—volcanism—rather than by meteorite bombardment. The evidence is to be found in the way the rills in the immediate vicinity of these craters have been filled in by material from the moon's interior. This material has also filled in older craters nearby, so that for a considerable area around the dark-haloed craters the main floor of Alphonsus is less pockmarked than elsewhere.

The last three P_1 photographs taken by *Ranger IX* appear at the bottom of the opposite page. The impact point is marked by a white circle at the top of each picture. The crater adjacent to the point of impact is about eight meters in diameter; it is estimated that *Ranger IX* made a crater of about the same size .45 second after the last picture was taken. In the lower right corner of the last picture one can see a small dome-like formation. Representative of several seen in the last few *Ranger IX* photographs, it measures slightly more than two meters across and is no more than .3 meter in height. These shallow domes are the closest things to rocks that can be seen in any of the photographs. Whatever their original shape, they have been eroded into mere bumps by the constant rain of small meteorites.

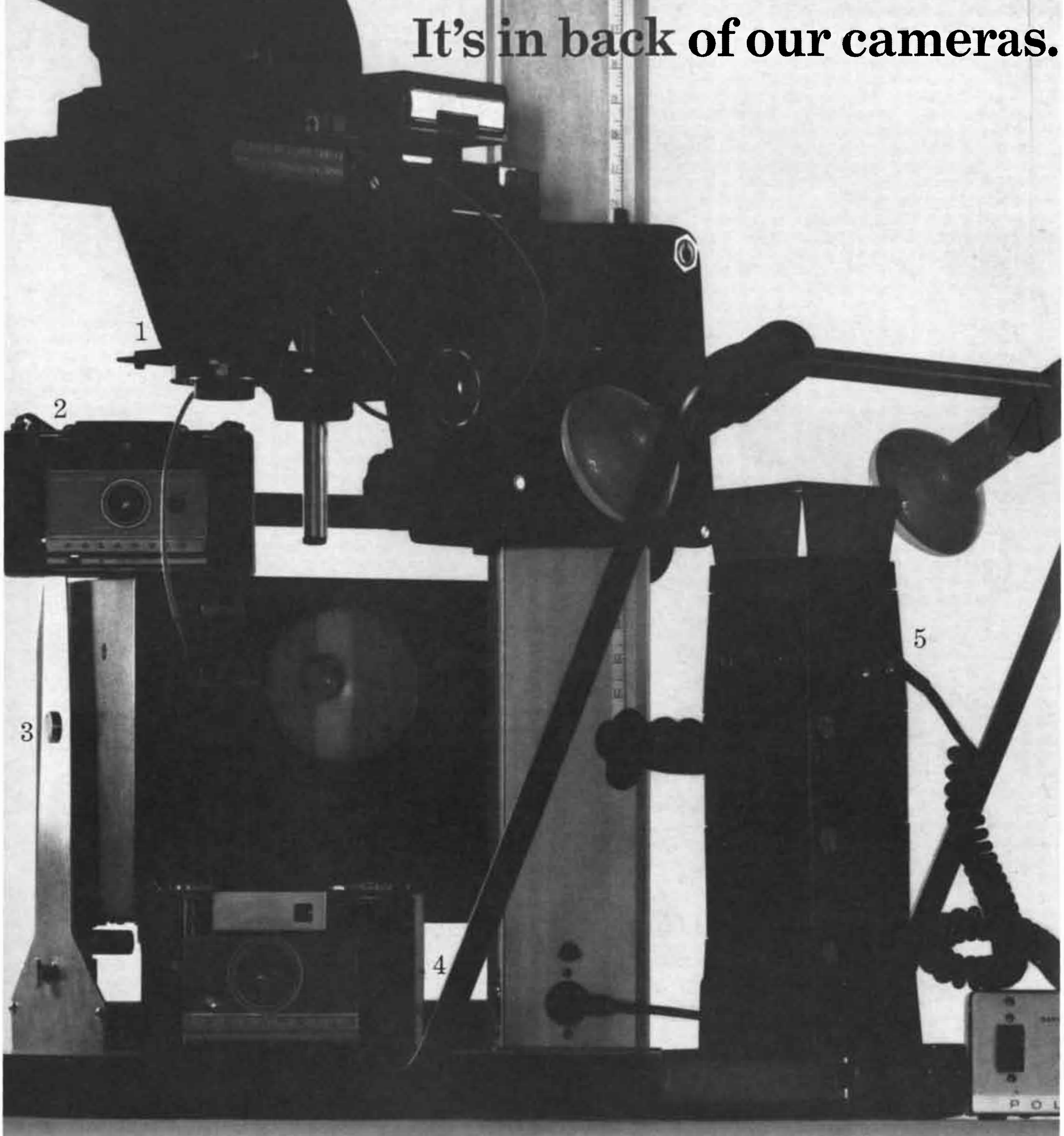
The thousands of clear photographs produced by the last three Rangers exceeded the most optimistic expectations of the Jet Propulsion Laboratory engineers who had worked so long and hard on the project. The Ranger photographs had fully satisfied the primary objective of determining the small-scale topographical hazards for future soft landings on the lunar surface. The volume of new data is so great that its analysis and interpretation will require years. For this task the computer will be indispensable.

The next step in lunar exploration will be carried out by the Surveyor series of spacecraft, which are designed to land softly and make a close-up study of the lunar surface. The four Soviet failures to soft-land instruments on the moon have demonstrated that this next step will not be an easy one. When it is successfully taken, the Surveyors should report the hardness of the moon's surface and provide details about its composition. The final chapter in the exploration of the moon will be written by the astronauts and cosmonauts who one day will land there.



***RANGER IX* IMPACT POINT, as determined from the final photographs, was only three miles from the aiming point. The ellipse shows the probable impact area as computed from the tracking data while the spacecraft was on its way to the moon.**

It's in back of our cameras.



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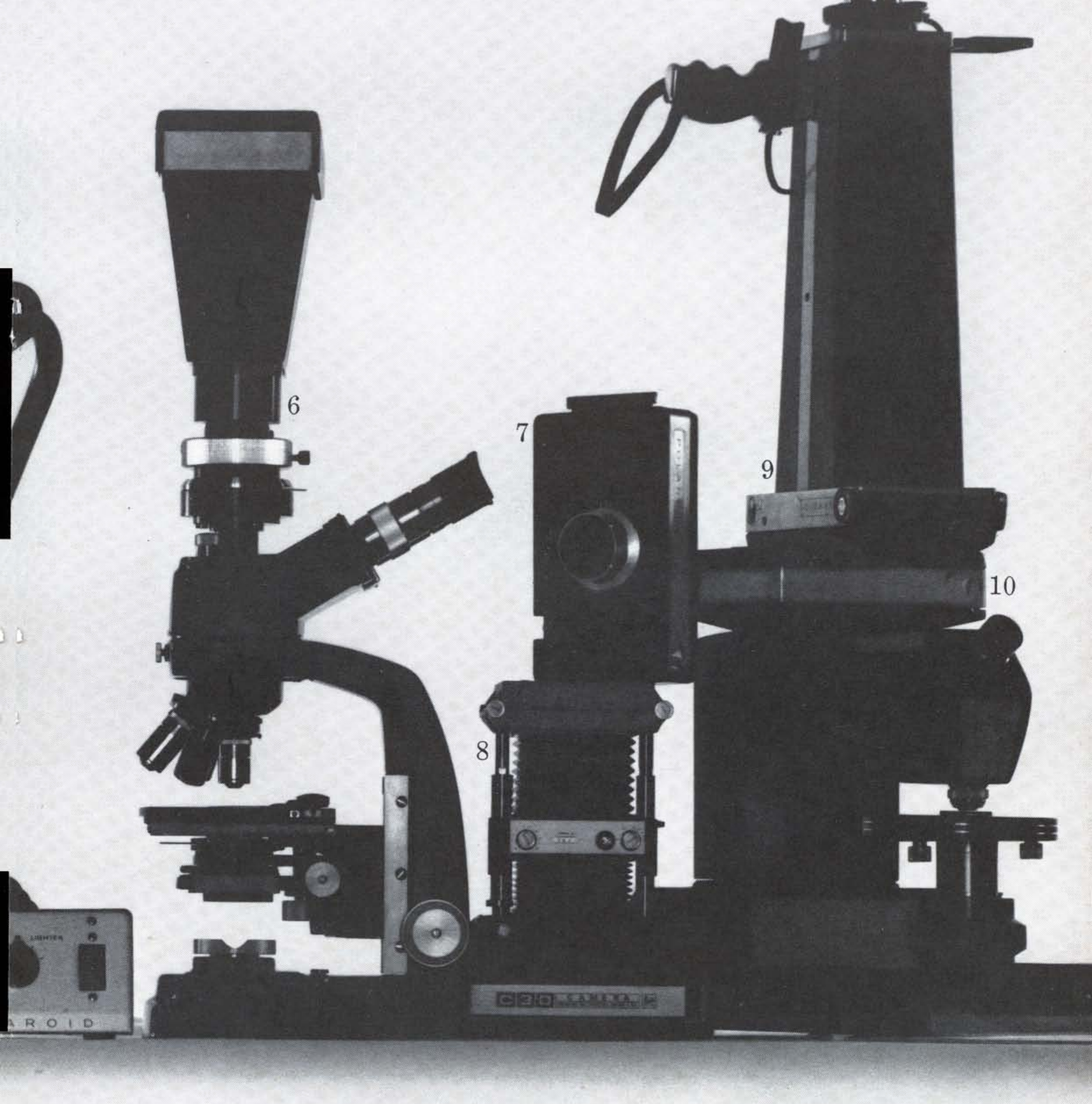

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ORCHIDS

There are more than 20,000 species of them, comprising the largest family of plants. Not all of them bear the ornate flowers used for corsages, but their evolutionary adaptations are remarkably diverse

by Joseph Arditti

Late in the 17th century a German botanist named Jacob Breynius undertook to gather information on plants that were unfamiliar to Europeans at the time. When he published his compendium *Exoticarum Aliarumque Minus Cognitum Plantarum,* he commented in particular on the extraordinary diversity of orchids. "If nature ever showed her playfulness in the formation of plants," he wrote, "this is visible in the most striking way among the orchids.... They take on the form of little birds, of lizards, of insects. They look like a man, like a woman, sometimes like an austere sinister fighter, sometimes like a clown who excites our laughter. They represent the image of a lazy tortoise, a melancholy toad, an agile, ever-chattering monkey. Nature has formed orchid flowers in such a way that, unless they make us laugh, they surely excite our greatest admiration."

The plants Breynius was describing are now classified under the family name Orchidaceae. They comprise the largest of all plant families; it contains, according to various estimates, 500 to 600 genera and 20,000 to 35,000 species. Orchids are herbaceous (nonwoody and grasslike) perennials that occur as shrubs, vines and even grasses. They may bear a single flower or many flowers. They are found from the Arctic to the borders of the Antarctic. They grow in tropical rain forests, subtropical plains and alpine meadows; in bogs, moors and deserts; in deep valleys and on high mountains. Most of the tropical and subtropical species are epiphytic, that is, they grow on the trunks and limbs of trees and shrubs as independent nonparasitic plants. It is not uncommon, however, to find normally epiphytic species growing on rocks. I have also seen them perched on top of utility poles and wires. Some orchids, particularly those of regions outside the Tropics, are called terrestrial: they grow in the ground. Some orchids are saprophytic: they subsist on decaying organic matter.

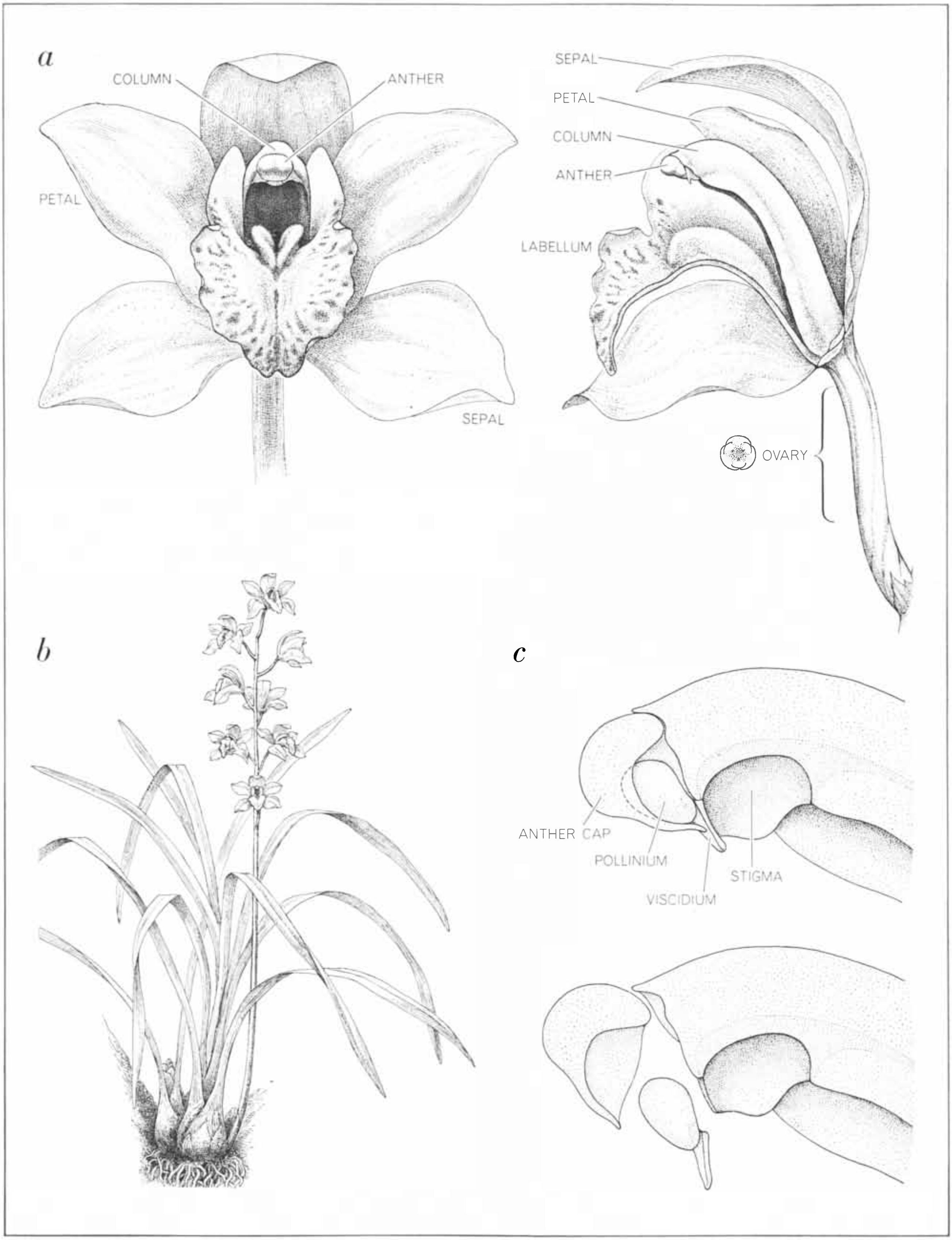
Orchid flowers range in size from less than a sixteenth of an inch to more than a foot. Some give off a pleasant odor, some an unpleasant one, and some are odorless. As Breynius wrote, the shapes of the flowers are so fantastically varied that many of them inevitably seem to be mimicking something else. *Habenaria blephariglottis* of North America is commonly called monkey face. The genus *Cycnoches,* which is native to Central America, is known as the swan orchid because of its resemblance to a swan's neck. In Israel *Ophrys sintenisii* is called the velvet bee orchid. The tropical genus *Stanhopea* is often called *torrito* (little bull) in parts of Latin America because of a structure that resembles two horns. The shoelike form of the genus *Cypripedium* is reflected in such names as lady's slipper, Venus's-shoe, *Frauenschuh, pantofella* and *scarpa della Madonna.*

Among other noteworthy characteristics of orchids are resupination, a twisting of the bud that occurs as the bud becomes a flower, and a fungus infection that is necessary for the germination of the orchid seed. Orchids also have some unusual mechanisms for pollination. Of all these matters I shall have more to say later.

The evolutionary steps that brought orchids to their present state of development are largely conjectural. The late Oakes Ames of Harvard University, who was one of the foremost American orchidologists, accorded the orchids a special place in the plant kingdom by suggesting that they represent a culmination of evolution, at least among the monocotyledonous plants—plants that have a single cotyledon, or embryonic leaf, in each seed. His suggestion, with which most other students of the family agree, is based partly on the complex structure of orchid flowers.

The term "orchid" goes back to classical Greek times. The scholar Theophrastus, who was one of Plato's students and is often called the father of botany, described a plant with paired roots that looked like testicles; he gave it the name *orchis* from the Greek word for testicle. Whether or not he was actually describing an orchid is uncertain, because his statement was rather vague, but the later Greek botanist Dioscorides interpreted the description as referring to an orchid. Carolus Linnaeus adopted the name in *Species Plantarum,* the monumental work of botanical classification that he published in 1753, and in 1836 the British botanist John Lindley introduced Orchidaceae as the name of the family.

The odd shapes of the flowers and other parts of orchids have suggested to many peoples that they have magical and medicinal powers. Medieval European herbalists collected what they called "dog stone roots" (apparently again in reference to the resemblance of some orchid roots to testicles) for the preparation of aphrodisiac potions. It was also thought that a married couple could predetermine the sex of a child by means of orchid roots. As a work of 1640 put it: "The roote thereof being boyled is eaten as other sorts of bulbes are, and ... if men eate the greater, they shall beget men children, and if women eate the lesser they shall bring forth women children." On the Indonesian island of Amboina a paste made from an orchid of the genus *Grammatophyllum* is used as a remedy for sores, and in



PRINCIPAL FEATURES of an orchid are identified. The orchid depicted is a species of the genus *Cymbidium*. At *a* the flower is shown in a front view and in a sectional view from the side. At *b* the full plant is depicted in a typical habitat, the crotch between the trunk and a limb of a tree. This species of orchid also grows in the ground. Details of the column are portrayed at *c*. The column is a structure that distinguishes orchids from other monocotyledonous plants; it includes the stamen, which is the male organ carrying the pollen-bearing anther, and the stigma, which is the part of the pistil, or female organ, that receives the pollen.

TWISTING MOVEMENT characteristic of orchid flowers is portrayed. The process is called resupination. At left an orchid of the genus *Vanda* is shown twisting so that the lip, which is on the top in the budding stage, is on the bottom in the flower. In a *Cymbidium* with several flowers (*right*) each flower twists enough to cause its lip to hang downward.

TWO FORMS OF GROWTH occur in orchids. The plant at left, an orchid of the genus *Cattleya,* is showing sympodial growth: the main stem stops growing at the end of a season and a new stem appears in the next season. Often the old stem forms a fleshy structure called a pseudobulb. At right a *Vanda* has monopodial growth: the main stem grows indefinitely.

Malaya a preparation from *Dendrobium* is applied in the treatment of skin infections. In Africa the Zulus employ *Habenaria* as an emetic, and the Swagi treat a children's disease with *Lissochilus.* In South America *Epidendrum bifidum* is used to expel tapeworms and *Spiranthes* as a diuretic.

How effective these medicinal uses of orchids are I do not know. It can be said, however, that orchids have a significant place in modern commerce beyond their use in corsages and other floral displays. True vanilla comes from the beanlike fruit of the orchid genus *Vanilla,* which is a tropical and climbing group of orchids. By far the most important vanilla orchid is *V. planifolia,* a plant that is cultivated widely throughout the Tropics.

The detailed features of orchids are no less diverse than their more obvious ones. The roots of orchids occur in several colors and many sizes and shapes. They are usually fleshy. In certain terrestrial orchids the roots are bulbous, but most tropical epiphytic species have elongated greenish or white roots that adhere tenaciously to the surface on which the plant lives, often forming a thick mat. This trait enables the plants to anchor themselves in somewhat improbable positions; *Cattleya citrina,* for example, is usually found hanging upside down. In several saprophytic orchids the entire plant consists mainly of red, purple or yellow roots that produce a flowering stem at appropriate times. A special characteristic of orchid roots is the velamen, a multilayered epidermis consisting of several tiers of spongelike cells. The function of this tissue is still being debated; it may be to provide space for water storage.

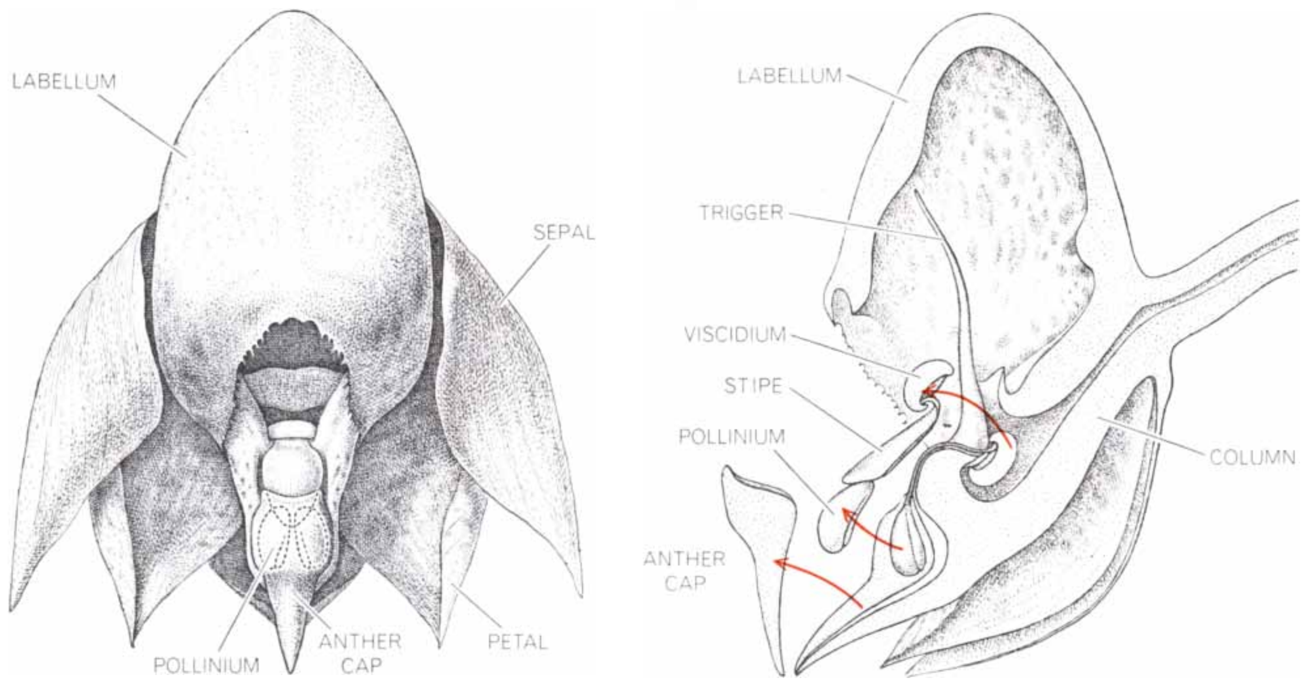
The stems of orchids grow in two different ways. Some species exhibit what is known as sympodial growth: the growth of the main stem ceases at the end of one season and does not resume in the next; instead a new stem develops. The old stem may become thick, short and fleshy, forming a structure known as the pseudobulb. In other species the form of growth is monopodial: main-stem growth continues indefinitely and no pseudobulbs are formed.

The most definitive characteristics of the orchids are undoubtedly to be found in their flowers. Some of the flowers are Lilliputian; for instance, the flower of *Platystele ornata* measures about a millimeter in diameter. Others, exemplified by certain hybrids of the genus *Cat-*

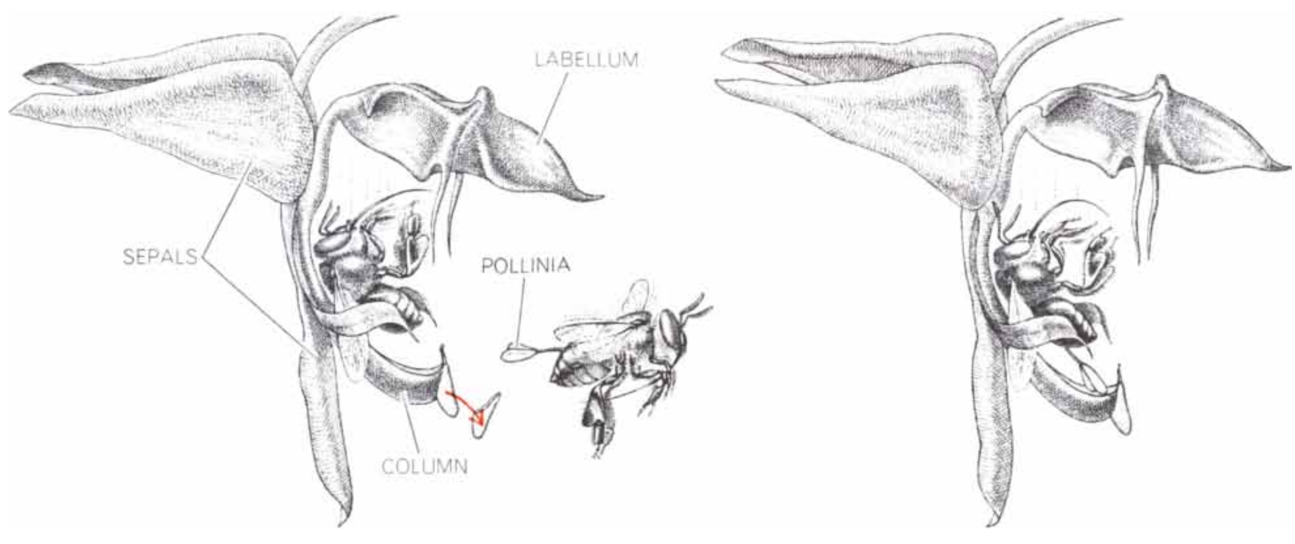
tleya, average 30 centimeters or more. Orchid flowers are borne either singly or in clusters of various forms and sizes. I once had a specimen of *Oncidium carthaginense* that produced a stem some 12 feet long with several hundred flowers. I am sure that this is by no means a record length.

The orchid flower has certain structural features in common with most other flowers, but these can be greatly modified and are often unrecognizable. Looking at the outer parts of the flower, one sees the sepals—the leaflike structures that are usually green in most other flowers but may be almost any color except black in orchids. Next come the petals. They too may be any color except pure black and are not necessarily the same color as the sepals. Inside the petals is one or both of two structures: the stamen, which is the male organ and carries the pollen, and the pistil, the female organ containing the ovules. Most orchid flowers contain both structures, with some of the parts united and highly modified to form a "column" [*see illustration on page 71*].

Orchid flowers are bilaterally symmetrical: they have distinct but similar



TRIGGER MECHANISM that begins the process of pollination in an orchid of the genus *Catasetum* is depicted. At left is a frontal view; the broken lines show the position of the pollen-bearing pollinium under the anther cap. At right is a sectional view, from the side, of the interior of the flower. The trigger, when touched by a bee, releases the sticky viscidium, which twists as indicated by the upper arrow and lodges against the bee's abdomen. Hence the departing bee carries the pollinium. The anther cap falls away.



POLLINATING DEVICE of an orchid of the genus *Gongora* is a slippery column. At left a bee, having penetrated the flower, encounters the slippery surface and gets a toboggan-like ride down the column. There the bee strikes the viscidium, which adheres to the insect's abdomen, so that when the bee flies off it carries the pollinia. At right the bee, still carrying the pollinia, enters another flower and gets another ride down the column. On this visit the pollinia adhere to the stigma and the flower is pollinated.

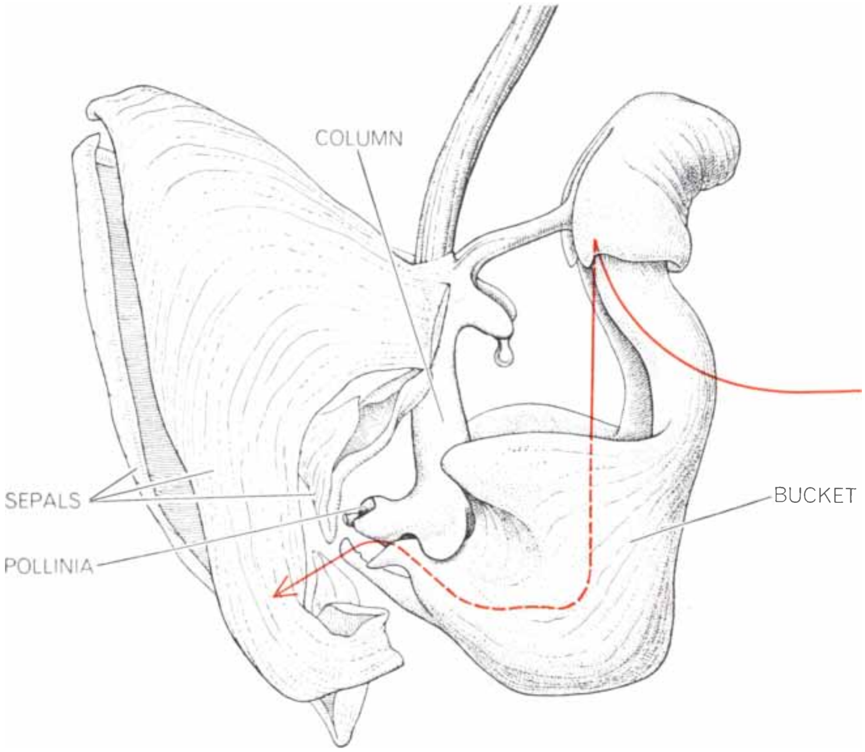
left and right sides. The sepals and petals are borne in threes; it is a characteristic of monocotyledonous plants to bear such structures in threes or multiples of three. Some orchids are unisexual, which is to say that they have either stamens or pistils but not both, and some are bisexual.

One of the sepals in the orchid flower—the one on the upper side of the flower's base—may differ from the other two. It may be larger or fleshier than the other sepals; it may also be richly colored and decorated. This type of dorsal sepal appears prominently in the lady's slipper orchids.

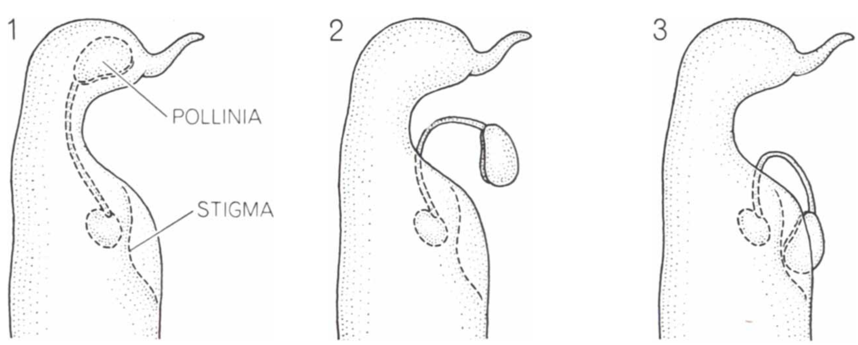
Usually one of the three petals in the orchid is also much different from the others. It forms the distinctive feature called the labellum, or lip. This structure assumes strikingly handsome shapes and may be further distinguished by spots of color in splashes, blotches or more intricate designs. The labella of many *Cattleya* species and hybrids are surely among the most beautiful objects in nature.

In most fully opened orchid flowers the labellum hangs below the other two petals. In the unopened bud, however, it is above them. The change in position is brought about by the phenomenon of resupination that I have mentioned. The entire bud twists on its axis, usually by about 180 degrees, as it opens [*see top illustration on page 72*]. This twisting movement is one of the hallmarks of the Orchidaceae. In some species the twisting facilitates pollination by placing the labellum at the bottom as a perch for visiting insects, and that presumably is the evolutionary reason for the phenomenon.

Although the beauty of the dorsal sepal and the labellum is the most spectacular feature of orchid flowers, the most unusual feature from the botanical standpoint is the column, or gynandrium. This is a structure not found among other monocotyledonous plants. It represents a fusion of three structures: the stamen, the stigma, which is the part of the pistil that receives the pollen, and the style, which provides a pathway for the pollen to reach the ovules. The anthers—the pollen-bearing parts of the stamen—are also borne on the column. The pollen grains occur separately or are compressed into masses known as pollinia.



LIQUID IN A TRAP facilitates pollination in the orchid *Coryanthes speciosa*. The colored line, followed from right to left, shows the path taken by the bee as it arrives at the flower and falls into the bucket, which contains a liquid produced by the gland at top center. The only way out for the bee is through a narrow opening that forces the bee against the pollinia.

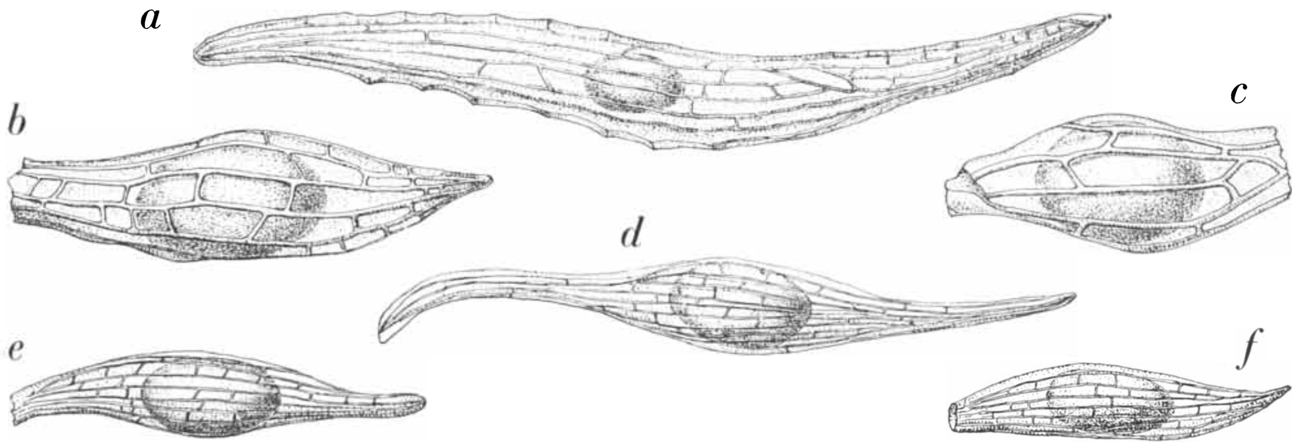


SELF-POLLINATION is shown in an orchid of the genus *Ophrys*. Before pollination (*1*) the column stands upright. As a result of autolysis, or self-digestion of certain tissues by the plant, the stipe bends (*2*), carrying the pollinia downward toward the sticky stigmatic surface. When the pollinia reach the stigma and adhere to it (*3*), pollination is complete.

As their diverse forms suggest, orchid flowers are pollinated by a multitude of agents. Among the reported pollinators are not only bees and a variety of other insects but also birds, bats, frogs and snails. Not all these reports have been fully substantiated. C. H. Dodson of the University of Miami found in a series of detailed observations that in the American Tropics he could confirm only insects and hummingbirds as pollinators of orchids.

The pollinating mechanisms of many orchids are remarkably intricate. The late Paul H. Allen, who worked as a botanist in Latin America, investigated the pollination of the orchid *Gongora maculata*. He suggested that the fragrance of the orchid attracts males of the bee *Euglossa cordata*. A bee lands on the flower in search of nectar. There, because parts of the flower are slippery, the insect loses its footing and gets a toboggan-like ride down the curved column. In the process it dislodges the pollinia, which become attached to its back [*see lower illustration on preceding page*]. The insect gets another ride on the next flower, but here the pollinia it is carrying are deposited on the sticky stigma.

Some orchids enlist the sexual behavior pattern of an insect to meet their own reproductive needs. In the early part of this century the French investigator A. Pouyanne, working in Algeria, noted that the orchid *Ophrys specu-*



ORCHID SEEDS are shown in relative scale but much enlarged. They include: *a, Paphiopedilum curtisii; b, P. specierum; c, P. parishii; d, Cattleya labiata; e, C. trianaei,* and *f, Odontoglossum pescatorei.* A single orchid flower produces a large number of seeds.

lum, like a legendary temptress, has assumed the shape and odor of an insect to facilitate its pollination. Its flowers resemble the female of the insect *Scolia ciliata.* Male insects attempt to copulate with the flowers; thus pollination is achieved. This phenomenon, called pseudocopulation, is reportedly responsible also for the pollination of the orchid *Ophrys sintenisii,* which is found in Israel.

In the male flowers of the orchid *Cycnoches* a visiting insect of the species *Centris fasciata* trips a trigger mechanism that causes forceful ejection of the pollinia, which become attached to the rear portion of the insect's abdomen. When the insect visits a female flower, the pollinia are caught by two notches on the stigma (which in this instance is not sticky). A similar but more powerful ejection mechanism operates in the orchid genus *Catasetum.*

Orchids of the genus *Coryanthes* have a bucket-like lip filled with a liquid that is apparently somewhat intoxicating. Visiting insects fall into the "bucket" and can get out only by crawling through a narrow opening just below the pollinia [*see upper illustration on opposite page*]. As the insects crawl out they pick up the pollinia and may eventually transport them to other flowers. Still another mechanism employed by orchids is self-pollination. The late Lewis Knudson of Cornell University observed that self-pollination can occur in older flowers of *Cattleya aurantiaca* as a result of the self-digestion of certain parts of the flower [*see lower illustration on opposite page*].

The depositing of pollen on the stigma triggers a series of profound changes in the form of the pollinated orchid flower. Within hours the flower begins to wilt and change color. The column sometimes turns dark red. The petals and sepals may swell. They may become fleshy and develop a pigmentation that is green or red or both.

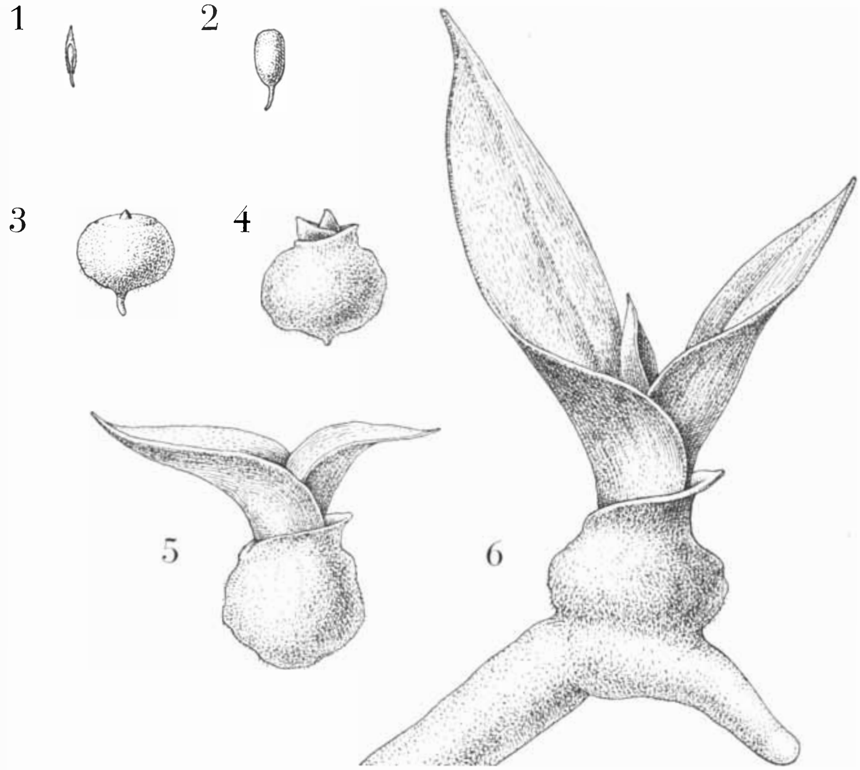
The physiological changes induced by the pollen, although subtler, are no less striking. Pollination stimulates the production of the plant hormone indoleacetic acid. In many orchids the ovules are not fully developed by the time of pollination; in these species pollination induces final development.

After the pollen grains have been deposited on the surface of the stigma, they germinate by forming thin tubes that grow toward the ovarian cavity. This growth proceeds slowly; there may be a considerable lapse of time between pollination and fertilization. In *Gastrodia clata* fertilization may occur after four days; in *Vanda suavis* the period between the two events may be six to 10 months.

When an orchid pollen grain is first deposited on the stigma, it contains two nuclei. On germination one of these divides to form two sperm nuclei. During fertilization one of the sperm nuclei may fuse with the egg nucleus inside the embryo sac. The third nucleus may disintegrate just before or immediately after fertilization. Alternatively it may combine with the "polar" nuclei, two of the eight in the embryo sac, in a process known as triple fusion, to produce the primary endosperm nucleus. In most plants this nucleus gives rise to the endosperm, which is the food-storage tissue of the germinating plant. In the Orchidaceae, however, the endosperm nucleus disintegrates either immediately or after a few divisions. Accordingly orchid seeds do not have an endosperm or any other specialized tissue for food storage. Knudson found that their food reserves are located within the embryo and contain about 32 percent fat and 1 percent sugar but no starch.

The development of the embryo in the Orchidaceae has been described by Carl L. Withner of Brooklyn College and his associate Michael Wirth as being complex and confusing. The reason for their statement is that they have found a large number of variations in the relatively few species they have studied so far. It can be said, however, that as the young embryo develops, its cells do not differentiate, or specialize. As a result the mature orchid seed is a cluster of undifferentiated cells enclosed in a flimsy and often transparent seed coat. The seeds are tiny. According to Hans Burgeff of the University of Würzburg their weight ranges from .3 microgram to 14 micrograms. Their average length is about one millimeter; their diameter probably averages from half a millimeter to three-quarters of a millimeter [*see illustration above*]. The cells in some embryos have been estimated to number as few as 120.

The exceedingly small size of orchid seeds is more than balanced by their vast numbers. Published counts range from 1,330 seeds per capsule in *Coeloglossum viride* to some four million per capsule in a variant of *Cycnoches ventricosum.* Orchids with 750,000 to a million seeds per capsule and three or more capsules per plant are not at all uncommon. Charles Darwin estimated that if the viable seeds produced by a single *Orchis maculata,* an English orchid with 6,200 seeds per capsule and 186,300 per plant, were to germinate and grow to maturity, they would cover an acre. He also estimated that the fourth-generation descendants of the



STAGES IN GERMINATION of a *Cattleya* seed begin (*1*) with a swelling of the embryo inside the seed coat. Succeeding steps are: *2*, embryo growing after it has burst out of the seed coat; *3*, embryo forming a protocorm with a pointed vegetative apex; *4*, the protocorm becoming disklike and showing leaflets; *5*, the protocorm forming a plantlet with two spreading leaves, and *6*, the plantlet forming larger leaves and the start of a root system.

plant would cover the entire globe. Obviously most orchid seeds fail to germinate.

An orchid seed that lands on a suitable growing surface and begins to germinate undergoes several structural changes [*see illustration above*]. It swells and its cells may divide a few times. It acquires a green color. It also develops a tiny structure that resembles a corm, or underground stem with rootlike functions; the structure is called a protocorm. The seed may remain in this condition for as long as 24 months. What it is waiting for, and what in most situations it must have before it can develop further, is the fungus infection I have mentioned.

If the young protocorm does become infected by any one of several species of fungus, it immediately resumes growth and forms a larger, disklike protocorm. This soon develops an apical meristem, a dome-shaped mass of cells that are rapidly dividing. The meristem gives rise to one leaf and later to more leaves. The appearance of roots completes the formation of a miniature orchid plant.

The fungus that penetrates the seed or young protocorm is eventually localized in the roots. It has therefore acquired the name mycorrhiza, from the Greek words for "fungus" and "root." Mycorrhizas are not limited to the Orchidaceae; they are found in many forest shrubs and trees. As knowledge of the subject expands it becomes apparent that such symbiotic relations between different kinds of plants may be the rule rather than the exception.

The existence of mycorrhiza in orchids was apparently first noted in 1824 (by the German naturalist Heinrich Link), but the role of the fungus infection in the germination of orchid seeds remained obscure. In fact, until 1804, when the English botanist Richard Salisbury reported having observed germinating orchid seeds, it was generally believed that these seeds were incapable of germination. In spite of strenuous efforts by horticulturists to induce orchid seeds to grow, the cultivation of orchids remained for many years a haphazard undertaking.

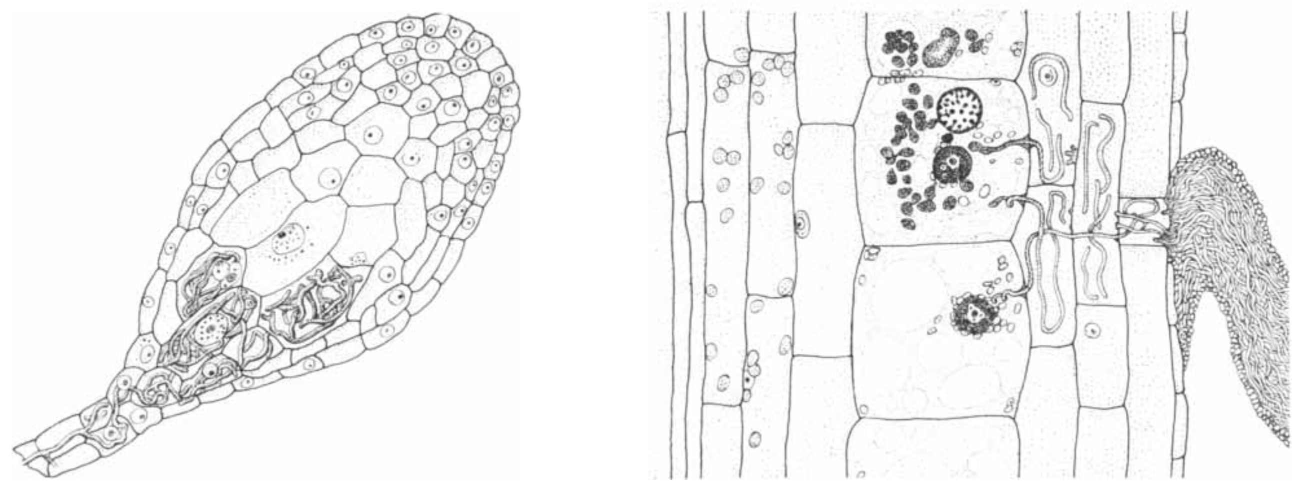
The discovery early in this century that a fungus plays a critical role in the germination of orchid seeds is said to have been made almost accidentally. Noël Bernard, a young French botanist, apparently discovered a clump of germinating seeds of the European bird'snest orchid (*Neottia nidus-avis*) during a stroll in a forest. On examining the seedlings he noted that all of them were infected with a fungus. Bernard advanced the idea that the infection was not parasitic or pathogenic but symbiotic and in fact a necessity for germination of the seed. Supplementing his shrewd insight with imaginative experimentation, Bernard succeeded first in isolating the fungus and then in causing orchid seeds to germinate by infecting them with it.

After Bernard's death in 1911 research on orchid symbiosis was taken up mainly at the University of Würzburg under Burgeff. He and his students found that many fungi are capable of promoting the germination of orchid seeds by penetrating the embryo and influencing its metabolic activity. The work of Bernard and Burgeff made possible the germination of orchid seeds in the laboratory. The method used by both men was to put seeds and fungus simultaneously in culture tubes. Most of the seeds died, but a few germinated and grew to maturity. By this time it was commonly believed that an orchid could neither germinate nor grow without its fungus. The British mycologist J. Ramsbottom went so far as to state that an orchid seedling without its fungus is "like *Hamlet* without the Prince of Denmark."

One investigator who was doubtful about the universal validity of this dictum was Knudson. He speculated that the fungus may contribute no more to the orchid than some enzymes that can break down polysaccharides—sugar polymers such as starch or cellulose—and other compounds, thereby making possible their utilization by the orchid as food. To test this hypothesis Knudson placed orchid seeds on a mixture of sugar and mineral nutrients. The seeds germinated and the seedlings grew.

Knudson's achievement did not convince all those who believed that orchids could not grow normally without fungus infection. Several critics argued that Knudson's seedlings were abnormal and would not produce flowering orchids. Knudson responded by growing an orchid plant from seed to flower on his culture medium with no mycorrhizal fungus present in the roots.

Knudson's experiments demonstrated that an orchid can exist without its fungus, but his findings did not elucidate the role of the fungus. That remains uncertain. It is possible, as Knudson speculated, that the fungus merely contributes its enzymes. If that is so, all orchid seeds should germinate on mix-



FUNGUS INFECTION that normally must occur before an orchid seed will germinate fully is shown in two stages. At left a fungus has penetrated a seed. Later the fungus takes up a permanent association with the root, as indicated at right in a depiction of a small section of root. The symbiotic association of fungus and orchid is called mycorrhiza from the Greek words for "fungus" and "root." The fungus apparently contributes certain enzymes and perhaps some vitamins and hormones that the orchid needs for development.

tures of sugar and minerals. The fact is that some orchid seeds do not germinate on Knudson's medium or similar ones, or on media containing highly purified sugars. Seeds planted in such media have responded, however, to the addition of fungus extracts, various other plant extracts and certain vitamins.

It may be, then, that the fungus is contributing more than its enzymes. Perhaps it supplies the seeds and seedlings with certain hormones, vitamins or other growth factors. Many investigators have studied the effect of vitamins on germinating orchid embryos. In most cases their investigations were designed to answer questions other than what role the fungus plays—questions relating to such matters as the embryology of flowering plants in general or to purely horticultural matters such as how to germinate more orchid seeds and achieve better growth of seedlings. In most of these studies it has been shown that the *B* vitamin niacin (nicotinic acid) promotes the germination of seeds and the growth of seedlings.

I have thought it worthwhile to explore this matter further, particularly with a view to explaining more fully the function of the fungus in the growth of orchids. The pathways by which most living things manufacture niacin have been thoroughly studied; they are well understood in mammals and in a few birds, some fungi and certain bacteria. The mode of synthesis of niacin in green plants, however, is obscure. Most of the evidence brought forward so far is contradictory, probably in part because the plants studied have not been appropriate for the experiments. It seemed to me that orchid seeds, being deficient in storage tissues and reserves of growth-promoting factors, were particularly well suited to such an investigation.

One approach commonly used to study what ingredients go into the synthesis of a vitamin and what pathways are taken in the process is to provide the organism with radioactively labeled ingredients that might be used in the synthesis and to follow the labeled intermediates through whatever synthetic pathways they take. It is also possible to provide an organism with unlabeled intermediates and look for evidence that they have indeed been used as precursors of the end product. This evidence can appear either in the form of improved growth rates or as increased amounts of the end product (or some of its precursors and metabolic products) in the experimental organism.

Because none of the labeled intermediates of the kind needed to experiment with niacin metabolism in orchids as I wanted to approach the problem were available commercially at the time, and because it was impractical for me to make them, I adopted the second approach. I placed orchid seeds on media containing the suspected precursors of niacin and also on some media that contained niacin and some that did not. Comparing the growth and differentiation of the seedlings on all media, I found that the experiments indicated that the synthesis of niacin in orchids may, at least in part, proceed along a pathway similar to that found in mammals and in the bread mold *Neurospora crassa*. The findings suggest that the fungus does indeed have a role in supplying vitamins to the orchid seedling.

I mentioned briefly that orchid seeds have been used by many investigators in experiments designed to yield new information on the embryology of flowering plants. The seeds are useful for this purpose because of their special structure, unique mode of development and peculiar requirements for germination. The use of culture media with varied components showed some time ago that young orchid seedlings prefer ammonium to nitrate as a source of nitrogen. Recently John G. Torrey of Harvard University, working with V. Raghavan, conducted experiments indicating that *Cattleya* seedlings cannot utilize nitrate until they are 60 days old, simply because they lack the necessary enzyme: nitrate reductase. At an age of 60 days the seedlings start to produce the enzyme and become capable of utilizing nitrate.

This finding can be taken as evidence that a subtle biochemical differentiation can occur in the young seedlings. The implications go far beyond orchids. Such findings open up avenues of research on the mechanism of differentiation, the role of the genetic code in it and the relation between the differentiation and the code in terms of the selective activation or suppression of genes. These avenues of research may lead in turn to further understanding of the anatomical and chemical changes that occur in living things as they grow.

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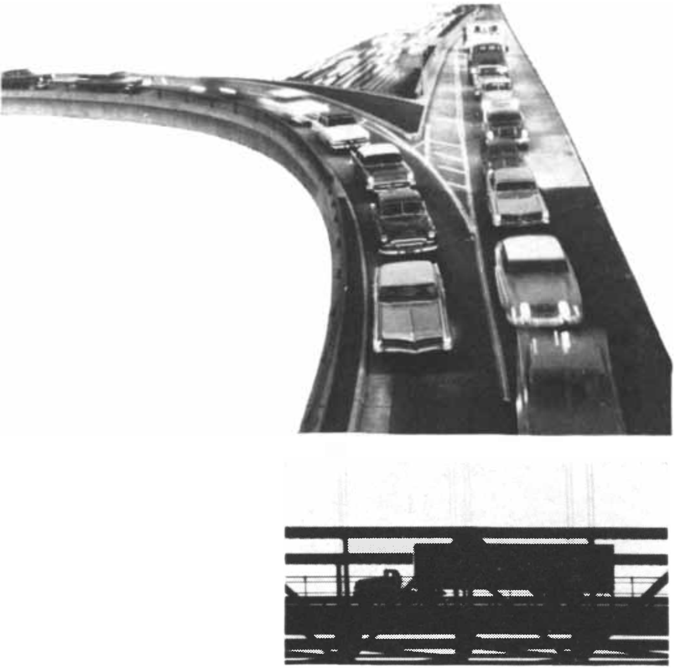

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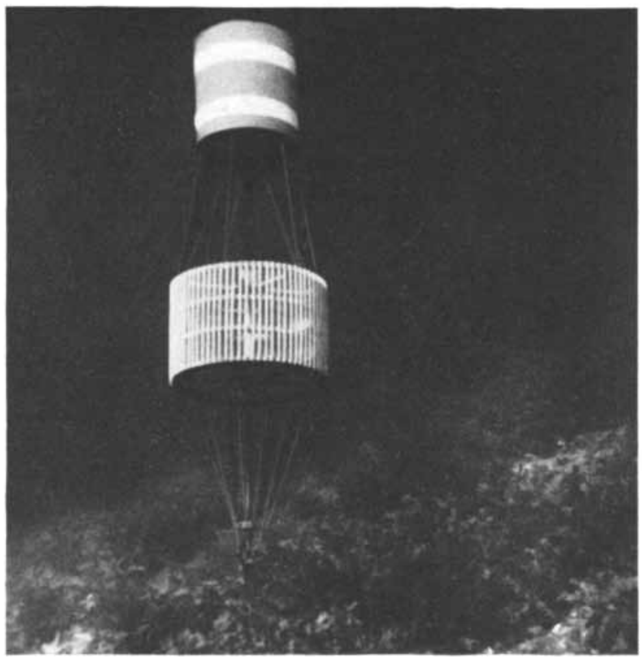

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Chemistry at High Velocities

Chemical change is classically studied as it occurs at minimum energies. "Hot" atoms, colliding at higher energies, yield new reactions and a broader view of the nature of chemical change

by Richard Wolfgang

It is a simple matter for a schoolboy, a housewife or a chemist to cause a chemical reaction. One heats the ingredients and hopes for the best. By this means one can make steel from iron ore and coke, gasoline from petroleum, water from hydrogen and oxygen and an omelet from eggs. In each case as the temperature rises the molecules and atoms move more rapidly and collisions between them become more vigorous. Eventually a certain energy threshold is reached and a reaction occurs. Increasing the temperature further will increase the number of collisions in which there is enough energy, and so the reaction goes faster. It nonetheless remains the same reaction, at least at ordinary temperatures.

For example, heating hydrogen with methyl fluoride within "normal" thermal limits invariably produces this result: $H + CH_3F \rightarrow H_2 + CH_2F$. Why only this reaction? Why do we not see any of the other conceivable reactions between the substances? Instead of plucking a hydrogen atom out of the methyl fluoride, the hydrogen reactant might displace the fluorine atom: $H + CH_3F \rightarrow F + CH_4$. The reason this reaction and the other possible reactions do not occur at ordinary temperatures is that they require a great deal more energy than is provided by ordinary heating.

In recent years investigators have explored the higher realms of energy and uncovered a new world of chemistry. Many kinds of reactions previously unknown have been produced. The study of "hot chemistry" is greatly widening our view of the nature of chemical change and reaction. Moreover, hot chemistry has become a matter of special interest because chemical reactions in extraterrestrial space—on the surface of the moon and in the upper atmospheres of planets and stars—appear to be largely hot reactions.

The idea of hot chemistry and its beginnings as a field of study can be traced back to before World War II [see "Hot Atom Chemistry," by Willard F. Libby; SCIENTIFIC AMERICAN, March, 1950]. It is only in the past decade, however, that experimental techniques and interpretations of results have advanced sufficiently to give a clear outline of the nature of hot reactions. Although the discipline is now entering a period of rapid growth, it is still in its infancy.

In view of the fact that chemists have been studying reactions systematically for a century or more, one might ask why it took so long to get around to investigating those that occur above thermal or threshold energies. In physics the study of nuclear reactions went the opposite way: from high energy to lower energy. Physicists began by investigating nuclear reactions at energies of many millions of electron volts; only recently have they proceeded to detailed studies of reactions produced by mere heating (thermonuclear reactions). The reason is obvious: high-energy nucleons (protons and neutrons) and nuclei could be produced with relative ease by means of accelerators or nuclear reactors, but it is quite difficult to create in the laboratory the temperatures required for thermonuclear reactions.

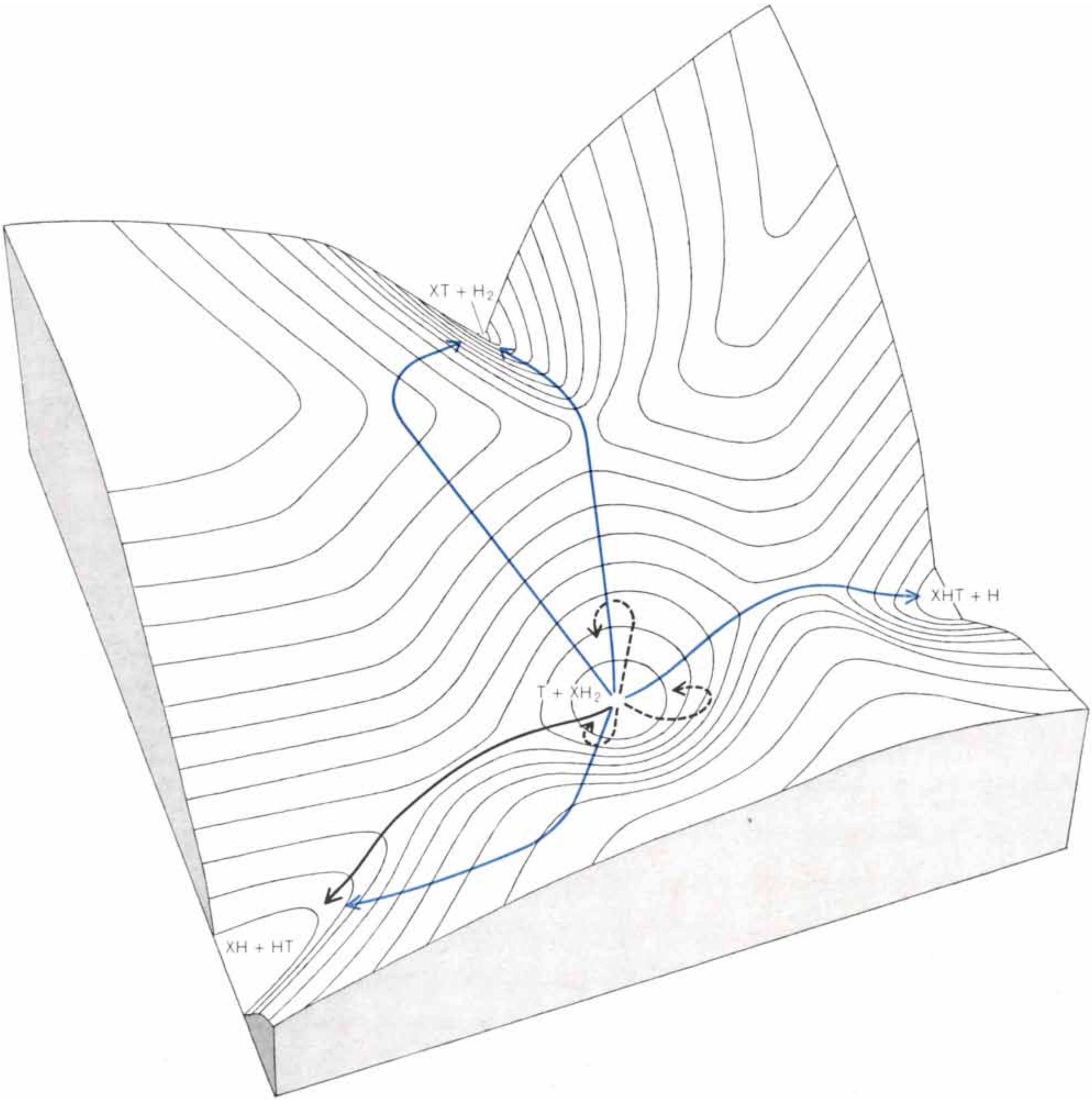
In chemistry, by contrast, the very ease with which reactions can be induced by heating has tended to make the chemist forget that this method restricts him to low-energy reactions and makes accessible to him only a narrow band in the full spectrum of chemical processes. In any case, until quite recently there has been no effective way to study hot chemical reactions. It is not simply a matter of heating the reactants to higher temperatures. At temperatures now attainable in shock waves and plasma devices—10,000 degrees centigrade and higher—hot reactions will occur. Even in a simple system, however, so many reactions can then proceed at once, involving not only the reactants but also the products, that it is extremely difficult to sort out what is actually going on and to identify and characterize the individual hot processes. These difficulties effectively discouraged chemists from exploring the high-energy portion of the chemical-reaction spectrum.

What opened the subject to detailed study was the arrival of a convenient method for obtaining individual hot atoms without heating the other reactants. It then became possible to observe the reactions of high-velocity atoms with substances that were otherwise stable because they were at normal temperature. The hot atoms could be produced, as Libby pointed out in his *Scientific American* article, by means of nuclear reactions that yield new atoms of high kinetic energy. For example, when the nucleus of helium 3, consisting of two protons and a neutron, absorbs a slow neutron, it is transformed into tritium, the radioactive isotope of hydrogen (hydrogen 3), with the emission of a proton: $He^3 + n \rightarrow p + T$. (For convenience we shall designate tritium T instead of H^3.) The vigorous emission of the proton gives the tritium a high recoil energy, amounting to about 200,000 electron volts.

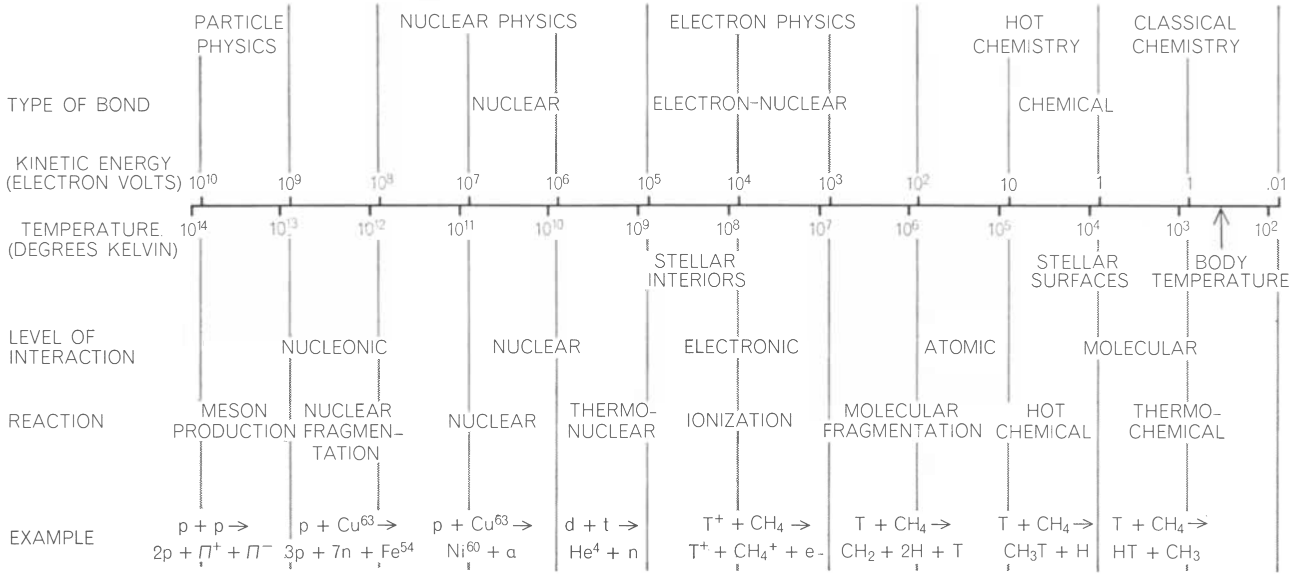
At that high energy the tritium at first behaves just like an alpha particle that has been emitted by a radioactive nucleus. Charging through matter, it will make a track—ionizing, exciting and disrupting molecules in its path. In the process of making this high-speed journey the tritium, which may originally have been produced as an ion, is converted to an atom in its lowest energy state. As long as it retains an excessive kinetic energy of thousands or hundreds of electron volts, however, it is not itself very interesting to the chemist. Its only reactions are to fragment and excite the molecules it encounters, and it does so in a way that cannot be called chemically specific because other fast particles do about the same thing.

Only after the tritium atom has been slowed by collisions to a kinetic energy of 10 electron volts or less does it begin to combine chemically with other substances. This energy level, roughly corresponding to the typical strength of a chemical bond (about five electron volts), is the realm of hot atom chemistry. (Most of the ordinary chemical processes induced by simple heating occur at less than one electron volt.) A tritium atom with an energy of several electron volts will produce the type of reaction, such as displacement of the fluorine atom from methyl fluoride, that never occurs in ordinary chemistry at the "thermal" level.

Let us consider an experiment in detail. We shall examine the reactions of hot hydrogen atoms (tritium atoms obtained from the transformation of helium 3) with methane (CH_4). We mix a small amount of helium 3 with methane



CHEMICAL REACTIONS are pictured in this highly schematic illustration as routes through a mountain range; the height of a pass or a mountain is analogous to the energy barrier for the reaction. The lowest-energy, or threshold, route (*black line*) leads over the lowest pass to only one destination. In contrast, extra energy makes it possible to cross higher passes or even the ridges, and to reach any destination (*colored lines*). By analogy, a thermal tritium atom (*T*) interacting with a hypothetical substance XH_2 can produce only XH + HT. Moreover, the reaction's efficiency is low: it must hit the pass just right or it will fail (*broken black lines*). A hot atom, on the other hand, can surmount the energy barrier at any point, reaching all product destinations with high efficiency.



HOT CHEMISTRY is placed in a "spectrum" of the various types of interaction in the physical universe. The temperatures at which particles have certain kinetic energies are shown. As the energy increases, more elementary particles can interact, ranging from molecules to nucleons, and the type of reaction varies from classical chemistry's molecular collisions to the processes of particle physics. The symbols π, *p*, *d*, *t* and α denote respectively pi mesons and the nuclei of hydrogen, deuterium, tritium and helium 4.

gas in a quartz ampule and irradiate the mixture with neutrons in a nuclear reactor. The irradiation must not be too long or too intense; otherwise it would decompose a substantial amount of the methane. A mild exposure will be sufficient, because we need only a tiny amount of tritium (about a trillion atoms, or five trillionths of a gram) in view of the fact that we shall be able to find the tritium in the reaction products by means of its radioactivity.

After a short time we remove the ampule from the reactor and make a search for the products of tritium's reactions with methane. We can separate the products from one another by gas chromatography, that is, by sending the contents of the ampule through a tube packed with a material that passes the various substances at different speeds, so that they come out separately at the other end. There a radiation counter detects and measures the amount of each tritium-labeled substance produced in the ampule.

How can we tell which of these products arose from hot reactions? Although some tritium atoms will react with methane molecules while they are still "hot," many may be reduced by collisions all the way to ordinary thermal energies. Such thermal atoms react quite slowly, but they do react eventually, either with the methane or with trace amounts of impurities that are inevitably present. The thermal products thus formed confuse the issue because one cannot always be sure that they were not actually produced in hot reactions.

We can eliminate the confusion by one of two devices. One is to get rid of the thermal tritium atoms before they have a chance to react with the methane or the impurities. This can be done by means of a "scavenger" substance, such as iodine or bromine, that reacts rapidly with thermal hydrogen atoms. As little as .1 percent of iodine in the mixture will remove nearly all the slow tritium. This small amount has a negligible effect on the hot reactions, which can occur only in the few collisions experienced by the hot atom when it has the right energy just before it is slowed to thermal velocities. These few collisions are unlikely to involve a scavenger molecule.

The second device, which is even more effective in distinguishing hot reactions, employs the opposite tactic. We can eliminate hot reactions by diluting the reaction mixture with a large amount of an inert "moderator" such as helium, neon or argon. The hot atom will then lose energy mostly in collisions with this moderator and is unlikely to encounter a molecule with which it can react before being slowed to thermal speeds. Just as a moderator in a nuclear reactor is used to slow neutrons to thermal energies before they react, so the moderator in this case ensures that nearly all the tritium atoms will reach low energy before reacting. Again as in a neutron reactor, atoms of a mass similar to that of the hot atoms should be most effective. This is what has been found. Helium is the best moderator for tritium, with the heavier neon, krypton and argon being less effective [*see illustration on page 86*]. The results of experiments with and without moderators can be compared; since the moderation procedure only enhances thermal reactions, the elimination of a given product is a certain indication that it was made by a hot process.

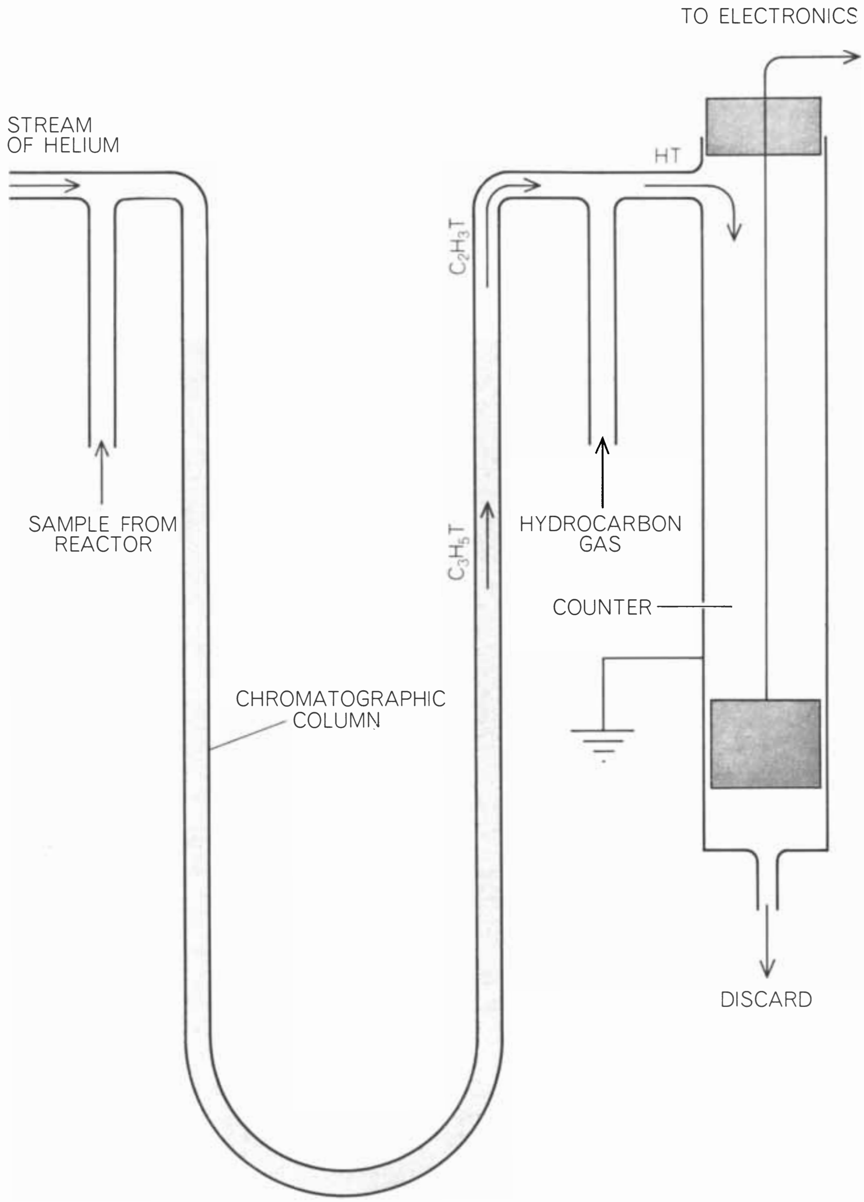
In our laboratory at Yale University the first experiments with tritium and methane showed striking differences between the results of thermal reactions and those involving hot atoms. Ordinarily atomic hydrogen reacts with methane only by abstracting a hydrogen atom from it to form molecular hydrogen. The reaction goes $H + CH_4 \rightarrow H_2 + CH_3$, or, if we use tritium as the hydrogen reactant, $T + CH_4 \rightarrow HT + CH_3$. A hot hydrogen atom, on the other hand, is capable of reactions other than this one. It can insert itself into the compound by displacing bound hydrogen atoms: $T + CH_4 \rightarrow CH_3T + H$, or $T + CH_4 \rightarrow CH_2T + 2H$. Thus the hot reaction of tritium produces not only radioactively labeled molecular hydrogen (HT) but also labeled methane (CH_3T) and methyl radical (CH_2T).

These results are quite reasonable. Thermal atoms with minimal energy can react only by the mode that has the lowest energy threshold, in this case abstraction. Hot atoms, however, can react by all possible modes, regardless of their energy threshold. Hence totally new reaction paths are found.

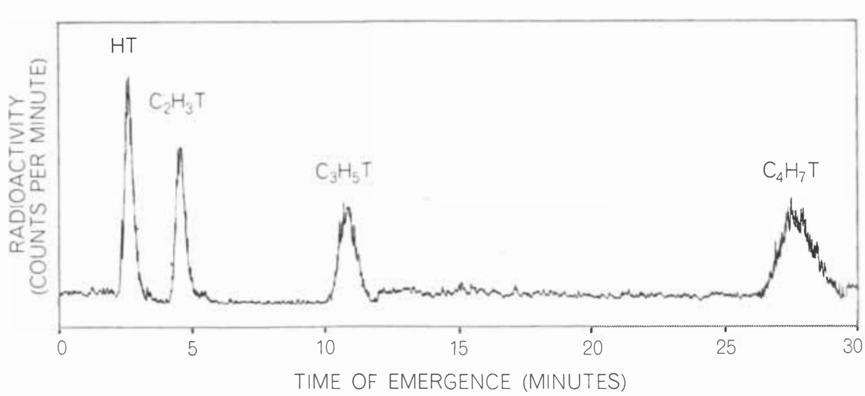
Such results give us a larger perspective on chemical reactions in general. We can picture the scheme of chemical reactions as a mountain range traversible by various passes leading to different destinations [*see illustration on page* 83]. At ordinary thermal energies there is only one way to get over the mountain: the reaction route goes inevitably over the lowest pass and only one possible product can be reached. If, on the other hand, the reaction system is raised to high energy, every pass and mountain can be surmounted, and so all the product destinations can be reached. The mountain analogy not only is intuitively illuminating but also has proved useful in theoretical calculations of reaction probabilities, because it serves as a model of the potential energies that control all chemical change. (This usually requires elaboration to many dimensions to represent the many spatial factors that are involved.)

The model also suggests a notable difference between hot reactions and reactions of minimal energy. A high-energy system would be expected to be able to cross the potential-energy mountain range on nearly every encounter, whereas a low-energy system would require many tries before it finally found the lowest pass. This means that hot reactions should be much more efficient, and experiment shows this to be the case. The probability of reaction in a collision between a hot hydrogen atom and a methane molecule is of the order of one in 10 or higher, whereas at the lowest reaction threshold only about one collision in 10,000 is effective. This difference in efficiency can be readily understood in terms of the actual mechanics of the collision. An atom at threshold energy must strike a molecule from exactly the right direction and in exactly the right spot if its minimal energy is to be sufficient to achieve a reaction. The probability of that occurring is of course quite low. On the other hand, a hot atom, with its excess of energy, should be able to combine with a molecule with much less regard to where or how it strikes.

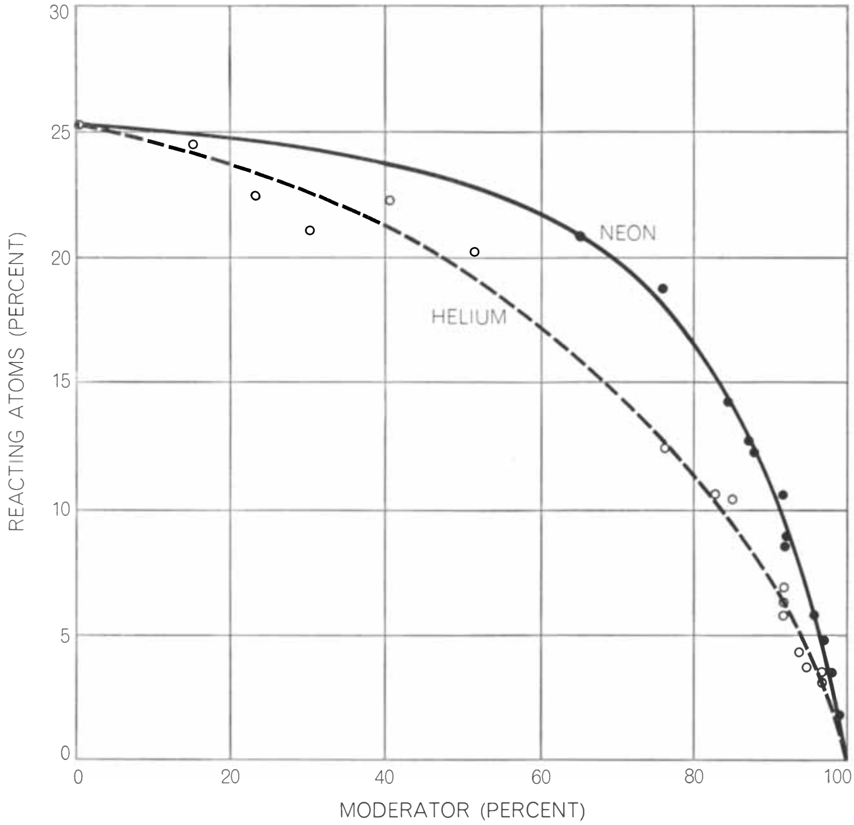
It soon became apparent that although a hot atom might be energetically capable of many possible reactions, not all of them actually take place, and even among those that do there are



ANALYSIS of hot reactions is accomplished by separating products through gas chromatography and then measuring them with a radiation counter. Helium gas carries the products through a column of coated firebrick powder, which passes different products at different speeds. Emerging in sequence, the products are measured by a radiation counter (*right*) that detects tritium. The hydrocarbon gas improves the counter's performance.



RADIATION COUNTER provides a record indicating the amount of each tritium-labeled product. Products are identified by their known speeds of passage through the column.



HOT REACTIONS are moderated by an inert gas added to the reactants. The graph shows how increasing the proportion of neon (*black dots*) or helium (*open circles*) decreases the percentage of hot atoms undergoing the reaction $T + CH_4 \rightarrow CH_3T + H$. As expected, helium, which has a mass closer to tritium's than does neon, is the more effective moderator.

some that under certain circumstances may be strongly discriminated against. Thus the notion that since energetically anything *can* happen everything *does* happen found no support in the early experimental results. Obviously there are some very specific factors that control the paths of hot processes. These factors are of such a nature as to be in large measure quite new to chemistry. Investigations with hot hydrogen atoms in particular have yielded some enlightenment on the nature of such factors.

Consider the various observed reactions between propane ($CH_3CH_2CH_3$) and hot hydrogen [*see illustration on opposite page*]. The most striking feature of this list of products is that 90 percent of the reactions seem to involve the rupture of only a single bond of the molecule. The dynamics of the situation suggests an explanation. We know that hot atoms generally enter into reactions when they have an energy between about one and 10 electron volts. At that energy a tritium atom is moving very fast: it takes the atom only about 10^{-14} second to travel a distance corresponding to the size of a molecule. Any collision between the small, high-speed hydrogen atom and the comparatively large propane molecule must be fast and highly localized; it directly affects only one or two bonds in the immediate area of impact. Atoms remote from the collision site do not "feel" the impact because it takes longer than 10^{-14} second for energy to be transferred down the molecule by the propagation of vibrations from bond to bond. In this light it is not surprising to find that in most cases a hot hydrogen atom apparently breaks only one bond when it combines with the propane molecule.

If only a few bonds are involved in a collision, it also follows that the amount of energy that can be transferred is limited to what can be stored as vibrational energy in these bonds. This means that the product acquires only a modest amount of excitation energy and is unlikely to undergo further extensive decomposition. The experimental results bear out such a conclusion. Thus in the reaction of tritium with propane, if the initial product containing tritium, say $CH_3CH_2CH_2T$, were highly excited, it would be expected to break apart into molecules such as ethylene (CH_2CHT) or acetylene (CHCT). There is, however, virtually no yield of such fragment molecules. F. S. Rowland and his co-workers at the University of Kansas have estimated the excitation energy remaining in certain molecules produced by hot-tritium-atom reactions by measuring the extent to which these molecules subsequently do decompose. They find that typically the excitation energy is only about five electron volts—just about the amount of vibrational energy a single bond can take up without rupturing.

These considerations make clear why hot atoms at energies above 10 electron volts are generally incapable of entering into a chemical reaction. Because a hot atom interacts strongly with only a few bonds in the molecule it strikes, the more energetic atoms simply cannot dispose of enough of their energy to be able to stop and combine. All they can do in a collision is knock a fragment from the molecule.

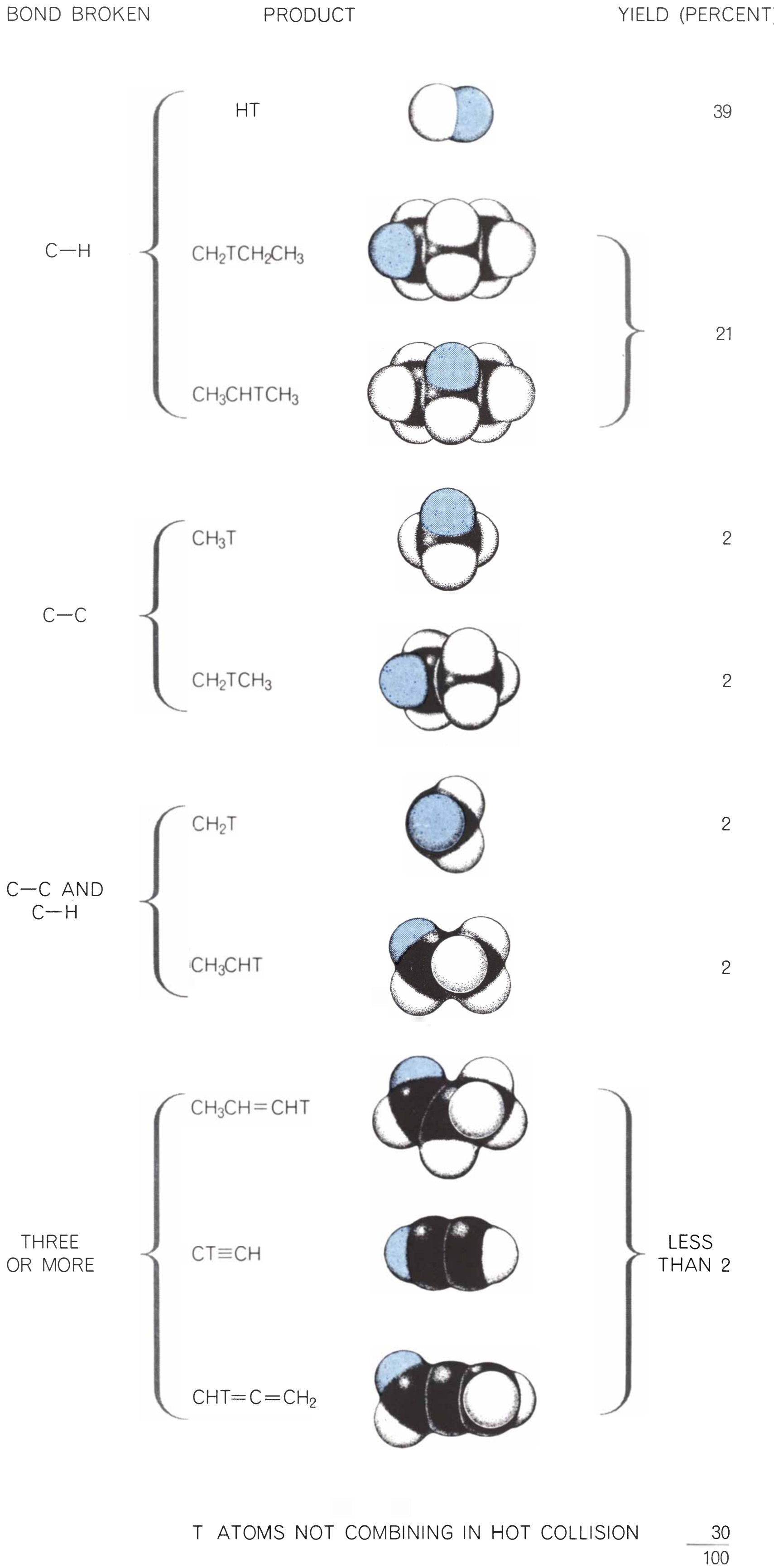
Given these basic concepts of hot atom collisions and interactions, we can visualize the several types of hot reaction [*see illustration on page 88*]. Here it is assumed that the path of the reaction is determined by just where and from what direction the hydrogen atom strikes the molecule—considerations termed steric factors. The importance of such factors is apparent in many results indicating that certain bonds seem to be relatively shielded from attack and that others are exposed. Thus the bonds between carbon atoms, although weaker than those between carbon and hydrogen, are less often broken, apparently because they are better protected by surrounding atoms. In the case of propane 60 percent of the yield in reactions with hot tritium atoms consists of HT and C_3H_7T, whose production involves the rupture of C-H bonds; on the other hand, the products C_2H_5T and CH_3T, which require the rupture of C-C bonds, account for only 4 percent of the yield. Taking into account the relative abundance of the two kinds of bond (six to two), the result is that a hot reaction is five times likelier to involve breaking a C-H bond than a C-C bond.

The steric factor is also important in ordinary chemistry, of course, but with this significant difference: in hot atom chemistry the direction of attack by the reactant determines which of several possible reactions will occur. In low-energy chemistry it determines if any reaction will take place.

The general scheme I have outlined so far accounted satisfactorily for most of the experimental results. There were, however, some phenomena it did not explain. For example, although a hot hydrogen atom readily replaces a bound hydrogen atom at the site of attack, it almost never combines with the molecule by the "inversion" mode: by occupying a bond made available through ejection of a bound atom on the opposite side of the molecule [*see "a" in illustration on next page*]. This was puzzling because theoretical calculations indicated that the available energy is quite sufficient to allow such an event. Another puzzle was that a hot tritium atom was much likelier to replace a fluorine atom in a molecule containing one fluorine than in a molecule containing two fluorines, that is, the reaction $T + CH_3F \rightarrow CH_3T + F$ had a threefold higher yield than $T + CH_2F_2 \rightarrow CH_2TF + F$. Still another group of peculiar observations is typified by results of attack on a C-C bond in a molecule such as neopentane, $C(CH_3)_4$. In this compound a central carbon atom is bonded to four methyl (CH_3) groups. If a hot tritium ruptures one of the C-C bonds, it could combine with either of the groups at the ends of that bond: CH_3 or $C(CH_3)_3$. In actuality it shows a strong preference for combining with the lighter group, forming much more CH_3T than $C(CH_3)_3T$.

It turned out that all these apparent oddities could be explained on the basis of a concept that is without precedent in the kinetics of thermal reactions. The idea is simply that a hot collision can be so fast that the inertia of the heavier atoms in the molecule that is struck is too great for them to move rapidly enough to make some reactions possible.

Consider the inversion reaction. The attack of a hot hydrogen atom can have the effect of ejecting the hydrogen bound to the other side of the carbon atom that is struck. However, the hot hydrogen atom cannot itself be bound until a valence bond becomes available at the site of its impact. This cannot occur until the atoms or groups of atoms bound by the other three valences have undergone their inversion, because the carbon atom can bind four other atoms strongly only if they are arranged around it in a tetrahedron. The "relaxation time" required for such a motion of heavy atoms is of the order of 10^{-13} second. The time required for

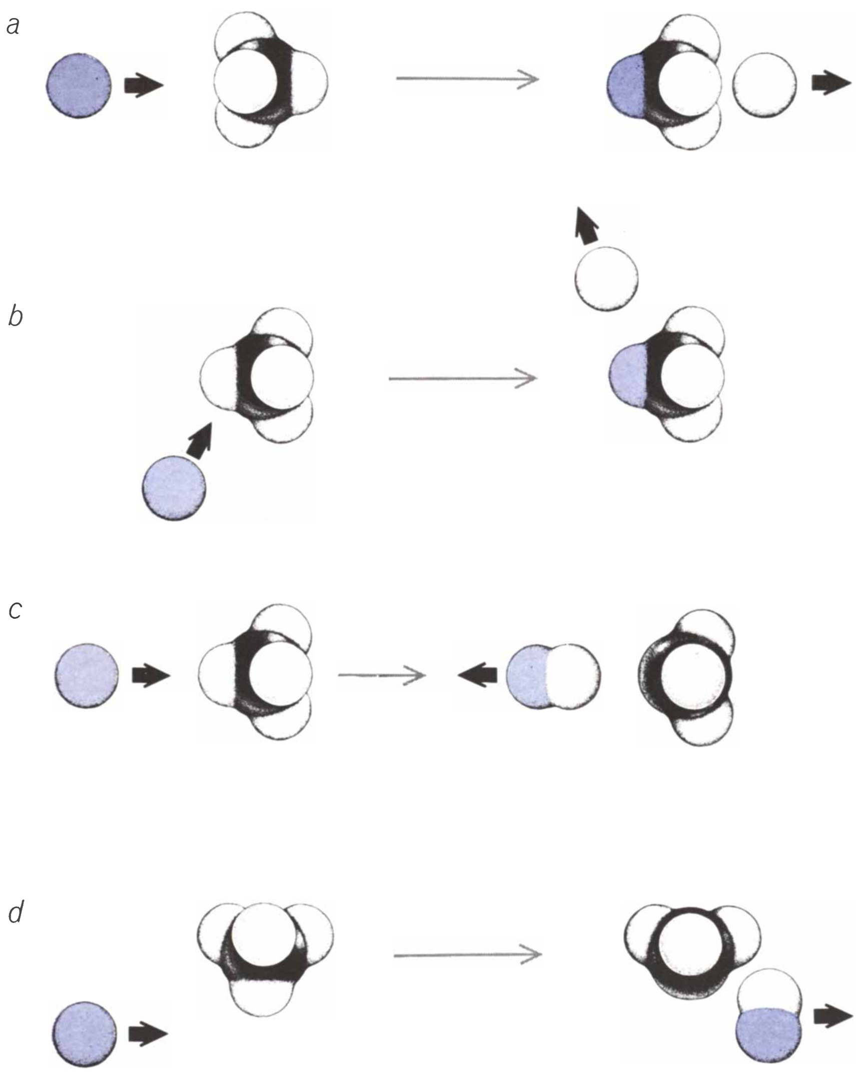


PRODUCTS AND YIELDS of the reaction of hot hydrogen, or tritium (*T*), with propane are listed. Usually only a single bond in propane is broken, tritium (*color*) substituting for displaced atoms. Only 30 percent of the hot atoms fall to a thermal level without reacting.

the hot hydrogen to arrive and rebound is, on the other hand, only about 10^{-14} second, so that it escapes before the inversion is completed and a valence bond becomes available to capture it. No such difficulty exists in hydrogen replacement by the noninversion mode [*see "b" in illustration below*]. The incoming hydrogen is captured by the bond vacated by the ejected atom, with no motion of electrons or other atoms required.

The replacement of fluorine by hot tritium in methyl fluoride (CH_3F) is somewhat more complex. The incident tritium atom can break the C-F bond, but the fluorine atom, because of its relatively large mass, cannot be pushed out of the way in the time of collision. This would seem to make it difficult for the valence bond that had bound the fluorine to capture the tritium before it escapes. The three hydrogen atoms also bound to the central carbon are so light, however, that they can reorient themselves within the collision period, enabling the bond to move and bind the tritium atom in a strong tetrahedral configuration [*see illustration on page 90*].

Now suppose there is another fluorine atom in the compound instead of a hydrogen, as in CH_2F_2. Since this second fluorine also cannot move rapidly, the reorientation of the valence bonds to provide quickly a strong tetrahedral bond for the incident atom is much more difficult. The hot hydrogen may be able to displace one of the



STERIC FACTORS, or where the hot atom strikes and from what direction, strongly influence the path of the reaction. Possible modes of reaction are shown here for a tritium atom and various hydrocarbons. In substitution with inversion (*a*) the hot atom occupies a bond made available by ejection of an atom on the other side of the molecule; in normal substitution the displaced atom is at the site of the attack (*b*). In abstraction the hot atom can pull an atom away as it rebounds axially from the molecule (*c*) or strip it off in passing (*d*).

fluorines, but it cannot readily be captured in its place. Interestingly enough, a similar effect occurs when the hydrogen in methyl fluoride is the isotope deuterium (H^2, or D), which is lighter than tritium but heavier than common hydrogen. The deuterium atoms have an inertia sufficiently greater than that of common hydrogen to make the probability of replacing fluorine with hot tritium 20 percent lower in CD_3F than in CH_3F.

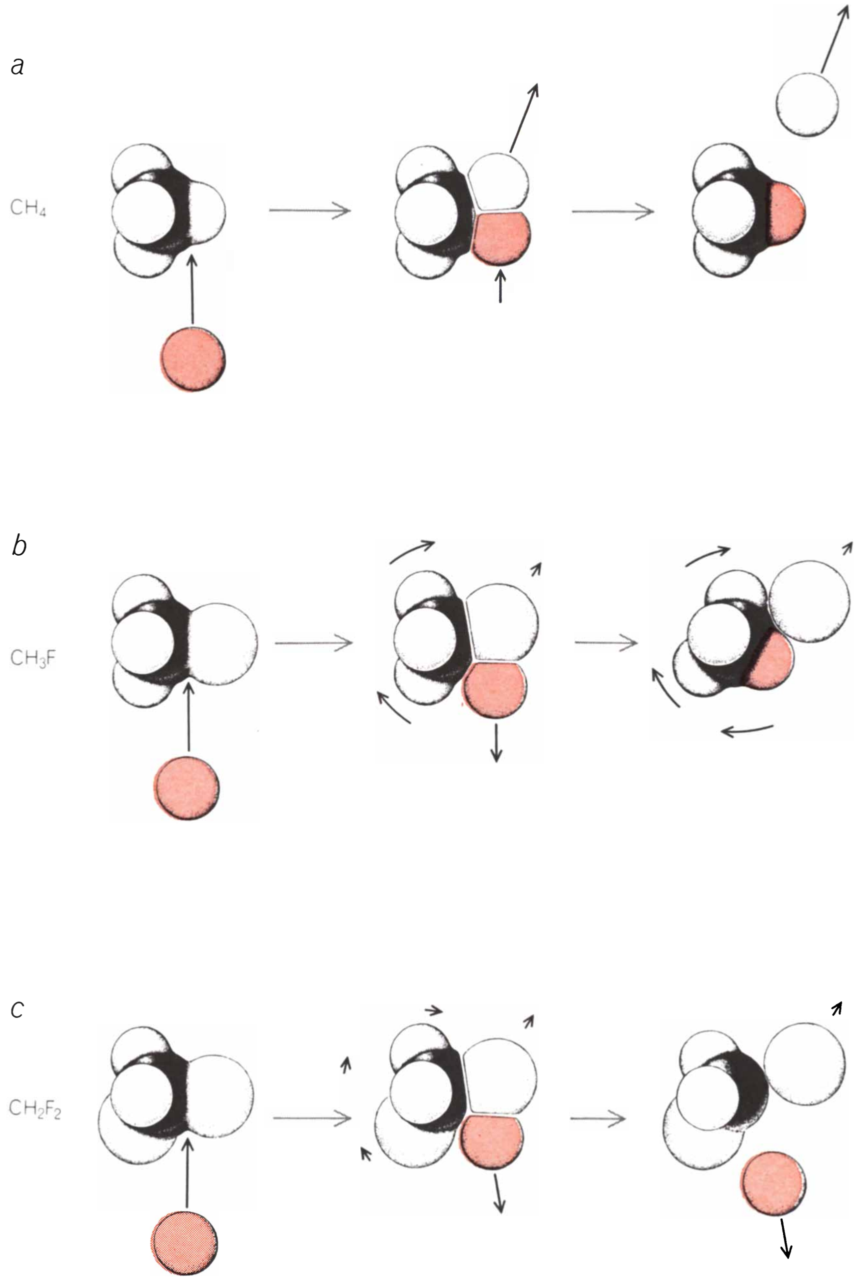
Clearly this same inertial factor must apply in the attack of hot hydrogen on a C-C bond in neopentane: $C(CH_3)_4$. As this bond is being broken, the hydrogen atoms around one carbon atom can move much more easily than the CH_3 groups around the other to provide a strong tetrahedrally oriented bond to capture the tritium. It is therefore not surprising that the yield of CH_3T is much larger than that of $C(CH_3)_3T$.

So far the work in hot atom chemistry has been concentrated mainly on hydrogen. We have only fragmentary information about the behavior of hot atoms of other elements. Some experiments we have done with hot fluorine in the form of the radioactive isotope fluorine 18 (F^{18}) show much the same pattern as experiments with hydrogen. There are, however, two important differences: the efficiencies of the reactions are lower and a larger proportion of them involve the rupture of more than one bond. This is reasonable, since the hot fluorine atom is somewhat bigger and, because of its greater mass, also much slower than a hydrogen atom with the same amount of energy. Since its collision with a molecule is therefore slower and less localized, more of the molecule's bonds can absorb the energy of the impact. With the energy distributed more widely in the molecule, it is less likely that any one bond will receive enough energy for rupture; consequently reaction is less probable than it is with hydrogen. On the other hand, if a reaction does take place, the immediate product is quite likely to be left with enough energy of excitation to break a second bond. For instance, the reaction of a hot fluorine atom with carbon tetrafluoride (CF_4) results in the rupture of two bonds (to form CF_2F^{18}) almost as frequently as in the replacement of only a single atom (to form CF_3F^{18}). Although this interpretation may be plausible, it is unlikely to be the whole story; we do not yet have enough information to tell.

Hot carbon atoms have been studied

rather more thoroughly and present a very different picture. Atomic carbon is one of the most reactive of all chemicals; for this reason very little has been known about its properties. It was therefore necessary to investigate the reactions of individual carbon atoms at ordinary thermal energies (below one electron volt) as well as at high energies. This was done by using neon as the moderator to slow hot carbon atoms to thermal speeds. In contrast to the case of hydrogen, the experimental results showed that the spectrum of reactions of carbon atoms at high energies is not markedly different from that at the thermal level. The reason is simply that the highly reactive carbon atom, with its four valence sites for binding, has a very low threshold for almost all the possible reactions, and hence the reactions take place at ordinary thermal energies. Raising the energy of the carbon atom to several electron volts will increase the efficiency of these reactions, but it introduces few new ones.

There has recently been considerable interest in a field related to hot-atom chemistry: the chemistry of high-velocity ions, which is investigated by mass spectrometric methods rather than by the techniques described in this article. The reactions of hot ions with molecules are apparently dominated by long-range electrostatic forces, but there is evidence that more specific chemical factors, of the kind shown to control reactions involving hot neutral atoms, also play a part.



EFFECT OF INERTIA on the reaction of tritium with methane (*a*), methyl fluoride (*b*) and methylene fluoride (*c*) is shown. In the case of methane a tritium pushes one of the hydrogen atoms away and takes its place in the molecule. The fluorine in methyl fluoride is too massive to be pushed out of the way quickly, but the rotation of the residual CH_3 fragment enables the free bond to capture the tritium. In methylene fluoride, on the other hand, the residual CH_2F fragment has too much inertia for such rapid rotation and fails to capture the tritium atom. The length of its black arrow indicates an atom's velocity.

To sum up, we are dealing here not with a chemical curiosity but with nothing less than a new dimension of chemical kinetics: the energy dimension. In the initial exploration of this new world of chemistry the technique of using hot atoms produced by nuclear reactions has been of decisive importance. It will continue to be of great value as a wider range of hot atoms are explored in greater detail. The technique nonetheless has some distinct limitations. In particular, the fact that it produces atoms reacting over the entire range of energies, while valuable for exploratory studies, makes it virtually impossible to determine the precise effect of a particular energy. Furthermore, the method is restricted to elements with convenient radioactive isotopes and reactions yielding stable products incorporating the hot atom.

The field therefore invites further studies with other techniques, and these are now being developed by several groups. Methods in which two beams of atoms or molecules are made to intersect have been successfully applied to thermal reactions in the past few years and are particularly encouraging, although some formidable technical problems must still be overcome [see "Molecular Beams," by O. R. Frisch; SCIENTIFIC AMERICAN, May, 1965]. Molecular-beam devices should eventually allow the study of reactions of hot atoms, molecules, ions and other molecular fragments, whether or not they yield stable products. It should be possible to control the energy at which the reactive collisions can occur and study the influence of factors such as the speed of rotation and the orientation of the molecule that is struck. With such devices chemists can begin to study chemical reactions in the same kind of detail, and presumably with the same prospect of exciting discoveries, that nuclear physicists have enjoyed in probing the nucleus of the atom with cyclotrons and other nuclear accelerators.

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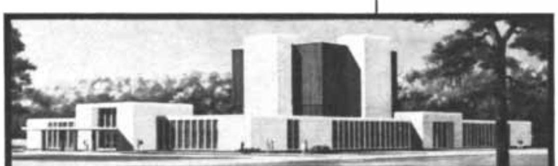

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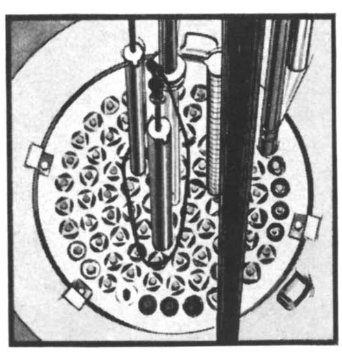

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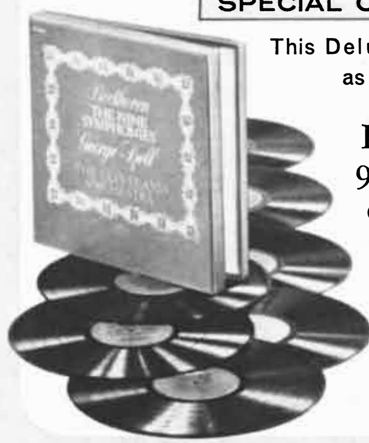

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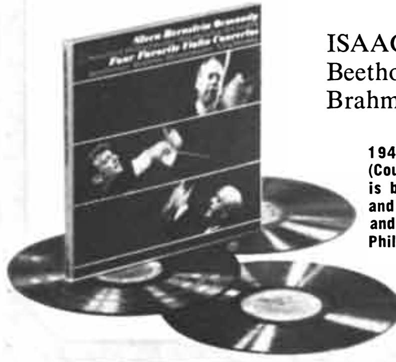

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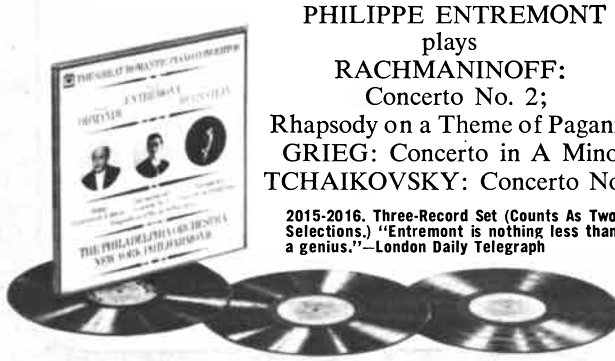

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Adaptations to Cold

One mechanism is increased generation of heat by a rise in the rate of metabolism, but this process has its limits. The alternatives are insulation and changes in the circulation of heat by the blood

by Laurence Irving

All living organisms abhor cold. For many susceptible forms of life a temperature difference of a few degrees means the difference between life and death. Everyone knows how critical temperature is for the growth of plants. Insects and fishes are similarly sensitive; a drop of two degrees in temperature when the sun goes behind a cloud, for instance, can convert a fly from a swift flier to a slow walker. In view of the general hostility of cold to life and activity, the ability of mammals and birds to survive and flourish in all climates is altogether remarkable.

It is not that these animals are basically more tolerant of cold. We know from our own reactions how sensitive the human body is to chilling. A naked, inactive human being soon becomes miserable in air colder than 28 degrees centigrade (about 82 degrees Fahrenheit), only 10 degrees C. below his body temperature. Even in the Tropics the coolness of night can make a person uncomfortable. The discomfort of cold is one of the most vivid of experiences; it stands out as a persistent memory in a soldier's recollections of the unpleasantness of his episodes in the field. The coming of winter in temperate climates has a profound effect on human well-being and activity. Cold weather, or cold living quarters, compounds the misery of illness or poverty. Over the entire planet a large proportion of man's efforts, culture and economy is devoted to the simple necessity of protection against cold.

Yet strangely enough neither man nor other mammals have consistently avoided cold climates. Indeed, the venturesome human species often goes out of its way to seek a cold environment, for sport or for the adventure of living in a challenging situation. One of the marvels of man's history is the endurance and stability of the human settlements that have been established in arctic latitudes.

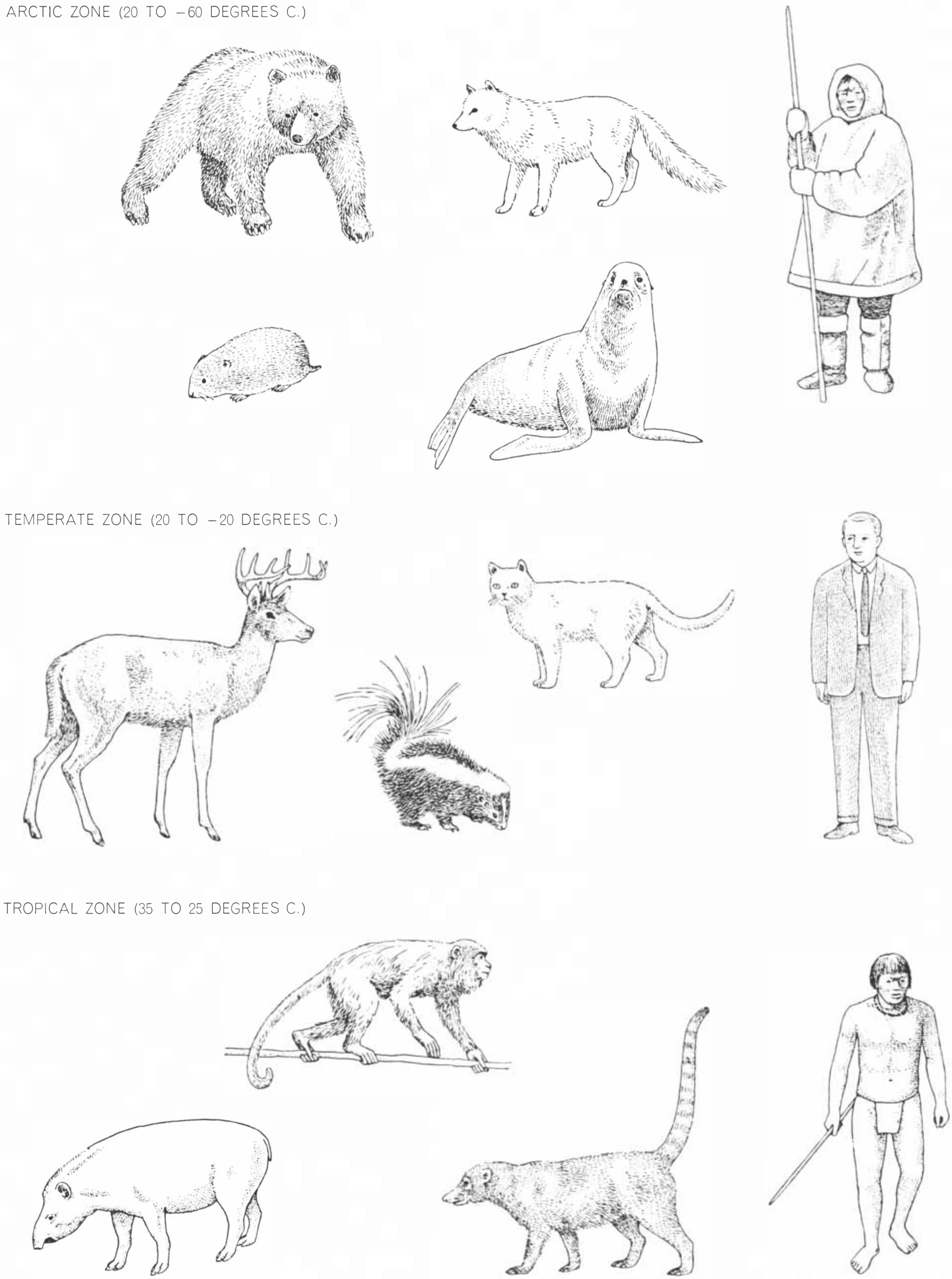
The Norse colonists who settled in Greenland 1,000 years ago found Eskimos already living there. Archaeologists today are finding many sites and relics of earlier ancestors of the Eskimos who occupied arctic North America as long as 6,000 years ago. In the middens left by these ancient inhabitants are bones and hunting implements that indicate man was accompanied in the cold north by many other warm-blooded animals: caribou, moose, bison, bears, hares, seals, walruses and whales. All the species, including man, seem to have been well adapted to arctic life for thousands of years.

It is therefore a matter of more than idle interest to look closely into how mammals adapt to cold. In all climates and everywhere on the earth mammals maintain a body temperature of about 38 degrees C. It looks as if evolution has settled on this temperature as an optimum for the mammalian class. (In birds the standard body temperature is a few degrees higher.) To keep their internal temperature at a viable level the mammals must be capable of adjusting to a wide range of environmental temperatures. In tropical air at 30 degrees C. (86 degrees F.), for example, the environment is only eight degrees cooler than the body temperature; in arctic air at –50 degrees C. it is 88 degrees colder. A man or other mammal in the Arctic must adjust to both extremes as seasons change.

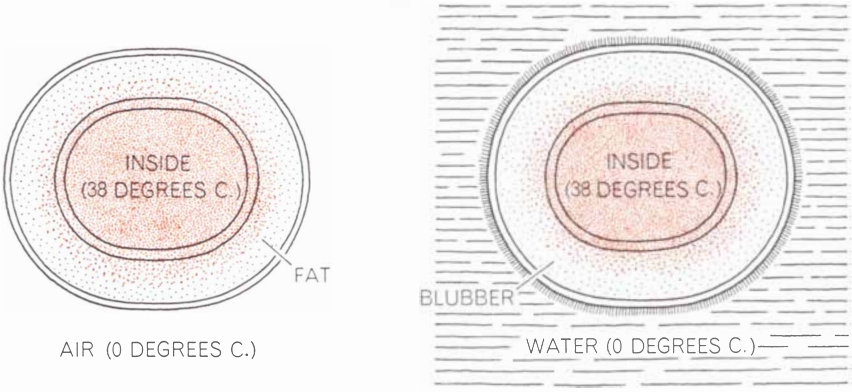
The mechanisms available for making the adjustments are (1) the generation of body heat by the metabolic burning of food as fuel and (2) the use of insulation and other devices to retain body heat. The requirements can be expressed quantitatively in a Newtonian formula concerning the cooling of warm bodies. A calculation based on the formula shows that to maintain the necessary warmth of its body a mammal must generate 10 times more heat in the Arctic than in the Tropics or clothe itself in 10 times more effective insulation or employ some intermediate combination of the two mechanisms.

We need not dwell on the metabolic requirement; it is rarely a major factor. An animal can increase its food intake and generation of heat to only a very modest degree. Moreover, even if metabolic capacity and the food supply were unlimited, no animal could spend all its time eating. Like man, nearly all other mammals spend a great deal of time in curious exploration of their surroundings, in play and in family and social activities. In the arctic winter a herd of caribou often rests and ruminates while the young engage in aimless play. I have seen caribou resting calmly with wolves lying asleep in the snow in plain view only a few hundred yards away. There is a common impression that life in the cold climates is more active than in the Tropics, but the fact is that for the natural populations of mammals, including man, life goes on at the same leisurely pace in the Arctic as it does in warmer regions; in all climates there is the same requirement of rest and social activities.

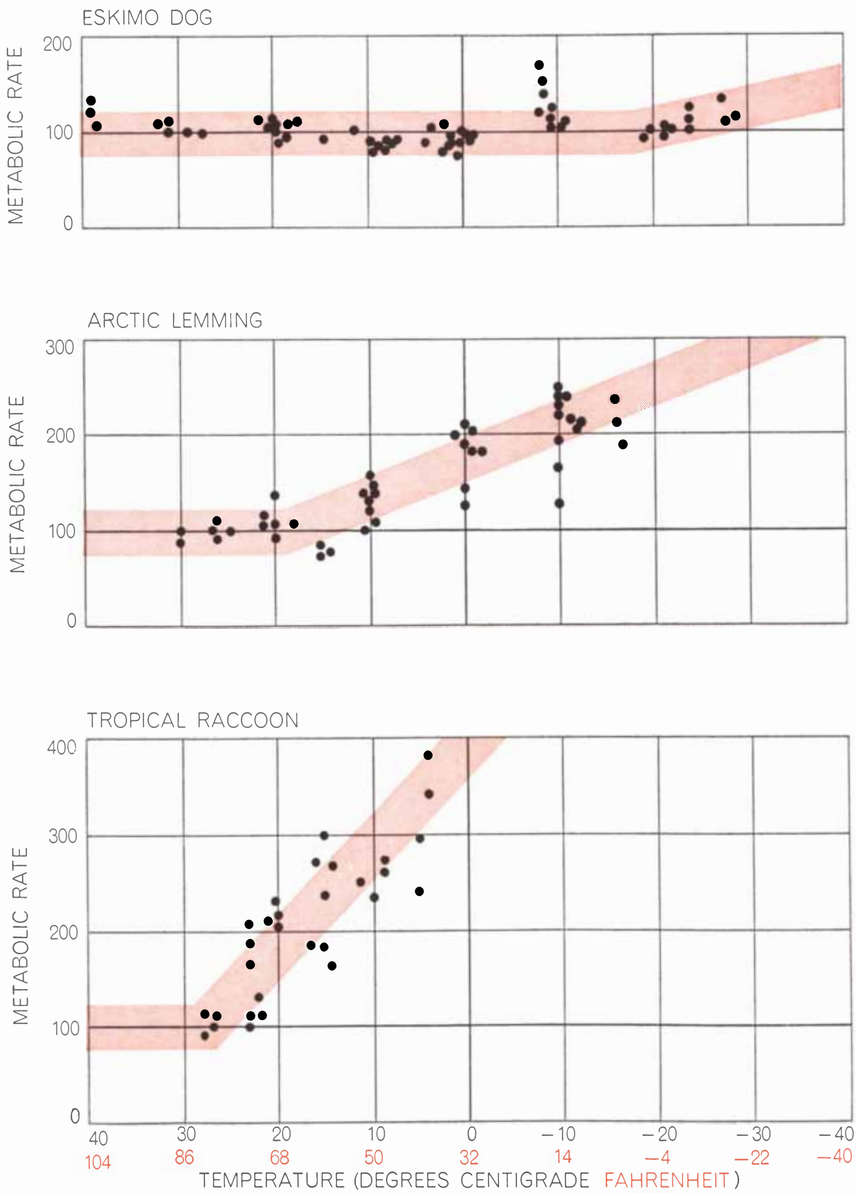
The decisive difference in resisting cold, then, lies in the mechanisms for conserving body heat. In the Institute of Arctic Biology at the University of Alaska we are continuing studies that have been in progress there and elsewhere for 18 years to compare the



RANGE OF TEMPERATURES to which warm-blooded animals must adapt is indicated. All the animals shown have a body temperature close to 100 degrees Fahrenheit, yet they survive at outside temperatures that, for the arctic animals, can be more than 100 degrees cooler. Insulation by fur is a major means of adaptation to cold. Man is insulated by clothing; some other relatively hairless animals, by fat. Some animals have a mechanism for conserving heat internally so that it is not dissipated at the extremities.



TEMPERATURE GRADIENTS in the outer parts of the body of a pig (*left*) and of a seal (*right*) result from two effects: the insulation provided by fat and the exchange of heat between arterial and venous blood, which produces lower temperatures near the surface.



RATE OF METABOLISM provides a limited means of adaptation to cold. The effect of declining temperatures on the metabolic rate is shown for an Eskimo dog (*top*), an arctic lemming (*middle*) and a tropical raccoon (*bottom*). Animals in warmer climates tend to increase metabolism more rapidly than arctic animals do when the temperature declines.

mechanisms for conservation of heat in arctic and tropical animals. The investigations have covered a wide variety of mammals and birds and have yielded conclusions of general physiological interest.

The studies began with an examination of body insulation. The fur of arctic animals is considerably thicker, of course, than that of tropical animals. Actual measurements showed that its insulating power is many times greater. An arctic fox clothed in its winter fur can rest comfortably at a temperature of –50 degrees C. without increasing its resting rate of metabolism. On the other hand, a tropical animal of the same size (a coati, related to the raccoon) must increase its metabolic effort when the temperature drops to 20 degrees C. That is to say, the fox's insulation is so far superior that the animal can withstand air 88 degrees C. colder than its body at resting metabolism, whereas the coati can withstand a difference of only 18 degrees C. Naked man is less well protected by natural insulation than the coati; if unclothed, he begins shivering and raising his metabolic rate when the air temperature falls to 28 degrees C.

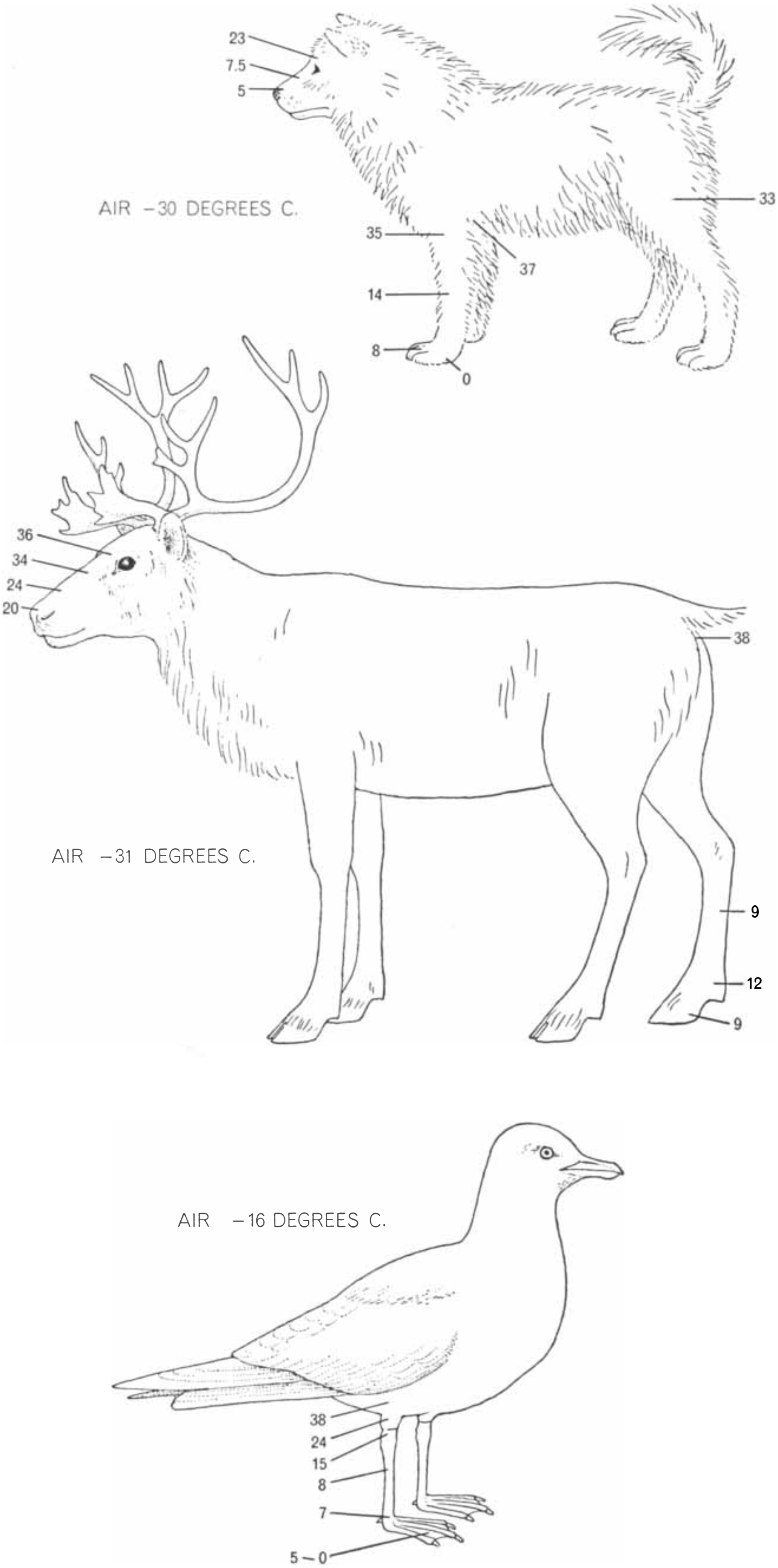
Obviously as animals decrease in size they become less able to carry a thick fur. The arctic hare is about the smallest mammal with enough fur to enable it to endure continual exposure to winter cold. The smaller animals take shelter under the snow in winter. Weasels, for example, venture out of their burrows only for short periods; mice spend the winter in nests and sheltered runways under the snow and rarely come to the surface.

No animal, large or small, can cover all of its body with insulating fur. Organs such as the feet, legs and nose must be left unencumbered if they are to be functional. Yet if these extremities allowed the escape of body heat, neither mammals nor birds could survive in cold climates. A gull or duck swimming in icy water would lose heat through its webbed feet faster than the bird could generate it. Warm feet standing on snow or ice would melt it and soon be frozen solidly to the place where they stood. For the unprotected extremities, therefore, nature has evolved a simple but effective mechanism to reduce the loss of heat: the warm outgoing blood in the arteries heats the cool blood returning in the veins from the extremities. This exchange occurs in the *rete mirabile* (wonderful net), a network of small arteries and veins near the junction between the trunk of the animal and the extremity [see " 'The Wonderful Net,' " by P. F. Scholander; Scientific American, April, 1957]. Hence the extremities can become much colder than the body without either draining off body heat or losing their ability to function.

This mechanism serves a dual purpose. When necessary, the thickly furred animals can use their bare extremities to release excess heat from the body. A heavily insulated animal would soon be overheated by running or other active exercise were it not for these outlets. The generation of heat by exercise turns on the flow of blood to the extremities so that they radiate heat. The large, bare flippers of a resting fur seal are normally cold, but we have found that when these animals on the Pribilof Islands are driven overland at their laborious gait, the flippers become warm. In contrast to the warm flippers, the rest of the fur seal's body surface feels cold, because very little heat escapes through the animal's dense fur. Heat can also be dissipated by evaporation from the mouth and tongue. Thus a dog or a caribou begins to pant, as a means of evaporative cooling, as soon as it starts to run.

In the pig the adaptation to cold by means of a variable circulation of heat in the blood achieves a high degree of refinement. The pig, with its skin only thinly covered with bristles, is as naked as a man. Yet it does well in the Alaskan winter without clothing. We can read the animal's response to cold by its expressions of comfort or discomfort, and we have measured its physiological reactions. In cold air the circulation of heat in the blood of swine is shunted away from the entire body surface, so that the surface becomes an effective insulator against loss of body heat. The pig can withstand considerable cooling of its body surface. Although a man is highly uncomfortable when his skin is cooled to 7 degrees C. below the internal temperature, a pig can be comfortable with its skin 30 degrees C. colder than the interior, that is, at a temperature of 8 degrees C. (about 46 degrees F.). Not until the air temperature drops below the freezing point (0 degrees C.) does the pig increase its rate of metabolism; in contrast a man, as I have mentioned, must do so at an air temperature of 28 degrees C.

With thermocouples in the form of needles we have probed the tissues of pigs below the skin surface. (Some pigs, like some people, will accept a little

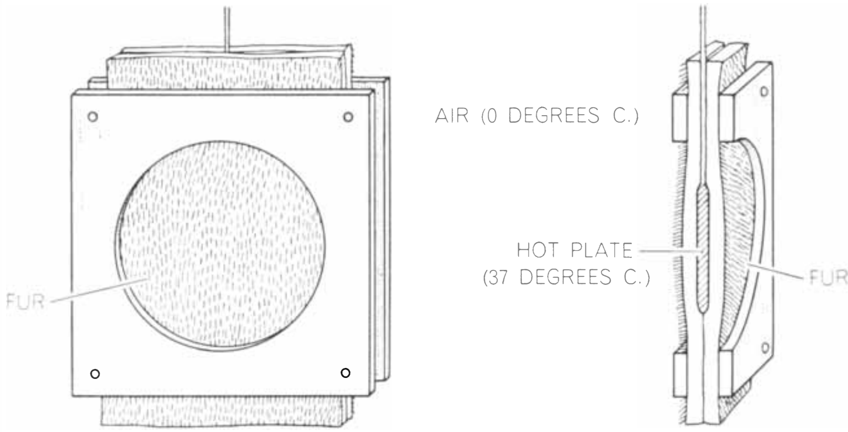


TEMPERATURES AT EXTREMITIES of arctic animals are far lower than the internal body temperature of about 38 degrees centigrade, as shown by measurements made on Eskimo dogs, caribou and sea gulls. Some extremities approach the outside temperature.

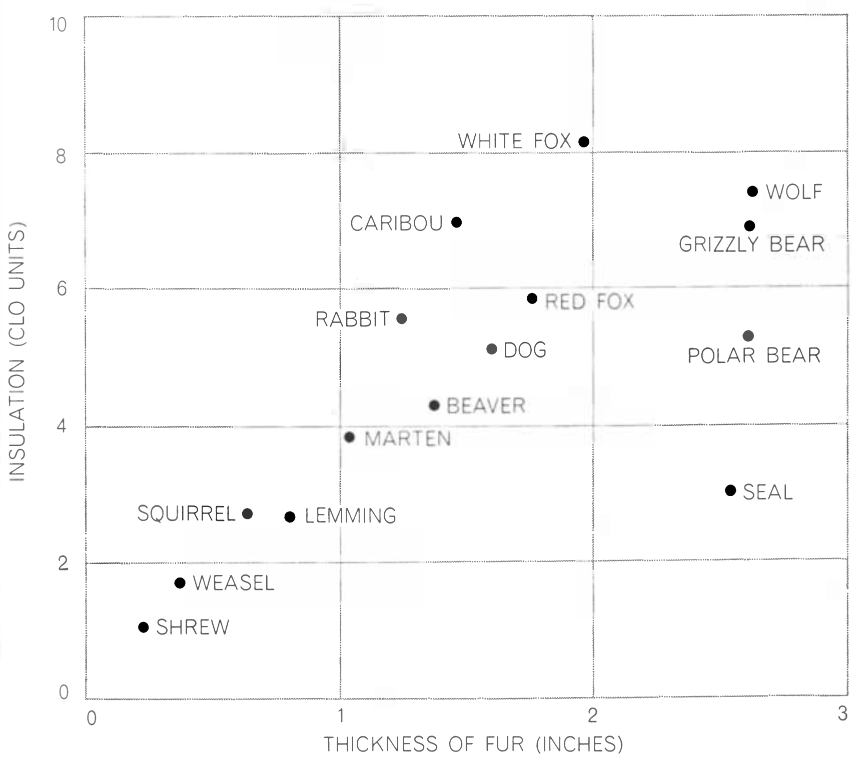
pain to win a reward.) We found that with the air temperature at −12 degrees C. the cooling of the pig's tissues extended as deep as 100 millimeters (about four inches) into its body. In warmer air the thermal gradient through the tissues was shorter and less steep. In short, the insulating mechanism of the hog involves a considerable depth of the animal's fatty mantle.

Even more striking examples of this kind of mechanism are to be found in whales, walruses and hair seals that dwell in the icy arctic seas. The whale and the walrus are completely bare; the hair seal is covered only with thin, short hair that provides almost no insulation when it is sleeked down in the water. Yet these animals remain comfortable in water around the freezing point although water, with a much greater heat capacity than air, can extract a great deal more heat from a warm body.

Examining hair seals from cold waters of the North Atlantic, we found that even in ice water these animals did not raise their rate of metabolism. Their skin was only one degree or so warmer



INSULATION BY FUR was tested in this apparatus, shown in a front view at left and a side view at right. The battery-operated heating unit provided the equivalent of body temperature on one side of the fur; outdoor temperatures were approximated on the other side.



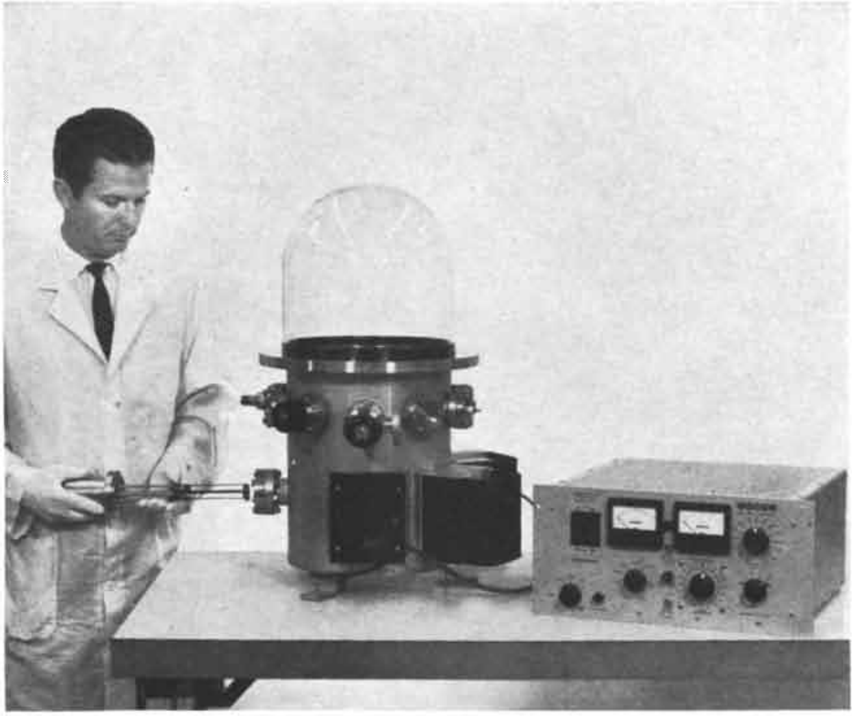
INSULATING CAPACITY of fur is compared for various animals. A "clo unit" equals the amount of insulation provided by the clothing a man usually wears at room temperature.

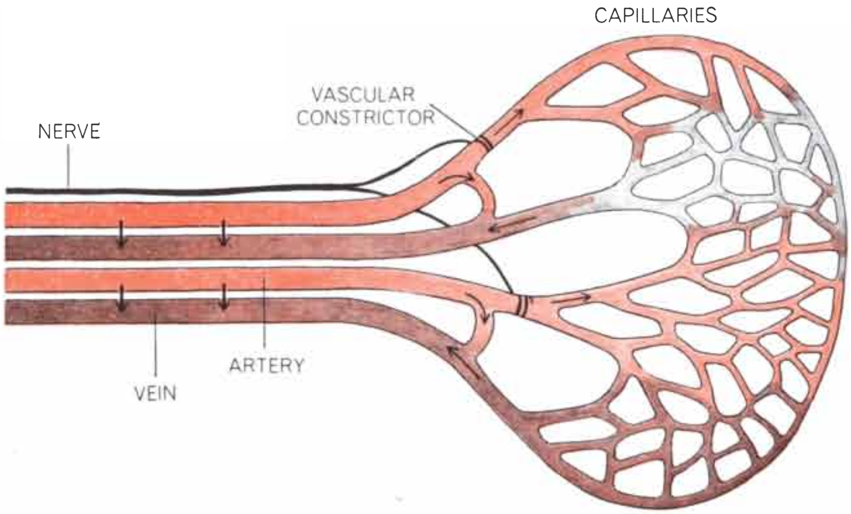
than the water, and the cooling effect extended deep into the tissues—as much as a quarter of the distance through the thick part of the body. Hour after hour the animal's flippers all the way through would remain only a few degrees above freezing without the seals' showing any sign of discomfort. When the seals were moved into warmer water, their outer tissues rapidly warmed up. They would accept a transfer from warm water to ice water with equanimity and with no diminution of their characteristic liveliness.

How are the chilled tissues of all these animals able to function normally at temperatures close to freezing? There is first of all the puzzle of the response of fatty tissue. Animal fat usually becomes hard and brittle when it is cooled to low temperatures. This is true even of the land mammals of the Arctic, as far as their internal fats are concerned. If it were also true of extremities such as their feet, however, in cold weather their feet would become too inflexible to be useful. Actually it turns out that the fats in these organs behave differently from those in the warm internal tissues. Farmers have known for a long time that neat's-foot oil, extracted from the feet of cattle, can be used to keep leather boots and harness flexible in cold weather. By laboratory examination we have found that the fats in the bones of the lower leg and foot of the caribou remain soft even at 0 degrees C. The melting point of the fats in the leg steadily goes up in the higher portions of the leg. Eskimos have long been aware that fat from a caribou's foot will serve as a fluid lubricant in the cold, whereas the marrow fat from the upper leg is a solid food even at room temperature.

About the nonfatty substances in tissues we have little information; I have seen no reports by biochemists on the effects of temperature on their properties. It is known, however, that many of the organic substances of animal tissues are highly sensitive to temperature. We must therefore wonder how the tissues can maintain their serviceability over the very wide range of temperatures that the body surface experiences in the arctic climate.

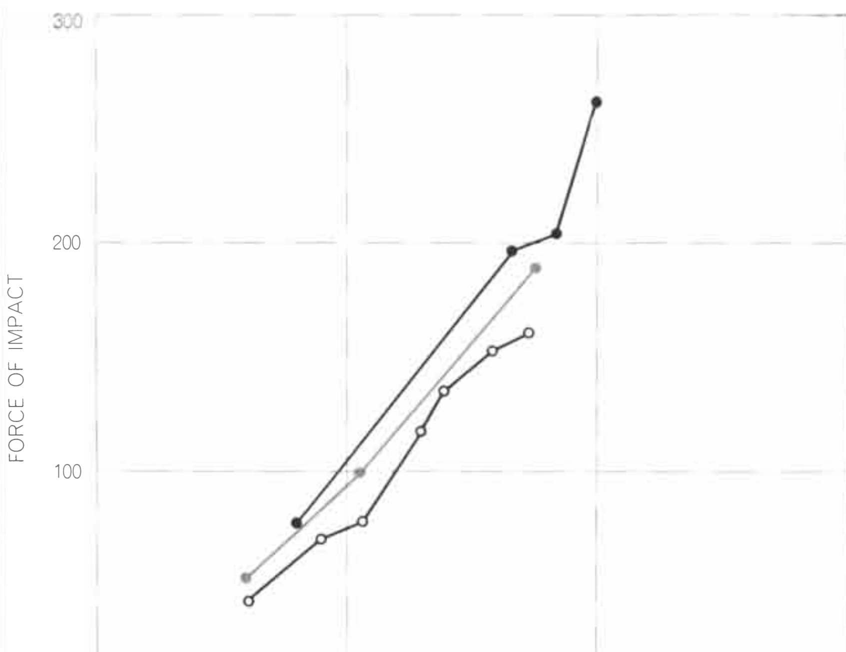
We have approached this question by studies of the behavior of tissues at various temperatures. Nature offers many illustrations of the slowing of tissue functions by cold. Fishes, frogs and water insects are noticeably slowed down by cool water. Cooling by 10 degrees





ROLE OF BLOOD in adaptation to cold is depicted schematically. One mechanism, indicated by the vertical arrows, is an exchange of heat between arterial and venous blood. The cold venous blood returning from an extremity acquires heat from an arterial network. The outgoing arterial blood is thus cooled. Hence the exchange helps to keep heat in the body and away from the extremities when the extremities are exposed to low temperatures. The effect is enhanced by the fact that blood vessels near the surface constrict in cold.

C. will immobilize most insects. A grasshopper in the warm noonday sun can be caught only by a swift bird, but in the chill of early morning it is so sluggish that anyone can seize it. I had a vivid demonstration of the temperature effect one summer day when I went hunting on the arctic tundra near Point Barrow for flies to use in experiments. When the sun was behind clouds, I had no trouble picking up the flies as they crawled about in the sparse vegetation, but as soon as the sun came out the flies took off and were uncatch-



FINGER EXPERIMENT performed by the author showed that the more a finger was chilled, the farther a one-milligram ball had to be dropped for its impact to be felt on the finger. The vertical scale is arbitrary but reflects the relative increase in the force of impact.

able. Measuring the temperature of flies on the ground, I ascertained that the difference between the flying and the slow-crawling state was a matter of only 2 degrees C.

Sea gulls walking barefoot on the ice in the Arctic are just as nimble as gulls on the warm beaches of California. We know from our own sensations that our fingers and hands are numbed by cold. I have used a simple test to measure the amount of this desensitization. After cooling the skin on my fingertips to about 20 degrees C. (68 degrees F.) by keeping them on ice-filled bags, I tested their sensitivity by dropping a light ball (weighing about one milligram) on them from a measured height. The weight multiplied by the distance of fall gave me a measure of the impact on the skin. I found that the skin at a temperature of 20 degrees C. was only a sixth as sensitive as at 35 degrees C. (95 degrees F.); that is, the impact had to be six times greater to be felt.

We know that even the human body surface has some adaptability to cold. Men who make their living by fishing can handle their nets and fish with wet hands in cold that other people cannot endure. The hands of fishermen, Eskimos and Indians have been found to be capable of maintaining an exceptionally vigorous blood circulation in the cold. This is possible, however, only at the cost of a higher metabolic production of body heat, and the production in any case has a limit. What must arouse our wonder is the extraordinary adaptability of an animal such as the hair seal. It swims in icy waters with its flippers and the skin over its body at close to the freezing temperature, and yet under the ice in the dark arctic sea it remains sensitive enough to capture moving prey and find its way to breathing holes.

Here lies an inviting challenge for all biologists. By what devices is an animal able to preserve nervous sensitivity in tissues cooled to low temperatures? Beyond this is a more universal and more interesting question: How do the warm-blooded animals preserve their overall stability in the varying environments to which they are exposed? Adjustment to changes in temperature requires them to make a variety of adaptations in the various tissues of the body. Yet these changes must be harmonized to maintain the integration of the organism as a whole. I predict that further studies of the mechanisms involved in adaptation to cold will yield exciting new insights into the processes that sustain the integrity of warm-blooded animals.

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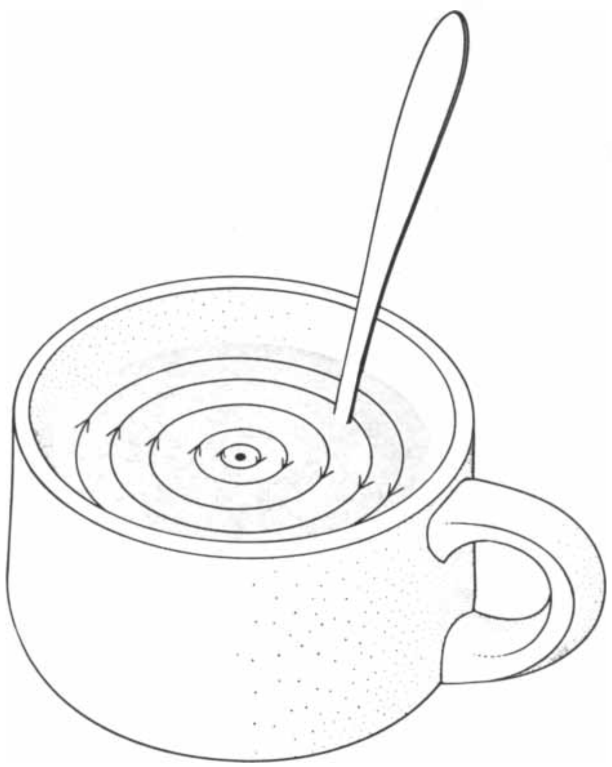
FIXED-POINT THEOREMS

These somewhat implausible laws state that points must reappear in their original positions when the surfaces on which they lie undergo certain deformations. Their practical uses are numerous

by Marvin Shinbrot

If you mark a series of points on a rubber band and then stretch it, the order in which the points appear does not change. This is an intuitively acceptable conclusion of topology: the study of properties that persist when geometric figures are bent, stretched, twisted or otherwise continuously deformed. Other topological facts are not so clear; their validity seems intuitively unacceptable. In this intriguing category are the fixed-point theorems, a group of results concerning points that reappear exactly in their original positions after the surfaces on which they lie have been deformed.

An example will serve to introduce them. Suppose we stir a cup of coffee, in any way and for any length of time but gently enough so that the surface is never disrupted. (As they say in cookbooks, "Stir, do not whip.") According to one of the simplest fixed-point theorems, when we have finished stirring and the motion of the liquid has stopped, at least one point on the surface will be back where it started! Such a point is called a fixed point. A particle at the exact center of the surface would be the fixed point in the simplest case: when the liquid is swirled only in circles. Usually the motion of stirred coffee is more complicated, with any particle susceptible to being moved to any position on the surface. The relevant fixed-point theorem, first proved by



CONTINUOUS DEFORMATION of a geometric surface is represented by the gentle swirling of coffee in which the thin film of cream on top is never disrupted. Here the coffee is being swirled in such a way that the particle in the exact center does not move.

FIXED-POINT THEOREM states that no matter how the surface of the coffee is continuously deformed, there will always be a point on the surface in the position it occupied at the start. This theorem does not stipulate which point is fixed at any instant in time.

the Dutch mathematician L. E. J. Brouwer, does not specify which point remains fixed but only that one or more points must do so.

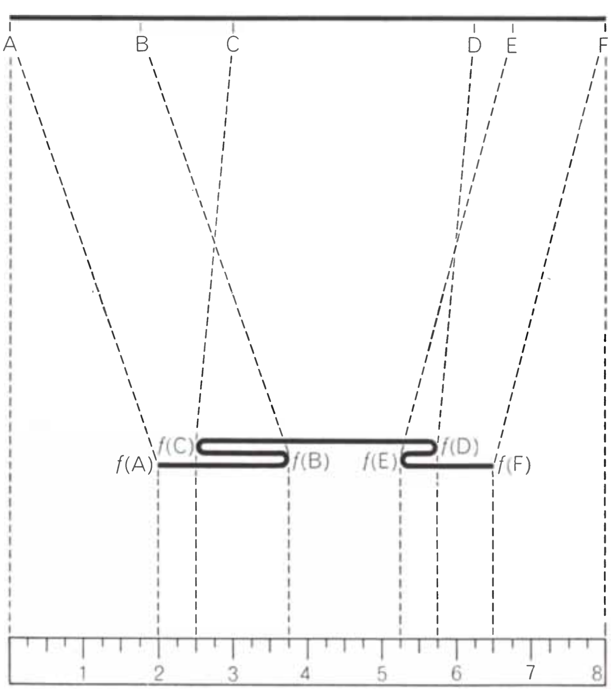
Consider another application of Brouwer's theorem. If this page of *Scientific American* were torn out, crumpled and folded in any way (but not torn) and then placed back on the magazine in such a way that no part of it extended beyond the edges of its original position, then at least one of the points on the crumpled page would lie directly above the spot it originally occupied. This fact, guaranteed by the Brouwer theorem, strikes many people as even more surprising than the certainty of a fixed point on the surface of the coffee. To the mathematician, however, it is more readily explained because the crumpling of a page is a simpler deformation than the swirling of coffee; the paper cannot be stretched, whereas the distance between two points on the surface of the coffee can easily change.

In order to understand how the proof of a fixed-point theorem might be constructed, it is simplest to look not at a two-dimensional surface such as the surface of the coffee or the sheet of paper but at a one-dimensional surface exemplified by a piece of string. Suppose we stretch a string to its full length so that it forms a straight line and then place it on a table. Next we fold the string any number of times and shift it around within the confines of the line made by the straight string. It can now be shown that a point on the string has returned to the exact spot it occupied before the manipulation and is therefore a fixed point. This is the one-dimensional version of the Brouwer theorem.

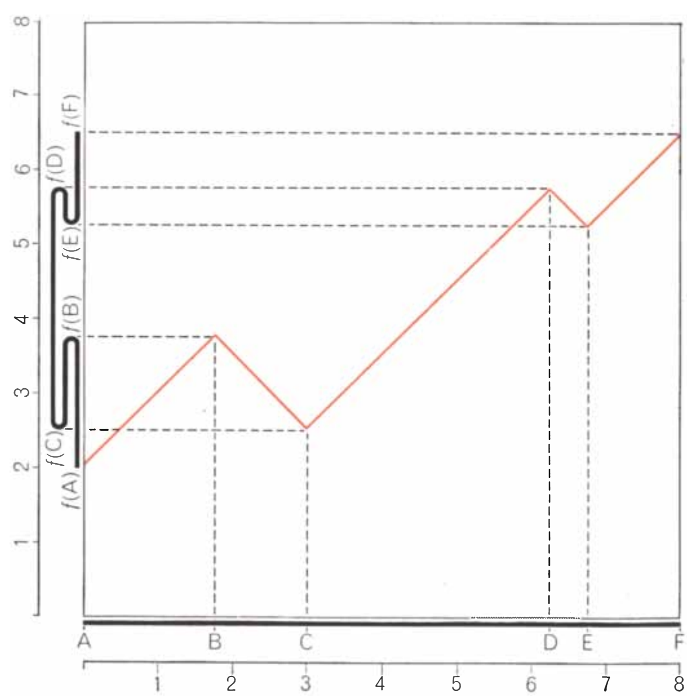
The theorem is proved by representing both the original string and the folded string as curves on a graph, comparing the curves and demonstrating that they intersect at some point [*see illustrations on these two pages*]. To begin, we measure the original straight string. We call the left end zero and specify each point on the string by its distance in inches from the left end. If the string is, say, eight inches long, we can speak of the point at the far right as "point eight." By the same token the position of each point on the folded string can be specified by its new distance from the left end of the string. If a point originally four inches from the left has been moved as a result of the deformation to three inches from the left, its new position is designated simply as "point three."

In this way we define a function, which can be denoted by $f(x)$. The value of this function at any point on the string is the number representing the position to which that point has been moved. Thus if point four is moved to point three, the value of f at four is three; in symbols $f(4) = 3$. To say that some point has not been moved—that is, to say that some point is a fixed point—is just a geometrically appealing way of saying that the equation $f(x) = x$ has a solution.

Now we construct a familiar Cartesian plane and graph the function $f(x)$. In this plane the horizontal axis designates the distance of each point from the left when the string was in its original position, and the vertical axis designates the distance of each point from the left after the string has been folded. On such a graph the point shifted from four to three can be plotted as a point with the coordinates four (on the horizontal axis) and three (on the vertical axis). When all the points on the folded string are plotted in this way, the curve connecting them is a mathematical representa-



FOLDING OF A STRING is a continuous deformation of a one-dimensional surface. Points on an eight-inch string (*top*) assume new positions when the string is folded (*middle*), with point *A*, for example, moving to point designated $f(A)$. A fixed-point theorem states that some point $f(P)$ on the folded string must be as far from the left of the ruler (*bottom*) as point *P* was on the straight string.



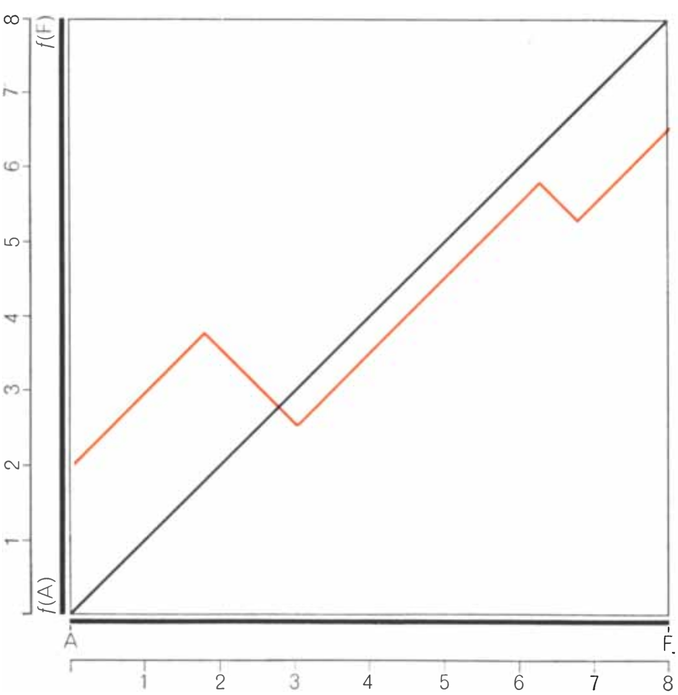
DESCRIPTION OF FOLDED STRING in illustration at left is provided by the jagged curve on this graph. Horizontal axis designates the distance of a point, in inches, from the left end of the original string. Vertical axis designates distance of a point on the folded string from same point on the original. Thus point *C* has the coordinates three (horizontal axis) and 2.5 (vertical axis).

tion of the physical folding of the string. This curve may be extremely complicated, but it has two nice and particularly significant properties. It lies entirely within one quadrant of the Cartesian plane; indeed, it lies within the square having zero to eight on the horizontal axis as its base. This is ensured by the fact that the deformed string was never moved off the original eight-inch segment; therefore the function $f(x)$ describing the deformation can be neither negative nor greater than eight. Moreover, the curve is continuous; since the string was not broken in the process of deformation, there are no breaks in the curve describing that deformation. These two properties of the curve suffice, as we shall show, to guarantee that the string has a fixed point.

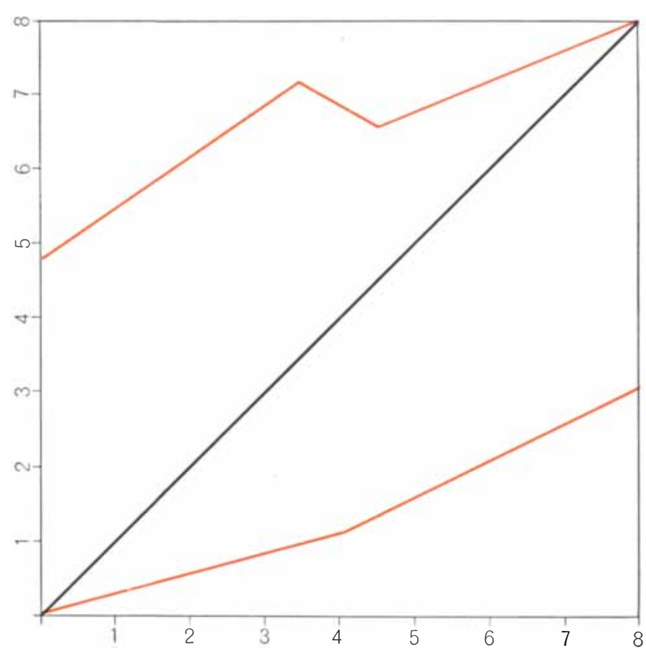
We know how to represent the folded string as a curve on a graph; we now have to demonstrate that if the original, undeformed string were also represented as a curve, the two curves *must* intersect. This is not difficult to show. Assume that we have picked up the straight string and returned it, still straight, to its original position. Even though it has not changed shape, we can consider that it has undergone a deformation and we can plot the function corresponding to this deformation. If we plot the "new" distances from the left end against the old, we get points that are equidistant from the two axes—points with coordinates one and one, two and two and so forth. When we connect these points, we have in fact drawn the diagonal of the square built on the base of zero to eight on the horizontal axis.

Now, recall the curve that represents the folded string. It must by definition begin at zero (the left side of our square) and end at eight (the right side). It also must lie between zero and eight on the vertical axis and can have no breaks. To get from one side of the square to the other it is necessary that this curve cross, or at least touch the diagonal. The only way for the curve representing the folded string not to cross the diagonal is for it to begin at the lower left corner of the square or end at the upper right corner. The first case, however, merely implies that point zero is a fixed point, and the second that point eight is fixed. Therefore in all cases there is some point of intersection between the two curves and thus a fixed point on the deformed string. This would hold true, incidentally, even if, instead of the string, we had used an elastic material such as rubber, provided only that the deformed piece was not broken and was replaced so as not to lie outside the position occupied by the undeformed piece. The only difference that the use of rubber would make is that the curve representing the stretched piece need not consist of line segments—as the representation of the folded string must—but may have a curved shape.

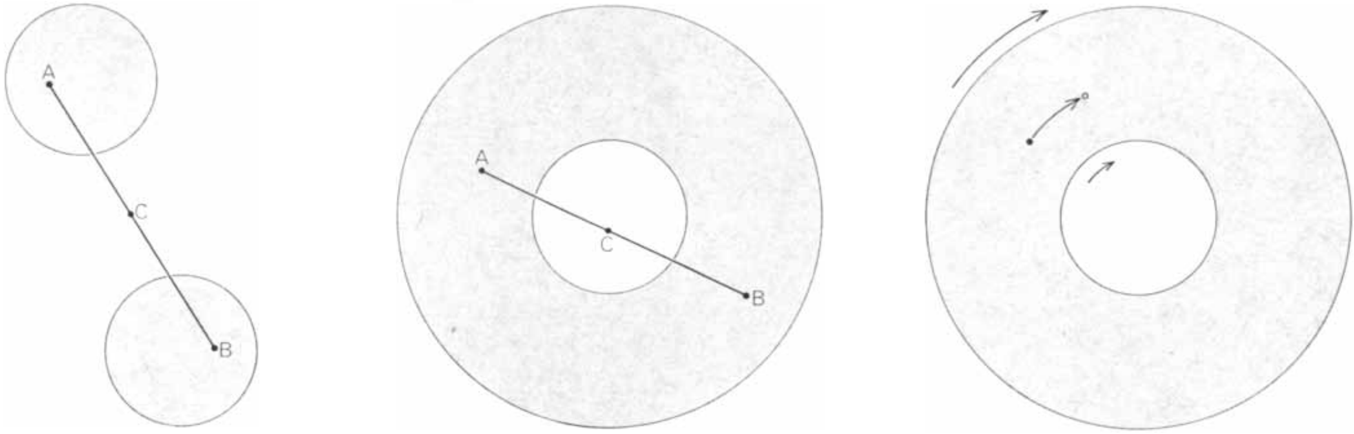
The form of the Brouwer theorem that applies to two-dimensional surfaces would also hold if, instead of the surface of coffee in a cup, we were considering an infinitely elastic circular piece of rubber. We can transform such a rubber disk by stretching and folding it in various ways, making sure only that the disk is not torn and that it is replaced within the original circumference. The proof of the two-dimensional version of the Brouwer theorem is most elegant. We first consider a disk and assume that, contrary to the theorem, no point on it remains fixed after a deformation; it is then possible to show that this assumption is untenable. The steps of the proof (which holds not only for a disk but also for a



DESCRIPTION OF STRAIGHT STRING eight inches long is, by the same mathematical convention, the diagonal connecting the bottom left and top right corners of a square built on zero to eight on the horizontal axis (because the original and the "new" position of each point are the same). The intersection of the diagonal and the curve describing the folded string specifies a fixed point.



PROOF OF FIXED-POINT THEOREM depends on fact that every curve describing a folded string that is replaced uncut on top of a straight one must cross the diagonal describing the straight string. Two special cases are the curves of string with fixed point at right (*top*) and string with fixed point at left end (*bottom*). The theorem was set forth by the Dutch mathematician L. E. J. Brouwer.



CONVEXITY is one of two conditions a surface must satisfy if fixed-point theorems are to hold true on it (the other is boundedness). An area is convex if it contains every point on the line connecting any two of its points. The two circles at left do not form a convex surface; if one switches their position, the surface is transformed so that no fixed point remains. The ring (*second from left*)

rectangle such as our sheet of paper) are outlined in the illustration on the opposite page.

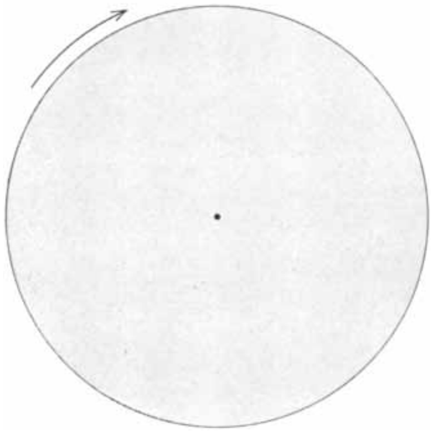
The Brouwer theorem does not apply to any area regardless of shape. An infinite domain, for example, need have no fixed point, even in one dimension. An infinitely long string can be moved in such a way that no point remains fixed. We need only to shift every point of the string one inch to the right. Since every point of the string has been moved an inch away from its original position, there is no fixed point. Hence we see that for an area always to have a fixed point when it is transformed, it must be bounded. It must also satisfy some other condition of shape, one that mathematicians call convexity. An area is defined as convex if it is possible to draw the line connecting any two points in the area so that no point of the line lies outside the area [*see illustration at top of these two pages*].

The Brouwer fixed-point theorem we have described as being applicable to one-dimensional and two-dimensional surfaces is in fact applicable to surfaces with any finite number of dimensions. The theorem does not hold, however, if the surface is infinite-dimensional. Fortunately there are fixed-point theorems that do apply in infinite-dimensional situations. We say "fortunately" because, surprising as it may seem, the greatest interest in fixed-point theorems is in the infinite-dimensional case. To understand why, let us consider Newton's famous second law of motion, which states that force is the product of mass and acceleration ($F = ma$). In most instances when the law is used, the force is a given function of the position of an object, and this position can always be found, given the acceleration of the object, by the techniques of calculus known as integration. Thus Newton's formula can be considered an equation for the position with the general form $f(x) = x$, where x denotes the position of the object and the known function, f, is determined by the forces, the masses and the initial positions and velocities. Fixed-point theorems are of great usefulness in helping us to understand equations of this type; indeed, a fixed-point theorem is usually cited in the proof that such equations have solutions.

Now consider the following question: Is it possible to put a satellite into a figure-eight orbit around both the earth and the moon? An affirmative answer amounts to saying that an equation $f(x) = x$ has a solution describing an orbit of the desired type. Any solution to such a problem is, of course, a function of time. It follows that we are trying to find if there is a function of time that satisfies the equation. The function $f(x)$ can be considered a transformation of functions of time into new functions of time in the same way that stirring coffee can be looked on as a transformation of points on a disk into new points. Accordingly the question becomes: Does the transformation represented by the function $f(x)$ have a fixed point? Such a function, since it is dependent on time, must be regarded as a "point" in an infinite-dimensional space. It is in trying to ascertain if such equations—equations involving unknown functions—have solutions of a given type that we require fixed-point theorems holding true even for infinite-dimensional surfaces.

Such questions of orbits can also be attacked by other methods; in fact, other methods, not involving fixed-point theorems directly, would normally be used to answer them. The most powerful methods of which we are aware, however, are those that appeal directly to fixed-point theorems in infinite-dimensional surfaces. It should come as no surprise, then, that there are many physical problems for which the only known method of solution involves fixed-point theorems. Problems of fluid flow are often of this type. Consider a stream bed with a bottom that rises and falls periodically like a sine curve [*see middle illustration on page 110*]. Is it possible for water to flow over this bottom in such a way that the surface of the water exhibits the same general periodicity as the bottom, or is every kind of flow necessarily nonperiodic? The answer is found to be that the surface can be periodic. This suggests a further question: Can the high points and low points of the surface occur directly above the high points and low points of the bottom, or must they be shifted slightly, either upstream or downstream? It has recently been demonstrated that there can be a flow with the high points of its surface lying directly over the high points of the bottom. There is no known way to show this without relying on high-powered fixed-point theorems, which cannot easily be visualized for cases involving simple surfaces such as a plane.

There is, however, one fixed-point theorem that can be readily described for finite-dimensional spaces and that remains valid in the infinite-dimensional case. Let us describe the theorem as it applies to a plane, which is of course a two-dimensional surface. Let P and Q represent points on the plane. If



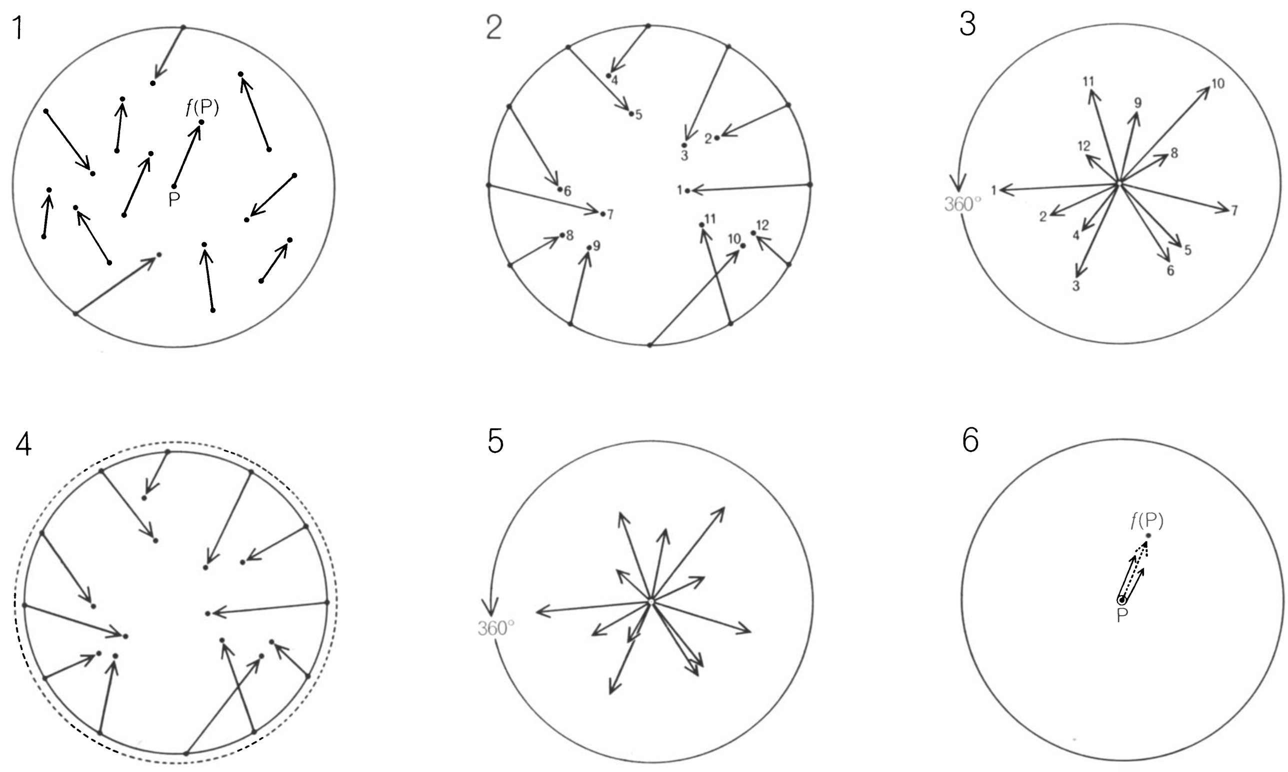
is not convex either, since rotation of the ring would cause every point on it to move. The circular disk at far right *is* convex.

the plane is transformed by stretching, twisting or folding part or all of it, the two points P and Q are transformed into new points that are determined by the deformation process and are therefore functions of P and Q. We denote this function by f, so that P is transformed into the point $f(P)$ and Q into $f(Q)$. If, following a certain transformation, the distance between the two points $f(P)$ and $f(Q)$ is always strictly smaller than the distance between the original points P and Q, then the transformation is called a contraction. There is a fixed-point theorem stating that every contraction has a fixed point; in other words, there must be a point in the same position before and after any contraction.

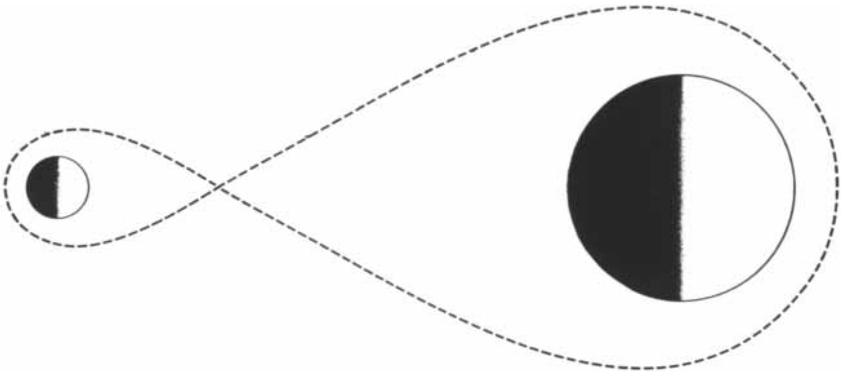
The proof of this theorem is not difficult to visualize [*see bottom illustration on next page*]. When a contraction takes place, any point P_1 on the original plane assumes a new position P_2. The point we have just designated P_2 occupies the spot originally occupied by a point that we say has moved to P_3. This point in turn now occupies the spot originally occupied by a point that we say has moved to P_4; and so on. Since we know that the transformation under consideration is a contraction, the distance between P_2 and P_3 must be smaller than the distance between P_2 and P_1. Similarly, the distance between P_4 and P_3 is smaller than the distance between P_3 and P_2, and so on. We obtain a sequence of points, $P_1, P_2, P_3 \ldots$, that get closer and closer together. This implies that the sequence must have a limit, which means only that all these points get closer and closer to some one point on the plane. This limiting point is a fixed point for the transformation.

The theorem for contractions has been stated and the idea of its proof has been outlined for transformations of a plane. In the preceding argument, however, the concept of dimension is never used. It follows that the theorem remains valid even in infinite-dimensional spaces whose "points" consist of functions of time.

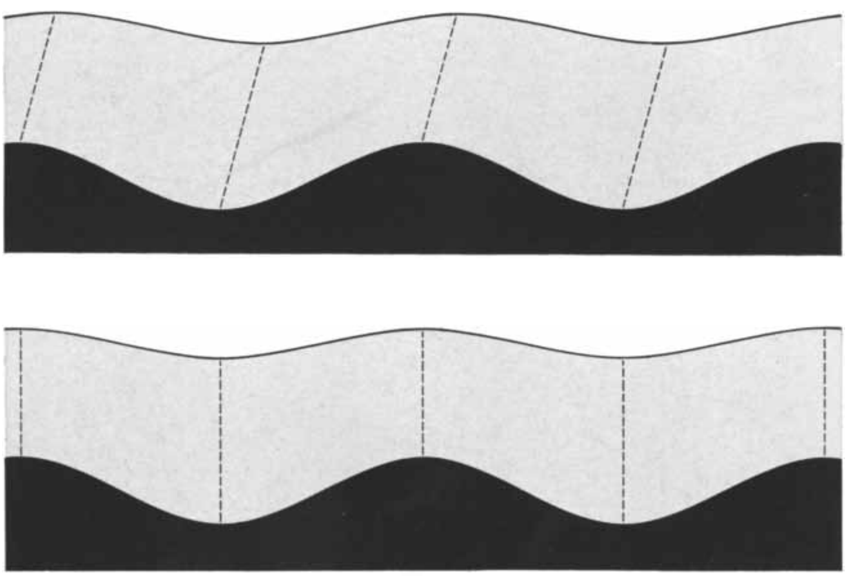
Not only does every contraction have a fixed point; it has only one fixed point. The proof of this is straightforward. Suppose P and Q were two different fixed points of the contraction $f(P)$. If this were the case, we should have $P = f(P)$ and $Q = f(Q)$. Now consider the distance between P and Q. Since these are fixed points, the dis-



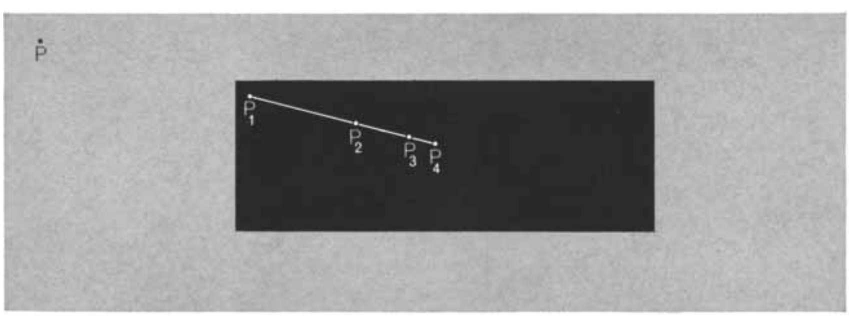
PROOF OF BROUWER'S THEOREM for two-dimensional surface such as a circular disk begins with the assumption, contrary to the theorem, that after deformation no point remains fixed. An arrow is drawn from each point to the position to which it is moved (*1*). Since no point is moved outside the disk all arrows from points on the boundary must head into the circle (*2*). These arrows are drawn again as if they emanated from a point within the circle (*3*). Considered thus, the arrows (called transformation vectors) make one complete rotation of 360 degrees around the circle. If we next trace the movement of points on the boundary of a concentric circle only slightly smaller than the original one (*4*), the number of rotations made by the arrows must, by the nature of continuous deformation, remain one (*5*). This must be true for all concentric circles because the rotation of the transformation vectors represents a continuous function. But when we consider a very small circle, all the arrows on its boundary head in roughly the same direction (*6*) and the net number of rotations is not one but zero. This contradiction shows that the assumption of no fixed point is untenable.



FEASIBILITY OF AN ORBIT by which a satellite would revolve around earth and moon is the type of question to which mathematicians apply fixed-point theorems for infinite-dimensional surfaces. The element of time in any equation for the orbit makes the problem infinite-dimensional, rendering such simple theorems as Brouwer's theorem inapplicable.



FEASIBILITY OF WATER FLOW of a certain type over a periodically rising and falling bottom can only be demonstrated by use of fixed-point theorems. Until recently it was not known if the surface of the water could rise and fall according to the same general period as the bottom. Now it has been demonstrated that such a flow is possible and that the high and low points of the surface can lie directly above the high and low points of the bottom.



CONTRACTION of a surface must result in one point remaining in the position it occupied before the contraction. The larger rectangle represents the original surface, a sheet of rubber stretched taut; the darker, smaller rectangle represents the sheet after it has sprung back to its relaxed position. We consider the point, P, near the corner at top left on the original rectangle. After the contraction it assumes a position we designate P_1. The point that was at P_1 originally has moved inward to a new position, P_2. The point originally at P_2 has moved to P_3, and so on. The interval between P_2 and P_3 is smaller than the interval between P_1 and P_2. In fact $P_1, P_2, P_3 \ldots$ form a series approaching a limit: the fixed point.

tance between them should be the same as the distance between $f(P)$ and $f(Q)$. But the distance between $f(P)$ and $f(Q)$ must, by the definition of a contraction, be strictly less than the distance between P and Q. This contradiction, calling for the distance between P and Q to be less than itself, shows that the original assumption that P and Q are two different fixed points is untenable and thus proves that there can be only one fixed point.

The fact that every contraction has a fixed point is customarily used to prove that differential equations (of which Newton's second law of motion, $F = ma$, is an example) have solutions. And, as we have seen, such equations can have only one solution. This suggests one highly practical consequence of the fixed-point theorems on contractions: in any mechanical system, whether it is the moon and the earth or a swinging pendulum, the motions of the system are completely determined by its initial displacements and velocities.

Much was made of this fact by the great French mathematician and astronomer Pierre Simon de Laplace. In his *Essai Philosophique sur les Probabilités* Laplace used it as the basis for commenting: "Given for one instant an intelligence which could comprehend all the forces by which nature is animated and the respective situation of the beings who compose it—an intelligence sufficiently vast to submit these data to analysis—it would embrace in the same formula the movements of the greatest bodies of the universe and those of the lightest atom; for it, nothing would be uncertain and the future, as the past, would be present to its eyes." There has probably never been a more definite statement of the doctrine of predestination. It stood, seemingly irrefutable, for more than a century, until the theories of thermodynamics and quantum mechanics enabled it to be contradicted.

This discussion of fixed-point theorems serves to illustrate a phenomenon characteristic of mathematics. A purely geometric idea—the concept of a fixed point of a transformation of a plane or a line—has been generalized by analogy to apply to problems in mechanics and hydrodynamics and ultimately to the philosophical problem of predestination. Although it would be hard to maintain that all keys to philosophy lie in mathematics, it is true that modern mathematics, concerned with such interactions of geometric, algebraic and analytic ideas as we have described, does lend itself to philosophical applications.

MATHEMATICAL GAMES

Dr. Matrix returns, now in the guise of a neo-Freudian psychonumeranalyst

by Martin Gardner

Dr. Matrix, readers of this department will recall, seldom remains long at one address. His numerological schemes are often on the shady side; one suspects that his peripatetic life is designed as much to avoid the police as to escape local creditors. Last winter I visited him in Miami, where he and his half-Japanese daughter, Iva, were spending some of the loot they had won at the blackjack tables of Las Vegas. For the next 10 months I lost all track of them, and then early in November I received a cryptic postcard from Iva. Its entire message was: "A, B, ..." The card was postmarked in Philadelphia, and Iva had added a phone number. I puzzled over the message for several days before the meaning suddenly came to me: "Long time no see."

Two days later I was standing outside the door of an office in an old building in Philadelphia, inspecting the brass shingle above the bell. It read: "Dr. Irving J. Matrix, psychonumeranalyst."

Iva's smile, when I stepped into the anteroom, was as dazzling as ever. But before we had had time for more than preliminary pleasantries she escorted me into Dr. Matrix' large, dimly lighted sanctum, then quietly disappeared. A tall figure rose from behind an enormous marble-topped desk.

"Good to see you again, Gardner," Dr. Matrix said, with a thick, fairly convincing Viennese accent. Since I had last seen him he had also acquired a small goatee, reddish brown and pointed like a triangle. A pince-nez was clipped to his hawklike nose, and through its lenses (probably plain glass) his emerald eyes glittered with inscrutable humor.

Did he seriously believe in the principles of his new profession? If not, he gave no indication; indeed, there was a curious ring of plausibility about the techniques he explained. He was working, he said, in the analytic tradition of Freud, but combining it with a much stronger emphasis on the unconscious mind's awareness of the symbolic properties of numbers and letters, and with therapeutic methods borrowed from Russian psychiatry. Freud had been on the right track, he maintained, in those early years when he had taken seriously the numerological theories of his good friend Wilhelm Fliess.

"Unfortunately," said Dr. Matrix, "Freud was, by his own admission, a poor mathematician, and so his attempts at numerological analysis tended to be either trivial or absurd. Do you recall his explanation of the number 2,467?"

I nodded. Freud had written Fliess that he had finished checking the page proofs of his *Interpretation of Dreams* and would make no more corrections even if they contained 2,467 mistakes. Before mailing the letter Freud asked himself: Why did that particular number, seemingly random, pop into his skull? "Nothing that happens in the mind is arbitrary or undetermined," he wrote in the letter's famous postscript. He then proceeded to give what he believed were the unconscious determinants of 2,467, an analysis he later added to the section on numbers in the last chapter of his *Psychopathology of Everyday Life*.

"Freud's explanation of 2,467," I said, "always seemed farfetched."

"It is completely unconvincing," agreed Dr. Matrix. "If Freud had known something about number theory, he might have recognized 2,467 as a prime. He had just finished writing his greatest book. It was the 'prime' year of his life. A year contains 365 days, so what could be more natural than to seize on the 365th prime, which is 2,467?"

"But," I said incredulously as I jotted this in my notebook, "if Freud was so poor in mathematics, how could his unconscious mind have picked out the 365th prime?"

"You forget, my dear Gardner, the *collective* unconscious, so brilliantly revealed in the work of Jung. Primes, the building blocks of the integers, are deeply etched in the collective memory of the human species. The power of our unconscious to manipulate numbers and other symbols is far greater than even Jung and his disciples dared imagine."

Dr. Matrix reached for a book on his desk—a copy of *The Scientist Speculates: An Anthology of Partly-Baked Ideas* (1962)—and opened it to page 331. On that page I. J. Good, a mathematician at Trinity College, Oxford, wonders why space has three dimensions. "We may try to run away from the question," Good writes in a passage Dr. Matrix had marked, "by saying that 3 is a small enough number not to need an explanation. An explanation would have been more in demand if the dimensionality had been 32650494425."

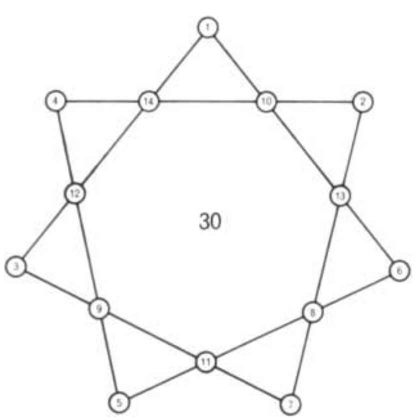
"Why," Dr. Matrix asked, "did *that* number come into Good's conscious mind?"

I chuckled when he showed me how simply Good's number could be obtained. The reader is invited to try his analytical skill on this—30 minutes is par—before I give Dr. Matrix' interpretation next month.

One of Dr. Matrix' diagnostic techniques, he explained, is to have the patient lie comfortably on his back, in a dark room, and free-associate while single numerals are projected in colored light on the ceiling. "I had a patient last week," he told me, "who became unusually agitated whenever a green 4 appeared. It turned out that he was stealing money—green stuff—from the cash register of the store where he worked. His superego was disturbed by 4's symbolic honesty."

"Its *honesty?*"

"Yes. Four is the only number, among



Solution to the septagram problem

all the infinity of numbers, that states correctly the number of letters in its English name."

Another diagnostic test, also invented by Dr. Matrix, consists of giving the patient 10 large cards, bearing the numerals 0 through 9, and asking him to arrange them in any order to form a 10-digit number. He cited the case of a woman patient with the unusual name of Aniba Di Figby. Using the familiar code of A = 1, B = 2 and so on, her names translate to 114,921, 49 and 697,225, all square numbers. Moreover, she boasted the attractive measurements 36–25–36, her height was 64 inches and she had been born in the square year 1936. Dr. Matrix was therefore not surprised when she arranged the 10 cards to form 9814072356, the largest square that can be made with the 10 digits. Its square root, 99066, is interesting in its own right, Dr. Matrix pointed out: it remains unchanged when it is inverted.

"Another patient," Dr. Matrix went on, "was a businessman whose chief concern in life was maximizing his firm's profits. His unconscious naturally arranged the 10 cards so that, if you made a dividing line between two cards, the cards on the left and right sides of the line formed two numbers that multiplied together to give the largest possible product. You might ask your readers to discover what those two numbers were."

"Excellent," I said as Dr. Matrix showed me a clever way to find the answer.

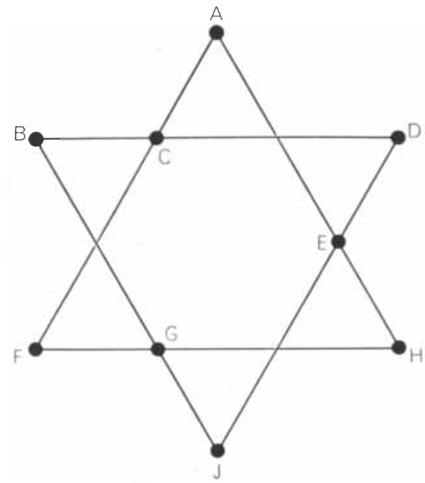
"Your readers might also enjoy searching for the unconsciously determined order behind *this* number." Dr. Matrix paused to write 8549176320 in my notebook. "The first name of the woman who produced that arrangement of the 10 digits is Betty. As another clue, you can add that she suffers from a compulsion to put things in order, a compulsion that has found an outlet in her job as indexer for a large textbook publisher in Manhattan."

Any number that comes to one in a dream, Dr. Matrix emphasized, is of special significance in psychonumeranalysis, but the analyst must be ingenious and flexible if he is to interpret the number correctly. Dr. Matrix had a low opinion of Freud's dream-number explanations in his book on dreams, and he thought the later attempts recorded by Jung, Adler, Stekel and Jones were equally humdrum. "I had a Pentecostal minister in to see me recently," he said, "who repeatedly dreamed of 7734. When I asked him to write that number and then turn it upside down, he confessed at once that he had been suffering for years from a fear that his religious doubts would deprive him of his place among the saved. His dream censor was, of course, concealing 'hell,' the feared word, by inverting it. I doubt if Freud would have thought of that."

The name of the city in which one lives also plays a major role in psychonumeranalytic diagnosis. Dr. Matrix told me he had several patients from Pleasantville, in northern Westchester County, N.Y., who were severely disturbed by the contrast between the town's name and the kind of life they lived there as employees of *Reader's Digest*. In Philadelphia, he said, the slightest feelings of hostility toward a brother are magnified by the slogan "City of Brotherly Love." Street names also reflect unconscious correlations. Can anyone doubt, he asked, that the high incidence of mental breakdowns among New York advertising men is associated with the "mad" in Madison Avenue? I myself, he reminded me, live on Euclid Avenue. And did I know that William Feller, the probability expert, lives in Princeton on Random Road?

One's own name and its initials are also basic psychonumeranalytic symbols. It is no accident, said Dr. Matrix, that Adam Clayton Powell's initials are the last three letters of the N.A.A.C.P. Did the fact that James Augustine Aloysius Joyce's initials form a palindrome have anything to do with his compulsion toward wordplay? Dr. Matrix said he had once treated a woman with the maiden name of Mary Belle Byram, who was always doing things backward and had not realized, until he called it to her attention, that her name was a palindrome.

I find in my notes a few other startling instances of similar correlations that Dr. Matrix had encountered clinically. A man named Dennis ("sinned" backward) was tortured by guilt feelings over his relationship with a Russian girl named Natasha ("Ah, Satan!" backward). A teen-aged boy named Stewart wanted to be a baseball player because his name was an anagram of "swatter." An attractive spinster schoolteacher whose last name was Noyes had turned down many marriage proposals because her name could be partitioned into "no-yes," so that she could never make up her mind. Reversing the "yes" produced "nosey," a fact that explained her fondness for malicious gossip about her colleagues.



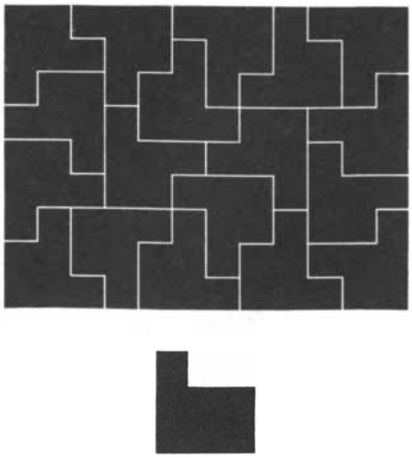
Hexagram graph for the prism problem

Publishers, Dr. Matrix assured me, have an unconscious tendency to sign up authors whose last names are anagrams of the house. He cited the case of Selden Rodman, who edited a poetry anthology for Random House, and Robert Gover, whose books are published by Grove Press. "You can understand," he said, "why Salvador Dali chose Dial Press as the publisher of his autobiography."

He spoke also of the subtle sexual symbolism invariably concealed in the names of all the great love goddesses of the screen. Jean Harlow's last name is only one letter away from "harlot." Among the capital letters the two strongest breast symbols are obviously *M* and *B*. It is no accident, Dr. Matrix said, that the names Marilyn Monroe and Brigitte Bardot have the initials *MM* and *BB*.

I wish I had space to discuss some of Dr. Matrix' clinical experiences with the hidden meanings of phone numbers, social security numbers, car licenses, street addresses, ZIP codes and Blue Cross numbers. Nor can I give details of his conditioned-reflex therapy beyond saying that it involves administering electric shocks to a reclining patient whenever certain words and numbers are flashed on the ceiling and simultaneously recited aloud by the patient. After a series of 30 such shocks there is a period of relief from shock while words and numbers of opposite symbolic meaning are projected and recited.

The last entry in my notes records a remarkable property of the President's name. Dr. Matrix said that it had been discovered recently by his friend Harry Hazard of Princeton, N.J., and I could have the honor of being the first to pub-



Hexomino rectified (top) *and heptomino*

lish it. If Johnson's name is written as a multiplication problem,

$$\begin{array}{r} \text{LYNDON} \\ \text{B} \\ \hline \text{JOHNSON} \end{array},$$

there is a unique substitution of digits for letters that gives the problem a correct numerical form. Solving it is another pleasant exercise that I leave unanswered until next month.

On my way out I stopped at Iva's desk to ask her a series of curious questions that had been suggested to me by Kirby Baker, a Harvard mathematician. "I have three questions," I said, "each to be answered by yes or no. The first is: Will you promise to answer this and the next question truthfully?"

Iva's lovely black eyes narrowed a trifle, but she seemed amused. "Okay," she said. "What's the second?"

"The second is: If my third question is 'Will you have dinner with me tonight?' will you answer that question the same way you answer *this* one?"

The poor girl was trapped, of course; no matter how she answered my second question, she had to say yes to the third. But she was a good sport about it, and we enjoyed, in that most unhurried of U.S. megalopolises, a relaxed and unhurried evening.

A few weeks later a story in *The New York Times* caught my attention. A wealthy Main Line widow in Philadelphia had died, leaving a small bequest of $50,000 to the Psychonumeranalytical Institute. By the time the story was released to the press the money had actually passed into Dr. Matrix' hands, and the *Philadelphia Inquirer* sent a reporter to ask him how the institute would use the money. The reporter found the offices completely empty. Dr. Matrix, Iva and the furniture had vanished without a trace.

The first of last month's magic star problems—to put the integers 1 through 14 on the vertices of a seven-pointed star so that every row of four numbers sums to 30—is said to have 56 different solutions. One, with the first seven integers on the star's outer points, is shown on page 112.

The second problem was to determine if it is possible to label the nine edges of a triangular prism with the integers 1 through 9 so that the sum of the three edges meeting at every vertex is 15. The problem was shown to be the same as that of putting the nine digits on the spots of the hexagram in the illustration on the preceding page so that each row of three sums to 15.

Assume that there is a solution. Then:

$$A + C + F = A + E + H$$
$$(1)\quad C + F = E + H$$

$$B + C + D = D + E + J$$
$$(2)\quad B + C = E + J$$

$$F + G + H = J + G + B$$
$$(3)\quad F + H = J + B$$

Combining (1) and (2), we write:

$$(C + F) - (B + C) = (E + H) - (E + J)$$
$$(4)\quad F - B = H - J$$

Combining (3) and (4), we write:

$$(F - B) + (F + H) = (H - J) + (J + B)$$
$$2F - B + H = H + B$$
$$2F = 2B$$
$$F = B$$

But F cannot equal B because the problem called for nine *different* integers. One must therefore conclude that the original assumption is false and the problem has no solution. Note that this proves a much stronger result than the one asked for. It is impossible to make the figure magic with different numbers of any kind whatever, consecutive or otherwise, rational or irrational.

Several readers have pointed out that the formulas for supercircles and superellipses that were given in the September issue should have had their terms bracketed with vertical lines to indicate that they are taken with respect to their absolute values (values without regard to sign). Otherwise, if the exponent n is an odd integer, one gets into plus-and-minus trouble and the formulas give the curve only within the first quadrant of the Cartesian plane. It is sometimes customary to omit brackets in formulas of this type, it being understood that absolute values are intended.

A more serious mistake was involved in the proof in the October issue that supereggs with any exponent are stable. Commander C. E. Gremer, U.S.N. (Ret.), was the first of many readers to call attention to the surprising fact that at the base point of *all* supereggs the center of curvature is infinitely high! If we affinely stretch a superegg upward while its width remains the same, the curvature at the base point remains "flat." In other words, all supereggs, regardless of their height-width ratio, are theoretically stable. Of course, as the model of a superegg is made taller and thinner the degree of tilt that causes it to fall becomes so close to zero that such factors as inhomogeneity of the material, surface imperfections, vibrations, air currents and so on make it practically unstable, but in an ideal sense there is no critical height-width ratio. Norton Black, Joseph M. Diamond, William Hogan, Peter Moretti and Anthony A. van Ammers calculated topple angles for supereggs of various exponents and height-width ratios, and other readers raised and solved other questions about superellipses that I hope to discuss at some future time.

In November's answers to the pentomino-game problems of the previous month it was a mistake to say that the winning first move depicted on the five-by-six board is unique. Eugen Bosch of Washington, D.C., discovered three other winning moves. David Klarner, a mathematics student at the University of Alberta, sent the results of work he did several years ago on the rectification problem that establish that nine hexominoes are rectifiable. The only hexomino that requires more than four replications to form a rectangle is the piece shown, in its minimal pattern, at the top in the illustration on the opposite page. Among the septominoes, Klarner proved that the only rectifiable piece requiring more than four replicas to make a rectangle is the one shown at the bottom in the illustration. Its smallest rectangle (discovered by James E. Stuart of Endwell, N.Y.) is believed to be the 14-by-14 square, requiring 28 pieces. If the reader will cut 28 replicas of this septomino from cardboard or thin wood, he will find it a splendid puzzle to fit them into a square. (Pieces may be turned over and placed with either side up.)

THE AMATEUR SCIENTIST

How to cultivate the slime molds and perform experiments on them

Conducted by C. L. Stong

You can usually stump players in guessing games such as Twenty Questions by introducing into play one of the 450 species of amoeboid slime molds. These are organisms that do not fit neatly into the conventional categories of animal, vegetable or mineral. Strictly speaking they are none of these. Some player may argue that the zoologist classifies the organisms as animals—protozoa in the group of animals called Mycetozoa—on the basis that they cannot manufacture food and that during much of their life cycle they move freely in response to light, heat and chemical stimuli. To this argument the botanist can respond just as stoutly that slime molds are plants, which he calls Myxomycophyta, because at maturity they develop cell walls of cellulose, become securely attached to some feature of the environment, produce fruiting bodies and release spores.

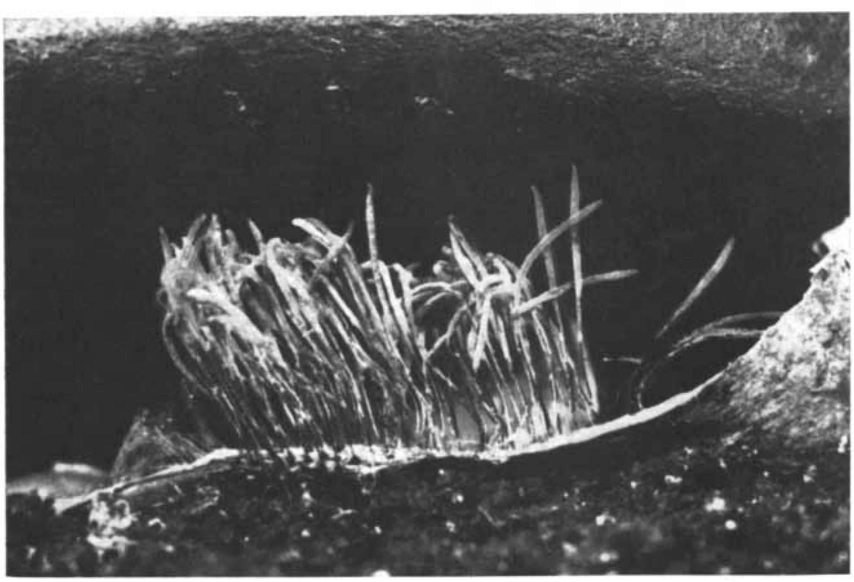
Some biologists take the position that the concept of plant or animal simply cannot be applied to these organisms. At some point in the course of evolution the slime molds ran up a blind alley, where they are now trapped—relatively harmless and apparently good for nothing except as specimens for some of the most engaging experiments in biology. A. C. Lonert, who is director of research at the General Biological Supply House in Chicago, explains how to culture and experiment with two of the most interesting species. "I shall discuss two kinds of slime mold belonging to different orders," he writes, "because of the astonishing diversity of their life cycles and the ease with which they can be cultured. Both organisms offer a rich field for experimentation.

"The first, *Physarum polycephalum*, is a member of an extremely interesting order, the widely distributed Myxogastrales (also called Myxomycetes) of the subclass Mycetozoa. Viewed from the perspective of an imaginative microscopist, the sporangia, or fruiting bodies, of the many species appear as enchanted forests in which the fruits become pulsating, devouring monsters.

"When found in the early stage of growth, the myxomycete is most like an animal and generally consists of an unattractive patch of naked protoplasm, either colorless or pigmented, that can attain a diameter of several feet. This hungry protoplasmic mass, called a plasmodium, creeps about in a moist and well-shaded environment, seeking food in rotting vegetation and decomposing wood. In the process of feeding, the organism aids the economy of nature by processing waste into compounds that can be utilized by other organisms.

"At a propitious time, governed by the availability of food and such factors as temperature and moisture, the oozy mass leaves its dank haunts and, as it reaches toward the light, transforms itself into upright plantlike structures. These are the sporangia. The shape, color and size of these bodies vary considerably among the many genera of Myxogastrales, but the bodies usually have two features in common: a delicate network of noncellular threads and strands, called the capillitium, in which the spores are enmeshed, and a fragile, sometimes beautifully formed and tinted spore case, called the peridium.

"After the drying and rupture of the spore case, expansion of the threads of the capillitium exposes the spores to the action of wind and rain. At the same time the expansion controls the rate at which the spores are released. The life cycle is repeated when spores fall in a suitable environment. Free-swimming swarm cells, or myxamoebae, are then released. They feed for a time and multiply by splitting in two. Eventually two of the cells fuse to form a zygote, which is equivalent to a fertilized egg. This fusion constitutes the beginning of a new plasmodium, which can grow by nuclear division or by fusion with other zygotes. Unfortunately for those who enjoy the exotic and



A slime mold growing in a natural environment beautiful in nature, these fantastic groves are usually at ground level. Because they are underfoot they usually remain unobserved and unappreciated except by those who know where to look.

"Most of the slime molds, when taken from their natural environment, are difficult to culture. This difficulty need not stop anyone from enjoying the real-life adventure of observing the strange organism at home or in the laboratory. A culture can be started easily from a fragment of *Physarum polycephalum* plasmodium in the sclerotial stage, a dried condition. This stage is sometimes found in nature and can be induced in the laboratory by the method to be described.

"Sclerotia that will remain viable for a long time and have the ability to transform themselves into active plasmodium within several hours are available commercially. One can also buy the necessary supplies for experimenting with the organisms. All the items can be obtained from distributors such as General Biological Supply House, Incorporated, 8200 South Hoyne Avenue, Chicago, Ill. 60620.

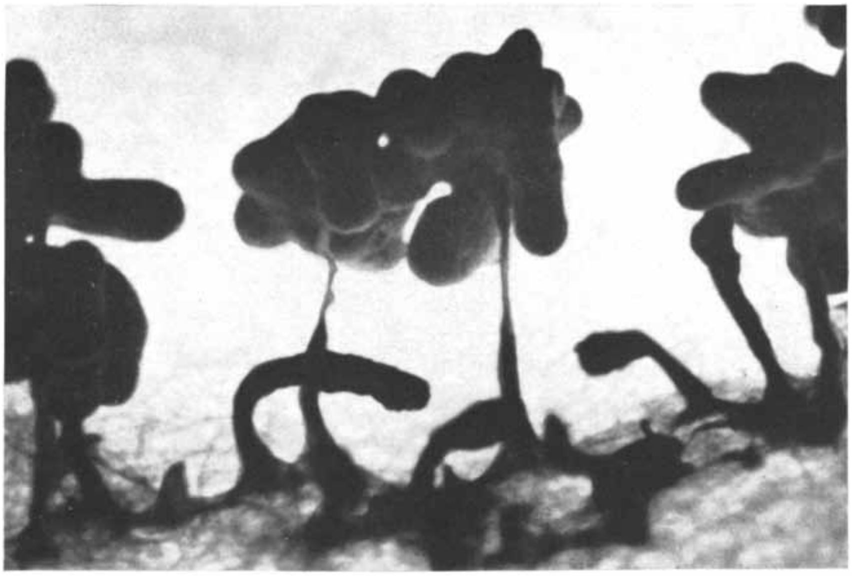
"To grow a plasmodium of *Physarum polycephalum* from the sclerotial stage, first improvise a culture chamber by placing a dish—for example an inverted saucer or a Petri dish—within a larger, covered container, such as a casserole or a pair of facing Pyrex pie plates, so that the smaller dish serves as a platform [*see lower illustration on next page*]. For this experiment omit the rubber separators shown in the illustration. Lay a sheet of filter paper or paper toweling across the platform. The paper should droop to the bottom of the dish. Wet the paper thoroughly with distilled water, pouring off the excess. From time to time add enough water to prevent drying. Incidentally, distilled water should be used in all experiments to be described.

"Place a small fragment of sclerotium on the platform and wet it with a drop of water. Within a few hours the organism will awaken from its deathlike torpor. Keep the unused portion of sclerotium in the refrigerator. When the plasmodium has emerged and has begun to seek food, put a flake of uncooked oats in contact with the rapidly spreading growth. Use old-fashioned rolled oats, not the 'quick' variety.

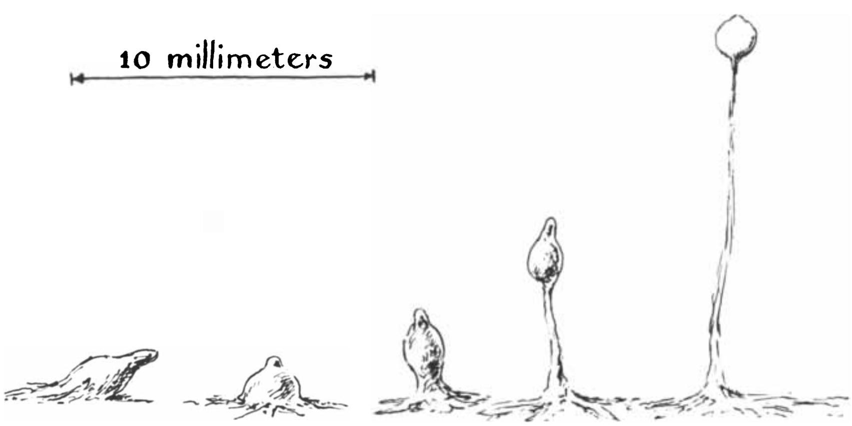
"Keep the covered dish at room temperature in an area that does not get direct sunlight. As the plasmodium increases in size, place more oat flakes along the growth front. A rapidly moving plasmodium will consume a larger number of oat flakes than a sluggish one. In either case the feeding organism will show a decided preference for fresh oat flakes and will abandon partially digested ones. Flakes that have first been moistened with a drop of water are accepted more readily than dry oats. To maintain a clean culture, transfer the organisms to a fresh sheet of filter paper or paper toweling weekly, avoid overfeeding and remove abandoned food that shows signs of becoming moldy or slimy. Occupied oat flakes (those covered with yellow plasmodium) or sections of paper bearing plasmodium can be transferred repeatedly to clean sheets of paper to perpetuate the plasmodial stage.

"The organism at this stage has been compared to a giant amoeba: a thin, irregularly shaped mass of creeping jelly that is threaded by a network of veins. To observe the complex circulation in these vessels, transfer several occupied oat flakes to a Petri dish containing a thin layer of nonsterile, nonnutrient 1.5 percent agar. The agar culture is maintained in the same way as the paper culture, but there is no need to add water. The protoplasmic streaming and its periodic reversal can be observed with any microscope capable of magnifying to 50 diameters or more. Observation should be made with light transmitted through the specimen from the substage. Cut one of the vessels when the circulation is active and observe the effect. Make a transfer of scraped plasmodium and watch it reconstitute itself. Place a drop of vinegar near the plasmodium and note the reaction.

"Usually cultures can be kept in the plasmodial stage for some weeks by



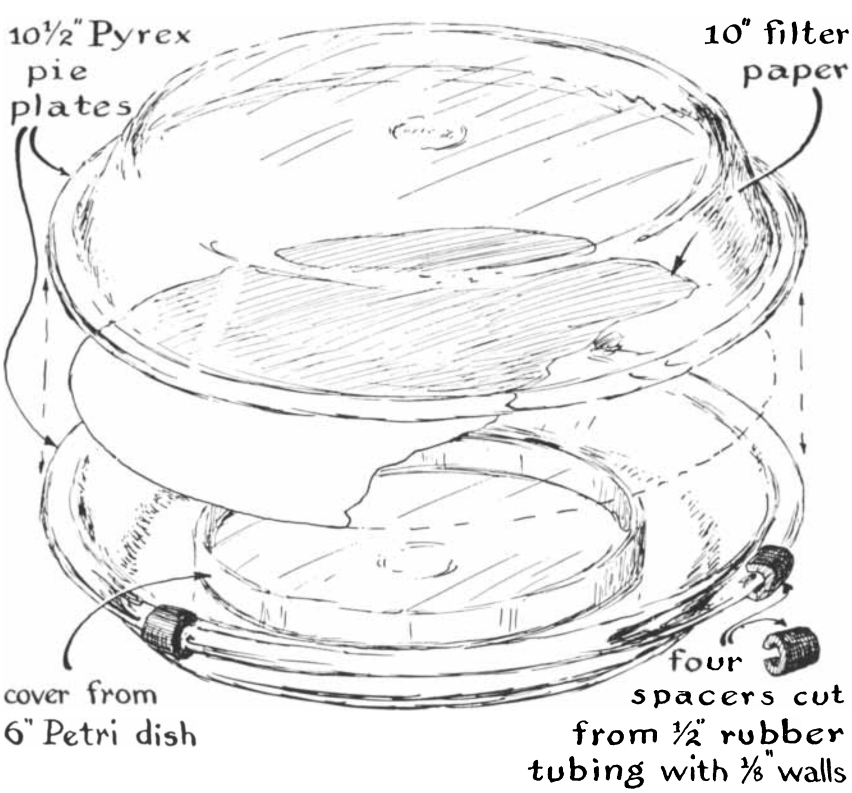
Sporangia of the species **Physarum polycephalum,** *magnified 25 diameters*



Stages in the fruiting of **Dictyostelium discoideum** maintaining ample food and water and periodically transferring specimens as described. Occasionally, however, specimens will for some unknown reason enter the sporangial, or fruiting, stage spontaneously. This stage can be induced at any time by removing most of the food and allowing the plasmodium to roam while simultaneously keeping the organism moist. The transformation will occur suddenly, usually at night, within a week or so. If the observer is fortunate enough to witness the actual transformation, he will see the entire plasmodium, now more orange than yellow, appear to separate into uniformly rounded masses that ascend from the surface on stalks and then develop into weird, multilobed bodies [*see top illustration on preceding page*].

"Under the higher powers of the microscope, spores obtained from crushed sporangia can be seen to germinate with the emergence of an amoeba-like protoplast, which afterward gives rise to an amoeboid and then to flagellum-bearing swarm cells—cells equipped with whiplike tails for swimming. The series of transformations usually requires about three days. Eventually pairs of swarm cells fuse to become zygotes. From these a new plasmodium originates.

Arrangement of an improvised chamber for cultivating slime mold



Details of the culture chamber

"The germination and subsequent transformations up to, but usually not including, the plasmodial stage can be observed by setting up a hanging-drop preparation. This consists of a drop of water, containing specimens, that clings to the underside of a thin sheet of glass. The glass is usually a cover slip of the type used to protect specimens on a microscope slide. Evaporation is prevented by enclosing the drop in a small, airtight vessel. The vessel may consist of a microscope slide into which a depression has been ground. The other items needed for doing the experiment are a sterilized medicine dropper, a quarter-inch loop of fine wire supported at the end of a pencil-sized piece of wood, a pair of tweezers, Vaseline, a 70 percent solution of isopropyl alcohol and a gas burner or an alcohol lamp.

"Sterilize a microscope slide and cover slip in the flame. A few sporangia are then placed in isopropyl alcohol for one minute and dried on the sterilized slide. Next the dried specimens are placed between another pair of sterilized slides with a drop or two of water and crushed. The sterilized cover slip is held horizontally, by an edge, with the tweezers. A drop of water is applied to the underside of the cover slip at the center.

"This suspended drop is inoculated with spores by first stirring the crushed specimen with the wire loop and touching the loop to the bottom of the drop. The rim of the depression in the microscope slide is now lightly coated with Vaseline. Finally, the cover slip is placed on the coated slide with the suspended drop centered over the depression. The cover slip is pressed gently into place to seal with Vaseline the space between the cover slip and the slide. The combination is placed on the stage of the microscope, which is focused on the contents of the suspended drop. The recommended sterile technique is not absolutely necessary, but it increases the probability that more of the early stages will develop. It is difficult, however, to generate a fresh plasmodium by this technique.

"To preserve *Physarum polycephalum* for possible future use, return the organism to the dormant, sclerotial stage, from which it can be conveniently aroused again when it is needed. A method that I developed is quite simple and produces a good yield of very durable sclerotia. Set up a culture chamber with 10½-inch Pyrex pie plates, 10-inch disks of paper and either the top or the bottom of a six-inch Petri dish to serve as an elevated platform. Lay the paper across the platform and center it on the lower pie plate. Moisten the paper with distilled water and push down the portion of the paper that extends beyond the platform. The depressed paper forms a circular moat. Pour off excess water. Transfer oat flakes occupied by plasmodium from a desired culture to the center of the paper. Cover the pie plate with a similar but inverted dish.

"When the plasmodium begins to move about, place fresh oat flakes along the growth front—wetting each flake to facilitate rapid occupation. By the following day plasmodial fronts, moving toward the edge of the culture chamber, will have developed. Put fresh oat flakes along these more distant fronts and, when they are occupied, lift them from the paper with a knife, replacing them promptly with fresh flakes, and reposition the occupied flakes toward the center of the platform. Place the flakes next to each other. Continue this procedure until a circular area of occupied flakes about three inches in diameter has been concentrated centrally on the platform. As much specimen material as desired can usually be gathered after 48 hours of consecutive feeding. Occupied flakes can be taken from more than one culture; if several cultures are maintained simultaneously, a good supply can be accumulated in a much shorter period of time.

"To begin the induction of sclerotization, take the plasmodium-bearing paper out of the culture chamber. Remove surplus moisture by superposing the paper gently, with occupied oat flakes uppermost, on a piece of clean, dry paper of the same size. Allow the papers to remain in contact. Wash and dry the platform and bottom culture plate, then promptly reassemble the chamber and restore the partly drained culture paper to its former position, reforming the moat.

"Circle the paper moat with dry oat flakes. The flakes form an entangling barrier that prevents wastage of active plasmodium by premature drying at the edge of the plate. Next insert one or two thicknesses of rubber tubing, which have been slit lengthwise, between the upper and the lower culture plates at four equidistant points [*see upper illustration on opposite page*]. If the relative humidity is high (from 50 to 60 percent at temperatures ranging from 80 to 90 degrees Fahrenheit), use two thicknesses of rubber tubing and increase the spacing of occupied flakes; if the relative humidity is low (from 15 to 25 percent at 75 to 80 degrees F.), use one thickness of rubber tubing. These are, of course, rough approximations. The object is to dry the culture paper in not less than 24 hours and not more than 48 hours. (One should avoid, however, the use of an artificially created air current to promote drying.) The crustlike sclerotia produced by this method will retain viability for years if they are stored in closed jars under refrigeration at 42 degrees F.

"The second slime mold, *Dictyostelium discoideum,* a member of the order Acrasiales, differs in a number of remarkable ways from *Physarum polycephalum* and other members of that order. It is a bacterial feeder and also exhibits both animal and plant characteristics. The events of its life cycle can be ascertained rather easily, but several of its other properties have not yet yielded to the assaults of the investigator. Apparently similar cells play at least three distinctive roles on a simple level—first, as free-living myxamoebae; second, as massed structures of cells exhibiting interdependence and coordination, and third, as cells differentiating into several kinds of structure.

"About 18 to 24 hours after inoculation of a bacterial culture with spores of *Dictyostelium discoideum* there will appear within the bacterial growth numerous minute, refractive lumps that have bright centers when they are viewed slightly above focus at a magnification of 100 diameters. These lumps are actually the minute myxamoebae busily eating their way through what, on the scale of comparative sizes, must be described as jungles of bacteria. Simultaneously the organisms multiply at a prodigious rate through binary fission, or splitting. Even a hand magnifier will show the digestion of circular patches of bacterial growth at this stage. Incidentally, if the experimenter is working with an inexpensive microscope objective of .25 or .65 numerical aperture (corrected for use with a cover slip) and a 160-millimeter tube length, a fairly good compensation for the aberration caused by the absence of the cover slip can be made by increasing the tube length by 30 mm.

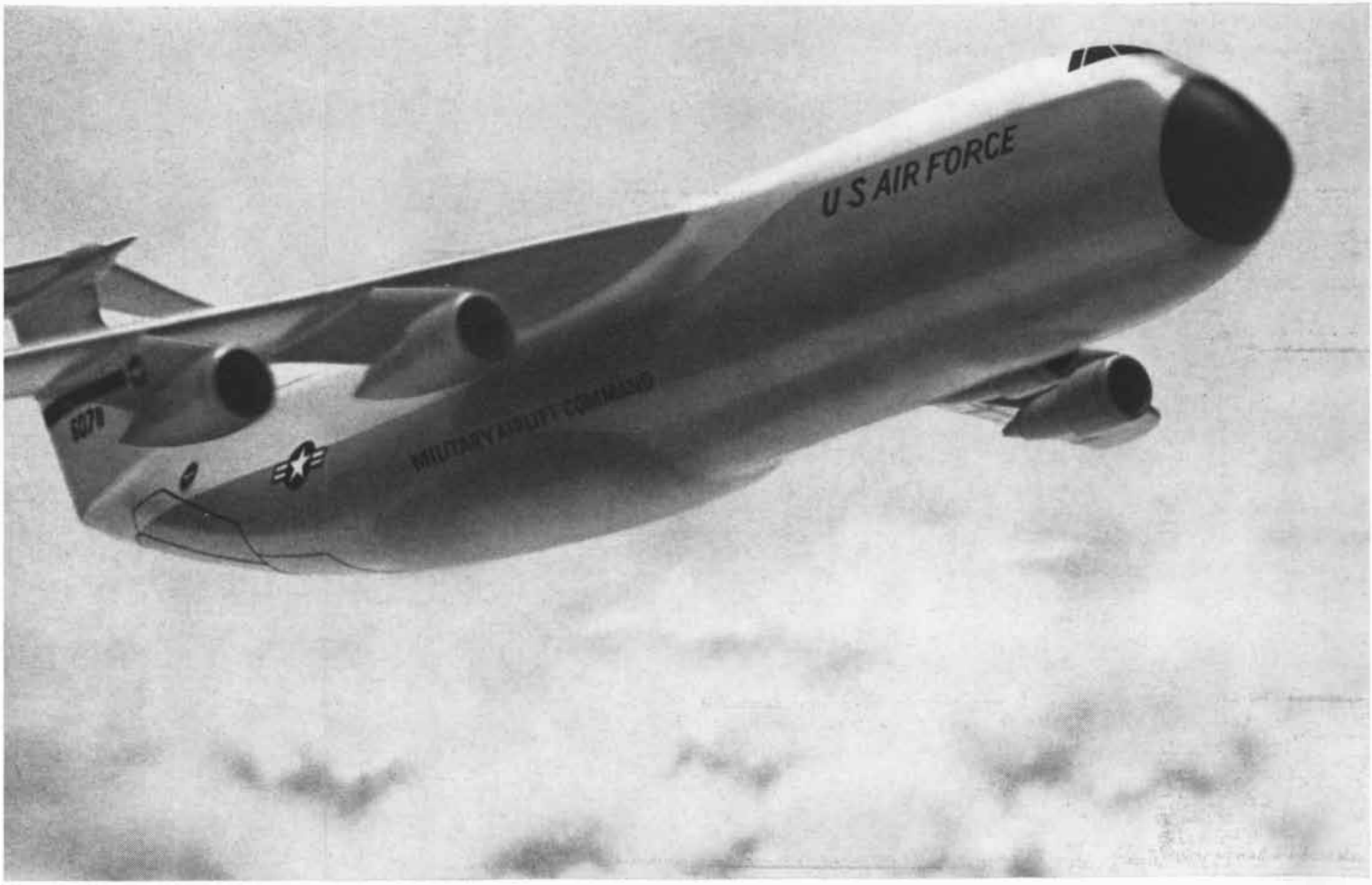
Wandering myxamoebae, enlarged 525 diameters

"At the end of 24 hours the culture will begin to teem with hordes of the voracious organisms, which are now clearly visible as they sweep the agar surface clean of bacteria. The disorganized, searching myxamoebae as they appear with a fairly oblique illumination are shown in the accompanying photomicrograph [*above*]. The organisms are difficult to see except under such oblique lighting or with phase illumination.

"By the end of 48 hours, with the food supply nearing depletion in some portions of the plate, a remarkable change will begin to take place. The organisms stop feeding and spontaneously converge on centers of aggregation. According to John Tyler Bonner of Princeton University, the release of acrasin, a chemotactic substance, is responsible for the strange phenomenon. As the myxamoebae continue to press themselves into these centers of aggregation several moundlike structures are built up, each with a characteristic tip. The myxamoebae pack themselves together but persist in maintaining their individuality. There is no fusing of cells into a mass that contains a large number of nuclei as there is in the case of *Physarum polycephalum;* the pseudoplasmodium remains associational in character. The individual aggregates

YOU HAD TO MISS KITTY HAWK

BUT YOU DON'T HAVE TO MISS THE C-5A



USAF's C-5A is the biggest thing to come along in years. So big, in fact, that the first Wright Brothers' plane could have taken off and landed on the wing of the C-5A—if it could have flown that high off the ground. ☐ More than a giant in size, the C-5A will usher in another whole new age of aviation. And it will bring new sophistication to air transport through such on-board advances as Lockheed's exclusive Malfunction Detection System. To engineers, the C-5A means long term careers in aviation unmatched anywhere in the aerospace industry today. Exciting. Challenging. With room to grow. And they're all here at Lockheed. ☐ If you don't want to wait a number of years for your next really big opportunity to come along, only one question needs to be answered. Are you big enough for the C-5A? ☐ Find out. Send your resume to Charles E. Storm, Professional Employment Manager, Lockheed-Georgia Company, 834 West Peachtree St., Atlanta, Georgia, Dept. 166-SA. Lockheed is an equal opportunity employer.

C-5A

LOCKHEED-GEORGIA

The opportunities don't come any bigger

Lockheed-Georgia Company, Marietta, Georgia: A Division of Lockheed Aircraft Corporation grow rapidly through the continued accretion of myxamoebae, elevating at first and then, after a period of elongation, tipping horizontally to become migrating, sluglike creatures.

"The slug soon assumes the characteristics of a creature equipped with special organs. For example, it has a front-to-back orientation, with the tip, observed to form early in the mound stage, exhibiting sensitivity to light and heat. In the presence of such a stimulus the top appears to head the parade with the rest of the body following, leaving a trail of slime behind it. The motion of the slug is apparently produced by the concerted action of the individual myxamoebae, but it is not yet known what coordinates their remarkable performance. It is possible, by exerting gentle pressure, to dissociate amoebae from the mass. Subsequently they recombine to reconstitute the slug! Even a stained section of the slug fails to demonstrate the mechanism of communication. It is at this stage of development that the slime mold lends itself particularly well to experimentation.

"Bonner has shown that when the tip of one slug is cut and joined to the tail end of another slug, or replaces the tail of another slug, it becomes evident that differentiation has occurred, that certain groups of the amoebae have acquired unique traits [see "Differentiation in Social Amoebae," by John Tyler Bonner; SCIENTIFIC AMERICAN, December, 1959]. Myxamoebae of the tip that have been transplanted, for example, will begin to migrate to their own social level and join the tip cells of the host. On the other hand, a graft of the hind part of one slug to replace the hind part of another slug produces no appreciable migration. To tag the myxamoebae for these and other experiments Bonner stained the specimens with a harmless dye. The stains must be used in highly diluted form; they include Janus green B, methylene blue, neutral red and brilliant vital red. Pink slugs can also be developed from colorless slugs for experimentation by starting a culture with the red *Serratia marcescens* bacterium as the food organism. The myxamoebae are unable to eliminate the bacterial pigment.

"The final stage should develop in about 60 hours. By that time a number of slugs will have begun to elevate and change into fruiting bodies. In the process the myxamoebae located toward the front end and along the central axis of the slug undergo a drastic change, literally giving up their lives to become a firm supporting core of cellulose-lined dead cells constituting the sporophore, or stalk. The rest of the myxamoebae begin to be raised upward. Those amoebae that do not become stalk cells are eventually lifted in a body to the top of the stalk, where they are transformed into capsule-shaped spores encased in a globular mass of slime. This body constitutes the sorus. The complete fruiting sequence is shown in the accompanying illustration [*bottom of page 117*]. If spores are sown on a clean agar surface without food organisms, freshly hatched myxamoebae, the beginning of a new cycle, may be observed in about 18 hours.

"A suitable culture medium can be made by first cooking 35 grams of hay for 10 minutes in one liter of tap water. Filter this solution and add enough water to restore the original volume. Add the filtered infusion to a flask containing 15 grams of agar. Boil to dissolve the agar. Sterilize in steam at 15 pounds of pressure for 20 minutes.

"Another satisfactory medium is described in *Plants in Perspective*, by Eldon H. Newcomb, Gerald C. Gerloff and William F. Whittingham, published by W. H. Freeman and Company in 1964. It consists of .1 percent lactose and .1 percent peptone in 2 percent agar sterilized as above. Melt the agar first and then add the other ingredients.

"To start the culture pour the medium into sterile Petri dishes and test tubes. Avoid aerial contaminants. Test-tube media are usually sterilized after pouring. After preparing fresh stock cultures inoculate the selected medium with a nonmucoid strain of *Escherichia coli* or *Serratia marcescens* and then inoculate the same plate with *Dictyostelium discoideum* spores. By restricting to limited areas the spore inoculation of the Petri-dish culture (the entire plate, however, can be inoculated with bacteria) almost any stage of development can be found in other portions of the culture for several days after formation of the first organisms. The bacteria that serve as the food organism can be transferred in the form of a suspension or they can be streaked over the agar surface. Incubate the culture at room temperature.

"To prepare stock cultures transfer the food organism to two or more agar plates and add *Dictyostelium discoideum* spores to one of them. When the stock culture has developed, stopper it with the separate culture of bacteria and store under refrigeration. Transfer the stock cultures every three months."

BOOKS

Will the human species stay ahead of the flies?

by Howard E. Evans

THE NATURAL HISTORY OF FLIES, by Harold Oldroyd. W. W. Norton & Company, Inc. ($8.50). A CATALOG OF THE DIPTERA OF AMERICA NORTH OF MEXICO, under the direction of Alan Stone, Curtis W. Sabrosky, Willis W. Wirth, Richard H. Foote and Jack R. Coulson. Agriculture Handbook No. 276, Agricultural Research Service, U.S. Department of Agriculture. U.S. Government Printing Office ($5.50).

The noun "fly" has three separate meanings. Originally it meant any flying insect, and as such it has become the basis of many vernacular insect names: dragonfly, mayfly, ichneumon fly and the like. Students of insects find the word useful only when it is applied to a coherent group—the order Diptera, defined as a group of insects exhibiting complete metamorphosis and possessing as adults a single pair of wings. (Actually flies have a second pair of wings, but they are modified to form a pair of halteres, or balancers.) To most people a fly is a housefly or any of several similar species found in and around human habitations. One can forgive the nonspecialist who is confused when he is told that a firefly is not a fly but a mosquito is (although in fact the word "mosquito" is merely a diminutive of *mosca,* the Spanish word for fly). Here we have a familiar dilemma in science: should a word in common use be abandoned because it is imprecise, or should it be defined more precisely and the public educated to accept the definition? Scientists almost always choose the second alternative, and therein lies a major source of misunderstanding between the scientist and the nonscientist.

Harold Oldroyd, senior dipterist at the British Museum (Natural History), has probably had more flies cross his desk than anyone else in the world. This may seem a dubious distinction to some, but readers of the readable and attractive book Oldroyd has produced are likely to conclude that it is, after all, a rare and exciting privilege. The book is particularly recommended for those who so eagerly study the photographs of the surface of Mars for signs of life. There may not be much of anything on Mars, but on the earth there are some 80,000 species of flies, many of them little known and most of them a good deal stranger than the organisms that fill the dreams of exobiologists.

Have you heard, for example, of the downlooker fly, which sits head down on the trunk of a tree "as if it were looking for a victim"—when in fact no one knows what it feeds on? Or of the coffin fly, which maintains itself through many generations in human bodies buried in coffins, although no one knows how it gets into them? Or of the petroleum fly, known only from pools of crude petroleum in California, where it lives on other insects that become trapped in the oil? Or of mosquitoes of the genus *Malaya,* which subsist by filching honeydew from the jaws of worker ants? There is hardly a page in Oldroyd's book that does not introduce the reader to one fantastic fly or another, and hardly a paragraph that does not contain a confession of ignorance and an implicit plea for more studies on the life histories of these ubiquitous but little-understood animals.

In his introduction Oldroyd admits that a book such as his may easily degenerate into "a series of anecdotes of the 'wonders' of fly-life" unless it has a theme. Oldroyd's theme is the evolution of flies, and his approach is a comparative one. The flies are seen as representing two evolutionary lines. One comprises the crane flies and various groups of midges, gnats and mosquitoes; it is treated in five chapters. The other consists of the "flies proper," which for the most part possess more robust bodies and shorter antennae, and culminate in the housefly, the bluebottle fly and other flies less well known to man. Eleven chapters are required to survey the "flies proper," and even then some important groups are disposed of summarily. I find it difficult to condone Oldroyd's dismissal of the tachina flies in three short paragraphs. As he says, tachina flies play an important role in the biological control of other insects; in this post-*Silent Spring* era we need to be informed on such control agents.

Be that as it may, Oldroyd has on the whole done an admirable job of surveying the flies, and the book's many excellent photographs and line drawings do much to help the reader visualize the life stages of many of the forms discussed. No such survey has previously been available in English. Eugène Séguy's classic *La Biologie des Diptères,* published in 1950, contains a great wealth of detail, but it is unavailable to most people and already somewhat out of date. Oldroyd's summaries of recent research on flies, as well as his bibliography, will be found particularly useful. His anecdotes enliven the text, perhaps not always in quite the way intended. We read, for example, of the housewife who pricked some sausages in the frying pan and saw maggots pop out of the holes—the consequence of a sausage-making machine not being thoroughly cleaned. We read also that "Professor G. C. Varley [of Oxford] told me that he himself had been bitten in California by *Symphoromyia sackeni.*" To bite Californians is one thing, but to bite Professor Varley—tsk, tsk.

One of Oldroyd's pet themes is that adult flies, "where necessary, make up for the deficiencies of the larva"; that is, when the larval diet is deficient in protein, the adult is likely to be a bloodsucker, but when the larva is carnivorous, the adult is likely to concentrate on carbohydrates. Oldroyd cites many examples, none better than the mosquito *Megarhinus,* which has carnivorous larvae but adults that feed on flowers, in strong contrast to other mosquitoes. Still, there seem to be many exceptions. For example, both the larvae and the adults of most of the larger horseflies are carnivorous, and the plant-feeding larvae of gall midges most certainly do not give rise to bloodsucking adults. Since one of the major selective advantages of complete metamorphosis is that it enables the insect to exploit quite different habitats at different stages of its life, one should expect many cases in which the food habits of larvae and adults differ. We know much too little, however, about the nutritional requirements of the majority of flies to indulge in such broad generalizations.

Another theme running through the book is the frequency of evolutionary convergences occurring in the Diptera: gall-making has evolved independently on several occasions; so have bloodsucking, parasitism of mammals, symbiosis with ants or termites, and in fact a vast number of the biological features of flies. This theme is a sound one, but it does not mark the flies as being very different from most other major groups of animals.

Perhaps the most striking aspect of the evolution of flies is simply that this originally rather heterogeneous array of gnats and midges gave rise to something of a "utility model"—a fly of rather standardized appearance developing from maggots and pupae of decidedly standardized appearance, yet physiologically *capable de tout*. Most of the higher flies seem "stamped in the same mold"; the consistent displacement of a few bristles may result in their being assigned to different superfamilies by taxonomists. The development of such a "standard type" of animal, apparently incapable of much further morphological improvement but capable of rapid evolution in physiological features (as indicated, for example, by the development of strains of houseflies resistant to certain insecticides), represents a challenge to biologists and perhaps to all mankind. One cannot help thinking of the first individualistic automobiles and comparing them with modern mass-produced models, all of which look very much alike.

Indeed, the term "mass production" fits the flies quite well. The housefly, one of the most complex miniaturized systems in existence, is able to produce a new generation of its kind in less than a week. As Oldroyd remarks, it has been calculated that in the course of a single summer a pair of flies could produce enough offspring, if all survived, to cover the earth to a depth of 47 feet. Oldroyd checked these calculations and found "that a layer of such a thickness would cover only an area the size of Germany, but that is still a lot of flies."

All of this is cause for concern when one considers that the housefly habitually breeds in human feces and then travels to human foods and feeds by first regurgitating onto them, and that other flies are capable of burrowing under man's skin or developing in his intestine. I rather wish Oldroyd had quoted from the accounts of people who have described the sensation of *Dermatobia* larvae burrowing in their skin, or of individuals suffering from intestinal or nasopharyngeal myiasis. For example, the following gruesome case history is cited by W. B. Herms in his book *Medical Entomology* (1939):

"While traveling in Kansas in the latter part of last August, a citizen of this place had the misfortune to receive while asleep a deposit of eggs from [the screwworm] fly. He had been troubled for years with catarrh, hence the attraction for the flies.... Monday, my first day, his appearance was that of a man laboring under a severe cold.... Tuesday, saw him again. His nose and face were still swollen, and in addition to the other symptoms he was becoming slightly delirious and complained a great deal of the intense misery and annoyance in his nose and head. A few hours after, I was sent for in haste with the word that something was in his nose. I found on examination a mass of the larvae of this fly ... completely blocking up one nostril. On touching them they would instantly retreat en masse up the nostril. Making a 20 per cent solution of chloroform in sweet milk I made a few injections up both nostrils, which immediately brought away a large number, so that in a few hours I had taken some 125 of them.... Friday I was able to open up two or three canals that they had cut, extracting several more that had literally packed themselves, one after another, in these fistulous channels. His speech becoming suddenly much worse, I examined the interior of his mouth and found that a clear-cut opening had been made entirely through the soft palate and into his mouth."

The man finally died of an abscess caused by larvae that had invaded the eustachian tube. The reader is doubtless thinking that this sort of thing could never happen in the blacktopped, air-conditioned world of 1965. Malaria, yellow fever, filariasis, sleeping sickness—fly-borne diseases that once swayed empires—have all become minor diseases; the apple maggot and cheese skipper have been banished from the A&P. Farmers nonetheless pay several million dollars a year to control crop-infesting flies, and local outbreaks of encephalitis, a mosquito-borne disease with a high rate of mortality, are reported in the U.S. every summer. We learn from E. C. Cushing, quoted by Oldroyd, that during World War II the U.S. armed forces employed 4,407 men for antimalarial work in the South Pacific alone; in spite of this the Army had 546,230 cases of malaria. Can we afford to let down our guard against the flies? Can we ever have confidence that a catastrophe in human affairs will not force us to lower our guard?

Man has been pestered by flies ever since the dawn of civilization, and doubtless before. In Harry Eltringham's words,

Profound research does not disclose
The epoch when the fly arose
To plague creation.

The Philistines made obeisance to Beelzebub, the god of flies, in the hope of propitiating him and so reducing the curse of flies. Malcolm Burr, in *The Insect Legion: The Significance of the Insignificant* (1939), speaks of this as "the first historical account of the appointment of a Fly Control Officer." Then came the 10 plagues of Egypt, six of which (according to Burr) were entomological, and at least two and perhaps four of which were attributable to flies. Fly-borne diseases are said to have hastened the decline of both Athens and Rome. Sleeping sickness long delayed the civilizing of Africa and yellow fever the opening of the American Tropics.

These stories have been told many times before; what of the future? Oldroyd believes that with luck and persistence we may keep most bloodsucking flies under control. The higher flies may have better prospects: "They have learned to use decaying, fermenting, or putrefying organic materials, universal media that will always exist. No doubt we shall continue to campaign against the house-fly, but we shall not defeat it by chemicals, because it evolves resistant strains too quickly for us. Hygiene will keep it at bay in superior districts, but there will always be plenty of breeding material left about for it. As quickly as urban areas are denied to the house-fly the tourist and his motor-car make more rural areas attractive to it."

Oldroyd does not seem to place much confidence in control by means of releasing males sterilized chemically or by irradiation [see "The Eradication of the Screw-Worm Fly," by Edward F. Knipling; Scientific American, October, 1960], nor does he explore the possibility of using insect hormones or related substances as control agents. Successful, wide-ranging control by

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these methods is indeed well in the future, if it can be achieved at all. We are likely to have to wait a bit for the "chemically sterile, insect-free world" feared by Rachel Carson. In fact, if human populations (and their wastes) are to double every few generations as predicted, there may be a rich future in store for the filth flies. Perhaps we had better learn to understand and appreciate them. Vincent G. Dethier, in his delightful book *To Know a Fly* (1962), makes a strong case for the blowfly. As for me, I hope to seek out the coffin fly; by the time he finds me, it will be too late to enjoy him.

The possibility that we are already becoming more fly-conscious is suggested by the second book under review; it is the first catalogue of flies of America north of Mexico to appear since 1905. This catalogue is the work of a devoted band of dipterists in the Entomology Research Division of the U.S. Department of Agriculture, assisted by more than 40 collaborators, each of them a specialist on some particular group of flies. One needs to use numbers to describe this great tome: it is 6.7 centimeters thick and has 1,696 pages, the bibliography contains nearly 4,800 references, the index occupies 147 pages. These figures are, however, insufficient to suggest the amount of perspiration expended in various museums and libraries in putting the volume together. Cataloguing is not fun; it is hard, often frustrating work, and the cataloguer is rarely rewarded with acclaim, to say nothing of more material considerations. Neither is a catalogue fun to read; it is nonetheless a *sine qua non* of fruitful research on any group of organisms—a summary of accumulated knowledge and a guide post to the future. As it is summed up in the introduction to *A Catalog of the Diptera of America North of Mexico:*

"The most important functions of a catalog are to list all published names with a reference to the original publication of each, to distinguish between valid and synonymous names, to present as sound a classification as possible, and to give an indication of the distribution of the species. A catalog should also serve as a guide to important revisionary works, keys and significant accessory information."

If I were to complain about this particular catalogue, it would be that the amount of accessory information is somewhat small. Under each family heading and under some subfamilies and a few genera one learns a little about the biology of the group, with or without a reference or two, but this information is quite limited, and there are no references to the biology or behavior of individual species. In this respect, and in some matters of format, this catalogue seems to me to fall short of the generally similar Hymenoptera catalogue of 1951 (U.S. Department of Agriculture Monograph No. 2). The use of smaller type would have allowed inclusion of much more accessory information in the same number of pages.

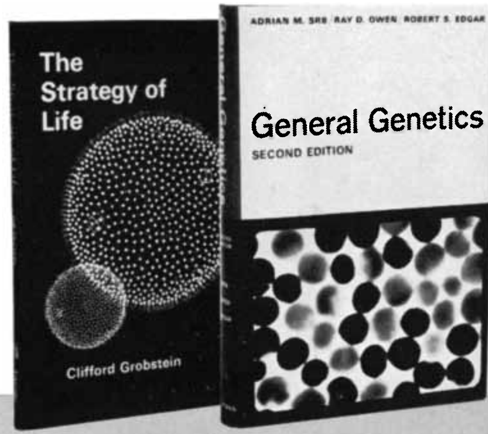
I really should not complain at all, particularly about matters that may well have been out of the hands of the compilers of this volume. Like several thousand other entomologists, I shall be eternally grateful to them for completing such a tedious and thankless task. Why, indeed, should it be thankless? I hereby thank the 47 dipterists listed on pages 13 and 14 of the catalogue, not 1,000 times but 16,130 times—the number of species of flies they record from America north of Mexico. These flies, we learn, are included in 1,971 genera distributed among 105 families. The Tipulidae (crane flies) turn out to be the largest family, with 1,458 species. The Tachinidae (tachina flies) rank second, with 1,281 species. (There are, however, 414 genera of tachina flies and only 59 genera of crane flies.) Ranking third and fourth in family size are the Cecidomyiidae (gall midges) and the Dolichopodidae; the latter do not even have a well established common name, although there are nearly twice as many species of Dolichopodidae as species of birds in the U.S. and Canada. Under group after group in the catalogue one finds such comments as "many vexing taxonomic problems remain unsolved" and "very little is known of the habits or immature stages." Let us hope that publication of this catalogue ushers in a new era in the study of Diptera, as in some measure the publication of the Hymenoptera catalogue of 1951 did. When we consider the many ways in which flies impinge on man, and the remarkable life histories of so many of them, it is not much of a tribute to man's intellect that while reaching for the stars he ignores the fly on his windowpane.

Short Reviews

SERENDIPITY AND THE THREE PRINCES, edited by Theodore G. Remer. University of Oklahoma Press ($4.95). "Serendipity," in recent years an overworked vogue word, was coined by Horace Walpole, the 18th-century English author, art critic, sometime politician and indefatigable correspondent. In a letter to a friend, Horace Mann, he defined the word as follows: "I once read a silly fairy tale, called *The Three Princes of Serendip:* as their highnesses travelled, they were always making discoveries, by accidents and sagacity, of things which they were not in quest of: for instance, one of them discovered that a mule blind of the right eye had travelled the same road lately, because the grass was eaten only on the left side, where it was worse than on the right—now do you understand Serendipity?"

The book to which he refers was printed in Venice in 1557 by Michele Tramezzino, who was probably also its author, although it purported to be a translation from the Persian; later it was translated from Italian into other languages, including French and English. It was the French translation, published in Amsterdam, that Walpole read. In retelling the story to Mann, Walpole made a number of errors—for instance, the mule was actually a camel—and the example he gives fails to support his definition. Since then the word, even as he defined it, has been abused and misused. *The Oxford English Dictionary* in its 1914 edition describes serendipity as "the faculty of making happy and unexpected discoveries by accident"; *Webster's Third New International Dictionary* defines it as "an assumed gift for finding valuable or agreeable things not sought for." It was certainly no "happy" discovery, nor a "gift," to find the tracks of a blind animal; in fact, the three noble brothers, showing off their Holmesian powers of deduction, were suspected of having stolen the camel and were put in jail. Writers about science, including scientists, have a penchant for using "serendipity" in the "happy accident" sense; they also tend to link it to Pasteur's remark that chance favors the prepared mind. Dragging in the latter notion is presumably intended to offset the possible interpretation of serendipity as covering the circumstance of the man who falls into a sewer and comes up with a gold watch. To enjoy the benefits of serendipity one must, as Walpole insisted, be sagacious. Whatever the word's usage, it sheds no light whatever, as its users seem to think it does, on the mysterious processes of invention and discovery. Whether a doctor who finds a kidney stone while looking for a gallstone is as fortunate and sagacious as Fleming in finding penicillin, Balboa the Pacific or Becquerel radioactivity is a question neither Walpole nor the dictionaries can answer.

Theodore G. Remer, a Chicago at-



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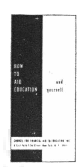


College is Business' Best Friend

torney, has gone to a great deal of trouble to describe the true sources of Walpole's word and the errors and confusions surrounding it. For good measure he has thrown in a fresh English translation of the *Peregrinaggio di tre giovani figliuoli del re di Serendippo.* A pleasant labor of scholarship.

THE AGE OF REPTILES, by Edwin H. Colbert. W. W. Norton & Co., Inc. ($8.50). From the vantage point of the precarious Age of Man, which has lasted only a few hundred thousand years and may not last much longer, we look back with respect, admiration and fascination on the long and successful reign of the reptiles, in many respects "the most spectacular phase of life history." It is thought to have spanned about 130 million years, beginning in the Permian period and ending in the Cretaceous, and through much of it the dinosaurs ruled the land. Descended from the amphibians, the first reptiles were much like them but differed in one very important respect, namely in producing an amniotic egg. With the embryo protected from its environment by a shell, reptiles were freed from their ancestral habitat in the sea and were able to wander far and wide over the world. Edwin H. Colbert, a leading paleontologist, has in this book given an admirable account of the rise of the reptiles, of the many forms they took, of their intercontinental migrations, of their relation to other forms of life and the environment through millions of years. He describes the principal species in beautifully clear detail, thus making them come to life again. He explains the effect of climate on the evolution of diverse species and tells the intricate story of the discovery of fossils in different geologic layers, which has made it possible to reconstruct not only the appearance of the creatures but also their evolution. The mystery of the great extinction that brought the Age of Reptiles to an end, leaving behind only a few brilliantly adapted orders such as the turtles, remains, in spite of a plethora of hypotheses, as inscrutable as ever. It seems likely that a combination of factors, rather than any single cause, led to the termination of the reptiles' ascendancy on earth. Many illustrations and charts.

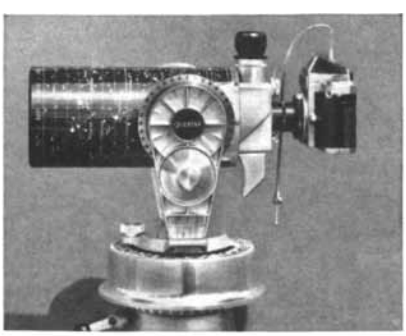
THE EXPRESSION OF THE EMOTIONS IN MAN AND ANIMALS, by Charles Darwin. The University of Chicago Press ($5). In his preface to the reissue of this enduring work, first published in 1872, Konrad Lorenz says that so far-reaching, so universal and so fertile were the implications of Darwin's principle of natural selection that even today scientists have not fully explored its meaning and that Darwin himself did not realize what he had set in motion and how much he knew. The study of animal behavior, as Lorenz remarks, has a special right to claim Darwin as its patron saint, not only because it is immediately dependent on the evolutionary approach but also because "it has done its fair share in verifying Darwin's theories." Both in his approach to the study of the expression of emotions—observing infants, the insane, dogs, cats, monkeys; using photographs of expressions submitted to different judges; comparing expression among different peoples—and in his emphasis on the inheritance of certain behavior patterns, their persistence and their evolution he was profoundly foresighted and laid foundations for the modern study of ethology. The writing is clear and direct, full of penetrating insights and enlivened by anecdotes, examples and trenchant observations. It discusses such matters as the expression of "low spirits, anxiety, grief, dejection, despair" by means of "oblique eyebrows" and "depressed corners of the mouth." It also takes up the uses of laughter and the different ways of showing tender feelings; the dilation of the pupils when fear is felt; the "most peculiar and the most human of all expressions," namely blushing; snarling as an expression of rage. This is a superb book, and the illustrations are marvelous.

MAX BORN: AUSGEWÄHLTE ABHANDLUNGEN. Göttingen, Vandenhoeck & Ruprecht ($25). A selection of the mathematical and physical papers of one of the greatest living scientists, with a useful introduction by Born himself that describes the scope of his work and explains in detail the circumstances in which his various investigations were undertaken. Born's versatility and sweep are well demonstrated. The first group of papers deals with mechanics, relativity, thermodynamics and related topics and includes his uncommonly interesting dissertation on the stability of an elastic line in a plane and in space, a topic to which he returned some 35 years later, when he was professor at the University of Edinburgh and was asked to investigate major damage done to certain building structures by earth waves caused by blasting operations. The second group of papers is concerned with one of Born's favorite topics, namely crystal lattices, about which he wrote papers with the late Theodor von Kármán, Alfred Landé, E. Brody and others. Atoms, molecules and liquids are the subjects of the papers in the third group; quantum mechanics is dealt with in a fourth group, where among his collaborators are Wolfgang Pauli, Werner Heisenberg, James Franck, Pascual Jordan, Norbert Wiener and J. Robert Oppenheimer. A fifth group is devoted to field theory and a sixth to miscellaneous memoirs of leading physicists and mathematicians: Max von Laue, H. A. Lorentz, J. J. Thomson, Max Planck, Arnold Sommerfeld, Albert Einstein, Erwin Schrödinger, Hermann Minkowski. The two volumes are in many respects a history of the 20th-century revolution in physics.

THE PHILOSOPHY OF GRAMMAR, by Otto Jespersen. W. W. Norton & Co., Inc. ($1.95). A reissue of a major work, first published in 1924, that sets forth the principles underlying the grammars of all languages. Rousseau said it requires a great deal of philosophy to be able to know how to observe even once what one sees every day; this high capacity, which Jespersen fully possessed, accounts not only for the innovating value of his linguistic studies but also for their established status as reference works. A paperback.

OLDUVAI GORGE 1951–61: VOLUME I, by L. S. B. Leakey. Cambridge University Press ($14.50). This volume, described as a preliminary report, is based on the many discoveries of tools, artifacts, bones of animals and pre-men (including the famous skull of *Zinjanthropus*) Leakey made at this site beginning in 1951. The volume is concerned, however, only with the mammalian fauna and the geography of the area, the intention being to use this material as background for further reports. Of particular interest are the speculations by Leakey and his collaborators about the climatic sequence in the Olduvai region, which is inferred by applying skilled and imaginative scientific reasoning to the geological data, including the stratigraphy of the beds and the fossil deposits. Numerous plates.

CHEMISTRY AND BEYOND, edited by Herbert Dingle and G. R. Martin. John Wiley & Sons, Inc. ($6). A selection from the historical and philosophical writings of the late F. A. Paneth, the German scientist who was trained as an organic chemist, switched to the new discipline of radiochemistry, taught at Königsberg until the Nazis came to power and then moved to Britain, where



he pursued his distinguished career until the 1950's. With Georg von Hevesy he discovered and developed the radioactive-tracer technique and made many contributions to geochemistry and nuclear physics. The selections are in a more or less popular vein and include such topics as John Newlands' periodic system, Thomas Wright and Immanuel Kant, memories of the early days of the Vienna Radium Institute, the origin of meteorites, Goethe's scientific background. An attractive selection.

PSYCHOSOMATIC DISORDERS IN ADOLESCENTS AND YOUNG ADULTS, edited by John Hambling and Philip Hopkins. Pergamon Press ($8.50). Papers and discussions of a conference held by the Society for Psychosomatic Research in London in 1960. The main objectives were to consider psychosomatic disorders occurring between the ages of 15 and 25, and to discuss the mental transformation from childhood to mature adulthood. Among the topics discussed are the adolescent in industry and the university, psychosexual development in adolescents, menstrual disorders, epilepsy in adolescents, the psychosomatic aspects of acne, tuberculosis and acute appendicitis. Some of the papers bring up fresh material that is of interest, but the discussions—evidently presented verbatim—are pointless and frequently incoherent. Why proceedings of this kind deserve to be put between hard covers is one of the higher mysteries of our day.

SCIENTIFIC PAPERS, by Lord Rayleigh. Dover Publications, Inc. ($30). Lord Rayleigh (1842–1919) was a versatile and uncommonly gifted physicist. He made major contributions to the theory of sound, based on both mathematical researches and experiments; he investigated optics and color vision, polarization and light-scattering; he advanced hydrodynamics (particularly with respect to the propagation of waves), thermodynamics, electricity and magnetism (with famous studies on the ohm); he worked on surface tension, black-body radiation, the densities of gases, and with Sir William Ramsay he discovered the element argon. The honors conferred on him—including the Nobel prize in physics, the presidency of the Royal Society and the Order of Merit—were as numerous as his interests were broad. This three-volume work, an unabridged edition of the six-volume collection published by Cambridge University Press between 1899 and 1920, contains the corpus of his scientific

papers (with the exception of *A Treatise on Sound*), a brief bibliography and a 16-page supplement consisting of photographs pertaining to his life and work. Indispensable to any scientific library.

THE AFRICAN GENERA OF ACRIDOIDEA, by V. M. Dirsh. Cambridge University Press ($37.50). This handsome book, published on behalf of the Anti-Locust Research Center in London, describes all genera and lists all species of the African locusts up to the end of 1958, and contains a large number of carefully drawn illustrations. The foreword notes that although at present most of the major species of plague locusts in Africa and Asia are quiescent, the locust problem is far from solved. The expansion of agriculture taking place or impending in most developing countries is "tending to augment infestation by both locusts and grasshoppers," making it all the more important to systematize and widen knowledge of the insects' biology.

SOURCEBOOK ON THE SPACE SCIENCES, by Samuel Glasstone. D. Van Nostrand Company, Inc. ($7.95). This volume written under the sponsorship of the National Aeronautics and Space Administration presents an overall survey of the science and technology of the exploration of outer space with chapters on such topics as orbits and trajectories, propulsion and power, guidance and tracking, the solar system, the earth and its environment, man and space. No advanced scientific knowledge is required to follow the text, and mathematics is used sparingly.

HISTORY UNDER THE SEA, by Mendel Peterson. Smithsonian Institution ($3). A handbook of underwater exploration for archaeological purposes. It describes the location and condition of various underwater sites, sketches the history of some recent expeditions in the Western Hemisphere and explains search techniques, the surveying of underwater sites, the preservation of materials recovered from the water and the identification of shipwrecks. Many excellent illustrations.

Notes

EQUALITY, by R. H. Tawney. Barnes & Noble, Inc. ($1.50). A soft-cover reprint, with a new introduction by Richard M. Titmuss, of Tawney's Halley Stewart Lectures of 1929, concerned with the social and economic inequalities of English society and the strategy of overcoming them. A powerfully written, elegant and humane book.

PROBABILITY AND ITS ENGINEERING USES, by Thornton C. Fry. D. Van Nostrand Company ($15). A revised edition of a textbook of exceptional quality, first published in 1928 and still, particularly because of its many examples, a work that will enhance the understanding of any college student of probability and statistics.

EARLY PHOTOGRAPHY IN CANADA, by Ralph Greenhill. Oxford University Press ($12.50). The main feature of this account of the development of photography in Canada from the daguerreotype to the dry plate is the collection of 106 photographs of city and country, of Indians, Eskimos, soldiers and workmen, and of various historic events.

THE BIRDS OF NATAL AND ZULULAND, by P. A. Clancey. Oliver & Boyd Ltd. (84 shillings). A detailed description, abundantly illustrated with line drawings and colorplates by the author, of the rich avifauna of Natal and Zululand, based on a study of the literature and of museum specimens and on personal observations in the field over more than a dozen years.

XEROGRAPHY AND RELATED PROCESSES, edited by John H. Dessauer and Harold E. Clark. Focal Press, Inc. ($38). Contains articles on the history, scientific background and practical applications of xerography, the electrostatic-imaging process now in such wide use.

THE UNIVERSAL ENCYCLOPEDIA OF MATHEMATICS. The New American Library ($1.50). A soft-cover edition of a handy, authoritative reference guide, alphabetically arranged, containing information about almost every branch of mathematics that engages the attention of the average student.

BIOGRAPHICAL MEMOIRS, NATIONAL ACADEMY OF SCIENCES OF THE UNITED STATES OF AMERICA: VOLUME XXXVIII. Columbia University Press ($5). Fourteen memoirs of leading scientists, among them Arthur Holly Compton, Ernest W. Goodpasture, Theodor von Kármán and Robert M. Yerkes.

THE CHURCHILL YEARS: 1874–1965. The Viking Press ($16.50). A collection of photographs covering Winston Churchill's life from his childhood to his funeral. There is a supporting text by *The Times* of London.

INDEX OF ADVERTISERS

JANUARY 1966

BIBLIOGRAPHY

Readers interested in further reading on the subjects covered by articles in this issue may find the lists below helpful.

COMMUNICATION BY LASER

ADVANCES IN OPTICAL MASERS. Arthur L. Schawlow in *Scientific American*, Vol. 209, No. 1, pages 34–45; July, 1963.

THE EVOLVING TECHNOLOGY OF COMMUNICATION. E. I. Green in *Electrical Engineering*, Vol. 78, No. 5, pages 470–480; May, 1959.

THE FUTURE OF MICROWAVE COMMUNICATIONS. S. E. Miller in *Proceedings of the IRE*, Vol. 50, No. 5, pages 1215–1219; May, 1962.

RESOURCE LETTER MOP-1 ON MASERS (MICROWAVE THROUGH OPTICAL) AND ON OPTICAL PUMPING. H. W. Moos in *American Journal of Physics*, Vol. 32, No. 8, pages 589–595; August, 1964.

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Orbiting over Africa—two million square miles of Sahara Desert flash on satellite periscope. Photo courtesy Perkin-Elmer Corporation.