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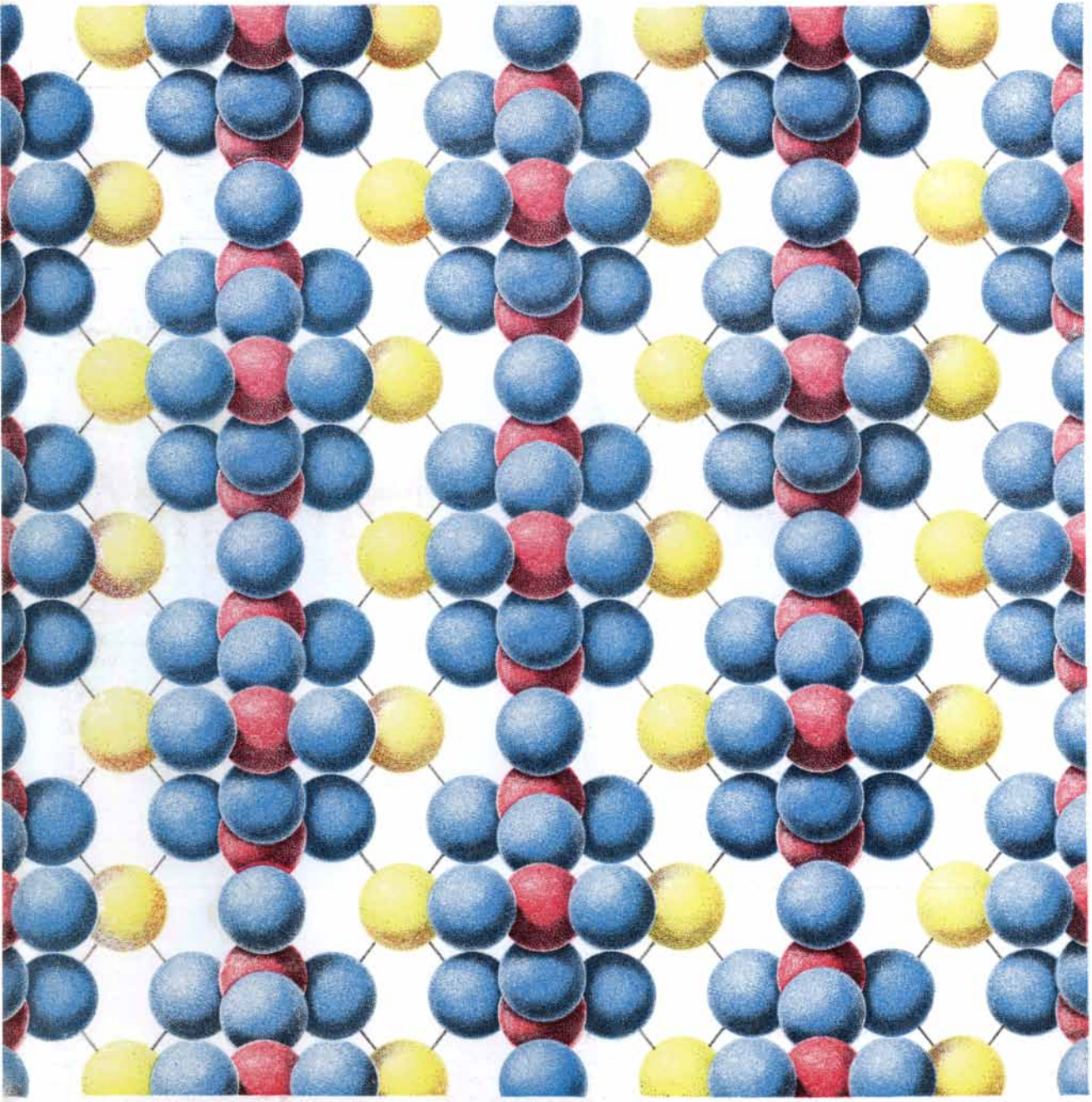
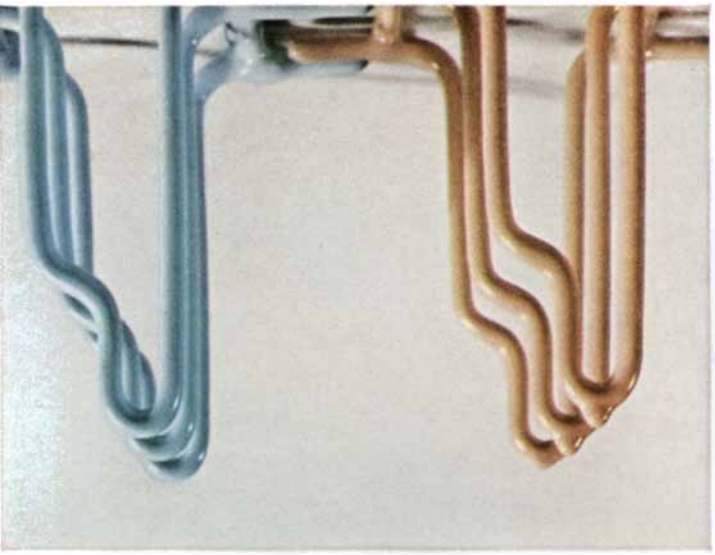


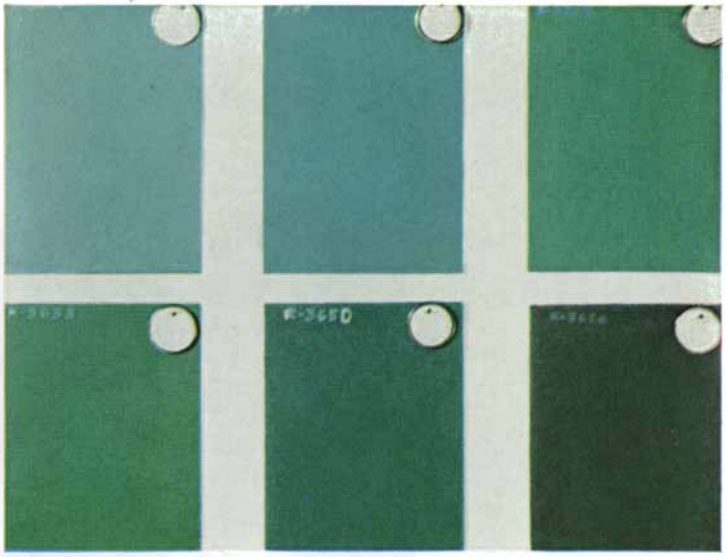
CEMENTING CRYSTAL OF CONCRETE

SIXTY CENTS

April 1964



Change of color changes properties: Spectrophotometers and color computers help to control color in M&T vinyl coatings to within one MacAdam unit. But change colors significantly and you often change physical properties, as indicated above. Here human capability comes in. Putting experience to work, M&T chemists often come up with entirely different formulations for two colors to have the same physical and chemical properties.



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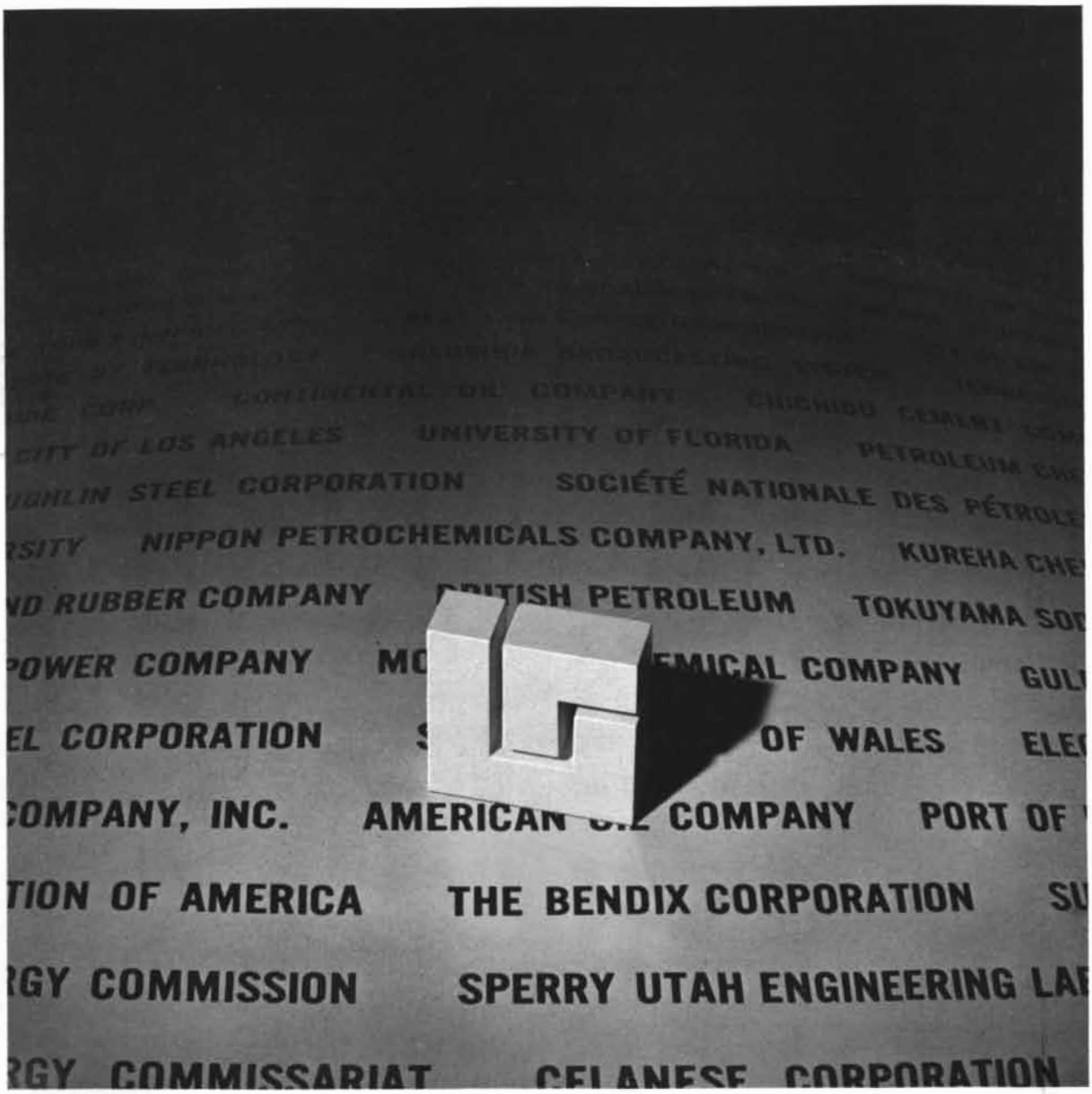

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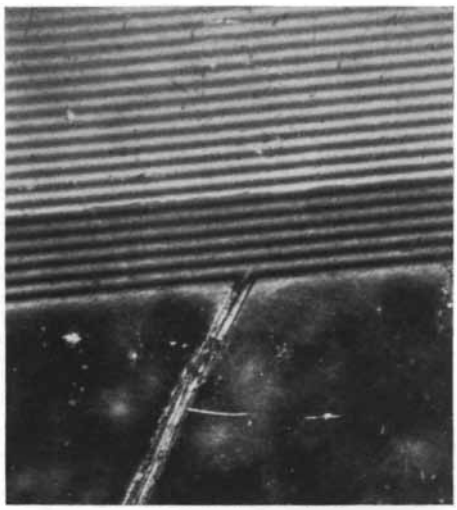

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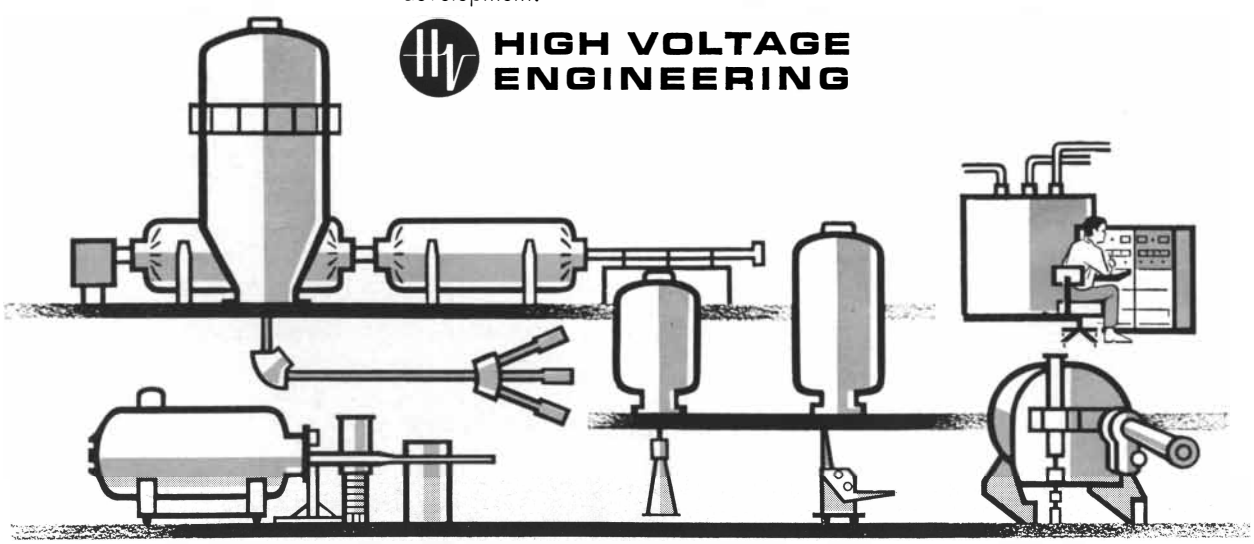

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Established 1845 **SCIENTIFIC AMERICAN** April 1964 Volume 210 Number 4

ARTICLES

DEPARTMENTS

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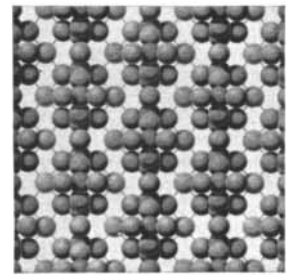

THE COVER

The design on the cover shows the arrangement of atoms in a thin layer of a crystal of the natural mineral tobermorite. It has recently been discovered that a partly crystallized form of tobermorite, called tobermorite gel, is the main product of the chemical reaction between portland cement and water. Tobermorite gel is thus the principal cementing constituent of concrete (see "The Chemistry of Concrete," page 80). Chemically tobermorite is a calcium silicate hydrate. In the cover design the yellow spheres represent calcium atoms; the red spheres, silicon atoms; the blue spheres, oxygen atoms. Attached to some of the oxygen atoms are hydrogen atoms, which are not shown. The structure of tobermorite was determined in 1956 by H. D. Megaw and C. H. Kelsey of the University of Cambridge; this presentation was worked out by H. F. W. Taylor of the University of Aberdeen.

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in national defense—the words "reliability" and "necessity" are synonymous

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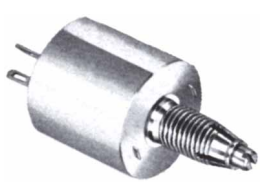
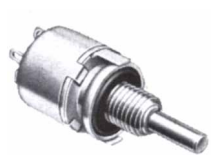
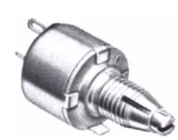


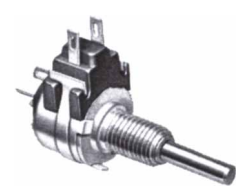
TYPE GWEL
WITH ENCAPSULATION



TYPE GWP AND LWP
WITH WATERTIGHT PANEL SEAL



TYPE GWL AND LWL
WITH LOCKING BUSHING



TYPE GWX
WITH LINE SWITCH

Electronic Communications' AN/ART-42 UHF 1 KW AM/FM Transmitter in service with the SAC, and internal view showing use of A-B's Type G controls.

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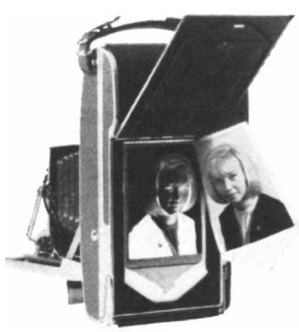

Getting on-the-spot results, of course, is the big difference between the 110B and any ordinary camera you happen to have around.

The developing and printing, we confess, is automated. But the camera itself isn't. And if you aren't—then this is your camera.

LETTERS

Sirs:

James R. Newman's review of *Interstellar Communication* in your February issue is written with his usual mixture of wit and wisdom. As one of the authors, I am grateful for the general blessing he has given to our enterprise, and I only wish to rebut two of his offhand pronouncements I consider untrue.

The first pronouncement concerns interstellar space travel. Newman quotes the calculations of Edward Purcell and Sebastian von Hoerner and remarks that these "expose the hoax" of interstellar space travel. The calculations are, of course, perfectly correct and show that interstellar voyages cannot be completed within the span of a normal human lifetime. However, this does not by any means dispose of the problem of interstellar space travel, either in relation to the future of our own species or to the possible present activity of others. It is rather easy to envision propulsion systems that would economically propel large vehicles at a speed of a few light-years per century, such speeds being characteristic of nuclear power sources. Interstellar voyages would then require thousands of years. For a society to be capable of making such voyages it would be sufficient that the society either consist of very long-lived organisms or have solved the problem of reversible freezing and cold-storage of individuals. Thus interstellar travel is essentially not a problem in physics or engineering but a problem in biology. There is no reason to exclude arbitrarily the possibility that other species in our galaxy may have solved this problem, or that we may later solve it ourselves. Many of us, no doubt including Newman, would find thousand-year trips unappealing, but we have no right to impose our tastes on others.

Newman's second objectionable statement is his jibe at "a few of the contributors to this book" who "are silly enough to impute to the societies of other planets the same murderous impulses, military ambitions, obsessions and follies that shape our own civilization." I do not know if he includes me in this category, but I hope he does. I am glad to speak for all scientists interested in interstellar communication who do not share Newman's peculiarly optimistic preconceptions.

Our business as scientists is to search the universe and find out what is there. What is there may conform to our moral sense or it may not. Our business is to try to imagine and find means to detect the possible manifestations of intelligence in the universe. It is just as unscientific to impute to remote intelligences wisdom and serenity as it is to impute to them irrational and murderous impulses. We must be prepared for either possibility and conduct our searches accordingly. I personally cannot accept Newman's view that interstellar communication will necessarily be "the perfect, deliberate, philosophical discourse." Intelligence may indeed be a benign influence, creating isolated groups of philosopher-kings far apart in the heavens and enabling them to share at leisure their accumulated wisdom. Or intelligence may be a cancer of purposeless technological exploitation, sweeping across a galaxy as irresistibly as it has swept across our own planet. In this connection it is of importance that, even at the slow rate of interstellar travel that is unquestionably feasible, the technological cancer could spread over a whole galaxy in a few million years, a time very short compared with the life of a planet.

All of us who think seriously about the detection of extraterrestrial intelligence know that we suffer from one basic limitation. Our imagined detectors detect technology rather than intelli-

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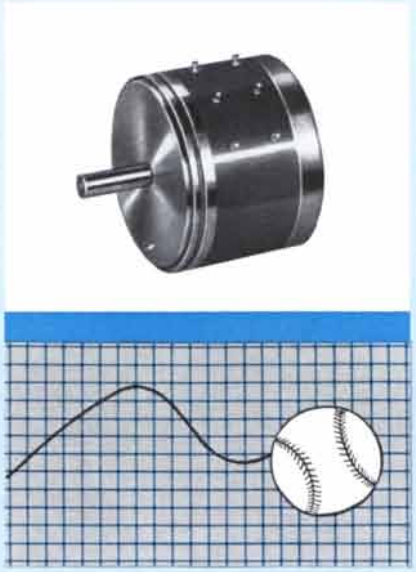

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ACTUAL SIZE

gence. And we have no idea whether or not a truly intelligent society would retain over millions of years an interest in or a need for advanced technology. Under these circumstances it is best to admit frankly that we are searching for evidence of technology rather than of intelligence. And we must be aware that we have perhaps a greater chance of discovering first a technology run wild, insane or cancerously spreading than a technology firmly under control and supporting the rational needs of a superior intelligence.

FREEMAN J. DYSON

Institute for Advanced Study
Princeton, N.J.

Sirs:

In his article on the mitochondrion [SCIENTIFIC AMERICAN, January] David E. Green makes a statement that is incidental to his exciting story but should not be allowed to pass without contradiction. He calls mitochondria and chloroplasts "particles with a common function"; both produce high-energy phosphate (ATP), the first in animal tissues and the second in plant tissues. In both cases, he suggests, three ATP molecules are produced for each electron pair transferred.

However, the functions of the mitochondrion and the chloroplast are opposite rather than similar. The mitochondrion is supplied with reagents of high energy—an organic substrate and oxygen—and given the task of subdividing the free energy of their combination into small units suitable for a variety of cellular processes. The mitochondrion does not "produce" energy—nothing can! It converts, with remarkable efficiency, one form of chemical energy into another: the oxidation-reduction energy of the system "organic substrate plus oxygen" into the hydrolytic energy of the system "ATP plus water."

The chloroplast, on the other hand, is supplied with low-energy reagents—water and carbon dioxide—and with light energy and given the task of reversing what the mitochondrion has done, recreating the system "organic matter and oxygen" and converting light energy into chemical energy in this process.

Although in chloroplasts the hydrogen atoms are moved not "downstairs" as in mitochondria but "upstairs," some ATP formation does occur in them, but it is only a minor aspect of the energy-storing process. The ATP formed is destined for internal use: to make possible some enzymatic steps in the photosynthetic reaction sequence that require small amounts of energy. This ATP is used up when photosynthesis is completed; the net result is to convert light energy into oxidation-reduction energy. Mitochondria are energy-dispersing centers; chloroplasts, energy-saving "banks." Without this activity of the chloroplasts mitochondria would have no high-energy reagents to work on! The sequence of transformations is: light energy → (chloroplasts) → oxidation-reduction energy → (mitochondria) → ATP-energy.

That the structure of chloroplasts is similar to that of mitochondria—both consist of thin layers of protein alternating with thin layers of lipoid material—is certainly fascinating. (The existence of particles similar to those found by Humberto Fernández-Morán in mitochondria had not yet been proved in chloroplasts, but they may exist there too.) It should not be forgotten, however, that the same structural principle —alternating protein and lipoid lamellae —is used by nature not only in chloroplasts and mitochondria but also in many other structures, such as visual rods, the myelin sheaths of nerves, and cell membranes. It may be suitable not only for electron-transfer reactions but also for a variety of other processes, having in common the need for an extended two-dimensional structure.

EUGENE RABINOWITCH

University of Illinois
Champaign, Ill.

Sirs:

Professor Eugene Rabinowitch is on unassailable grounds in contending that the chloroplast differs from the mitochondrion in some fundamental respects. But I would like to submit that the similarities of the two systems are real and profound—so much so that the two systems can be looked on as derivatives of a common primordial system. In the mitochondrion the passage of an electron pair through a chain of graded oxidation-reduction components is coupled to the synthesis of ATP. In all chloroplast systems that have been studied by Daniel Arnon and others the existence of an electron-transfer chain has been established, and the movement of electrons through this chain has been shown to be coupled to the synthesis of ATP. This capacity for coupled synthesis of ATP is not an incidental prop-

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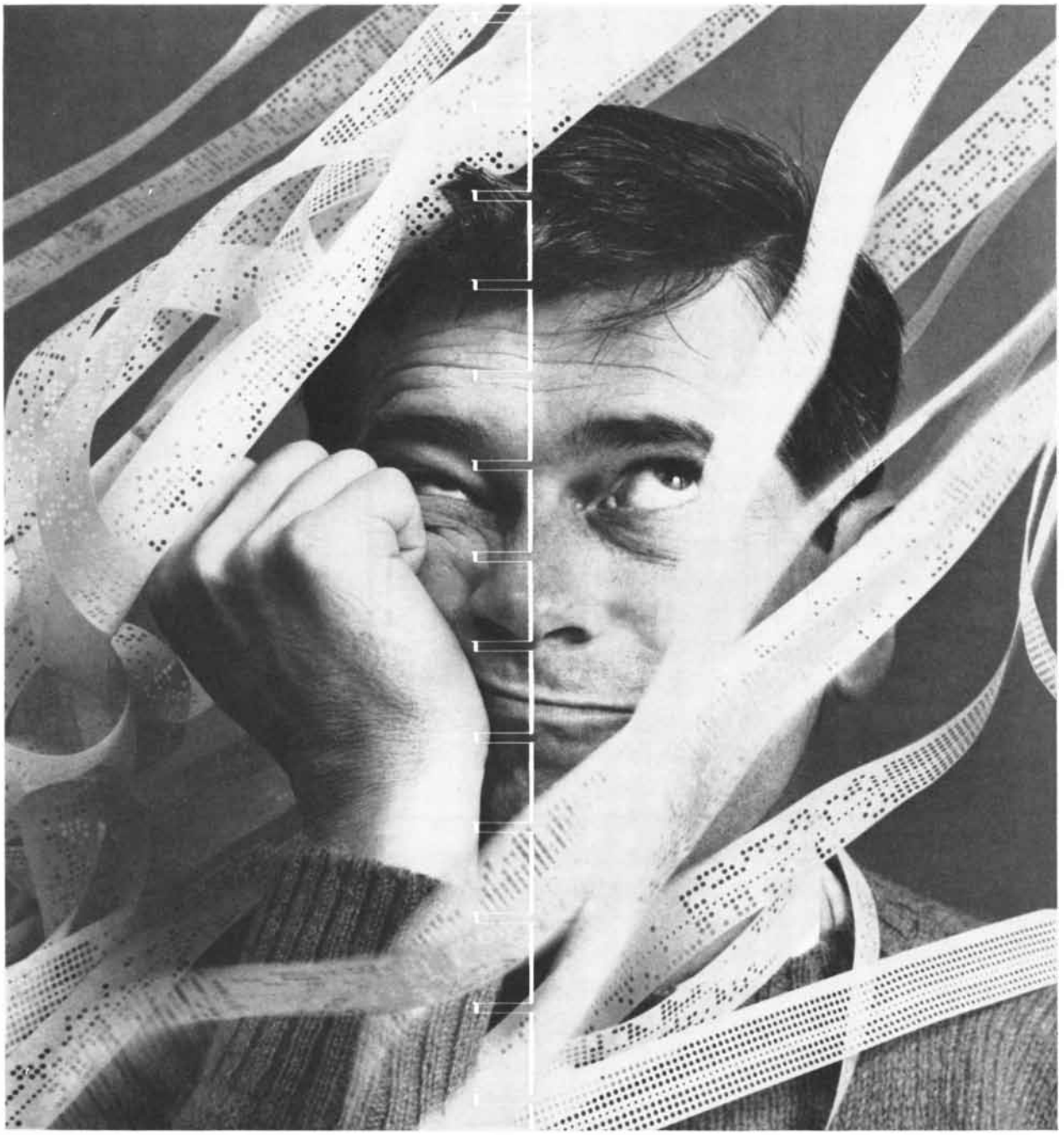
erty of some chloroplasts but is apparently a property of all the chloroplasts that have been examined so far. I am unaware of a single authenticated case of a chloroplast that does not contain an electron-transfer chain and that does not give rise to ATP by coupled electron flow. The components of the electron-transfer chain of the chloroplast (nonheme iron proteins such as ferredoxin, cytochromes and plastoquinone) contain virtually the identical functional groups as the corresponding components of the mitochondrial electron-transfer chain. Moreover, one of the fundamental repeating units of the chloroplast (the quantasome) has been shown by Melvin Calvin and his colleagues to resemble the mitochondrial counterpart (the elementary particle) in molecular size and shape and in lipid composition. These are the similarities that justify considering the chloroplast and mitochondrion as functional first cousins. As I see it, the difference between the two systems relates to the mode by which electrons enter or leave the electron-transfer chain. In the mitochondrion electrons are supplied via an oxidative pathway and are eventually transferred through the chain to molecular oxygen. In the chloroplast electrons are ultimately supplied via a photochemical process involving chlorophyll, and the electrons that move through the electron-transfer chain are transferred not to molecular oxygen but to a cytochrome component that becomes regenerated by photochemical means. Various sites are known at which photochemical processes intervene, but these processes are superimposed on what is basically the principle of the mitochondrial electron-transfer chain. The one property that clearly distinguishes the chloroplast from the mitochondrion is the capacity for catalyzing the photochemical reduction of triphosphopyridine nucleotide (TPN). However, there is an analogous process mediated by all mitochondria tested: the ATP-catalyzed reduction of diphosphopyridine nucleotide (DPN) or TPN by succinate. Britton Chance and Lars Ernster have fully documented this coupled reductive step that involves the reversal of the electron-transfer process. In sum, the similarities between mitochondria and chloroplasts more than outweigh the differences.

DAVID E. GREEN

Institute for Enzyme Research
University of Wisconsin
Madison, Wis.



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AMPEX

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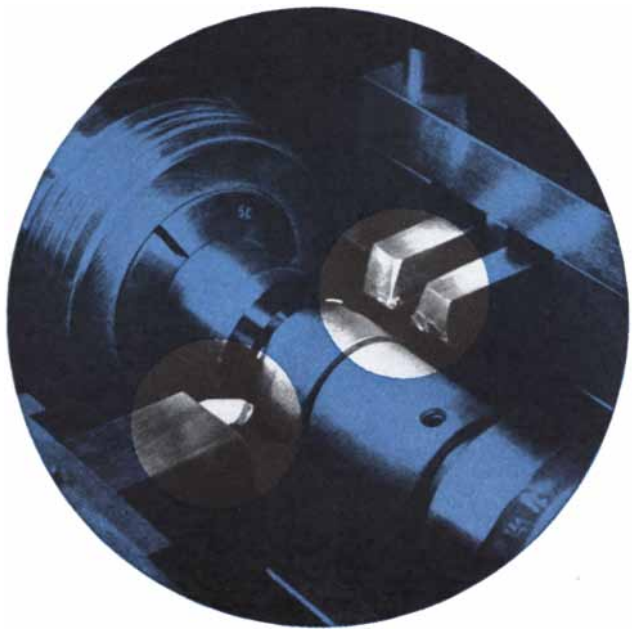
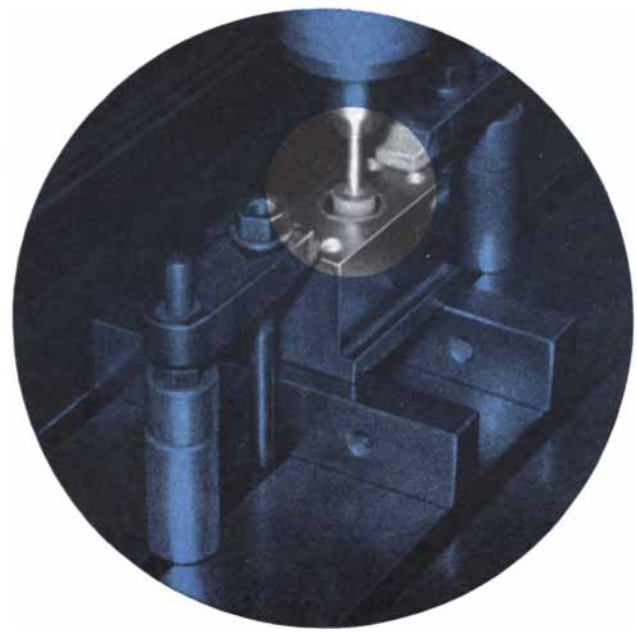


THREE SINGLE-POINT natural-diamond tools turn final finish on mineral-filled plastic resistance elements for precision potentiometers at Markite Corp., Ramsey, N. J., plant. The tools make a transverse cut, a surface cut and an assembly groove sequentially. Carbide tools failed to maintain required specifications.



A ⅝-INCH RESINOID WHEEL with 120-mesh natural-diamond grit finishes inside diameter in a carbide sleeve at AA Jig Grinding Inc., Detroit. Special jigs, tools or gages are generally made to tolerances of ±.0001 inch. In order to meet specifications, this assembly will have to be checked at 68° F.

The grinding, cutting and finishing jobs shown on these pages are being performed on carbide, abrasive plastic and reinforced epoxy. But they all share one detail: in every case natural diamonds are doing the job quickly—and economically.

When you use diamonds, you get the unique combination of excellent cutting ability linked with fantastic endurance. Result: diamond tools last longer than any others. Your people spend more time producing, less time changing tools.

If you cut, sharpen, grind or smooth anything in your business, you can probably use natural dia-

INDUSTRIAL DIAMONDS CUT PRACTICALLY EVERYTHING . . . ESPECIALLY YOUR PRODUCTION COSTS

A RECIPROCATING DIAMOND FILE is used at Textile Machine Works, Reading, Pa., for roughing, finishing and polishing carbide tools and dies. Flat, triangular, and oval files are used. Rotating head can also be used with diamond quills, which can be operated at 45,000 rpm for grinding internal surfaces of dies.

HIGH-SPEED MOTOR turns diamond-coated router blade at 17,000 rpm as it cuts around the access door in a reinforced epoxy plastic panel. Distance of 69 lineal inches for each panel is cut in about 30 minutes. Even for this low-production job, diamonds have proved the most economical material.

monds to advantage. Test them against the method you're now using. You'll discover how efficient—and economical—a diamond tool can be.

Best grit for metal-bond wheels developed by the Diamond Research Laboratory in Johannesburg

A special impact crushing method for natural diamonds is producing the strongest and most durable grit ever obtained for metal-bond wheels. Your tool and wheel manufacturer is ready to help you select the diamond tool that's right for your job.

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50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

APRIL, 1914: "Col. Goethals has announced that unless unforeseen developments occur at the Cucuracha slide, and this is not likely, the Panama Canal will be opened to commercial vessels about July 1st of this year. The dredges are working on the channel which has been cut through the slide, and the present effort is to make the channel so broad that these dredges will not interfere with the passing of ships."

"The vicissitudes attending the task of building a 100-inch reflector—by far the largest telescope in the world—for the Mount Wilson Observatory have been watched with interest and anxiety by astronomers for nearly eight years. At last the successful grinding of the great mirror is so far assured that active work has been begun on the construction of the mounting and dome. Foundations have been laid for the observatory building and the telescope pier is about finished."

"In a recent lecture Kamerlingh Onnes, who has been awarded the Nobel prize for physics, remarked that we can now obtain experimentally a temperature which is only removed from the absolute zero of temperature by one degree. The temperature thus obtained is lower by two or three degrees than the temperature of sidereal space, which according to the calculations of the astrophysicists is about four degrees above absolute zero."

"The two stars Mizar and Alcor form a double star system which can easily be perceived by the naked eye. This was not the case formerly, as the Arabs used the resolution of the system into its two components as a test for good eyes. It would seem, therefore, that this system has increased in brightness since the 10th century, a supposition which is supported by the fact that it is not mentioned by the ancients. The history of this system was familiar to astronomers when it was found in 1907 that Alcor is itself a double star. It is now discovered by Mr. Harlow Shapley that Alcor varies in brightness, the variations having a feeble amplitude and a short period. The spectrum type of Alcor, which is an A5 star, that is to say a white star with hydrogen predominating, and the doubling of the lines announces a variation of the Algol type, i.e., by eclipse rather than continuous variation. It is supposed that there exists a couple of elliptic stars very close together and inclined on their orbit in such a way that the mutual eclipse is feeble or almost nothing, the variations of brightness resulting from their marked ellipticity."

"An Italian engineer, Signor Marzi, has invented a new microphone for use in wireless telephony, so that from the Eiffel Tower in Paris it is now possible to hear concerts taking place in Brussels, a distance of about 225 miles. The singing could be distinctly heard, although it was not possible to make out the words of the songs."

Scientific American.

APRIL, 1864: "A 30-pound Parrott gun in Fort Putnam, Morris Island (off Charleston, S.C.), was recently tested by firing until it burst. The weapon threw 4,615 shells into Charleston, five miles distance, at regular intervals of five minutes before it burst. Such endurance is unprecedented."

"A recent reference in the London *Times* to a statement that 'three centuries ago Blasco de Garay attempted to propel a boat by steam in the harbor of Barcelona' called forth a counter-statement from a correspondent who has had access to the original letter from Blasco himself written in A.D. 1543, which contains the evidence often cited by the Spaniards for this assertion. This letter describes minutely a vessel propelled by paddles worked by 200 men, but there is not a word about steam in the whole document. The first well-authenticated instance of a steamboat actually used is found in the manuscript correspondence between Leibnitz and Papin in the Royal Library at Hanover, where Papin relates his experiments with a model steamboat on the river Fulda in the year 1707."

"M. Blondeau has examined the changes produced in Roquefort cheese when it is stored away in cellars to acquire the flavor which recommends it to the taste of some people. He found fresh cheese contained: casein, 85.43 per cent; fatty matter, 1.85 per cent; lactic acid, .88 per cent; water, 11.84 per cent. After being two months in a cellar similar cheese contained: casein, 42.28 per cent; margarine, 18.30 per cent; olein, 14 per cent; butyric acid, 1.67 per cent; salt, 4.45 per cent; water, 19.30 per cent. The remarkable change of casein into margarine and olein, the author believes, is due to a mycoderm of the genus *Penicillium*."

"The all-absorbing topic at present is the great New York Sanitary Fair and its prospects. War for a time is placed in the back ground and, as if it never existed in the land, the merry-makers and staid busy people of the metropolis strive, each in his own way, to make this Fair the crowning triumph of the others which have preceded it in different parts of the country. It is well known to most of our readers that an immense building has been erected in this city, upon 14th street and Sixth avenue, to accommodate the contributions which have been so lavishly handed in for the benefit of the Sanitary Commission, and also another one, subordinate but nearly as large, upon Union Square and 17th street. In these two buildings are stored vast quantities of the most costly goods, all of which were given freely to be sold for the benefit of our sick and wounded soldiers. The enterprise was formally opened on Monday the 4th instant; all New York enjoyed a holiday and in the evening the ceremonies took place."

"The French submarine-boat *Plongeur*, it is stated, does not draw more than eight feet of water, her engine is of 80 horse-power, steam is replaced by compressed air, and her crew of 12 men are completely protected from all danger. The *Plongeur* is intended to be a formidable engine of destruction. Her spur is formed like a tube and an incendiary shell may be placed in it. Should an enemy's fleet be at anchor the *Plongeur* will drive her spur into the nearest ship and then retreat, unrolling at the same time a metallic wire. When at a safe distance, an electric spark will cause a great explosion, the enemy's ship being blown up."

"Mr. Bessemer, the inventor of the process of converting iron quickly into steel, now says he can produce a block of it, 20 tuns in weight, from flint cast iron in 20 minutes!"

NEW DEEP-SEA AMPLIFIER TRANSMITS 128 TELEPHONE CONVERSATIONS

Our engineers have developed a new amplifier which simultaneously transmits 128 telephone conversations in both directions over a single cable. It is designed to operate without repair or maintenance on the ocean floor for 20 years.

The new amplifier (illustration below) is an important advance in deep-sea communications technology.

To make a single amplifier operate in two directions, it was necessary to provide a precise, complex filter system to separate the signals. Signals traveling in one direction occupy a frequency band from 116 to 512 kc., and those traveling in the other direction, from 652 to 1052 kc.

The gain of each amplifier must accurately compensate for its share of cable loss. The total loss varies over the frequency band and, in a transatlantic system, reaches a maximum of 9000 decibels. Since there is no way to adjust an amplifier on the ocean floor, the performance of each one must be pre-established with extreme precision.

A 3600-mile cable link, with its 180 amplifiers, includes 36,000 electronic components. Each component has to be endowed with a reliability far in excess of the requirements of conventional land systems.

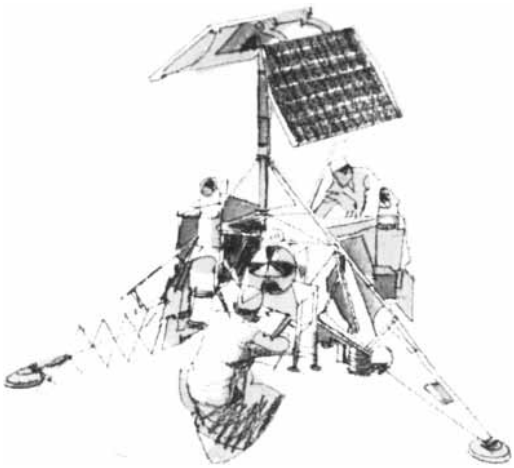
The casing and its seal to the cable must prevent minute water seepage at ocean bottom pressures. This could accumulate fatally over the years, and so production tests employing radioactive isotopes are used to search for any such microscopic leakage.

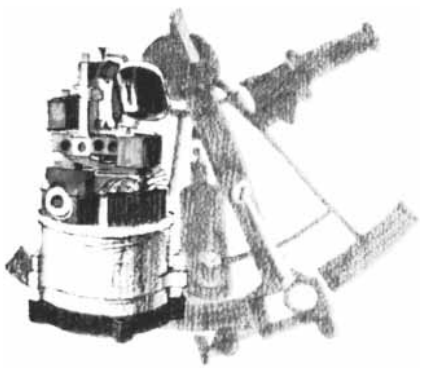
In bringing the new underseas system to production we worked closely with Western Electric, the manufacturing unit of the Bell System. Our joint objective was to create a system of high reliability that could be manufactured economically. The new amplifiers are being used first in the new deep-sea telephone link from Florida to Jamaica and Panama.

BELL TELEPHONE LABORATORIES

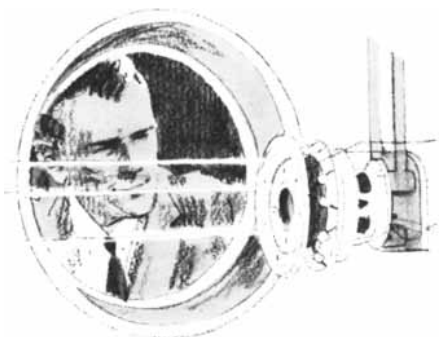
World center of communications research and development

View of deep-sea amplifier with casing cut away. The casing is of noncorrosive beryllium copper, tested to withstand pressures up to 11,000 psi.

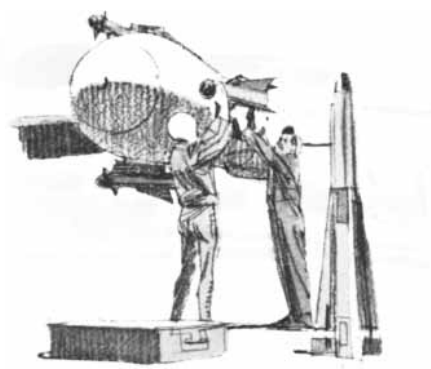


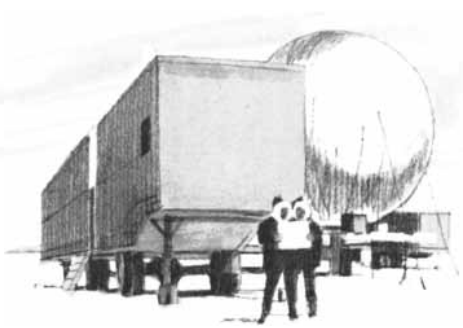


Hughes is: Surveyor, star tracker,

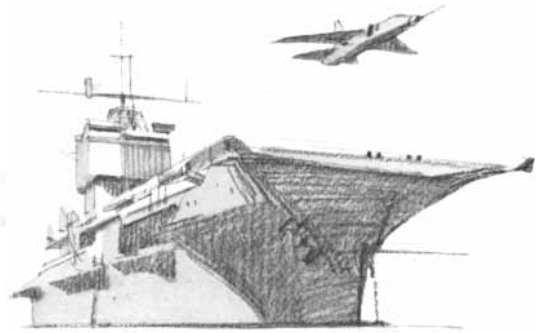


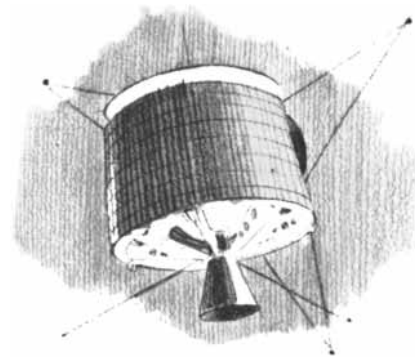
ion space engines, microelectronics,



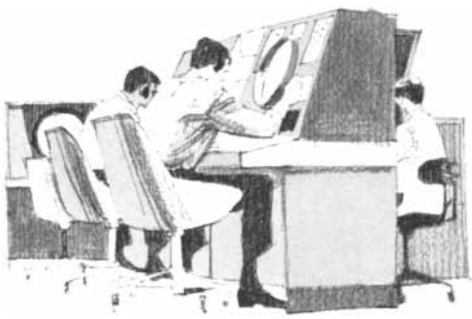


missile systems, and more . . .





Enterprise 'eyes', Syncom satellites,



command and control, laser-rangers,

Hughes is a company of nearly 30,000 – including over 7,000 engineers and scientists – applying their skill and imagination in space, in national defense, and for commercial purposes.

The examples: **Surveyor** – Will soft land a scientific package on the Moon. Will gather and relay information about the Moon to earth, paving the way for our astronauts. **Star Tracker** guidance device for the Surveyor. One of Hughes' many infrared advances. **Enterprise 'eyes'** – Large, flat radars that show aircraft in 3-D. **Syncom** – the first communications satellite "parked" over the earth. The first to operate 'round the clock to break all records. **Ion engines** promise to be the most efficient way to propel space ships to distant planets. **Microelectronics** – saving power, space and weight by making the electron work in new ways. **Command and Control Systems** – using computers to give battle commanders up to the second information for decision-making. **Laser-rangers** – applying the laser in measuring distances. **Missile systems** – In service: thousands of Falcon missiles. Soon, Phoenix missiles and guidance electronics for the Navy's new F-111B jets. **And more!** There are more than 553 projects, products and services at Hughes.

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HUGHES

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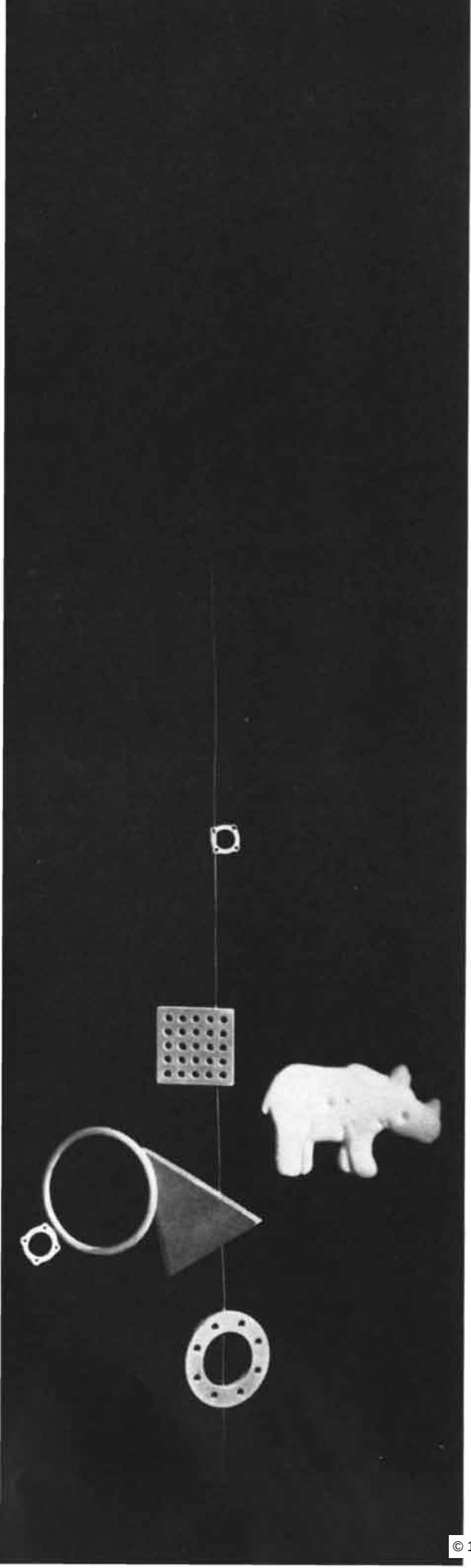
Engineers and scientists with related interests are invited to inquire. Hughes is an equal opportunity employer. Please address: Mr. S. L. Gillespie, Mgr., Employment and Manpower, Hughes Aircraft Company, Culver City 67, California.



One of a series briefly describing GM's research in depth

SQUARE LOOP FERRITES NOW IN ODDBALL SHAPES

Ceramic ferrites are versatile magnetic oxides usually made by the press forming of powdered ingredients. Here at the Laboratories, a recent spill-over from our fundamental research in ferrites has resulted in a new fabrication technique. It makes ferrites of virtually any type or shape practicable: permanent magnetic ferrites, high frequency core materials, computer elements with square hysteresis loops.

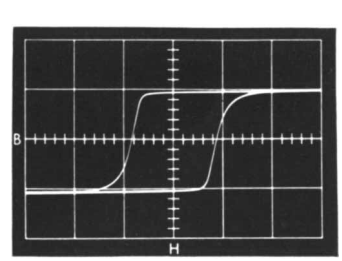
The new "cookie cutter" process begins with ferrite powder mixed with a plastic binder on a rubber mill. This forms a flexible sheet of almost any thickness down to 0.005 inch. From it, ferrites of any desired shape can be cut or molded—easily and economically—before the special presintering and sintering treatments. The fired ferrites shrink evenly and are exceptionally uniform in material density and magnetic characteristics.

Our electronics engineers have found the new fabrication technique particularly valuable for making multiaperture devices—wafer-thin square loop ferrites used in computer memory cores and switching circuits. Practical development of these and other applications is continuing as a team effort of the Laboratories and GM divisions.

Involving a blend of scientific understanding and engineering know-how, this new process is another example of the advances in technology being made by GM's research in depth.

General Motors Research Laboratories

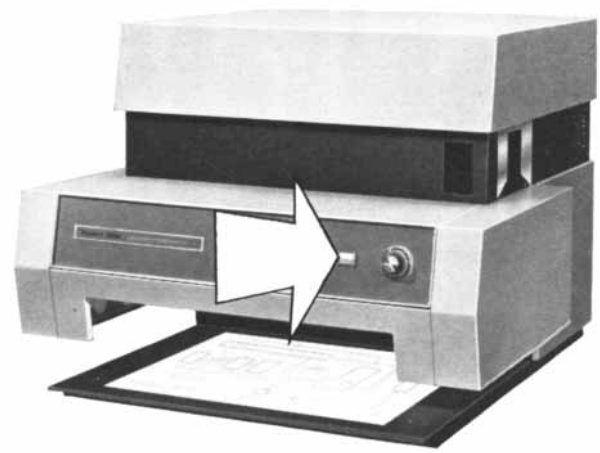
Warren, Michigan



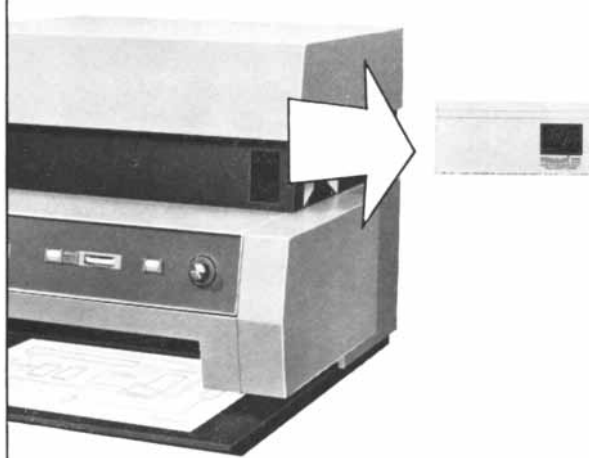
Hysteresis loop from ferrite memory core prepared by new GMR process.

Unique 3M Invention produces complete microfilm record in just 54 seconds!

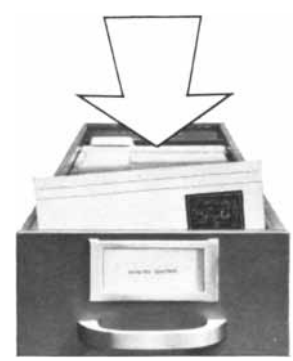
Place the original here.



Push a button.



Complete in 54 seconds.



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Today space planners know the U. S. has a *simple, working* fuel cell. Perhaps you have seen it in operation. A 50 pound, 1000 watt fuel cell has been transported across the country several times *for a series of public demonstrations.*

Allis-Chalmers research for NASA's *Marshall Space Flight Center* and the *Air Force* has produced a fundamental breakthrough in the art of fuel cell moisture control and removal in the *vapor phase* by a *static method.* A bonus is the great simplification for thermal control at *low temperature.*

The result is a hydrogen-oxygen fuel cell system that is much lighter than any other known system. Pictured on the right is the 1-kw unit weighing just 50 pounds and measuring 20″ x 10″ in diameter. And, as the repeated demonstrations have proved, it is operational *right now!*

A further indication of confidence is the fact that the *Air Force Aeronautical Systems Division* has selected Allis-Chalmers to build a 50 watt hydrogen-oxygen system for the first orbital fuel cell flight. This system has successfully passed shock, vibration, acceleration, zero gravity and full power testing.

What are the other significant facts about Allis-Chalmers fuel cell capability?

1. We are studying mobile energy depot systems for the *AEC* and the *Army. Significance: These systems would use nuclear reactors to generate fuel. Fuel cells would power the vehicles, alleviating logistical problems of supplying fuel to a modern army on the move.*

2. Under development now — a fuel cell and the integration of a 5-kw hydrocarbon-reforming fuel cell system for the *Army's Engineer Research and Development Laboratories. Significance: This system will "crack" inexpensive hydrocarbon fuels to obtain hydrogen for the first major air-breathing fuel cell.*

3. Our 7-kw hydrazine-oxygen fuel cell powers an experimental, 2000 lb fork lift truck. Our 3-kw hydrazine-oxygen fuel cell powers an experimental golf cart. *Significance: Multiple kw fuel cell systems have been applied to vehicles like the experimental golf cart that have been demonstrated to thousands of people from coast to coast.*

4. We've announced discovery of nickel boride as the material to replace platinum for the anode catalyst. *Significance: This is the first inexpensive and efficient anode catalyst for fuel cells using hydrogen-oxygen or hydrazine-oxygen.*

Now, may we discuss your aerospace or defense fuel cell application?

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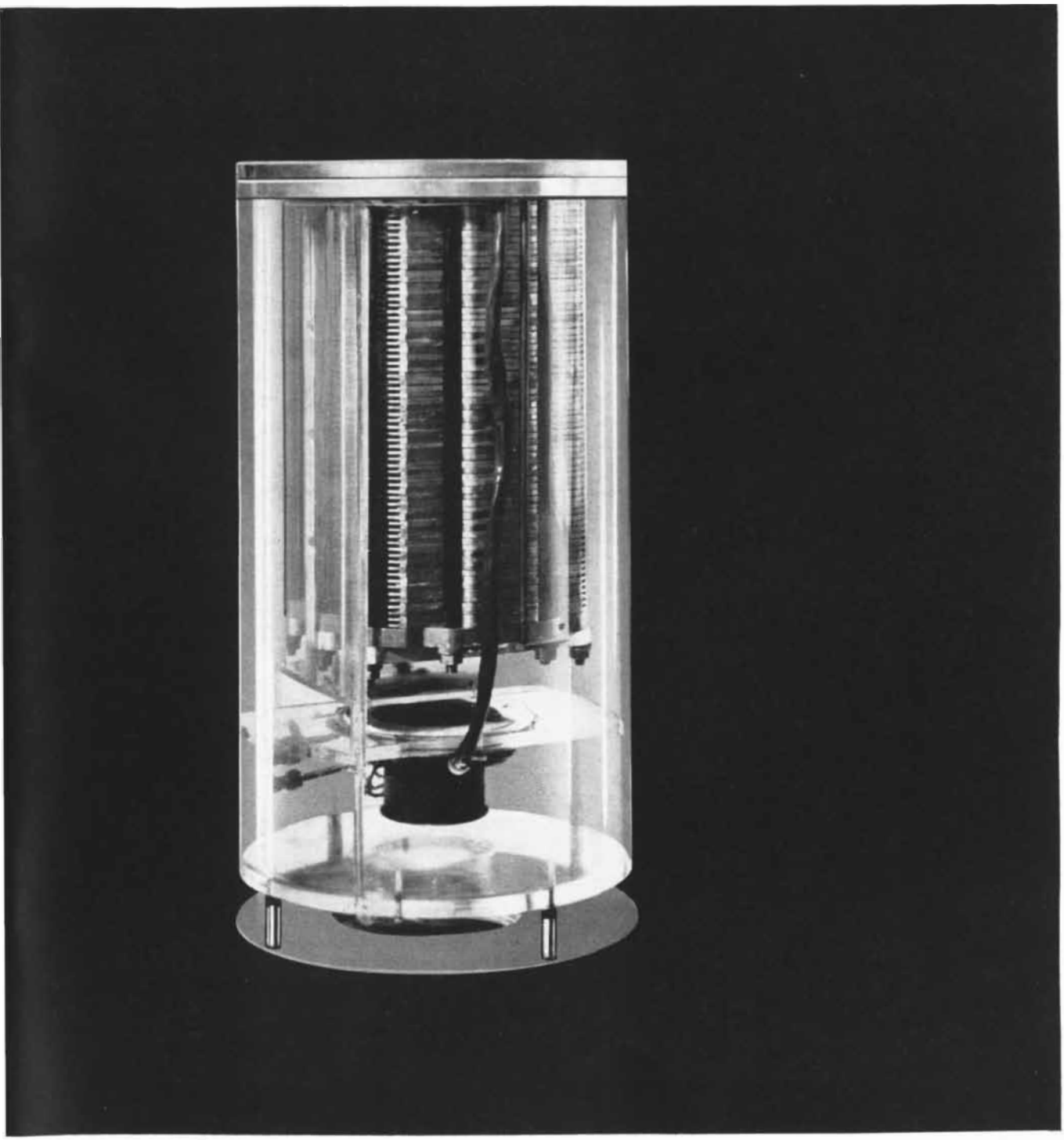
* * *

FUEL-CELL design for space application is but one of the opportunities open today for qualified scientists and engineers at Allis-Chalmers. For information concerning employment write to: Director of Research, Allis-Chalmers, Milwaukee, Wisconsin 53201. A-1840

ALLIS-CHALMERS

for space power



THE AUTHORS

FRANK BARRON, MURRAY E. JARVIK and STERLING BUNNELL, JR. ("The Hallucinogenic Drugs"), do research on this subject in New York and California. Barron is a research psychologist at the University of California's Institute of Personality Assessment and Research in Berkeley. A graduate of La Salle College in Philadelphia, he received an M.A. from the University of Minnesota in 1948 and a Ph.D. from the University of California at Berkeley in 1950. He has taught at Bryn Mawr College, Harvard University, Wesleyan University and the University of California. Jarvik is associate professor of pharmacology at the Albert Einstein College of Medicine and attending physician at Bellevue Hospital in New York. He was graduated from the City College of the City of New York in 1944 and subsequently acquired an M.A. in psychology from the University of California at Los Angeles in 1945, an M.D. from the University of California School of Medicine in 1951 and a Ph.D. in psychology from the University of California at Berkeley in 1952. He has taught and done research in the fields of pharmacology, psychology and neurophysiology at various institutions. Bunnell is a resident in psychiatry at the Mount Zion Medical Center in San Francisco. He received an M.D. from the University of California School of Medicine in 1958 and is currently working on a Ph.D. in neurophysiology at the University of California at Berkeley.

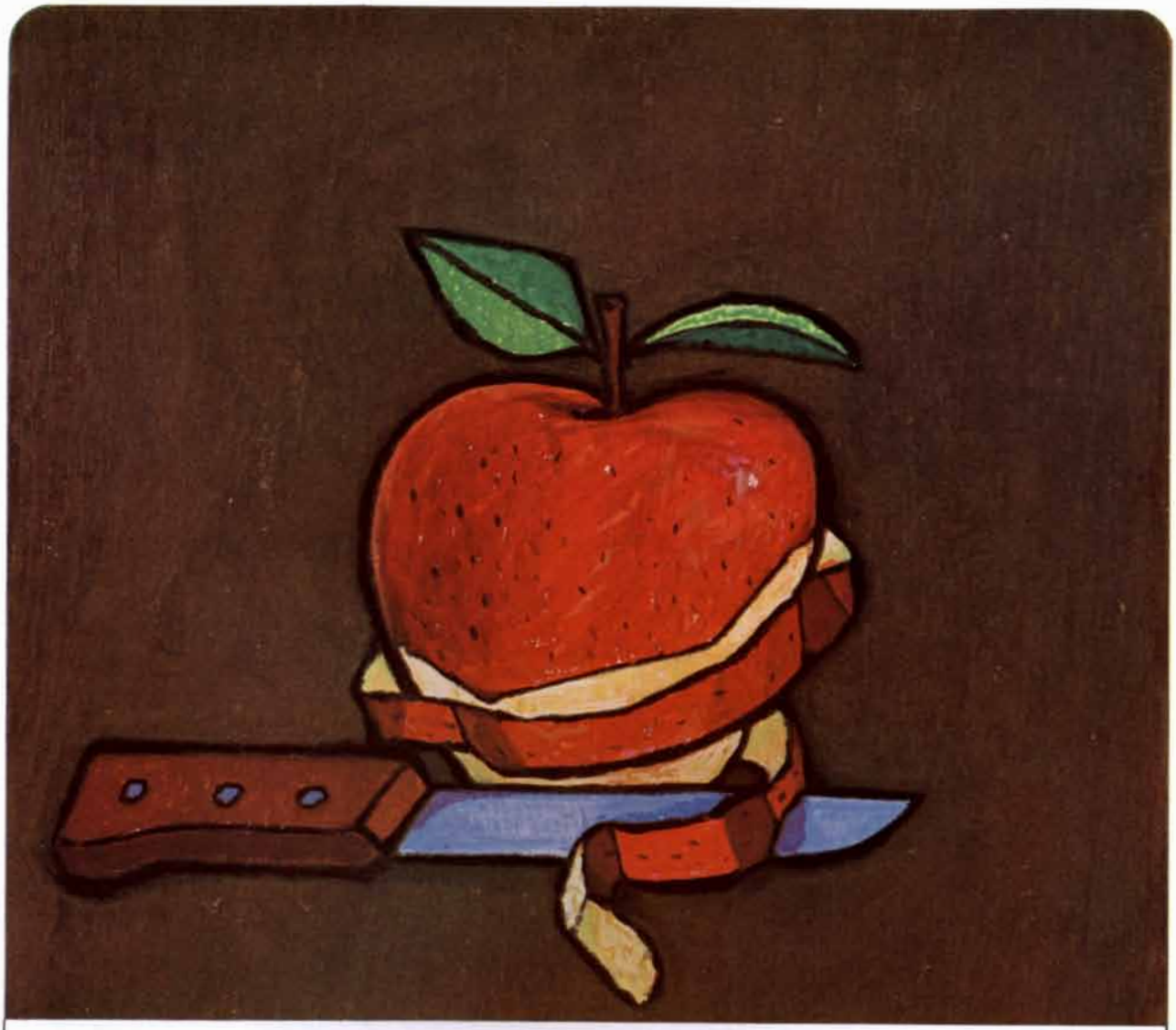
J. A. GIORDMAINE ("The Interaction of Light with Light") is a member of the staff of the Solid State Electronics Research Laboratory of the Bell Telephone Laboratories. He was born in Toronto in 1933 and received a B.A. in physics and chemistry from the University of Toronto in 1955. He did graduate work in physics at Columbia University under the direction of Charles H. Townes, obtaining a Ph.D. in 1960. He taught physics at Columbia from 1959 to 1961, when he took up his present post.

WOLFGANG BEERMANN and ULRICH CLEVER ("Chromosome Puffs") work at the Max Planck Institute for Biology in Tübingen. They are also members of the faculty of the University of Tübingen. Beermann is a director of the Max Planck Institute in Tübingen and professor of zoology at the university. A native of Hanover, he received his doctorate from the University of Göttingen in 1952. He did research at the Max Planck Institute for Marine Biology in Wilhelmshaven from 1952 to 1954, when he was appointed assistant professor at the Zoological Institute of the University of Marburg. He took up his present post in 1958. Clever is a research associate at the Max Planck Institute in Tübingen and lecturer in zoology and genetics at the university. He received his doctorate from Göttingen in 1957 and did research for a year at the Federal Research Institute for Viticulture before going to Tübingen in 1958.

E. N. PARKER ("The Solar Wind") is professor of physics at the University of Chicago; he is also a member of the staff of the university's Enrico Fermi Institute for Nuclear Studies. A graduate of Michigan State University, Parker received a Ph.D. in theoretical physics from the California Institute of Technology in 1951. He taught mathematics and astronomy at the University of Utah from 1951 to 1955, when he joined the staff of the Fermi Institute.

STEPHEN BRUNAUER and L. E. COPELAND ("The Chemistry of Concrete") are respectively manager and principal research chemist in the Basic Research Section of the Research and Development Division of the Portland Cement Association. Brunauer was born in Budapest in 1903 and was graduated from Columbia College in 1925. He received an M.S. in chemistry from George Washington University in 1929 and a Ph.D. from Johns Hopkins University in 1933. From 1928 to 1942 he did research on fertilizers, catalysts and adsorbents for the U.S. Department of Agriculture. During World War II he served as a commander in the U.S. Naval Reserve and following the war he stayed with the Department of the Navy, first as chief technical administrator of High Explosives Research and Development and later as chief chemist of the Bureau of Ordnance. He joined the staff of the Portland Cement Association in 1951. For his contributions to colloid and surface chemistry Brunauer received the Hillebrand Award of the Chemical Society of Washington in 1945 and the Kendall Award of the American Chemical Society in 1961. Copeland was born in Meridian, Miss., in 1909 and was graduated from John Fletcher College in 1930. After nine years of industrial work he entered the graduate school of the University of Chicago, where he received a Ph.D. in 1941. He did research

INNOVATION!



A NEW TECHNIQUE FOR PROTECTING SPACE METALS
(IT'S BASED ON THE PRINCIPLE OF AN APPLE PEEL)

If this picture were a movie taken in slow motion, you could watch the apple turn brown where the skin has been peeled off. Oxidation is the culprit. It also causes other, more serious problems in hardware that becomes extremely hot – parts of space vehicles, rocket nozzles, turbine and jet engines, for example. Even metals designed for high temperatures can flake and peel off from oxidation.

GT&E scientists developed a remarkable new coating that beats the heat and oxidation. Very simply, it's a mixture of aluminum and tin. When applied to surfaces that become hot, this coating acts as a protective skin similar to the apple peel.

Working on this coating, GT&E scientists had the advantage of wide experience with high-temperature (refractory) metals – we make and use them in projects as diverse as lighting products and space systems.

GT&E's progress in metallurgy springs from a broad research program – nurtured by a climate of innovation that also extends to our other fields: communications, electronics, lighting, chemistry and atomic energy. Research: our solid base for future growth. General Telephone & Electronics Laboratories, Inc., 730 Third Ave., N.Y., N.Y. 10017.

FROM THE LABORATORIES OF GT&E
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Surprise package

This little device helps direct electronic traffic in computers, missile controls and mobile communications equipment. It's a very special kind of high-performance capacitor developed by Mallory, making ingenious use of exotic tantalum. In withstanding searing temperatures, in serving well above and beyond the call of duty, it's a package of happy surprises for electronic engineers who before now were limited by the old standards of capacitor reliability.

Mallory's work in electronics and metallurgy constantly turns up happy surprises for designers who are seeking new flexibility in creating new products . . . for production men who are looking for extra value and reliability at sensible prices. Mallory's continuing research in electronics and powder metallurgy can help put better performance in your products for industry, for defense and for the consumer. P. R. Mallory & Co. Inc., Indianapolis 6, Indiana.

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MALLORY

on emulsion polymerization and the thermodynamics of elastomers for the U.S. Rubber Company from 1942 to 1947, when he joined the staff of the Portland Cement Association.

JAMES MELLAART ("A Neolithic City in Turkey") is an archaeologist who has lived and worked in Turkey for more than a decade; he is presently lecturer in prehistoric archaeology at the University of Istanbul. Mellaart was born in London in 1925 and educated in the Netherlands, where his family moved when he was four years old. He studied Egyptology for a year at the University of Leiden, returned to England in 1947 and acquired a B.A. in ancient history and Egyptology from the University of London in 1951. From 1951 to 1961 he was associated with the British Institute of Archaeology in Ankara, first as a fellow and later as assistant director.

ERLING DORF ("The Petrified Forests of Yellowstone Park") is professor of geology and curator of paleobotany at Princeton University. He also teaches at the Wagner Free Institute of Science in Philadelphia and at Villanova University. Dorf was born in Nysted, Neb., in 1905 and received a B.S. and a Ph.D. from the University of Chicago in 1925 and 1930 respectively. Since joining the Princeton faculty in 1926 he has led geological expeditions to Venezuela, Mexico, Canada and India as well as to various sites in the U.S. He has spent the past 10 summers studying the fossil flora in the Yellowstone Park region. These expeditions have been supported in part by grants from the National Science Foundation and Princeton University, with the co-operation of the National Park Service, for which Dorf has served as scientific collaborator.

ADRIAN M. WENNER ("Sound Communication in Honeybees") is assistant professor of biology at the University of California at Santa Barbara. A native of Minnesota, Wenner received a B.S. in mathematics from Gustavus Adolphus College in 1951. He also acquired an M.S. in biology from Chico State College in California in 1955 and a Ph.D. in zoology from the University of Michigan in 1961. He joined the Santa Barbara faculty in 1960.

EDWIN G. BORING, who in this issue reviews *The Vital Balance: The Life Process in Mental Health and Illness,* by Karl Menninger, with Martin Mayman and Paul Pruyser, is professor emeritus of psychology at Harvard University.

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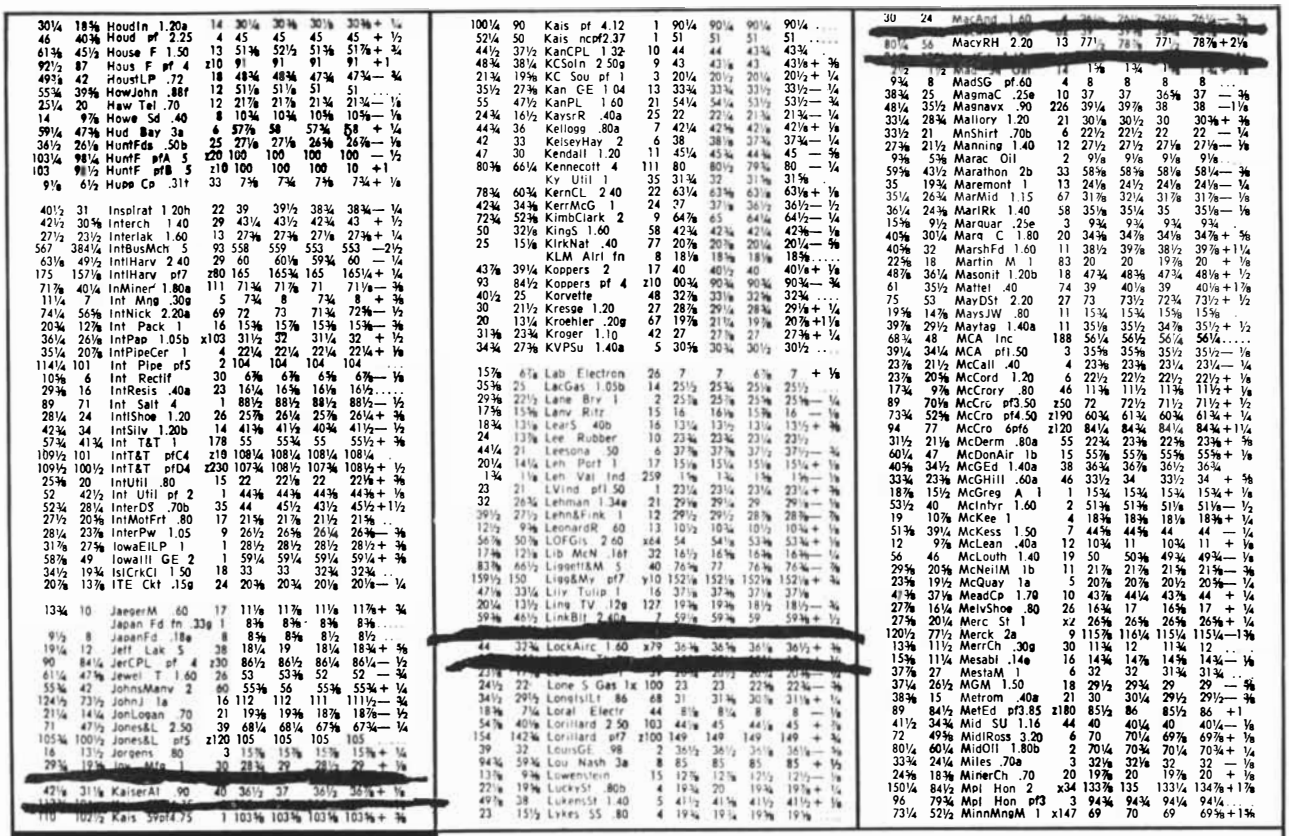

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The Hallucinogenic Drugs

These powerful alkaloids, tools for investigating mental illness and perhaps for treating it, have become the subject of a debate: Do their constructive potentials outweigh their admitted hazards?

by Frank Barron, Murray E. Jarvik and Sterling Bunnell, Jr.

Human beings have two powerful needs that are at odds with each other: to keep things the same, and to have something new happen. We like to feel secure, yet at times we like to be surprised. Too much predictability leads to monotony, but too little may lead to anxiety. To establish a balance between continuity and change is a task facing all organisms, individual and social, human and nonhuman.

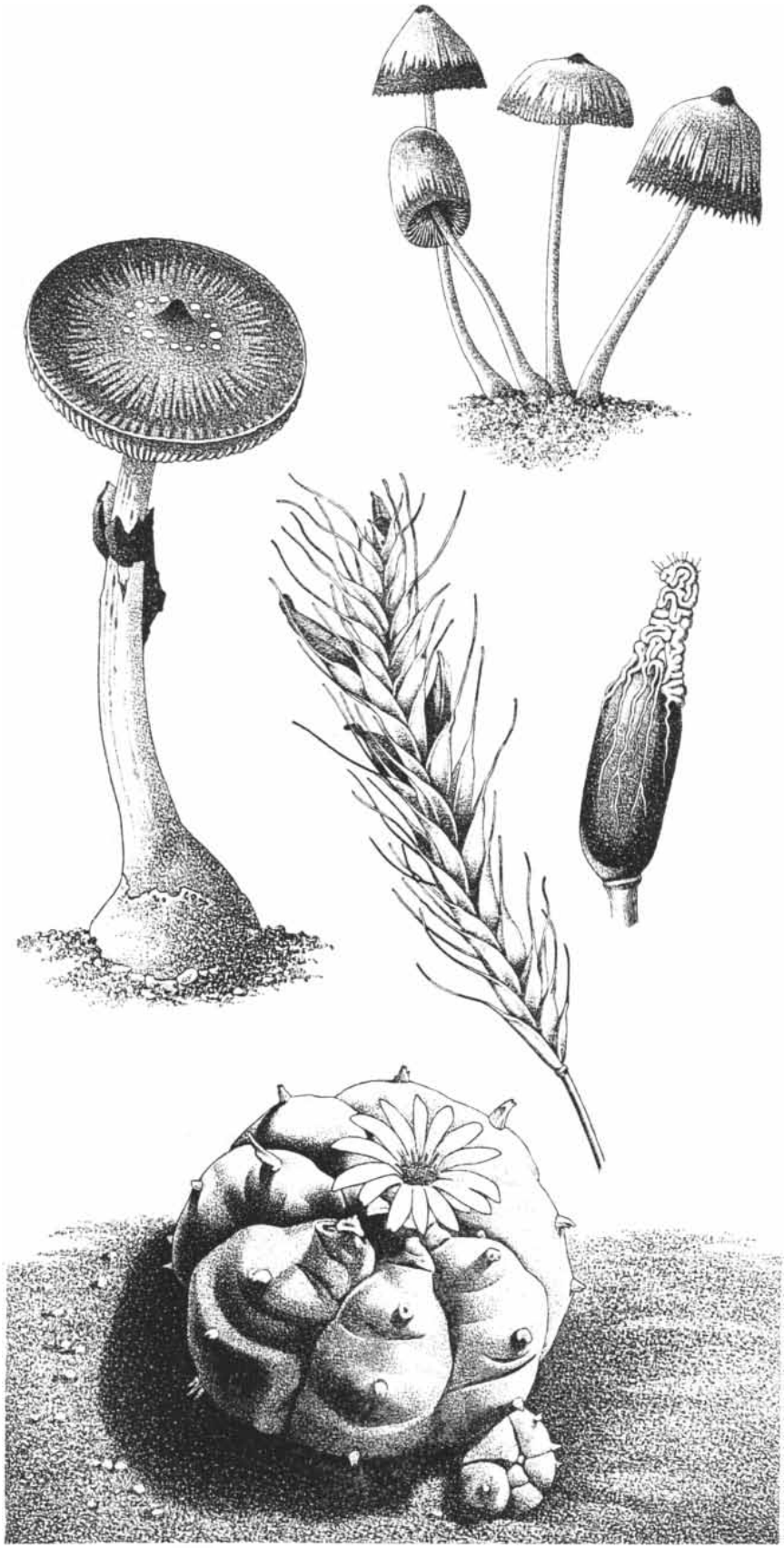
Keeping things predictable is generally considered one of the functions of the ego. When a person perceives accurately, thinks clearly, plans wisely and acts appropriately—and represses maladaptive thoughts and emotions—we say that his ego is strong. But the strong ego is also inventive, open to many perceptions that at first may be disorganizing. Research on the personality traits of highly creative individuals has shown that they are particularly alert to the challenge of the contradictory and the unpredictable, and that they may even court the irrational in their own make-up as a source of new and unexpected insight. Indeed, through all recorded history and everywhere in the world men have gone to considerable lengths to seek unpredictability by disrupting the functioning of the ego. A change of scene, a change of heart, a change of mind: these are the popular prescriptions for getting out of a rut.

Among the common ways of changing "mind" must be reckoned the use of intoxicating substances. Alcohol has quite won the day for this purpose in the U.S. and much of the rest of the world. Consumed at a moderate rate and in sensible quantities, it can serve simultaneously as a euphoriant and tranquilizing agent before it finally dulls the faculties and puts one to sleep. In properly disposed individuals it may dissolve sexual inhibitions, relieve fear and anxiety, or stimulate meditation on the meaning of life. In spite of its costliness to individual and social health when it is used immoderately, alcohol retains its rank as first among the substances used by mankind to change mental experience. Its closest rivals in popularity are opium and its derivatives and various preparations of cannabis, such as hashish and marijuana.

This article deals with another group of such consciousness-altering substances: the "hallucinogens." The most important of these are mescaline, which comes from the peyote cactus *Lophophora williamsii;* psilocybin and psilocin, from such mushrooms as *Psilocybe mexicana* and *Stropharia cubensis;* and d-lysergic acid diethylamide (LSD), which is derived from ergot (*Claviceps purpurea*), a fungus that grows on rye and wheat. All are alkaloids more or less related to one another in chemical structure.

Various names have been applied to this class of substances. They produce distinctive changes in perception that are sometimes referred to as hallucinations, although usually the person under the influence of the drug can distinguish his visions from reality, and even when they seem quite compelling he is able to attribute them to the action of the drug. If, therefore, the term "hallucination" is reserved for perceptions that the perceiver himself firmly believes indicate the existence of a corresponding object or event, but for which other observers can find no objective basis, then the "hallucinogens" only rarely produce hallucinations. There are several other names for this class of drugs. They have been called "psychotomimetic" because in some cases the effects seem to mimic psychosis [see "Experimental Psychoses," by six staff members of the Boston Psychopathic Hospital; SCIENTIFIC AMERICAN, June, 1955]. Some observers prefer to use the term "psychedelic" to suggest that unsuspected capacities of the imagination are sometimes revealed in the perceptual changes.

The hallucinogens are currently a subject of intense debate and concern in medical and psychological circles. At issue is the degree of danger they present to the psychological health of the person who uses them. This has become an important question because of a rapidly increasing interest in the drugs among laymen. The recent controversy at Harvard University, stemming at first from methodological disagreements



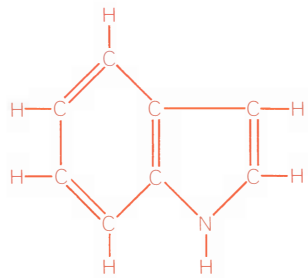
NATURAL SOURCES of the main hallucinogens are depicted. Psilocybin comes from the mushrooms *Stropharia cubensis* (*top left*) and *Psilocybe mexicana* (*top right*). LSD is synthesized from an alkaloid in ergot (*Claviceps purpurea*), a fungus that grows on cereal grains; an ergot-infested rye seed head is shown (*center*) together with a larger-scale drawing of the ergot fungus. Mescaline is from the peyote cactus *Lophophora williamsii* (*bottom*).

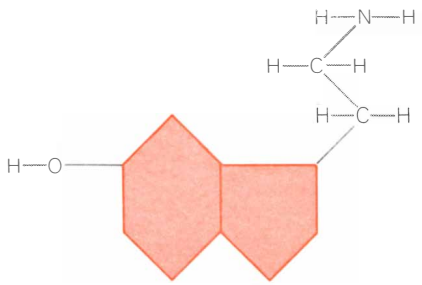
among investigators but subsequently involving the issue of protection of the mental health of the student body, indicated the scope of popular interest in taking the drugs and the consequent public concern over their possible misuse.

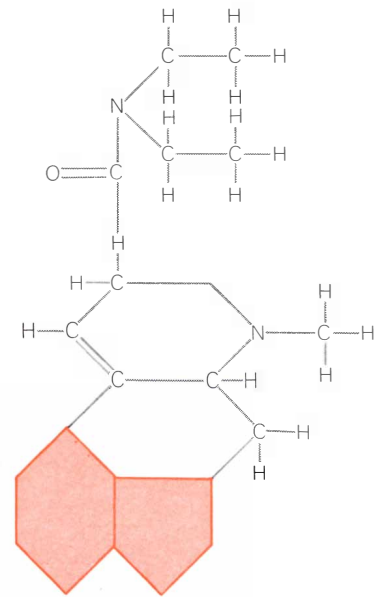
There are, on the other hand, constructive uses of the drugs. In spite of obvious differences between the "model psychoses" produced by these drugs and naturally occurring psychoses, there are enough similarities to warrant intensive investigation along these lines. The drugs also provide the only link, however tenuous, between human psychoses and aberrant behavior in animals, in which physiological mechanisms can be studied more readily than in man. Beyond this many therapists feel that there is a specialized role for the hallucinogens in the treatment of psychoneuroses. Other investigators are struck by the possibility of using the drugs to facilitate meditation and aesthetic discrimination and to stimulate the imagination. These possibilities, taken in conjunction with the known hazards, are the bases for the current professional concern and controversy.

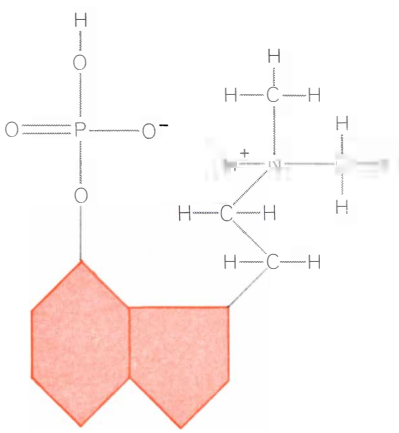
In evaluating potential uses and misuses of the hallucinogens, one can draw on a considerable body of knowledge from such disciplines as anthropology, pharmacology, biochemistry, psychology and psychiatry.

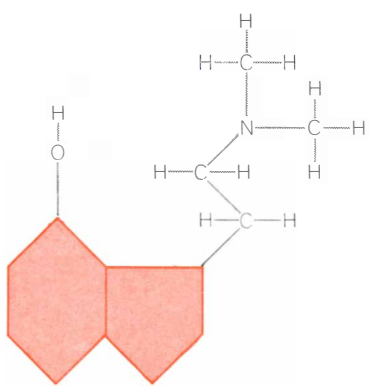
In some primitive societies the plants from which the major hallucinogens are derived have been known for millenniums and have been utilized for divination, curing, communion with supernatural powers and meditation to improve self-understanding or social unity; they have also served such mundane purposes as allaying hunger and relieving discomfort or boredom. In the Western Hemisphere the ingestion of hallucinogenic plants in pre-Columbian times was limited to a zone extending from what is now the southwestern U.S. to the northwestern basin of the Amazon. Among the Aztecs there were professional diviners who achieved inspiration by eating either peyote, hallucinogenic mushrooms (which the Aztecs called *teo-nanacatyl*, or "god's flesh") or other hallucinogenic plants. *Teonanacatyl* was said to have been distributed at the coronation of Montezuma to make the ceremony seem more spectacular. In the years following the conquest of Mexico there were reports of communal mushroom rites among the Aztecs and other Indians of southern Mexico. The communal use has almost died out today, but in several

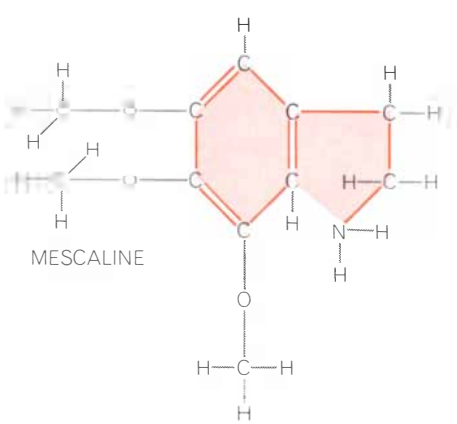


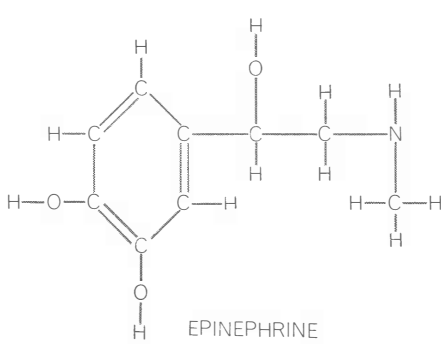


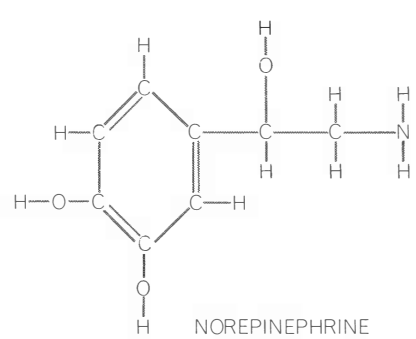




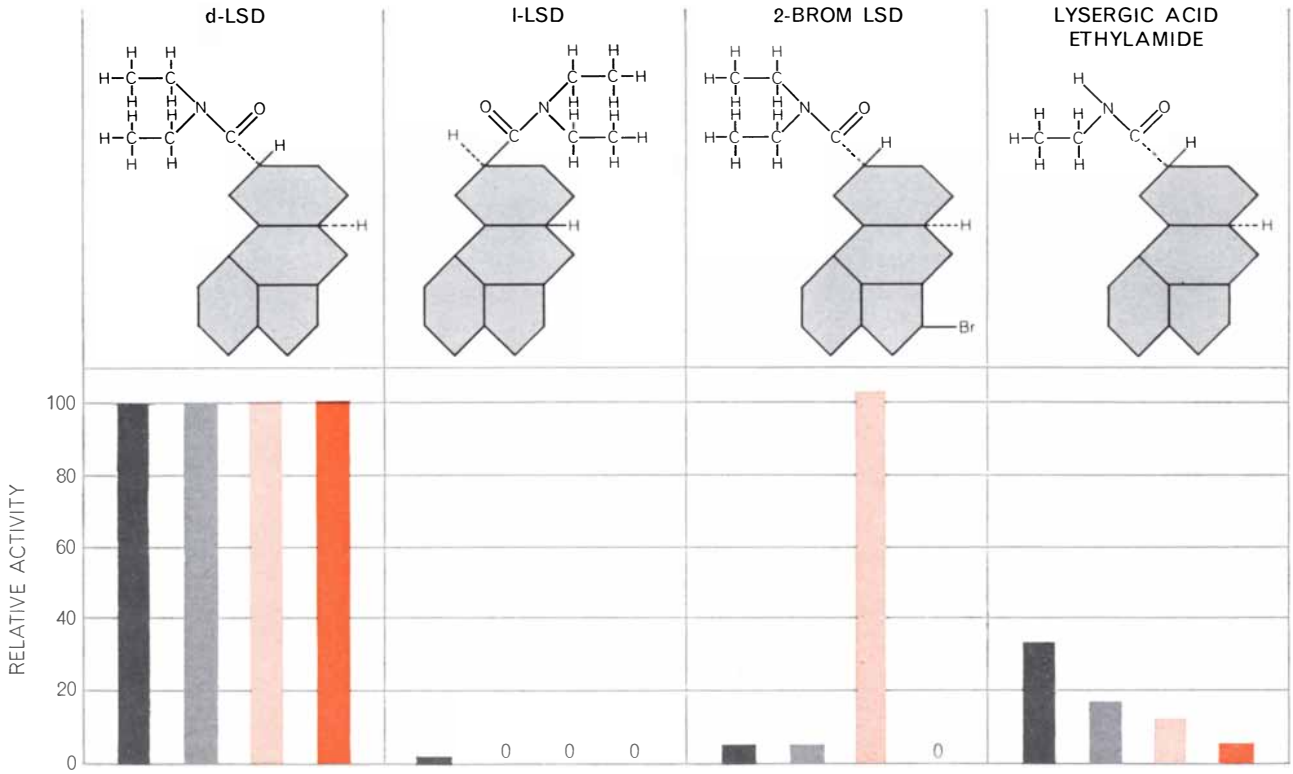








CHEMICAL RELATIONS among several of the hallucinogens and neurohumors are indicated by these structural diagrams. The indole ring (*in color at top*) is a basic structural unit; it appears, as indicated by the colored shapes, in serotonin, LSD, psilocybin and psilocin. Mescaline does not have an indole ring but, as shown by the light color, can be represented so as to suggest its relation to the ring. The close relation between mescaline and the two catechol amines epinephrine and norepinephrine is also apparent here.



SLIGHT CHANGES in LSD molecule produce large changes in its properties. Here LSD (*left*) is used as a standard, with a "relative activity" of 100 in toxicity (*dark gray bar*), fever-producing effect (*light gray*), ability to antagonize serotonin (*light color*) and typical psychotomimetic effects (*dark color*). The stereoisomer of LSD (*second from left*) in which the positions of the side chains are reversed, shows almost no activity; the substitution of a bromine atom (*third from left*) reduces the psychotomimetic effect but not the serotonin antagonism; the removal of one of the two ethyl groups (*right*) sharply reduces activity in each of the areas.

tribes the medicine men or women (*curanderos*) still partake of *Psilocybe* and *Stropharia* in their rituals.

In the arid region between the Rio Grande and central Mexico, where the peyote cactus grows, the dried tops of the plants ("peyote buttons") were eaten by Indian shamans, or medicine men, and figured in tribal rituals. During the 19th century the Mescalero Apaches of the Great Plains acquired the plant and developed a peyote rite. The peyotism of the Mescaleros (whence the name mescaline) spread to the Comanches and Kiowas, who transformed it into a religion with a doctrine and ethic as well as ritual. Peyotism, which spread rapidly through the Plains tribes, became fused with Christianity. Today its adherents worship God as the great spirit who controls the universe and put some of his power into peyote, and Jesus as the man who gave the plant to the Indians in a time of need. Saturday-night meetings, usually held in a traditional tepee, begin with the eating of the sacramental peyote; then the night is spent in prayer, ritual singing and introspective contemplation, and in the morning there is a communion breakfast of corn, game and fruit.

Recognizing the need for an effective organization to protect their form of worship, several peyote churches joined in 1918 to form the Native American Church, which now has about 225,000 members in tribes from Nevada to the East Coast and from the Mexican border to Saskatchewan. It preaches brotherly love, care of the family, self-reliance and abstinence from alcohol. The church has been able to defeat attempts, chiefly by the missionaries of other churches, to outlaw peyote by Federal legislation, and it has recently brought about the repeal of antipeyote legislation in several states.

The hallucinogens began to attract scholarly interest in the last decade of the 19th century, when the investigations and conceptions of such men as Francis Galton, J. M. Charcot, Sigmund Freud and William James introduced a new spirit of serious inquiry into such subjects as hallucination, mystical experience and other "paranormal" psychic phenomena. Havelock Ellis and the psychiatrist Silas Weir Mitchell wrote accounts of the subjective effects of peyote, or Anhalonium, as it was then called. Such essays in turn stimulated the interest of pharmacologists. The active principle of peyote, the alkaloid called mescaline, was isolated in 1896; in 1919 it was recognized that the molecular structure of mescaline was related to the structure of the adrenal hormone epinephrine.

This was an important turning point, because the interest in the hallucinogens as a possible key to naturally occurring psychoses is based on the chemical relations between the drugs and the neurohumors: substances that chemically transmit impulses across synapses between two neurons, or nerve cells, or between a neuron and an effector such as a muscle cell. Acetylcholine and the catechol amines epinephrine and norepinephrine have been shown to act in this manner in the peripheral nervous system of vertebrates; serotonin has the same effect in some invertebrates. It is frequently assumed that these substances also act as neurohumors in the central nervous system; at least they are present there, and injecting them into various parts of the brain seems to affect nervous activity.

The structural resemblance of mescaline and epinephrine suggested a possible link between the drug and mental

illness: Might the early, excited stage of schizophrenia be produced or at least triggered by an error in metabolism that produced a mescaline-like substance? Techniques for gathering evidence on this question were not available, however, and the speculation on an "M-substance" did not lead to serious experimental work.

When LSD was discovered in 1943, its extraordinary potency again aroused interest in the possibility of finding a natural chemical activator of the schizophrenic process. The M-substance hypothesis was revived on the basis of reports that hallucinogenic effects were produced by adrenochrome and other breakdown products of epinephrine, and the hypothesis appeared to be strengthened by the isolation from human urine of some close analogues of hallucinogens. Adrenochrome has not, however, been detected in significant amounts in the human body, and it seems unlikely that the analogues could be produced in sufficient quantity to effect mental changes.

The relation between LSD and serotonin has given rise to the hypothesis that schizophrenia is caused by an imbalance in the metabolism of serotonin, with excitement and hallucinations resulting from an excess of serotonin in certain regions of the brain, and depressive and catatonic states resulting from a deficiency of serotonin. The idea arose in part from the observation that some laboratory preparations of LSD act rather like serotonin but other preparations are powerful antagonists of serotonin; thus LSD might facilitate or block some neurohumoral action of serotonin in the brain.

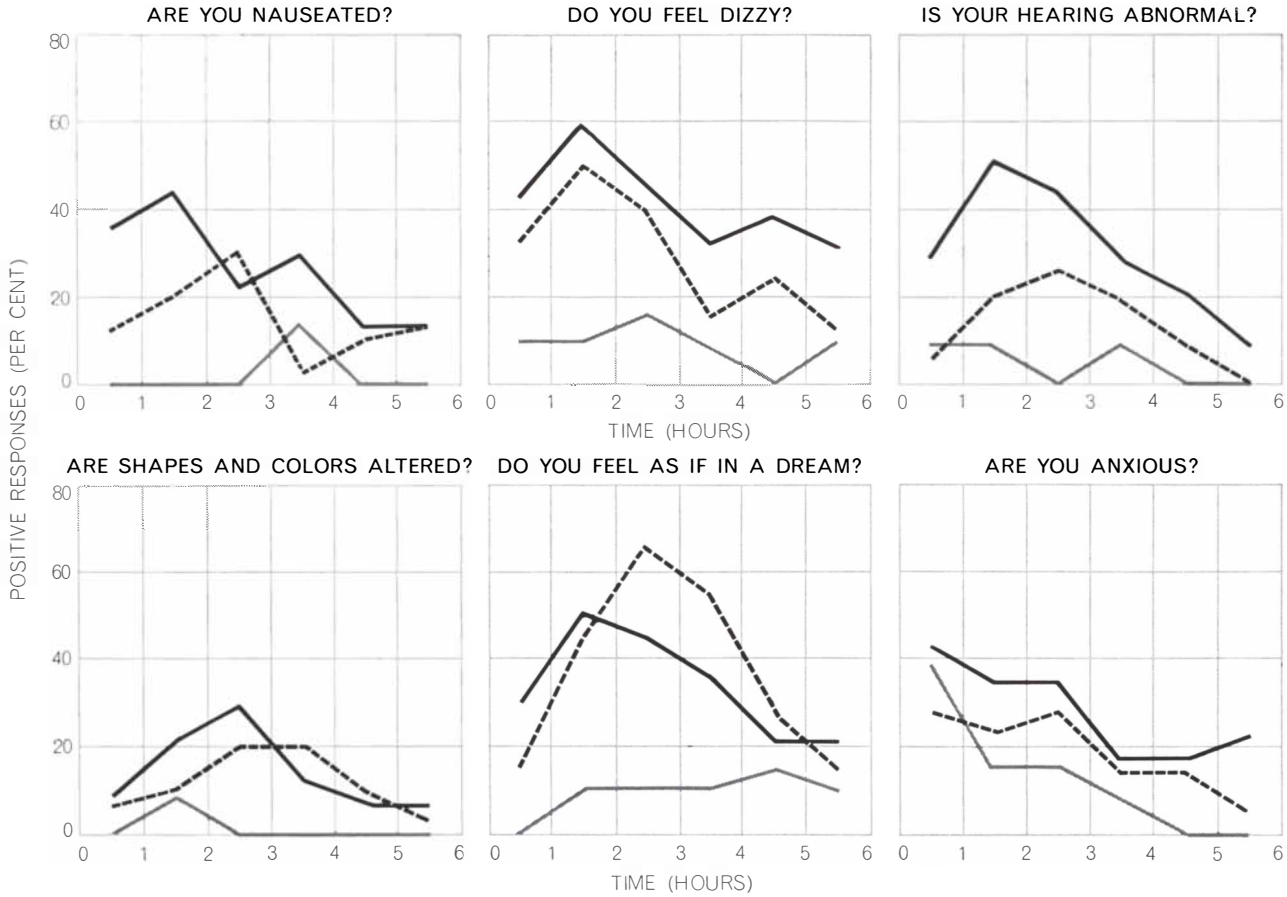
The broad objection to the serotonin theory of schizophrenia is that it requires an oversimplified view of the disease's pattern of symptoms. Moreover, many congeners, or close analogues, of LSD, such as 2-brom lysergic acid, are equally effective or more effective antagonists of serotonin without being significantly active psychologically in man. This does not disprove the hypothesis, however. In man 2-brom LSD blocks the mental effects of a subsequent dose of LSD, and in the heart of a clam it blocks the action of both LSD and serotonin. Perhaps there are "keyholes" at the sites where neurohumors act; in the case of those for serotonin it may be that LSD fits the hole and opens the lock, whereas the psychologically inactive analogues merely occupy the keyhole, blocking the action of serotonin or LSD without mimicking their effects. Certainly the resemblance of most of the hallucinogens to serotonin is marked, and the correlations between chemical structure and pharmacological action deserve intensive investigation. The serotonin theory of schizophrenia is far from proved, but there is strong evidence for an organic factor of some kind in the disease; it may yet turn out to involve either a specific neurohumor or an imbalance among several neurohumors.

The ingestion of LSD, mescaline or psilocybin can produce a wide range of subjective and objective effects. The subjective effects apparently depend on at least three kinds of variable: the properties and potency of the drug itself; the basic personality traits and current mood of the person ingesting it, and the social and psychological context, including the meaning to the individual of his act in taking the drug and his interpretation of the motives of those who made it available. The discussion of subjective effects that follows is compiled from many different accounts of the drug experience; it should be considered an inventory of possible effects rather than a description of a typical episode.

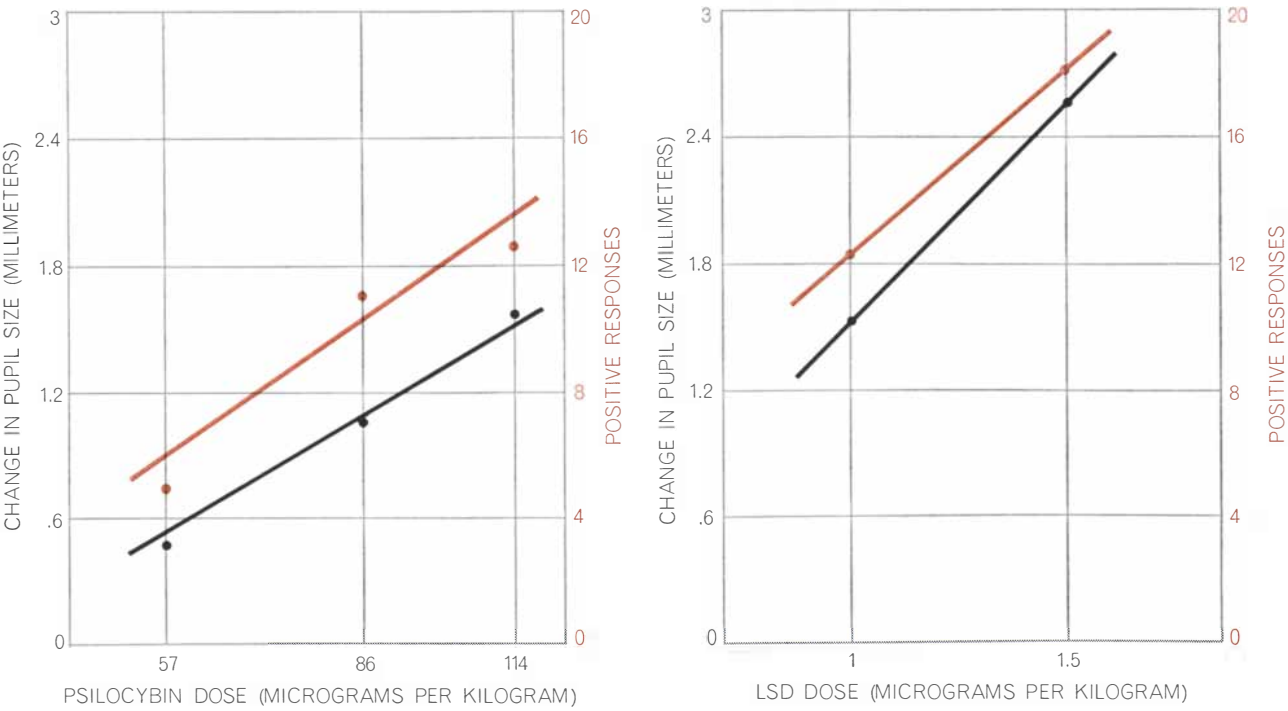
One subjective experience that is frequently reported is a change in visual perception. When the eyes are open, the perception of light and space is affected: colors become more vivid and seem to glow; the space between objects becomes more apparent, as though space itself had become "real," and surface details appear to be more sharply defined. Many people feel a new awareness of the physical beauty of the world, particularly of visual harmonies, colors, the play of light and the exquisiteness of detail.

The visual effects are even more striking when the eyes are closed. A constantly changing display appears, its content ranging from abstract forms to dramatic scenes involving imagined people or animals, sometimes in exotic lands or ancient times. Different individuals have recalled seeing wavy lines, cobweb or chessboard designs, gratings, mosaics, carpets, floral designs, gems, windmills, mausoleums, landscapes, "arabesques spiraling into eternity," statuesque men of the past, chariots, sequences of dramatic action, the face of Buddha, the face of Christ, the Crucifixion, "the mythical dwelling places of the gods," the immensity and blackness of space. After taking peyote Silas Weir Mitchell wrote: "To give the faintest idea of the perfectly satisfying intensity and purity of these gorgeous color fruits

WATER COLORS were done, while under the influence of a relatively large dose of a hallucinogenic drug, by a person with no art training. Originals are bright yellow, purple, green and red as well as black.



SUBJECTIVE REPORT on physiological and perceptual effects of LSD was obtained by means of a questionnaire containing 47 items, the results for six of which are presented. Volunteers were questioned at one-hour intervals beginning half an hour after they took the drug. The curves show the per cent of the group giving positive answers at each time. The gray curves are for those given an inactive substance, the broken black curves for between 25 and 75 micrograms and the solid black curves for between 100 and 225.



OBJECTIVE AND SUBJECTIVE effects vary with dosage as shown here. The data plotted in black are for the increase in size of pupil; the number of positive responses to questions like the ones at the top of the page are shown in color. The objective and subjective measures vary in a similar manner. The data are from an experiment done by Harris Isbell of the University of Kentucky.

is quite beyond my power." A painter described the waning hours of the effects of psilocybin as follows: "As the afternoon wore on I felt very content to simply sit and stare out of the window at the snow and the trees, and at that time I recall feeling that the snow, the fire in the fireplace, the darkened and book-lined room were so perfect as to seem almost unreal."

The changes in visual perception are not always pleasant. Aldous Huxley called one of his books about mescaline *Heaven and Hell* in recognition of the contradictory sensations induced by the drug. The "hellish" experiences include an impression of blackness accompanied by feelings of gloom and isolation, a garish modification of the glowing colors observed in the "heavenly" phase, a sense of sickly greens and ugly dark reds. The subject's perception of his own body may become unpleasant: his limbs may seem to be distorted or his flesh to be decaying; in a mirror his face may appear to be a mask, his smile a meaningless grimace. Sometimes all human movements appear to be mere puppetry, or everyone seems to be dead. These experiences can be so disturbing that a residue of fear and depression persists long after the effects of the drug have worn off.

Often there are complex auditory hallucinations as well as visual ones: lengthy conversations between imaginary people, perfectly orchestrated musical compositions the subject has never heard before, voices speaking foreign languages unknown to the subject. There have also been reports of hallucinatory odors and tastes and of visceral and other bodily sensations. Frequently patterns of association normally confined to a single sense will cross over to other senses: the sound of music evokes the visual impression of jets of colored light, a "cold" human voice makes the subject shiver, pricking the skin with a pin produces the visual impression of a circle, light glinting on a Christmas tree ornament seems to shatter and to evoke the sound of sleigh bells. The time sense is altered too. The passage of time may seem to be a slow and pleasant flow or to be intolerably tedious. A "sense of timelessness" is often reported; the subject feels outside of or beyond time, or time and space seem infinite.

In some individuals one of the most basic constancies in perception is affected: the distinction between subject and object. A firm sense of personal identity depends on knowing accurately the borders of the self and on being able to distinguish what is inside from what is outside. Paranoia is the most vivid pathological instance of the breakdown of this discrimination; the paranoiac attributes to personal and impersonal forces outside himself the impulses that actually are inside him. Mystical and transcendental experiences are marked by the loss of this same basic constancy. "All is one" is the prototype of a mystical utterance. In the mystical state the distinction between subject and object disappears; the subject is seen to be one with the object. The experience is usually one of rapture or ecstasy and in religious terms is described as "holy." When the subject thus achieves complete identification with the object, the experience seems beyond words.

Some people who have taken a large dose of a hallucinogenic drug report feelings of "emptiness" or "silence," pertaining either to the interior of the self or to an "interior" of the universe—or to both as one. Such individuals have a sense of being completely undifferentiated, as though it were their personal consciousness that had been "emptied," leaving none of the usual discriminations on which the functioning of the ego depends. One man who had this experience thought later that it had been an anticipation of death, and that the regaining of the basic discriminations was like a remembrance of the very first days of life after birth.

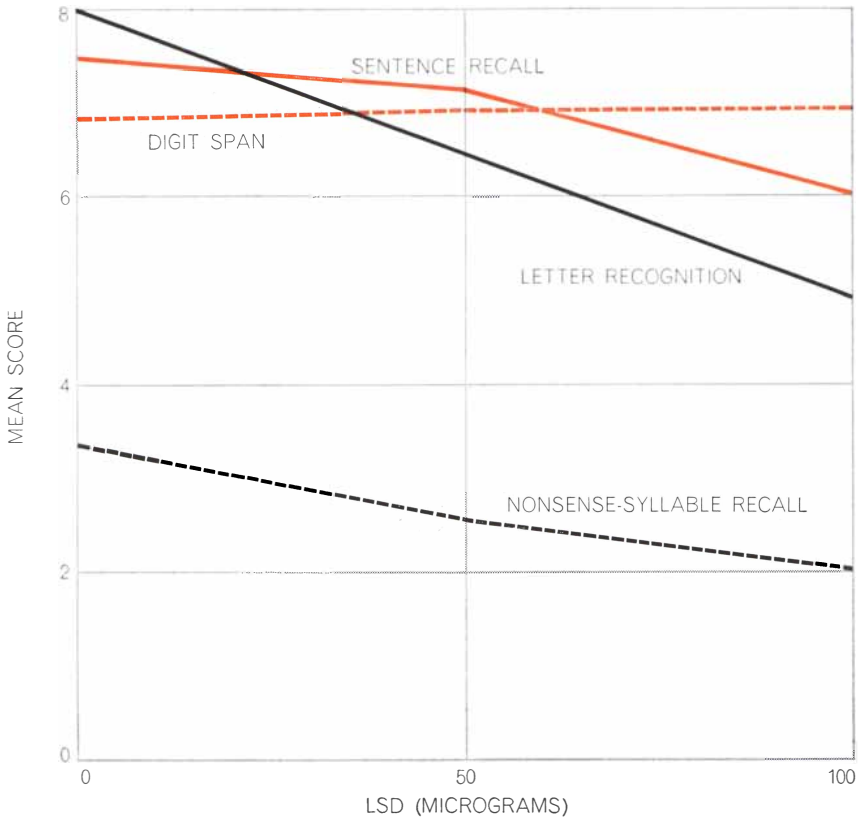
The effect of the hallucinogens on sexual experience is not well documented. One experiment that is often quoted seemed to provide evidence that mescaline is an anaphrodisiac, an inhibitor of sexual appetite; this conclusion seemed plausible because the drugs have so often been associated with rituals emphasizing asceticism and prayer. The fact is, however, that the drugs are probably neither anaphrodisiacs nor aphrodisiacs—if indeed any drug is. There is reason to believe that if the drug-taking situation is one in which sexual relations seem appropriate, the hallucinogens simply bring to the sexual experience the same kind of change in perception that occurs in other areas of experience.

The point is that in all the hallucinogen-produced experiences it is never the drug alone that is at work. As in the case of alcohol, the effects vary widely depending on when the drug is taken, where, in the presence of whom, in what dosage and—perhaps most important of all—by whom. What happens to the individual after he takes the drug, and his changing relations to the setting and the people in it during the episode, will further influence his experience.

Since the setting is so influential in these experiments, it sometimes happens that a person who is present when someone else is taking a hallucinogenic drug, but who does not take the drug himself, behaves as though he were under the influence of a hallucinogen. In view of this effect one might expect that a person given an inactive substance he thought was a drug would respond as though he had actually received the drug. Indeed, such responses have sometimes been noted. In controlled experiments, however, subjects given an inactive substance are readily distinguishable from those who take a drug; the difference is apparent in their appearance and behavior, their answers to questionnaires and their physiological responses. Such behavioral similarities as are observed can be explained largely by a certain apprehension felt by a person who receives an inactive substance he thinks is a drug, or by anticipation on the part of someone who has taken the drug before.

In addition to the various subjective effects of the hallucinogens there are a number of observable changes in physiological function and in performance that one can measure or at least describe objectively. The basic physiological effects are those typical of a mild excitement of the sympathetic nervous system. The hallucinogens usually dilate the pupils, constrict the peripheral arterioles and raise the systolic blood pressure; they may also increase the excitability of such spinal reflexes as the knee jerk. Electroencephalograms show that the effect on electrical brain waves is usually of a fairly nonspecific "arousal" nature: the pattern is similar to that of a normally alert, attentive and problem-oriented subject, and if rhythms characteristic of drowsiness or sleep have been present, they disappear when the drug is administered. (Insomnia is common the first night after one of the drugs has been taken.) Animal experiments suggest that LSD produces these effects by stimulating the reticular formation of the midbrain, not directly but by stepping up the sensory input.

Under the influence of one of the hallucinogens there is usually some reduction in performance on standard tests of reasoning, memory, arithmetic, spelling and drawing. These findings may not indicate an inability to perform well; after taking a drug many people simply refuse to co-operate with the tester. The very fact that someone should want to



EFFECT OF LSD on memory was determined with standard tests. Curves show results of four tests for subjects given an inactive substance, 50 micrograms of the drug and 100 micrograms respectively. Effect of LSD was to decrease scores except in a test of digit-recall ability.

test them may seem absurd and may arouse either hostility or amusement. Studies by one of the authors in which tests of attention and concentration were administered to subjects who had been given different doses of LSD indicated that motivation was perhaps as important in determining scores as the subject's intellectual capacity.

The hallucinogenic drugs are not addictive—if one means by addiction that physiological dependence is established and the drug becomes necessary, usually in increasing amounts, for satisfactory physiological functioning. Some individuals become psychologically dependent on the drugs, however, and develop a "habit" in that sense; indeed, there is a tendency for those who ingest hallucinogens habitually to make the drug experience the center of all their activities. LSD, mescaline and psilocybin do produce physiological tolerance. If the same quantity of LSD is administered on three successive days, for example, it will not suffice by the third day to produce the same subjective or physiological effects; tolerance develops more slowly and less completely with mescaline and psilocybin. When an individual becomes tolerant to a given dosage of LSD, the ordinarily equivalent dose of psilocybin produces reduced effects. This phenomenon of cross-tolerance suggests that the two drugs have common pathways of action. Any tolerance established by daily administration of the drugs wears off rather rapidly, generally being dissipated within a few days if the drug is not taken.

The three major hallucinogens differ markedly in potency. The standard human doses—those that will cause the average adult male weighing about 150 pounds to show the full clinical effects—are 500 milligrams of mescaline, 20 milligrams of psilocybin and .1 milligram of LSD. It is assumed that in a large enough dose any of the hallucinogens would be lethal, but there are no documented cases of human deaths from the drugs alone. Death has been brought on in sensitive laboratory animals such as rabbits by LSD doses equivalent to 120 times the standard human dose. Some animals are much less susceptible; white rats have been given doses 1,000 times larger than the standard human dose without lasting harm. The maximum doses known by the authors to have been taken by human beings are 900 milligrams of mescaline, 70 milligrams of psilocybin and two milligrams of LSD. No permanent effects were noted in these cases, but obviously no decisive studies of the upper limits of dosage have been undertaken.

There are also differences among the hallucinogens in the time of onset of effects and the duration of intoxication. When mescaline is given orally, the effects appear in two or three hours and last for 12 hours or more. LSD acts in less than an hour; some of its effects persist for eight or nine hours, and insomnia can last as long as 16 hours. Psilocybin usually acts within 20 or 30 minutes, and its full effect is felt for about five hours. All these estimates are for the standard dose administered orally; when any of the drugs is given intravenously, the first effects appear within minutes.

At the present time LSD and psilocybin are treated by the U.S. Food and Drug Administration like any other "experimental drug," which means that they can be legally distributed only to qualified investigators who will administer them in the course of an approved program of experimentation. In practice the drugs are legally available only to investigators working under a Government grant or for a state or Federal agency.

Nevertheless, there has probably been an increase during the past two or three years in the uncontrolled use of the drugs to satisfy personal curiosity or to experience novel sensations. This has led a number of responsible people in government, law, medicine and psychology to urge the imposition of stricter controls that would make the drugs more difficult to obtain even for basic research. These people emphasize the harmful possibilities of the drugs; citing the known cases of adverse reactions, they conclude that the prudent course is to curtail experimentation with hallucinogens.

Others—primarily those who have worked with the drugs—emphasize the constructive possibilities, insist that the hallucinogens have already opened up important leads in research and conclude that it would be shortsighted as well as contrary to the spirit of free scientific inquiry to restrict the activities of qualified investigators. Some go further, questioning whether citizens should be denied the opportunity of trying the drugs even without medical or psychological supervision and arguing that anyone who is mentally competent should have the right to explore the varieties

of conscious experience if he can do so without harming himself or others.

The most systematic survey of the incidence of serious adverse reactions to hallucinogens covered nearly 5,000 cases, in which LSD was administered on more than 25,000 occasions. Psychotic reactions lasting more than 48 hours were observed in fewer than two-tenths of 1 per cent of the cases. The rate of attempted suicides was slightly over a tenth of 1 per cent, and these involved psychiatric patients with histories of instability. Among those who took the drug simply as subjects in experiments there were no attempted suicides and the psychotic reactions occurred in fewer than a tenth of 1 per cent of the cases.

Recent reports do indicate that the incidence of bad reactions has been increasing, perhaps because more individuals have been taking the hallucinogens in settings that emphasize sensation-seeking or even deliberate social delinquency. Since under such circumstances there is usually no one in attendance who knows how to avert dangerous developments, a person in this situation may find himself facing an extremely frightening hallucination with no one present who can help him to recognize where the hallucination ends and reality begins. Yet the question of what is a proper setting is not a simple one. One of the criticisms of the Harvard experiments was that some were conducted in private homes rather than in a laboratory or clinical setting. The experimenters defended this as an attempt to provide a feeling of naturalness and "psychological safety." Such a setting, they hypothesized, should reduce the likelihood of negative reactions such as fear and hostility and increase the positive experiences. Controlled studies of this hypothesis have not been carried out, however.

Many psychiatrists and psychologists who have administered hallucinogens in a therapeutic setting claim specific benefits in the treatment of psychoneuroses, alcoholism and social delinquency. The published studies are difficult to evaluate because almost none have employed control groups. One summary of the available statistics on the treatment of alcoholism does indicate that about 50 per cent of the patients treated with a combination of psychotherapy and LSD abstained from alcohol for at least a year, compared with 30 per cent of the patients treated by psychotherapy alone.

In another recent study the results of psychological testing before and after LSD therapy were comparable in most respects to the results obtained when conventional brief psychotherapy was employed. Single-treatment LSD therapy was significantly more effective, however, in relieving neurotic depression. If replicated, these results may provide an important basis for more directed study of the treatment of specific psychopathological conditions.

If the hallucinogens do have psychotherapeutic merit, it seems possible that they work by producing a shift in personal values. William James long ago noted that "the best cure for dipsomania is religiomania." There appear to be religious aspects of the drug experience that may bring about a change in behavior by causing a "change of heart." If this is so, one might be able to apply the hallucinogens in the service of moral regeneration while relying on more conventional techniques to give the patient insight into his habitual behavior patterns and motives.

In the light of the information now available about the uses and possible abuses of the hallucinogens, common sense surely decrees some form of social control. In considering such control it should always be emphasized that the reaction to these drugs depends not only on their chemical properties and biological activity but also on the context in which they are taken, the meaning of the act and the personality and mood of the individual who takes them. If taking the drug is defined by the group or individual, or by society, as immoral or criminal, one can expect guilt and aggression and further social delinquency to result; if the aim is to help or to be helped, the experience may be therapeutic and strengthening; if the subject fears psychosis, the drug could induce psychosis. The hallucinogens, like so many other discoveries of man, are analogous to fire, which can burn down the house or spread through the house life-sustaining warmth. Purpose, planning and constructive control make the difference. The immediate research challenge presented by the hallucinogens is a practical question: Can ways be found to minimize or eliminate the hazards, and to identify and develop further the constructive potentialities, of these powerful drugs?

NATIVE AMERICAN CHURCH members take part in a peyote ceremony in Saskatchewan, Canada. Under the influence of the drug, they gaze into the fire as they pray and meditate.

The Interaction of Light with Light

Intense beams of laser light interact with crystals to yield novel optical effects. For example, when two beams meet in a crystal they can add or subtract to produce beams of two new wavelengths

by J. A. Giordmaine

One of the best-known characteristics of light is that the transmission, refraction and reflection of a beam of light in a transparent material are not affected by the intensity of the light or the presence of a second beam. According to James Clerk Maxwell's theory of electromagnetism the behavior of a light beam can be predicted solely from the wavelength of the light and its velocity in the material. Now, however, that we have lasers to generate intense beams of coherent light—light whose waves are all in step—many new and striking properties of light can be demonstrated.

It has recently been shown, for example, that in transparent materials an intense beam of light can generate harmonics, or overtones, of the original light frequency. It has also been shown that in the presence of matter two light beams can interact with each other. There is good reason to expect small but observable interactions of intense light beams even in a vacuum. These, however, have not yet been demonstrated, and it is not likely that they are within reach of existing lasers.

One type of interaction of light with matter has been known since 1927, when it was discovered by the Indian physicist C. V. Raman. In the Raman effect a quantum of light gives up some of its energy to a molecule and reappears as a scattered quantum with a lower frequency. It has now been discovered that the ordinarily weak Raman-scattered light is strongly enhanced if it is coupled to an intense beam of laser light.

The electromagnetic wave that constitutes light is made up of an electric component and a magnetic component; these components are locked in step at right angles to each other and oscillate together. It is possible to alter the velocity of light in a transparent material by applying an additional electric or magnetic field to the material. As early as 1845 Michael Faraday, whose experiments touched almost every aspect of electricity and magnetism, discovered that a static magnetic field affects the way light travels through glass. He showed that the plane of polarization of a beam of light is rotated as the light travels along the lines of force in a magnetic field. Thirty years later the Scottish physicist John Kerr produced double refraction of light in glass by applying a strong electric field. In these two experiments the application of either an intense magnetic field or an intense electric field slightly changes the refractive index of the material, that is, the ratio of the velocity of light in a vacuum to the velocity of light in the material. In the Faraday experiment a beam of plane-polarized light acts as if it were composed of two circularly polarized beams rotating in opposite directions. The application of the magnetic field makes the index of refraction of the glass for one of the beams different from that for the other.

The Faraday and Kerr effects, as well as later experiments, suggest that by virtue of its own electric and magnetic field, light of sufficient intensity can change the refractive index of the medium supporting it, affecting its own propagation and that of other light beams present. It is evident that alterations in the refractive index, if produced, will have a periodicity, or frequency, equal to the optical frequency of the light beam that has created them. This implies that if a second beam of light of a different frequency is simultaneously present, its velocity will be altered periodically by the high-frequency changes in refractive index produced by the first beam. As a result of this interaction one light beam should be able to modulate another, producing sum and difference frequencies.

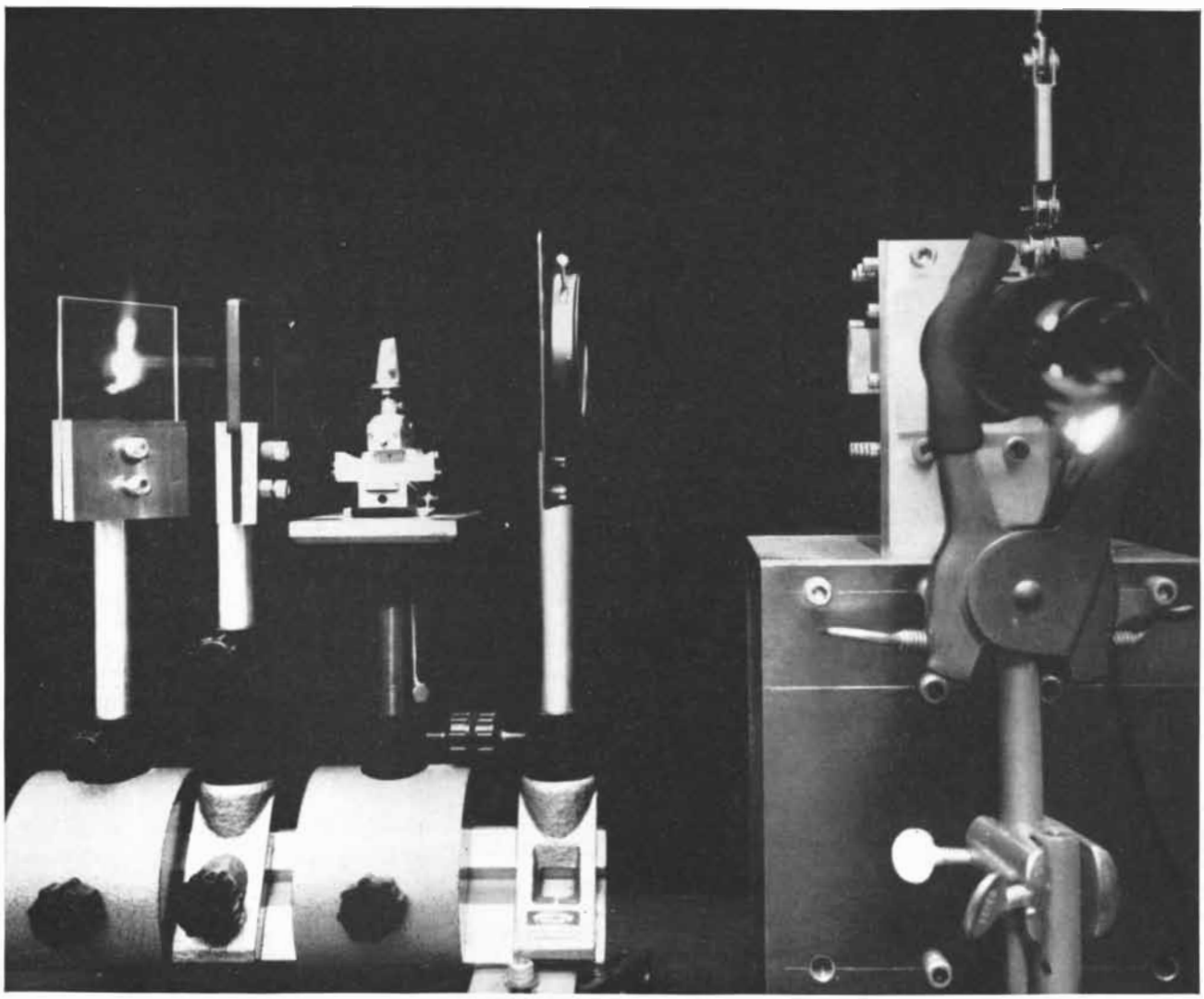
In the language of the quantum theory of radiation, according to which light propagates in discrete bundles called photons, these processes represent interactions of photons. For example, two photons can be annihilated to produce a new photon embodying the energy of the two that disappeared. Since the frequency of a photon is proportional to its energy, the new photon will exhibit the sum frequency of the two annihilated photons. Other interactions of light beams can be regarded as the collision and scattering of pairs of photons.

Such "nonlinear" interactions have not been observed in experiments with ordinary light sources because the electric and magnetic fields associated with these sources are too small. The electric field of sunlight at the surface of the earth has an amplitude of about 10 volts per centimeter, enough to change the refractive index of glass in the Kerr effect by only about one part in 10^{15}. The magnetic field of sunlight is about a thirtieth of a gauss, less than a tenth of the strength of the earth's magnetic field and enough to change the refractive index of glass in the Faraday effect by only one part in 10^{12}. Although brighter sources such as the carbon-arc lamp and high-pressure discharge lamps have been available, their broad emission spectra, like that of the sun, make the search for nonlinear effects difficult. For the effects to be readily observable a great deal of energy must be concentrated in a narrow band of wavelengths, the narrower the better. Without such mon-

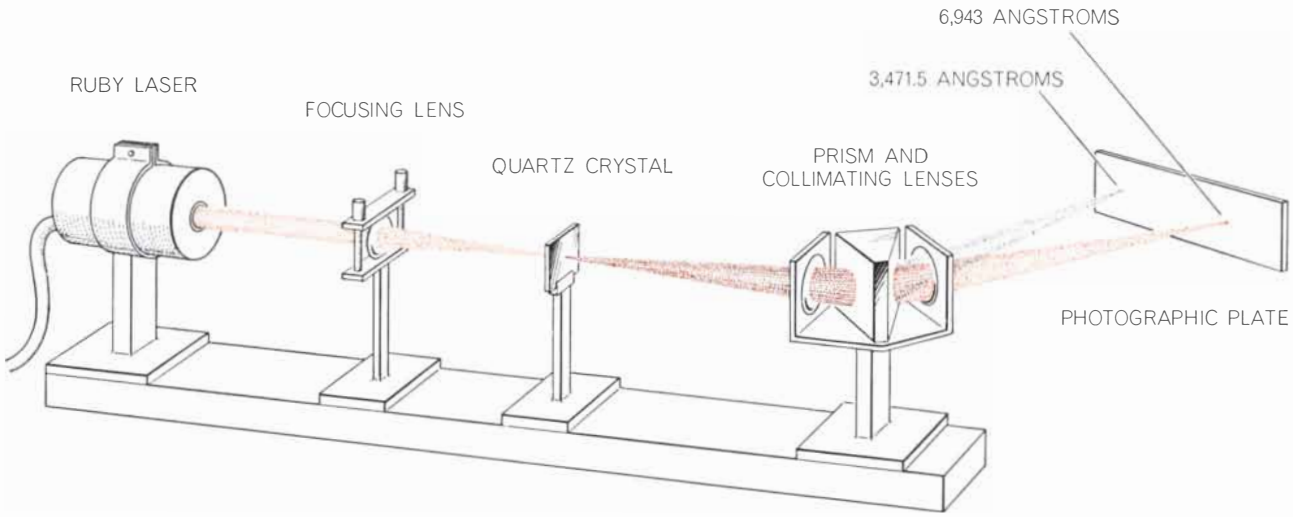
ochromatic and coherent radiation there is no opportunity for the waves to interact with matter or with each other in an orderly way.

With the development of the laser in 1960, physicists finally obtained a light source that seemed capable of producing nonlinear optical effects. Its output was concentrated in a narrow band of frequencies and its waves were highly coherent [see "Optical Masers," by Arthur L. Schawlow; SCIENTIFIC AMERICAN, June, 1961]. In the summer of 1961 a search for nonlinear effects was undertaken by Peter A. Franken, Allen E. Hill, C. W. Peters and Gabriel Weinreich of the University of Michigan. They focused onto a quartz crystal the beam of a ruby laser that emitted a three-kilowatt pulse of red light at a wavelength of 6,943 angstrom units. Of the light striking the crystal one part in 10^8 was converted to second-harmonic light with a wavelength of 3,471.5 angstroms; this wavelength, which lies in the ultraviolet region of the spectrum, is exactly half the wavelength and therefore twice the frequency of the laser light [*see illustrations on next page*]. The possibility that the emitted light might be some kind of ultraviolet fluorescence induced by the laser beam could be ruled out because its wavelength was precisely half the laser wavelength and because it was emitted in as highly directional a beam as the incident laser beam.

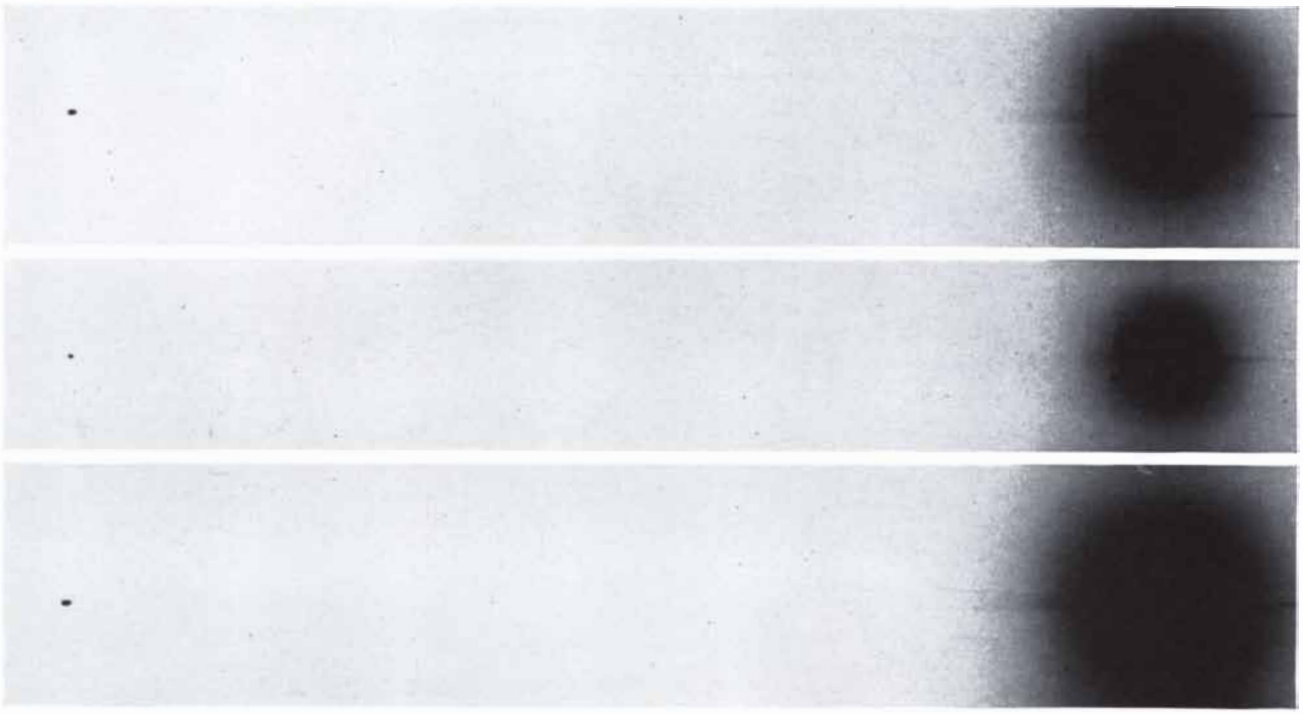
Many related experiments and some



"SECOND HARMONIC" ULTRAVIOLET LIGHT is generated when red light from a ruby laser passes through a crystal of potassium dihydrogen phosphate (KDP). The laser beam, which has a wavelength of 6,943 angstrom units, originates at the right off the edge of the photograph. The blocklike assembly at the right houses a rotating partially reflecting mirror that is part of the laser mechanism. A fully reflecting mirror at the other end of the laser's optical path is fixed. Laser action does not occur until the rotating mirror and the fixed mirror are parallel. If this alignment is postponed until the population of excited atoms in the ruby laser rod has reached a peak, laser action is intensified. Between the rotating mirror and the triangular crystal of KDP there is a diaphragm and red filter to exclude stray light. Inside the crystal about .1 per cent of the laser beam is converted to ultraviolet light of 3,471.5 angstroms, which is exactly half the wavelength of the incident light. The unconverted red light is removed by a deep blue filter mounted to the left of the crystal. The second-harmonic ultraviolet light, here barely visible, creates a bright flash when it strikes the fluorescent screen at far left. The experiment was photographed in the author's laboratory.



FIRST DEMONSTRATION that ultraviolet light could be generated by the intense flash of a ruby laser was made with this experimental arrangement in 1961 at the University of Michigan. The investigators were Peter A. Franken, Allen E. Hill, C. W. Peters and Gabriel Weinreich. The quartz crystal converted only a hundred-millionth of the incident light to ultraviolet light. On being passed through a prism the ultraviolet is bent more than the red laser light and the two can be photographed separately (*see below*).



FIRST PHOTOGRAPHS of second-harmonic ultraviolet light were made by Franken and his associates. In each case the amount of ultraviolet (*small spots at 3,471.5 angstroms*) is roughly proportional to the square of the amount of red light at 6,943 angstroms.

unexpected developments quickly followed. Up to 20 per cent efficiency has been obtained in converting laser light to harmonic frequencies. By means of nonlinear processes coherent light has been made available at hundreds of new wavelengths in the ultraviolet, visible and infrared regions of the spectrum. The nonlinear optical effects show themselves in a variety of striking ways and represent a new branch of optics of considerable technological promise.

To understand how harmonic light was generated in the experiment of the Franken group it is necessary to understand how the electric field of the laser light wave acted on electrons in the crystal of quartz. A free atom consists of a positively charged nucleus surrounded by a cloud of one or more electrons; when there are several electrons, they form a series of discrete shells. The electrons in the outermost shell are loosely bound and are called valence electrons. When one atom is close to another, as it is in a crystal, the valence electrons are available to be shared by,

or transferred to, other atoms. The result of this process is to fill completely the outer shells of adjacent atoms, which are thereby bound together. Some crystals, such as sodium chloride, are termed ionic because electrons are transferred from atoms that have one or a few electrons in excess of a complete shell to atoms whose outer shells lack electrons. Both the lenders and the borrowers of electrons are left with a net electric charge, either positive or negative. These ions arrange themselves regularly in a lattice in such a way that oppositely charged ions are as close together as possible. Other kinds of crystals, such as diamond, are called covalent because the outermost electrons are shared among atoms to provide each with a filled outer shell. In both ionic and covalent crystals the over-all crystal is electrically neutral.

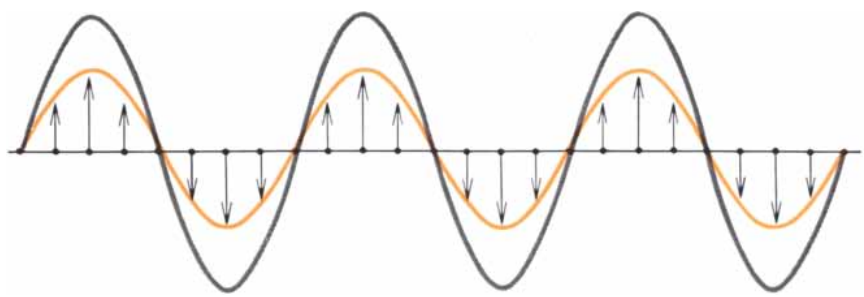
Let us see what happens when visible light waves pass through a transparent crystal. One component of the light wave is an alternating electric field. The nuclei of atoms are too heavy to respond to this rapidly alternating field, and the inner electrons are too tightly bound to the nuclei to respond significantly. The weakly bound valence electrons, however, redistribute themselves in step with the field [*see upper illustration on this page*]. Their redistribution involves a polarization, or a displacement of negative charge, inside the crystal. This polarization induced by light is not to be confused with the polarization that can be induced in a light beam by the use of a polarizing filter. The periodically changing polarization inside the crystal corresponds to an oscillating motion of the negative charge density and therefore to a weak alternating current at the light frequency.

As long as the optical electric field is small compared with the cohesive electric fields within the crystal, the polarization current faithfully follows the electric field of the light wave [*see upper illustration on next page*]. The crystal now behaves like a highly directional antenna, supporting a wave of current that travels through the crystal precisely in step with its parent light wave and radiating primarily in the same direction. The energy in the light wave is not significantly changed; the only effect of the polarization and subsequent reradiation is to slow down the velocity of light in the medium.

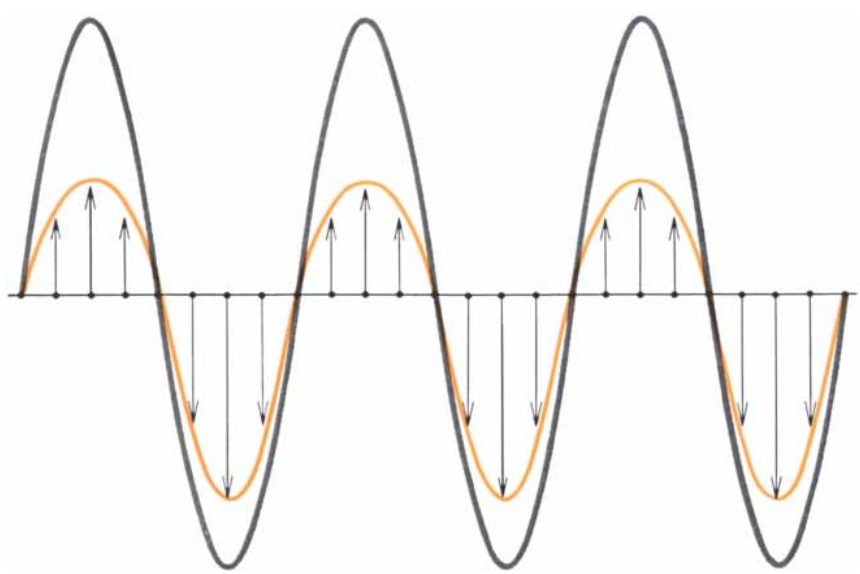
The situation is quite different for intense light. The focused light from certain lasers has an electric field as strong as 10 million (10^7) volts per centimeter. Such strong fields are comparable to the cohesive local electric fields in the crystal, which are of the order of 10^8 to 10^{10} volts per centimeter. Consequently when intense laser beams enter a transparent crystal, they cause a massive redistribution of the electrons and the resulting polarization is no longer proportional to the optical electric field. In fact, at optical fields of 10^7 volts per centimeter and higher many materials break down completely.

The simplified diagram at the bottom of this page illustrates the characteristic response when an intense optical electric field travels through a nonlinear, or ionic, material. It shows that an intense field in the "right" direction is more effective in polarizing the material than a field in the "left" direction. Such a situation can occur only in a crystal that has a "one-wayness" in its structure, or, to be more precise, one that has no center of symmetry. Of the crystals found in nature only about 10 per cent fall in this class, and they usually exhibit the phenomenon called piezoelectricity. When a piezoelectric crystal is subjected to mechanical pressure, its asymmetry leads to unequal distortions in the distribution of positive and negative charge and a voltage appears across the faces of the crystal.

The distorted polarization wave produced by an intense laser beam travels at the same velocity as the light wave. It can be shown, moreover, that the dis-



LINEAR POLARIZATION WAVE (*color*) is created when a light wave of moderate intensity passes through a transparent medium. The light wave carries an optical electric field (*black curve*), which causes a symmetrical displacement of loosely bound electrons (*black arrows*). The displacement takes place in step with the optical electric field and forms an optical polarization wave. The wave radiates a light wave of its own frequency.



NONLINEAR POLARIZATION WAVE (*color*) is created when light of sufficient intensity passes through certain crystals with a "one-wayness" in their structure. Loosely bound electrons are moved more easily to one side than to the other by the light's optical electric field (*black curve*). The result is a distorted polarization wave that gives rise to light containing a second harmonic, or overtone, of the fundamental wave frequency.

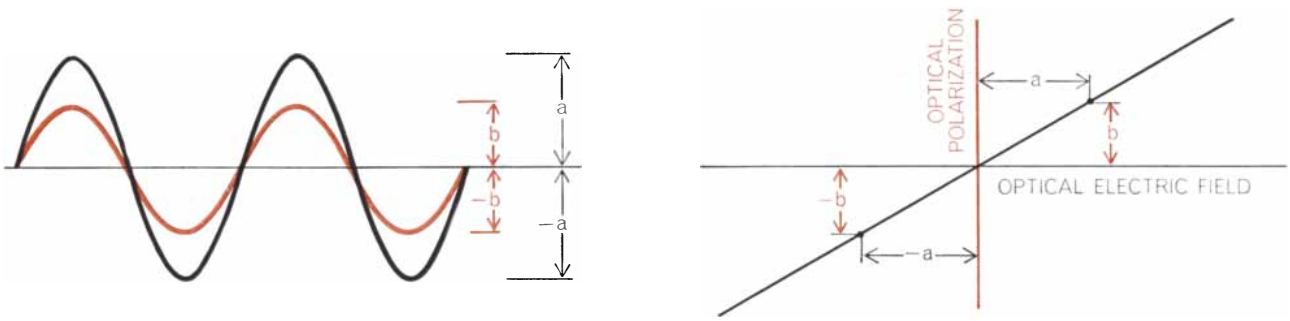
torted wave is the sum of three components: a wave at the fundamental frequency (f) of the light wave, a wave at the second-harmonic frequency ($2f$) and a third component that corresponds to a "direct current," or steady, polarization [*see illustration on opposite page*].

The second-harmonic polarization wave travels in step with the fundamental, or f, light wave and radiates light at frequency $2f$ in the same direction. In almost all materials, however, the velocity of $2f$ light is slower by a few per cent than the velocity of f light. This is another way of saying that a material's refractive index for high-frequency light is usually greater than it is for light of lower frequency. It is this variation in refractive index that creates a spectrum when white light is passed through a prism. The variation in refractive index with wavelength is called normal dispersion.

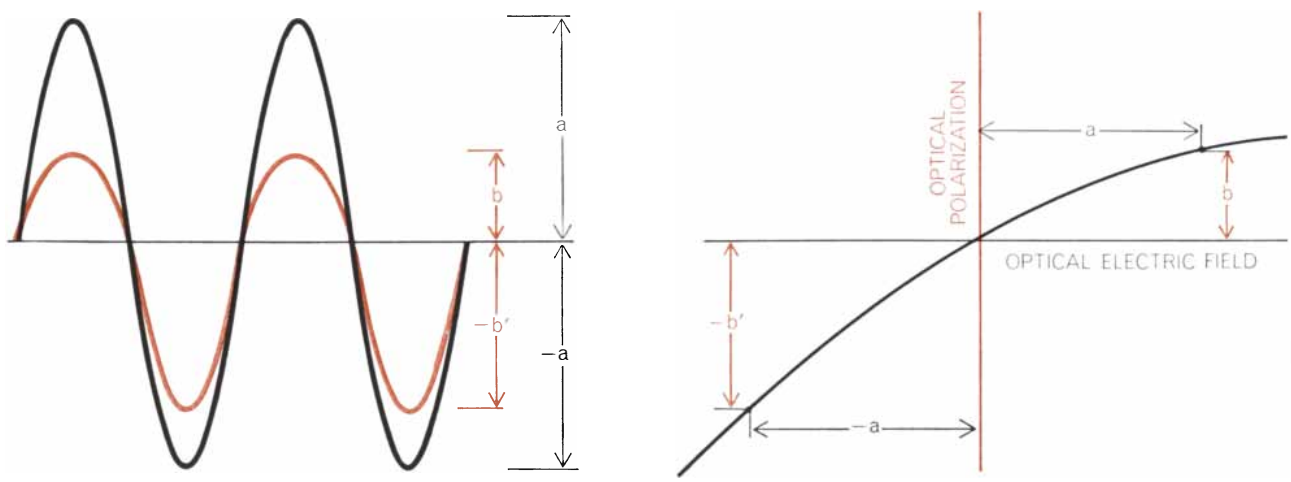
The difference in velocity between fundamental (f) light and harmonic ($2f$) light means that the harmonic light radiated from the $2f$ polarization wave will travel at a velocity a few per cent slower than the $2f$ polarization wave itself. It is evident that the light radiated by the $2f$ polarization wave at any instant will be slightly out of step with the light it radiated a fraction of a second earlier; the two radiated waves will begin to interfere destructively [*see top illustration on page 44*]. The distance required for the $2f$ polarization wave and its radiated light to get completely out of phase is called the coherence length; it is only about a thousandth of a centimeter. If the crystal thickness is made equal to the coherence length, or any even multiple of it, the harmonic radiation disappears completely. As a result of the interference it is usually impossible to make use of crystals longer than about a thousandth of a centimeter in generating harmonics.

A number of techniques have been proposed to overcome this difficulty in practical experiments. The one most commonly used exploits the double refraction exhibited by certain crystals. The technique was developed independently by Paul D. Maker, Robert W. Terhune, Martin Nisenoff and Carleton M. Savage of the Scientific Laboratory of the Ford Motor Company and by the author at the Bell Telephone Laboratories.

Certain asymmetric crystals such as calcite are doubly refracting because in them light can travel at two different velocities, described as ordinary and extraordinary. These velocities actually vary with propagation direction and polarization as well as with wavelength. Ordinary and extraordinary velocities in potassium dihydrogen phosphate (KDP), a piezoelectric crystal commonly used for harmonic generation, are illustrated in the middle diagram on page 44. The diagram shows that at an angle of 50 degrees to the optic axis of the crystal, ordinary fundamental light at 6,943 angstroms travels at exactly the same velocity as extraordinary harmonic light at 3,471.5 angstroms. When this direction is used for harmonic generation, the retardation of the ultraviolet harmonic light due to dispersion is precisely compensated by the higher velocity of extraordinary light at the harmonic wavelength.



WHEN CRYSTAL RESPONSE IS LINEAR, the optical polarization wave (*color*) is directly proportional to the optical electric field (*black*). When values of the wave and field are plotted against each other, as shown at right, the result is a straight line.



WHEN CRYSTAL RESPONSE IS NONLINEAR, the optical polarization wave (*color*) is no longer proportional to the optical electric field (*black*). When values of the wave and field are plotted against each other (*right*), the resulting curve is nonlinear.

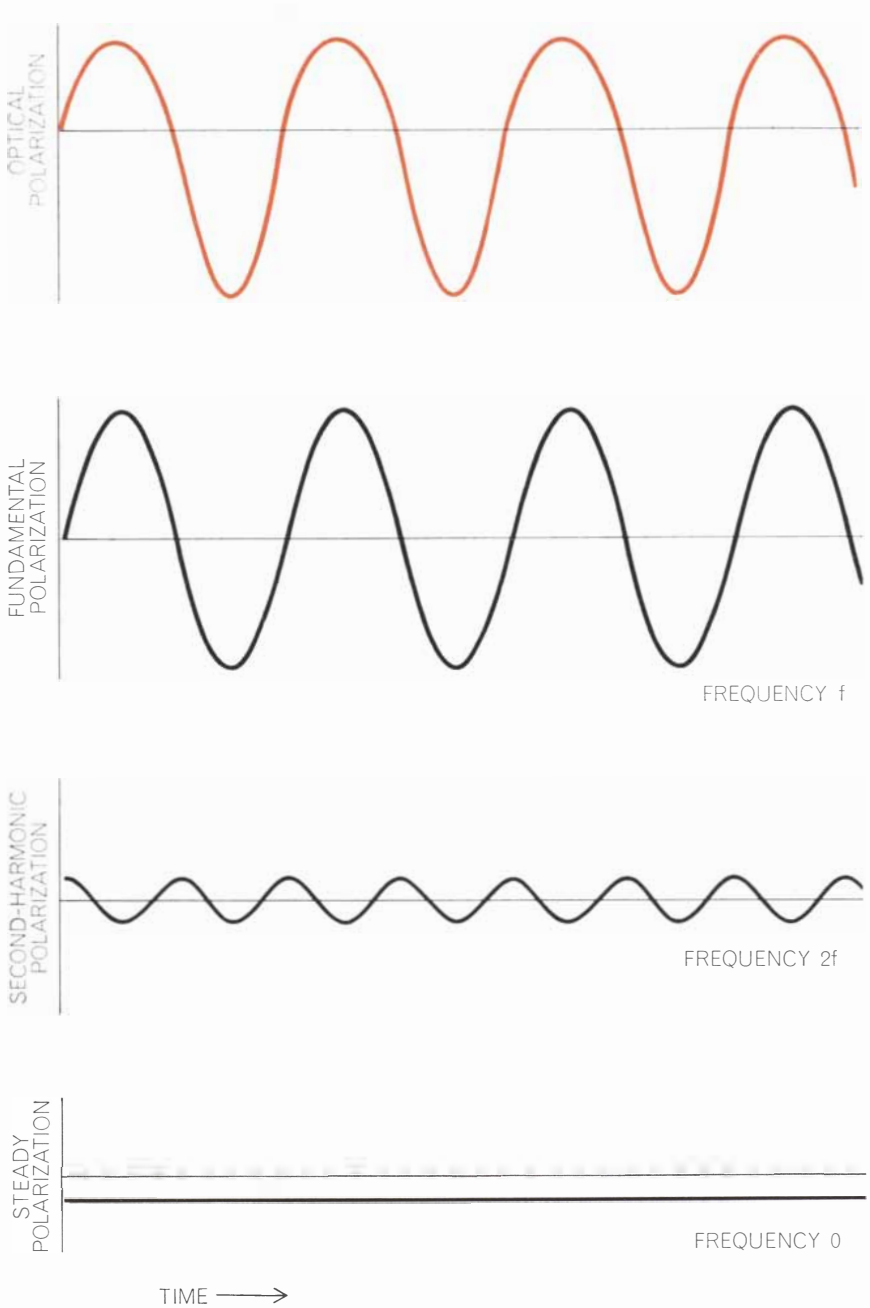
This technique has made possible an increase in coherence length from a thousandth of a centimeter to more than a centimeter and has led to a million-fold increase in conversion efficiency. In KDP a 20 per cent conversion efficiency from red to ultraviolet has been observed by Maker, Terhune and Savage with a million-watt pulsed laser. Arthur Ashkin, Gary D. Boyd and Joseph M. Dziedzic of the Bell Laboratories, also using KDP, have observed harmonics from a continuously operating gas laser at power levels as low as 50 millionths of a watt.

A second method of avoiding the interference problem has been developed by Robert C. Miller of the Bell Laboratories and is applicable in ferroelectric crystals such as barium titanate. Ferroelectric crystals can be obtained in the form of a multilayered sandwich in which the layers are regions, called domains, that have different properties. In barium titanate adjoining domains are completely equivalent except that one is inverted with respect to the other. The phase of the harmonics generated in successive domains is reversed, with the result that the interference effect is partially offset and harmonic generation greatly enhanced. Franken, Hill and Peters have observed similar enhancement with stacked quartz plates that have axes pointing in alternate directions.

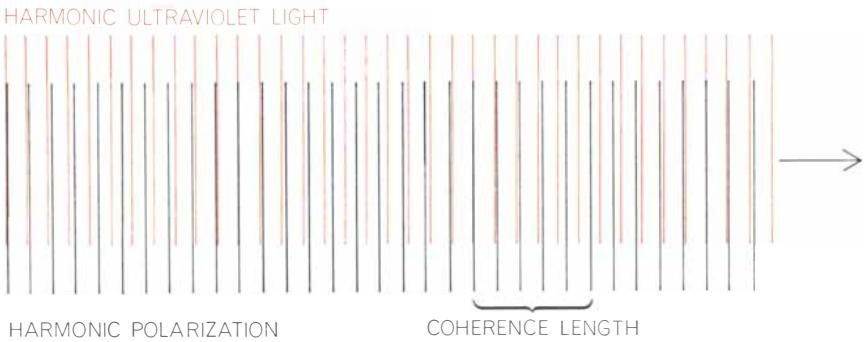
Franken and his associates have also detected the "direct current" polarization mentioned earlier as the third component of the distorted polarization wave that can be produced by intense laser beams. The direct-current signal can be detected simply by connecting plates to opposite surfaces of a piezoelectric crystal that is transmitting the light output from a laser. The direct-current signal appears as a voltage pulse proportional to the laser intensity. The crystal action in this experiment is analogous to that of a vacuum-tube (or crystal) diode in rectifying, or "detecting," a radio signal. Detailed theories of all the above processes, as well as others, have been presented by Nicolaas Bloembergen, Peter S. Pershan, John A. Armstrong and J. Ducuing of Harvard University and also by David A. Kleinman of the Bell Laboratories.

Included in these new theories is an analysis of the interaction that takes place when two light beams of different frequencies are sent through a transparent medium in different directions. When intense monochromatic beams are used, they "beat" together to produce new frequencies that correspond to the sum and difference frequencies of the primary beams. This phenomenon has been observed in independent experiments by Franken and his colleagues, by A. W. Smith and Norman Braslau of the International Business Machines Research Center, by Miller and Albert Savage, as well as by the author. A novel feature of the Smith-Braslau experiment is that one light source was the 5,461-angstrom green line of a standard mercury-arc lamp. Its beats with the red ruby laser (6,943 angstroms) occur in the ultraviolet at 3,056 angstroms. If these wavelengths are expressed as frequencies, it is apparent that the first two add to produce the third.

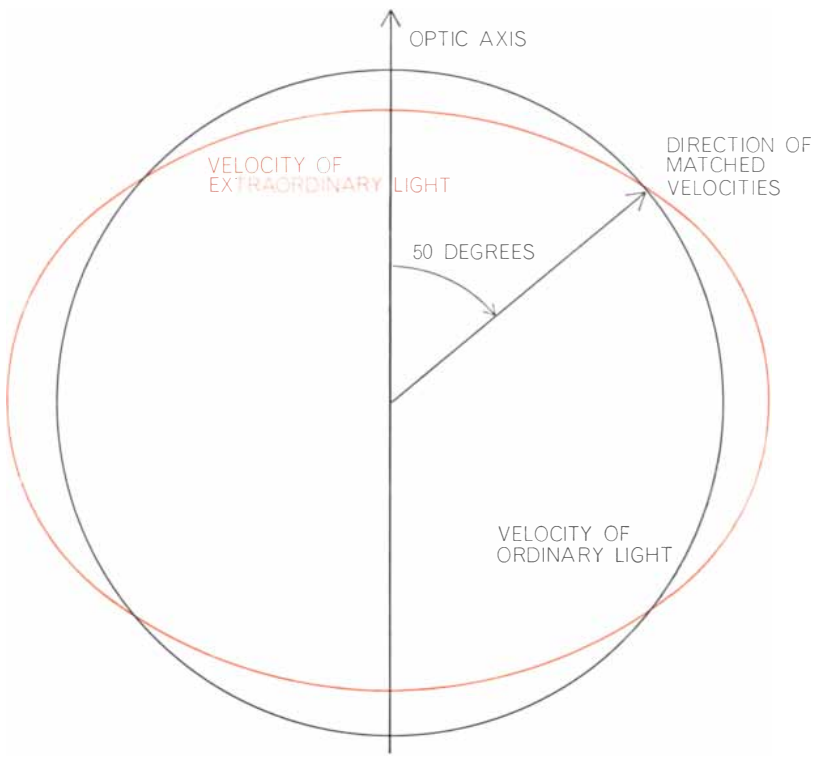
How this addition of frequencies comes about is illustrated at the top of page 45. The diagram shows the superposition of two light waves of different frequencies and wavelengths. The super-



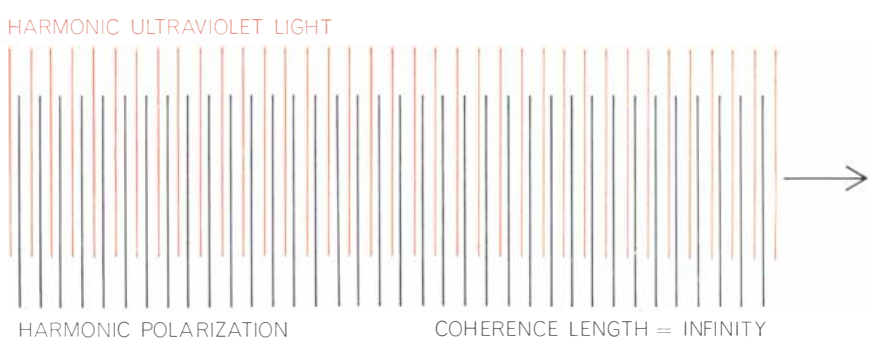
ANALYSIS OF NONLINEAR POLARIZATION WAVE (*top*) shows it to be the sum of three components: a wave at the fundamental frequency (*f*) of the light wave that created it, a wave at the second-harmonic frequency (*2f*) and a component that corresponds to a steady polarization (*bottom*). The first and second of these components radiate their own light waves at frequencies of *f* and *2f* respectively. In almost all materials the velocity of *2f* light is a little slower than that of *f* light, with result shown at top of next page.



DESTRUCTIVE WAVE INTERFERENCE occurs in a crystal because the polarization wave (*black*) normally travels a little faster than its harmonic radiation (*color*). The polarization and its radiation get completely out of step in a distance called the coherence length.



INTERFERENCE CAN BE OVERCOME by generating harmonic light in a crystal that exhibits double refraction such as KDP. The black circle represents the velocity of ruby laser light of 6,943 angstroms polarized perpendicularly to the page. The colored oval represents the velocity of second-harmonic light of 3,471.5 angstroms polarized in the plane of the page. At 50 degrees to the optic axis both waves travel at the same velocity.



ELIMINATION OF WAVE INTERFERENCE is achieved by sending a ruby laser beam into a crystal of KDP at 50 degrees to the optic axis. Now the harmonic polarization wave (*black*) and the harmonic ultraviolet light it radiates (*color*) stay in step indefinitely.

position produces a moiré pattern in which the crossover points identify regions of maximum electric field strength. The two sets of moiré lines drawn through these regions of maximum electric field identify the crests of two new nonlinear polarization waves that propagate through the medium. It can be seen in the geometry of the moiré pattern that one of the new waves has a frequency equal to the sum of the frequencies of the two primary waves. The other new wave has a frequency equal to the difference in frequency between the primary waves.

The illustration also identifies a quantity called the propagation vector and designated K. The K vector of any wave points in the direction of the wave motion and has a length proportional to the reciprocal of the wavelength (that is, 1 divided by the wavelength). Just as one of the new polarization waves has a frequency equal to the sum of component frequencies, so too it has a K vector equal to the sum of component K vectors. The other polarization wave has a K vector equal to the difference between component K vectors.

In the quantum theory of radiation the frequency of a light wave is proportional to the energy of a photon and the propagation vector K is proportional to its momentum. When two photons interact, both energy and momentum must be conserved. In the case where two beating waves interact to produce a wave whose frequency is the sum of the frequencies of the primary waves, the conservation is straightforward: the sum-frequency photon appears with the combined energy and momentum of the two primary photons that have been annihilated.

In the case where two beating waves interact to produce a wave whose frequency is the difference between the frequencies of the primary waves, energy and momentum have to be conserved in a rather curious way. Let us say that the two primary photons have frequencies of f_1 and f_2 and that the difference photon has a frequency f_3 equal to f_1 minus f_2. In the interaction of f_1 and f_2 only the f_1 photon is annihilated. In its place appear another f_2 and an f_3 photon. In being transformed into an f_2 photon the f_1 photon gives up enough energy to create an f_3 photon. In other words, it can be predicted that such an interaction will yield as many new photons of f_2 light as of f_3 light. Because a great deal of primary f_2 light is needed to make the interaction take place, it

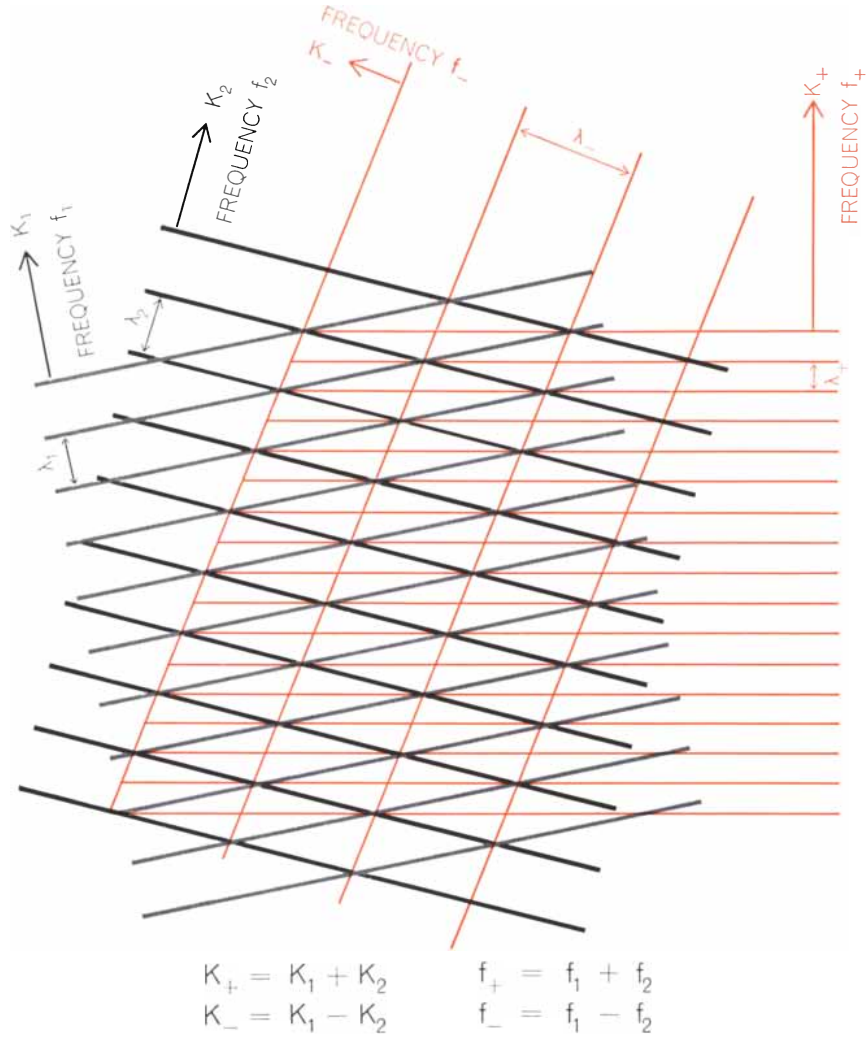
will be quite difficult to observe the small amount of additional f_2 light produced.

All the experiments described so far make use of the asymmetric properties of piezoelectric crystals to produce nonlinear optical effects. It is appropriate to ask if such effects can also be obtained with ordinary symmetrical crystals and isotropic materials such as glass and liquids. The answer is yes. As one might expect, all materials become nonlinear in the presence of sufficiently intense fields, but the effects are much weaker than those found in asymmetric materials.

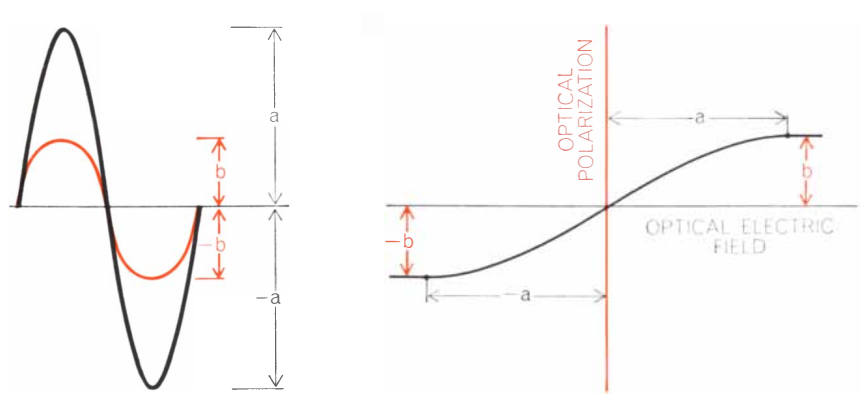
Because symmetrical materials lack an intrinsic one-wayness, the polarization wave produced by an intense light beam is not skewed left or right as it is in asymmetric materials. Instead the electronic charges in the material are displaced equally to the left and to the right. The nonlinearity arises from the fact that the displacement can no longer follow in exact proportion as the electric field rises to peak intensity. When this sort of distorted polarization wave is analyzed into its components, it is found to consist mainly of a pure wave of the fundamental frequency and a weak third-harmonic wave. The third harmonic of ruby laser light (6,943 angstroms) occurs in the far ultraviolet at 2,314 angstroms. It has been produced in calcite by Terhune of the Ford Laboratory; the conversion efficiency was three parts per million.

In the intense electric fields of laser light not only the transmission of light but also its reflection and refraction begin to depart from the classical rules of optics. Bloembergen and Pershan have shown that the laws of reflection and refraction must be generalized to include harmonic generation at surfaces. Ducuing and Bloembergen have observed harmonic generation of light on reflection from piezoelectric crystals such as tellurium that are opaque at both the fundamental and second-harmonic frequencies.

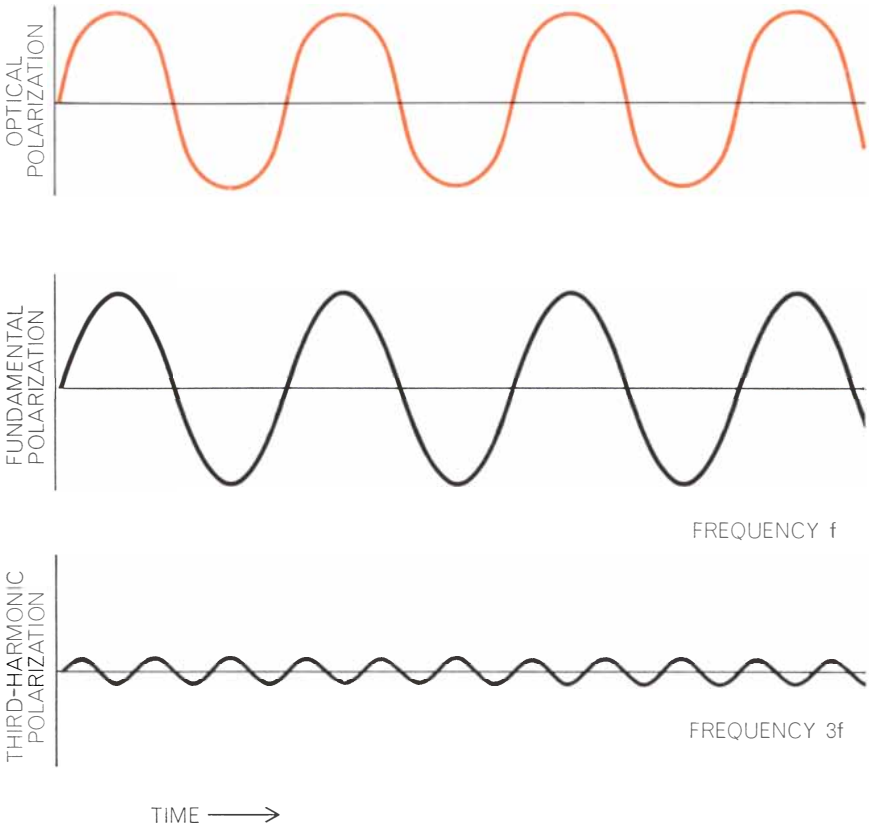
At high intensities the absorption of light also exhibits new features. In 1961 W. Kaiser and C. G. B. Garrett of the Bell Telephone Laboratories showed that intense laser light is absorbed in transparent materials that normally absorb light only at twice the laser frequency. In this process two photons are absorbed simultaneously, leaving an atom in the excited state that would be produced by absorption of a single photon of twice the frequency. (The process



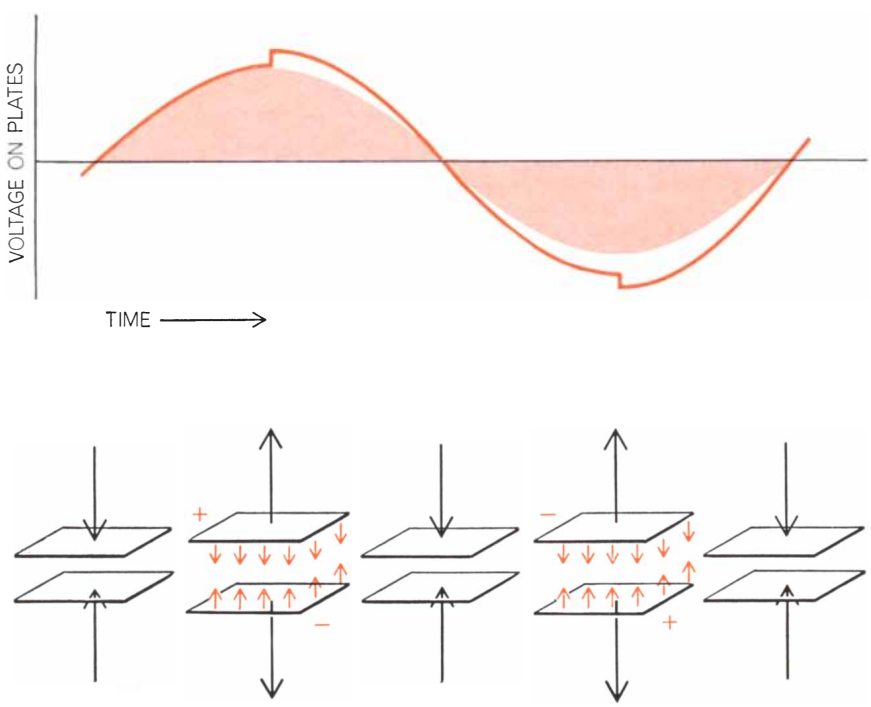
MOIRÉ PATTERNS are produced by the interaction of two light waves of different frequencies. Their frequencies and wavelengths are labeled f_1 and f_2 and λ_1 and λ_2 respectively. Their propagation vectors designated K_1 and K_2 point in the direction of the wave motion and have a length proportional to the reciprocal of the wavelength. The points where the wave fronts intersect identify regions of maximum electric field strength. Moiré lines drawn through these maxima identify the crests of two new nonlinear polarization waves that radiate light. One wave radiates light of frequency f_+, which is the sum of f_1 and f_2. The other wave radiates light of frequency f_-, which is the difference between f_1 and f_2. New K vectors, K_+ and K_-, are likewise produced by sum and difference.



NONLINEAR POLARIZATION WAVE (*color*) can be created in liquids and symmetrical solids as well as in asymmetric crystals. Polarization wave is plotted against optical electric field (*black*) at right. Components of polarization wave appear at top of next page.



ANALYSIS OF DISTORTED WAVE (*top*) created by intense light in a symmetrical medium shows that it can be broken down into two components: a pure wave at the fundamental frequency (*f*) and a low-amplitude wave at the third-harmonic frequency (*3f*).



"PARAMETRIC" AMPLIFIER PRINCIPLE suggests a way in which visible laser light could be used to produce coherent infrared radiation. The diagram demonstrates the principle with capacitor plates, which are mechanically pushed apart (*black arrows*) when an alternating voltage applied to the plates is at a peak. Such peaks coincide with the maximum electric force (*colored arrows*) acting to pull the plates together. The plates are moved together when the voltage and electric force are zero. The motion of the capacitor plates at frequency *f* amplifies the electric signal at a frequency of half *f*.

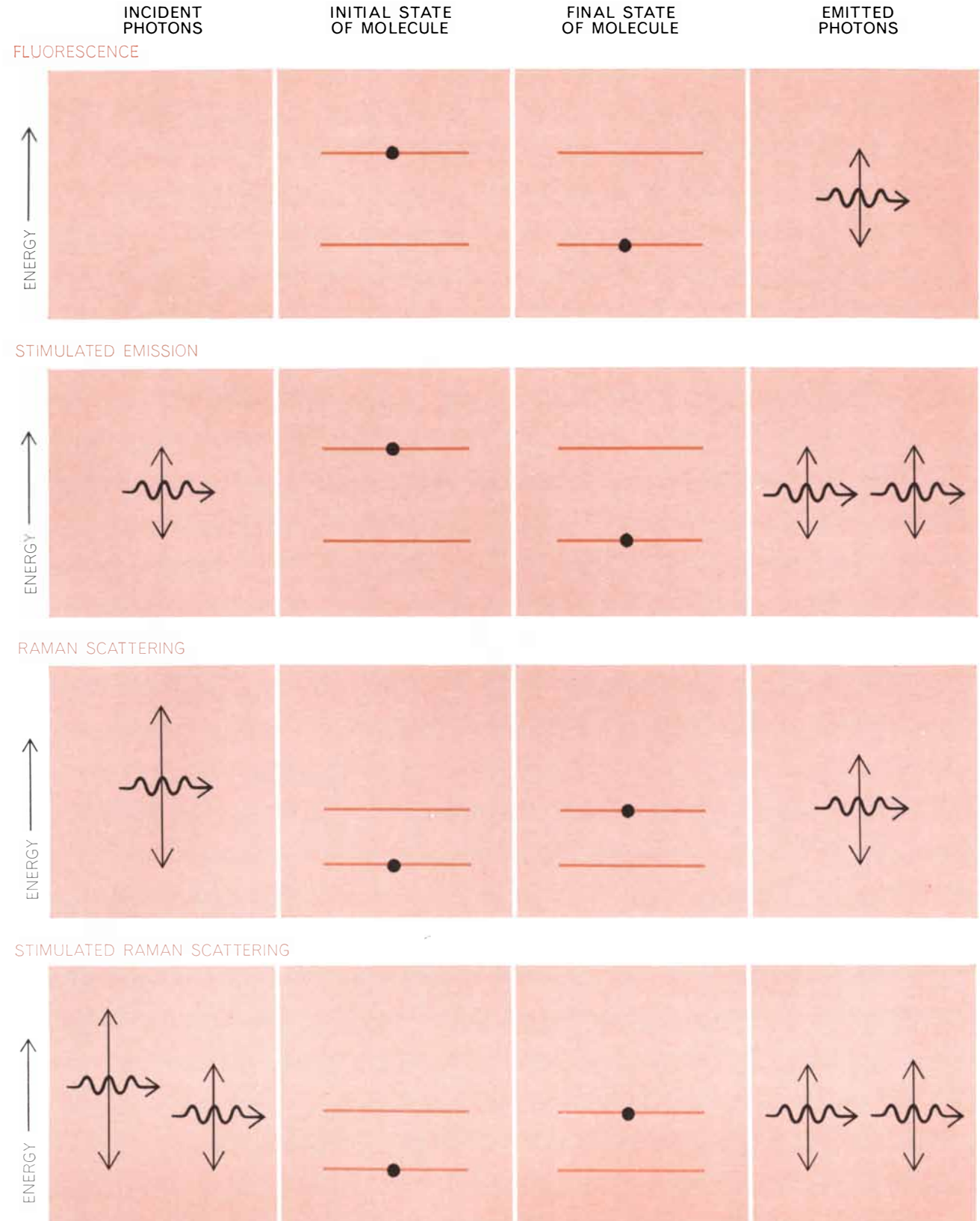
was predicted theoretically in 1931 by Maria Goeppert Mayer, who last year won a Nobel prize for her work on the structure of the atomic nucleus.) John A. Howe and the author have found that many normally transparent materials become opaque to intense laser light as a result of nonlinear processes. Recent work by John J. Hopfield, John M. Worlock and Kwangjai Park of the University of California at Berkeley has shown that the two-photon absorption process can provide information about excited states in solids not obtainable from ordinary spectroscopy.

One of the more interesting potential applications of the laser is its use as a source of "pump" light to generate far-infrared radiation. The far-infrared region, which holds great interest for spectroscopists, has been largely inaccessible for lack of tunable strong infrared sources. Proposals for using lasers together with nonlinear processes to remedy this shortcoming have been outlined by Robert H. Kingston of the Lincoln Laboratory of the Massachusetts Institute of Technology, Norman M. Kroll of the University of California at San Diego and Bloembergen.

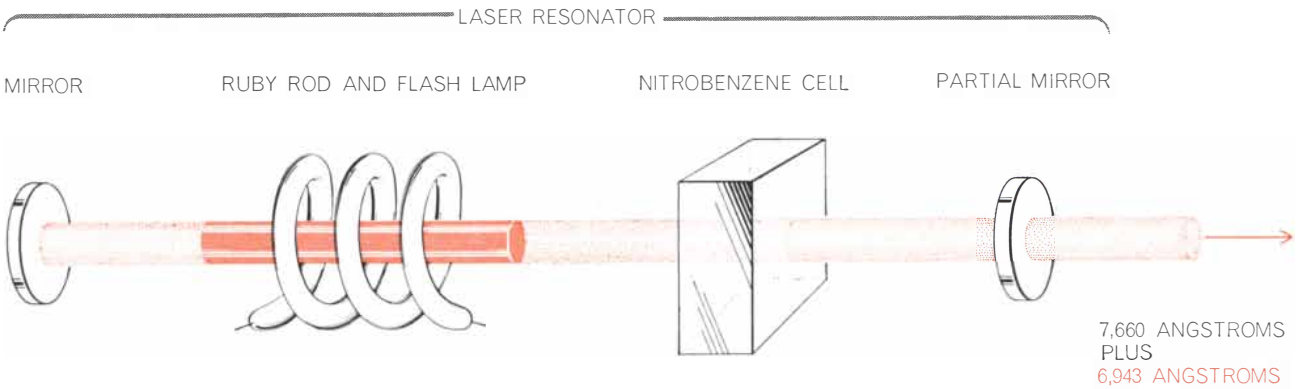
The principle they propose involves the "parametric" process diagramed at bottom left, which shows how a voltage wave can be amplified in an apparatus that contains condenser plates. If the plates are pulled apart slightly at each voltage peak against the electric forces tending to pull them together and are returned to their original position at the times of zero voltage when the electric forces are absent, the mechanical work done goes into amplifying the voltage wave. In a device that uses laser light for pumping, some dielectric material would be substituted for the condenser plates. A periodic change in the dielectric constant would serve the same function as moving the plates.

Notice that if the plates are pulled apart at frequency *f*, the voltage wave being amplified has the subharmonic frequency $f/2$. More significantly, it is possible to pump at frequency *f* and amplify any two lower frequencies f_1 and f_2 whose sum is equal to *f*. Several laboratories are now trying to develop a pumping device that will produce useful quantities of coherent infrared light at suitable pairs of infrared frequencies using a laser as a pump.

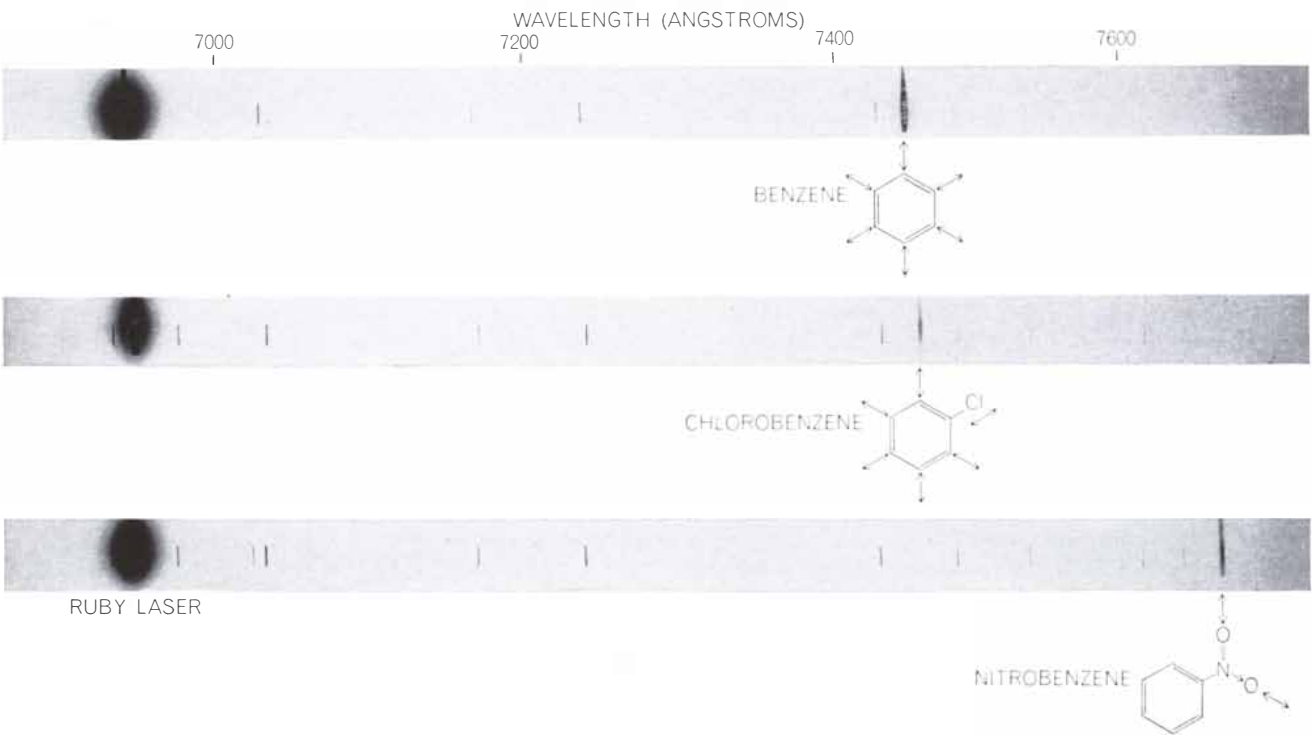
A laser-driven process that is already being put to practical use in spectroscopy is stimulated Raman emission, which was discovered two years ago by



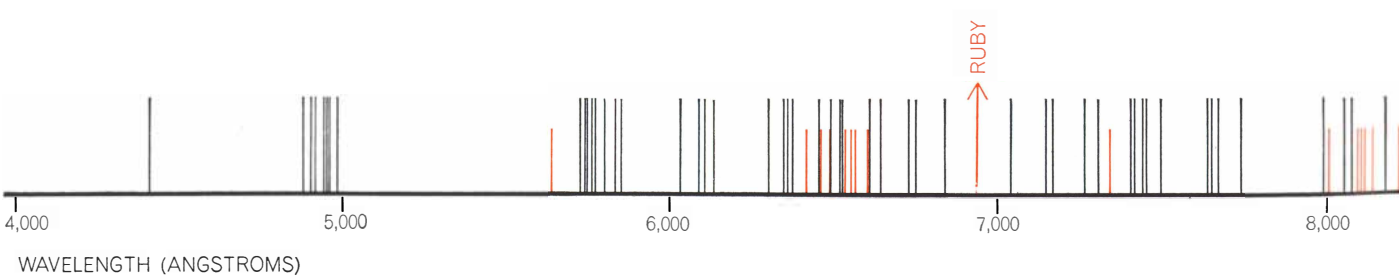
RADIATION PROCESSES involve transitions between two excited states of a molecule or atom. In fluorescence a photon is spontaneously emitted with energy equivalent to that lost by the molecule. In stimulated emission a photon with exactly the excitation energy of the molecule stimulates it to emit another photon of like energy. In the presence of many excited molecules a chain reaction, or laser action, can occur. In Raman scattering a molecule that is in a de-excited state absorbs a photon of arbitrary energy and re-emits it after subtracting the energy needed for excitation. In stimulated Raman scattering the production of a scattered photon is stimulated by the presence of a photon of exactly the same energy. Consequently a chain reaction can occur.



RAMAN LASER ACTION is an enhanced form of the effect first observed in 1927 by the Indian physicist C. V. Raman. In this effect a photon of light is absorbed by a molecule and re-emitted at a lower frequency. In the diagram laser photons of 6,943 angstroms are reflected back and forth through nitrobenzene. After losing energy to nitrobenzene a portion of the beam emerges at 7,660 angstroms. Raman laser action was discovered in 1962 by Eric J. Woodbury and Won K. Ng of the Hughes Aircraft Company.



STIMULATED RAMAN SPECTRA are shown for three similar molecules. Each molecule tends to vibrate in only one or two of its strongest modes. The many narrow, short lines are produced by materials used for calibration. The Raman emission of the upper two molecules represents the synchronous vibration of the entire benzene ring. The vibration in the bottom spectrum is characteristic of the nitro (NO_2) group attached to the benzene ring. The spectra were photographed by John A. Howe and the author.



OVER 100 COHERENT LIGHT SOURCES have now been produced by Raman laser action in various materials. The black lines identify wavelengths created by using pulses from ruby lasers; the colored lines are wavelengths available from neodym-

Eric J. Woodbury and Won K. Ng of the Hughes Aircraft Company. In the course of precise measurements of the light emitted from a million-watt pulsed ruby laser it was observed that about 10 per cent of the expected light at 6,943 angstroms seemed to be missing. The missing light was soon found to be emerging as a coherent beam at a new wavelength: 7,660 angstroms in the infrared region [*see top illustration on opposite page*].

The new emission occurs at a frequency differing from the laser frequency by 4×10^{13} cycles per second. This difference was subsequently identified as the frequency of a characteristic vibration of the nitrobenzene molecule by Woodbury in collaboration with another group at Hughes Aircraft (Gisela M. Eckhardt, Robert W. Hellwarth, Frederick J. McClung, Jr., Steven E. Schwarz and Daniel Weiner). Woodbury had just happened to use a laser arrangement that included a cell of nitrobenzene as an optical component. Although Raman laser emission had been predicted a few years earlier by Ali Javan, now at the Massachusetts Institute of Technology, its discovery was a happy accident.

In the Raman effect a photon of incident light is absorbed by a molecule and re-emitted at a lower frequency. The energy removed from the light beam appears as mechanical energy of vibration or rotation of the molecule. The striking new feature of the Woodbury-Raman effect is that if enough photons are emitted in the ordinary Raman effect and if they are prevented from escaping too quickly (by being reflected back and forth inside a resonator), they begin to stimulate further Raman emission [*see bottom diagram on page 47*]. This stimulation is similar to the process by which light is amplified in a laser, except that prior excitation of the molecules is unnecessary. In the chain reaction that follows, a large fraction of the incident laser light is converted into Raman light of lower frequency. With the Woodbury-Raman effect it is possible to photograph a Raman spectrum in a single burst of laser light lasting a ten-millionth of a second; by conventional techniques the exposure would require from a minute to an hour.

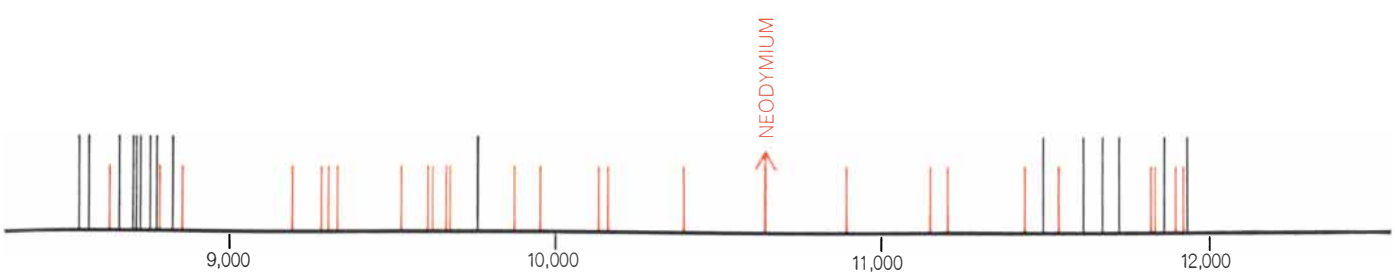
It has recently been discovered that when intense laser pulses are focused in solids, liquids and high-pressure gases, the stimulated Raman process can occur even without a resonator cavity. These advances have been made by Terhune, Robert W. Minck and William G. Rado of the Ford Laboratory and by Gisela Eckhardt, David P. Bortfeld and Myer Geller of Hughes Aircraft. Near the focus, where the light intensity can exceed one billion watts per square centimeter, the amplification of Raman light is as high as 10^{50} per centimeter, enough to amplify stray background light up to the 100,000-watt level in one pass through the focus.

A new feature of the focused-light experiments is that the molecular vibrations stimulated by the Raman effect become so violent that the refractive index of the material oscillates strongly at the molecular-vibration frequency. Light passing through the focus acquires a modulation at this frequency. As a result the characteristic vibration frequency of the molecule is not simply subtracted from the laser frequency but is added to it as well. These shifted frequencies, called upper and lower side bands, are emitted in sharply defined directions determined by the conservation of momentum condition described earlier. The large variety of substances showing the Raman effect provide hundreds of new coherent sources of light from the ultraviolet through the infrared [*see bottom illustration on these two pages*].

Charles H. Townes and his associates at the Massachusetts Institute of Technology have predicted further that in an intense light beam a Raman-like process should also lead to the generation of intense waves of high-frequency sound. In this process the energy lost by a photon of light should reappear as a quantum of sound.

All the effects described so far involve the interaction of light with light in a material medium. It has been recognized for some time, however, that interactions of intense light beams should occur even in a vacuum. From the viewpoint of quantum electrodynamics a vacuum is a polarizable medium with a refractive index slightly different from 1. Gamma ray photons can interact in a vacuum to create electron-positron pairs, if the photons have sufficient energy to make up the rest mass of the created particles (about a million electron volts). Although optical photons, which have energies of only one to three electron volts, lack the energy to produce electron-positron pairs, two optical photons can interact to form what is called a virtual pair. Such a pair can be observed only indirectly when they annihilate to yield two new photons with the same total energy as the original photons, which can go off in directions different from either of the colliding photons. This rather unlikely type of scattering occurs as if the refractive index of the vacuum underwent small changes in response to the presence of intense electric and magnetic fields carried by light. Estimates show, however, that this scattering would be impossibly difficult to observe with existing lasers.

The nonlinear optical experiments that have been performed to date have suggested a variety of new optical techniques that would be of use in spectroscopy. Beyond that, together with the laser they bring closer the time when the entire electromagnetic spectrum will be manipulated with the precision and usefulness of modern electronic and radio techniques.



ium lasers. By interacting these sources in nonlinear crystals of the KDP type one can obtain, by sum and difference combinations, more than 5,000 light sources of distinctively different wavelengths. Ultimately they should be useful in spectroscopic investigations.

CHROMOSOME PUFFS

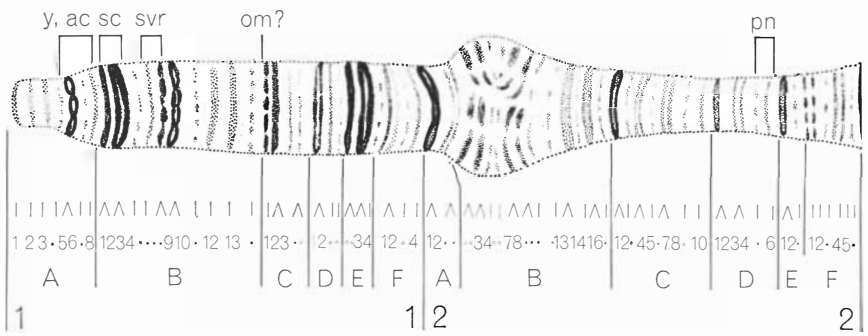
These enlarged regions on the giant chromosomes found in some insect cells have been shown to be active genes. They probably produce the nucleic acid that translates the genetic information

by Wolfgang Beermann and Ulrich Clever

The genetic material performs two functions that are basic to life: it replicates itself and it ultimately directs all the manifold chemical activities of every living cell. The first function is expressed at the time of cell division in the manufacture of more of the genetic material: deoxyribonucleic acid (DNA). The second is accomplished during the "interphase" between cell divisions; DNA directs the synthesis of ribonucleic acid (RNA), which in turn directs the synthesis of proteins, which as enzymes in turn catalyze the other reactions of the cell. In this way RNA translates the genetic information of DNA into the language of physiology and growth, into the everyday processes of synthesis and metabolism.

As readers of SCIENTIFIC AMERICAN are aware, the work of elucidating the genetic code is now being carried out by investigators in laboratories throughout the world, largely by the breeding and statistical study of certain bacteria and the viruses that infect them. In recent years our laboratory at the Max Planck Institute for Biology in Tübingen and several other laboratories have adopted somewhat different techniques for investigating the relation between DNA and RNA in the genetic material of higher organisms—those belonging to the insect order Diptera, such as the fruit fly *Drosophila* and the midge *Chironomus*. In these insects, as in all higher organisms, the DNA resides in the structures called chromosomes. In certain exceptionally large cells of *Drosophila* and *Chironomus* we have found that we can actually see the ultimate units of heredity—the genes—at work. These active genes take the form of "puffs" scattered here and there along the giant chromosomes of the giant cells. We have found that the puffs produce RNA and that the RNA made in one puff differs from the RNA made in another. Observations of the puffs have also enabled us to trace the time patterns of gene activity in several tissues of developing insect larvae. Furthermore, by administering hormones and other substances we can start, stop and prevent some of these activities.

The giant chromosomes were first observed late in the last century, but it was not until 1933 that Emil Heitz and Hans Bauer of the University of Hamburg recognized them as chromosomes. By 1933 breeding studies of the fruit fly had resulted in detailed "maps" on which genes were placed in relation to each other along the chromosomes. The genes, however, were still conceptions rather than physical entities, and the chromosomes had been recognized only during cell division, when they are coiled like a spring and present a condensed, rodlike appearance. During interphase, when they are directing cellular activity, the chromosomes in typical cells are virtually invisible because, although they are long, they are so thin that they can be seen only at the extremely high magnifications provided by the electron microscope, a comparatively recent invention.

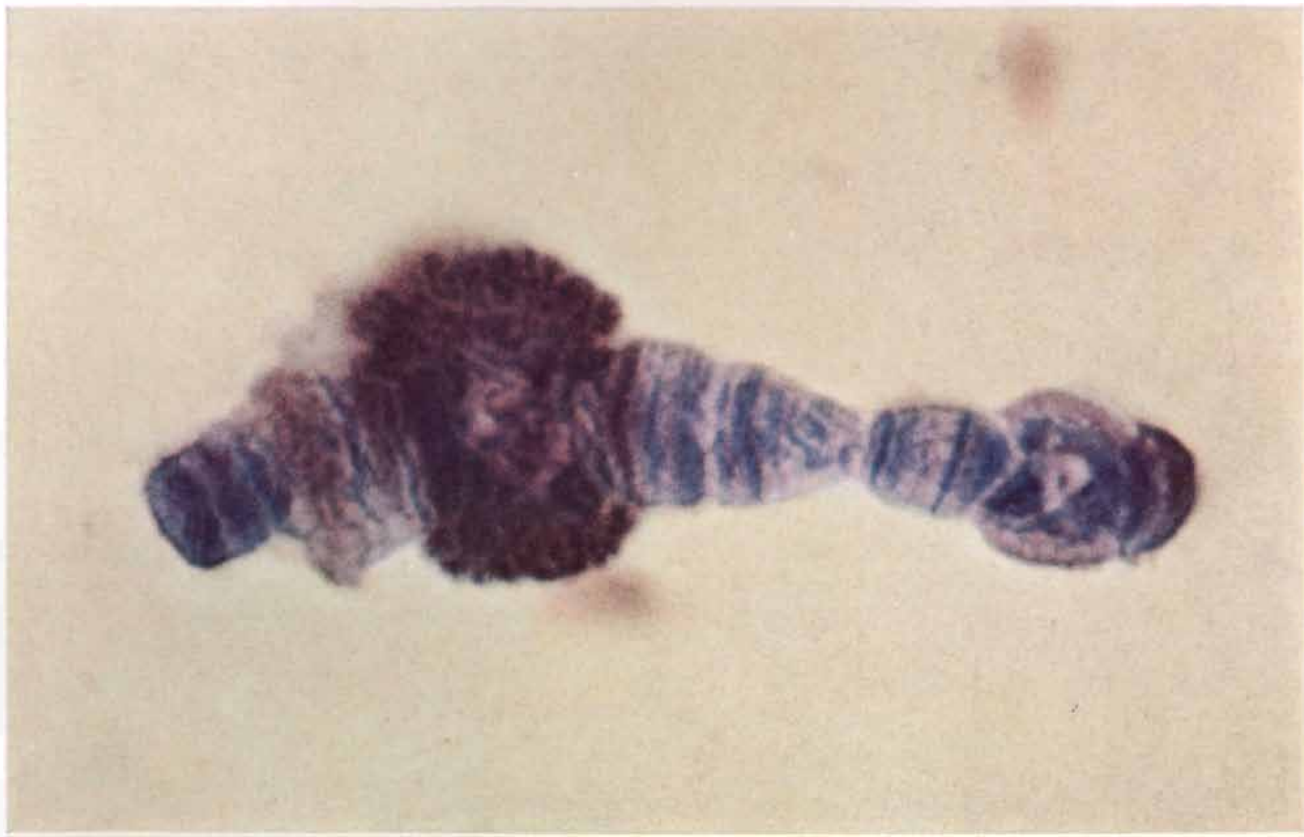


TIP OF A GIANT CHROMOSOME from the salivary gland of the fruit fly *Drosophila melanogaster* is shown in this diagram. The reference system below it was devised by Calvin B. Bridges of the California Institute of Technology. The letters and brackets above it mark certain sites known to be associated with specific bodily characteristics. For example, the "y" at left denotes the band or gene responsible for yellow body color.

Heitz and Bauer realized that giant chromosomes, which are clearly visible in the light microscope, are the equivalent of the interphase chromosomes of typical cells. In the words of T. S. Painter of the University of Texas, the giant salivary-gland chromosomes of fruit fly larvae were "the material of which every geneticist had been dreaming. The way led to the lair of the gene." Intensive work by Painter and others in the U.S., including H. J. Muller, Calvin B. Bridges and Milislav Demerec, soon identified specific characteristics of flies with particular loci, or bands, on the giant chromosomes. Since then the bands have been considered the material equivalent of the conceptual Mendelian genes.

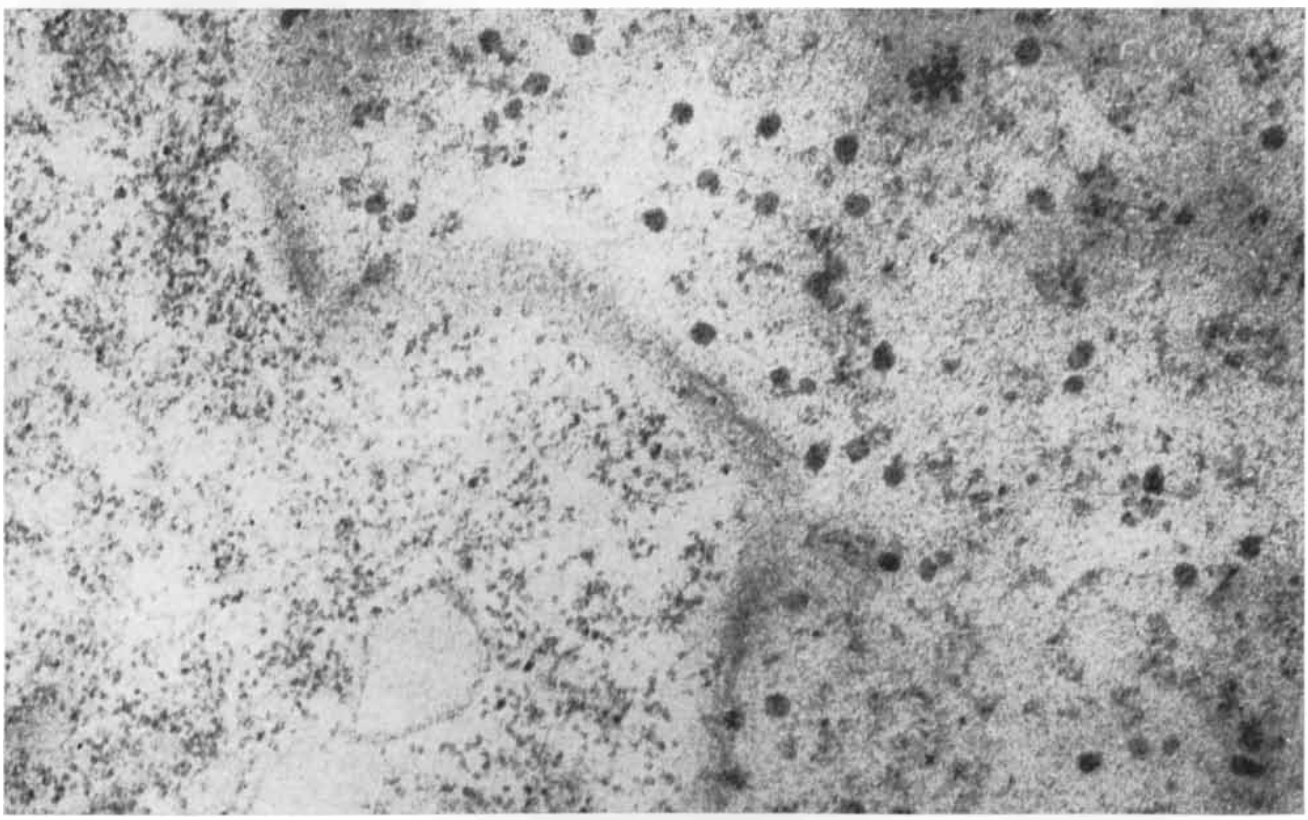
The giant chromosomes are found primarily in well-differentiated organs that are engaged in vigorous metabolic activity, such as salivary glands, intestines and the Malpighian tubules (excretory

CHROMOSOME PUFFS are the protuberances on the left-hand portion of the giant chromosome in this photomicrograph. Very large puffs, of which two are seen, are called Balbiani rings. Protein has been stained green, deoxyribonucleic acid (DNA) brown.



PRODUCT OF PUFFS, ribonucleic acid (RNA), is reddish-violet when dyed with toluidine blue. Here the DNA is blue. The photomicrographs on this page show two different specimens of the giant chromosome IV from the salivary gland of the midge *Chironomus tentans*. Both were made at the Max Planck Institute for Biology in Tübingen. The magnification in each is some 2,500 diameters.

SET OF FOUR GIANT CHROMOSOMES from a cell in the salivary gland of *Ch. tentans* is here magnified some 700 diameters. The enlarged regions on two of the long chromosomes are nucleoli. Chromosome IV is the shortest of the four; it has a Balbiani ring. The banding pattern on each of the four chromosomes is visible in corresponding giant chromosomes from entirely different tissues.



MIGRATING GRANULES, consisting of ribonucleic acid and protein (*right*), are penetrating pores in the nuclear membrane (*bottom center*) in this electron micrograph. Cytoplasm of cell is to left of membrane. The small particles in it are ribosomes, the sites of protein synthesis. The RNA in the large particles may be on its way to the ribosomes to act as a template for proteins.

organs). These tissues grow by an increase in cell size rather than in cell number. Apparently the giant cells require more genetic material than typical cells do; as they expand, the chromosomes replicate again and again and also increase in length. Along individual chromosome fibers there are numerous dense spots where presumably the structure is drawn into tight folds. These locations are called chromomeres.

As the chromosome filaments in giant cells increase in number, those of a particular chromosome remain tightly bound together; each chromomere is fastened to the homologous, or matching, chromomere of the neighboring filaments. Such locations become the bands, which are also known as chromomeres. The chromosome that results from this growth process is said to be "polytene": it has a multistrand structure resembling a rope. At full size the giant chromosomes are almost 100 times thicker and more than 10 times longer than the chromosomes of typical cells at cell division.

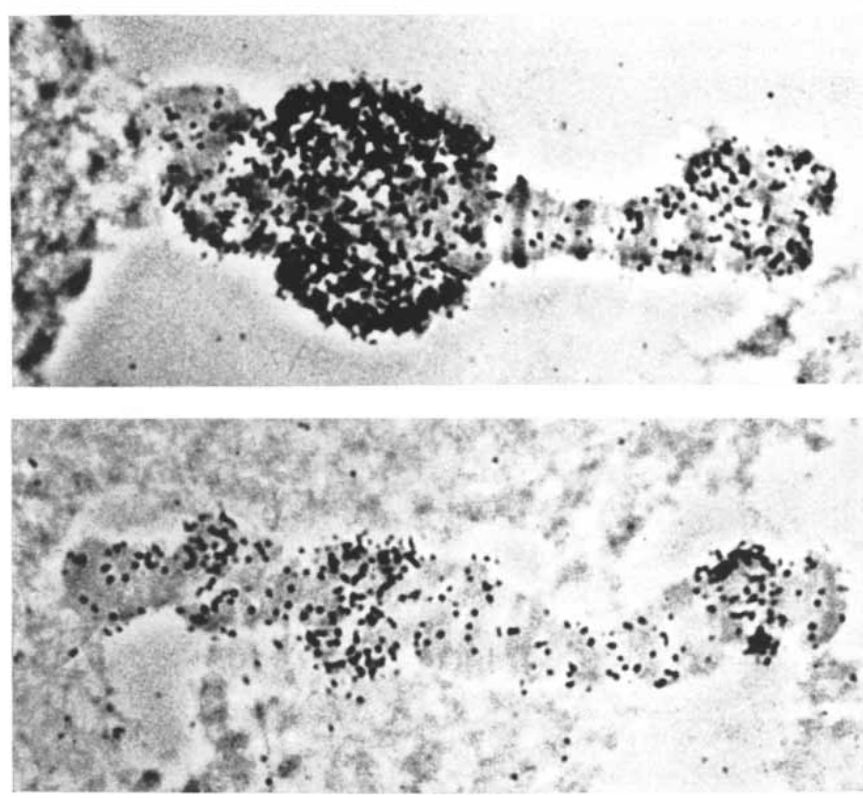
The bands, which vary in thickness, contain a high concentration of DNA and histone, a protein associated with DNA. The spaces between the bands, known as interbands, contain a very low concentration of these substances. It was discovered in 1933 that each giant chromosome in a set within a cell has its own characteristic sequence, or pattern, of banding and that, even more striking, every detail of the pattern recurs with the utmost precision in the homologous giant chromosome of every individual of the species.

In the past most cell geneticists were so occupied with localizing the genes in the salivary-gland chromosomes that they did not investigate the giant chromosomes in other tissues. Yet the presence of such chromosomes in cells with quite different functions poses an obvious challenge to the biologist interested in development and differentiation. It had long been held that every cell of an individual possesses exactly the same set of chromosomes and the same pattern of genes. Giant chromosomes in a variety of tissues provided an opportunity for testing this idea, that is, for determining if the special metabolic condition or function of a cell influences in any way the state of its chromosomes and genes. For example, in spite of the constancy of the banding pattern found in salivary-gland chromosomes, the same chromosomes in other organs of the same species might present a different banding pattern. If this were true, the localization of genes in specific bands would lose all general meaning.

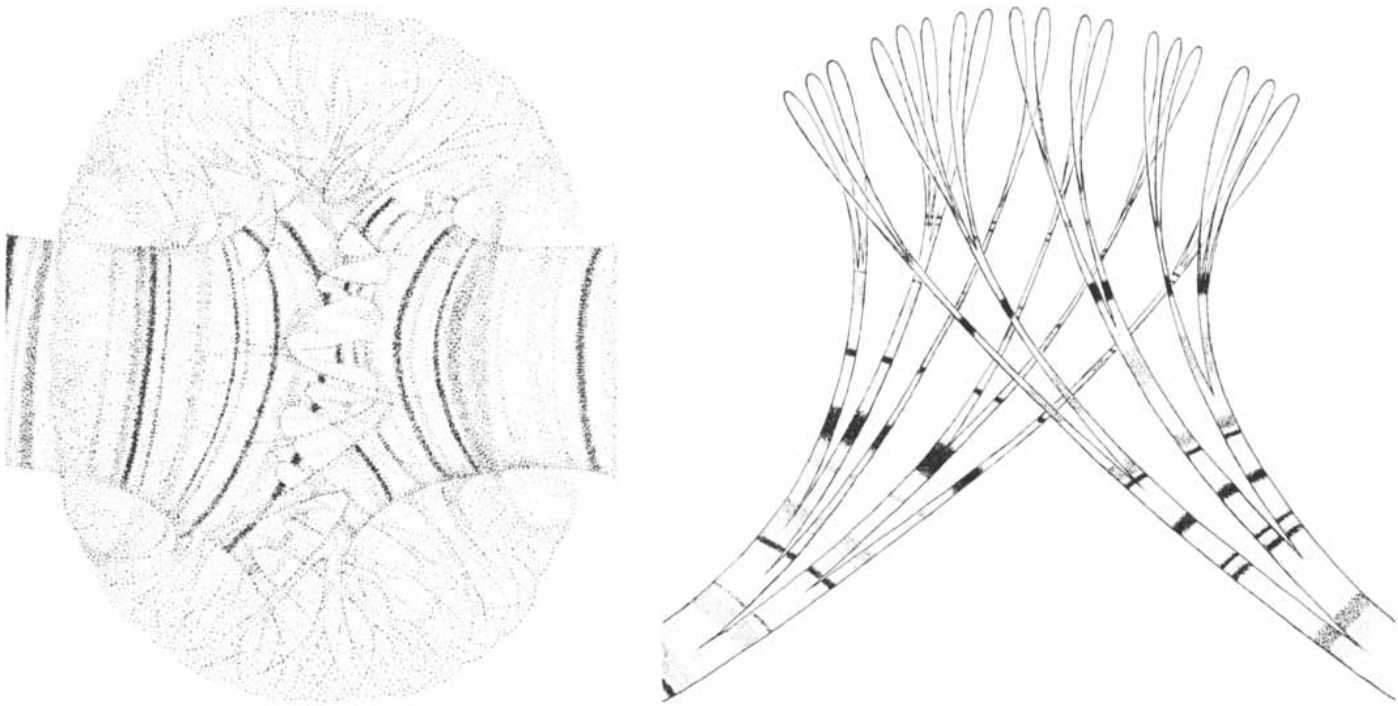
Assertions that different tissues have different banding patterns were actually made 15 years ago by Curt Kosswig and Atif Şengün of the University of Istanbul. One of us (Beermann, then working in the laboratory of Hans Bauer at the Max Planck Institute for Marine Biology in Wilhelmshaven) checked these claims by a detailed comparative study of the banding of giant chromosomes from four different tissues of the midge *Chironomus tentans*. Independently Clodowaldo Pavan and Martha E. Breuer of the University of São Paulo carried out similar investigations on the fly *Rhynchosciara angelae*. We could not find any detectable variation in the arrangement and sequence of bands along the chromosomes in different tissues. The uniformity of chromosome banding lends strong support to the basic concept that the linear arrangement of the genes as mapped in breeding experiments corresponds to the pattern of the bands on giant chromosomes.

At the same time, however, we found that chromosomal differentiation of a very interesting kind does exist. The fine structure of individual bands can differ with respect to puffs that are in one location on a chromosome in one tissue and in another location on the same chromosome at another time or in another tissue. These localized modifications in chromosome structure of various Diptera had been noted many years earlier, but their possible significance was overlooked.

The coherence of the chromosome filaments is loosened at the puffed regions. The loosening always starts at a single band. In small puffs a particular band simply loses its sharp contour and presents a diffuse, out-of-focus appearance in the microscope. At other loci or at other times a band may look as though it had "exploded" into a large ring of loops around the chromosome [*see top illustrations on next two pages*]. Such doughnut-like structures are called Balbiani rings, after E. G. Balbiani of the Collège de France, who first described them in 1881. Puffing is thought to be due to the unfolding or uncoiling of individual chromomeres in a band. On observing that specific tissues and stages of development are characterized by



INHIBITION OF PUFFING and of RNA synthesis is accomplished by treatment with the antibiotic actinomycin D. At top an autoradiogram of a chromosome IV of *Ch. tentans* shows the incorporation of much radioactive uridine (*black spots*), which takes place during the production of RNA, as explained in the text. Another chromosome IV (*bottom*) that had been puffing shows puff regression and little radioactivity after half an hour of treatment with minute amounts of actinomycin D. which inhibits RNA synthesis by DNA.



STRUCTURE OF A LARGE PUFF is diagramed. At left is a Balbiani ring as seen in the light microscope. Some of the fibrils that make it up are visible. Next is a drawing of the appearance of a few of the fibrils at very high magnification in the light microscope. The much greater magnification provided by the electron microscope (*third from left*) shows two puff fibrils with granules

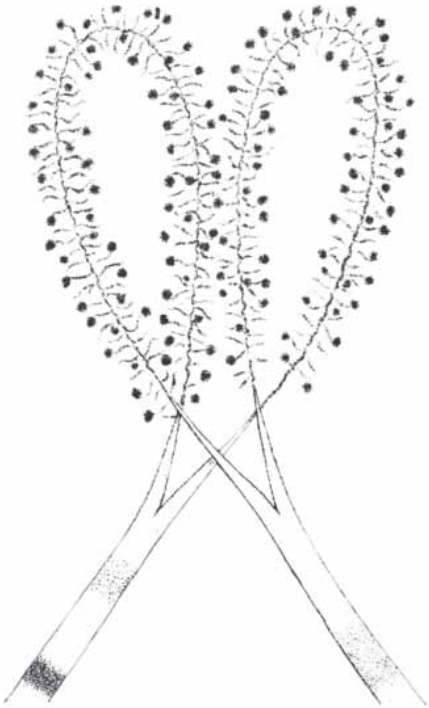
definite puff patterns, one of us (Beermann) postulated in 1952 that a particular sequence of puffs represents a corresponding pattern of gene activity. At about the same time, Pavan and Breuer arrived at a comparable conclusion based on their experiments with *Rhynchosciara.*

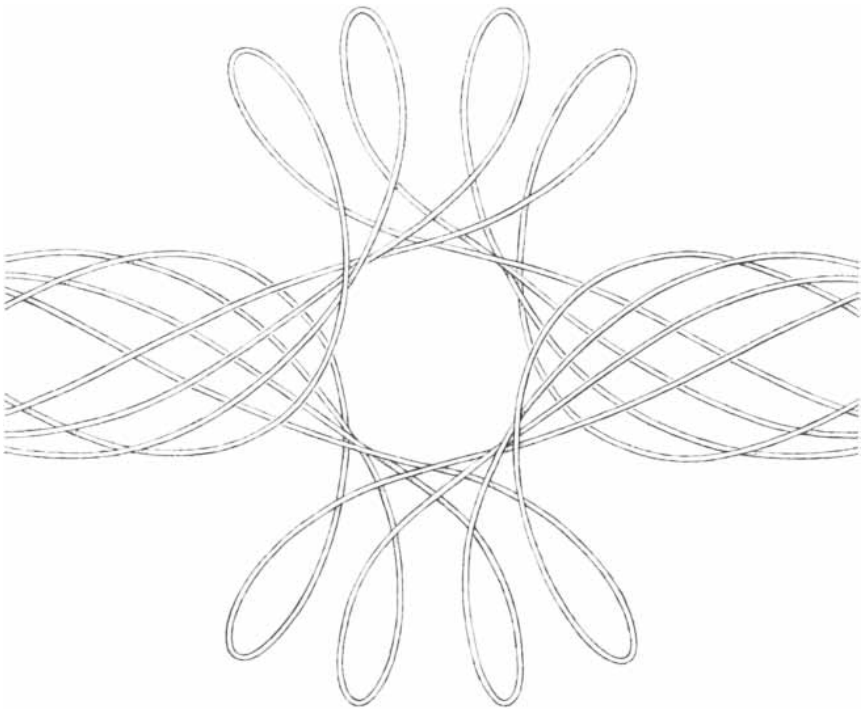
If differential gene activation does in fact occur, one would predict that genes in a specific type of cell will regularly puff whereas the same gene in another type of cell will not. A gene of exactly this kind has been discovered in *Chironomus.* A group of four cells near the duct of the salivary gland of the species *Chironomus pallidivittatus* produces a granular secretion. The same cells in the closely related species *Ch. tentans* give off a clear, nongranular fluid. In hybrids of the two species this characteristic follows simple Mendelian laws of heredity. We have been able to localize the difference in a group of fewer than 10 bands in one of *Chironomus*' four chromosomes; the chromosome is designated IV. The granule-producing cells of *Ch. pallidivittatus* have a puff associated with this group of bands, a puff that is entirely absent at the corresponding loci of chromosome IV in *Ch. tentans.* In hybrids the puff appears only on the chromosome coming from the *Ch. pallidivittatus* parent; the hybrid produces a far smaller number of granules than that parent. Moreover, the size of the puff is positively correlated with the number of granules. This reveals quite clearly the association between a puff and a specific cellular product.

Such analysis can demonstrate only that a specific relation exists between certain puffed genes and certain cell functions. We therefore sought to find a biochemical method for showing that puffing patterns along chromosomes are in fact patterns of gene activity. According to the current hypothesis the sequence of the four bases that characterize DNA—guanine, adenine, thymine and cytosine—represents a code for the sequence of the 20 kinds of amino acid unit that make up a protein. Most, if not all, protein synthesis takes place not in the nucleus of the cell but in the surrounding cytoplasm. The DNA always remains in the nucleus. As a result the instructions supplied by DNA must be carried to the cytoplasm, where the translation is made. The carrier and translator of the DNA information is thought to be the special form of RNA called messenger RNA. Each DNA molecule serves as a template for a specific messenger RNA molecule, which then acts as a template in the synthesis of a particular protein. Hence what we have termed gene activity becomes equivalent to the rate of production of messenger RNA at each gene.

It has been known for some time that chromosome puffs contain significant amounts of RNA. As we have noted, the normal, unpuffed bands chiefly contain DNA and histone. In general the amount of these compounds remains unchanged in the transition from a band to a puff, whereas the amount of RNA increases considerably. The presence of RNA is beautifully demonstrated by metachromatic dyes such as toluidine blue, which simultaneously stains RNA red-violet and DNA a shade of blue. A great increase in the amount of RNA, however, is not sufficient to demonstrate that RNA synthesis is the main function of puffs. For one thing, some dyes show that a protein other than histone accumulates in the puffs along with RNA. Perhaps it too is made there.

In order to find out if RNA is the major puff product, Claus Pelling of our laboratory employed the technique of autoradiography. His "tracer" was uridine, a substance the cell tends to use to make RNA rather than DNA, that had been labeled with the radioactive isotope hydrogen 3 (tritium). He injected the uridine into *Chironomus* larvae, which he later killed. When giant cells from the larvae were placed in contact with a photographic emulsion, the radioactive loci in their chromosomes darkened the emulsion [*see illustration*



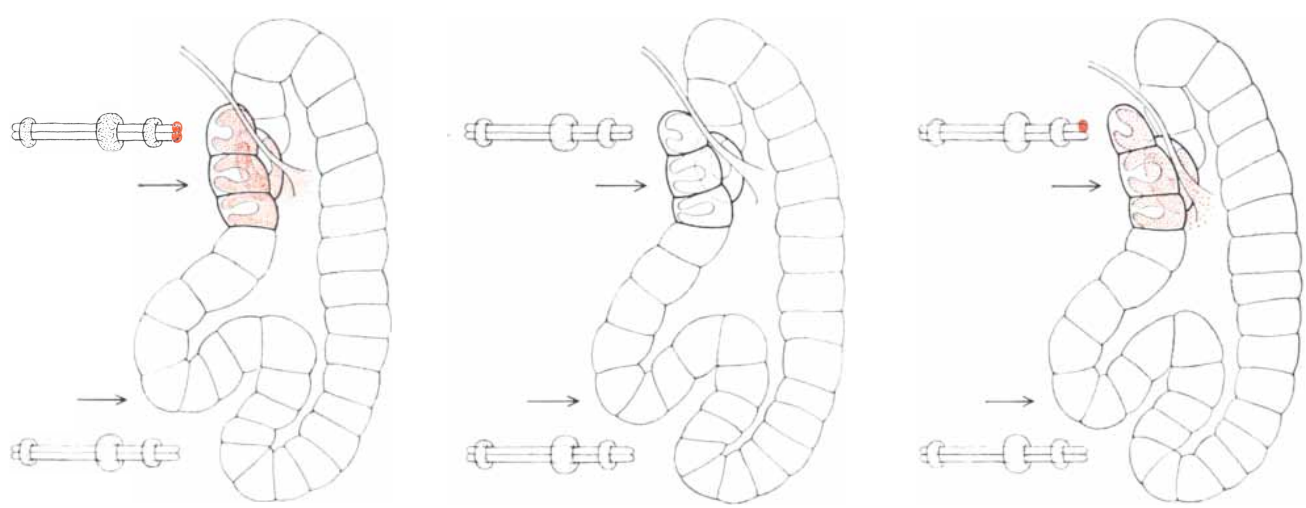


that are believed to be messenger RNA produced by the genes. In particularly small puffs the loops cannot actually be observed.

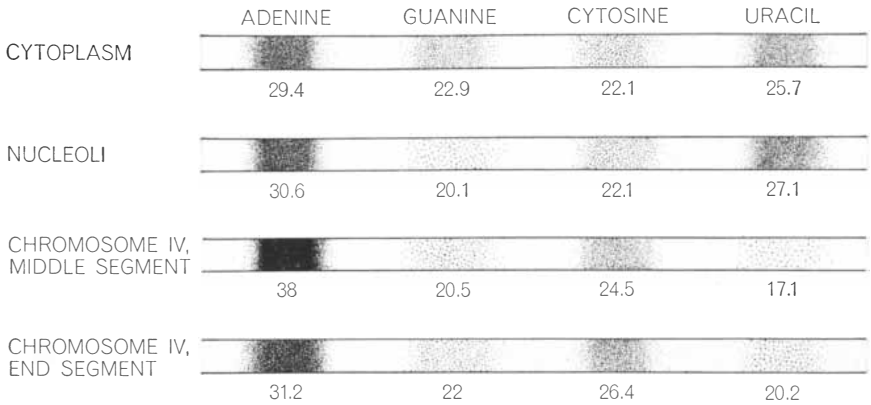
SCHEMATIC REPRESENTATION of how a large puff is formed shows fibrils untwisted and "popped out" of the cable-like structure. A giant chromosome in reality contains thousands of fibrils. Those untwisted here are tightly coiled when in the form of bands.

on page 53]. In every case in which Pelling killed the larvae soon after injection, sometimes as quickly as two minutes afterward, only the puffs, the Balbiani rings and the nucleoli were labeled. (Nucleoli are large deposits of RNA and protein that are formed in all types of cells by chromosomal regions known as nucleolar organizers. Presumably they are involved in the formation of ribosomes, which are the sites of protein synthesis in the cytoplasm.) The rest of the chromosomal material and the cytoplasm showed very little radioactive label until long after the injection.

When the preparations were treated with an enzyme that decomposes RNA before placing them in contact with the emulsion, the label was absent. Pelling demonstrated further that the rate of RNA synthesis is closely correlated with the relative size of the puffs. The administration of the antibiotic actinomycin D, a specific inhibitor of any RNA synthesis that depends directly on DNA, stopped the formation of RNA.



DIFFERENTIAL GENE ACTIVATION occurs on homologous, or matching, chromosomes of *Chironomus*. Four salivary-gland cells in the species *Ch. pallidivittatus* (*left*) produce granules (*colored stippling*). The species *Ch. tentans* (*center*) makes no granules. Chromosome IV from the four granule-producing cells (*at left of cells*) has a puff at one end (*color*), whereas the same chromosome from other cells (*lower left*) of the same gland and from all salivary-gland cells of *Ch. tentans* have no puff there. (In each case the chromosome inherited from both parents is shown.) Hybrids of the two species (*right*) have a puff only on the chromosome from the *Ch. pallidivittatus* parent in the four granule-producing cells. As indicated in the drawing, they make far fewer granules.



RNA'S FROM VARIOUS REGIONS of salivary-gland cells of *Chironomus* differ from one another in percentages of the four RNA bases. The RNA from each place was decomposed by an enzyme and the bases were then separated by electrophoresis on rayon threads. Samples from chromosome IV differ widely from nucleolar and cytoplasmic RNA's.

This proved that the synthesis was taking place at the site of the DNA in the chromosome. All these results agree with the assumption that the pattern of puffing along chromosomes is a quantitative reflection of the pattern of synthetic activities from gene to gene.

The protein in the puffs, in contrast to RNA, takes up little or no radioactive material if we inject the larvae with radioactively labeled leucine or another labeled amino acid. The labeled protein always appears first in the cytoplasm and does not reach the chromosomes for at least an hour. One of us (Clever) obtained the same result when he injected labeled leucine together with the hormone ecdysone, which elicits puffing at several sites in a short time. We have concluded, therefore, that the puff protein is made elsewhere than in the chromosome. Probably some of this protein is the enzyme RNA polymerase, which presides at the synthesis of RNA.

In order to learn if the RNA made in the puffs is messenger RNA, we collaborated with Jan-Erik Edström of the University of Göteborg in Sweden. He has developed an elegant microelectrophoretic technique that makes it possible to determine the base composition of very small amounts of RNA. He applies RNA that has been decomposed by an enzyme to moist rayon threads, which are then laid between two electric poles. Thereafter the different bases move different distances along the threads in a given time. Their quantities can be determined by photometry and their relative proportions established. We made separate analyses of the proportions of bases in RNA's from various parts of the salivary-gland cells of *Chironomus,* including the cytoplasm, the nucleoli, the entire chromosome I and the three large Balbiani rings of chromosome IV. This involved, among other things, cutting several hundred IV chromosomes into three pieces. The base compositions of all these RNA's differ from one another. The RNA's of the cytoplasm and the nucleoli appear to be nearly identical, but both differ from the RNA of the entire chromosome I and particularly from the RNA of puffs. In addition, there are slight but significant differences among the RNA's of the three Balbiani rings. One conclusion is that puff RNA certainly represents a special type of RNA. Is it therefore messenger RNA? An unusual feature of its base composition suggests that it is.

The RNA of salivary-gland chromosome puffs consistently contains more adenine than uracil—twice as much in the case of one Balbiani ring. (RNA contains uracil in place of the thymine in DNA.) Deviations from a one-to-one ratio are also found with respect to guanine and cytosine. In typical DNA the ratios of adenine to thymine and of guanine to cytosine invariably equal one because the bases are paired in the double-strand helix of the DNA molecule. RNA, being single-stranded, is not subject to this rule. In the case of messenger RNA, however, if one assumes that both strands of DNA make complementary copies of RNA, the ratios of adenine to uracil and guanine to cytosine should also be one. Most investigators confirm this expectation. Our data, on the other hand, strongly suggest that puff RNA is a copy of only one DNA strand. This appears to us to be a more reasonable way to make messenger RNA, since in protein synthesis only one of the two putative RNA copies of double-strand DNA could serve as a template. Messenger RNA fractions similar in composition to ours have now been discovered in other organisms.

Evidence for the physical movement of our messenger RNA has been found recently in electron micrographs of sections through the Balbiani rings that reveal the presence of ribonucleoprotein (RNA and protein) particles. In other electron micrographs such particles are seen floating freely in the nuclear sap and through pores in the nuclear membrane [*see bottom illustration on page 52*]. They break up in the cytoplasm. We believe these particles carry the messenger RNA to the ribosomes, where it would serve as the template for the synthesis of proteins.

In the hope of delineating at least some of the forces that control the behavior of genes, one of us (Clever) set out to learn about the conditions under which puffs are produced or changed. Since insect metamorphosis has been studied rather fully, a good starting point seemed to be the changes of the puff pattern in the course of metamorphosis.

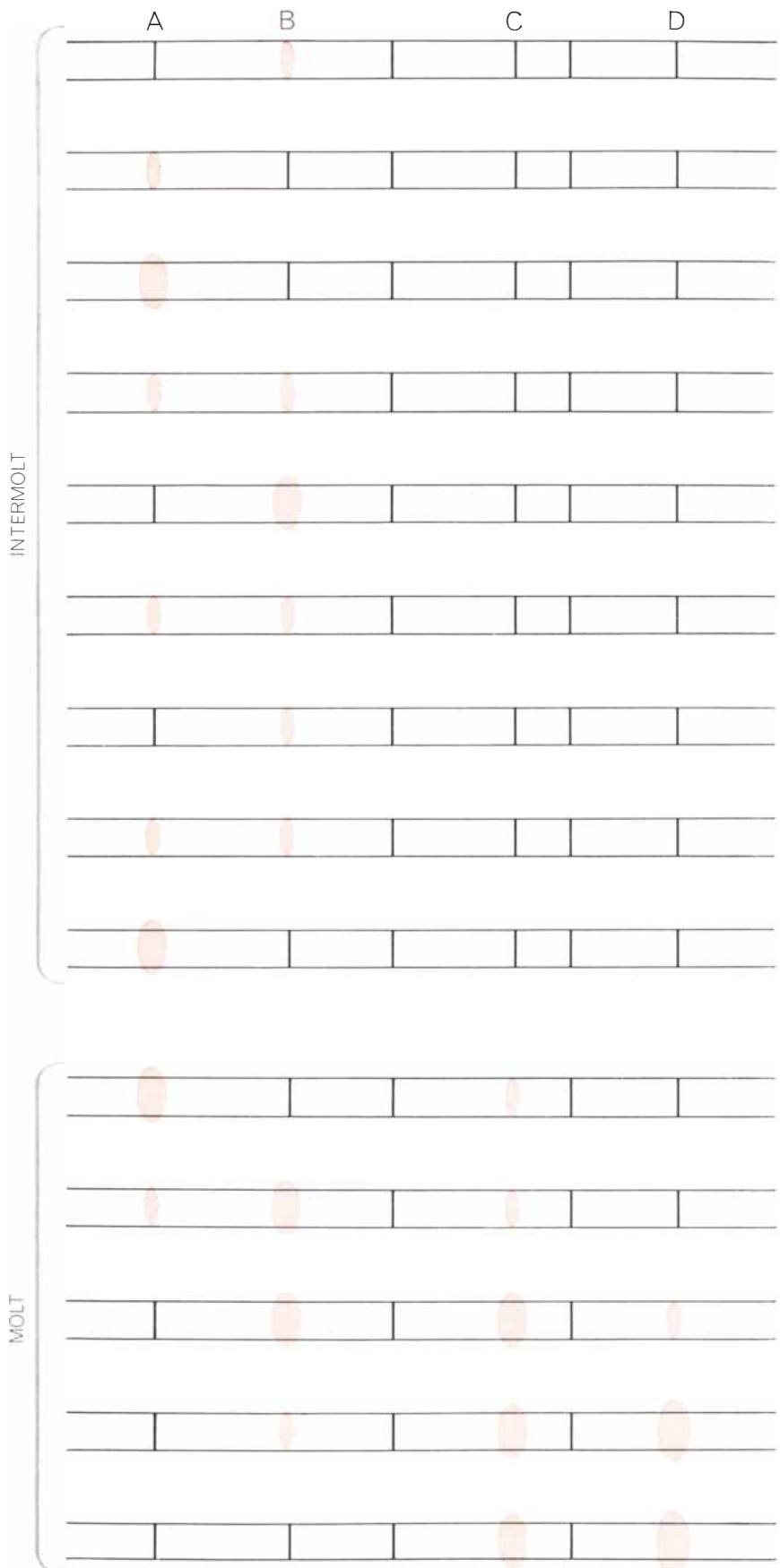
Insect metamorphosis is the transformation from the larva to the adult. In the higher insects, to which the Diptera belong, it begins with the molting of the larva into the pupa and ends with the molting of the pupa into the imago, or adult. The moltings are caused by the hormone ecdysone, which is produced by the prothorax gland located in the thorax. So far this is the only insect hormone that has been purified. Because ecdysone affects single cells directly, injection of it induces changes related to molting in all cells of the insect body.

First we examined the time relation between the changes in puffing of individual loci and the metamorphic processes in the larvae. In the great majority of the puffed loci in the salivary glands, phases in which a puff is produced alternate with phases in which a puff is absent [*see illustration on opposite page*]. Some of the phases of puff formation have no recognizable connection with the molting process. Other puffs, however, appear regularly only after the molting of the larva has begun; some at the start of molting, others later. Apparently these chromosomal sites participate in metabolic processes that take place in the cell only during the molting stage. Finally, a third group of puffs, which are found in larvae of all ages, always become particularly large during metamorphosis. This indicates that some components of the metabolic process not specific to molting are intensified at that time.

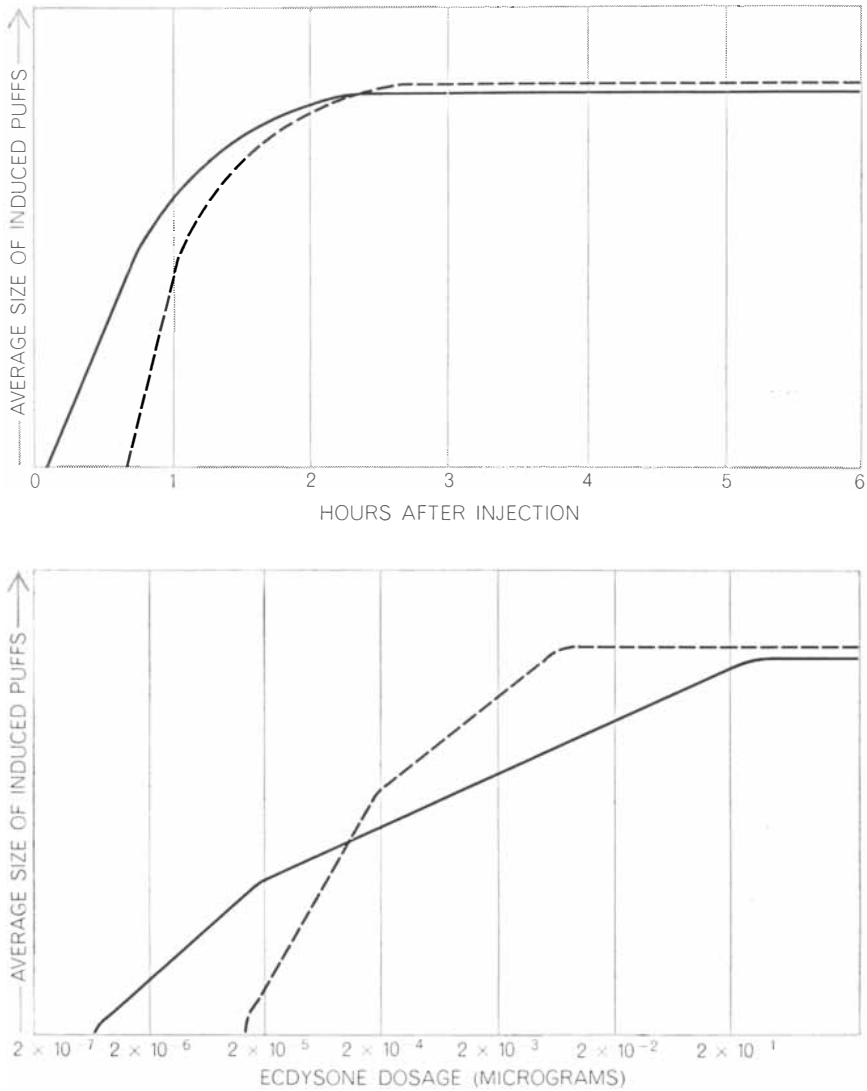
Further experiments and observations have given some indication of how ecdysone regulates the activity of single sites during molting. In the first place, the hormone not only initiates the process; it must also be present continuously in the hemolymph, or blood, of the insect if molting is to continue. The secretion of ecdysone may stop for a time in *Chironomus* larvae that had begun to molt. In such larvae all the puffs characteristic of molting are absent, which shows that the hormone controls the pattern of gene activity specific to molting. Hans-Joachim Becker of the University of Marburg confirmed this by knotting a thread around *Drosophila* larvae at the start of metamorphosis so that the prothorax gland and part of the salivary gland were in front of the knot and another part of the salivary gland was behind it, cut off from the prothorax secretions. After a time he killed the larvae and found that the puff pattern of metamorphosis was absent in the salivary-gland cells behind the knot but present in cells in front of it.

In detail ecdysone affects the puffs in a variety of ways. If we inject the hormone into *Chironomus* larvae, most of the puffs do not react until long afterward. For some the interval is a few hours, for others one or more days, and this is independent of the quantity of ecdysone. Two puffs, on the other hand, appear quite soon after the injection of ecdysone into larvae that have not begun to molt. One puff arises in 15 to 30 minutes at locus 18-C of chromosome I, the other in 30 to 60 minutes at locus 2-B of chromosome IV. These are the earliest observable gene activations produced so far by the administration of ecdysone. At both loci the higher the dosage of hormone, the longer the puffs last. The injection of more hormone slows the regression of the puffs at both loci, and if ecdysone is injected after the puffs have regressed, they swell up again. From this we conclude that the cause of puff regression is the elimination of the hormone.

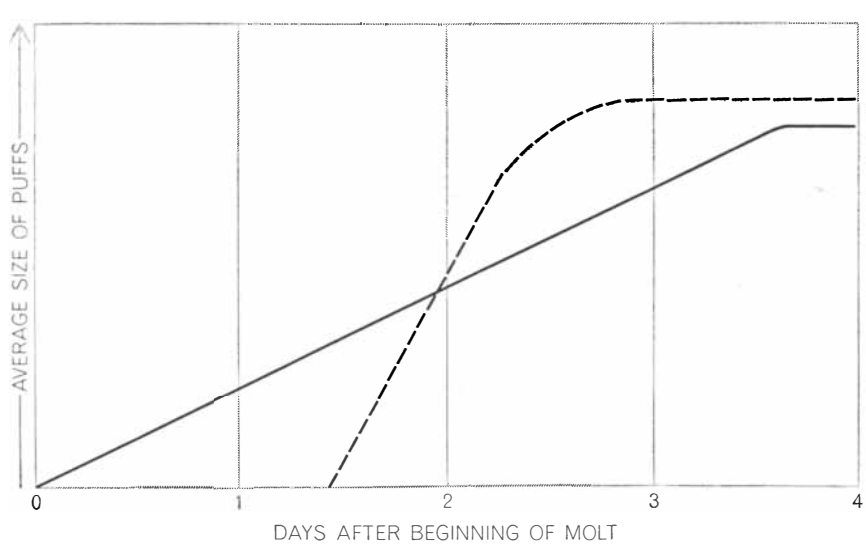
The two loci exhibit different reaction thresholds. At locus 18-C on chromosome I a minimum ecdysone concentration of about 10^{-7} microgram (one ten-trillionth of a gram) per milligram of larval weight is required to induce puffing. The locus 2-B on chromosome IV reacts only to about 10^{-6} microgram per milligram of larval weight. In these concentrations there can be no more than 100 ecdysone molecules at each of the chromosome strands in a puff, assuming that each giant chromosome



SEQUENCE OF PUFFING at four sites (*A, B, C, D*) of one chromosome in the salivary gland of *Ch. tentans* is diagramed. Some bands that do not puff are also shown. Starting from the top, the changes occur before and during the molt that begins pupation.



INDUCED PUFFING follows injection of the hormone ecdysone at locus 18-C of chromosome I in *Ch. tentans* (*solid curves*) and locus 2-B of chromosome IV (*broken curves*). Upper diagram shows time schedule of puffs, lower diagram the relation of puff size to quantity of hormone. Dosage is in micrograms per milligram of total weight of larva.



NORMAL PUFFING SEQUENCE at loci 18-C of chromosome I (*solid curve*) and 2-B of chromosome IV (*broken curve*) follows a schedule different from that of induced puffing.

consists of 10,000 to 20,000 single strands and that the hormone is distributed evenly throughout the larva. The puff at locus 2-B attains maximum size at a lower concentration than that at locus 18-C.

By applying these findings to a record of the growth and change of the two sites during normal molting, we find that the hormone level apparently increases gradually during metamorphosis. Thus the different activity patterns of these two loci can be explained as responses to the same factor: the changing hormone concentration.

In the case of locus 2-B, however, ecdysone is not the only active agent. The puff at this locus begins to regress during the second half of the prepupal phase (the last larval stage before pupation) even though the puff at locus 18-C persists to the end of the phase. In larvae that are ready to pupate, the puff at locus 2-B has usually regressed altogether. Yet when we inject hemolymph from these prepupae into young larvae, puffing is induced both at locus 18-C and locus 2-B. The former puff is quite large, which indicates that the hemolymph from the older larvae still contains ecdysone in high concentration. Evidently in these larvae, although not in their hemolymph, there is an antagonistic factor that actively represses puffing at locus 2-B in spite of the presence of ecdysone. This demonstrates that in higher organisms the activity of genes falls under the control of more than one factor.

Whereas gene activity at the loci 18-C and 2-B is subject to stringent regulation by very specific factors, other tests show that later puffs elsewhere are not the result of changes in the concentration of ecdysone. Rather they behave in an all-or-nothing manner that appears to depend on the duration and size of puffing at the two sites of earliest reaction.

We know nothing as yet about the mechanism by which the hormone regulates the genes. We are not even certain of the exact point of action of the hormone, although we would like to believe that it is the gene itself. The induction of puffing can be prevented with inhibitors of nucleic acid metabolism such as actinomycin or mitomycin, but inhibitors of protein synthesis, such as chloramphenicol and puromycin, have no apparent effect on the puffing. Thus ecdysone does not seem to act through the stimulation of protein synthesis in the cytoplasm, or to depend for its action on this synthesis. Only further investigation will solve such problems.

Kodak advertises:

an emulsion fine-grained enough to be a subject for electron micrography itself . . . decent-sized color prints in 8 minutes . . . the work of moonlighting astronomers

A work of art

This electron micrograph at 30,000× of a salamander cell in which the nuclear DNA has been tritium-labeled may look to artists like nothing but science, though scientists will recognize it as a work of art. Note the delicacy of those dense specks over the nucleus. Each marks the final resting place of a β-particle, delineated in a new KODAK Nuclear Track Emulsion, Type NTE, which has been coated over the tissue section. This new medium much reduces error in locating the organelle whence came the β-particle. The artists who did us the honor of pioneering this medium were Dr. Miriam M. Salpeter and Dr. Luis Bachmann, their *atelier* the Department of Engineering Physics of Cornell University, their sponsor the U. S. Public Health Service. In fulfilment of their role as scientists, they have prepared a detailed description of the technique. Any other scientist who then does it exactly the same fails his role as an artist.

For those details, write Eastman Kodak Company, Special Sensitized Products Division, Rochester, N. Y. 14650. May the marriage of autoradiography and electron micrography prosper!

A place for art and a place for hot water

Since just about any laboratory that ever undertakes photomicrography, metallography, or makes any other use of decent-sized color photographic prints would be embarrassed to have to explain undue delay in acquiring at least one of these devices, we had better explain what it does.

It converts a sheet of KODAK EKTACOLOR Professional Paper into an 11″ x 14″ color print in less than 8 minutes after leaving the enlarging easel. Using well under a dollar's worth of processing chemicals. And an operator who perhaps learned only the same morning of his interest in darkroom artistry. Who proceeds to deliver even and more reproducible results than can be expected from many high-rent square yards of workspace occupied by big trays. Because the drum spins at 200 ft/min. Whipping a homogeneous film of fresh solution over the print. Which is held stationary by the nylon net blanket. Pictured below rolled up as furnished. Along with the thermometer. For checking the hot water. That flows into the drum to keep it at 100°F. So that only 2½ minutes suffices for development. Followed by a tilt of the tray to dump the 4 ounces of developer. And 4-oz. chasers of each of the four other solutions. Punctuated by shots of plain water. With full roomlight permissible for 4½ of the 8 minutes. And that's about all there is to the perfect processing of an 11″ x 14″, 8″ x 10″, or pair of 4″ x 5″ color prints. When enjoying the freedom of choice in number and size of prints that the color-negative method leaves open to you.

Camera shops all across the country are asking less than $200 for this KODAK *Rapid Color Processor, Model 11. No, a digit has* not *been dropped through typographical error.*

Price subject to change without notice.

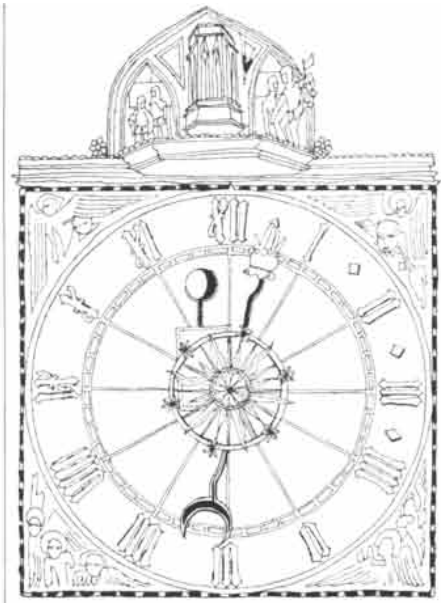
Where it's a little warmer

Policemen often moonlight. Many male schoolteachers moonlight. Work by the light of the moon to supplement one's income can be honorable, stimulating, and even necessary. When an astronomer (whose professional concerns encompass moonlight) wants to moonlight, he acquires some KODAK IRTRAN 4 Optical Material from Apparatus and Optical Division, Eastman Kodak Company, Rochester, N. Y. and fabricates it into a small converging lens. This transmits infrared from 1 to 20μ, a band wherein falls nearly all the energy emitted by sources around 300°K. Knowing that the human epidermis is normally a 310°K emitter, he builds the lens into a portable instrument for measuring temperature variation over small epidermal areas without actual contact and the error so introduced. He arranges for the lens to image a small area on a thermistor in a bridge circuit with microammeter. The lens makes the response independent of exact distance.

After permitting use of this instrument in clinical practice for several months, the moonlighting astronomer sounds like this:

> A female who had Raynaud's disease was scanned 5 days after 2 fingers had been amputated to the first joint. At the site of amputation the indicated temperature was lower than 2 cm back from the end of the wound. The surgeon wouldn't use a skin thermometer for fear of causing an infection in the open wound.
>
> A female presented herself with a small mass at the outer quadrant of the right breast; palpable with difficulty. It showed a 0.7°F rise in the area. She was hospitalized and a biopsy performed. An adenocarcinoma was found and removed.
>
> An elderly male with a deformed, ulcerated lesion of the right ear cartilage was examined. An 0.5°F increase over the involved area was noted. It was resected and a basal cell carcinoma was found.
>
> A female came in with psoriasis which gave rises of about 1°F over the involved areas. It was inflamed. It is notable that temperature elevations are not obtained over static cases of psoriasis.
>
> A 17-year-old female with a soft mass in the left breast presented herself. The reading was 0.5°F cooler than the surrounding tissue. One week later surgery showed that it was benign.
>
> A male was burned on the right leg. The leg was bandaged. On the third day an elevation in body temperature was noted, suggesting an infection. On scanning the bandage a reading at the knee showed a 2°F rise. On removal of the bandage the infection site was verified.

From astronomy to medicine and what new direction the story takes may be up to you. Best bet, if curious, is to get in touch directly with The Dudley Observatory (Chartered 1852), 140 South Lake Avenue, Albany, N. Y.

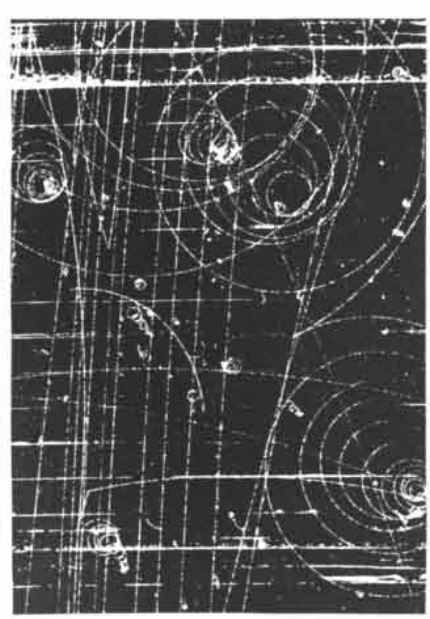


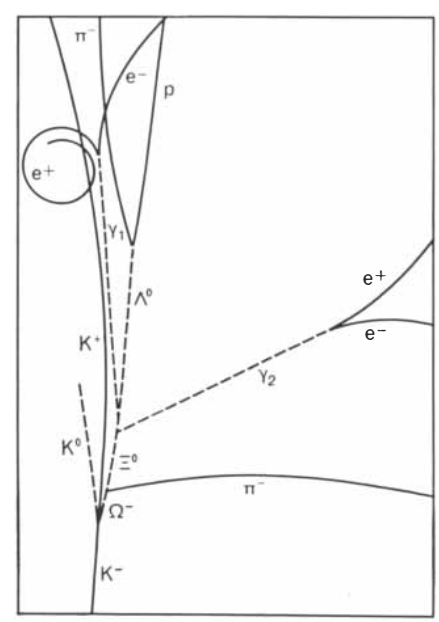
Prediction Confirmed

The recent discovery of the omega-minus particle at the Brookhaven National Laboratory fulfills perhaps the most remarkable prediction to be made in high-energy physics in more than two decades. The new particle, the symbol for which is Ω^-, was predicted to satisfy the theoretical requirements of a concept known formally as "SU(3) symmetry" and informally as the "eightfold way." The concept was developed independently in 1961 by Murray Gell-Mann of the California Institute of Technology and Yuval Ne'eman of Tel Aviv University. The eightfold way was described in detail in the February issue of SCIENTIFIC AMERICAN (see "Strongly Interacting Particles," by Geoffrey F. Chew, Murray Gell-Mann and Arthur H. Rosenfeld).

The omega-minus particle was required by the eightfold way to complete a supermultiplet, or superfamily, of 10 particles that share certain basic characteristics. Members of a supermultiplet must have the same spin angular momentum (J) and the same parity (P): two of the seven quantum numbers, or physical quantities, associated with strongly interacting particles. These are the particles, now numbering more than 80, that interact through the strong, or nuclear, force, which is responsible for the binding of particles in atomic nuclei.

Members of a supermultiplet have different values of mass, electric charge (Q), hypercharge (Y) and isotopic spin (I). The values of these various properties for the decuplet including the omega-minus particle are shown in the illustration on the opposite page. The arrows indicate how the system of symmetries postulated in the eightfold way connects particles with different values of mass, Q, Y and I. It will be noted that the three groups of multiplets making up the bottom of the pyramid—the delta (Δ) quartet, the sigma (Σ) triplet and the xi (Ξ) doublet—are separated in





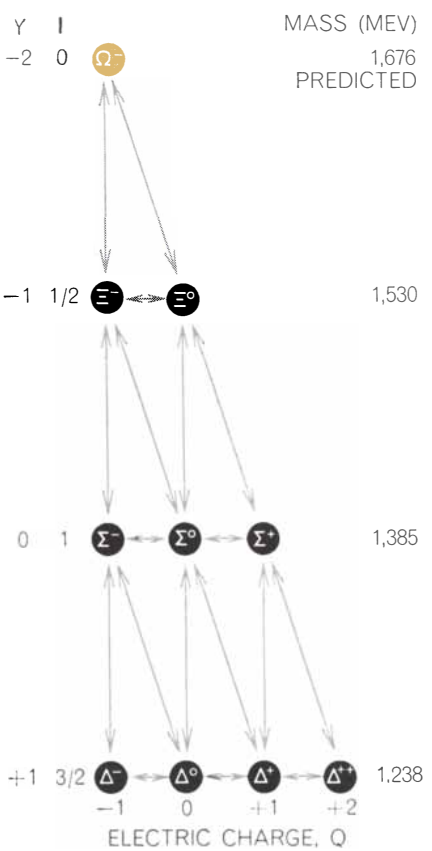
Bubble-chamber photograph of production of omega minus* (left) *and map of events

THE CITIZEN

mass by about 145 million electron volts (Mev). It was predicted by Gell-Mann and Susumu Okubo of the University of Rochester that the omega minus should be heavier than the xi doublet by approximately the same amount, leading to a predicted mass of 1,676 to 1,680 Mev.

The search for the omega minus was begun at Brookhaven last summer by a team of investigators headed by Ralph P. Shutt. Nicholas P. Samios was in direct charge of the experiment, which ultimately involved a staff of 31 other professional workers. The principal elements in the experiment were the 33-billion-electron-volt alternating-gradient synchrotron and the recently completed 80-inch liquid-hydrogen bubble chamber.

Protons from the synchrotron were used to produce a beam of negative K mesons. Every few seconds a carefully isolated beam of about 10 K mesons was allowed to enter the bubble chamber, and the interaction of the beam with



Scheme that predicted particle

the protons (hydrogen nuclei) in the chamber was photographed. After subjecting 100,000 photographs to analysis, the Brookhaven workers found two events that could be identified as the production of omega-minus particles. The first bubble-chamber photograph containing an omega minus is reproduced at the left on page 60. To its right is a diagram identifying the various particles created in the reaction.

A K^- particle enters from the bottom of the photograph and reacts with a proton to form the omega minus (Ω^-), a K^+ and an invisible K^0. The omega minus decays in about 10^{-11} second into a Ξ^0 and a π^-. The Ξ^0, which leaves no tracks, decays into a Λ^0 and a π^0 (not labeled), which also leave no tracks. The π^0 decays almost instantly into two gamma rays (γ_1 and γ_2), each of which produces an electron-positron pair. The electron (e^-) and positron (e^+) arise at a common point and curve sharply away from each other. The Λ^0 decays into a proton (p) and a π^-.

A careful analysis of the track lengths and curvatures makes it possible to estimate the momentum carried by each particle in the reaction. From these calculations the mass of the omega minus was computed to be 1,686 ± 12 Mev, a figure that straddles the predicted value.

Open Windows

Fears that radio signals generated by man would close all the radio astronomer's windows on the universe have been partly allayed by a decision of the International Telecommunications Union. Meeting in Geneva, delegates from 70 nations voted to reserve 13 channels of the radio spectrum for radio astronomy, although some would have to be shared with the communication systems of weather and navigation services and meteorological satellites. The Federal Communications Commission has also helped by reserving the ultra-high-frequency television channel 37 for radio astronomy for 10 years. The channel extends from 606 to 614 megacycles per second, an important range of frequencies for certain astronomical studies.

At the international meeting, according to a report in *Sky and Telescope*, representatives of the eastern European nations agreed to stop using for radio communication the band lying athwart the frequencies from 1,400 to 1,427 megacycles. Other countries had already done so. These frequencies correspond to the 21-centimeter radio waves emitted by un-ionized hydrogen in space.

Radio astronomers still do not find the situation completely satisfactory. The band from 1,664.4 to 1,668.4 megacycles, for example, extends across the recently discovered faint signals emitted by hydroxyl (OH) ions in space. The international body has earmarked it for astronomy, but its decisions are not binding and 26 nations are using the band for communication.

The Inter-Union Committee on Frequency Allocations for Radio Astronomy and Space Research Services, an international scientific body, had asked that 16 channels be reserved for radio astronomy. Of the three not granted in Geneva, the band between 326.4 and 328.4 megacycles is the most significant; it blankets the wavelength that would, if it could be detected, be emitted by deuterium (hydrogen 2) in space.

Ultraviolet Eye

An optical organ in the horseshoe crab, the function of which has heretofore been a mystery, has been found to be a receptor of ultraviolet radiation. The evidence for this conclusion is presented in *Proceedings of the National Academy of Sciences* by George Wald and James M. Krainin of Harvard University and the Marine Biological Laboratory in Woods Hole, Mass.

Most animals with eyes at the sides of their heads have another "eye"—or several of them—in the middle. In vertebrates this median eye exists only as a "pineal body" that in nearly all species is within the brain; it is at most a vestigial sense organ. In the horseshoe crab (*Limulus*) and many other arthropods, however, the median eye takes the form of two "ocelli," each of which has a lens and a retina. The retina has seemed too coarse-grained and the lens too rudimentary to allow for true image vision; exposing the ocellus to light was known to evoke an electrical response in the nerve fibers of the organ but no identifiable behavioral response.

Wald and Krainin worked with young horseshoe crabs in which the ocelli are about half a millimeter in diameter. Each ocellus has a retina with 50 to 80 receptor cells, and each receptor ends in a nerve fiber; the fibers fuse to form a single nerve that is connected to the brain. The investigators measured the sensitivity of the ocellus and the much larger compound eye of the horseshoe crab at various wavelengths by recording the electrical response to radiation of these wavelengths.

The sensitivity of the ocellus, they found, is concentrated in the near ultraviolet, with a major peak at a wave-

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length of 360 millimicrons. There is a secondary but much lower peak at 530 millimicrons, about the same as the major peak of the compound eye. Apparently each of the peaks is associated with a different visual pigment.

The response of the horseshoe crab's compound eye continues as long as the stimulus light remains on, but the response of the ocellus falls back almost to zero soon after it is stimulated. This suggests that the ocellus is a receptor primarily concerned with signaling a sudden increase, rather than a decrease, in ultraviolet illumination. Wald and Krainin do not know what behavioral purpose the response serves, but they point out that in the water flea *Daphnia magna* behavior patterns associated with vertical migration are governed by the ocelli and are particularly sensitive to violet and ultraviolet radiation.

Life from a Lava Bed?

Students of the origin of life have in recent years synthesized various organic compounds from substances thought to have been present in the primordial atmosphere of the earth. To make the reactions go they have used such strong sources of energy as electric discharges, ultraviolet radiation and gamma rays. Now Sidney W. Fox and Kaoru Harada of Florida State University have succeeded in synthesizing amino acids in a "postulated primitive terrestrial atmosphere" with heat alone. The temperatures they employed (about 1,000 degrees centigrade) can normally be found only in volcanic regions but are energetically weak compared with the sources used earlier. Whereas electric discharges have produced eight different amino acids, the method of Fox and Harada, as described in *Nature,* has yielded at least 13.

To test their "thermal theory of biochemical origins," Fox and Harada bubbled the gas methane, which is composed of carbon and hydrogen, through a water solution of ammonia, composed of hydrogen and nitrogen. The three elements are the sole constituents of most amino acids. Fox and Harada passed the resulting mixture of methane and gaseous ammonia into reaction tubes containing a solid, such as silica gel, quartz sand, volcanic sand or alumina, which had been heated to between 900 and 1,100 degrees C. The solids selected are common in the crust of the earth. After leaving the reaction tube the gas was absorbed in an ammonia solution and kept at 75 degrees in a sealed bottle for 35 hours. Evaporation, treatment of the residue with acid and another evaporation left various quantities of the amino acids.

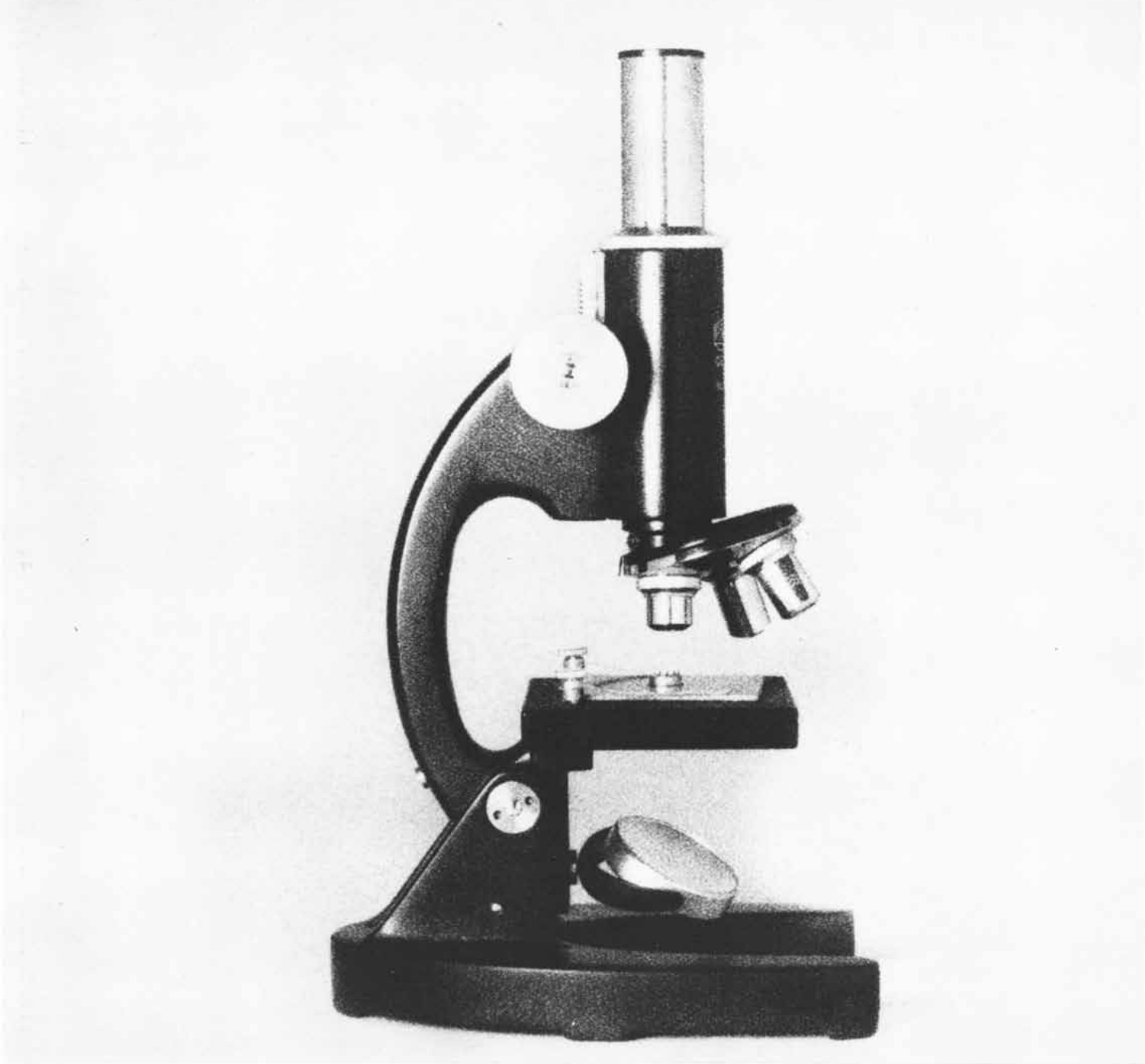
In a second paper in *Nature* Fox describes a step toward linking the amino acids into proteins. He set up a model of a hot, dry lava bed by placing a mixture of amino acids in a depression in a piece of lava. This he held at a temperature of 170 degrees in the open air of the laboratory for three to four hours. The amino acids formed a viscous amber liquid. To simulate rain or tide he washed the stone with boiling sterilized water. After the water had cooled he recovered from it large numbers of tiny spherical particles. These turned out to be made up of amino acids strung together in chains. The temperatures chosen for this experiment, Fox notes, are found within a few inches of the surface of lava flows from active Hawaiian volcanoes.

Transpacific Telephone

The first telephone cable to be laid across the Pacific Ocean is now in service. Together with a transatlantic cable laid in 1961 and a chain of microwave relay stations across Canada, it completes a 16,000-mile circuit from London to Sydney, Australia. A second cable, now being laid between Hawaii and Japan by the American Telephone and Telegraph Company, will go into service this summer.

Long-distance telephony by cable, which is not affected by the variations in the ionosphere that often interfere with radio transmission, was made possible only some 10 years ago by the development of small, highly reliable repeaters that are spaced along the cable to amplify the signal. The cable now operating runs from Vancouver to Sydney by way of Hawaii, Fiji and New Zealand, its 318 repeaters spaced 20 miles apart in shallow waters and 30 miles apart in the deep ocean.

Telephone signals are sent over the cable on two bands of frequencies: from 60 to 300 kilocycles per second in one direction and from 360 to 608 kilocycles in the other. Each of these bands accommodates five narrower bands 48 kilocycles wide, each of which can carry 16 telephone channels. The cable can thus carry 80 conversations simultaneously. Whereas earlier telephone cables were wrapped with steel wire, the new cable is covered only with polyethylene. Tensile strength is provided by a central core of wire; the result is a cable that weighs only a fifth as much as a comparable armored strand.



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THE SOLAR WIND

Comet tails and other phenomena indicate that a thin, hot gas of solar particles flows past the earth at supersonic speeds. This gas is simply the expanding corona of the sun

by E. N. Parker

A swift wind of hydrogen blows continuously through the solar system. Emanating from the sun, it speeds past the earth at 400 kilometers per second (about 900,000 miles per hour) and rushes on past the planets into interstellar space. Like a broom, it sweeps up the gases evaporated from planets and comets, fine particles of meteoritic dust, and even cosmic rays. It is responsible for the outer portions of the Van Allen radiation belts around the earth, for auroras in the earth's atmosphere and for terrestrial magnetic storms. It may even play a part in shaping the general pattern of the earth's weather.

The existence of this solar wind, which had long been suspected, has now been verified by space vehicles. They have measured its velocity and density. And studies of another kind have unraveled the mystery of its origin and given us an understanding of its effects.

The realization of the solar wind's existence came only gradually, over a period of several decades. The first explicit assertion that something besides light was coming to the earth from the sun was made in 1896 by the Norwegian physicist Olaf K. Birkeland. He suggested that the aurora borealis might be caused by electrically charged "corpuscular rays" shot from the sun and "sucked in" by the earth's magnetic field near the poles. He was led to this suggestion by the fact that the aurora looked very much like the electric discharge in the then newly invented tubes generating streams of charged particles ("cathode rays").

Birkeland's idea was taken up by the Norwegian mathematician Carl Størmer, who went on to calculate the paths that streams of charged particles from the sun should follow when they entered the earth's magnetic field. As it happened, his theoretical scheme of looped and spiral paths did look like patterns seen in the aurora, but this resemblance turned out to be a coincidence; nothing else in his theory worked. To this day there is still no complete theory explaining how the solar wind produces the aurora, although some interesting ideas are beginning to develop. The fact remains, however, that Birkeland and Størmer were on the right track and started an important new line of thinking by calling attention to the possibility of charged particles coming from the sun.

Magnetic Storms

Further evidence for the sun's emission of particles came from another phenomenon (and many years later). This had to do with the magnetic storms that are associated with the disruption of radio, telephone and telegraph communication. The storms are evidently caused by fluctuations in the earth's magnetic field. Because they usually came a couple of days after a flare on the surface of the sun, they were at first attributed to a burst of ultraviolet radiation from the flare or some similar cause. Then the British geophysicist Sydney Chapman surmised that corpuscular emissions from the sun offered a more reasonable explanation. In the 1930's he and V. C. A. Ferraro carried out a series of calculations and demonstrated that a cloud of ions ejected from the sun, traveling at 1,000 or 2,000 kilometers per second, would reach the earth in a day or two and ruffle the earth's magnetic field as it passed. Their theoretical picture of such a disturbance of the field so closely resembled the actual fluctuations during a magnetic storm that Chapman's idea was widely accepted.

The third manifestation of the solar corpuscles was noted in the late 1940's. This time they came up in connection with fluctuations in the bombardment of the earth by cosmic rays. Scott E. Forbush of the Carnegie Institution of Washington had discovered that the intensity of cosmic radiation reaching the earth was low during the height of solar activity in the sunspot cycle and often fell abruptly during a magnetic storm. In other words, the more active the sun, the smaller the number of cosmic ray particles impinging on the earth. It was at first supposed that this effect must be due to solar-caused changes in the earth's magnetic field and atmosphere that deflected the cosmic particles away from the earth. But the University of Chicago physicist John A. Simpson, who began to keep track of cosmic ray variations with a neutron monitor he had just developed, soon found that the fluctuations were much greater than had been supposed. They could not be produced merely by changes on the earth; they must reflect a rise and fall of cosmic ray intensity in solar-system space as a whole.

Apparently something in the sun's radiation tended to impede the flow of cosmic rays into the solar system, and this obstruction increased when the sun was particularly active. What might the impeding agent be? The general mechanism is to be found somewhere in the magnetohydrodynamic theory of the Swedish physicist Hannes Alfvén [see "Electricity in Space," by Hannes

"SOLAR-WIND SOCK," the tail of a comet, always points away from the sun, blown back by the high-speed stream of hydrogen in space. Comet Mrkos (*opposite page*) was photographed in August, 1957, with a five-inch camera on Palomar Mountain. Irregularities in the comet tail are probably caused by turbulence in the solar wind.

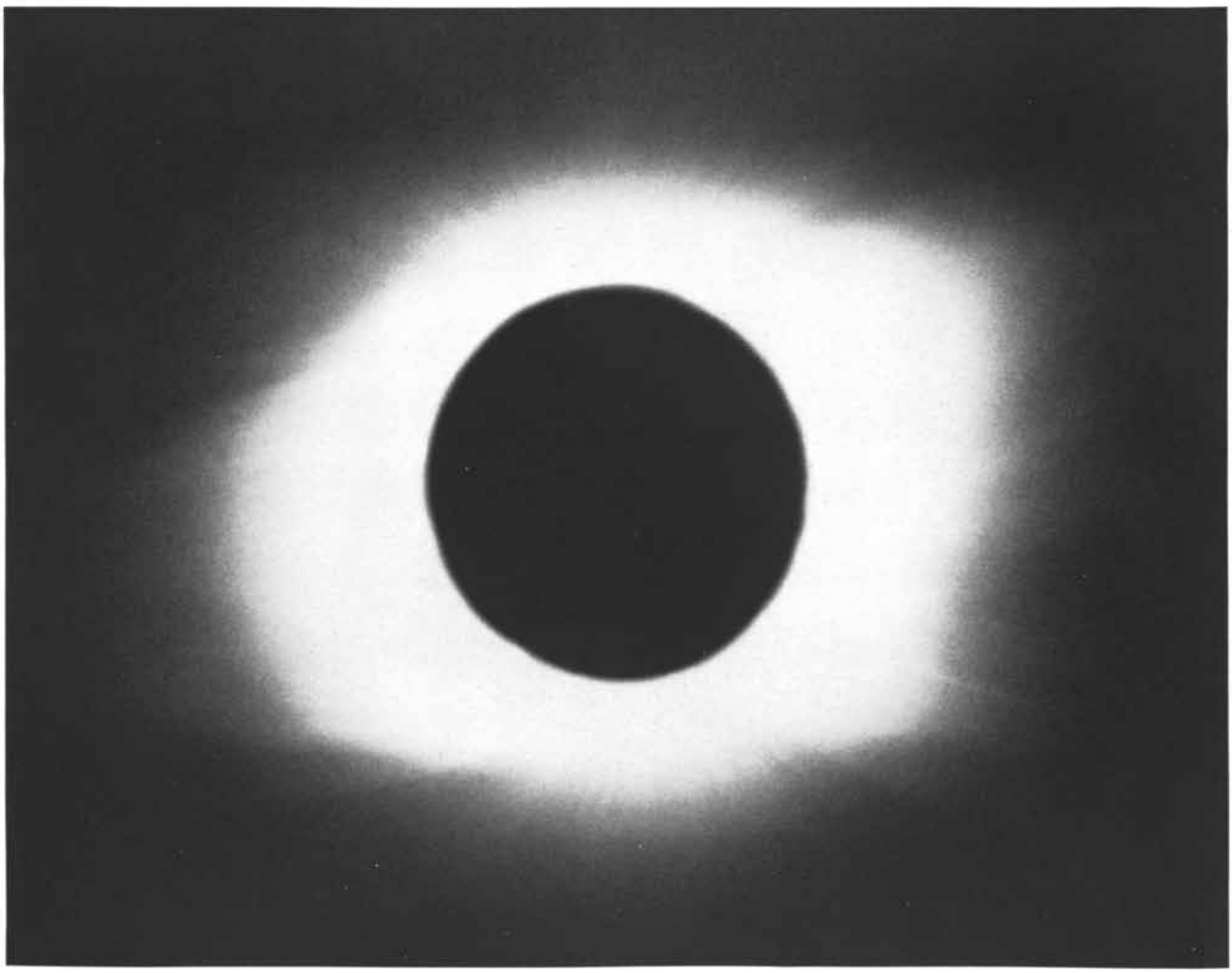
Alfvén; SCIENTIFIC AMERICAN, May, 1952]. He had pointed out that an ionized gas in motion must carry a magnetic field with it. This being so, it was suggested by Philip Morrison of Cornell University and by others that a stream of charged corpuscles from the sun, carrying a magnetic field, would tend to sweep cosmic ray particles out of the solar system, and the effect would be strongest when the solar radiation was most intense. Such a theory would explain the cosmic ray fluctuations.

At about the same time there emerged a fourth and decisive line of evidence for the corpuscular radiation from the sun. For centuries it has been known that the tails of comets always point away from the sun. No matter where a comet may be in its orbit through the solar system, its head is always toward the sun and its gaseous tail streams away. Why is this so? In modern times the almost universally accepted theory has been that it is the pressure of sunlight, pushing the extremely tenuous matter of the comet, that drives the tail in the opposite direction. But in the 1950's Ludwig F. Biermann of the University of Göttingen showed that the pressure of the sun's light was not nearly sufficient to account for the violence with which a comet's gases are blown away from the head. He suggested instead that the only solar radiation that could account for the pushing away of the comet's tail was a stream of actual particles. He pointed out that such radiation from the sun would also account for the existence of excited, light-emitting ions seen in comet tails [see "The Tails of Comets," by Ludwig F. Biermann and Rhea Lüst; SCIENTIFIC AMERICAN, October, 1958].

Biermann's discovery conveyed something else that had considerable bearing on the question of how this corpuscular radiation from the sun originated. Speculation up to that time had centered on two possibilities: that the corpuscles were sent out in bursts by solar flares (which were known to emit very energetic protons, or hydrogen nuclei) or were projected in beams from sunspots (by some unknown electromagnetic acceleration process). But Biermann's evidence now made it plain that the corpuscular radiation could not be coming merely in bursts or isolated beams. The comet tails showed that the radiation was blowing continuously in all directions outward from the sun. The comet tails were in effect interplanetary "wind socks" demonstrating the existence of a steadily blowing, space-filling radiation. The streaming of the particles might intensify when the sun became particularly active, but it was present all the time, with or without sunspots or flares.

The Corona and the Wind

So it seemed that the flow of corpuscles must stem from something that went on all the time all over the sun's



SOLAR CORONA, the source of the solar wind, was in a fairly quiet state during the eclipse of July 20, 1963. The photograph at the left was made at Talkeetna, Alaska, by an expedition from the High Altitude Observatory of Boulder, Colo. That at the

surface. The sun was continuously shooting a thin hail of projectiles in all directions out into space. By what process could it do such a thing? A suggestion of a possible answer came one afternoon in 1957 when I was visiting Chapman at the laboratories of the High Altitude Observatory in Boulder, Colo., where he was then working.

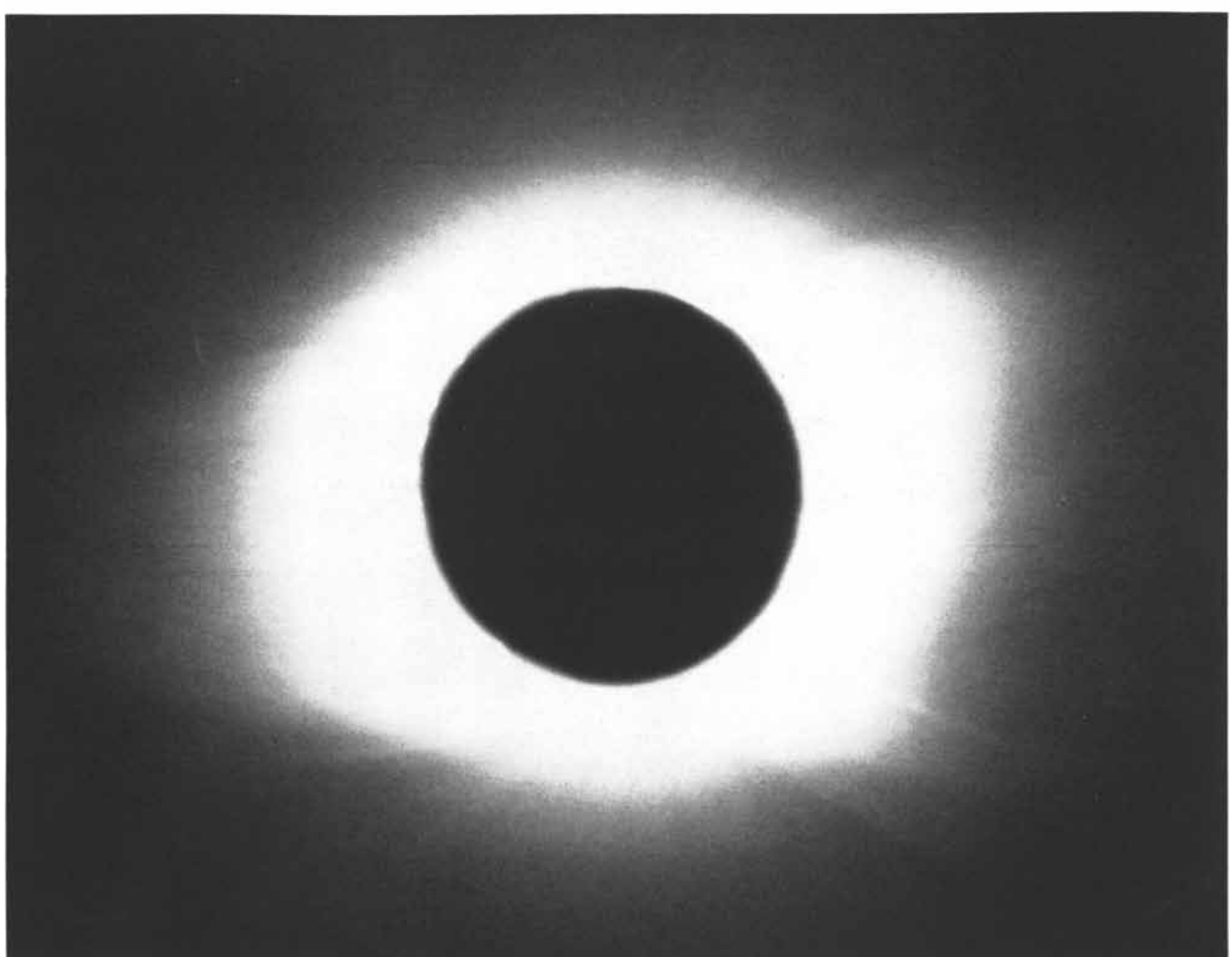
Chapman was studying the sun's corona, from the standpoint of whether or not it might be responsible for heating the outer regions of the earth's atmosphere. Soundings of the upper atmosphere had brought out the curious fact that it got hotter, rather than colder, with increasing altitude. This suggested that the upper air was heated by hot gases in outer space. Chapman suspected that these hot gases might be maintained by the solar corona.

The corona is the tenuous outer atmosphere of the sun. It is very thin indeed: even close to the sun it contains only about 100 million to a billion hydrogen atoms per cubic centimeter, a density only a hundred-billionth that of the air we breathe. The temperature of the corona, however, as measured by the velocity of its atoms, is extremely high: about a million degrees centigrade near the sun. Because of its high temperature the coronal gas is completely ionized and therefore consists of separate protons and electrons.

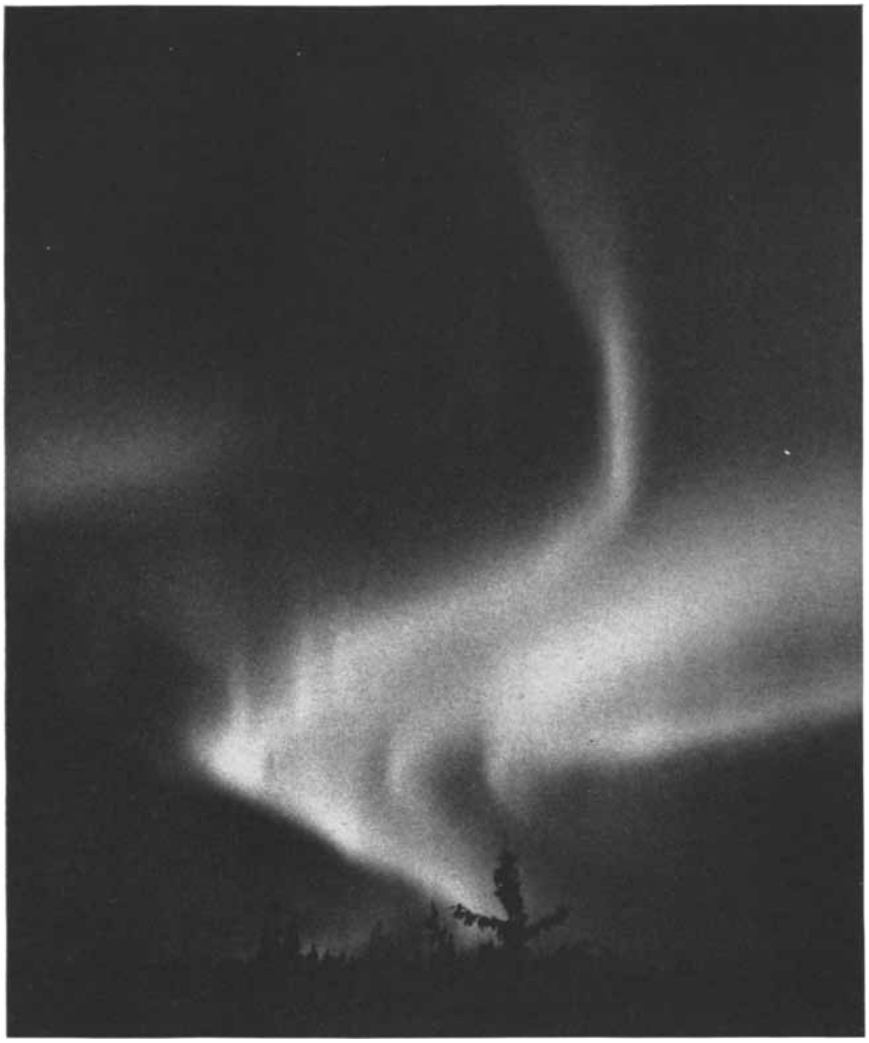
Because the corona is so tenuous it is not self-luminous, in spite of its high temperature. It is visible, however, by virtue of the fact that its atoms scatter the light from the sun's luminous photosphere, just as grains of dust in the earth's atmosphere become visible by scattering sunlight. When the brilliant light of the sun itself is dimmed by an eclipse, the white corona can be seen stretching far out from the hidden solar disk. Photographs of the corona show that it extends for millions of miles from the sun, and were it not for interfering haze and light in the sky we could probably see its fainter reaches extending many times farther than that.

Now, Chapman knew from his pioneering theoretical studies of the properties of ionized gases that a tenuous ionized gas at a million degrees must have an extraordinary ability to conduct heat. According to his calculations, the heat flow through ionized gas increases at a rate almost equal to the fourth power of the increase in temperature. At a million-degree temperature this means a great deal of heat flow. Chapman calculated that, if the corona extended as far as the earth's orbit, its temperature that far from the sun would be about 200,000 degrees, owing to its high conduction of heat. This was a very interesting figure as support for his theory that the corona might heat the earth's upper atmosphere.

But Chapman had made another discovery that impressed me even more as he told me his results in our talk that afternoon. He had gone on to make



right was made 115 minutes later by another team from Boulder on Cadillac Mountain in Maine. Careful measurements show motions of solar plumes: either lateral displacements or "virtual" motions due to appearance and disappearance of adjacent plumes.



AURORAL DISPLAY, which results from interaction of earth's atmosphere and solar wind, was photographed in Alaska by Victor P. Hessler of the University of Alaska. Lines of force of the earth's field funnel solar particles into the atmosphere at high latitudes.

some calculations to determine if the corona did reach to the earth. For these he used the equation of the barometric law, which states the obvious fact that in an atmosphere the pressure at any given height must be just sufficient to support the weight of the portion of the atmosphere above it. (If it were not, the atmosphere would collapse.) Starting from the known density of the corona near the sun (which can be ascertained approximately), he was able to estimate its density at the earth's distance. This turned out to be roughly 100 to 1,000 hydrogen atoms per cubic centimeter. In other words, the corona, although it was highly tenuous at this distance, did reach all the way from the sun to the earth and beyond!

It was a startling idea: The earth in its orbit around the sun moves within the sun's hot corona. The corona is not a limited blanket enveloping the sun the way our atmosphere envelops the earth; on the contrary, the corona fills the whole solar system.

The Corona in Motion

It took a while for Chapman's statement to sink in. When it did, I recalled Biermann's description, during a visit to Chicago, of the corpuscular radiation that blows comet tails away from the sun. Now there were apparently two bodies of solar vapor to think about: the steady corona and the stream of particles flowing out from the sun at high speed. This, however, was impossible. In a magnetic field one stream of charged particles cannot pass freely through another, and it was known that solar-system space was filled with magnetic fields. Therefore the corona and the solar stream could not be separate entities. They must be one and the same. The corona, behaving like a static atmosphere near the sun, must become a high-velocity stream farther out in space. How could this come about?

I examined the mathematics of the barometric law in more detail and saw that, in the absence of a large inward pressure from outside the solar system, the high-temperature corona must flow away from the sun. To find the nature of this flow I then applied the hydrodynamic equations for the flow of a gas. These nonlinear equations are so complex that it was out of the question at the time to find a general solution covering all possible assumptions; I settled for a simple case that approximately represented what Chapman had calculated, namely, that the temperature of the corona remains high for a distance of several million kilometers from the sun and then drops to a lower figure. This made the mathematics relatively straightforward.

The mathematical solution of the equations produced a result that must be considered surprising in view of the traditional idea that the corona is a static atmosphere. It showed that with increasing distance from the sun the corona tends to expand. At first the expansion is slow, but as the distance increases, the pressure within the corona gradually overcomes the weight of the overlying gas and rapid expansion takes over. At 10 million kilometers (some six million miles) from the sun the corona is expanding at a speed of several hundred kilometers per second—faster than the speed of sound. At that point it must be considered a supersonic wind rather than the sun's atmosphere. It continues to accelerate and reaches velocities several times the speed of sound as it moves out of the sun's gravitational field [*see top illustration on page 74*].

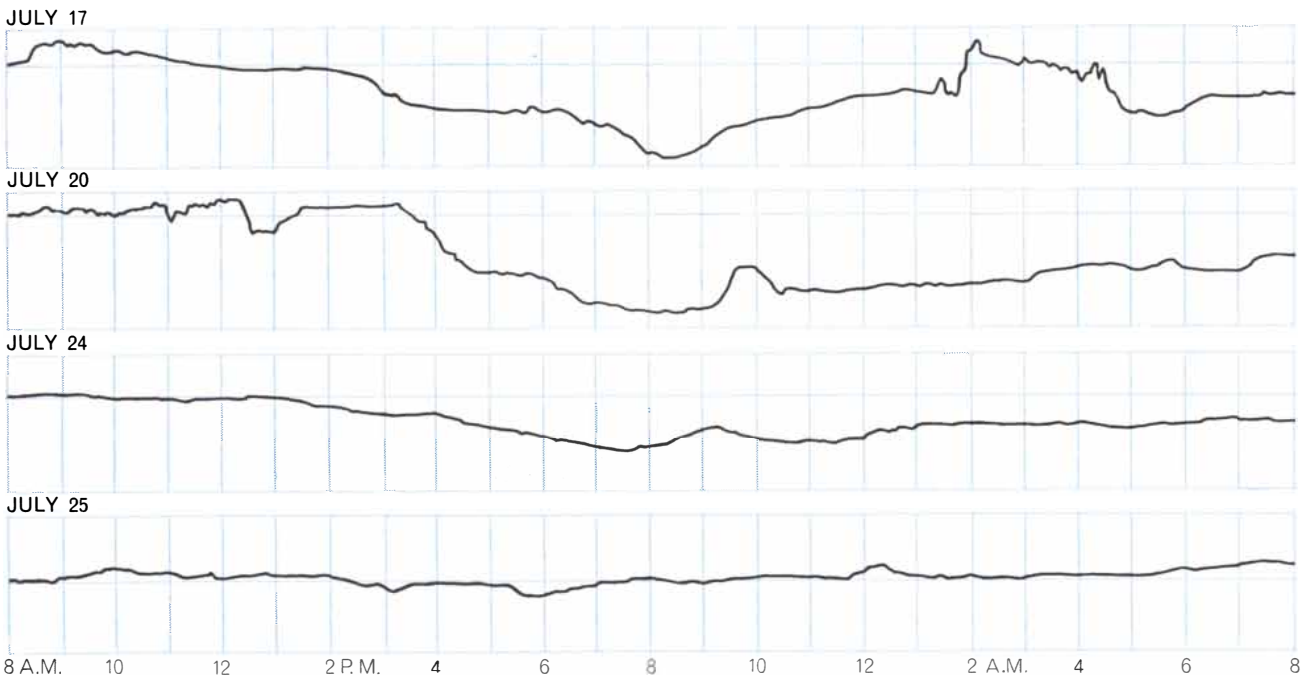
The application of the equations showed that away from the sun the erstwhile corona *must* expand rapidly and become a high-velocity stream. I have called it the "solar wind" because this seems to me now a more accurate description of the phenomenon than the older pictures of a static "atmosphere" or a bullet-like "corpuscular radiation." Biermann's comet tails are truly "solar-wind socks," signaling the direction and strength of the corona's expansion.

The Heat of the Wind

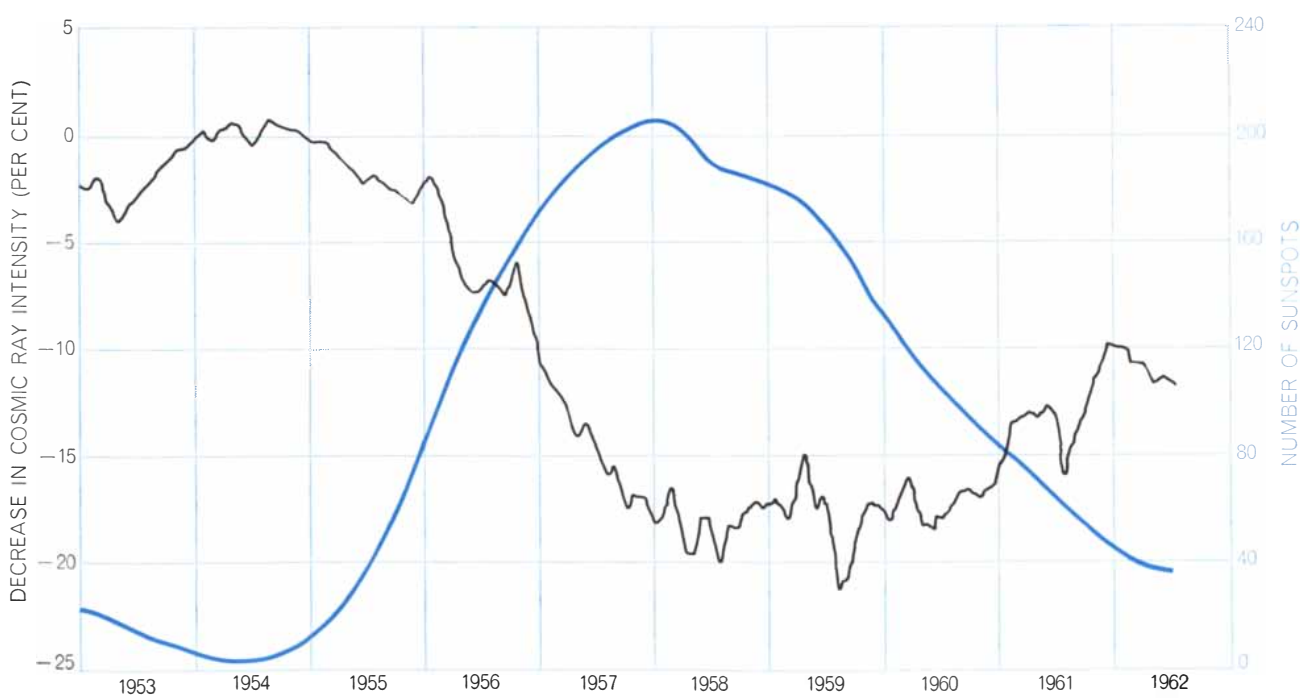
The corona's expansion arises from the fact that its temperature at the sun is of the order of a million degrees. What makes it so hot? We know that the temperature at the sun's photosphere is only about 6,000 degrees, and one would suppose that the nonincan-

descent corona outside it should be cooler. But about 15 years ago Martin Schwarzschild of Princeton University and Biermann independently presented a now accepted explanation of the paradox of the corona's high temperature. The corona is so tenuous that it takes very little heat to raise its temperature. Schwarzschild and Biermann suggested that the churning motions of the gas at the surface of the sun generate low-frequency waves that provide enough energy to heat the corona to a million degrees. The action is somewhat akin to that of the boy scout who, although his body temperature is only 37 degrees C., produces enough heat to start a fire by rubbing two sticks of wood together until they reach a temperature of several hundred degrees.

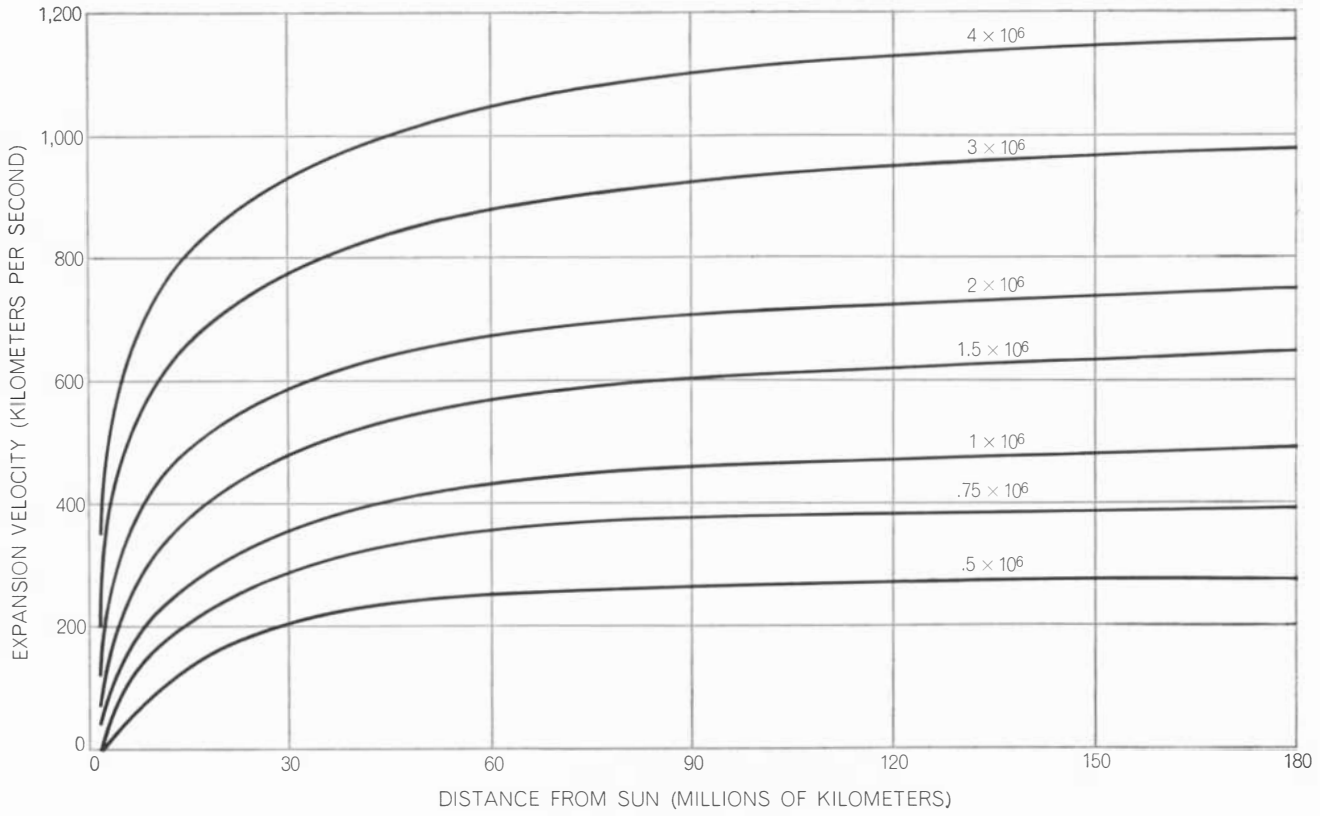
Our theoretical calculations cannot give us really accurate numbers for the speed and density of the solar wind, because this would require precise knowledge of the temperature and density of the corona near the sun—for which we have only rough estimates. But if we



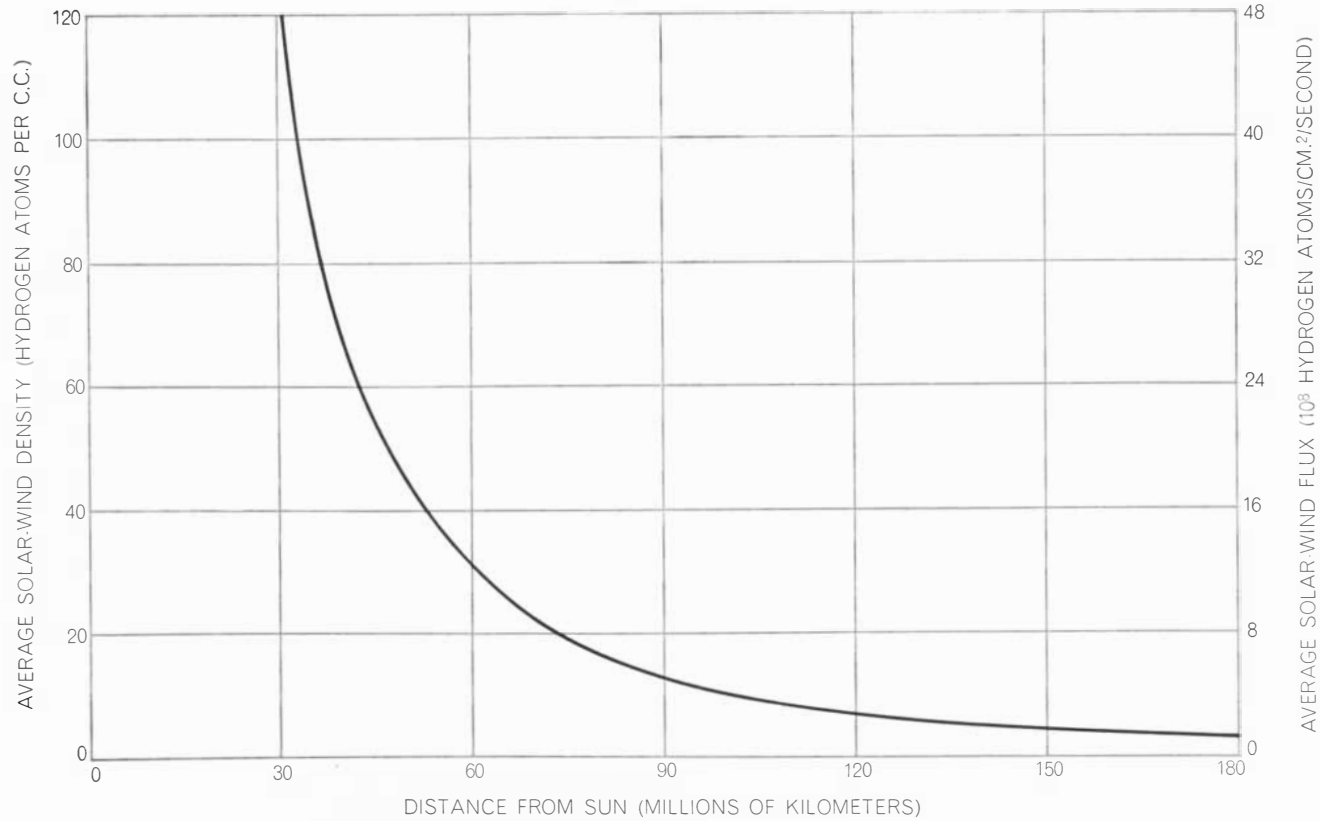
EARTH'S MAGNETIC FIELD fluctuates in response to changes in the solar wind as it blows past. These records of variations in strength of the horizontal component of the earth's field cover four full days during July, 1961. They were made in Honolulu.



COSMIC RAY BOMBARDMENT of earth decreases as solar activity and wind increase during the 11-year "sunspot cycle." Black curve shows changes in cosmic ray intensity compared with maximum in 1954. Colored curve is a plot of solar activity as indicated by the number of sunspots. Spots are another manifestation of processes on the sun that cause fluctuations in solar wind.



RATE OF EXPANSION of the solar wind into space depends in part on temperature of the corona. Temperatures are given on each curve in degrees absolute, ranging from 500,000 (*bottom*) to four million degrees. Orbit of earth is at 150 million kilometers.



DENSITY AND FLUX of solar wind as function of distance from the sun are plotted from calculations. Scales are at left and right. The flux of the wind is defined as the number of hydrogen atoms passing through an area one centimeter square in one second.

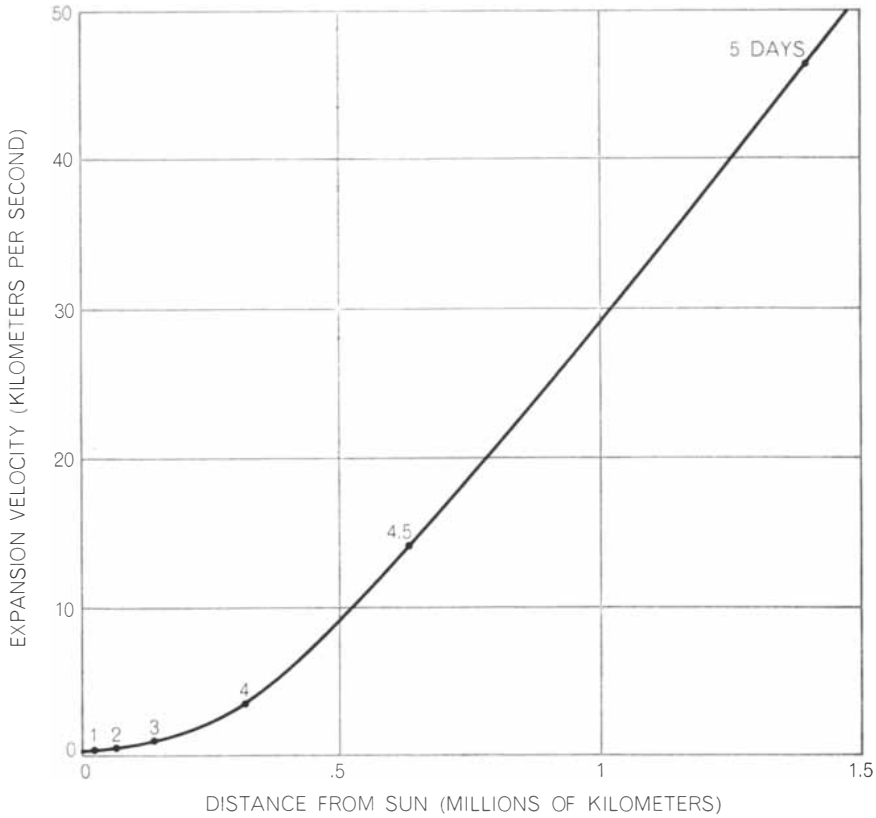
assume that the temperature at the base of the corona is a million degrees, we can draw the following approximate picture of the rise and progress of the solar wind. At the bottom of the corona the gas is almost stationary (in cosmic terms): it moves away from the sun's surface at the rate of only a few hundred meters per second. As it moves on it is replaced by more gas rising from below the photosphere. The coronal gas streaming slowly away is accelerated very gradually: it takes about five days and about a million kilometers of travel to get really under way. Thereafter it speeds up to hundreds of kilometers per second, and in four more days it has spanned the 93 million miles to the earth. The gas we see at the bottom of the corona on a Sunday will be passing us about Tuesday of the following week. Two weeks after this gas zooms by us it will pass Jupiter.

The Magnetism of the Wind

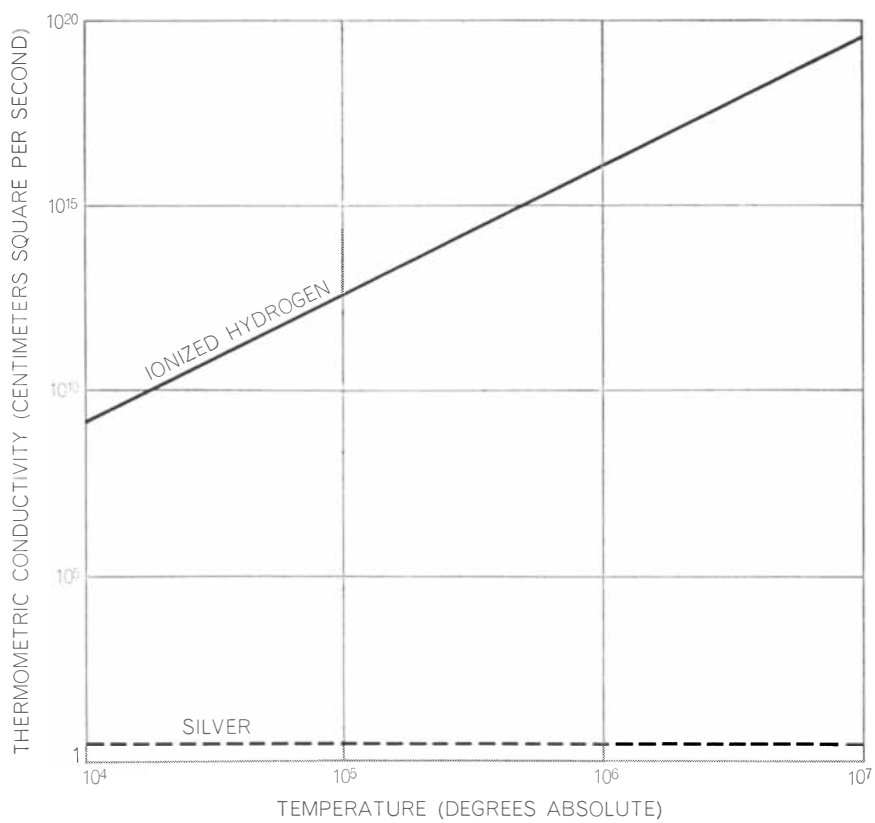
The solar wind carries a magnetic field along with it because the gas is ionized. (It remains ionized all the way out through the solar system, even though its temperature may drop to a low level; the gas is so tenuous that the separated protons and electrons have only a small probability of combining.) What is the nature of this magnetic field? Presumably its source is the general magnetic field of the sun. The corona cannot carry away the sun's concentrated local fields associated with sunspots and active regions, because these are strong enough to prevent the portions of the corona in their vicinity from streaming away at all. The sun's general field amounts to one or two gauss. (The earth's is about half a gauss.)

If the sun did not rotate (as it does once every 25 days), the solar wind would draw its general magnetic field straight out into space, so that the lines of force would stretch radially from the sun and a compass in solar-system space would always point straight toward or away from the sun. The sun's rotation, however, imposes on this radial field a circular field, with the result that the field carried by the solar wind takes a spiral form [*see illustrations on page 76*].

The strength of a radial magnetic field, like that of gravity and light, weakens at a rate proportional to the square of the increase in distance from the source. It can be calculated, therefore, that at our distance from the sun



EXPANSION VELOCITY of solar corona near the sun increases rapidly after a relatively slow start. This is because the particles from the sun meet no resistance in space.



ABILITY TO CARRY HEAT of the solar wind is indicated by the thermometric conductivity of ionized hydrogen at a pressure typical of lower corona. Broken horizontal line is approximate value for solid silver, which could not exist at such temperatures.

the magnetic field carried by the solar wind should be down to about three or four hundred-thousandths of a gauss.

Evidence from Spacecraft

What have space probes shown about the solar wind? Many of the vehicles have carried equipment for recording charged particles encountered in space. In the first place, it can be said that they have unmistakably confirmed the existence of the wind. It was detected and measured by the Soviet vehicles *Lunik I* and *Lunik II* and by several U.S. vehicles, including the Venus craft *Mariner II* and the satellite *Explorer X*. They have shown that the wind blows continuously throughout the space they have traversed and that near the earth it is traveling at the expected velocity of about 400 kilometers per second. It blows straight out from the sun, sometimes steadily and sometimes in gusts. It tends to be turbulent and to move faster when the sun is active. The density of the wind has been hard to pin down. *Lunik I* and *Lunik II* indicated a flow rate of perhaps 100 million protons per square centimeter per second. *Explorer X* and *Mariner II* found that the wind's mean density near the earth lies in the range of one to 10 protons per cubic centimeter most of the time. This is in accord with the model of the corona that assumes that its temperature is close to a million degrees throughout the gas for a considerable distance from the sun.

In addition, the space vehicles' measurements of the magnetic field in interplanetary space bear out the theoretical picture of the solar wind. *Mariner II* and *Pioneer V* measured the field as being a few hundred-thousandths of a gauss, and *Mariner II* indicated that on the average the field had the expected spiral pattern. There were kinks and wiggles in the observed pattern, but this would merely confirm that the solar wind is sometimes gusty.

Fortified with all these confirmations of the nature of the solar wind and with some definite measurements, we can proceed to explore several interesting questions. For example, there is the matter of how much energy and mass the solar wind carries off into space. It can be calculated that it removes hydrogen from the sun at the rate of about a million tons per second. This is not a significant drain on the sun; in the estimated 15-billion-year lifetime of the sun it would amount to only a little more than a hundredth of 1 per cent of the

solar mass. Similarly, the energy consumed in expanding the corona to the solar-wind velocity is only about a millionth of the total energy output of the sun. The wind's energy per unit of volume is so slight that an object in space is not warmed significantly by it.

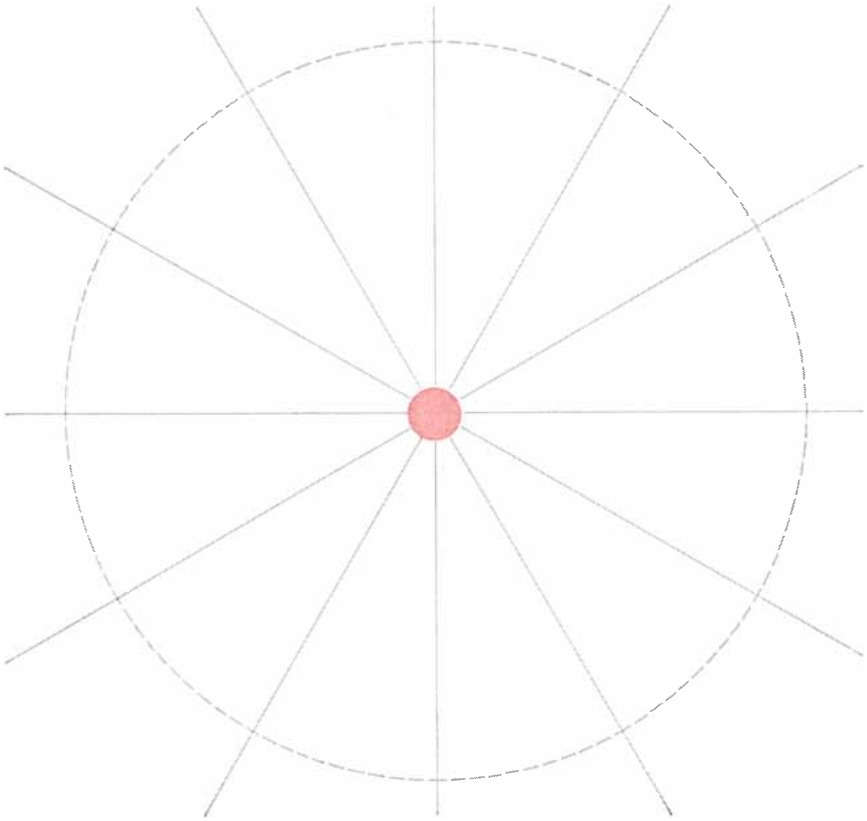
How Far Does the Wind Blow?

There is also the question of how far the solar wind goes into space. This is considerably more interesting than the drain on the sun because it offers the possibility of using the solar wind as a probe into interstellar space.

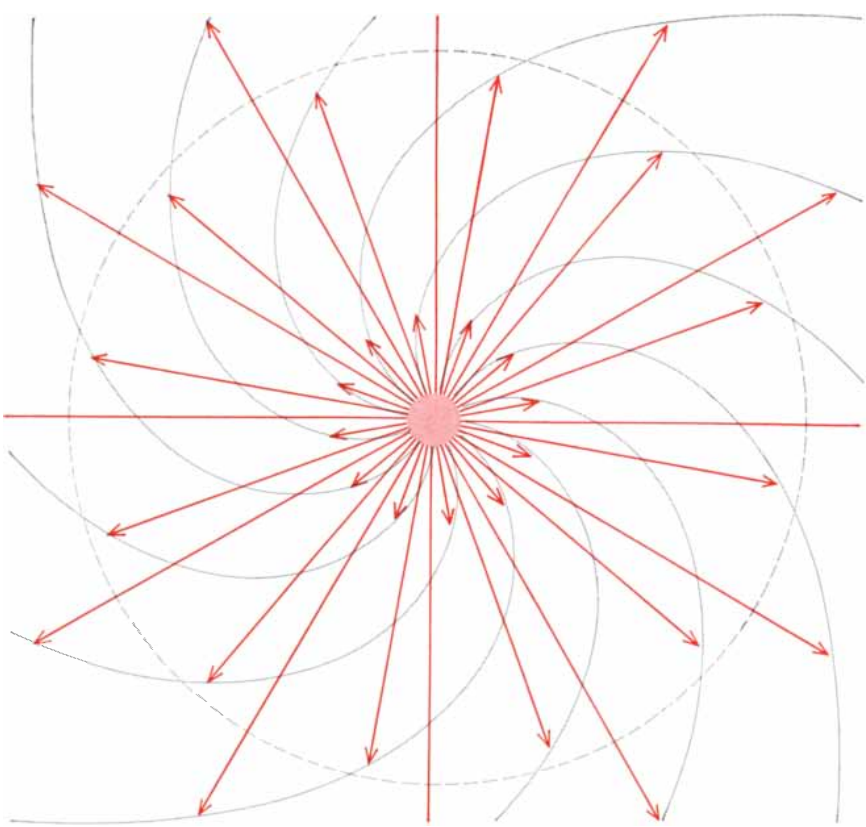
The density of the wind must drop off in proportion to the square of the increase in distance from the sun. Eventually the wind must become so tenuous that it is stopped by the other thinly dispersed gases and weak magnetic fields in interstellar space. The general magnetic field of space in our galaxy is estimated to be no more than two hundred-thousandths of a gauss. If we take this maximum figure as the strength of resistance to the solar wind and use as our index of the wind's density the smallest value that has been measured near the earth (one atom per cubic centimeter), we can calculate that the solar wind ends at about 12 astronomical units (12 times the sun-earth distance) from the sun—that is, a little beyond Saturn. At the other extreme, if we take the smallest estimate of the resisting magnetic field (one two-hundred-thousandth of a gauss) and the highest measurement of the wind's density near the earth (10 atoms per cubic centimeter), then the wind goes out to 160 astronomical units —four times the distance of the farthest planet, Pluto. These, then, seem to be the lower and upper limits: the solar wind apparently extends to at least 12 but not more than 160 astronomical units from the sun.

Two possibilities are at hand for exploring the outer limits of the wind. One is based on the fact that the hydrogen in interstellar space has been observed to emit faint ultraviolet radiation when it is excited. A recent analysis of such emission by Thomas N. L. Patterson, Francis S. Johnson and William B. Hanson of the Graduate Research Center of the Southwest in Dallas, Texas, suggests that the solar wind ends at perhaps 20 astronomical units from the sun.

The second possibility stems from the fact that the solar wind's magnetic field tends to sweep cosmic rays out of the solar system. During the years of high



MAGNETIC LINES OF FORCE associated with the solar wind would appear as shown above if the sun did not rotate. The lines are in the equatorial plane of the sun. The broken circle marks the orbit of the earth, which is one astronomical unit from the sun.



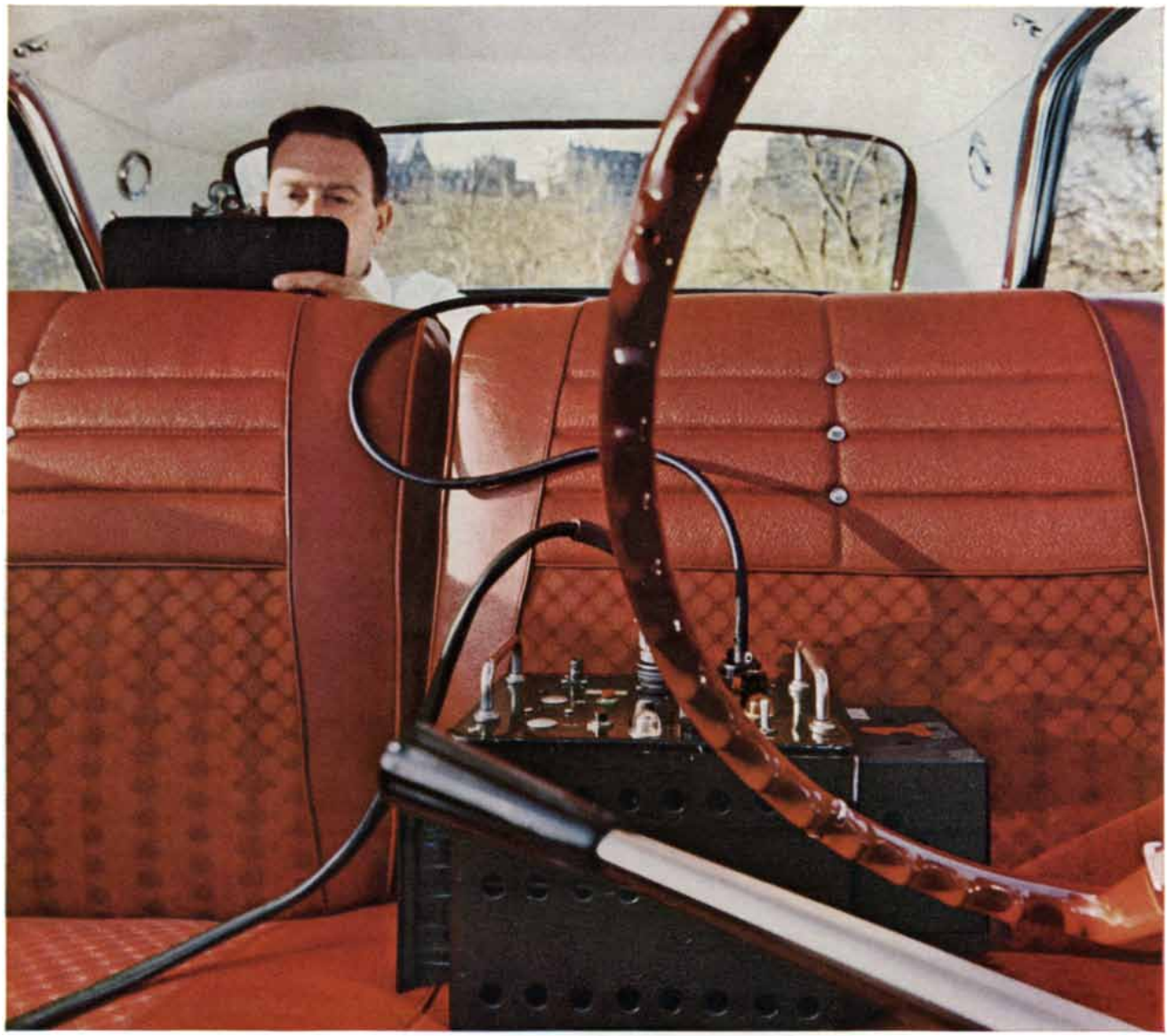
ACTUAL LINES OF FORCE are spirals due to solar rotation. They show how a compass needle would line up at any particular spot. The arrows are paths of solar-wind particles. Here the wind is assumed to be traveling through space at a steady 300 kilometers per second.

solar activity the intensity of cosmic rays coming to the earth is cut at least in half. We have calculated that a reduction of this size means that the solar wind extends well beyond Jupiter (five astronomical units from the sun). Simpson recently presented direct evidence that it probably goes out to at least 40 or 50 astronomical units. Analyzing the decline and recovery of cosmic ray intensity during the 11-year sunspot cycle, he found that the increase of the intensity of the higher-energy cosmic ray particles lags at least six months behind the drop in solar activity. The time lag apparently is a measure of the distance to the farthest extent of the solar wind. Just as it takes a certain time for a given ripple started in the middle of a pond to reach the edge of the pond, so will it take a certain time for an increase or decrease in the strength of the solar wind to be communicated to the outer boundaries of the wind. Therefore there is a delay between a drop in the sun's activity, with the consequent weakening of the solar wind, and the arrival of the weakened wind at the limit of the space in which it acts as a barrier to the entry of cosmic rays into the solar system. Since Simpson finds the delay to be at least six months, and the wind travels at the rate of one astronomical unit in four days, simple computation shows that the distance to the borders of the solar wind is at least 40 to 50 astronomical units.

There is a great deal more to the observations than this one distance number. All in all, the fluctuations in cosmic ray intensity provide us with a natural probe for exploring the fields and other conditions in space out to the borders of the solar system and beyond, because the fluctuations bear the mark of the distant fields.

Do other stars have winds like the sun's? Very likely. The main requirement is that the star have a hot corona. Our sun's corona is generated by churning and convection of the gas beneath its photosphere. According to the theoretical picture of the interior of stars, subsurface convection is likely to occur in any ordinary hydrogen star with a surface temperature of less than 6,400 degrees. Most of the stars in our galaxy fall into this class, therefore stellar winds must be rather common.

The light from distant stars cannot tell us whether they have a corona or not. One really has to live in the midst of the wind to detect it. So most of our knowledge of stellar winds in general must come from studying the wind of the nearby star, the sun.



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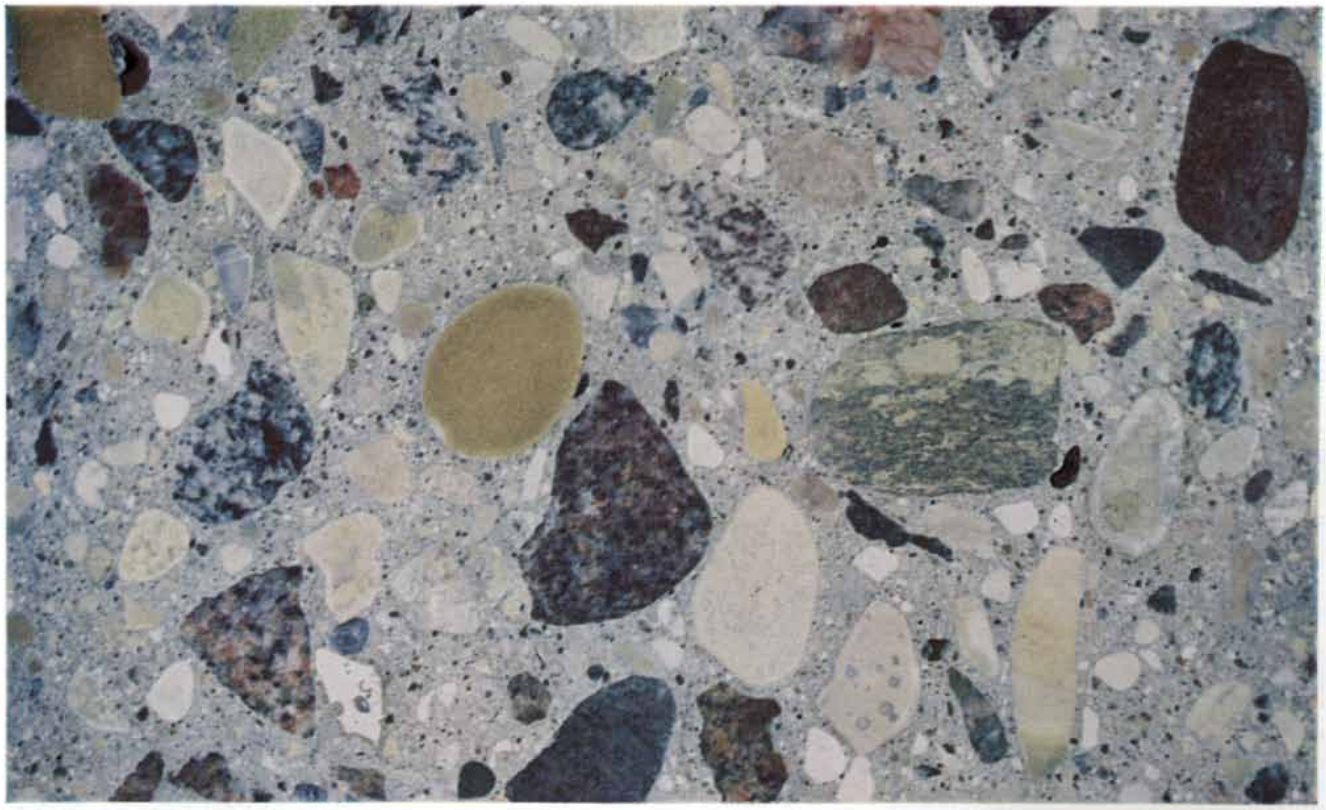
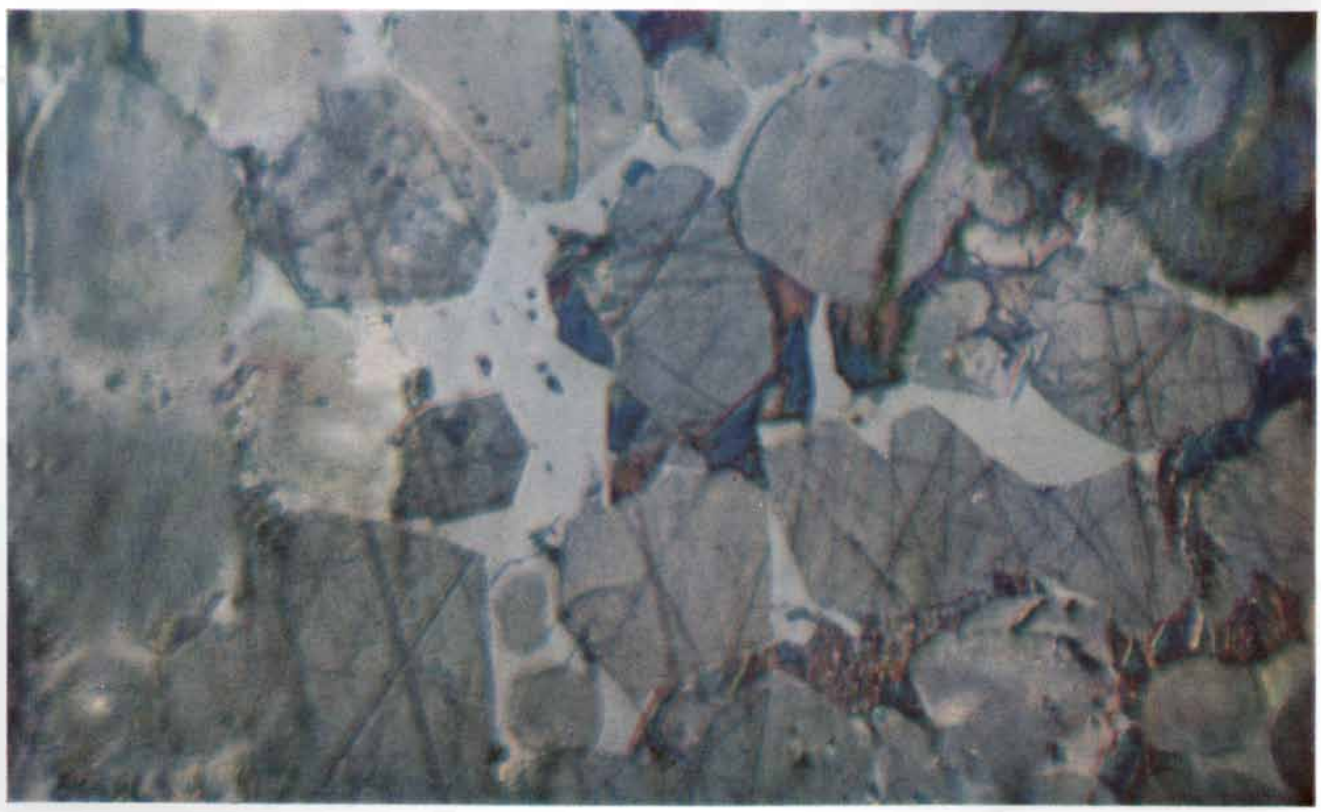


SECTION OF CONCRETE is shown approximately actual size. Pieces of coarse aggregate, consisting normally of crushed stone or gravel, and the grains of sand constituting the fine aggregate are bound into a solid by a hardened paste of portland cement. For the cementing action to be effective the paste must coat every particle of aggregate and fill all spaces between particles.



MAJOR COMPOUNDS of portland cement are identifiable in this photomicrograph of a section of clinker enlarged 1,800 diameters. Major compounds are: tricalcium silicate (grains with striations), dicalcium silicate (grains without striations), tricalcium aluminate (grains appearing blue or pink) and tetracalcium aluminoferrite (the glassy material appearing as clear areas between grains).

THE CHEMISTRY OF CONCRETE

The chemical reactions that occur when water is added to portland cement in the mixing of concrete continue for months. Recent studies have elucidated the process

by Stephen Brunauer and L. E. Copeland

The most widely used construction material is concrete, commonly made by mixing portland cement with sand, crushed rock and water. Last year in the U.S. 63 million tons of portland cement were converted into 500 million tons of concrete, five times the consumption by weight of steel. In many countries the ratio of concrete consumption to steel consumption exceeds 10 to one. The total world consumption of concrete last year is estimated at three billion tons, or one ton for every living human being. Man consumes no other material except water in such tremendous quantities.

For all its familiarity and antiquity, concrete has presented the chemist and the engineer with many puzzles. The setting and hardening of concrete involve a number of complex and simultaneous chemical reactions and the process continues for a remarkably long time. It has been particularly difficult to correlate the observable physical properties of hardened cement paste with the principal engineering properties desired in concrete: strength and dimensional stability. Major advances in correlating these two sets of properties have been made only in the past two decades.

The remote ancestor of modern concrete is mortar made from lime (calcium oxide). The remains of primitive kilns indicate that lime was made from limestone (calcium carbonate) as far back as 5,000 years ago. The Egyptians used lime plaster extensively in building pyramids; samples of this plaster more than 4,500 years old are still in good condition. The first cement, a hydraulic lime that would set under water, was invented by the Romans. It consisted of a mixture of lime paste and volcanic ash.

A great many types of cement were developed over the succeeding centuries, but the next major advance was not made until 1824. That year an English bricklayer, Joseph Aspdin, patented a new cementing material he had produced by burning limestone and clay together in his kitchen stove. He named his product Portland cement because its color resembled that of a stone quarried on the Isle of Portland, a peninsula on the English coast. Because of its strength and stability portland cement concrete eventually replaced the older types of concrete.

Although present-day portland cements are a vast improvement on Aspdin's product, they are still made from the same basic ingredients: a lime-containing material (such as limestone, shell or chalk) and a claylike material (such as shale, slate or clay itself). Before being fed into a kiln the raw materials are carefully proportioned to supply the desired amount of lime, silica, aluminum oxide and iron oxide; then they are ground to facilitate burning. In the kiln, at temperatures around 2,700 degrees Fahrenheit, the raw materials react chemically to form hard, walnut-sized pieces of a new material referred to as clinker. The clinker is discharged from the kiln and cooled; a few per cent of gypsum is added to control the rate of setting and the mixture is ground to a fine powder. This powder is portland cement.

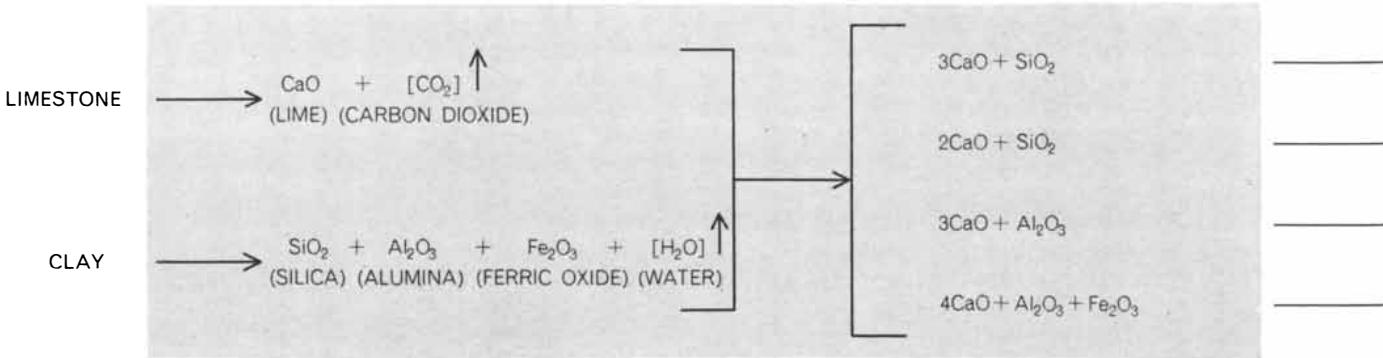
When portland cement is mixed with about half its own weight of water, the result is a plastic, mudlike mixture called cement paste. In the course of a few hours the paste sets. "Initial set" is said to occur when a weighted needle dropped on the paste does not penetrate completely. "Final set" is reached when the needle does not penetrate the paste at all.

The setting of cement paste is neither the beginning nor the end of the hardening process. Portland cement starts to react with water immediately on contact, and the presence of the reaction products manifests itself in an immediate increase in the viscosity of the paste. As the hydration process continues the compounds that collectively make up cement disappear and are replaced by their hydration products. After the final set the hardening process continues for months and to some extent even for years. It is a common misconception that drying is the cause of the hardening process. Just the opposite is true: without water there is no reaction and no hardening.

Concrete is the artificial rock created when portland cement paste is mixed with fine aggregate (sand) and coarse aggregate (gravel or crushed stone). The cement paste must completely coat every particle of aggregate and it must also completely fill all spaces between the aggregate particles [*see top illustration on opposite page*].

The chemistry of concrete is essentially the chemistry of the reaction between portland cement and water. (Ordinarily the aggregates are inert. If they should happen to react unfavorably with the cement, ways can usually be found to control such reactions.) In any chemical reaction the main features of interest are the changes in matter, the changes in energy and the speed of the reaction.

These three aspects of a reaction have great practical importance for the user of portland cement. Knowledge of the substances formed when portland cement reacts is important because the cement itself is not a cementing material;



REACTION IN KILN is the first step toward the production of portland cement. Limestone and clay are burned in a kiln in a proportion dependent on the amount of calcium oxide in the limestone and the amount of silicon dioxide, aluminum dioxide and

its hydration products have the cementing action. Knowledge of the amount of heat released when concrete sets is important because the heat is sometimes a help and sometimes a hindrance. The heat is useful in winter for keeping the water in the cement paste from freezing. The heat is harmful in massive structures such as dams because it may produce stresses. To help solve this problem a low-heat portland cement, known as Type IV, was developed.

Knowledge of reaction speed is important because it determines the time of setting and hardening. The initial reaction must be slow enough to enable the concrete to be poured into place. On the other hand, after the concrete has been placed rapid hardening is often desirable. In manufacturing concrete blocks, for instance, the number of molds needed to sustain a given output can be reduced if blocks can be removed from their molds quickly. For such purposes a special portland cement that attains high strength in a shorter time was developed. It is called Type III, or "high early strength" cement.

The chemist represents changes in matter by means of a chemical equation. The amounts and compositions of the reactants appear on the left side of the equation, and the amounts and compositions of the substances produced appear on the right. In the reaction under consideration portland cement and water should be on the left. But how does one represent portland cement?

Actually there is no way to represent portland cement by a chemical formula. It is a mixture of many compounds. Four of these make up more than 90 per cent of cement by weight. They are tricalcium silicate ($3CaO{\cdot}SiO_2$), dicalcium silicate ($2CaO{\cdot}SiO_2$), tricalcium aluminate ($3CaO{\cdot}Al_2O_3$) and tetracalcium aluminoferrite ($4CaO{\cdot}Al_2O_3{\cdot}Fe_2O_3$). Since each of the compounds contains dissolved impurities in appreciable quantities, the formulas in parentheses are not accurate. In addition to the major compounds, several others play important roles in the hydration process. Only one of these, gypsum ($CaSO_4{\cdot}2H_2O$), will be considered here.

Different portland cements contain the four major "phases," or compounds, in different proportions. (The chemist prefers to use the word "phase" because "compound" usually designates a pure substance with a definite formula.) The relative amounts of the four phases depend on the selection and proportioning of the raw materials. For example, if the raw materials do not contain iron, the iron-containing phase (tetracalcium aluminoferrite) is missing from the cement and the cement will be a "white cement." Ordinary portland cement is gray because of the iron-containing phase in it.

The amounts of the elements (calcium, silicon, aluminum, iron and so on) in a portland cement can be determined by chemical analysis, but the amounts of the compounds cannot. The four major compounds have quite different properties; it is important, therefore, to know how much of each is present in a portland cement. Some 35 years ago R. H. Bogue, who was working on a Portland Cement Association Fellowship at the National Bureau of Standards, proposed a method by which one can calculate the amounts of the compounds in a cement if the amounts of the elements are known from chemical analysis. Although these calculations are based on the assumption that certain ideal conditions exist in the kiln and during the cooling of the clinker, which in practice do not exist, the calculated values have been of great importance to the cement and concrete industry. More recent work has shown that Bogue's "potential" compound values are seldom very far from the correct values.

In a microscope of high magnification the grains of the individual cement compounds can be identified [*see bottom illustration on page 80*]. By a laborious process one can also determine the amounts of the compounds with the microscope. The smallest grains, however, elude visual determination. For a quantitative determination of the major phases one must turn to the technique of X-ray diffraction.

When an X-ray beam is directed at a crystalline compound, the layers of atoms in the crystals diffract the X rays and produce a characteristic pattern. The top illustration on page 84 shows part of the X-ray diffraction pattern of tricalcium silicate. The diffraction peaks appear in definite positions. The middle illustration on the same page shows the corresponding part of the diffraction pattern of a typical portland cement. The peaks of tricalcium silicate appear in the same positions in the portland cement. Naturally the cement produces other peaks as well, since it contains compounds in addition to tricalcium silicate.

The value of X-ray diffraction for studying complex mixtures such as portland cement is that it provides a quantitative measure of each compound present. This is because the areas under the peaks arising from a compound are proportional to the amount of the compound in the mixture. To study the rate at which a given compound in portland cement disappears during hydration one has only to make X-ray diffraction patterns of the cement paste at various intervals after water has been added. (In actual practice the sample must be thoroughly pulverized before analysis; this does not affect the results.)

		I	II	III	IV
→ $3CaO \cdot SiO_2$	TRICALCIUM SILICATE	53	47	58	26
→ $2CaO \cdot SiO_2$	DICALCIUM SILICATE	24	32	16	54
→ $3CaO \cdot Al_2O_3$	TRICALCIUM ALUMINATE	8	3	8	2
→ $4CaO \cdot Al_2O_3 \cdot Fe_2O_3$	TETRACALCIUM ALUMINOFERRITE	8	12	8	12
	TOTAL	93	94	90	94

ferric oxide in the clay. Burning yields four major cement compounds, shown at right.

PROPORTIONS OF MAJOR COMPOUNDS in the four basic types of portland cement are shown in average percentages obtained by X-ray diffraction analysis of several cements.

The X-ray pattern of a partially hydrated portland cement is shown on the next page directly under the pattern of the nonhydrated sample. In these two patterns one can see that a double peak contributed by the two calcium silicates is only about half as high in the hydrated sample as in the nonhydrated one. This means that hydration has partially transformed the calcium silicates into new compounds that are represented by other peaks.

Even though one cannot write a chemical formula for portland cement, X-ray diffraction is able to provide a detailed knowledge of the reaction products as well as of the reactants. The illustration on page 85 shows the diffraction pattern of a completely hydrated portland cement. The peaks corresponding to the four major compounds in cement have disappeared and their places are taken by peaks produced by a number of new compounds.

The two calcium silicates, which constitute about 75 per cent of portland cement by weight, react with water to form two new compounds: calcium hydroxide and a calcium silicate hydrate called tobermorite gel. (The reasons for calling it a gel will be explained below.) Calcium hydroxide makes up about 25 per cent by weight of a fully hydrated cement, and the tobermorite gel makes up about 50 per cent.

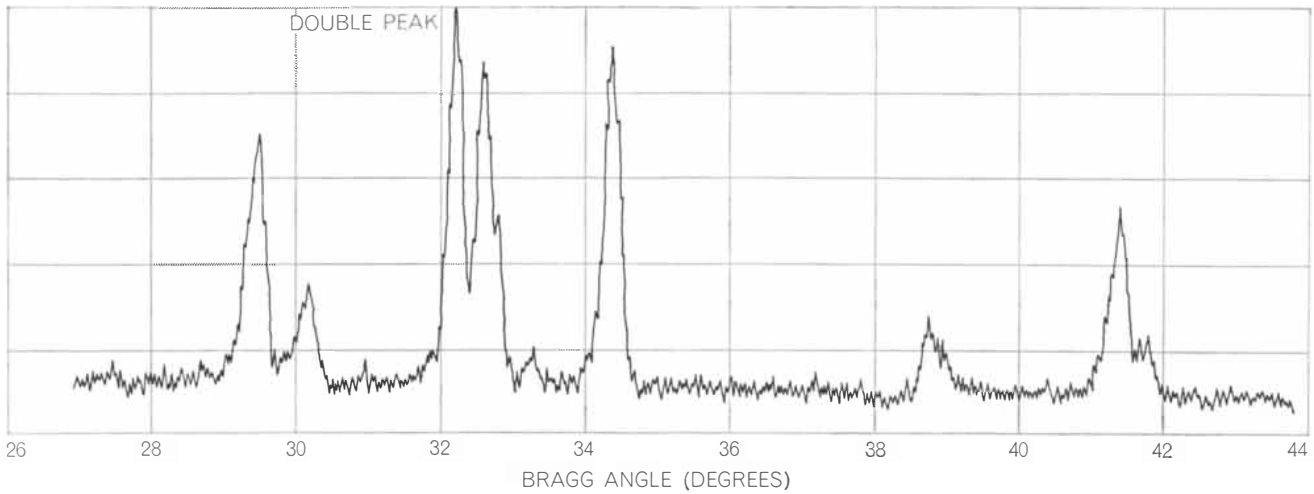
Other peaks represent calcium aluminoferrite hydrate, which resembles a class of natural minerals called hydrogarnets. It is formed by the reaction between tetracalcium aluminoferrite and water. The reaction between tricalcium aluminate, water and calcium hydroxide yields tetracalcium aluminate hydrate. And the reaction between tricalcium aluminate, water and gypsum produces a calcium sulfoaluminate [*see bottom illustration on this page*].

Each of these compounds plays some role in the life of concrete, but they do not play equal roles. By far the most important is tobermorite gel, which is the main cementing component of concrete. The engineering properties of concrete—setting and hardening, strength, dimensional stability and so on—depend primarily on tobermorite gel. It is the heart of concrete and we shall discuss it in some detail.

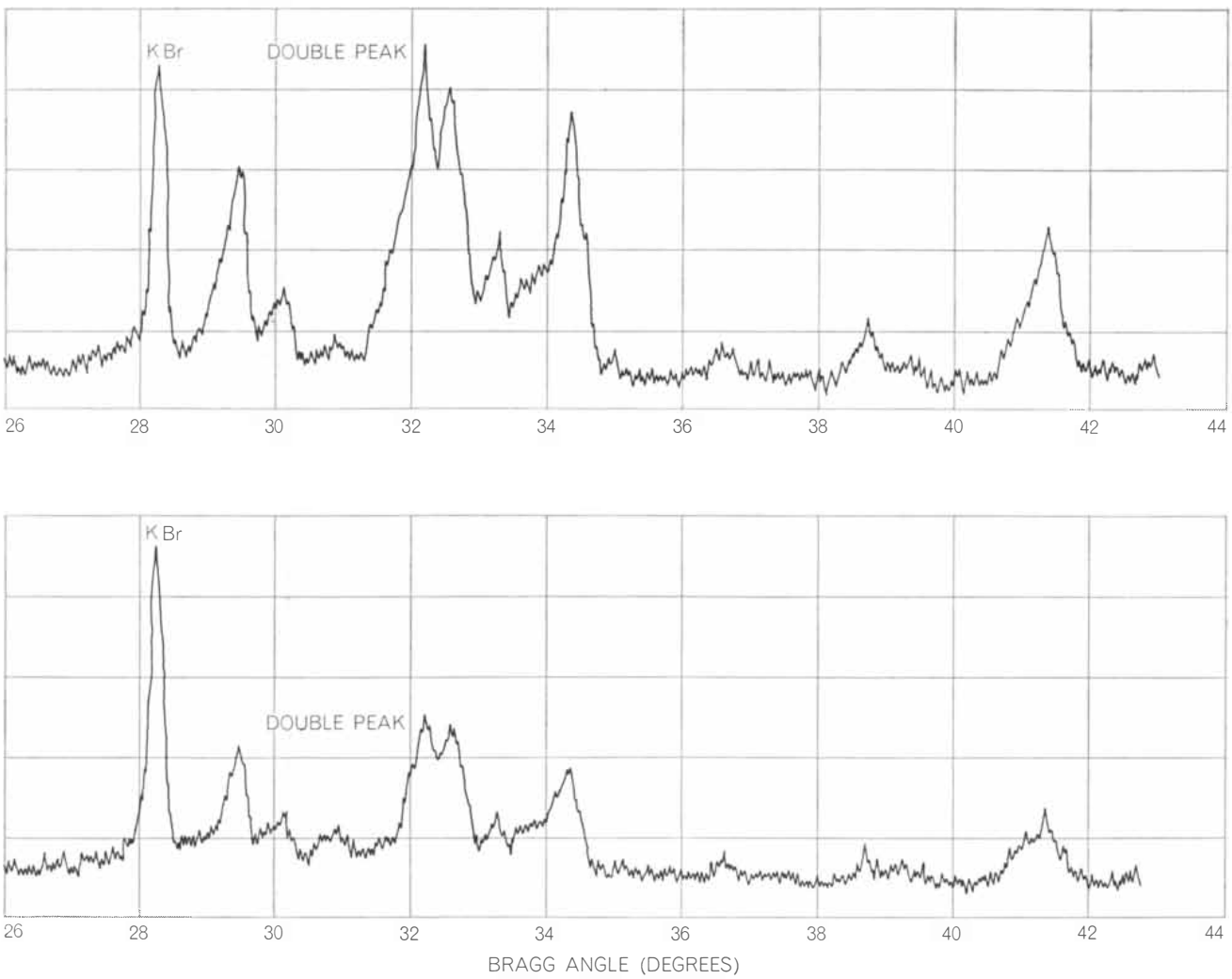
First, however, we shall describe the energy changes that take place when

$2(3CaO \cdot SiO_2)$ (TRICALCIUM SILICATE)	+	$6H_2O$ (WATER)	=	$3CaO \cdot 2SiO_2 \cdot 3H_2O$ (TOBERMORITE GEL)	+	$3Ca(OH)_2$ (CALCIUM HYDROXIDE)
$2(2CaO \cdot SiO_2)$ (DICALCIUM SILICATE)	+	$4H_2O$ (WATER)	=	$3CaO \cdot 2SiO_2 \cdot 3H_2O$ (TOBERMORITE GEL)	+	$Ca(OH)_2$ (CALCIUM HYDROXIDE)
$4CaO \cdot Al_2O_3 \cdot Fe_2O_3$ (TETRACALCIUM ALUMINOFERRITE)	+	$10H_2O$ (WATER)	+	$2Ca(OH)_2$ (CALCIUM HYDROXIDE)	=	$6CaO \cdot Al_2O_3 \cdot Fe_2O_3 \cdot 12H_2O$ (CALCIUM ALUMINOFERRITE HYDRATE)
$3CaO \cdot Al_2O_3$ (TRICALCIUM ALUMINATE)	+	$12H_2O$ (WATER)	+	$Ca(OH)_2$ (CALCIUM HYDROXIDE)	=	$3CaO \cdot Al_2O_3 \cdot Ca(OH)_2 \cdot 12H_2O$ (TETRACALCIUM ALUMINATE HYDRATE)
$3CaO \cdot Al_2O_3$ (TRICALCIUM ALUMINATE)	+	$10H_2O$ (WATER)	+	$CaSO_4 \cdot 2H_2O$ (GYPSUM)	=	$3CaO \cdot Al_2O_3 \cdot CaSo_4 \cdot 12H_2O$ (CALCIUM MONOSULFOALUMINATE)

TRANSFORMATION OF COMPOUNDS occurs when water is added to portland cement. As shown in the top two lines, the two calcium silicates, which constitute about 75 per cent of a portland cement by weight, react with water to produce two new compounds: calcium hydroxide and a calcium silicate hydrate called tobermorite gel. Next two lines show how the other two major compounds in portland cement react with water. The bottom line shows the reaction involving gypsum, a fifth compound in cement.



X-RAY DIFFRACTION PATTERN of tricalcium silicate, one of the major compounds in portland cement, is reproduced. The use of a particular X-ray wavelength, in this case the K-alpha radiation of copper, causes the layers of atoms in the tricalcium silicate to diffract the rays and produce these characteristic peaks. Horizontal scale gives angles of diffraction; height of peaks indicates intensity.



EFFECTS OF HYDRATION are indicated by portions of two diffraction patterns: at top for a Type I portland cement and at bottom for the same cement after partial hydration. Each of the patterns shows at left a peak contributed by potassium bromide, which was added to the samples in known amounts for purposes of comparison. The characteristic peaks of tricalcium silicate appear at the same angles as in the illustration at the top of the page. The double peak is contributed by the two calcium silicates; it is considerably lower in the diffraction pattern of the partially hydrated cement than in that of the cement before hydration because some of the calcium silicates have disappeared in hydration, giving way to new compounds, which appear in diffraction pattern on opposite page.

portland cement is hydrated and then we shall discuss reaction rates. In a chemical reaction heat is liberated if the sum of the energies possessed by the reactants is greater than the sum of the energies possessed by the reaction products. The reaction is said to be exothermic. If the reverse is true and energy is absorbed, the reaction is endothermic. We have already indicated that the hydration of portland cement is exothermic.

Several groups of workers have measured the individual heats of hydration of the four major compounds in portland cement and also the heat released by each compound when it is present in synthetic and in industrial cements. When the compounds are together, it is possible to isolate the contribution of each by mathematical analysis. The results of these studies are in close agreement for three of the four compounds and indicate a heat release of approximately 60 to 120 calories per gram of material. The fourth compound, tricalcium aluminate, releases about 200 calories per gram when it is hydrated by itself and about 325 calories per gram when it is part of a portland cement mixture. In the latter case the aluminate reacts not only with water but also with gypsum, a reaction that releases more energy than simple hydration does.

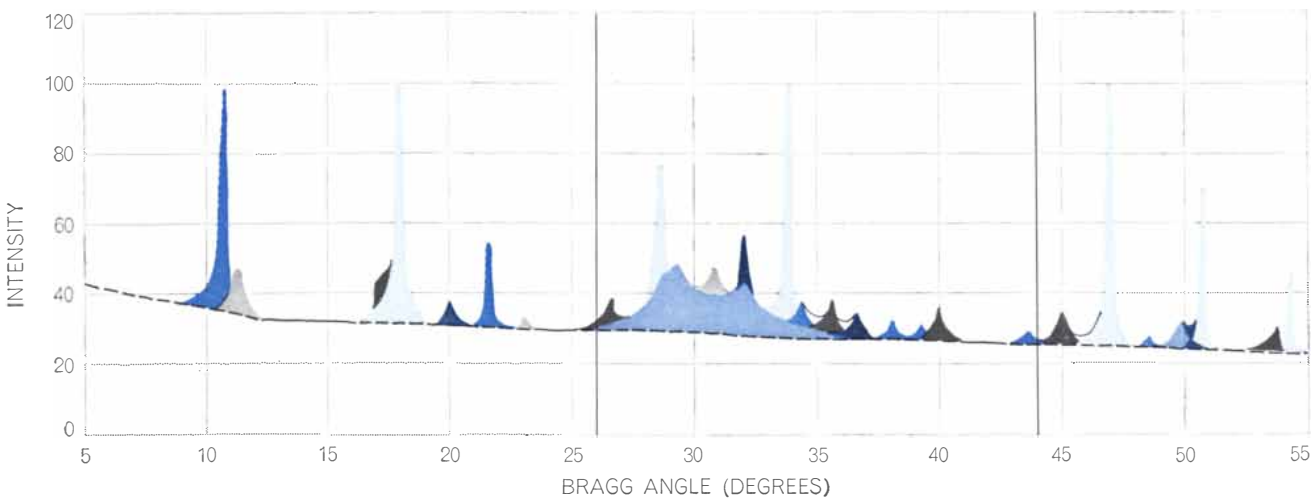
Portland cements have been classified into basic types by the American Society for Testing and Materials. Within each type there is considerable variation in composition, but the different types identify cements with distinctly different properties. This difference shows up clearly when one compares their average heats of hydration. The top illustration on the next page shows the heat evolved when four types of cement were hydrated for periods ranging from three days to 13 years. The measurements were obtained by George J. Verbeck of the Portland Cement Association.

Type I, the commonest type of portland cement, releases a little more than half of its total heat of hydration in three days. Type III, the high-early-strength cement, releases 50 per cent of its heat in much less than three days. Type II, a moderate-heat cement, releases less heat over-all than do Types I and III, and more than three days are required for half of its heat to be released. Type IV, the lowest-heat cement, gives off only about half as much heat in the first three days as the high-early-strength Type III does, and over the full 13-year period it releases only about 75 per cent as much heat as Types I and III do.

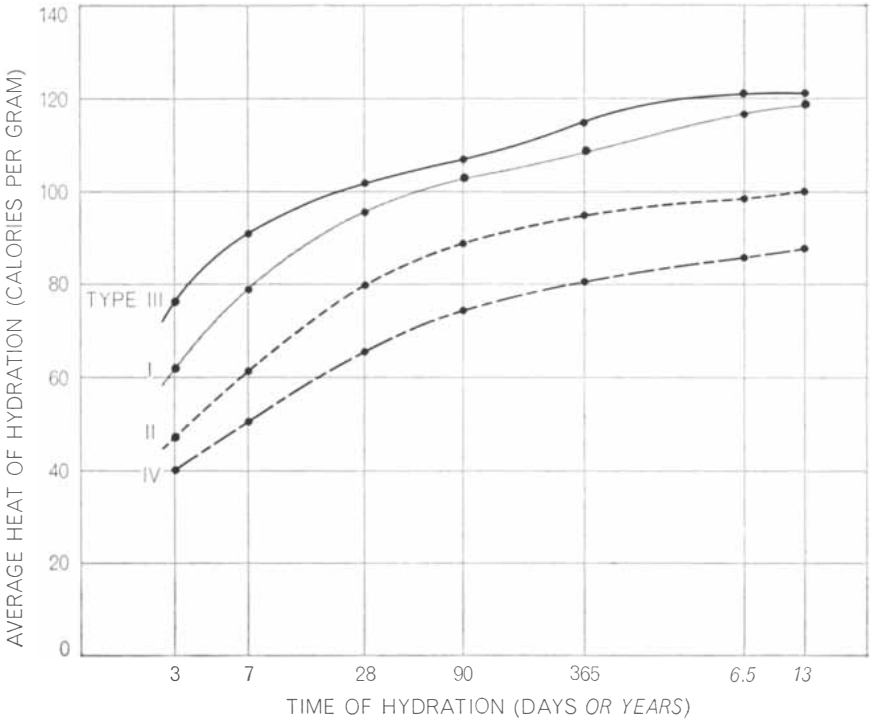
The large variations in total heat release and in rate of release are achieved by altering the proportions of the four major compounds that make up portland cement. The bottom illustration on the next page shows the amount of heat released in a few hours to 100 days by these compounds. Type I cements usually contain about 50 per cent tricalcium silicate, which releases about 120 calories per gram, and about 25 per cent dicalcium silicate, which releases only about 60 calories per gram and releases it much more slowly. It is apparent that by reversing these proportions one should obtain a cement that releases less total heat and releases it more slowly than Type I does. Indeed, the proportions are reversed in low-heat Type IV cement, which was developed specially for the Hoover Dam by the Riverside Cement Company in California.

Type II, or moderate-heat, cements are intermediate in composition between Type I and Type IV cements. And high-early-strength Type III cements usually contain even more of high-heat tricalcium silicate and less of low-heat dicalcium silicate than Type I cements do [*see illustration at top right on page 83*].

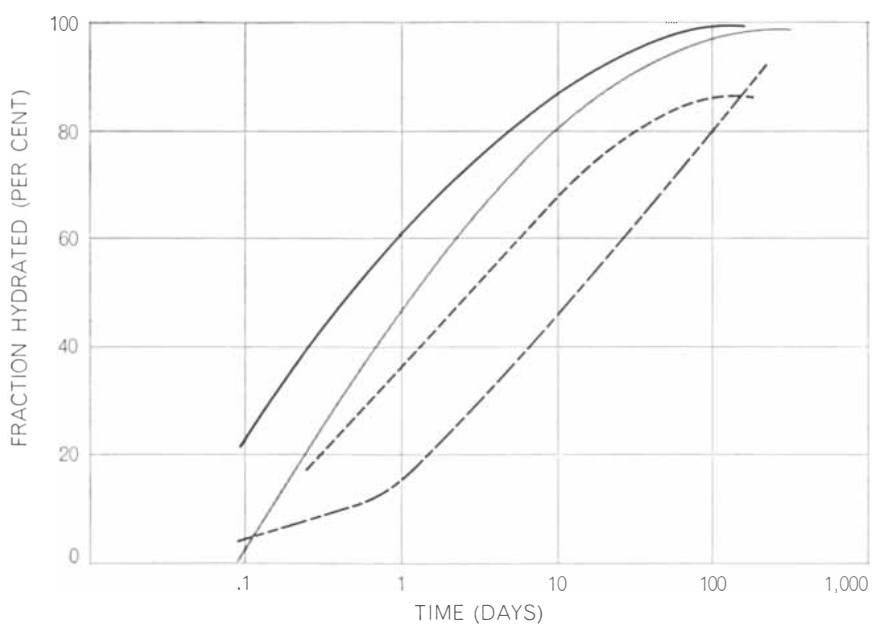
The third of the four major ingredients found in normal portland cements—tricalcium aluminate—also has a large influence on the rate of heat release and hardening rates. As the bottom illustration on the next page shows, it has the fastest rate of reaction with water. As a result as much as 15 per cent of it can be used in Type III cements to speed the setting rate. In Types II and IV, in which low-heat release is desired, tricalcium aluminate may be almost absent. The tricalcium aluminate content of portland cement cannot be increased indiscriminately, otherwise a "quick set," or "flash set," will occur when the cement powder is mixed with water. Gypsum is added to the clinker as a "retarder" to slow down the hydration of



FULLY HYDRATED CEMENT shows this diffraction pattern. The peaks that appear in the diffraction patterns on the opposite page (peaks representing the major compounds in the cement before complete hydration) have disappeared because new compounds have been produced during hydration. In place of those peaks are the peaks of the new compounds constituting a completely hydrated cement (in this case Type I). Solid lines bracket area covered by patterns on opposite page. Vertical scale for intensity is arbitrary.



HEAT OF HYDRATION of the basic types of portland cement is charted for hydration periods ranging from three days to 13 years. Variations reflect the different properties of cements. Type III, for example, releasing heat rapidly, gives high early strength; Type IV, which releases heat slowly, is valuable in big structures that cannot dissipate heat easily.



SPEED OF HYDRATION of the four major compounds in portland cement during approximately 14 weeks is charted. If a fast reaction is desired, as in Type III portland cement, the cement should be high in the fast-reacting compounds, tricalcium silicate and tricalcium aluminate. If a slow reaction is desired, as in Type IV portland cement, the cement should be high in the slow-reacting compounds, dicalcium silicate and tetracalcium aluminoferrite.

tricalcium aluminate in portland cement.

Composition, however, is not all that influences the speed of hydration. Fineness of grinding, the amount of water added and the temperature at the time of mixing all have important effects on reaction speed. To achieve a faster hydration Type III cements are ground finer than Type I cements. In fact, two cements of the same composition can be classified as Type I and Type III simply because of differences in fineness.

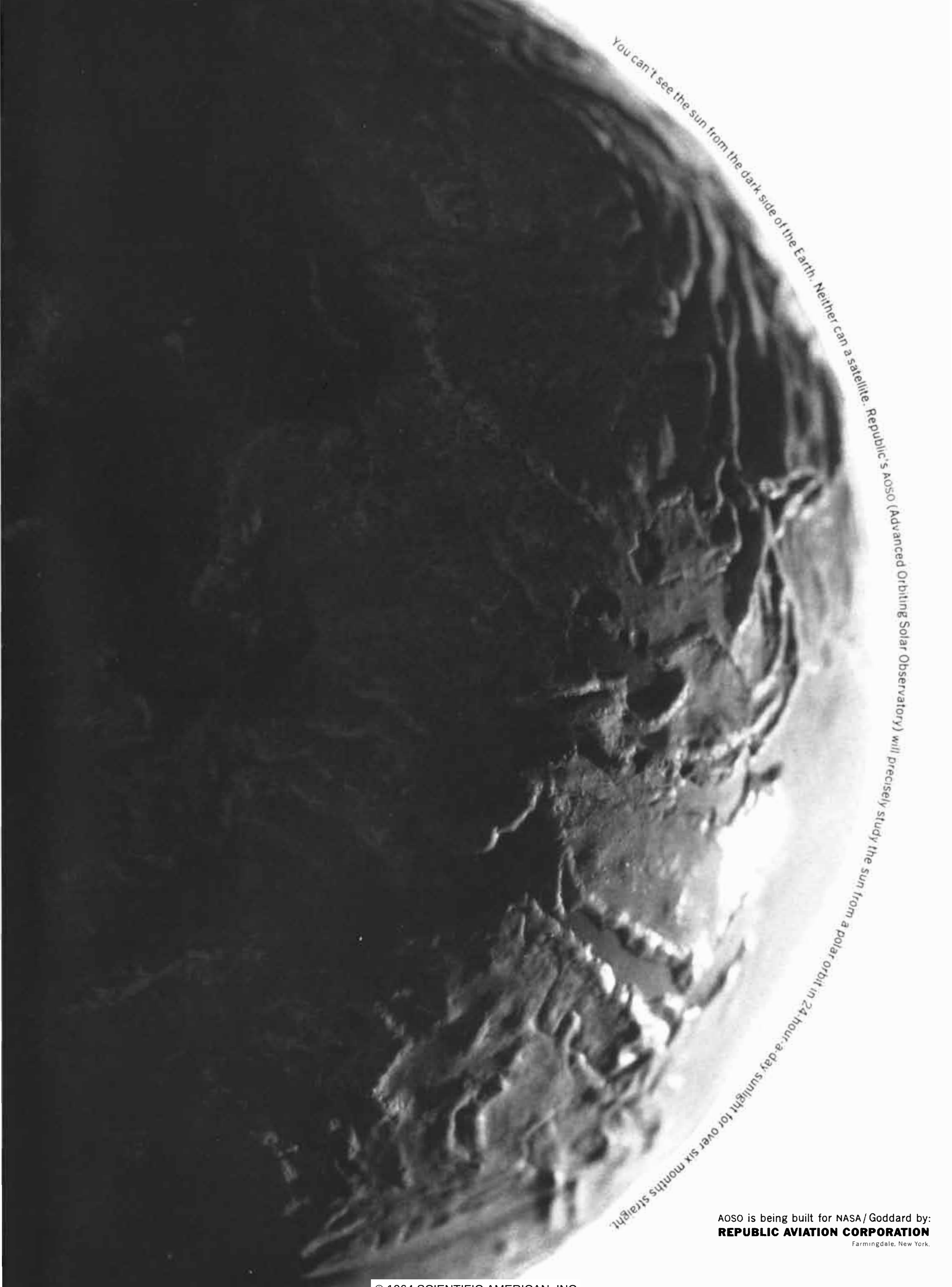
Let us return to tobermorite gel and observe the critical role it plays in establishing the physical and engineering properties of hardened portland cement paste. T. C. Powers and his co-workers at the Portland Cement Association were the first to show that two physical properties of cement paste—surface and porosity—are decisive in determining the two most important engineering properties: strength and dimensional stability. Powers applied the term "cement gel" to the part of hardened paste that is responsible for surface and porosity. The word "gel" signifies an extremely finely divided substance that has a coherent structure.

Later work has shown that the most important constituent of cement gel is the calcium silicate hydrate called tobermorite gel. The word "tobermorite" indicates that this substance has a composition and crystal structure resembling that of the natural mineral called tobermorite [*see illustration on the cover of this issue*]. The natural mineral takes its name from Tobermory in Scotland, where it was discovered.

A little simple geometry will indicate what happens to the surface area when a substance is finely divided. When a cube of a given size is divided into eight smaller cubes of equal size, the surface area is doubled. As the original cube is divided into smaller and smaller cubes, the surface area grows progressively.

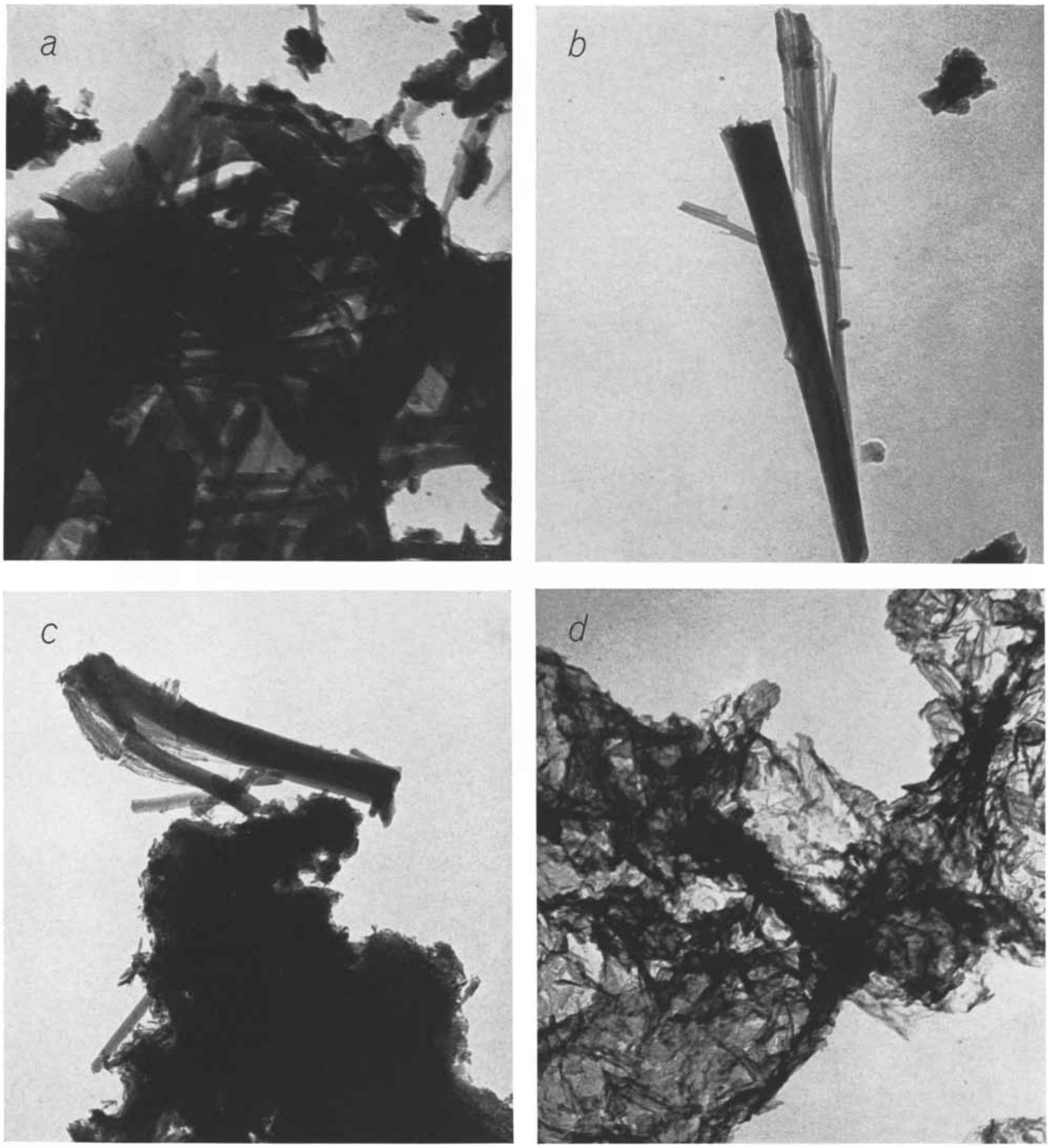
Let us now suppose that out of a clinker of cement we cut a cube weighing one gram. Its surface area will be about three square centimeters. If we grind this cube to the average fineness of portland cement, the surface area will be some 3,000 square centimeters. The average diameter of a typical cement grain is 10 microns, or a hundredth of a millimeter; in a pound of portland cement there are about 150 billion such grains. The powder is so fine it passes through a metal screen that can hold water.

Small though the cement grains are, they are gigantic compared with particles of tobermorite gel. The surface

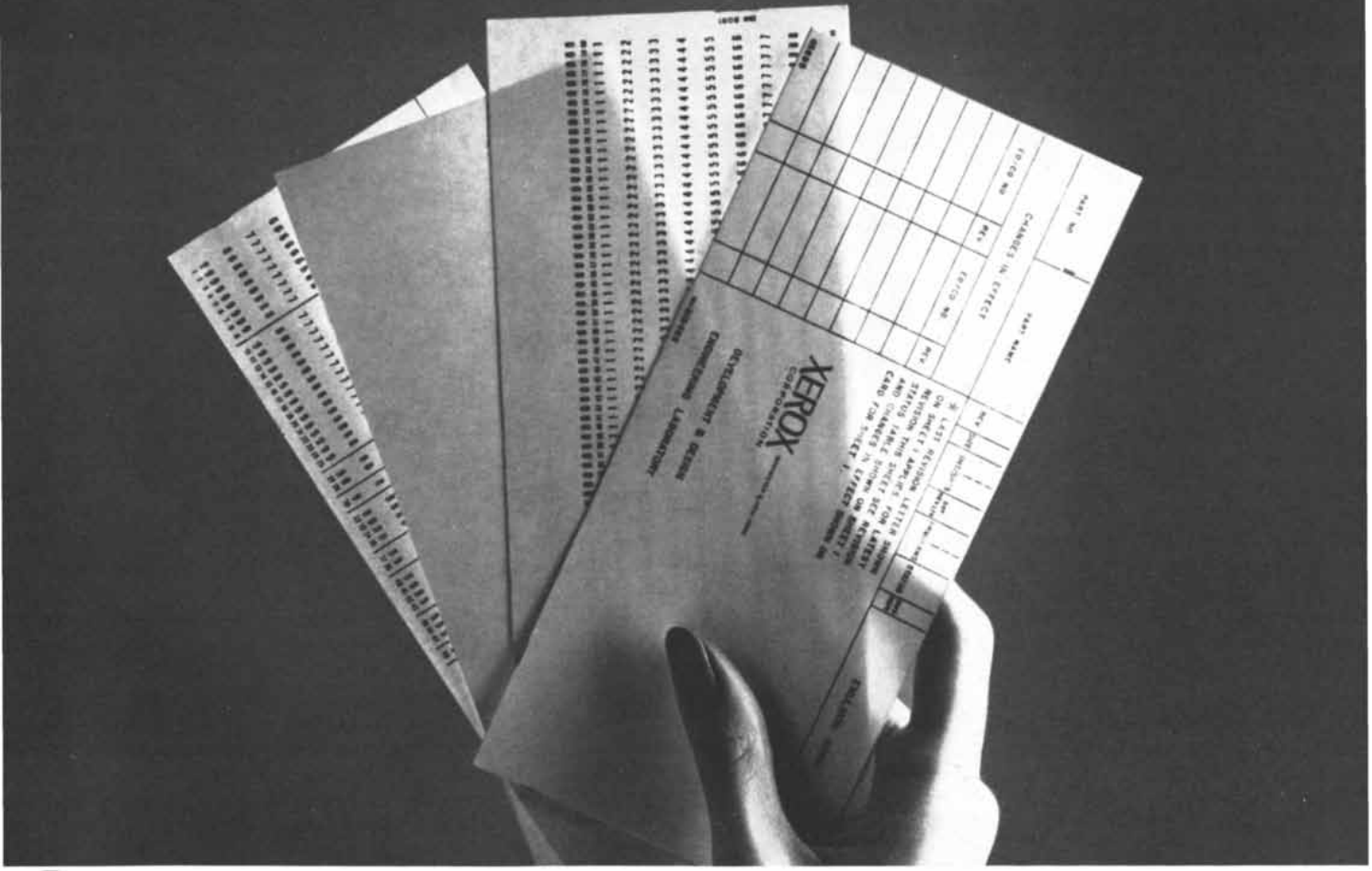


area of one gram of tobermorite gel is some three million square centimeters, which implies that the average diameter of a tobermorite gel particle is only a thousandth of that of a typical cement grain. Particles of such small size can be seen only in an electron microscope [*see illustration below*]. Evidently in undergoing hydration the tiny grains of portland cement are replaced by still smaller particles.

One may ask: What does the small particle size of tobermorite gel have to do with the engineering properties of hardened cement paste? The answer is that the enormous surface area of the gel gives rise to the forces responsible for the paste's cementing action. The surface forces can be visualized by imagining a cube representing a crystal of sodium chloride. A chlorine atom in



STRUCTURE OF TOBERMORITE GEL is apparent in these electron micrographs, which enlarge the gel particles some 65,000 diameters. Micrograph *a* shows an aggregation of tobermorite gel fibers obtained from a hardened paste of tricalcium silicate; in *b*, which is from a hard paste of dicalcium silicate, the particles appear as thin, rolled sheets. Pastes of portland cement rarely show such sheets, but a few appear in micrograph *c*, which is from a Type IV cement. Usually the gel appears in the form of unrolled, crumpled sheets, as in *d*, obtained from a Type I cement. Structures give clues to moisture problem illustrated on page 90.



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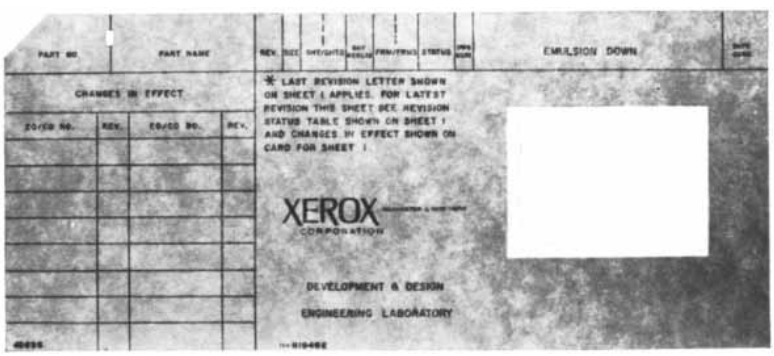

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the body of the crystal is surrounded by six sodium atoms, four on the sides, one above and one below. Similarly, each sodium atom is surrounded by six chlorine atoms. A sodium atom located at the surface of the crystal, however, is surrounded by only five chlorine atoms: four on the sides and one below. To compensate for the missing chlorine atom the sodium atom tends to seize some other atom or molecule from its surroundings; for example, it may attract a water molecule in the atmosphere. A chlorine atom at the surface of the crystal also exhibits a tendency to attract external substances.

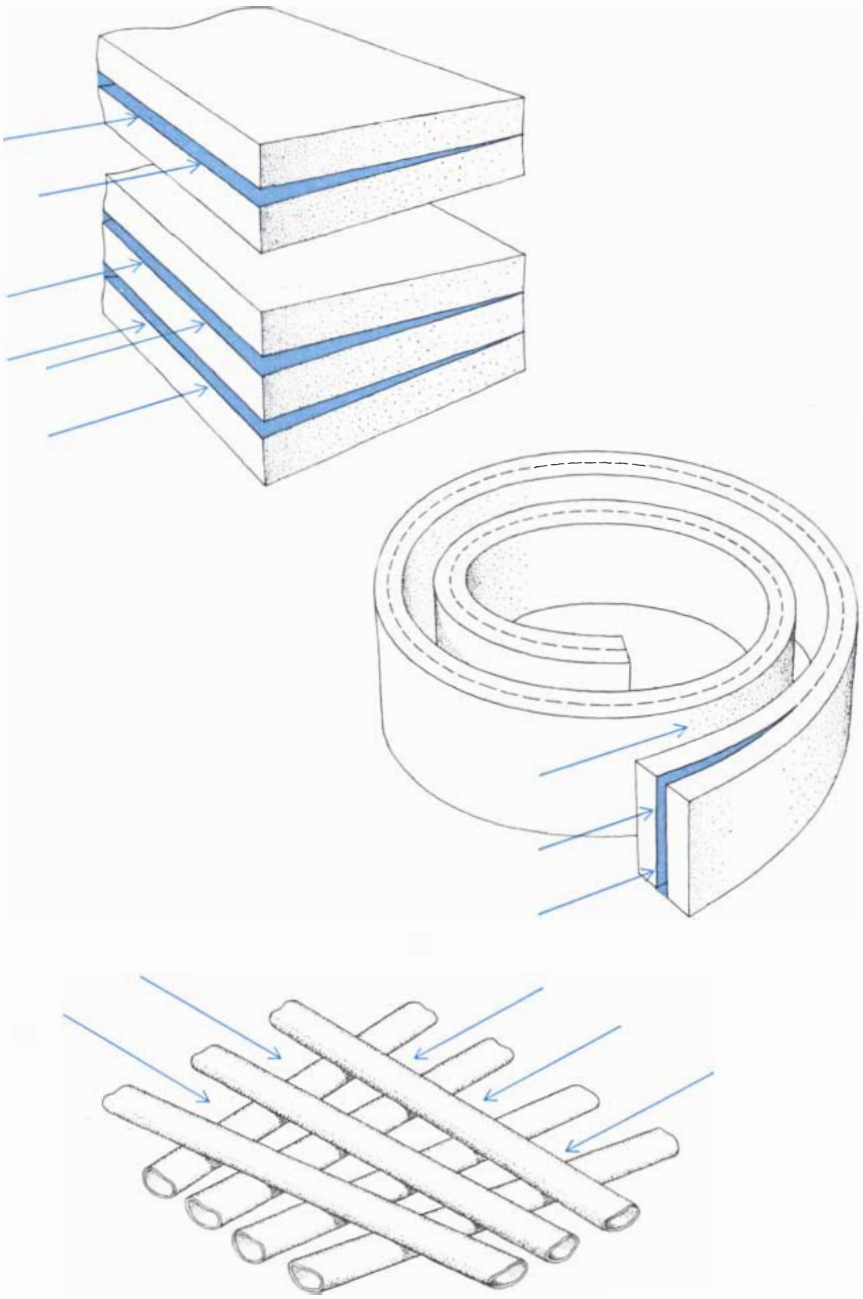
This propensity of atoms or molecules on the surface of a crystal to attract substances outside the crystal is called adsorption. When two surfaces are brought close together, they also attract each other and for similar reasons. This is called adhesion. The particles of tobermorite gel adhere to each other; they also adhere to small crystals in the hardened cement paste, to grains of sand and to pieces of coarse aggregate, cementing everything together.

The cementing action depends on the extent and nature of the surface. There are substances such as silica gel (a form of silicon dioxide) that have more surface area, gram for gram, than tobermorite gel does, but the latter is a better cementing material because it possesses much greater force per unit of surface. On the other hand, calcium hydroxide, also found in cement paste, exerts a stronger attractive force per unit of area than tobermorite gel, but it is a poorer cementing material because one gram of the most finely divided calcium hydroxide has only about a tenth of the surface area of one gram of tobermorite gel.

In addition to surface area and surface force the other important property in determining the strength and dimensional stability of hardened portland cement paste is porosity. Inevitably there are tiny pores of molecular dimensions between particles of tobermorite gel, and there are still larger pores between aggregations of gel particles. The former are called gel pores; the latter, capillary pores or cavities. Even the capillary pores are too small to be visible in an ordinary light microscope.

The volume of the pore space in a cement paste depends on the amount of water mixed with the cement at the start. When the paste sets, it acquires a stable volume that is approximately equal to the volume of the cement plus the volume of the water. Let us suppose we prepare two pastes from the same cement, using the same amount of cement but different amounts of water. After setting, the paste with the greater amount of water will have the greater volume. After hydration the two pastes will contain the same amounts of solid material, because the same amounts of cement will produce the same amounts of hydration products. The volume of one paste, however, is greater; consequently that paste will have a larger pore space.

This effect has an important influence on the strength of the hardened paste, which is the dominant factor in the strength of concrete. Pores are filled with water and air and they have no strength. The strength resides in the solid part of the paste—primarily in the tobermorite



SWELLING AND SHRINKING of concrete occur with changes in moisture and present a problem of cracking. Tobermorite gel particles have the major role in the water movement, which occurs by means of the mechanisms illustrated here. At top, water penetrates between molecular layers of a tobermorite gel sheet, causing the sheet to expand. In a similar action (*middle*) water enters between the layers of a rolled sheet of tobermorite gel; moreover, it can enter (*upper arrow*) into the convolutions of the fiber, where expansion will occur by adsorption. At bottom water enters the pores between fibers of tobermorite gel.

Basic Research at Honeywell
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Hopkins, Minnesota

Studies of Small Gap Semiconductors for Infrared Detection

The window in the atmosphere between 8 and 14 microns has stimulated work on devices that will detect longer wave lengths. New semiconductor materials may make practical the detection of longer wave lengths and therefore targets with far lower temperatures.

The atmosphere offers several windows for energy transmission in the infrared spectrum. One particularly good one occurs between 8 and 14 microns where energy is transmitted freely. However, radiation on either side of the window is blocked due to absorption by the molecules in the atmosphere.

All objects at temperatures above absolute zero give off radiations and the lower the temperature the longer the wave length. Therefore, if long wave lengths can be detected by a practical means, targets of much lower temperatures could be recognized.

Infrared detectors use either intrinsic or extrinsic semiconductors. Intrinsic detectors use electron transitions within the atoms that make up the semiconductor material itself. The extrinsic type utilizes electron transitions that occur due to the presence of impurity atoms introduced into the semiconductor material. (See Fig. A.)

While the extrinsic materials permit detection of infrared radiation beyond 6 microns, these materials require cooling to below 40°K. This calls for bulky, heavy apparatus undesirable for airborne applications and difficult to design into multielement detectors.

Until now no one has been able to make an intrinsic conductor that will detect photons in the longer wave lengths. In an intrinsic detector the narrower the energy gap between the valence band and the conduction band the easier it is to excite an electron across the gap. This excitation occurs two ways: by photon excitation and by thermal excitation. The problem is to produce a material with a gap narrow enough to respond to long wave lengths (that is, low energy photons) but wide enough so that practical cooling temperatures will be sufficient to minimize thermal excitation.

Honeywell scientists have performed a theoretical analysis which shows the feasibility of making an 8 to 14 micron intrinsic detector capable of operating at liquid nitrogen temperature, 77°K. (−320°F.)

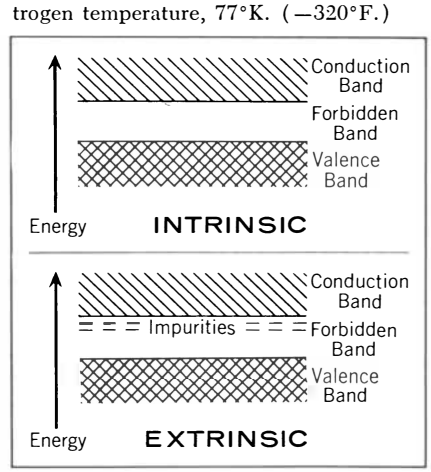

FIG. A

The analysis also shows that by the use of intrinsic material the detectors operating at 77°K could be made so sensitive that the only limitation is imposed by the randomness of the photons coming from the radiation background. Problems present themselves in selecting elements for the semiconductor. For example: while some narrow gap materials meet many of the requirements, their gap is so narrow that the required cooling is impractical. (This is the case with mercury telluride.)

Honeywell's contribution to the development of a suitable detector has been to prepare a compound semiconductor composed of different proportions of mercury, cadmium and tellurium and to develop a theory capable of explaining the behavior of this material.

The compound is difficult to synthesize. Mercury evaporates readily at room temperature yet the compound requires heating to 800°C. At this temperature the pressure of mercury within the capsule is very high.

A number of different compositions have been formulated. Most promising is a compound of approximately 80% mercury telluride and 20% cadmium telluride. With this compound Honeywell scientists, for the first time, have been able to demonstrate photon detection at wave lengths out to 14 microns. Previous workers had been able to demonstrate only thermal effects in these materials.

Further work is under way at Honeywell's Research Center on purification of the material and improvement of its crystal structure. At the same time additional theoretical work is under way to further understand the very complex band structure of small gap semiconductors. If the transitions in these materials can be explained, new insights in semiconductor theory will be attained. This research is partially supported by the Aeronautical Systems Division, Air Force Systems Command.

If you are engaged in scientific work involving small-gap semiconductors and would like to have copies of papers on the subject by Honeywell scientists, you are invited to correspond with Dr. Paul W. Kruse, Honeywell Research Center, Hopkins, Minnesota.

If you are interested in a career at Honeywell's Research Center and hold an advanced degree, you are invited to write Dr. John Dempsey, Director of Research at this same address.

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gel. The less porous paste will produce the stronger concrete. In the mixing of concrete, therefore, no more water should be used than is absolutely necessary.

The porosity is also a vital factor in the dimensional changes of hardened paste. Two types of volume change are of practical significance. One of these is caused by the freezing of water in the capillary pores of the paste. Ice has a volume 9 per cent greater than that of water; hence when water freezes in the pores, the expansion develops internal pressures that may lead to cracking of the concrete.

The second type of volume change results from movement of water into and out of the pore system because of changes in atmospheric humidity. When the humidity increases, water enters the paste and the paste swells; when the humidity drops, water leaves the pore system and the paste shrinks. In actual practice the volume changes are quite small. A drop in the humidity of the environment from 100 per cent to 10 per cent, which almost never happens, causes a change of no more than 2 per cent in the volume of cement paste. Because the aggregates in concrete restrain the shrinkage of the paste, concrete shrinks only a tenth as much as hardened paste. Nevertheless, even this tiny volume change may produce cracking.

Of the possible improvements in concrete, the one most needed is a substantial reduction in dimensional change. One aspect of this problem, the freezing of water in the pores, has already been solved by a product called air-entraining portland cement. Small amounts of soaplike materials are ground together with the cement clinker. When the cement is mixed with water, billions of microscopic air bubbles are produced by the soaplike material and become entrained in the cement paste. The bubbles relieve the internal pressure created when water freezes in the pores. The porosity introduced by the air bubbles themselves causes only a small reduction in strength, which, if necessary, can be easily compensated by a slight reduction in the ratio of water to cement.

The problem of volume changes caused by the movement of water has not yet been solved. Before it can be solved much more must be learned about the mechanism of swelling and shrinkage, in which tobermorite gel plays a dominant role.

Some clues to the way in which tobermorite gel takes up water can be inferred from close inspection of the four electron micrographs labeled *a, b, c* and *d* on page 88. Illustration *a* shows an aggregation of tobermorite gel particles obtained from a hardened paste of tricalcium silicate. The particles are straight fibers and the aggregation resembles a pile of matches in which the matches of each layer are at right angles to the matches in the layer below. Illustration *b* shows a few individual fibers obtained from a hardened paste of dicalcium silicate. The fibers are actually rolls of very thin sheets only two or three molecular layers thick. The fiber on the left is a partly unrolled sheet. Such sheets are seldom found in pastes of portland cement. Illustration *c,* obtained from a paste of a Type IV cement, shows a few rolled-up sheets. Ordinarily, however, tobermorite gel appears as unrolled crumpled sheets, as shown in illustration *d,* obtained from a paste of a Type I portland cement.

Such micrographs provide the basis for three probable mechanisms illustrated on page 90, by which water may enter tobermorite gel in hardened pastes of calcium silicates. The diagrams show (1) the swelling of stacks of essentially flat sheets, (2) the penetration of water into rolled-up sheets and (3) the penetration of water into the pores that separate crisscrossed fibers. Because tobermorite gel sheets usually do not form rolls in portland cement pastes, the second mechanism is probably not too important in the practical technology of concrete. But a fourth mechanism, which is not illustrated, may be the most important cause of dimensional changes at high humidities. We have mentioned that in addition to gel pores there are larger pores in the paste between the aggregations of gel particles. Water has ready access to these pores and swells the hardened paste.

These mechanisms do not exhaust the sources of dimensional changes in cement pastes due to moisture. The reason is that portland cement pastes contain not only tobermorite gel but also the hydration products of tricalcium aluminate, which similarly contribute to dimensional changes. The fraction of the total volume change attributable to various mechanisms has yet to be determined. When the mechanisms are quantitatively understood, one can expect to find ways to influence them. A concrete of greater dimensional stability than any now produced is a distinct possibility. Even if the new product is not "just around the corner," it will exist in the not too distant future.

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A Neolithic City in Turkey

An ancient mound now known as Çatal Hüyük has yielded evidence that communities with highly developed economic structure, religion and art existed as long ago as 7000 B.C. and perhaps even earlier

by James Mellaart

Excavations on the Anatolian plateau of Turkey a few years ago provided an answer to an archaeological question of long standing about Neolithic culture. The Neolithic is the stage of civilization at which men began to cultivate crops and to domesticate animals and as a result of these activities to dwell in permanent settlements; in the Near East this stage occurred roughly between 7000 B.C. and 5000 B.C. The question was how Neolithic culture had moved from the Near East into Europe. The answer was that the movement was overland, by way of the Anatolian plateau. Such a route had long seemed to archaeologists a logical supposition, but until Neolithic communities were excavated on the plateau there had been no direct evidence to support the supposition [see "Hacilar: A Neolithic Village Site," by James Mellaart, SCIENTIFIC AMERICAN, August, 1961].

In answering one question, however, these excavations raised another: What were the origins of the culture of which Hacilar was representative? The Late Neolithic culture found at Hacilar had arrived there fully developed. The long gap between its arrival, probably about 6000 B.C., and the desertion of a pre-pottery village on the same site some 500 years earlier needed investigation. The gap appeared to correspond to the Early Neolithic period. If an Early Neolithic site could be excavated on the plateau, it might indicate the origin of the Hacilar culture and provide a longer culture sequence.

We had such a site in mind. I had found it about 30 miles southeast of the modern city of Konya in 1958: an ancient mound (*hüyük* in Turkish) bearing the name Çatal. The mound, covered with weeds and thistles, stood in the middle of a great plain. Lying on what was once the bank of a river (now canalized into other channels to prevent flooding) that flows from the Taurus Mountains onto the plain, it rose gently from the fields to a height of 50 feet.

Çatal Hüyük seemed to be the most promising of some 200 sites we had visited on the Konya plain. A preliminary investigation indicated, to our delight, that the site belonged substantially, if not wholly, to the Early Neolithic period. Small fragments of pottery and broken obsidian arrowheads showed an unmistakable resemblance to those found in the deepest Neolithic levels at Mersin on the southern coast of Turkey, and at Çatal Hüyük they were on top of the mound. Moreover, the pottery looked more primitive than anything we had found at Hacilar.

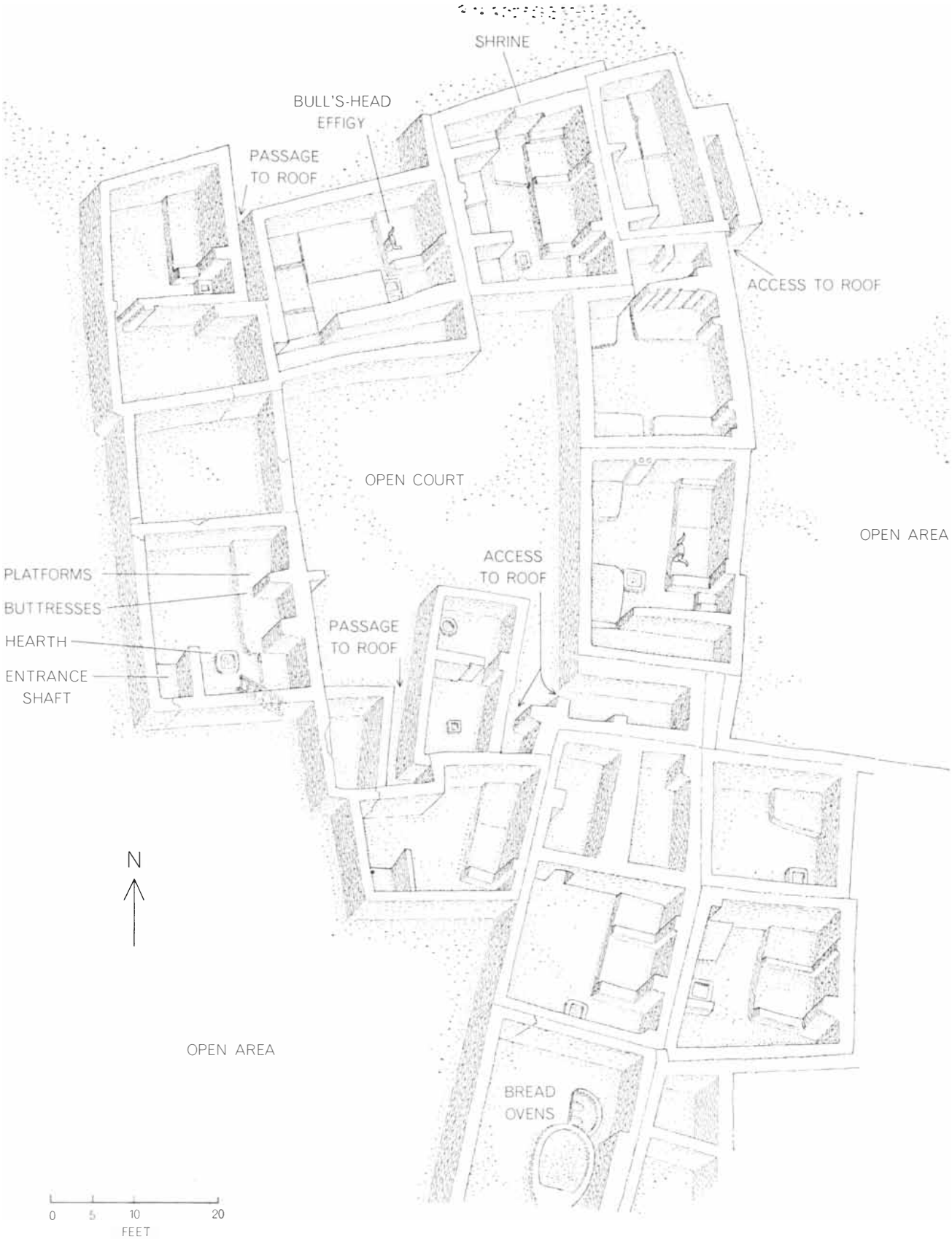
So it was that Çatal Hüyük's 8,000 years of slumber came to an end on May 17, 1961, when our party began excavations. Ten days later the first Neolithic paintings ever found on man-made walls were exposed, and it was clear that Çatal Hüyük was no ordinary site. Succeeding excavations in 1962 and 1963 have confirmed this impression. With its story only partly revealed by the excavations to date, Çatal Hüyük has already added to the archaeological evidence that the development of towns and cities (as distinct from villages) goes farther back in antiquity than had been thought. Çatal Hüyük deserves the name of city: it was a community with an extensive economic development, specialized crafts, a rich religious life, a surprising attainment in art and an impressive social organization.

For the opportunity to explore this story we are indebted to several organizations. Our excavations have been supported by the Wenner-Gren Foundation for Anthropological Research, the Bollingen Foundation, the British Academy, the University of London, the University of Edinburgh, the Royal Ontario Museum, the Australian Institute of Archaeology, the University of Canterbury in New Zealand and the late Francis Neilson. The Shell Oil Company and British Petroleum Aegean Limited provided technical help. Numerous other institutions have contributed in such ways as sending experts to the site or making analyses of material found at the site.

Çatal Hüyük covers 32 acres and so is easily the largest known Neolithic site, although how much of the site was occupied at any given period cannot be said with certainty. Apparently the settlement grew up from the riverbank, and the substantial part of the mound that spreads back from the river therefore dates from later phases of settlement. Our excavations, covering about one acre, have so far been concentrated on the southwest side of the mound, in a quarter that appears to have been sacred and residential. Because we have found nothing but finished goods in this area, we assume that the bazaar quarter with the workshops lies elsewhere in the mound.

With different quarters for different activities, a clear specialization in crafts and a social stratification that is obvious in both the size of the houses and the quality of burial gifts, this settlement was not a village of farmers, however rich. It was far more than that. In fact, its remains are as urban as those of any site from the succeeding Bronze Age yet excavated in Turkey.

We have found at Çatal Hüyük 12 superimposed building levels, which we have numbered from 0 to VI-A and VI-B to X according to their apparent



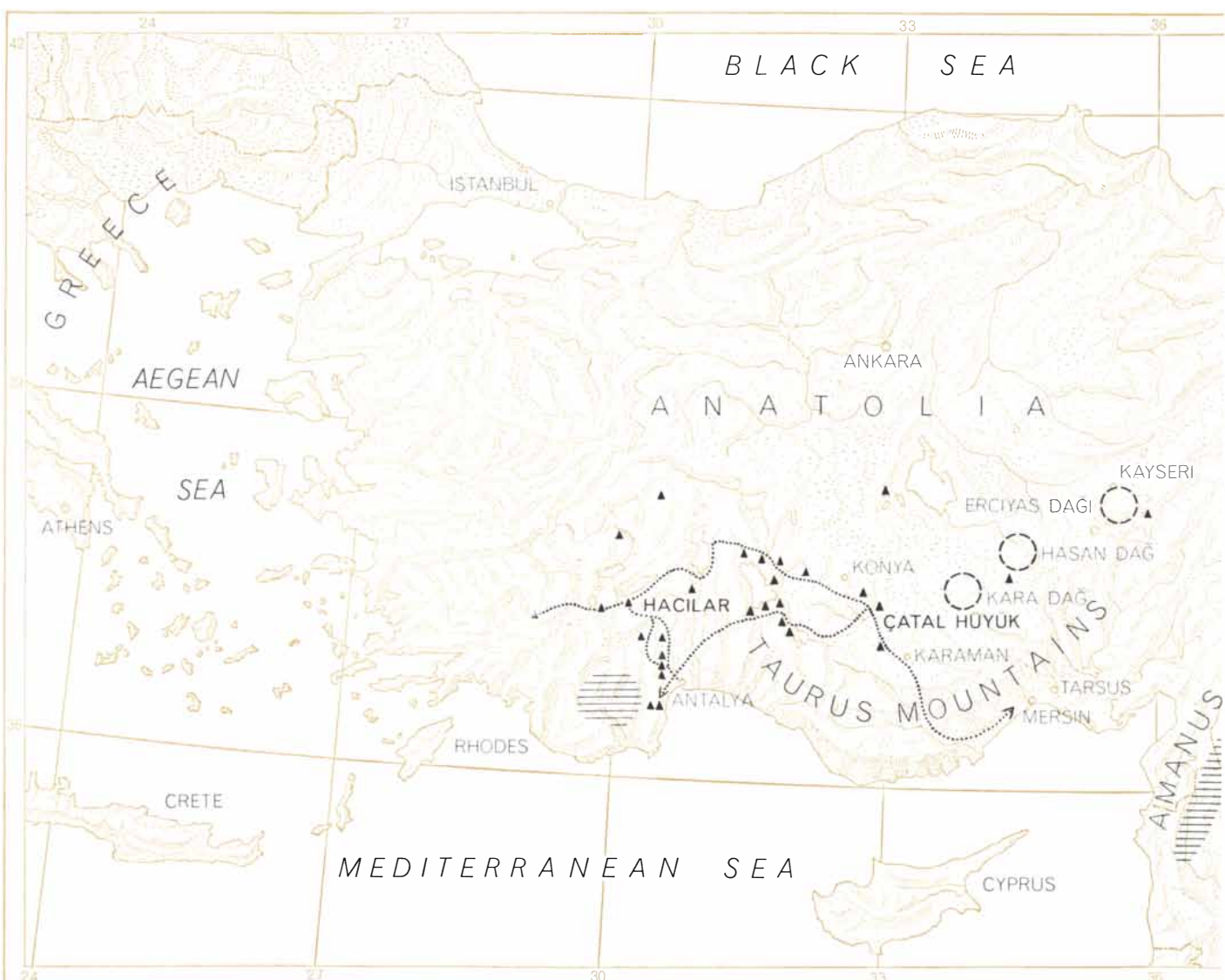
COMMUNITY ARRANGEMENTS of 8,000 years ago in a Neolithic city are depicted on the basis of recent excavations. This is a reconstruction of an area in the fifth of 12 building layers so far found at the Çatal Hüyük site on the Anatolian plateau of Turkey. Access to the buildings was solely from the roof, so that the exterior walls presented a solid blank face, which served effectively as a defense against both attackers and floods. Çatal Hüyük showed a surprising evolution of civilization for so early a community.

chronology from latest to earliest [*see illustration on page 99*]. All these levels belong to a single culture that was uninterrupted in development and shows no signs of destruction attributable to outside forces. The entire sequence so far discovered appears to cover the seventh millennium B.C., although radiocarbon dating of Çatal Hüyük materials now in progress at the University of Pennsylvania may provide a more precise time scale. The core of the mound, however, remains to be sounded, and a full 10 meters of deposit there may take the origins of Çatal Hüyük back to the end of the last continental glaciation.

Houses at Çatal Hüyük were built of shaped mud brick of standard sizes. Because the nearest stone was several miles away and would have been difficult to bring to the site, the foundations of the houses also consist of mud brick, laid in several courses. By these foundations it is possible to recognize buildings even if their floors are gone, as is the case in Level 0. The houses were rectangular, usually with a small storeroom attached [*see illustration on preceding page*]. Apparently these dwellings were one-story structures, perhaps with a wooden veranda.

The houses show a remarkable consistency of plan inside. Along the east wall there were two raised platforms with a higher bench at the southern end. This arrangement constituted a "divan," used for sitting, working and sleeping. The smaller corner platform evidently belonged to the male owner and the larger central platform to the women and children. This hierarchic convention appears from Level X to Level II and probably existed in Levels I and 0, of which little remains. There are numerous variations on this arrangement of built-in furniture, including situations in which platforms appear along the north or west wall. The hearth was invariably at the south end of the room, sometimes accompanied by an oven and less often by a kiln. There was a reason for this location of the fires: it had to do with the manner in which the houses were entered.

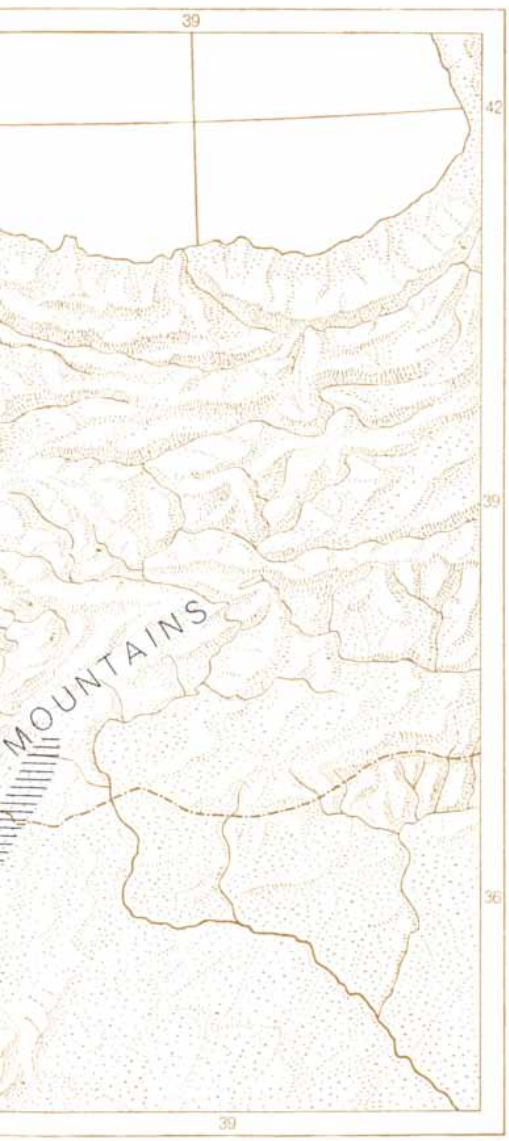
The entrance was, as in some American Indian villages, a hole in the roof, over which there was surely some sort of canopy-like shelter. The roof opening was always on the south side of the



AREA OF NEAR EAST in which the culture represented by Çatal Hüyük was located is shown. Triangular symbols show Neolithic sites; circled areas indicate sources of obsidian; hatched areas, sources of flint. Çatal Hüyük was chosen for extensive archaeological work after excavations at Hacilar revealed a Late Neolithic culture that had arrived fully developed from some other place. Çatal

dwelling; thus it served both as a smoke hole and as an entrance. All access from the outside to the roof was by a movable ladder. From the roof into the dwelling the usual access was by a fixed ladder, although some buildings had another entrance through a well-plastered ventilation shaft that apparently had a movable ladder. Communication between dwellings was accomplished over the rooftops. There is little evidence of lanes and passages, and the courtyards that exist (often merely a ruined house) appear to have been used only for rubbish disposal and excreta.

The system of roof entrances meant that the outside of the settlement presented a solid blank wall. This was a check against enemies and also against floods. It was evidently a successful defense system, as is indicated by the absence of any signs of massacre. About all any attackers could do—armed as they were with nothing more than bow and arrow, slings and stone tools—was to raid the cattle kept in corrals on the edge of the settlement or to set fire to the roofs. The defenders, in contrast, had the advantage of height and probably of superior numbers. In any case, because of the successful defense the only form of destruction suffered by Çatal Hüyük was fire. Most of the buildings in levels from VI to II were destroyed by fire; but with numerous hearths and ovens and the high winds of the region a disastrous fire about once a century is no more than could be expected.



Hüyük apparently represents a culture that was a forerunner of Hacilar's and eventually may be traced back farther than 7000 B.C.

As a result of these fires the carbonized remains of cereal grains and other foods are plentiful at Çatal Hüyük. There are also many animal bones. The food remains and the bones tell a great deal about the domestic economy of the settlement; the studies being made of them by the paleoethnobiologist Hans Helbaek of the National Museum of Denmark and the zoologist Dexter Perkins, Jr., of Harvard University will probably yield important additional information.

On the basis of what is now known Helbaek has described the grain finds as "the largest, richest and best preserved of all early cereal deposits so far recovered," providing "some of the most significant genetical and cultural" data yet obtained about early civilization. The grains, unlike the finds in other early Near Eastern settlements of cultivated plants little removed from their wild ancestors, include such hybrids and mutants as naked six-row barley and hexaploid free-threshing wheat, which were introduced into Europe from Anatolia in the sixth millennium B.C. The use made of the grains is indicated by the grain bins found in every house and the many mortars for dehusking and querns for grinding. In addition to cereals, peas and lentils the community grew bitter vetch and some other crops; the residents also collected nuts, fruits and berries.

The zoological remains are no less interesting: they show the presence of domesticated sheep even below Level X and cows as early as Level VII. Goats and dogs also appear to have been domesticated, but there is no indication that pigs were. Their absence may be due to religious considerations. Although the domesticated animals provided the community with wool, milk, meat and skins, the people had by no means abandoned hunting. Wild cattle and red deer were extensively hunted, as were wild asses, wild sheep, boars and leopards.

With such an abundant diet it is not surprising to find from the skeletons that the inhabitants were generally healthy. Bone disease was rare, teeth were good and this dolichocephalic (long-headed) people were fairly tall: the males ranged from about five feet six inches to five feet 10 and the females from five feet to five feet eight. Still, as is to be expected of such an ancient era, few individuals reached middle age.

The burials were inside the houses, beneath the platforms. Most of the skeletons we have found are those of women and children; presumably many of the males died away from home on hunting or fighting forays. The dead were buried in a contracted position, usually lying on their left side with feet toward the wall. Isolated burials were rare; some buildings contain several generations of a family, with 30 or more burials. It appears to have been the practice before final burial to strip the bodies of flesh by a preliminary interment, or by exposure to vultures, insects or microorganisms on an outdoor platform, sheltered by gabled structures built of reeds and mats. Thereafter the bones, still more or less held in position by the ligaments, were wrapped in cloth and given final burial, often being laid out on mats of cloth, skin or fur.

The burials provide information about the dress, weapons and jewelry of the Çatal Hüyük people. Male dress consisted of a loincloth or a leopard skin, fastened by a belt with a bone hook and eye; the men appear also to have worn cloaks fastened with antler toggles in the winter. The women wore sleeveless bodices and jerkins of leopard skin, with fringed skirts or string skirts—the ends of the string being encased in copper tubes for weighting. The women used bone pins for fastening garments.

Weapons buried with the men included polished stone maceheads, obsidian arrowheads and javelin heads and sometimes an obsidian spearhead. Frequently there was a fine flint dagger with a chalk or bone handle and a leather sheath.

Jewelry was mainly for the women and children. They wore the necklaces, armlets, bracelets and anklets we found made of beads and pendants in a great variety of stone, shell, chalk, clay, mother-of-pearl and (as early as Level IX) copper and lead. Cosmetics were

SITE OF NEOLITHIC CITY is this mound on the Anatolian plateau of Turkey. The Turkish word for mound is *hüyük*, and this one, which rises 50 feet above the plain, has the modern name of Çatal. After the inhabitants left about 6000 B.C. it lay deserted for 8,000 years; when excavations were started in 1961, it was heavily overgrown. In this photograph the view is from west of the site.

GENERAL VIEW OF EXCAVATIONS at Çatal Hüyük shows work in progress in Level VI, which is near the middle of the 12 levels of construction explored to date. The author chose Çatal Hüyük as the most promising of more than 200 sites he visited on the Anatolian plateau in a search for a representative Early Neolithic community. The site proved to have been a major settlement.

widely used, judging from the number of related articles we found, such as palettes and grinders for their preparation, baskets or the shells of fresh-water mussels for their containers and delicate bone pins for their application. The cosmetics probably consisted of red ocher, blue azurite, green malachite and perhaps galena. The women, once arrayed, used mirrors of highly polished obsidian to see the effect.

Several times we found food remains with the dead: berries, peas, lentils, eggs or a joint of meat put next to the deceased in baskets or in wooden bowls and boxes, which are carved with great delicacy. These wooden vessels are a characteristic of the Çatal Hüyük culture, and even when pottery began to appear in quantity around 6500 B.C., baskets and wooden bowls continued in use and had a strong influence on the pottery. The ovals and boat shapes, the lozenges and rectangles that appear in the pottery, not only from Level VI-A upward at Çatal Hüyük but also in the following Late Neolithic of Hacilar, have their origins in the wood-carving tradition of early Çatal Hüyük. In the same way numerous pottery vessels have features such as handles that derive from the earlier basketry.

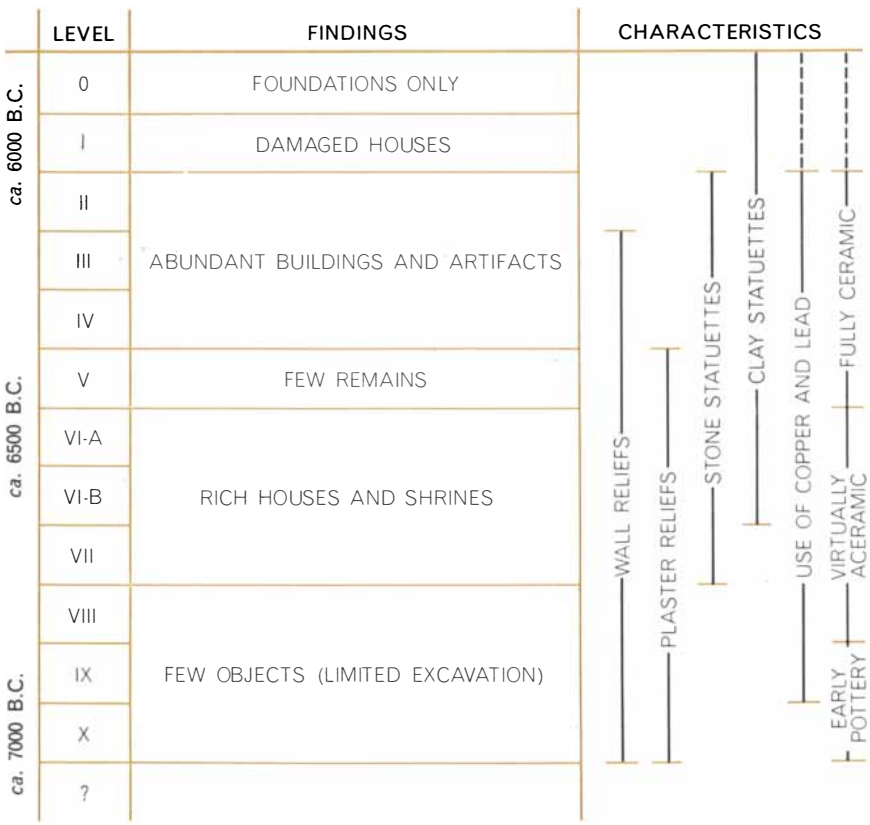
The first production of pottery at Çatal Hüyük is found in Levels X and IX, but evidently this soft ware could not compete with traditional wood and woven products. It was not until the end of Level VI-A, when technical improvements had led to the production of an excellent hard baked ware, that pottery came into general use. The pottery was handmade and highly burnished. At first it was all dark brown or black; cooking pots were left that way but other objects were soon turned out in red, buff or mottled tones. In the upper levels of the mound animal heads start to appear on oval cups, and an over-all red slip, or coating, is in use, but painting on pottery was apparently never achieved. This pottery develops without a break into that of Late Neolithic Hacilar.

Another area in which Çatal Hüyük shows a people of remarkable technical competence and sophistication is textiles. We found some carbonized textiles in burials as far down as Level VI. They appear to have been wool, and at least three different types of weaving can be distinguished. These are the earliest textiles yet known; Helbaek has written of them that "we shall be hard put to it to find evidence of more perfect work anywhere within the following thousand years."

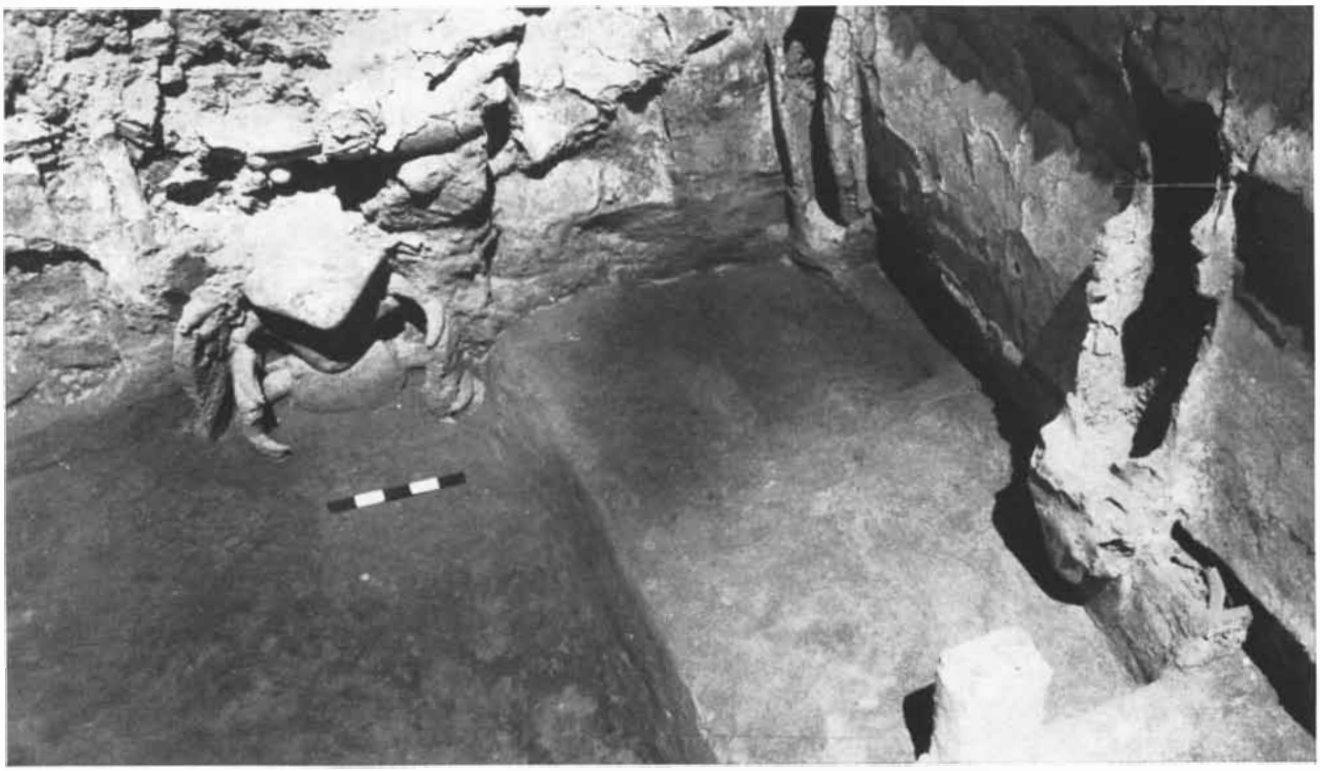
It is singular that with all these products of human workmanship we have found so few traces of the workmen. None of the 200 houses and shrines excavated so far has shown any evidence that any art or craft other than food preparation was carried on within. We have much fine woolen cloth but only one or two spindle whorls or loom weights, and these are from fill rather than from floor deposits. We have thousands of finely worked obsidian tools but only two small boxes of chips, thousands of bone tools but no piles of waste or splinters. Somewhere in the mound there must be the workshops of the weavers and basketmakers; the matmakers; the carpenters and joiners; the men who made the polished stone tools (axes and adzes, polishers and grinders, chisels, maceheads and palettes); the bead makers who drilled in stone beads holes that no modern steel needle can penetrate and who carved pendants and used stone inlays; the makers of shell beads from dentalium, cowrie and fossil oyster; the flint and obsidian knappers who produced the pressure-flaked daggers, spearheads, lance heads, arrowheads, knives, sickle blades, scrapers and borers; the merchants of skin, leather and fur; the workers in bone who made the awls, punches, knives, scrapers, ladles, spoons, bowls, scoops, spatulas, bodkins, belt hooks, antler toggles, pins and cosmetic sticks; the carvers of wooden bowls and boxes; the mirror makers; the bowmakers; the men who hammered native copper into sheets and worked it into beads, pendants, rings and other trinkets; the builders; the merchants and traders who obtained all the raw material; and finally the artists—the carvers of statuettes, the modelers and the painters.

The unusual wealth of the city of Çatal Hüyük, as manifested by this great variety of sophisticated workmanship, is a phenomenon as yet without parallel in the Neolithic period. At the base of course lay the new efficiency of food production, transplanted from its probable origin in the hills to the fertile alluvial plain. Although that may account for the unprecedented size of the city, something else is needed to explain the community's almost explosive development in arts and crafts.

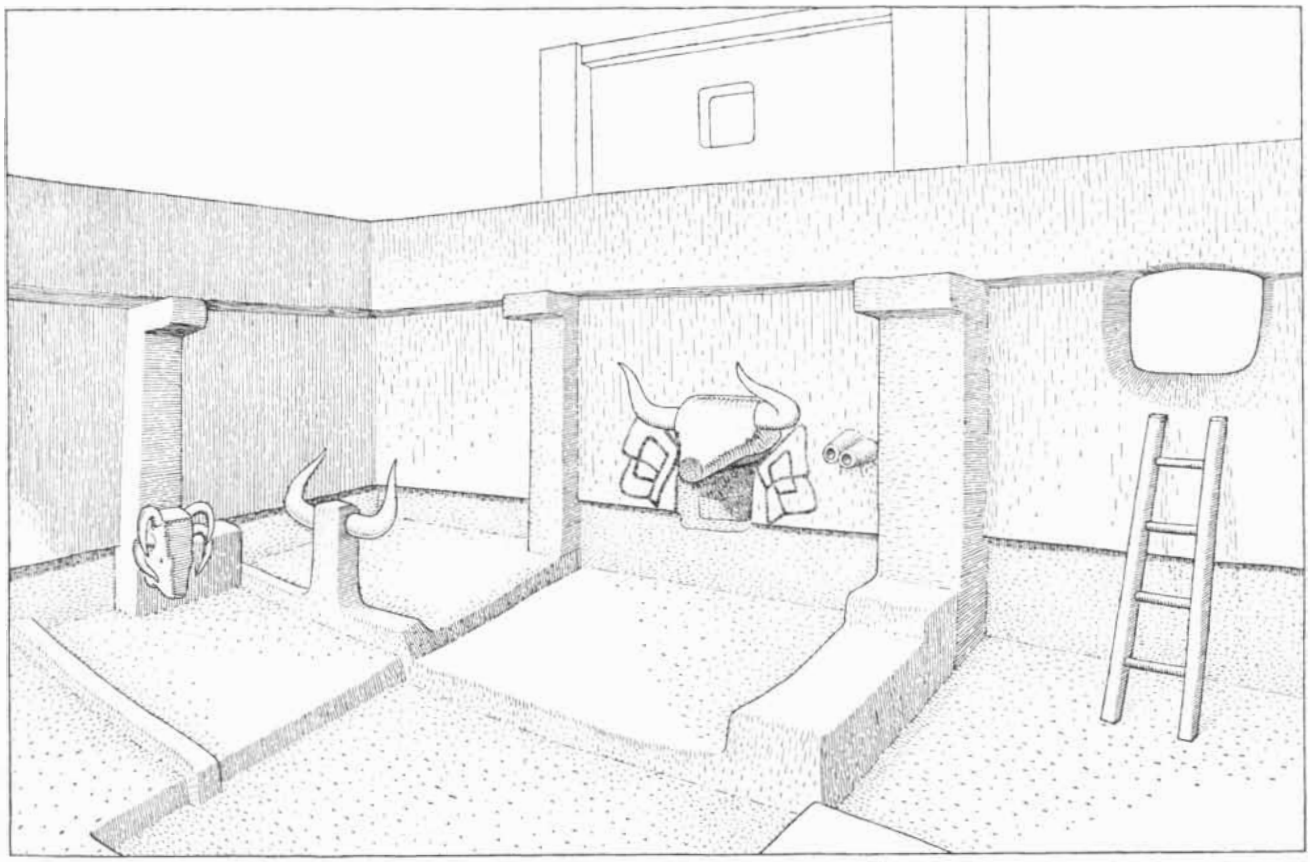
The key undoubtedly lies in the community's dependence on the import of



CHRONOLOGY OF HABITATION at Çatal Hüyük is indicated in this chart. Each level above VI-B apparently was built because of fire damage to the preceding level; the site appears to have been deserted after a fire in Level 0. Levels may yet be found below X.



EXCAVATED SHRINE is in Level VI. Three plaster heads of bulls appear atop one another on the west wall, with a half-meter scale below them; on the north wall is a ram's head made of plaster. At bottom right is the remaining part of a small pillar.



RECONSTRUCTED SHRINE is the same as that shown above. The drawing represents the author's conception, based on excavations of several shrines at Çatal Hüyük, of how the room might have looked in Neolithic times. The stylized heads of animals and women's breasts probably were fertility symbols. Many of the city's shrines also had wall paintings of remarkable sophistication.

raw materials (other than clay, timber and food) from near and far. One cannot possibly be wrong in suggesting that it was a well-organized trade that produced the city's wealth. Moreover, it appears likely that the trade in obsidian was at the heart of this extensive commerce. This black volcanic glass, which first appeared in the preceding Mesolithic period, became the most widespread trading commodity during the Neolithic period in the Near East. It has been found in the "proto-Neolithic" and prepottery Neolithic periods at Jericho; it occurs as far south as Beidha near Petra; it reached Cyprus in the sixth millennium. The origin of this obsidian, which was the best material of the time for cutting tools, was almost certainly central Anatolia, and it is extremely likely that the city of Çatal Hüyük controlled this source and organized the trade. The then active volcanoes of Hasan Dağ, Karaca Dağ, Mekke Dağ and others lie on the edge of the Konya plain. The nearest is some 50 miles east of Çatal Hüyük, and all are visible on a clear day. These sources of obsidian were well within the limits of the culture area of which Çatal Hüyük was the undisputed center.

This hegemony was not only economic but also religious and therefore political; in the ancient world no authority could exist without religious sanction. About the political system of Çatal Hüyük one can do little more than guess because there are no writings from the community. It seems likely, however, that at such an early stage of civilization only the priests could have been the bearers of authority.

Of the religious system one can say more because of the shrines and religious art we have found at Çatal Hüyük. In my view they constitute the community's most important archaeological contribution. I would maintain, perhaps wrongly, that the Neolithic religion of Çatal Hüyük (and of Hacilar) was created by women. In contrast to nearly all other earlier and later "fertility cults" of the Near East, it significantly lacks the element of sexual vulgarity and eroticism that is almost automatically associated with fertility and probably is the male's contribution. If the Çatal Hüyük religion is a creation of women, one has the rare opportunity of exploring Neolithic woman's mind by studying the symbolism she used in her effort to comprehend and influence the mysteries of life and death.

Of these symbols there is an abundance. In addition to schematic clay fig-

NEOLITHIC ARTIFACTS found at Level VI of Çatal Hüyük and dating from about 6500 B.C. include bone necklace, bone pin, stone beads, limestone bracelet and obsidian mirror.

WALL PAINTING found in Level VI shows children's hands. Çatal Hüyük yielded the earliest known paintings on man-made walls. Most of the painting had a religious purpose.

urines of people and more naturalistic animal figures, there is a unique collection of fine statuettes. Those from the upper layers are modeled in clay; those in the lower layers are carved from stone. Beyond these, which together with burial rites are usually the archaeologist's only sources of information about religion, Çatal Hüyük has produced no fewer than 40 shrines and sanctuaries. They are at every level, but the nine in Level VI-A, the 12 in Level VI-B and the eight in Level VII are particularly rich in information. Wall decorations occur in most: painted scenes with numerous human figures in Levels III and IV; modeled and sometimes painted reliefs in Levels VI-A through X.

The shrines, although frequently large and well appointed, do not differ in plan from the houses, but they are much more lavishly decorated [*see illustration on page 100*]. Even if they were not continuously lived in, they served as burial places, presumably for their priestesses and the priestesses' families. It is only in the shrines that we have found reliefs and symbolism connected with life and death. From these it is possible to reconstruct in some degree the Neolithic pantheon.

The supreme deity was the Great Goddess. Often represented beside her are a daughter and a young son. A bearded god, who is always shown on a bull, was perhaps the Great Goddess' husband. No other deities appear. This group, therefore, probably constitutes the "holy family." Statues and reliefs represent the female deities either as two goddesses or as twins. The idea behind the duplication is evidently that of age and fertility, the whole aim of the religion being to ensure the continuity of life in every aspect: wildlife for the hunter, domesticated life for the civilized communities and finally the life of Neolithic man himself.

It is doubtful that Neolithic thought regarded these as four distinct deities. More likely the representations show aspects of the goddess as mother or as daughter and virgin, with the god as consort or son. The role of the male deity is more pronounced at Çatal Hüyük than it is at Hacilar, perhaps because in Çatal Hüyük hunting and the domestication of wild animals still held major importance, but in general the male plays a subsidiary role.

Scenes dealing with life are generally found on the west wall of the shrines. A typical scene shows the goddess giving birth to a bull or ram. Scenes deal-

ing with death are found on the east wall: in three shrines the east-wall paintings show vultures attacking headless human corpses. Usually, however, the subject of death is expressed in more subtle ways. Representations of women's breasts, for example, which are of course symbolic of life, contained such items as the skulls of vultures, the lower jaws of wild boars and the heads of foxes and weasels—all scavengers and devourers of corpses.

The symbolism of west and east walls, or right and left, is matched by black and red: the red associated with life, the black with death. Panels of red hands are common, and several burial sites show remains of a coating of red ocher, which was evidently intended to be a substitute for blood and so a means of restoring life, at least symbolically. A great black bull covered the vulture paintings; both were symbolic of death. Contrasted with these was another painting of an enormous red bull surrounded by minute jubilant people.

There are some strange figures in the shrines. A stern-looking representation of the goddess was found with a headless bird, probably a vulture. Numerous figures roughly carved out of stalactites suggest a link with the dark world of caves, man's first refuge and sanctuary. An odd painting seems to represent a honeycomb with eggs or chrysalises on boughs and with bees or butterflies, which perhaps symbolize the souls of the dead. It is framed by alternate red and black hands along the top and gray and pink hands along the base. An earlier painting shows alternate red and black lines, resembling a net, similarly framed by hands. Net patterns decorate several other religious scenes, together with symbols of horns, crosses and hands. Crosses, perhaps a simplified form of a four-petaled flower, were painted on a statuette of the goddess as well as on numerous walls; probably they are to be interpreted as fertility symbols. Rosettes and the double ax (or butterfly) are in the same category.

In several shrines and houses schematized heads of bulls in the form of a pillar serve as a cult symbol for protection. We have found curious benches with one, two, three or seven pairs of the bone cores of horns stuck in the sides. These defy explanation. Perhaps they figured in the burial rites, conceivably serving as a bier while the grave was dug.

Of the rites performed in the shrines little can be said. It is apparent, however, from the absence of blood pits and

CLAY SEALS, most about the size of a postage stamp, apparently were used for identification. No house had more than one, and all the designs differed. These were in Levels II–IV.

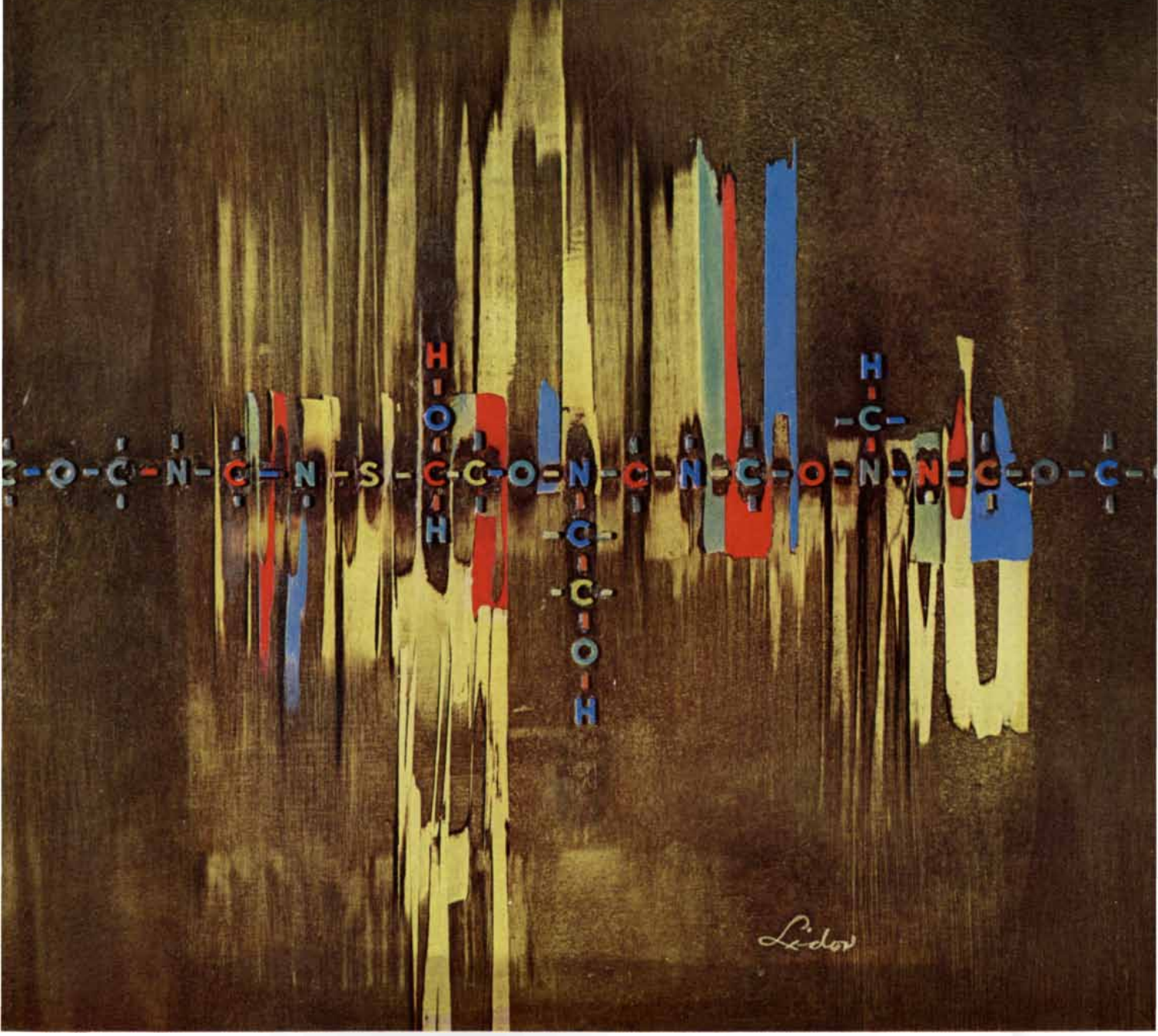
STATUE OF GODDESS, done in clay and about eight inches high, shows her giving birth. Many representations of the goddess were found at Çatal Hüyük; this was in Level II.

animal bones that there was no sacrificing of animals in the shrines. There were offerings of other kinds. In a shrine in Level II we found grain that had been burned on the plastered ceremonial altar and then covered by a new coat of plaster; this suggests the first offering after the harvest. In the earlier buildings, particularly in Level VI, there are offerings of all sorts: pots that doubtless contained food and drink; groups of hunting weapons, maces, axes and ceremonial flint daggers; tools; bags of obsidian; beads and many other objects, all unused or in pristine condition.

The wall paintings were mostly created for religious occasions and were covered with white plaster after they had outlived their usefulness. The paint was made of minerals mixed with fat; the painter worked with a brush on a white, cream or pale pink surface. The range of colors is extensive. Red in all shades, including pink, mauve and orange, is predominant. The other colors are white, lemon yellow, purple, black and (very infrequently) blue. We have yet to find green. In a class apart from the religious paintings are several paintings of textile patterns, which attest the importance attached to weaving. Many of them show kilims, or woven carpets, making carpet weaving an art that can now be traced back to Neolithic times.

Many seasons of work remain at Çatal Hüyük. It is therefore premature to speak definitively about the origins of this remarkable civilization. It can be said, however, that the discovery of the art of Çatal Hüyük has demonstrated that the Upper Paleolithic tradition of naturalistic painting, which died in western Europe with the end of the ice age, not only survived but flourished in Anatolia. The implication is that at least part of the population of Çatal Hüyük was of Upper Paleolithic stock.

These people may not have been the first to learn the arts of cereal cultivation and animal husbandry, but they improved on the techniques to such an extent that they were able to produce the surplus of food that permits the beginning of leisure and specialization. By the seventh millennium they had created the first Mediterranean civilization, of which Çatal Hüyük is such an impressive representative. In time the offshoots of that civilization reached the Aegean shore, and by the sıxth millennium Anatolian colonists were laying the foundations for the ultimate development of civilization in Europe.



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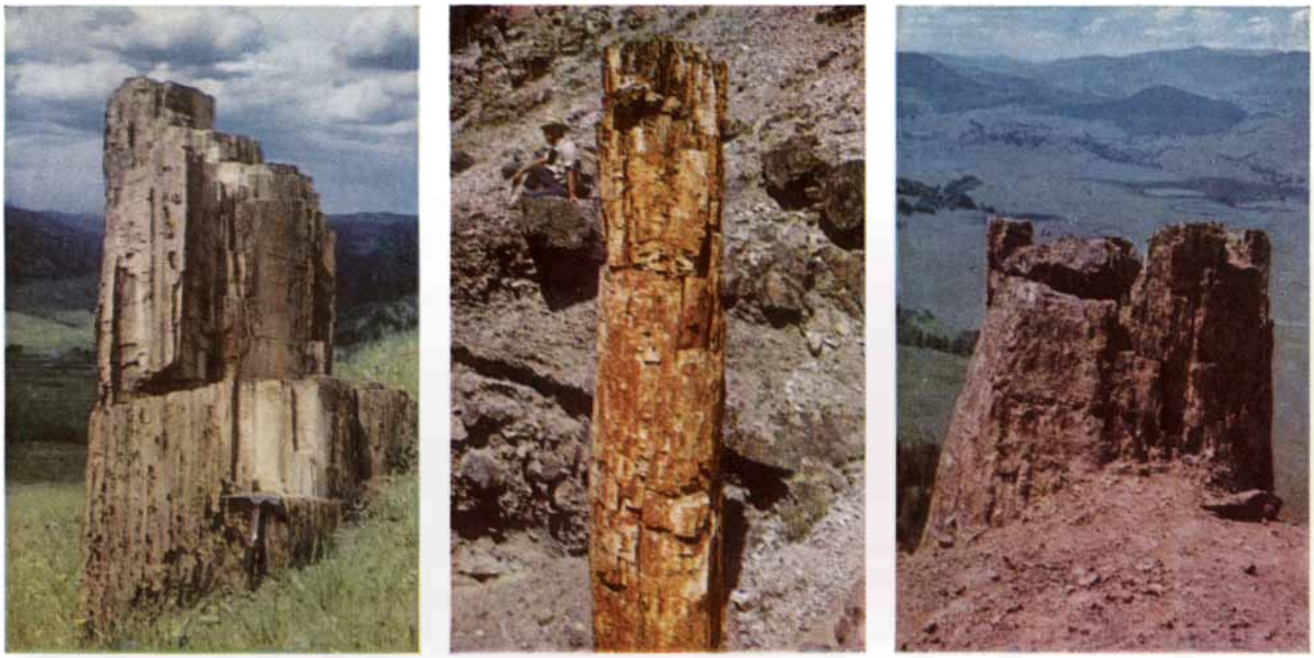
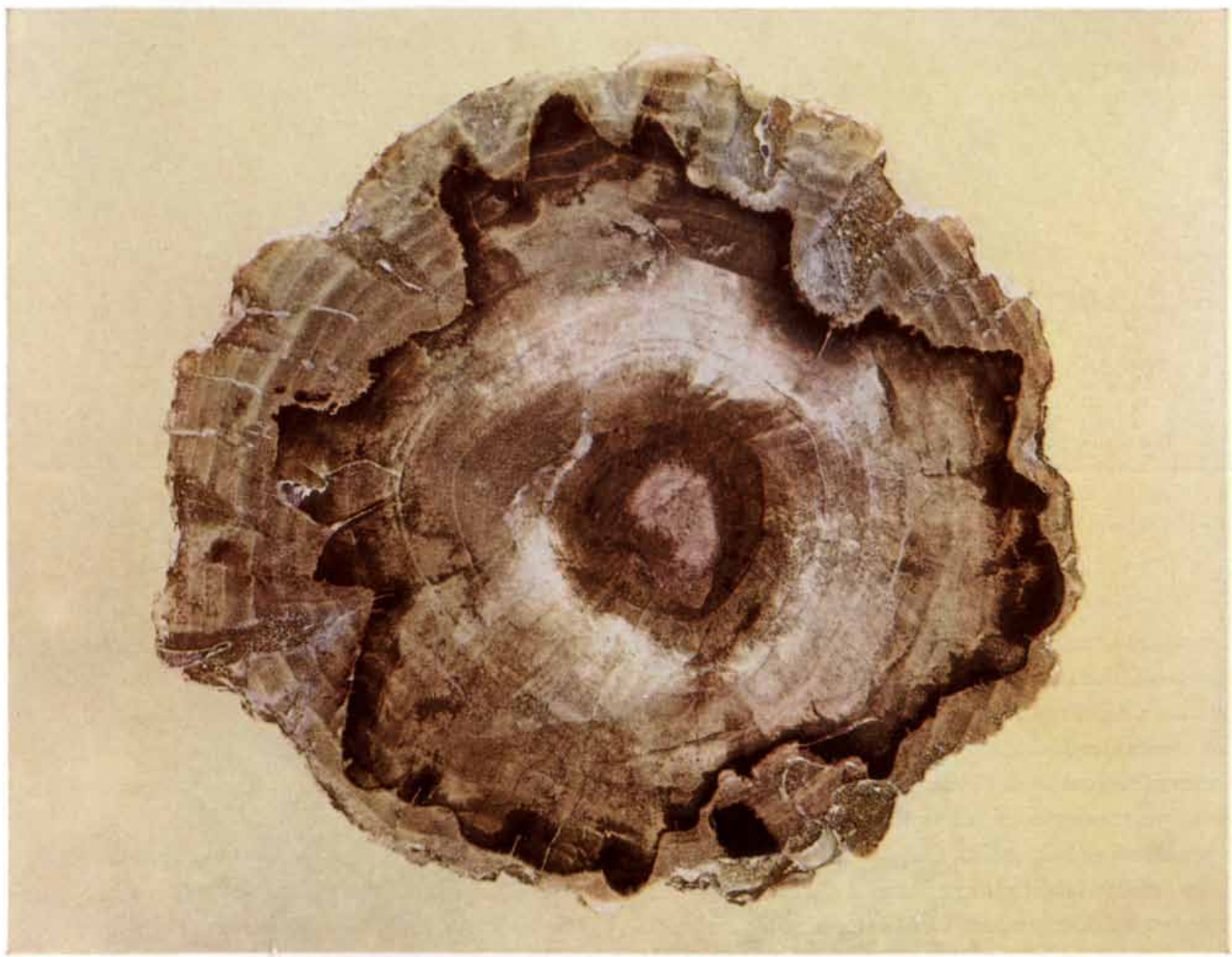


PETRIFIED TREE TRUNKS were all photographed in the vicinity of Specimen Ridge in northeastern Yellowstone Park (*see bottom map on page 108*). Pine stump (*left*) is on the grassy northern slope of the ridge. Sycamore (*center*) has been freed from the surrounding volcanic debris by erosion. Redwood stump (*right*) is one of the largest in the area, having a circumference of about 16 feet.



CROSS SECTION of a petrified branch of an extinct genus of pine (*Pityoxylon*) is shown slightly larger than actual size in this photograph. Colors are caused by impurities in the petrifying mineral (silica) and by residual carbon from the original wood.

The Petrified Forests of Yellowstone Park

The most extensive fossil forests of their kind in the world, they contain much information about the climate and geologic history of the Rocky Mountain region some 55 million years ago

by Erling Dorf

The northeastern quadrant of Yellowstone National Park is a rugged, mountainous region lying between 6,000 and 11,000 feet above sea level. Its climate is characterized as being from cool-temperate to subarctic; its forests consist of conifers with a small admixture of hardwoods. During the Eocene epoch, which lasted from some 60 million to 40 million years ago, the same area presented a strikingly different scene. The countryside was a series of broad, flat river valleys separated by gently rolling hills. The average elevation was between 2,000 and 4,000 feet and the climate ranged from warm-temperate in the hills to subtropical in the valleys. Rainfall was probably between 50 and 60 inches a year. The composition of the dense lowland forests was roughly the reverse of what it is today, with the hardwoods dominant and the conifers in the minority.

These and many other details of the geologic, climatic and botanical conditions prevailing in the region during the Eocene have been preserved by a remarkable series of events that transformed the ancient forests into forests of stone. The first stage in this transformation was sudden and catastrophic. Volcanic eruptions to the east and northeast of the present boundaries of Yellowstone Park showered the surrounding valleys with rocks, ash and other debris, which accumulated gradually over a number of years until, at the end of the period of volcanic activity, the forests in the valleys were buried to an average depth of 10 to 15 feet. After some 200 years a new forest began to grow on top of the desolate blanket of volcanic debris. Meanwhile mineral-bearing waters below the surface had begun the long process of turning the buried tree trunks into stone. Today, many millions of years later, the volcanic matrix surrounding the buried trunks has eroded away in places, leaving the petrified remains of the ancient trees standing upright exactly where the trees had been growing originally.

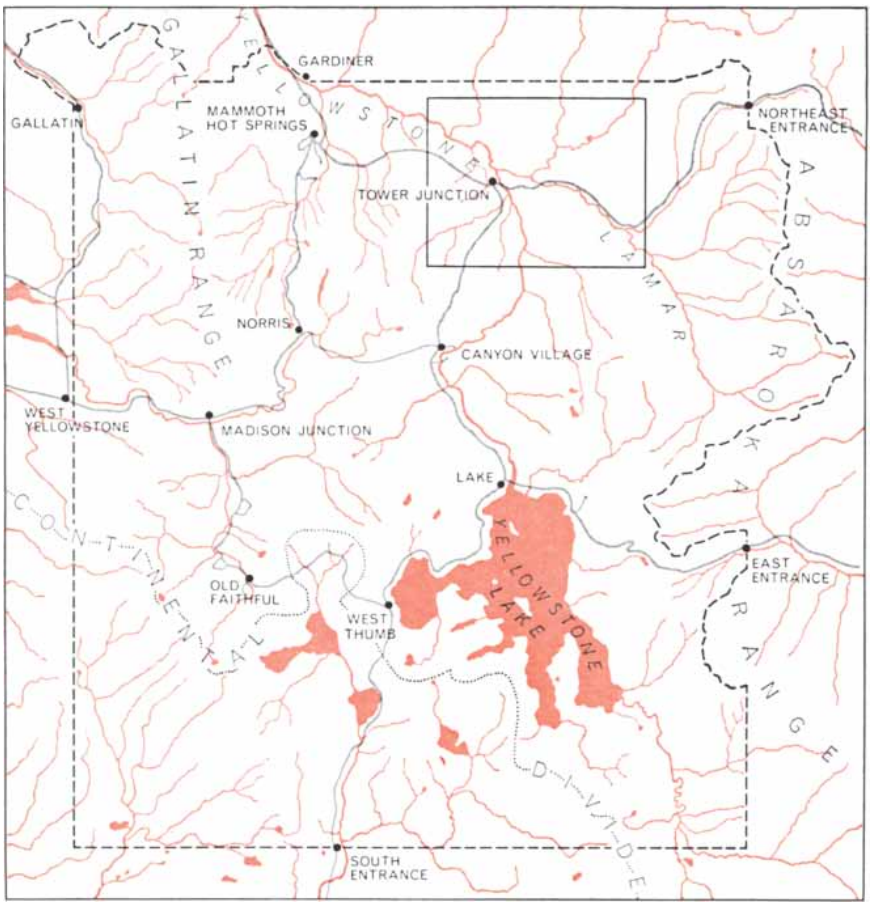
This remarkable accident of preservation alone would be enough to make the petrified forests of Yellowstone Park extremely valuable to the paleobotanist. The much more famous "petrified forest" in the Painted Desert region of eastern Arizona is really not a forest at all. The hundreds of huge stone logs that lie scattered in all directions in this region are far from the site where they once grew, having been carried downstream in an ancient "log drive" some 175 million years ago. Although there are a few other places in the western U.S. where petrified tree trunks still stand upright in their original position, the fossil forests of Yellowstone Park are by far the most extensive of their kind in the world, covering an area of more than 40 square miles.

What makes these forests even more extraordinary, however, is the evidence that in at least one location the whole process of burial and petrifaction took place not once but many times. On a steep bluff overlooking the Lamar River a few miles above its confluence with the Yellowstone River [*see bottom map on page 108*] no fewer than 27 distinct layers of petrified trees have been exposed by erosion. These layers, which total about 1,200 feet in depth, represent alternating periods of violent volcanic activity and quiet forest growth over a span of some 20,000 years. A detailed study of the petrified trunks, fossilized leaves and other plant remains in these layers has yielded much information about the climate and geologic history of the Rocky Mountain region during the Eocene epoch.

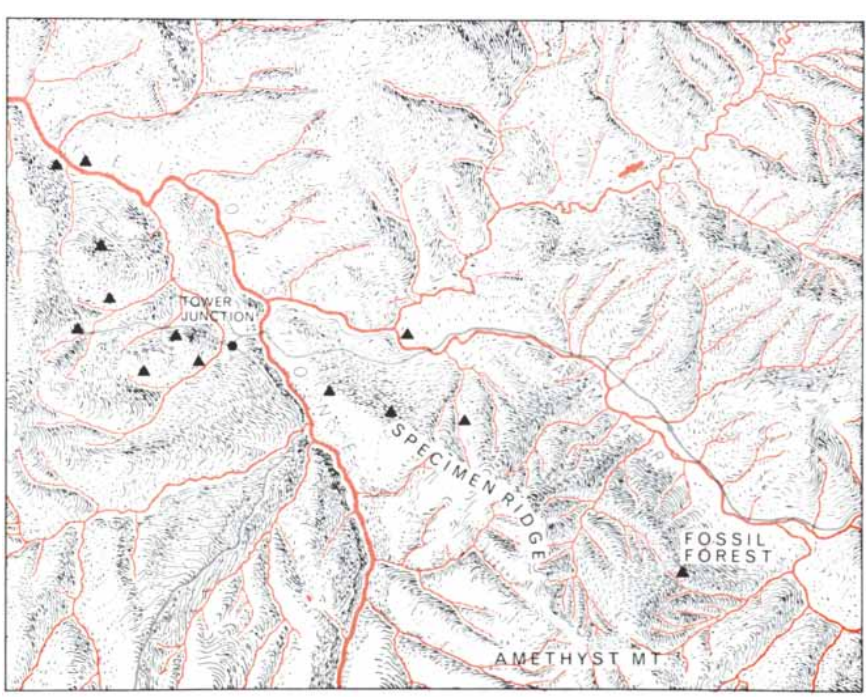
The "Fossil Forest" in the vicinity of the Lamar River and several other groups of petrified trees nearby were discovered in the 1870's by W. H. Holmes, an artist, explorer and geologist. In a report to the U.S. Geological Survey made in 1879 Holmes wrote: "The bleached trunks of the ancient forests . . . stand out on the ledges like the columns of a ruined temple." Holmes was able to count "10 or more buried forests," which he portrayed in a drawing accompanying his report. Over the past few years my students at Princeton University and I have visited the site on many occasions. Our investigations have added 17 layers of forest to Holmes's 10; our revision of his drawing appears on page 110.

The material in which the forests are buried consists chiefly of three different types of sedimentary rock: (1) conglomerates, or consolidated masses of rounded pebbles believed to have been laid down as stream deposits; (2) breccias, or similar masses composed mainly of angular fragments and probably deposited in the course of extensive mudflows or landslides, and (3) tuffs, or solidified volcanic ash deposited directly from the atmosphere, usually into lakes and streams. Of these only the tuffs contain fossilized plant remains other than petrified trunks; these remains include fossilized leaves, ferns, cones, needles and seeds [*see illustrations on page 112*]. Associated with the fossil-bearing volcanic layers are other beds—some of them 1,000 feet thick—of basalt, a dark, fine-grained, solidified lava. Since the lava was hot at the time it spread over the land, there are no petrified trunks or other plant remains in these beds.

Geologists have suspected for a long time that volcanic sediments are generally deposited much more rapidly



YELLOWSTONE PARK (*area inside broken black line*) **is the oldest and largest national park in the U.S., occupying more than two million acres in northwestern Wyoming, Idaho and Montana. Rectangular area inside solid black line at top right contains most of the petrified trees in the park and appears in larger scale in map below. Gray lines are roads.**



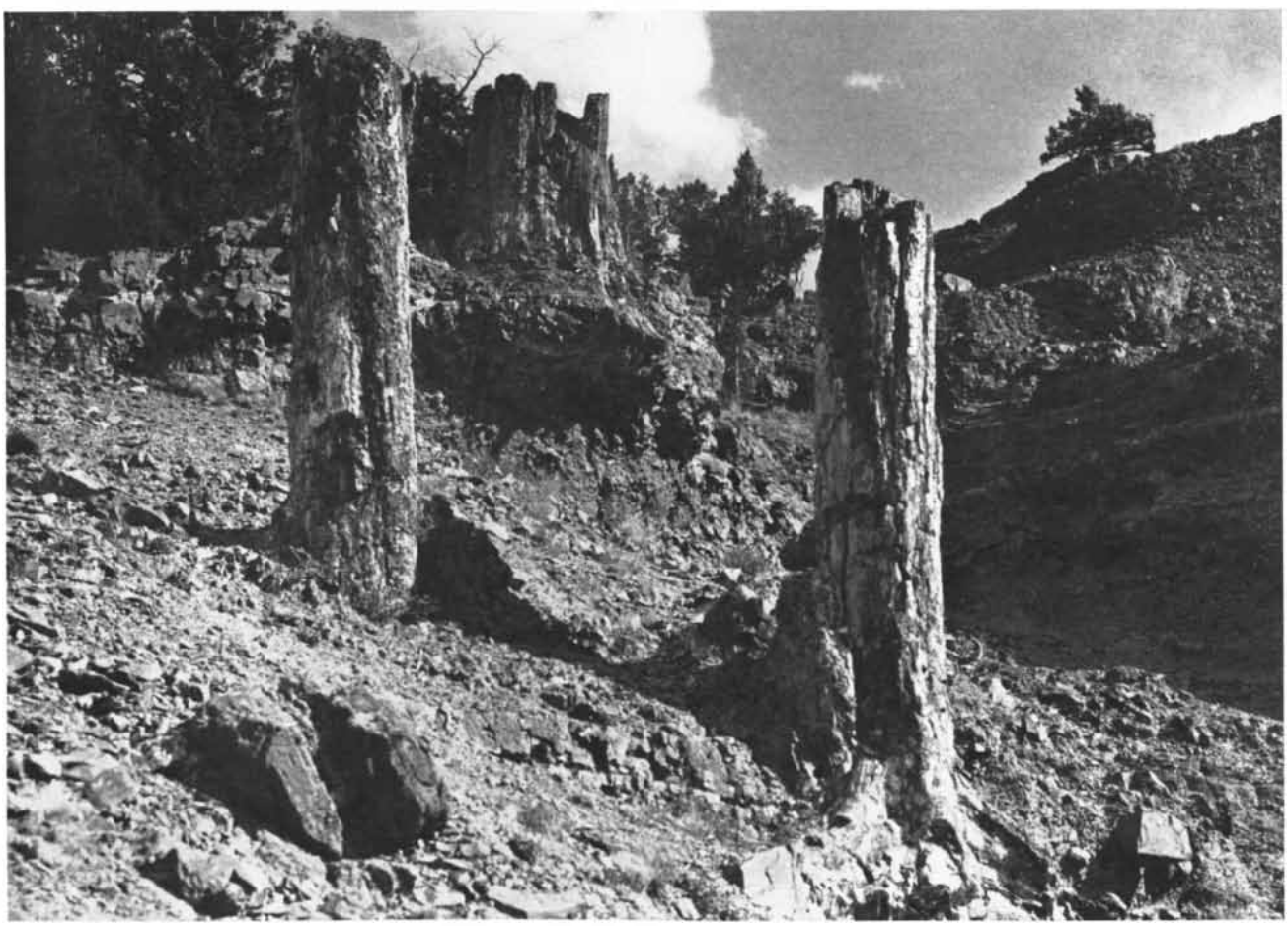
PRINCIPAL SITES where petrified trees and other fossilized plant remains have been discovered are indicated by black triangles on this map. "Fossil Forest" is at bottom right.

than other sediments. We were able to confirm this suspicion by calculating the rate of deposition of the fossil-bearing beds in the Lamar River region. We observed that each of the 27 forests in these beds was buried by a single deposit of volcanic debris. We also knew from more recent volcanic eruptions in Mexico that a new forest begins to grow on top of a volcanic sediment about 200 years after the sediment has been deposited. By counting the number of annual growth rings in the buried stumps we were also able to estimate the age of each forest at the time of its burial. In some cases we found as many as 500 of these growth rings. From these data we were able to calculate that the entire 1,200-foot "layer cake" of sediments exposed at this site must have been deposited over a period of some 20,000 years. This is equivalent to about three-quarters of an inch a year, a rate of deposition roughly 100 times more rapid than that estimated for shallow-water sand or mud sediments of a comparable age in the Gulf Coast region of southeastern North America.

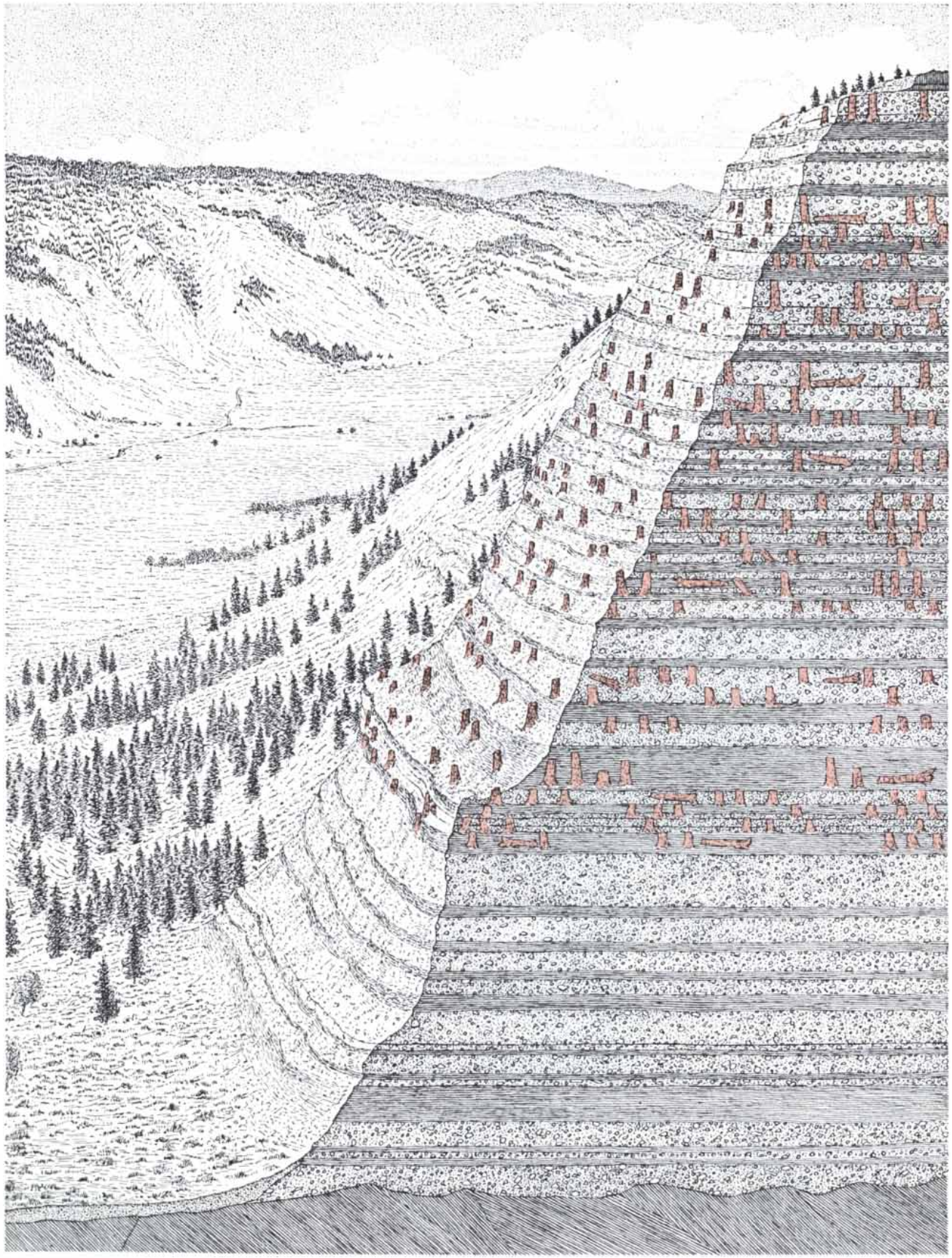
The mechanisms involved in the preservation of plant fossils in volcanic sediments vary considerably. The process of petrifaction, which transforms buried stumps or logs into stone, is now known to be quite different in most cases from the old textbook explanation of a "molecule-by-molecule replacement" of plant materials by mineral matter. In 1927 Ruth N. St. John of Cornell University showed that usually the mineral matter merely fills the cavities inside the empty wood cells. During the process the tough cellular walls of the wood become surrounded almost in their original state by the petrifying mineral matter. This preserves even the most delicate microscopic details of the original wood.

In the Yellowstone Park region the petrifying mineral is almost always silica, or quartz (SiO_2), which originated in the volcanic sediments and was circulated through the buried trees by underground water, some of which was probably hot. On the polished surface of a piece of petrified wood from the region the silica can be dissolved away by carefully immersing the sample in hydrofluoric acid; this will expose a projecting residue of the embedded wood, whose original cellular structure is usually found to be very well preserved. Often the original wood retains its shape and consistency well enough to be cut with a knife or sectioned into

"FOSSIL FOREST" is the collective name given to this site on the northeastern slope of Amethyst Mountain, where the petrified remains of no fewer than 27 Eocene forests have been exposed to view by erosion. A drawing of the site appears on the following page.



EROSION of the volcanic debris under which these large upright trunks were buried during the Early Eocene epoch (some 55 million years ago) has exposed them to view today. Trunks are on northern slope of Specimen Ridge. Roots are visible at bottom right.



CUTAWAY VIEW of a cliff in the Fossil Forest region of northeastern Yellowstone Park reveals the 27 layers of volcanic sediments that contain fossilized plant remains of Eocene forests. Petrified tree trunks are in color. The fossil-bearing beds total about 1,200 feet in depth. In this idealized landscape the cliff overlooks a portion of Lamar River valley (*left background*).

slices for study in exactly the same way as ordinary wood is prepared for examination. Sections can also be cut directly from the petrified wood [*see illustration on page 114*].

The fossilized leaves and other fragile plant remains were not preserved by the process of petrifaction. Instead the rapid burial of these materials in fine volcanic ash prevented their decay, preserving them either in the form of compressions, in which some of the original plant substance is still present, or impressions, in which some of the original the original plant remains. (The fossilized remnants of animals are extremely rare in the Yellowstone volcanic deposits, probably because animals are able to migrate out of a volcanic region as soon as the proportion of ash and dust in the air makes breathing difficult.)

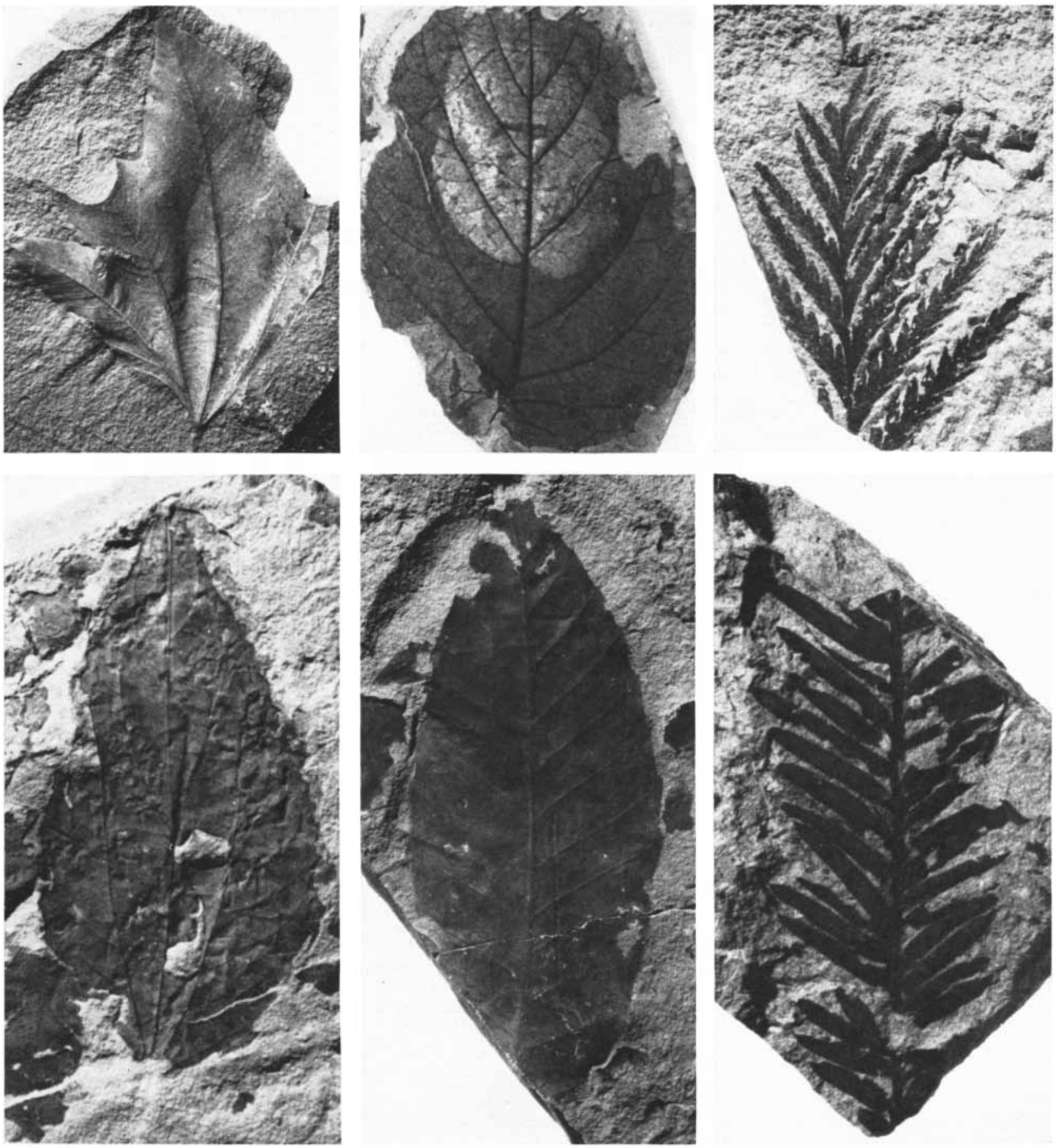
So far we have been able to identify more than 100 different species of plants in the fossil beds along the Lamar River valley. Of these about a fourth are conifers, ferns and other nonflowering plants. The remaining three-fourths are various flowering species, predominantly hardwoods. The most numerous hardwood species in the Eocene forests were apparently large-leaved sycamores, walnuts, magnolias, chestnuts, oaks, redwoods, maples and dogwoods. Most of these species have their nearest living relatives in today's warm-temperate to subtropical forests, such as those found in the southeastern U.S. Also fairly common were species of figs, laurels and bays, whose nearest living relatives are found chiefly in today's tropical forests. Exotic species, whose descendants have since been completely exterminated in North America, included ancient relatives of the Oriental katsura tree and the Asiatic chinquapin and breadfruit trees. Among the less abundant species were climbing ferns, pines, soapberries, hickories, bayberries, elms and willows.

The simple assumption on which our conclusions about the climatic conditions prevailing in this region during the Eocene epoch are based is that these fossil plant species must have had the same general climatic requirements as their nearest living relatives. Thus we conclude that the Eocene climate in the vicinity of what is now Yellowstone Park was essentially the same as that which now prevails in the Gulf Coast region of southeastern North America. The change from a humid, nearly subtropical climate to the present cool-temperate to subarctic conditions was probably the result of a general world-wide

cooling accompanied by a gradual uplifting of the entire Rocky Mountain area by as much as 7,000 feet over the past 40 million years.

Our study of the fossil plant species from Yellowstone's volcanic rocks has also enabled us to determine more accurately than ever before the age of these rocks. By comparing them with known fossil species from different parts of the world we have found that they date from either the latest part of the Early Eocene epoch or from the early part of the Middle Eocene (roughly 55 million years ago). The span of time covered by such a range is probably less than a million years.

Is volcanic activity of the type that produced these fossil forests likely to begin again in the Yellowstone Park



SIX EXTINCT SPECIES of plants native to the forests in the Yellowstone region during the Eocene epoch are represented by the fossils in these photographs. At top left is the impression of a leaf from an extinct species of sycamore, the most abundant tree in the Eocene forests. At top center is a leaf from an extinct grapevine. At top right is a fern related to today's spleenworts. Leaf at bottom left is from a tree related to the rare Chinese katsura tree. Leaf at bottom center is from a meliosma tree, whose nearest living relatives are restricted to tropical and subtropical forests. Needles at bottom right are from an ancient relative of today's redwood tree. All the fossils except sycamore leaf contain remnants of original plant substance and are called compressions.

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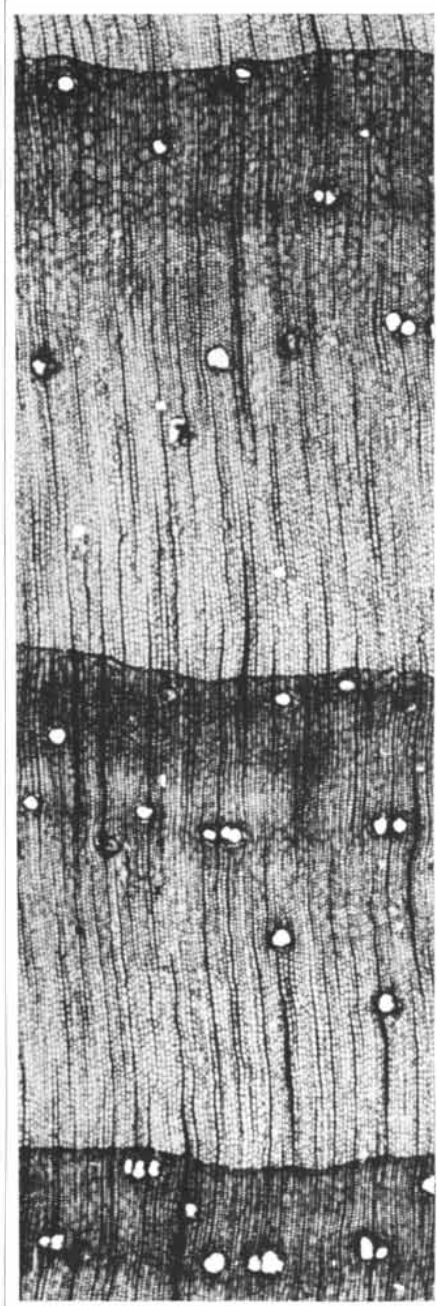
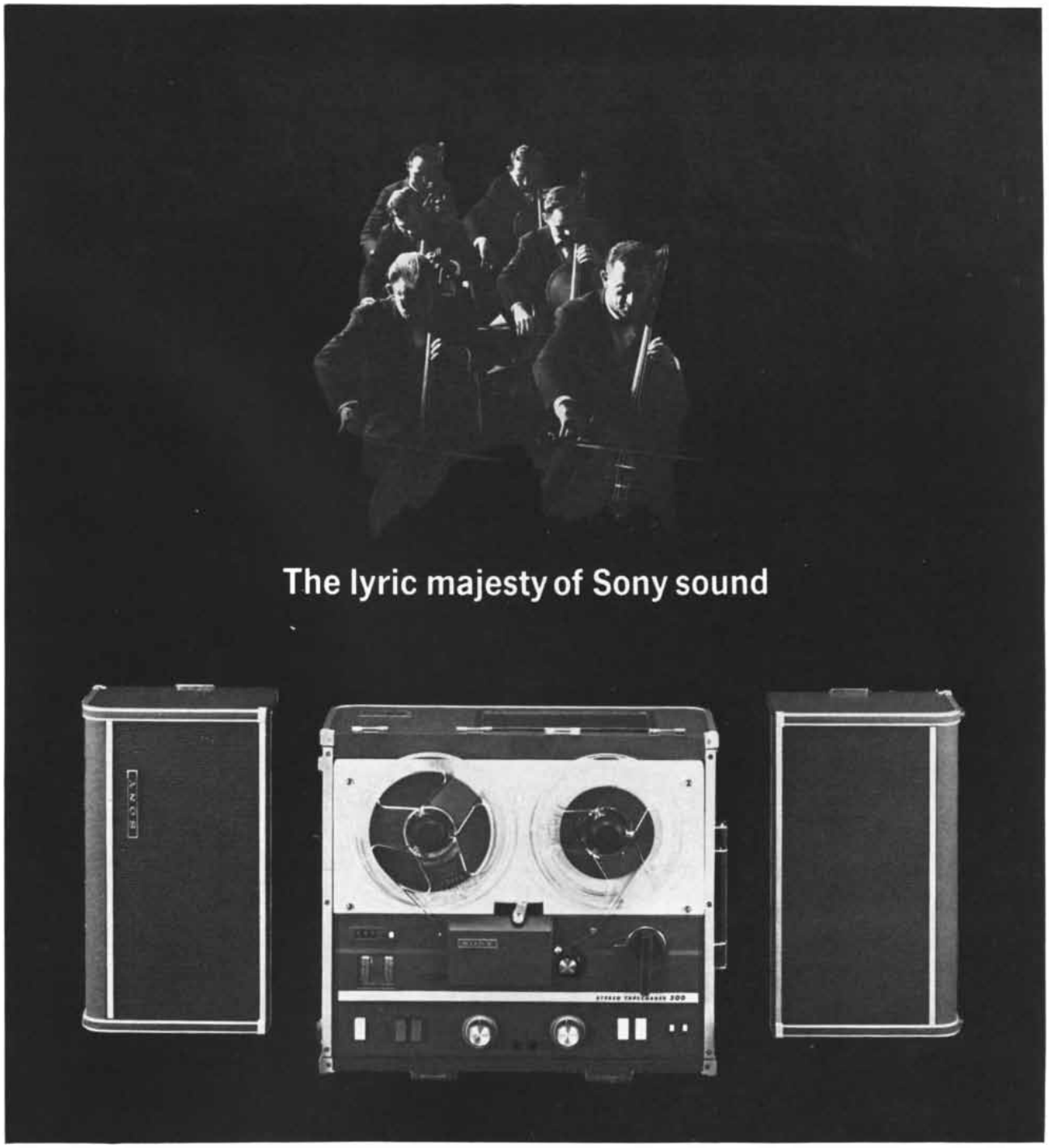
region? New evidence has recently been presented by F. R. Boyd of the Carnegie Institution indicating that the last outpouring of lava in this region occurred during the Pleistocene epoch, probably less than 100,000 years ago. In more recent years the continuing activity of geysers, hot springs and other hydrothermal phenomena as well as recurring earthquakes strongly suggest that volcanic activity is merely dormant in the Yellowstone Park region and may well resume at any time.



CELLULAR STRUCTURE of a petrified piece of extinct pine wood is exceptionally well preserved in this transverse section. The dark horizontal bands are annual growth rings. Section was cut directly from the petrified wood with a diamond saw.



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EFFECT OF SOUND on bees in a hive is illustrated by these photographs made by the author. Bees are normally in constant motion, but they quiet down at the sound of "piping," a beeping tone produced by workers. The normal motion is shown by the blurred images in the top photograph, which was made at a fifth of a second. When piping was simulated and transmitted to the hive wall by a vibrator, the bees became almost motionless, as shown by bottom photograph, made at the same aperture and speed.

Sound Communication in Honeybees

It has been known for some time that bees perform an intricate dance in directing their hivemates to a source of food. Now it appears that they also transmit information by means of sound

by Adrian M. Wenner

Can we ever fully understand how the members of another species communicate with one another? The question has been given a new implication by the recent proposals that we listen for messages from the planets of other stars. Whether we ever detect such messages or not, we can investigate the question here on earth. We now know of many forms of communication in other species. None is subtler or more interesting than the "language" of the honeybee.

It is no accident that Karl von Frisch of the University of Munich chose the bee for his now famous investigations of animal communication. A honeybee colony is a marvelously compact community of some 50,000 individuals; it takes care of itself and usually ignores its human investigator; its members are highly social and could not survive without constant intercommunication, and the more one looks into their methods of conversation, the more remarkable they are found to be.

The obvious features of honeybee communication have been reported widely and are now a familiar story. When a foraging bee finds a source of food, it flies back to the hive and conveys to its fellows the distance and direction of the source. In the course of doing so it performs on the vertical surface of the comb a waggling "dance" in which its abdomen traces a figure eight. The orientation and rate of the dance, it has been supposed, tells the location of the food source. This hypothesis runs into an awkward difficulty: the interior of most hives is so dark that the bees probably cannot see the dance. Investigators of the phenomenon have found, however, that the bees follow the dance by means of their antennae, which touch the dancer's body.

Robert C. King of Servomechanisms, Inc., and I, working in my laboratory at the University of California at Santa Barbara, looked into the question further. The dancing bee traces the figure eight with the tip of its abdomen. That is not, however, the part of the body on which the observing bees usually concentrate their attention: their antennae tend to rest on the dancer's thorax. Does the thorax also describe a figure eight during the dance? We marked foraging bees with a spot of white paint on the thorax and later photographed its movement during the course of the dance in the hive by means of a series of rapid-flash exposures. The pictures showed that the thorax did not describe a figure-eight pattern [*see lower illustration on page 119*].

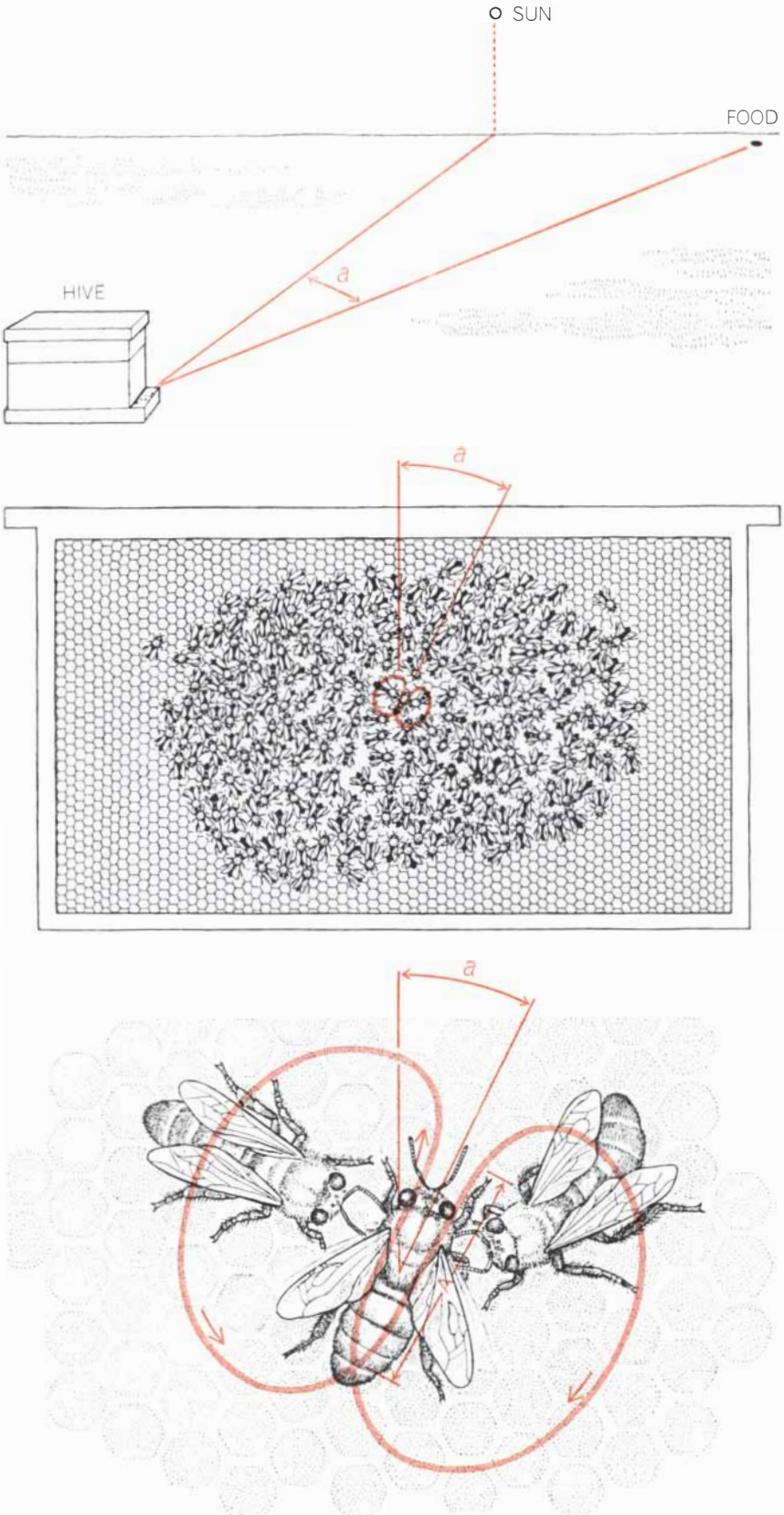
The dance pattern itself, then, can hardly convey an unequivocal message. What can? Using a tape recorder, I had discovered that during the dance the bee emitted a peculiar sound at the low frequency of 250 cycles per second. This sound was made while the bee was waggling along in the straight run of its dance. It suggested a surprising new outlook on the whole problem. Perhaps the honeybee communicated with its fellows not only by the dance movement but also by sound signals!

To test this possibility I made tape recordings of the sounds made by dancing bees after they had visited dishes of sugar syrup placed at different distances from the hive. Would the sound patterns show a relation to the distance traveled? In other words, did the foraging bee tell its hivemates the distance by means of a sound language?

Analyzed with the sound spectrograph, the sounds proved to be made up of trains, each train being further broken into pulses with a frequency of about 32 per second [*see top illustration on page 121*]. The bee emitted a train of sound during each straight run of its waggling dance. A careful analysis showed that the average length of the sound trains during a given dance (and also the average number of pulses in a train) was directly proportional to the distance the bee had traveled to the food source [*see bottom illustration on page 121*]. The correlation was so good that it seems altogether likely—certainly as likely as any other proposed mechanism—that the bee reports the distance by means of this sound language.

How is the sound produced? The first and most obvious guess was that the bee might create the pulses of sound with the waggling of its abdomen. To resolve this question I attached a small piece of cellophane to a microphone and placed the microphone so that with each waggle the dancing bee would tap the cellophane. The sound pulses proved to be about two and a half times more frequent than the waggling taps, so it became clear that the sound could not be arising from the waggling. Harald Esch, now at the University of Munich, who independently had discovered the honeybee's dance sound at about the same time as I had, also demonstrated that it was not produced by the waggling. Instead of a cellophane-and-microphone device, he used the ingenious method of attaching a small magnet to the bee's abdomen; as the bee moved the magnet it generated a fluctuating electric voltage that was recorded simultaneously with the pulsed sound, so that the waggle and pulse rates could be compared.

The function of the sound train was illuminated by considering the question of whether or not the bee's judgment of distances is affected by the wind. Analysis of the sound-train records showed that it is to some extent. When



FORAGING BEE must transmit to its hivemates information about the distance from the hive to the food source (*top drawing*) and the angle (*a*) between the direction of the source and the direction of the sun. It does a dance on the honeycomb in which its abdomen describes a kind of figure eight (*middle*). The "straight run" (*A*) of the dance (*bottom*) has a duration proportional to the distance to the food, and it is oriented at an angle from the vertical equal to angle *a*. "Recruit" bees track the dancer's side with their antennae.

a bee flies to a source of food against the wind, the sound trains indicating the distance tend to be a little longer than when it does not buck a wind. The deviation from the true distance is not nearly so much, however, as one might expect on the basis of the wind velocity. A possible explanation is that the bee adjusts its flying efforts to the wind so that it always flies at about the same ground speed; thus, whatever the wind velocity, it can still use the elapsed time of travel to a goal as the measure of its distance. I measured the flight speed of bees under various wind conditions and found that they do tend to fly at a constant ground speed. For example, flying against a wind of five meters per second (about 11 miles per hour) bees are slowed by only about a fourth of that amount. They minimize the wind effect by flying closer to the ground. When the wind is too strong (more than 13 miles per hour), the bees simply stay in the hive.

We may conclude, then, that the foraging bee's communication to its fellows in the hive is made up of two elements: the dance and the accompanying sounds. The angle of the dance from the vertical is correlated with the angle between the food source and the overhead sun, and the length of the train of sound during the straight run of the dance tells the distance. This may not be the whole story, however. Some current experiments indicate, for instance, a strong correlation between the rate of pulse production and the strength of the sugar concentration in a food source. It may conceivably turn out that the foraging bee's entire message is carried by sound signals.

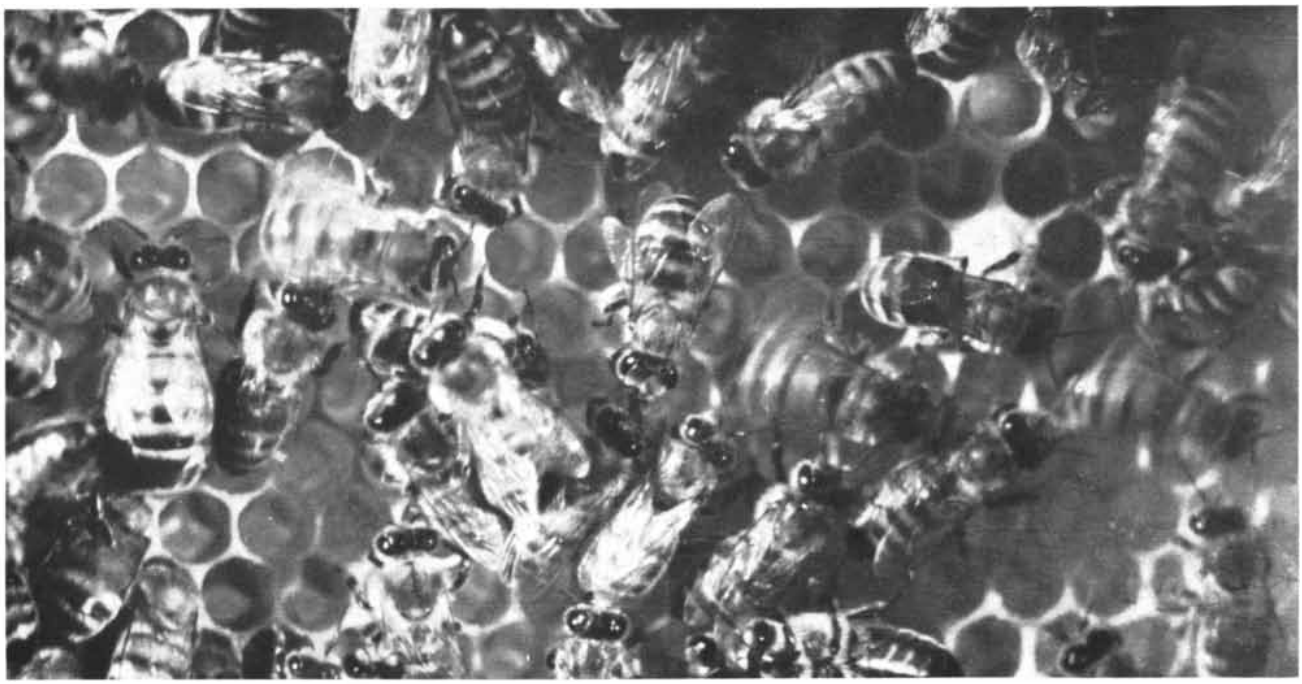
The sound spectrograph's indication of regularity and precision in the bee's dance sounds naturally drew attention to other forms of bee "talk." As everyone knows, the bee is a rather noisy animal. Even its buzz in flight, however, is not just noise. The buzz has modulations and variations. When bees begin to swarm, an experienced beekeeper can detect the event by the sound alone, even though he may be surrounded by other buzzing bees from hundreds of hives. When an individual bee is aroused to attack, its buzz rises in pitch and fluctuates in intensity. And recordings within the hive show that bees in the hive make at least 10 distinctly different sounds, some of which have already been related to specific activities.

Two of these sounds are particularly

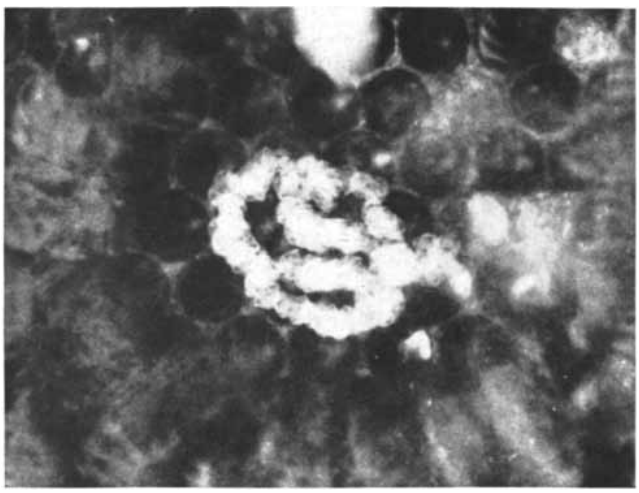
noticeable. One, known as the characteristic hum of a beehive, is produced by the "ventilating" worker bees: bees that stand anchored on the comb or some other structure in the hive and create currents of air by beating their wings. This sound, varying in intensity, has a basic frequency of 250 cycles per second and often has strong overtones. It is usually much louder than the buzz of a flying bee, undoubtedly because the sound emitted by the ventilating bee is enhanced by the resonant vibration of the structure on which it is standing.

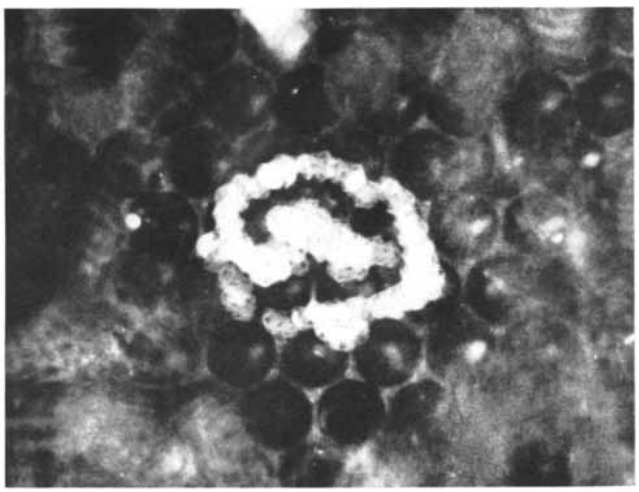
The other type of loud sound in the hive is heard when the hive is disturbed. When an intruder—for example an ant—approaches, the bees guarding the hive rock forward on their legs and issue a short burst of sound; they may go on repeating these warning bursts every two or three seconds for 10 minutes or more. When the hive is jarred, the collective reaction of hundreds of guarding bees is heard as a sharp, loud buzz. This is followed shortly by a "piping" of workers throughout the hive, which consists of faint beeps at half-second intervals, the sound being a complex one with a fundamental frequency of 500 cycles per second. The piping goes on for several minutes. Apparently it serves to soothe the hive; it has been found that a recording of such piping, played to the hive, will quickly quiet the disturbed bees.

The most interesting of all the hive sounds, however, is the piping of the

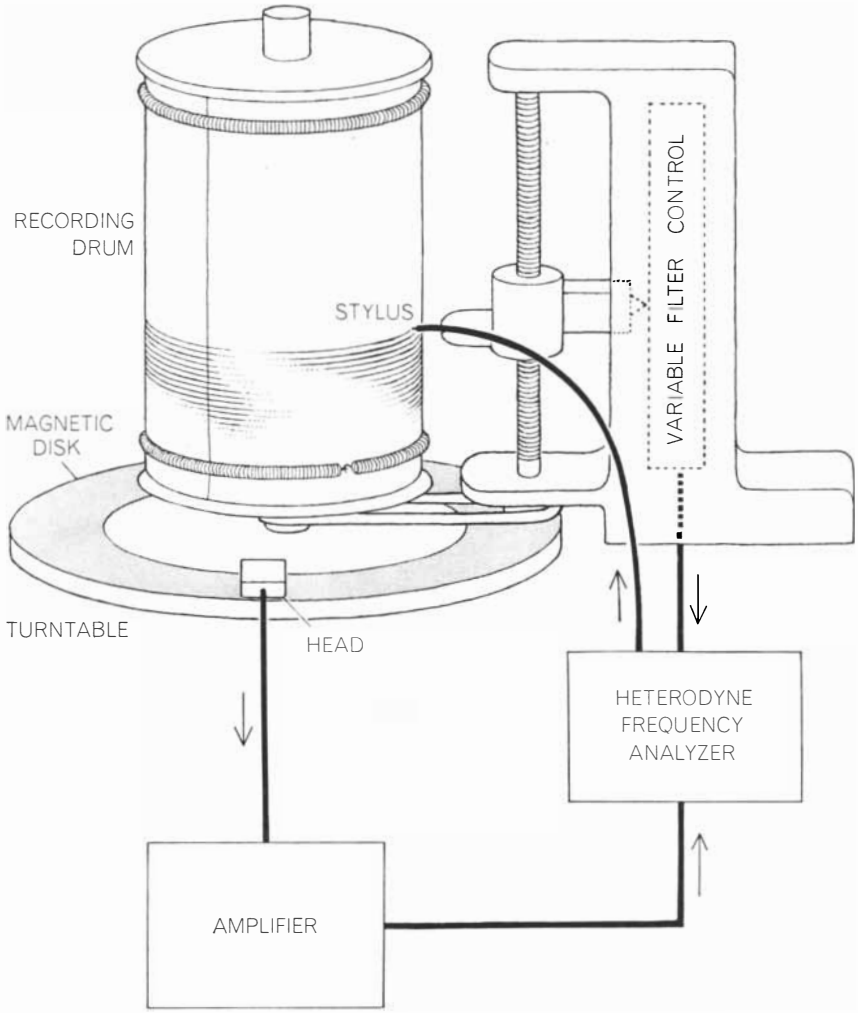


DANCING BEES and recruits are seen in this photograph. There are three dancers, or foragers (blurred images), heading to the right in a diagonal line starting near the upper left corner. The dancer nearest the left has a recruit on each side, the center one has two recruits on its right and the bee at the right, apparently nearing the end of its straight run, has a recruit at its right rear.

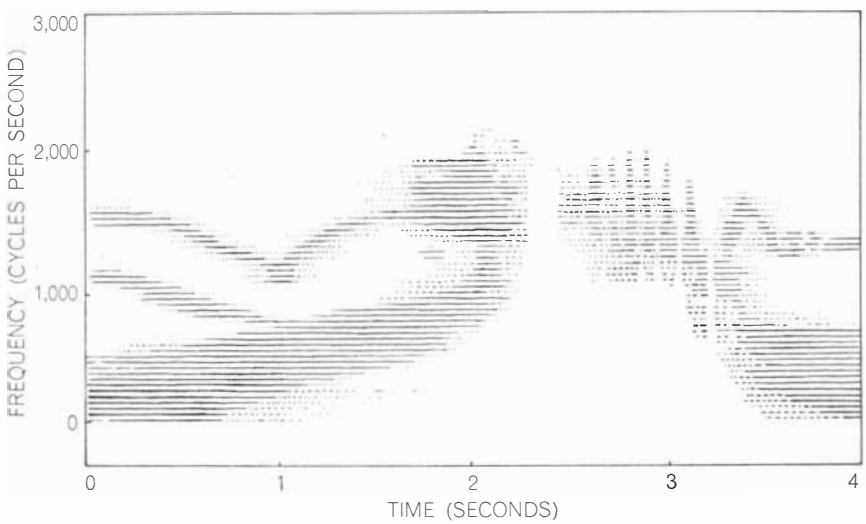




DANCE PATTERN described by the bee's thorax is not a well-defined figure eight with a distinctive straight run. This suggests that recruits would have difficulty gaining information by following the dance movements alone. To make these pictures Robert C. King and the author put a spot of white paint on the thorax of foragers and then photographed their dances by repetitive flash.



BEE SOUNDS are analyzed by a sound spectrograph. A short segment of a bee sound, recorded in the field, is transferred to the magnetic disk and then repeatedly sampled as the disk rotates with the recording drum. The stylus is a wire from which an electric spark passes to the drum, etching the recording paper. As the stylus rises, its position regulates the filter control so that the frequency analyzer extracts the proper frequency from the total sound, which is broken into a frequency "spectrum" changing with time.



SOUND SPECTROGRAM displays frequency against time as shown in this schematic tracing. The amplitude of the signal components is indicated by the darkness of the trace.

queen. Naturalists have long known that queens inside the hive emit two kinds of sound, called "tooting" and "quacking." A close analysis of these sounds and the circumstances of their emission now provides the strongest evidence that bees use sound to convey specific messages.

Tooting is the regal identification of a virgin queen soon after she has emerged from the cell in which she developed. A hive cannot tolerate more than one queen at a time. In a hive that lacks a queen several queen-bearing cells develop simultaneously in a comb, but one matures earlier than the others. Once this queen has emerged, has hardened and has become steady on her legs, she proceeds to visit other queen cells, tear them open and sting to death their potential but not yet mature queens. Often, however, the worker bees do not allow her to dispose of all her potential rivals in this way; they bar her from some of the cells. She then begins to toot and continues to do so day and night, perhaps for a week or more. Her tooting rises in intensity and sometimes can be heard more than 10 feet from the hive.

Meanwhile the maturing queen bees still in cells try to get out in their turn. The worker bees hold them back, however; as fast as one of them opens the cap of her cell the workers push it back in place and glue it shut. Thereupon the imprisoned queens also start to pipe, but in a different pattern and at a lower tone than the free queen. The workers let out some of these quackers, but only one at a time. The reigning queen and the newly released rival then battle until one is killed. Sometimes the series of fights between the survivor and the new rivals goes on until only one queen is left. This survivor, still a virgin, then flies away from the hive to mate successively with several drones (on the wing) and returns to begin laying eggs.

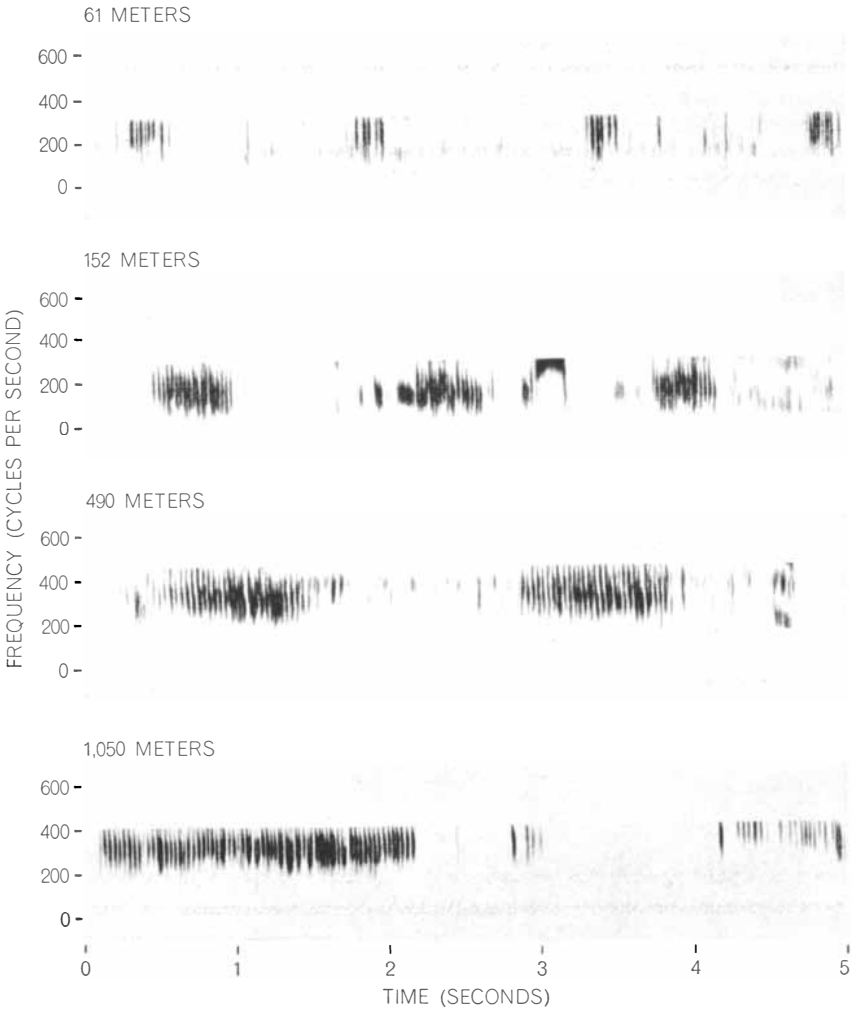
All this has been studied in hives set up for detailed observation. The tooting and the quacking have also been recorded and analyzed spectrographically. The pattern of the first turns out to be a long toot (lasting one second) followed by several shorter toots. Its fundamental frequency is 500 cycles per second, and this is overlaid with overtones that are varied considerably in emphasis, just as they are in human speech [see "Attention and the Perception of Speech," by Donald E. Broadbent; SCIENTIFIC AMERICAN, April, 1962]. The quack differs from the toot in two

ways: it has a lower fundamental frequency and it begins with short sounds instead of a drawn-out one.

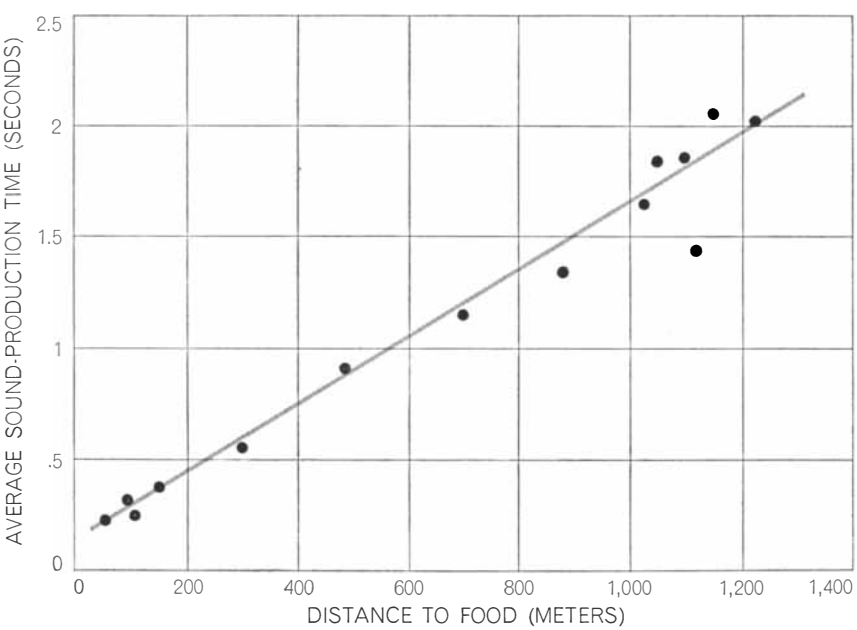
Do the tooting and the quacking say different things to the bees? We investigated this question with a set of controlled experiments. First we recorded the tooting of a free, reigning queen in its hive. Analysis with the sound spectrograph showed that this tooting put the major emphasis on the third harmonic. We therefore mimicked this harmonic with an oscillator and played it in the same tooting pattern (a long toot followed by several short ones) in a second hive that contained a free queen and a caged one. To each sounding of the artificial toots the caged queen almost invariably responded by quacking [*see upper two illustrations on page 124*]. We then tried varying the frequency of the tone, while keeping the long-toot-short-toot pattern constant. Within a wide frequency range (600 to 2,000 cycles per second) the change in frequency seemed to make little difference: the queen still responded with quacks as long as the typical pattern of toots was the same. On the other hand, when we played the quacking pattern, the caged queen did not respond at all.

There is not much doubt that the tooting and the quacking represent certain messages. What do the messages say, and what functions do they serve? A reasonable working hypothesis is that (1) the tooting announces the presence of a free queen in the hive, (2) the quacking reports the presence of challengers ready and yearning to be freed from their cells and (3) all this information guides the worker bees. One queen tooting and others quacking means that there is just one free queen, and a quacker (but not more than one) may be released to challenge her. This procedure will result in the rapid killing off of all but one of the contenders, but that may be to the good; it will enable the hive to settle down quickly to a peaceful regime. Occasionally, however, particularly in the spring, a virgin queen or an older egg-laying queen may leave the hive permanently, taking along half of the adult bees, in the phenomenon called swarming. In the swarming season, therefore, it is essential to have a queen in reserve when the free queen departs; a quacking queen may represent survival for the hive and is not to be released until the swarm has left.

We must come back now to the important questions: How does the bee produce sounds, and how does it



SPECTROGRAMS analyze the sound produced by forager bees during the dance. Sound trains are produced during the straight run; blank or light areas mark remainder of figure eight. The length of the sound train increases with the distance to the source of nectar.



DIRECT CORRELATION is shown between the sound-production time and the distance the bee had just traveled to obtain food. Each point is an average for several dancing bees.

perceive them? As to the production of sound, four hypotheses have been put forward, and the answer is still not clear.

The most interesting suggestion is that the bee makes its sounds by ejecting air through its spiracles: the breathing openings in the side of its body. On purely theoretical grounds it is quite plausible that the insect could produce the observed sounds by a whistling or a bagpipe effect. But recent experiments in our laboratory and also by other investigators generally negate this theory. For one thing, if helium is substituted for nitrogen in the air in which the bee produces its sounds, this does not change the frequency of the sound; if the spiracle theory is correct, it should, because the density of a gas affects the frequency of the sound produced by vibrating a column of the gas. For another thing, it has been found that the sounds of a piping queen do not always coincide with accordion-like movements of its abdomen, so that its abdominal spiracles cannot be producing the sound. Finally, James Simpson of the Rothamsted Experimental Station in England has shown by delicate spiracle-blocking experiments that the bee's thoracic spiracles play no part in sound production.

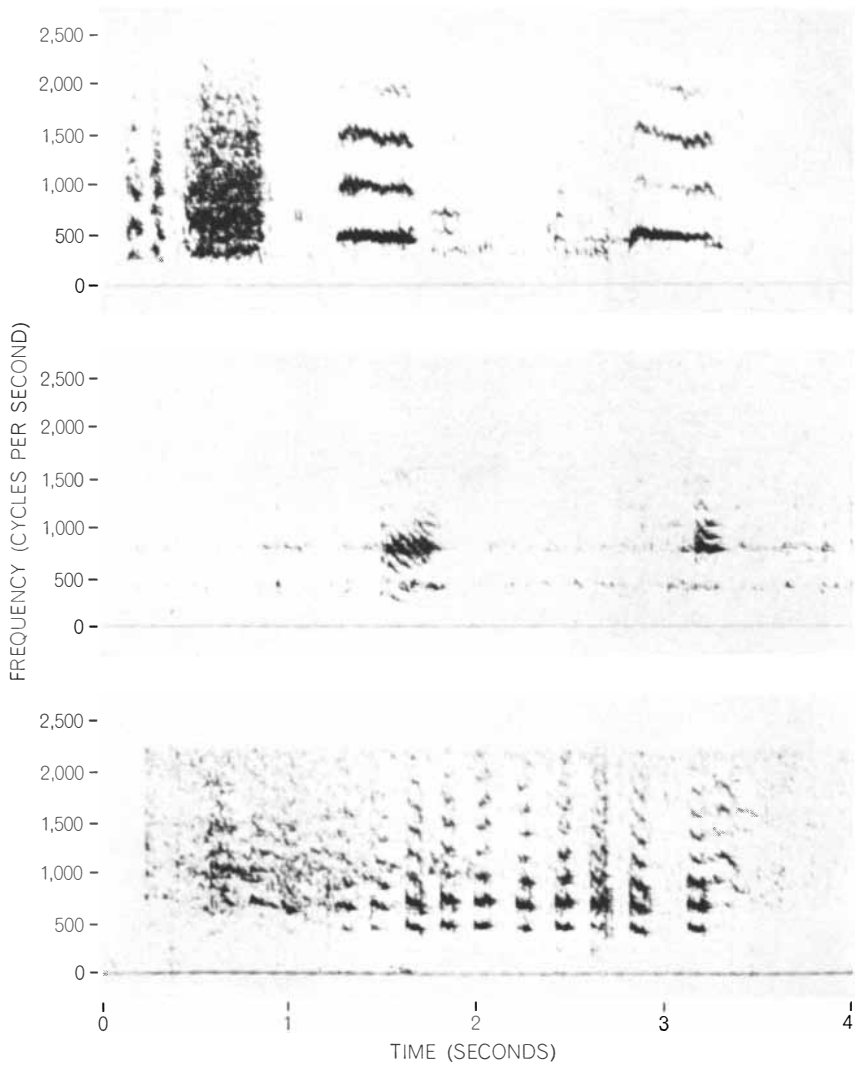
The other possibilities are that the bee produces sound by vibrating its wings or the sclerites (hard plates) at the base of its wings or the entire surface of the upper part of its body. Simpson and I and others have been investigating these possibilities. At the moment the wing-vibration theory seems to be the most promising.

Until recently this idea was rejected on two grounds: that a bee's wings are too small to produce sounds of the frequencies and intensities heard, and that experimenters who have clipped the wings have not found that this changed the intensity of the bee's piping. The second idea is simply wrong; careful experiments show that clipping the wings does affect the bee's sound-making. It raises the frequency and reduces the intensity of the sound, and the change is proportional to the amount of wing removed [*see bottom illustration on page 124*]. It appears, therefore, that wing vibration is responsible at least for amplification, and probably for production, of the bee's sounds. It is hoped that experiments now under way will answer the question more definitely.

Other recent studies have shed some light on how bees "hear" sound. In the experiments in which artificial tooting was played to a caged queen it was found that the queen responded only when the sound was transmitted via a vibrator attached to the hive; when it was transmitted through the air, even with the vibrator suspended close to the bee, she did not respond at all [*see second illustration from top on page 124*]. Similarly, worker bees show no reaction to piping when it is airborne. On the other hand, a disturbed hive can be quickly quieted by drawing a wet finger along the observation window, which causes a squeaking sound that arises from vibration of the glass. All these observations indicate that the bees receive sound through their legs from the vibrating structure on which they stand. Quite possibly they have receiving organs for sound on their legs below the knee.

There is also evidence that they receive sound through their antennae. Eleanor H. Slifer of the University of Iowa has found that each bee antenna has thousands of "plate organs" that are remarkably like the larger tympanic (eardrum-like) organs of other insects. She has established that these plate organs are not permeable to chemicals that might be used for communication. Although this finding does not eliminate the possibility that these organs are chemoreceptors, there is now good reason to entertain the notion that they do respond to mechanical stimuli. Charles Walcott of Harvard University has made some experimental findings that support this view: he discovered that vibrations transmitted to a bee's antennae caused electrical impulses to be generated in the antennal nerves.

Conceivably the honeybee receives sound both through its legs and through its antennae. Thus it may receive a



WORKER SOUNDS are shown in these spectrograms. The top tracing illustrates two sounds produced when a hive is disturbed: the sharp burst of a disturbed worker (*left*), followed by two faint beeps, or worker piping. The middle and bottom tracings show "croaking" and "bipping," two sounds that have yet to be related to any specific activity.

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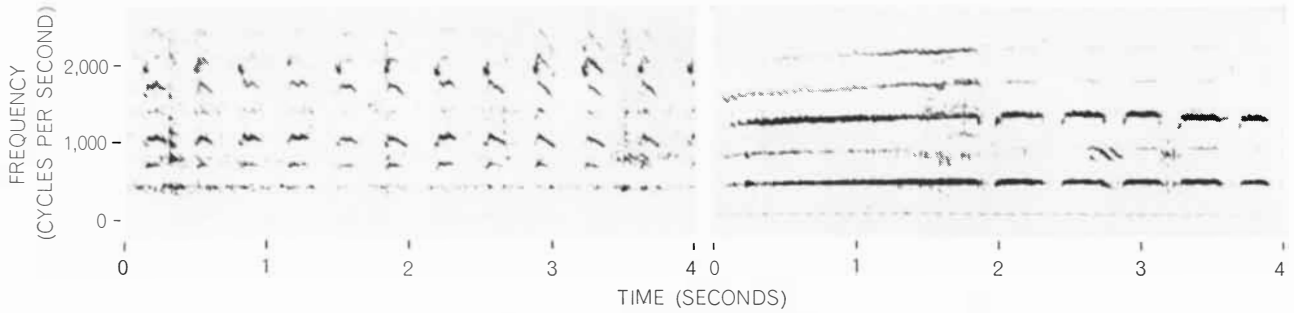
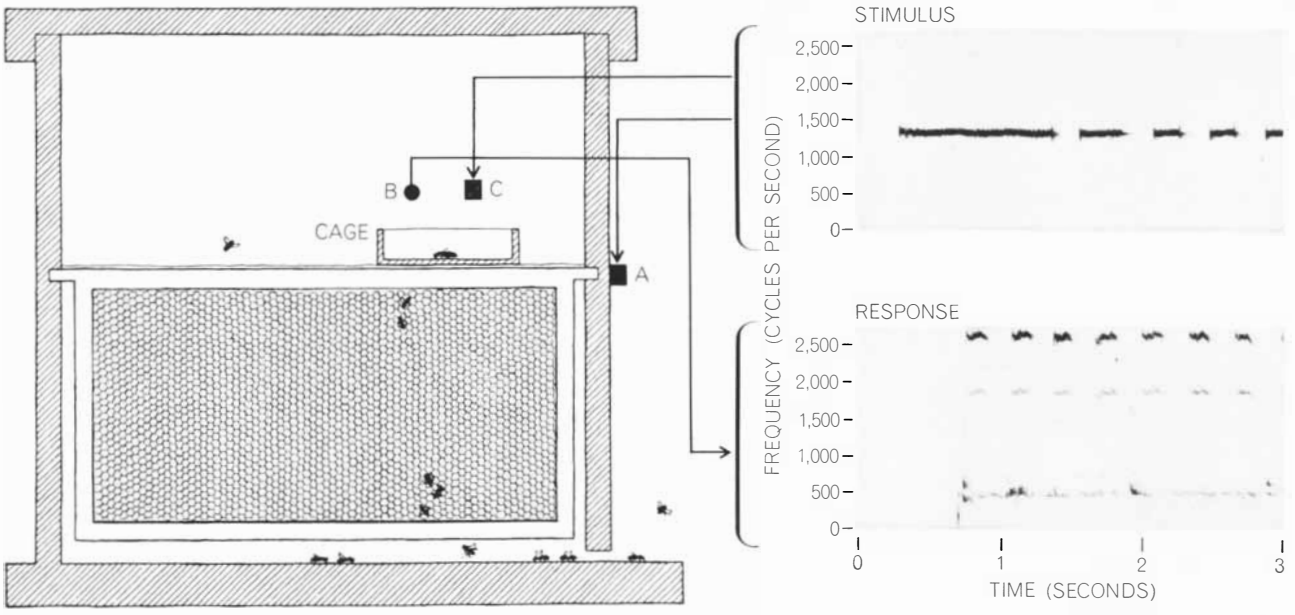


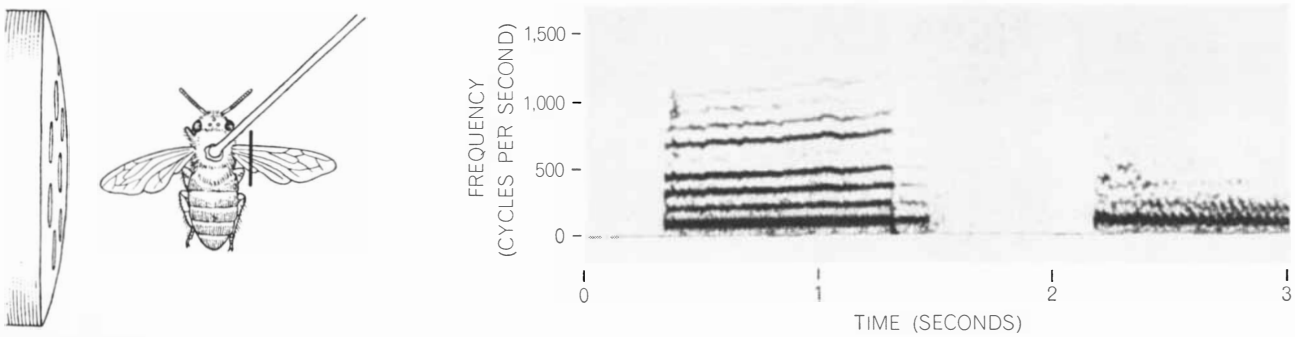
QUEEN PIPING includes "quacking" and "tooting." A queen in her cell produces quacking (*left*), a series of short pulses with emphasis on several harmonics. Once free in the hive a queen produces tooting (*right*), which begins with a long wail, has a somewhat higher fundamental frequency and usually emphasizes frequencies not simultaneously emphasized by quacking queens.



TOOTING was simulated (*upper tracing*) and played to a caged queen via a vibrator touching the hive (*A*). It elicited from the queen a response that was picked up by a microphone (*B*) and analyzed as quacking (*lower tracing*). When the tooting vibrator was suspended above the queen (*C*), there was no response, indicating that the queen perceived sound via the hive structure.

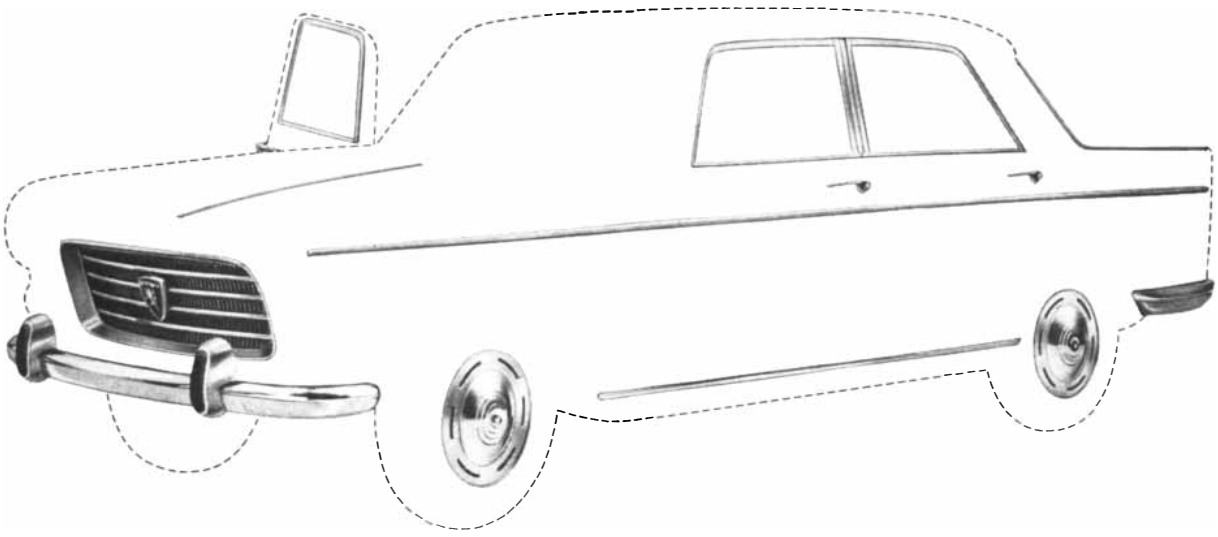
sound communication from another bee directly by touching the other bee's body with its antennae—as evidently occurs during the foraging bee's dance in the hive. The double receiving system would have a great advantage for bees in a noisy hive: in spite of the din of piping, which they apparently receive through their legs from the hive's vibrations, they would still be able to perceive the faint dance sounds by touching the dancer with their antennae.

Listening to the sounds of bees, recording them, analyzing them and designing experiments to explore their meaning, one cannot help feeling that much of this is akin to the problem of communicating with beings on another planet. With bees we have the advantage of being able to study them here and now.



RELATION OF WING to sound production was demonstrated by severing most of two wings of a bee (*left*). Comparison with the sound produced by the intact animal (*center*) showed that loss of wing area reduced the intensity and changed the harmonics (*right*).

Why is the trim stainless steel?



(it's indestructible)

Peugeot doesn't go in for trim for its own sake. What trim there is has a definite function. And what trim there is, is stainless steel, because it lasts far longer than chrome. That includes bumpers, grill, body trim and wheel covers. They'll all last indefinitely.

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MATHEMATICAL GAMES

Various problems based on planar graphs, or sets of "vertices" connected by "edges"

by Martin Gardner

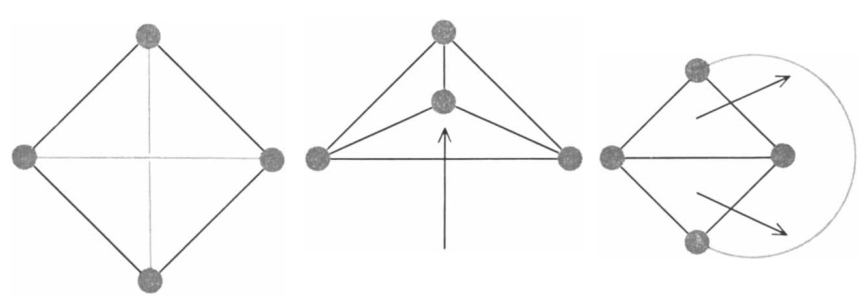
An engineer draws a diagram of an electrical network. A chemist makes a sketch to show how the atoms of a complex molecule are joined by chemical bonds. A genealogist draws an intricate family tree. A military commander plots a network of supply lines on a map. A sociologist traces in an elaborate diagram the power structure of a giant corporation.

What do all these patterns have in common? They are points (representing electrical connections, atoms, people, cities and so on) connected by lines. In the 1930's the German mathematician Dénes König made the first systematic study of all such patterns, giving them the generic name "graphs." (The confusion of this term with the "graphs" of analytic geometry is regrettable, but the term has stuck.) Today graph theory is a flourishing field. It is usually considered a branch of topology (because in most cases only the topological properties of graphs are considered), although it now overlaps large areas of set theory, combinatorial mathematics, algebra, geometry, matrix theory, game theory, logic and many other fields.

König's pioneer book on graphs (published in Leipzig in 1936) has yet to be translated, but an English edition of a later French book, *The Theory of Graphs and its Applications,* by Claude Berge, was published in England in 1962. Last year Oystein Ore's excellent elementary introduction, *Graphs and Their Uses,* was issued as a Random House paperback. Both books are of great recreational interest. Hundreds of familiar puzzles, seemingly unrelated, yield readily to graph theory. This month we center our attention on "planar graphs" and some of their more intriguing puzzle aspects.

A planar graph is a set of points, called vertices, connected by lines, called edges, in such a way that it is possible to draw the graph on a plane without any pair of edges intersecting. Imagine that the edges are elastic strings that can be bent, stretched or shortened as we please. Is the graph shown at the left below planar? (Its four vertices are indicated by spots. The crossing point at the center is not a vertex; think of one line as passing under the other.) Yes, because we can easily remove the intersection by shifting the position of a vertex, as shown in the middle graph, or stretching an edge as shown in the one at the right. All three of these graphs are "isomorphic": they represent three different ways of drawing the *same* planar graph. The edges of any solid polyhedron, such as a cube, are planar graphs because we can always stretch the solid's "skeleton" until it lies on a plane, free of intersections. The skeleton of a tetrahedron is isomorphic with the three graphs shown below.

It is not always easy to decide if a graph is planar. Consider the problem



Three ways to draw complete graph for four points

VARIAN INSTRUMENTS AT WORK

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Frequency and time measurements have progressed toward greater and greater precision

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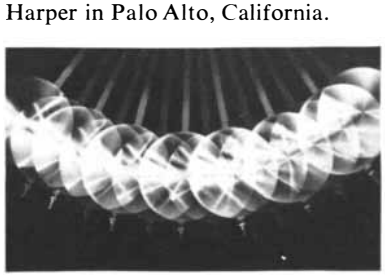
In the past decade, the study of quantum electronics has led to an understanding of the inherent stabilities associated with atomic resonance. As a result, several practical "atomic clocks" have been developed which provide the most accurate frequencies yet known—against which the most accurate measurements yet known can be made. Varian Associates produces three different devices of this nature.

Cesium beam tubes have provided the reference for the first practical atomic standard. Their acceptance and widespread use has revolutionized measurement concepts. At Beverly, Massachusetts, Varian makes tubes of this type which incorporate the most recent designs.

At Palo Alto, California, Varian has combined solid-state electronic circuitry with rubidium optical packages to create small, highly reliable, portable instruments.

Most recently, hydrogen masers have been developed at Beverly and are now being evaluated to determine the extent of their accuracy and stability. These devices have proven that the hydrogen maser furnishes the most stable reference yet discovered.

If frequency or time control is part of your work, Varian would like to help you. Contact Earle Benson in Beverly, Massachusetts or Gordon Harper in Palo Alto, California.



The strip chart recorder puts down in graphic form the data scientists search for in their experiments. The past few years have seen recorders become a necessary extension of a great many types of equipment.

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Fast pen speed is important. Ours is less than ½ second full scale. But accuracy is the thing, right? On 1 mv range, it's 0.25% + 5μv; on all other ranges it's simply 0.25%. We have three distinct models available now for laboratory, industrial or OEM applications. Discounts (from $985 base price) are available for quantity or OEM orders.

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Paramagnetism occurs in solids, liquids, and gases and is of great interest to biologists, chemists, and physicists. Varian Electron Paramagnetic Resonance (EPR) spectrometer systems provide scientists with the means of studying the microscopic environment of paramagnetic samples.

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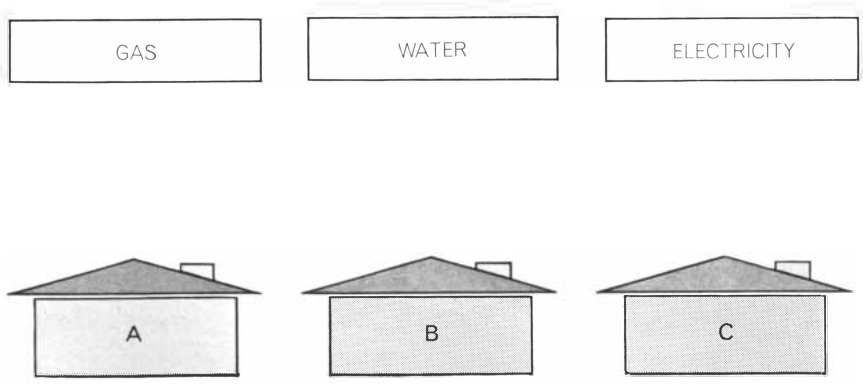
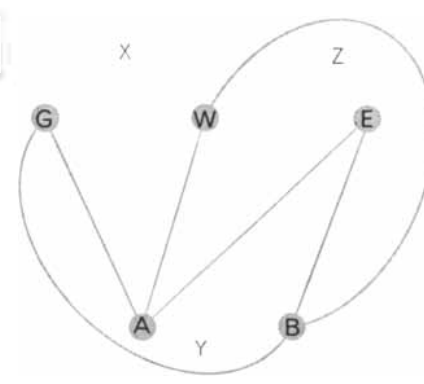
For more information and a brochure describing Varian's complete EPR product line, write Hank Gauthier, Analytical Instruments.



Problem of the three utilities



Impossibility proof for utilities problem

depicted at the left above, one of the oldest and most frustrating of all topological teasers. Since the English puzzlist Henry Ernest Dudeney gave it this form in 1917 it has been known as the "utilities problem." Each house must receive gas, water and electricity. Can lines be drawn to connect each house with each utility in such a way that no line intersects another? In other words, is the resulting graph planar?

The answer is no, and it is not difficult to give a rough proof. Assume that only houses *A* and *B* are to be connected to the three utilities. To do this without having any line cross another you must divide the plane into three regions as shown in the illustration at the right above. Your lines need not be as pictured, but however you draw them your graph will be isomorphic with the one shown. House *C* must go in one of the three regions. If it goes in *X*, it is cut off from electricity. If it goes in *Y*, it is cut off from water. If it goes in *Z*, it is cut off from gas. The same argument holds when the graph is drawn on a sphere, but not when it is drawn on certain other surfaces. For example, the graph is easily drawn without intersections on the surface of a doughnut.

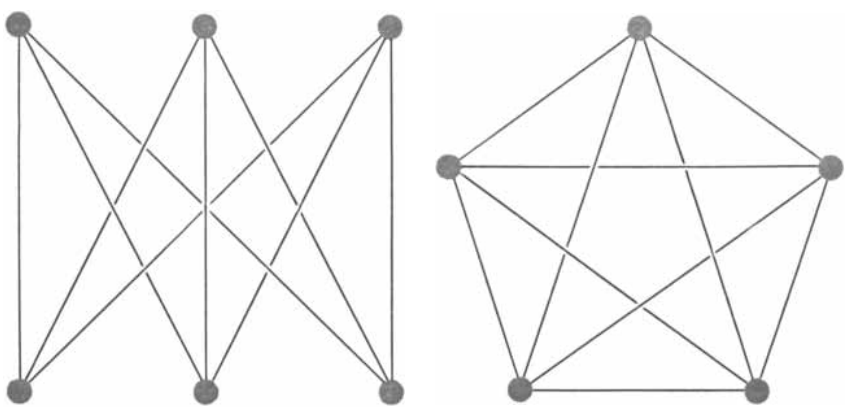
When every vertex of a graph is connected to each of the other vertices, the graph is said to be "complete." We saw in the illustration on page 126 that the complete graph for four points is planar. Is the complete graph for five points planar? Again an informal proof (the reader may enjoy working it out for himself) shows that it is not. The fact that a complete graph can be planar only if it has four or fewer points is not without philosophical interest. Many philosophers and mathematicians have tried to answer the question: Why does physical space have three dimensions? In his book *The Structure and Evolution of the Universe* (Harper Torchbooks, 1959) the British cosmologist G. J. Whitrow argues that intelligent life as we know it could not have evolved in a space of *more* than three dimensions because such spaces do not allow stable planetary orbits around a sun. How about spaces of one or two dimensions? Intelligent Linelanders and Flatlanders of the type described in this department in July, 1962, are ruled out, says Whitrow, by graph theory. A brain requires an immense number of nerve cells (points), connected in pairs by nerves (edges) that must not intersect. In three dimensions there is no limit to the number of cells that can be so connected, but in a Flatland the maximum number, as we have seen, would be four.

"Thus," Whitrow writes, "we may conclude that the number of dimensions of physical space is necessarily three, no more and no less, because it is the unique natural concomitant of the evolution of the higher forms of terrestrial life, in particular of Man, *the formulator of the problem.*"

The two simplest of all nonplanar graphs—the utilities graph (also known as a Thomsen graph) and the complete graph for five points—are involved in an important theorem called the Kuratowski theorem, after the Polish mathematician who first discovered it. It states that every nonplanar graph contains within it, as a subgraph, one or the other of these two graphs. In other words, if we trace over any nonplanar graph, we can always draw at least one graph that will be isomorphic with one of the two graphs at the bottom of this page.

Devising planar graphs is an essential task in many fields of technology. Printed circuits, for instance, will short-circuit if any two paths cross. The reader may wish to test his skill in planar graph construction by considering the two printed-circuit problems shown on page 130. In the upper problem five nonintersecting lines must be drawn within the rectangle, each connecting a pair of spots bearing the same letter (*A* with *A*, *B* with *B* and so on). The two lines *AD* and *BC* are barriers of some sort that may not be crossed. In the lower problem five lines are to be drawn —connecting pairs of spots labeled with the same letter, as before—but in this case all lines must follow the grid. Of course there must be no crossings. Neither of these printed-circuit puzzles is difficult.

Another well-known type of graph puzzle is the one that calls for drawing



Simplest nonplanar graphs

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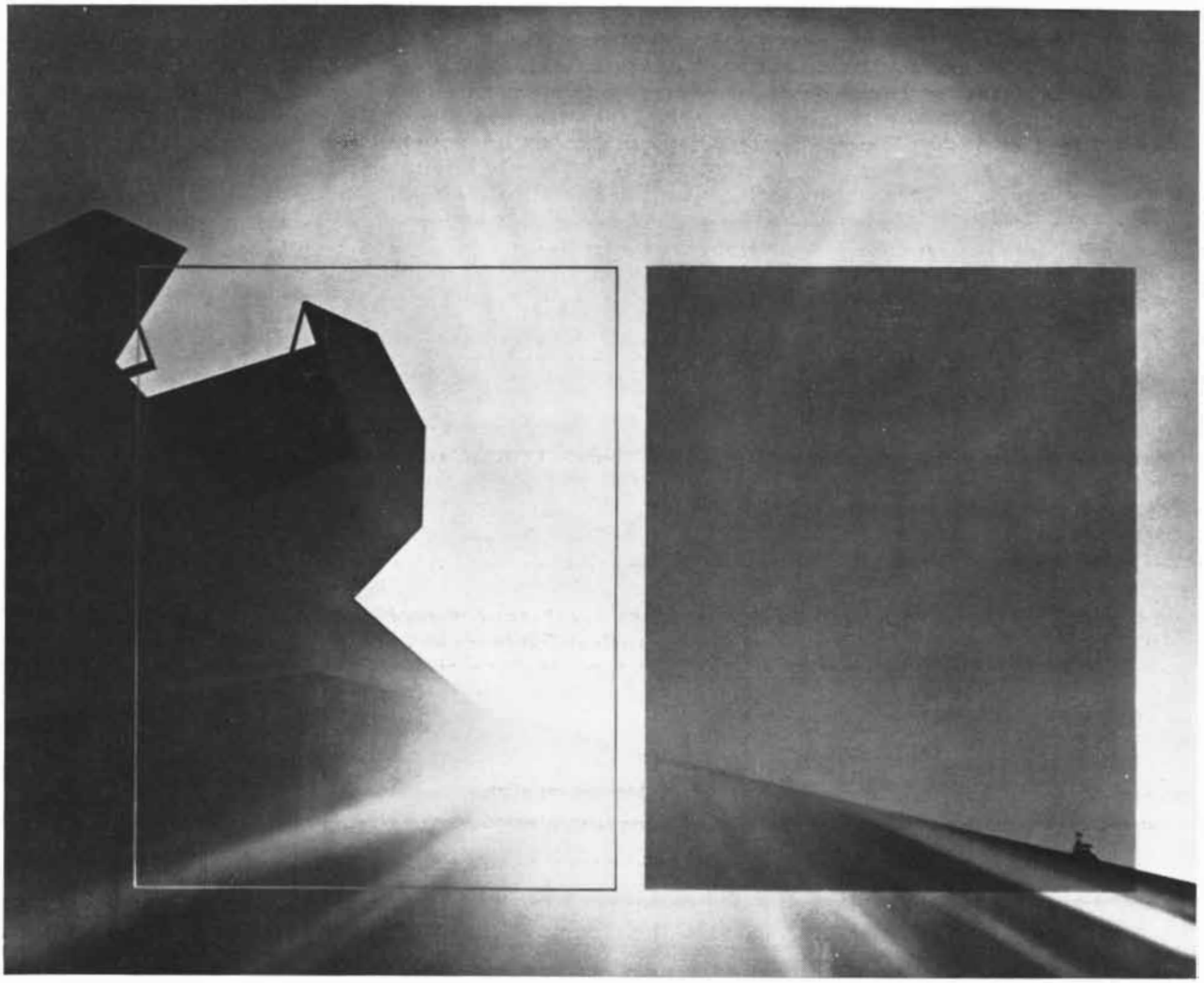

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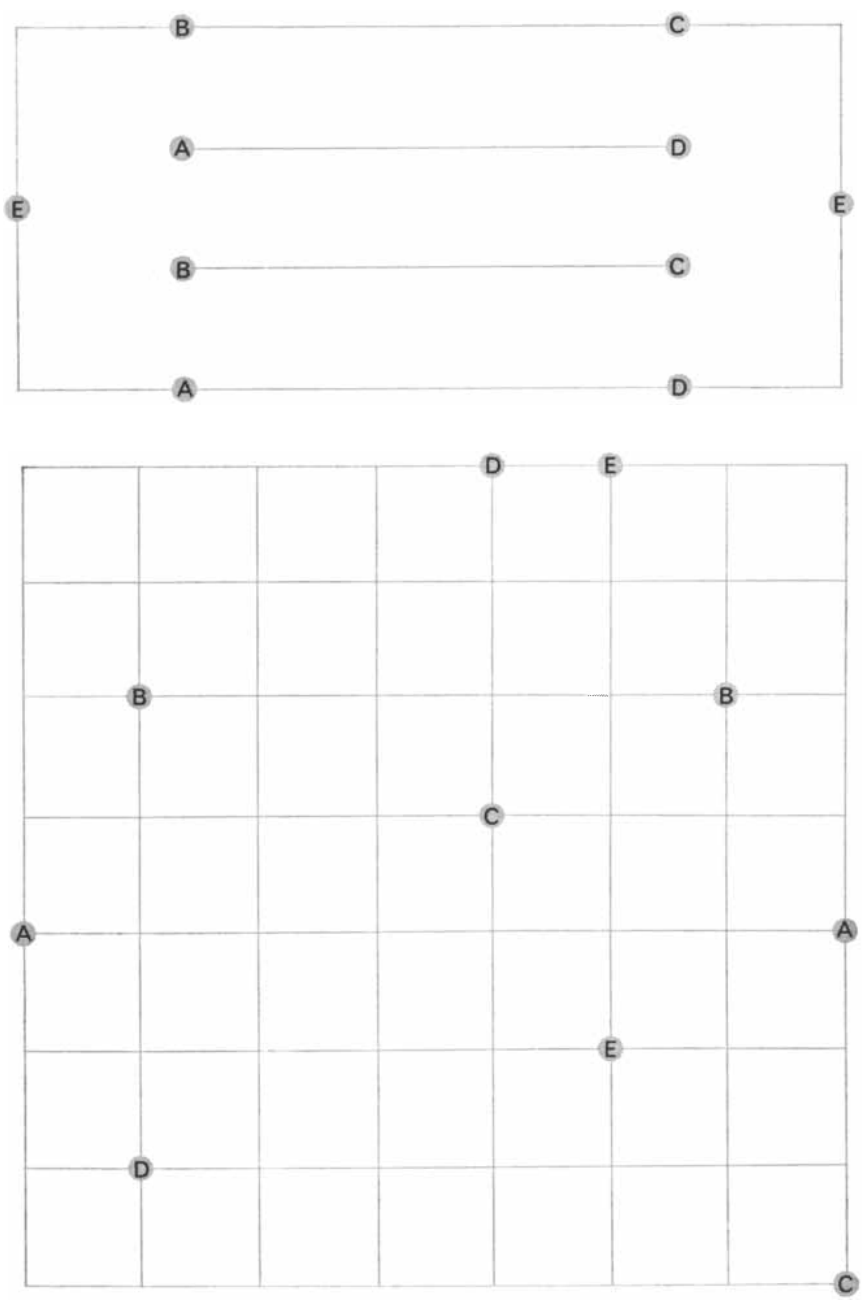
a given planar graph in one continuous line without taking the pencil from the paper or going over any edge twice. If such a line can be drawn as a closed loop, returning to the vertex from which it started, the graph is said to be an "Euler graph" and the line an "Euler line." In 1736 the Swiss mathematician Leonhard Euler solved a famous problem involving a set of seven bridges in the East Prussian town of Königsberg (now Kaliningrad). Was it possible to walk over each bridge once and only once and return to where one had started? Euler found that the problem was identical with that of tracing a simple graph. He showed, in the first paper ever written on graph theory, that if every vertex of a graph is of "even degree" (has an even number of lines meeting it), it can be traced in one round-trip path. If there are two vertices of odd degree, no round trip is possible, but the graph can be drawn by a line beginning at one odd vertex and ending at the other. If there are $2k$ vertices of odd degree (and the number of odd vertices must always be even), it can be traced by k separate paths, each starting and ending at an odd vertex. The graph for the bridges of Königsberg has four odd vertices, therefore it requires a minimum of two paths (neither of them closed circuits) to traverse all edges.



Two printed-circuit problems

Any Euler graph can be traversed by an Euler line that makes the entire round trip without intersecting itself. Lewis Carroll, we are told in a biography by his nephew, was fond of asking little girls to draw, with one Euler line, the graph at the left in the top illustration on page 133. It is easily done if lines are allowed to intersect, but it is not so easy if intersections are forbidden. A quick way to solve such puzzles has been proposed by Thomas H. O'Beirne of Edinburgh. One colors alternate regions as shown in the middle drawing, then breaks them apart at certain vertices in any way that will leave the colored areas "simply connected" (connected without enclosing noncolored areas). The perimeter of the colored region is now the Euler line we seek [*drawing at right*]. The reader can try this method on the Euler graph shown in the second illustration from the top on page 133 (proposed by O'Beirne) to see how pleasingly symmetrical an Euler line he can obtain.

An entirely different and, strangely, much more difficult type of graph-traversing puzzle is that of finding a route that passes through each vertex once and only once. Any route that passes through no vertex twice is known in graph theory as an arc. An arc that returns to the starting point is called a circuit. And a circuit that visits every vertex once and only once is called a Hamiltonian line, after Sir William Rowan Hamilton, the 19th-century Irish mathematician, who was the first to study such paths. He showed that a Hamiltonian line could be traced along the edges of each of the five regular solids, and he even sold a toy manufacturer a puzzle based on finding Hamiltonian tours along the edges of the dodecahedron.

It might be supposed that, as in the case of Euler lines, there would be simple rules for determining if a graph is Hamiltonian; the fact is that the two tasks are surprisingly dissimilar. An Euler line must trace every edge once and only once, but it may go through any vertex more than once. A Hamiltonian line must go through each vertex once and only once, but it need not trace every edge. (In fact, it traverses exactly two of the edges that meet at any one vertex.) Hamiltonian paths are important in many fields where one

Crown Compass (Danish—circa 1790)—Courtesy The Trustees of the National Maritime Museum, Greenwich, England.

from crown compass to missile guidance

"Surely oak and threefold brass surrounded his heart who first trusted a frail vessel to the merciless ocean," wrote Horace 2,000 years ago. Twelve centuries passed, and a dread of the sea was still part and parcel of every sailor's kit. Then someone discovered the directive properties of a magnetized needle. The mariner's compass was born; and with it came the means to set a course at sea without fear.

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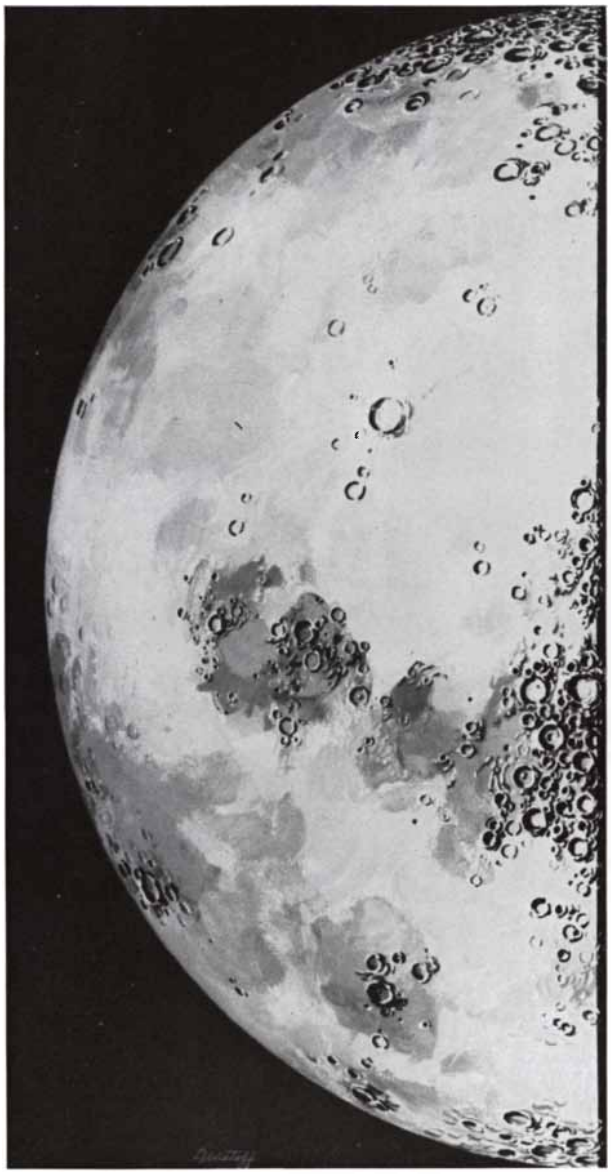
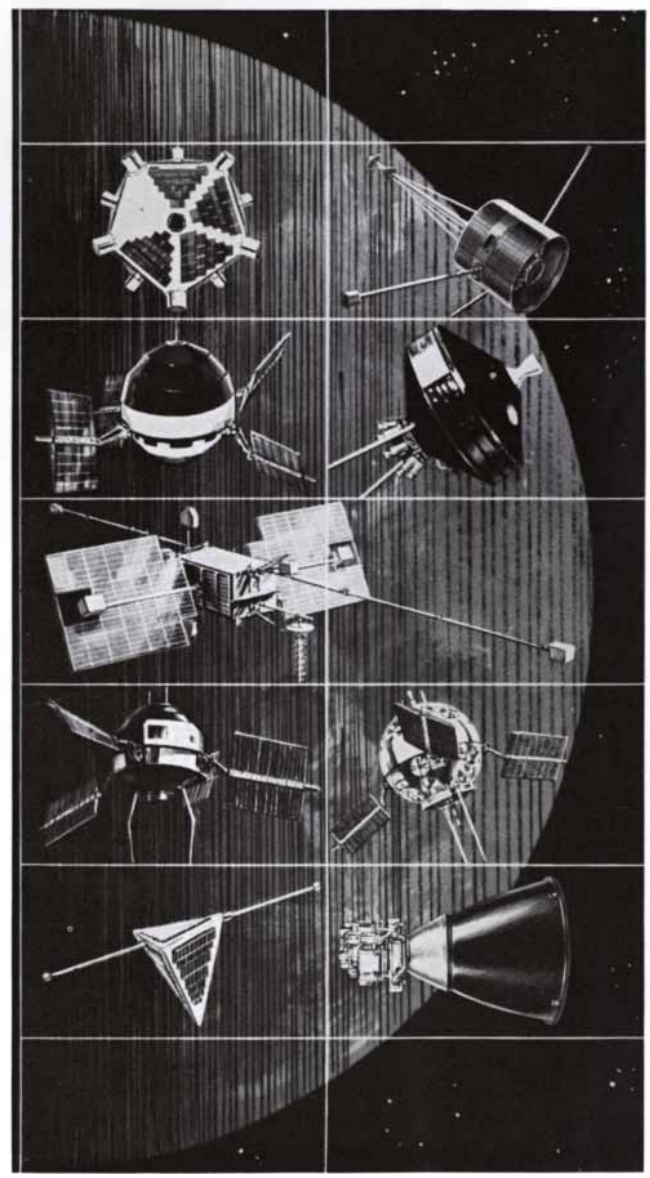


TRW SPACE TECHNOLOGY LABORATORIES In Perspective



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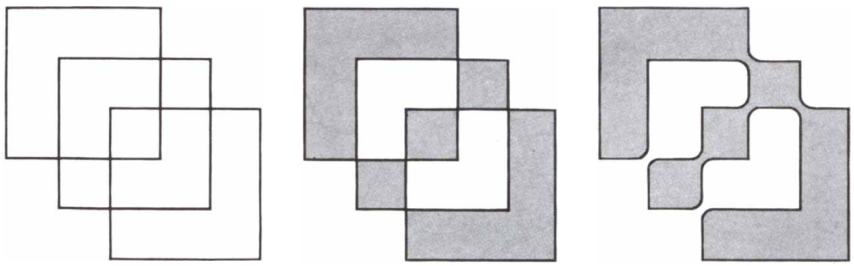
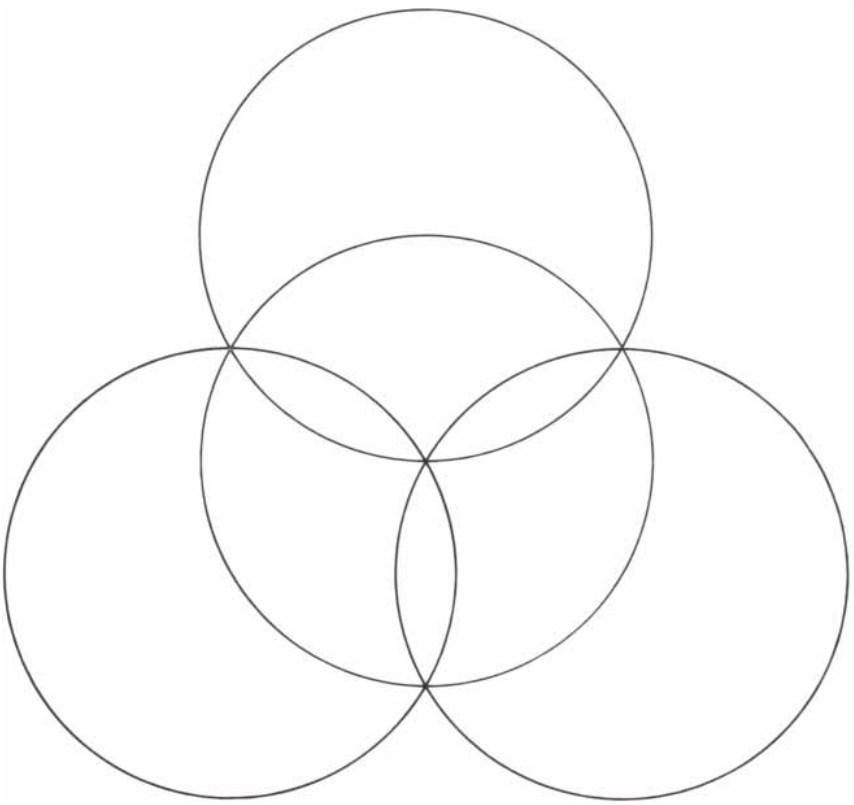


Lewis Carroll's three-square problem



O'Beirne's four-circle problem

would not expect to find them. In operations research, for example, the problem of obtaining the best order in which to carry out a specified series of operations can sometimes be diagramed as a graph on which a Hamiltonian line gives an optimum solution. Unfortunately there is no general method for deciding if a graph is Hamiltonian, or for finding all Hamiltonian lines if it is.

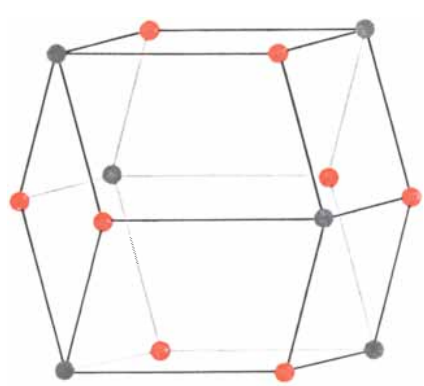
Many semiregular polyhedrons, but not all, have Hamiltonian skeletons. An exception is the rhombic dodecahedron shown at the right, a form often assumed by crystals of garnet. Even if the path is not required to be closed, there is no way to traverse the skeleton so that each vertex is visited once and only once. The proof, first given by H. S. M. Coxeter, is a clever one. All vertices of degree 4 are shown as black spots, all of degree 3 as colored spots. Note that every black spot is completely surrounded by colored spots and vice versa. Therefore any path through all 14 spots must alternate colored and black. But there are six black spots and eight colored ones! No path of alternating color is possible, either closed or open at the ends.

An ancient chess recreation that at first seems far removed from Hamiltonian paths is the re-entrant knight's tour. It consists of placing the knight on a square of the chessboard, then finding a path of continuous knight's moves that will visit every square once and only once, the knight thereupon returning in one move to the square from which it started. Suppose each cell of the board to be represented by a point and every possible knight's move by a line joining two points. The result is, of course, a graph. Any circuit that visits each vertex once and only once will be a Hamiltonian line, and every such line will trace a re-entrant knight's tour.

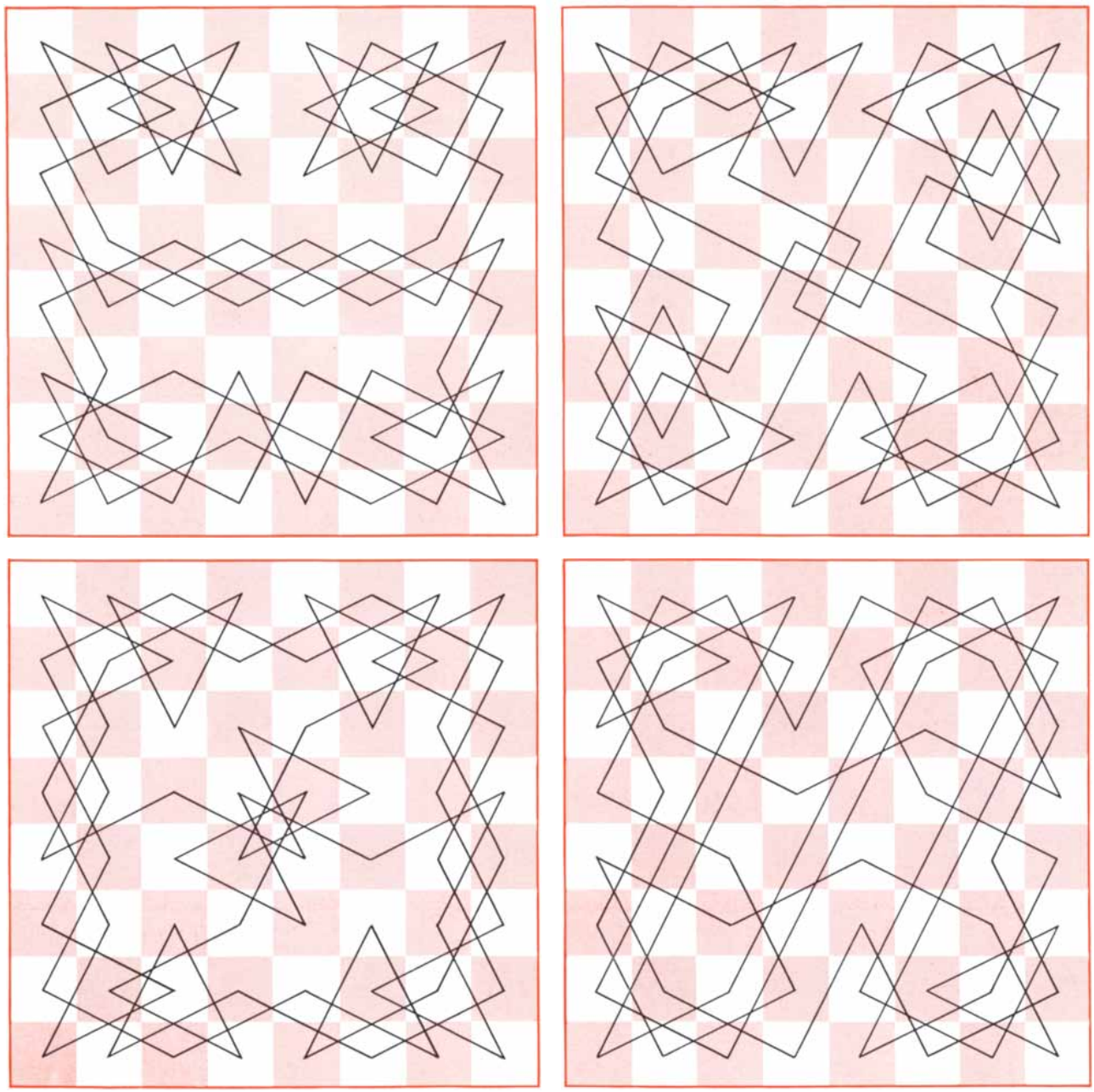
Such a tour is impossible on any board with an odd number of cells. (Can the reader see why?) If the number of cells is even, the tour is possible on any rectangle with one side equal to or greater than five. Thus the five-by-six is the smallest rectangle on which a closed tour is possible and the six-by-six is the smallest square. No one knows how many millions of different re-entrant knight's tours can be made on the standard eight-by-eight chessboard. In the enormous literature on the topic the search has usually been confined to paths that exhibit interesting symmetries. Thousands of elegant patterns, such as those shown on the next page, have been discovered. Paths with exact fourfold symmetry (unchanged by any 90-degree rotation) are not possible on the eight-by-eight board, although five such patterns are possible on the six-by-six.

As an introduction to this classic pastime readers are invited to search for a re-entrant knight's tour on a simple 12-cell board [*see illustration on page 135*]. After it has been found, a seemingly more difficult question arises: Is it possible to move the knight over this board in one chain of jumps and make every possible knight's move once and only once? There are 16 different knight's moves. A move is considered "made" whenever a knight connects the two cells by a jump in either direction. Of course, the knight may visit any cell more than once, but it must not make the same move twice. The path need not be re-entrant.

The reader will soon convince him-



Skeleton of rhombic dodecahedron



Re-entrant knight's tours

self that such a path is not possible; but what is the smallest number of *separate* paths that will cover all 16 of the possible moves? This can be answered in just a few minutes by applying one of the graph theorems discussed earlier in this article. Solutions to all problems will appear in this department next month.

The five problems given in last month's department are answered as follows:

1. The two composite numbers are 10,001 (the product of primes 73 and 137) and 123,456,789, which is evenly divisible by 3. The other numbers are primes.

2. Two meshed gear wheels of different sizes cannot return to the same position until a certain number of teeth, k, have passed the point of contact on both wheels. The number k is the lowest common multiple of the number of teeth on each wheel. Let n be the number of teeth on the small wheel. We are told that the large wheel has 181 teeth. Since 181 is a prime number, the lowest common multiple of n and 181 is $181n$. Therefore the small wheel will have to make 181 rotations before the two wheels will return to their former position.

3. How can the nine digits be arranged to make three primes with the lowest possible sum? We first try numbers of three digits each. The end digits must be 1, 3, 7 or 9 (this is true of all primes greater than 5). We choose the last three, freeing 1 for a first digit. The lowest possible first digits of each number are 1, 2 and 4, which leaves 5, 6 and 8 for the middle digits. Among the 11 three-digit primes that fit these specifications it is not possible to find three

that do not duplicate a digit. We turn next to first digits of 1, 2 and 5. This yields the unique answer

149

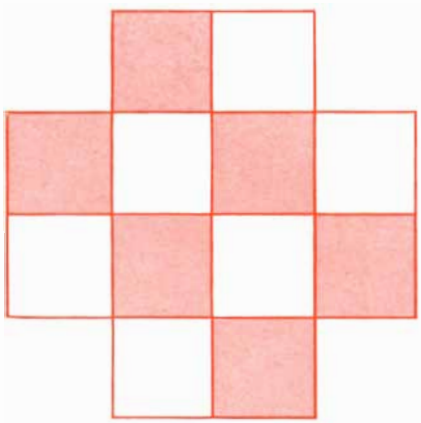
263

587

999 .

4. The last number, 333333331, has a factor of 17. (The problem is based on a result obtained by Andrzej Makowski of Poland, which was reported in *Recreational Mathematics Magazine* for February, 1962.)

5. It is easy to find as large an interval as we please of consecutive integers that are not prime. For an interval of a million integers, consider first the number 1,000,001! The exclamation mark means that the number is "factorial 1,000,001," or the product of $1 \times 2 \times 3 \times 4 \ldots \times 1{,}000{,}001$. The first number of the interval we seek is $1{,}000{,}001! + 2$. We know that 1,000,001! is divisible by 2 (one of its factors), so that if we add another 2 to it, the resulting integer must also be divisible by 2. The second number of the interval is $1{,}000{,}001! + 3$. Again, because 1,000,001! has a factor of 3, it must be divisible by 3 after we add 3 to it. Similarly for $1{,}000{,}001! + 4$, and so on up to $1{,}000{,}001! + 1{,}000{,}001$. This gives a consecutive sequence of one million composite numbers. Are these the smallest integers that form a sequence of one million nonprimes? No, as Ted L. Powell pointed out in *The Graham Dial* for April, 1960; we can obtain a lower sequence just as easily by *subtracting:* $1{,}000{,}001! - 2$; $1{,}000{,}001! - 3$; and so on to $1{,}000{,}001! - 1{,}000{,}001$.



A knight's-tour problem

THE AMATEUR SCIENTIST

A tuning fork with electric drive can make an inexpensive and highly accurate clock

Conducted by C. L. Stong

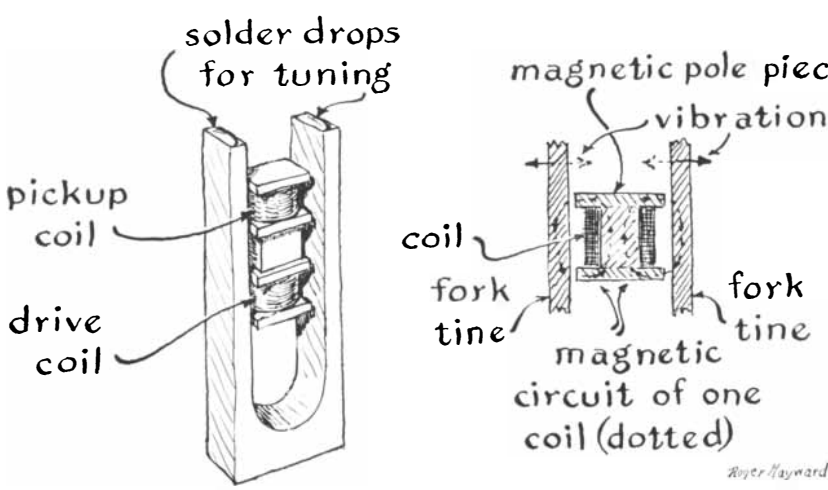
The electrically driven tuning forks that have appeared on the surplus market in recent years open to amateurs the opportunity for constructing a relatively inexpensive clock for use in experiments that require accurate timing. The tuning-fork clock is much simpler to build than its quartz-crystal counterpart. Small synchronous motors are available that operate directly on the 400-cycle frequency generated by the forks; no electronic frequency division is required, as in the case of quartz-crystal clocks. Moreover, the output of a well-designed fork is substantially greater than that of a quartz crystal and thus minimizes the amount of amplification required. About the only drawback is that the rate of the fork is not so constant as that of a quartz crystal. But the fork's advantages are such that it has been adopted as the timing unit in the watch-rate regulators used by most watchmakers and, in a miniaturized version, it constitutes the timing unit in a currently popular electronic wrist watch of high accuracy.

During a continuous 37-day test made recently, Tom Clements of Tappan, N.Y., found that typical forks do not deviate by more than .6 second in rate from the time as broadcast by radio station WWV of the National Bureau of Standards. The tuning-fork clock Clements designed does triple duty as an audio-frequency standard, a timekeeper and a perpetual electromechanical calendar that can be programed years in advance to switch other apparatus on or off automatically at any instant.

"All clocks," writes Clements, "have at their heart some regularly recurring phenomenon, such as the swing of a pendulum or the beat of a balance wheel, that serves as the generator of timing oscillations from which the clock eventually derives its display for the user. Several clocks built by amateurs that employ crystal oscillators for this purpose have been described in your column [September, 1957; June, 1961; March, 1963], and there is no doubt in my mind that all were fine examples of the amateur's art. In fact, the subject had been so well covered that about two years ago I began to look around for some way to be original rather than travel the trail so well laid out by others. Fortunately I happened to notice an offering of some rather good 400-cycle-per-second tuning-fork assemblies on the surplus market. It seemed to me that an interesting clock could be built by driving a 400-cycle synchronous motor from the oscillations of one of these forks and arranging for the motor to generate regular pulses that could then be counted using stepping relays of the type designed for telephone switching.

"In the form used for generating electrical oscillations, tuning forks are specially constructed for maximum stability; usually they are sealed in a controlled atmosphere. They dissipate energy through internal friction and, depending on the atmosphere, through acoustic radiation. These energy losses must be continually replaced to sustain oscillations of constant amplitude. This is achieved in the fork I used by making the tines of magnetic material and using an electromagnet between the tines to drive them. A second electromagnet, also located between the tines, acts as an alternating-current generator. The signal from this coil is amplified and then applied to the first electromagnet as the driving energy [*see illustration on this page*]. In other words, the electromagnets and the amplifier constitute a positive feedback loop.

"My fork came in a sealed can mounted on a module together with a two-tube amplifier for sustaining the oscillations. I found that it did not vibrate exactly at 400 cycles; the first model of my clock ran fast by a few seconds a day. Some study convinced me that it would be impossible to shift the frequency enough by electrical modifications of the drive circuit to achieve the desired 400 cycles. I opened the sealed can and found that the manufacturer had tuned the fork by first cutting it to vibrate at slightly more than 400 cycles. Drops of solder had then been added to the tips of the tines to lower the frequency. The final adjustment had been made by filing away the solder. I was relieved to discover that the fork seemed just as active in air as it had been in the can. This indicated that the pres-



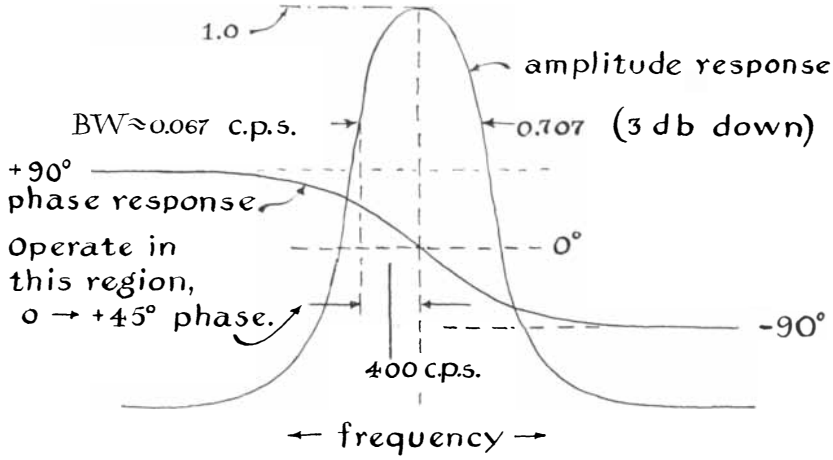
Details of the tuning fork

sure of the gas in the can had been approximately that of the atmosphere. Inspection of the can led me to guess that the unit had been flushed with dry nitrogen or some other inert gas just prior to seal-off. I also found that the activity of the fork could be improved by rubbing the center pole pieces of the electromagnets simultaneously with one pole of a strong bar magnet, thereby magnetizing the facing ends of the drive and pickup coils.

"The tuning procedure, for adjusting the fork so that it can be made to operate at 400 cycles, is fairly simple if some care is taken to understand what is happening. The idea is to tune the fork by adding or removing solder from the tips of the tines until the frequency is slightly higher than 400 cycles. When this has been done, the frequency can be shifted to exactly 400 cycles by changing the phase of the frequency that drives the fork in relation to that generated in the pickup coil. It turns out that it is not practical to shift the frequency upward by electrical means. All my attempts to do this resulted in parasitic oscillations that suppressed oscillation at 400 cycles.

"Before attempting to modify the fork I first measured its quality factor, or '*Q*.' This is easily done by setting the fork into oscillation in its electronic circuit and measuring the output of the pickup coil by using the amplifier as a preamplifier for feeding a signal to an oscilloscope. A measurement is then made of the time required for the oscillations to decay to .37, or $1/e$, of their initial amplitude. The circuit that supplies driving energy to the fork is opened when the signal has reached maximum amplitude and a stopwatch is started simultaneously. When the oscillations as observed on the face of the oscilloscope have decayed to about .37 of their original value, the stopwatch is stopped. *Q* is then calculated from the relation $Q = 3.14 \times f \times t$, where f is the frequency (in this case 400 cycles per second) and t the time in seconds as read from the stopwatch. Testing several forks, I found *Q*'s ranging from 5,000 to 7,000, with 6,000 being about average.

"Now, *Q* is also related to the band width or range of frequencies through which the fork vibrates at maximum amplitude. The relation is simply $BW = f/Q$. The amount that the phase of the input, or driving, frequency shifts with respect to the output of the fork can be expected to be 45 degrees when the frequency departs by half of this band width from the center of the band. Taking *Q* to be 6,000, I estimated that the frequency is lowered by one part in 12,000, in relation to the natural resonant frequency, when the phase of the drive signal is shifted so that it lags 45 degrees with respect to the fork output. Since the sides of a graph plotted to depict the band width of the fork steepen rapidly in this region, it is advisable to operate the fork well within the 45-degree region, as illustrated by the accompanying graph [*above*]. An electrical network I designed is used to shift the phase less than 20 degrees, and thus to the neighborhood of one part in 40,000 in frequency, or to about two seconds per day in clock error. This network constitutes the 'fast-slow' adjustment of my clock.



Graph of the tuning fork's characteristics

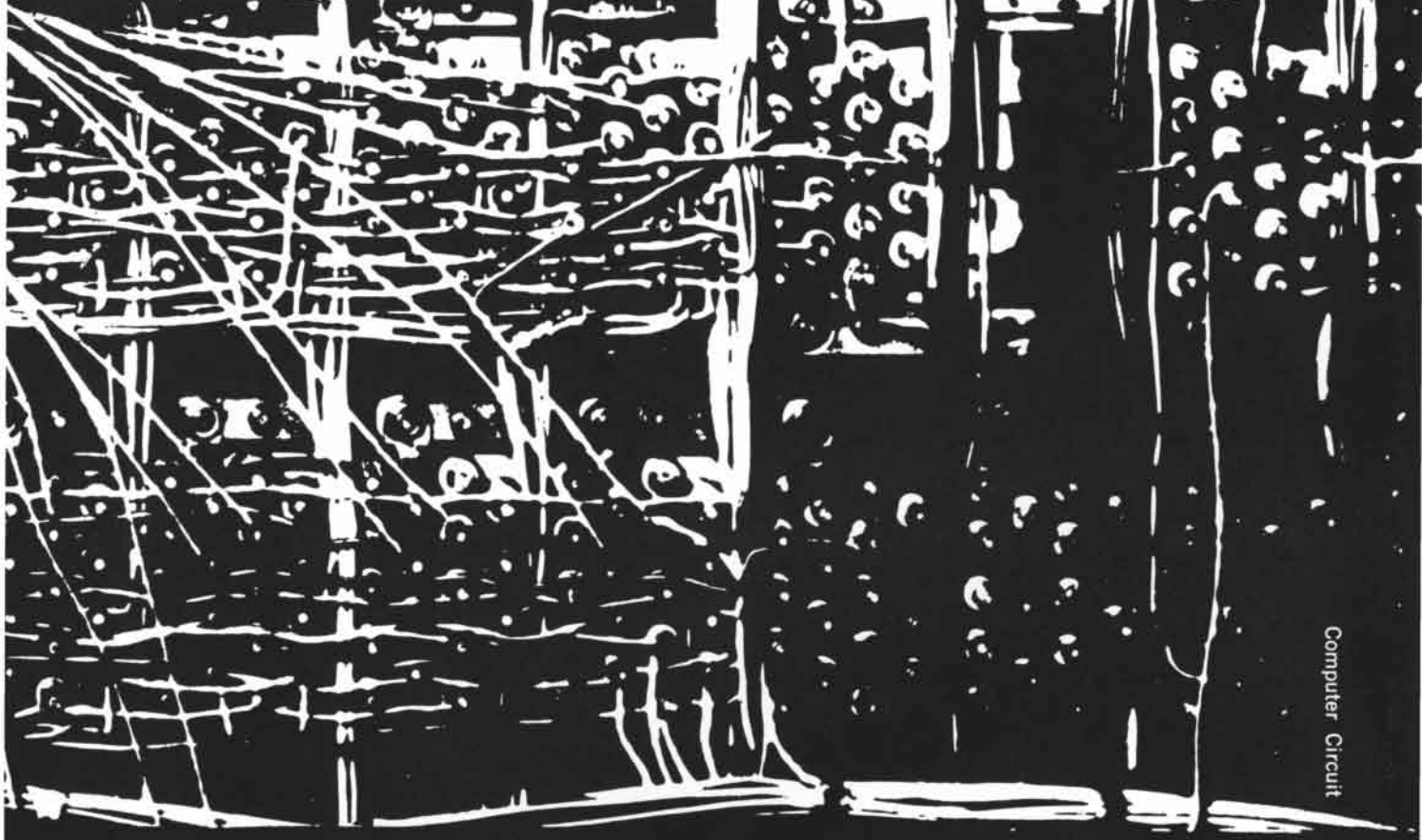
"The objective, then, is to tune the fork by adjusting the solder so that initially the clock runs not more than two seconds per day fast. The *Q* measurements are of great help when making the adjustment. If one tine is tuned to a frequency slightly different from the other, the band width begins to broaden. The broadening is quickly indicated by a lowered *Q*. The cure obviously is to adjust one tine or the other until the *Q* returns to its maximum value. Just add solder, tune by filing the solder a bit and observe the *Q*. A little practice enabled me to tune my fork without great difficulty.

"The incorporation of a phase-shifting network into the electronic circuit that is supplied by the manufacturer to drive the fork proved somewhat difficult. A little thought convinced me that it would be better in the long run to completely redesign this part of the circuit for transistors and thereby gain the additional advantage of a unit that could be operated by batteries, if desired, or to shift to battery operation automatically in the event of a power line failure. One summer's worth of ruined data was enough to convince me of the need for stand-by battery operation.

"The electronic circuitry that ultimately resulted is shown by the accompanying schematic diagram [*page 139*]. The oscillator amplifier is a hybrid circuit, chosen because I wanted an automatic gain control to stabilize the drive to the fork. The frequency is weakly dependent on the amplitude of the driving energy, and it is well to minimize this dependence as much as possible in order to improve stability. The automatic-gain-control circuit (AGC) is of the delayed type that enables the amplifier to approach full gain until almost full amplitude has been reached; then the AGC takes control of the gain and therefore of the amplitude.

"To achieve the desired performance I finally decided to include one vacuum tube of the new 'peanut' variety in the circuit, a tube designed to be compatible with transistor circuits. It has a 26.5-volt filament and operates well from a plate supply of the same voltage. A resistor in the cathode serves to bias the tube to its maximum gain when the AGC voltage is zero, and makes the circuit self-starting. The transistor Q1 is a current amplifier and Q2 is a voltage amplifier. The network in the emitter of Q2 introduces the phase lag for the adjustment of the fork frequency. It acts to increase the gain as phase shift is increased, thus tending to offset the decrease in fork output as the frequency is shifted away from the fork's natural period.

"Q3 is an amplifier of the emitter-follower type that isolates the oscillator



Computer Circuit

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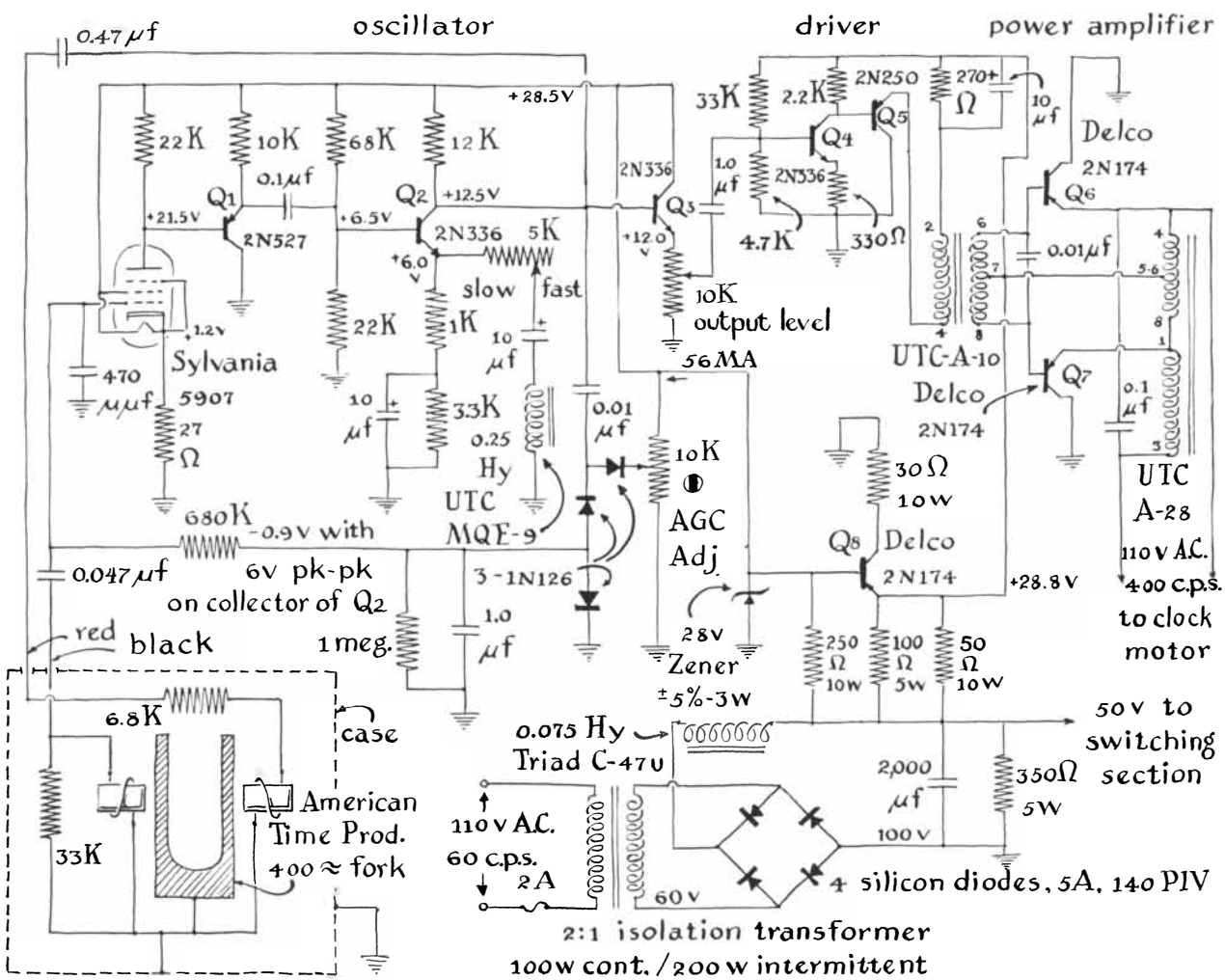
from the driver. Q's 4 through 7 form a power amplifier that generates about three watts for the clock motor. The emitter-follower circuit was also selected for the output stage, primarily because it is stable under no-load conditions. The autotransformer connection in the output stage helped to solve the problem of finding a transformer just right for the job.

"The power supply is fairly simple. The inductance-input filter helps to maintain the voltage at a constant value. The Zener diode supplies regulated potential at 28 volts to the oscillator and excitation for transistor Q8. This transistor functions as a voltage regulator of the shunt type; it supplies 28 volts to the driver and power amplifier. The resistor in the collector of Q8 helps to reduce the amount of power that is dissipated by this transistor. The 2N174 transistors are rated at 80 volts but no more than 60 volts is applied to them. The regulator must operate properly or these transistors may be destroyed.

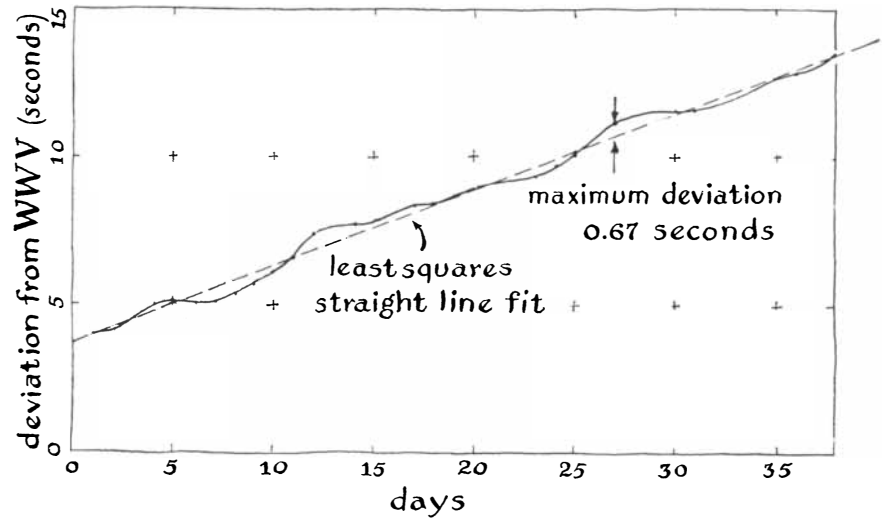
"Before undertaking the construction of the electronic part of the clock the inexperienced worker should review the literature of transistor construction. Transistors are easily damaged by heat. The leads must not be bent sharply at the point where they enter the housing. Transistors Q5, Q6 and Q7 and the Zener diodes are mounted directly on the chassis, which acts as a heat sink. Q8 requires at least a medium-sized, finned heat sink, from which it must be insulated with mica washers.

"I mounted the entire electronic assembly, including the fork and power supply, on a metal chassis two inches high, eight inches wide and 17 inches long. The fork must be kept vertical. When the circuit has been constructed, all connections should be carefully checked against the schematic diagram. Then disconnect Q8 and the supply lead to the power amplifier and apply power from the line. If a variable transformer is available, use it to apply the power gradually. Then, with an appropriate voltmeter, measure the output of the Zener diode. If it is regulating properly, the potential, as measured at its cathode, should be 28 volts. Ground the lead from the automatic gain control and set the wiper contact of the AGC potentiometer at the positive supply end. The fork should now oscillate.

"The shape of the wave form that the fork generates should be observable by connecting the oscilloscope at all points in the circuit that carry the signal. Next remove the ground that was previously placed in the lead from the AGC and gradually advance the wiper contact of the AGC potentiometer toward the grounded end. The AGC should now function. The output signal, as observed on the oscilloscope, should vary as the adjustment of the AGC is altered. Set the AGC adjustment for about two-thirds of full output, remove power, reconnect Q8 and the supply to the power



Schematic diagram of the tuning-fork oscillator



Graph of the fork's timekeeping performance

amplifier. Reduce the output to zero at the output-level potentiometer on Q3. Reapply power and measure the voltage at the emitter of Q8; it should be about 28 volts. By means of the oscilloscope observe the voltage on the emitter of either Q6 or Q7. The potential should be about 28 volts positive when no signal is present. Gradually increase the drive by means of the output-level control. Signal voltage should appear at the measured point. Increase the drive until the wave form just begins to develop a flat top. Do not increase the drive more than this amount. The maximum voltage on the emitter should measure between 56 and 60 volts. An alternating current of 110 volts (root-mean-square, not peak-to-peak) should appear across the clock motor, which must be connected when the measurement is made. I use a 400-cycle, synchronous clock motor that was manufactured by the Haydon Company, 245 East Elm Street, Torrington, Conn. The 400-cycle output of the amplifier can be divided by eight for operating a 50-cycle motor, if required, or divided by 20 and multiplied by three for 60-cycle output.

"My tuning-fork module was obtained from the R. E. Goodheart Company, P.O. Box 1220, Beverly Hills, Calif. 90213. By special arrangement the price has been reduced to $14.95 for amateur experimenters. This article should be mentioned when the fork is ordered to ensure that the proper model is supplied. The unit will arrive complete with vacuum tubes and a schematic diagram. Before making any modifications apply the specified voltages and check to make sure the fork oscillates. If it does not, return the unit. The supplier has agreed to replace defective units promptly. To start the oscillation gently tap the cylindrical can that houses the fork assembly. Full output, as observed on the oscilloscope, should develop within about 30 seconds.

"I attached a cam to the shaft of my motor, which turns at one revolution per minute. The cam closes a microswitch briefly during each revolution. The rate of the tuning fork is observed by measuring the difference between the trailing edge of the minute pulse so generated and the beginning of the minute tone that is broadcast by WWV. I made my comparisons each evening at about the same time of day. The results of one 37-day run are plotted on the accompanying graph [*above*]. Fluctuations of room temperature appear to account for most of the variations, although some inaccuracy is contributed by this stopwatch technique of observing. The maximum error of measurement amounts to about .15 second, which is not particularly good. Currently I am working on a 400-to-1 frequency divider. This unit, together with an oscilloscope display, will make observations easier and more accurate.

"Room temperature during this run varied about three degrees Fahrenheit, both above and below the normal temperature of the room. That these changes could produce such variations in rates of the tuning fork demonstrates that the fork is sensitive to temperature. Other measurements similarly indicate that for maximum stability the fork should be placed in an oven at constant temperature. I plan to construct a small oven in the near future. The Q of the

fork tends to vary to some extent with barometric pressure, and this too affects the stability. By far the best solution of this problem would be to operate the fork in a vacuum. A vacuum housing would increase the Q substantially and with it the stability. The fork comes in a gas-tight container that is fitted with a sealed inlet tube and therefore can be exhausted readily by those who have access to an air pump.

"Having progressed to this point, I decided to equip the timing unit with a digital display and perpetual calendar. The problems changed from the design of electronic circuits to those of counting circuits. Good counting devices of course include vacuum tubes and transistors. They can accept millions of pulses per second. For counting at lower rates one can use stepping switches of the type that accept dialing pulses in telephone exchanges. These are available inexpensively on the surplus market and, depending on the number of contacts, are remarkably versatile.

"The counting circuit includes seven principal stepping switches, together with several auxiliary relays, for counting minutes, tens of minutes, hours, days, the date, the month and the year. The circuit provides the appropriate skip every four years in February for leap year. By adding a few coincidence circuits, which can be selected by switches, I found it possible to generate pulses at preset times for actuating a variety of other apparatus in my basement shop, as well as appliances upstairs including the radio set and a digital display of the time. I wound up with what may well be the world's most complicated alarm clock!

"Basically the stepping switch is simply a multiposition switch whose shaft is driven by a ratchet-and-pawl arrangement. An electromagnet actuates the mechanism in such a way that a brief pulse of energy causes the switch to step one position. There are often auxiliary contacts provided so that the switch can be made to self-step, or to rotate continuously at its free-running rate until power is removed. This feature allows the skipping of unwanted positions and is used to set the switch to some preselected initial position. The self-step contacts usually operate just at the end of the full travel of the electromagnet armature and can be opened there or closed, like a common household-buzzer action that sets up an oscillation. The switch can be wired to move one position during each oscillation. Other auxiliary contacts on the switch itself can be used to halt the action when the

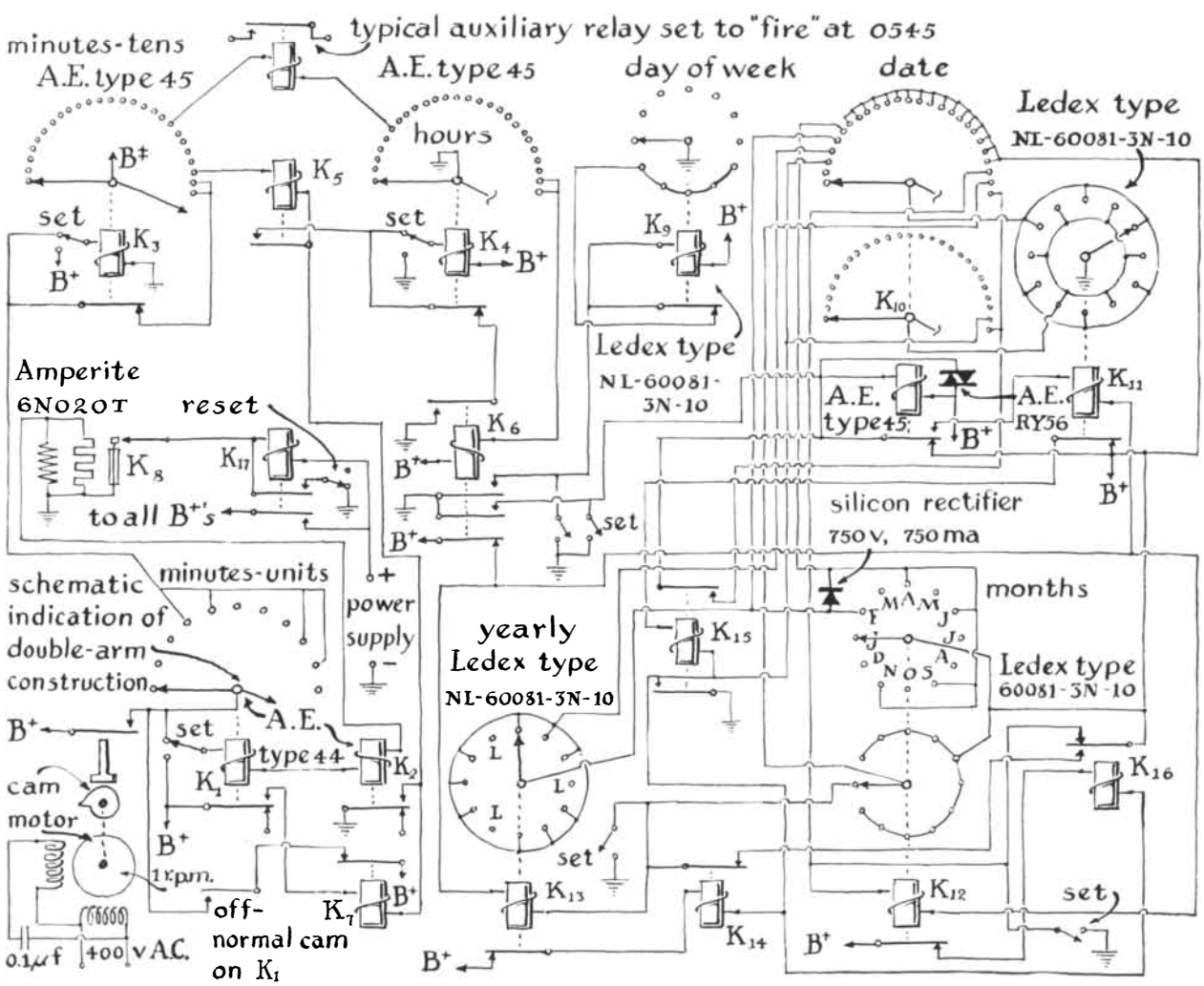
switch arrives at a desired position, designated as the 'home,' or 'normal,' position, or at other desired positions.

"Stepping switches are of two types: step-on energize and step-on de-energize. In the former the shaft moves when the pulse is applied to step; in the latter the pawl is cocked against a spring when the pulse is applied, and the spring releases its energy to step the switch when the pulse is removed. Most of my switches are of the second type in the minutes, hours and date part of my clock and of the first type in the days, months and years part, for the reason that the second type is easier to step synchronously [*see illustration below*].

"I adopted a design axiom that will explain why parts of this circuit may seem unnecessarily complex. It is far better, in my opinion, to design counting circuits so that they can operate in a single way or not at all than to trust to luck and hope that with a precisely timed sequence of operations the clock will count for months on end without making a mistake. It is discouraging to build any counting circuit only to discover after a few weeks of operation that it occasionally misses a count because the proper functioning of the parts was made to depend on two operations that occur at slightly different times, when by adding an auxiliary relay or two the designer could have achieved complete reliability. It should also be noted that almost all stepping switches are rated for momentary operation; prolonged application of power may overheat the relay coil. Care must be taken to ensure that sustained power cannot be inadvertently applied to any coil, unless the designer is prepared to replace an occasional coil, or even a complete switch.

"Care must also be taken to suppress arcs between the contact points of all stepping switches. Most manufacturers can supply instructions for minimizing arcs in their particular switches. In addition each unit should be tested as it is placed in the circuit, a time at which it is also advisable to check the contacts for proper alignment and adjustment.

"Beyond these considerations the counting circuit requires little discussion. I shall be glad, however, to forward a complete, mimeographed analysis of the action of the circuit on receipt of a stamped, self-addressed envelope. Address requests for the analysis to Tom Clements, P.O. Box 598, Palisades, N.Y. 10964. Finally, a small group of enthusiasts that makes a hobby of constructing accurate clocks and other timing devices has recently banded together in an informal organization known as the American Amateur Chronometric Society for the purpose of exchanging information concerning the measurement of time. A letter addressed to me will bring an invitation to join, together with an explanation of what we hope to accomplish."



Schematic diagram of an electromechanical calendar

"The blood more stirs to rouse a lion than to start a hare!"

William Shakespeare

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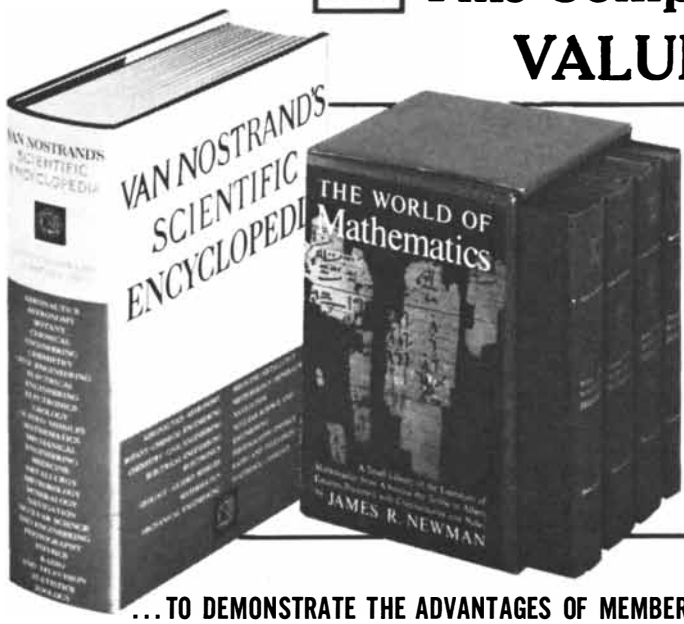

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BOOKS

About the humane psychiatric philosophy of Karl Menninger

by Edwin G. Boring

THE VITAL BALANCE: THE LIFE PROCESS IN MENTAL HEALTH AND ILLNESS, by Karl Menninger, with Martin Mayman and Paul Pruyser. The Viking Press ($10).

Man is so unalterably social a being that it is a bit silly to talk about him, in the way psychologists so often do, as an "individual" or "the organism." The organization of this particular organism extends far beyond the individual's skin to include both events in his environment and other people. Try to imagine a mental illness—purely a mental illness, not a physical one—in the legendary wild boy of the forest, who, nurtured by a wolf, grows into a wild man who has never seen another person. Catch him and take him to town and there he will be in trouble, but out in the forest the sort of mind he has is simply the sort of mind a wild man has. He could become physically ill and might even starve to death, but he would not be mentally ill. Back in town there might be in the mental health center, as it is called in these enlightened days, a withdrawn person down at the fourth level of "dysorganization" on the Menninger scale, a man who sits silent and immobile all day in a private world of his own—off "in the next room," as psychiatrists sometimes express this kind of mental isolation; yet even he would not be a social isolate. To understand him, and later to help or cure him, you have to know what it is he has shut himself off *from*, and it is always a world of people he is busy rejecting.

This is the theme of Karl Menninger's book: how man, a social unit, succeeds or fails in his never ending effort to maintain an equilibrium, a "vital balance," between on the one hand the forces from without and from within that favor his dysorganization and on the other hand the forces, also from without and within but mostly from within, that favor his integration and control. We know this balancing act in its physical aspects. Introduce an antigen into the blood and antibodies form against it. Menninger goes back to the 19th-century French physiologist Claude Bernard for his idea and for a more recent analogy cites Walter B. Cannon's concept of homeostasis. He may not have known that the term "vital balance" was used by the German philosopher Richard Avenarius in his *Kritik der reinen Erfahrung* of 1888–1890, a difficult book that had great influence on the positivistic psychologists of his day. Whenever a vital difference occurs, set up by destructive forces from outside, said Avenarius, adaptive vital events from inside are marshaled to restore the vital balance. In modern parlance this is also the way a servomechanism works, enabling a self-regulating system to maintain its equilibrium.

Menninger not only presents man as a social unit, inextricably related to his fellows; he also illustrates the point with his own personality. Karl Menninger is person-oriented—a clinician, teacher and writer. As a clinician his lifelong mission has been to restore faith and hope to those who are suffering or confused and who have retreated from reality. As a teacher he conveys to his many young disciples the doctrine that there is no line between the normal and the abnormal mind, that the struggle of the mentally ill may be different in degree but not in kind from the struggle that is the essence of every man's existence. As a writer he has produced at least eight books and more than 300 articles, many of them pounding at this same humanitarian theme.

His book has no preface, but it is possible to supply one. Karl Menninger was born in Topeka, Kan., in 1893. His father was a physician who was associated in the enterprise that later developed into the Menninger Clinic and is now the Menninger Foundation. Karl was graduated from the University of Wisconsin in 1914 and then went to the Harvard Medical School for his M.D.; soon he returned to Boston as an instructor at the Boston Psychopathic Hospital. At Harvard he came under the influence and stimulus of the magnetic E. E. Southard, 17 years his senior, then professor of neuropathology until his sudden death in 1920. Southard had a brilliant mind and was a friend and admiring disciple of William James, who was 34 years *his* senior. James, Southard and now the young Menninger were all of the same cast of mind: warm in human relations and patient with human frailty. Later, when Menninger read James's letters, he said he could hear Southard speaking. For Menninger, who cites him repeatedly, Southard had become an intellectual father image.

The editor of Menninger's selected papers, who had also been a pupil of Southard's, quotes Southard: "It is important for young psychiatrists to get in the habit of writing. Write about your cases. Whether you feel you have anything to say that has new significance or not, it is important for you to write. You must share with others what you have learned, and the task of writing clarifies your own thinking." That has been two-thirds of Karl Menninger's life—writing and teaching. The other third was his inspiring of hope in those who needed it. He writes almost as if he got all this from Southard, but of course any such view is bound to be wrong. Menninger himself warns against expecting to find any single force the sufficient cause of any attribute of present personality. James, Southard, Menninger and all the others who were associated with them were agents of a changing *Zeitgeist*.

Menninger's most important book may be *The Human Mind*, editions of which appeared in 1930, 1937 and 1945. The first edition brought him enough money to afford psychoanalysis with Franz Alexander; he was Alexander's first psychoanalytic subject. In the early 1930's anyone who undertook psychoanalysis was still considered a bit odd, but these young men saw correctly that

Freud was part of the *Zeitgeist*'s wave.

Menninger wrote steadily through the four decades after 1919. By 1963 he was 70, an age at which many men want to go over what they have done, bring it up to date and correct errors of judgment. *The Vital Balance* must be such a book, even though one cannot be sure that Menninger will not do the same thing all over again at 80 and 90.

It is not certain how Menninger's coauthors Mayman and Pruyser come into *The Vital Balance*. In places the text uses a studied "we" that does not mean the author and his reader but sounds as though it had been substituted in manuscript for "I." Then in other places and without warning you read "Mrs. Menninger and I" or "as my brother has suggested." Perhaps Menninger's associates took the whole manuscript and attempted to integrate it. The volume lacks the unity of *The Human Mind* in that you cannot tell the audience for whom it was written, and there is no preface to speak for it. Probably this is what Menninger wanted to say to young physicians, hoping that educated laymen would also read it and find it interesting.

Menninger starts out with diagnosis. He has first to attack the many classifications of mental disease that have come to us from Greek times up to the present. He once made a hobby of collecting such lists, and he has reproduced 77 of them, all banished to an appendix. (He includes William Cullen's 108 species and 27 genera of mental disease and also mentions Philippe Pinel's 2,400 species, which Pinel later reduced to four.) In psychiatry, as in biology, taxonomy may give you a start, but no man of action is content to live in a museum. Menninger scorns both the ancient and the modern classifications of mental disease as false diagnoses that tend to pigeonhole a person instead of leaving him free to move along a continuum between incompetence and competence. He notes how dementia praecox was once a rigid classification, how most of the patients in a mental hospital came to be so classified, and how the term first changed to "schizophrenia" and then went out of use because there was no common treatment appropriate for all these people. Often dementia praecox was only two words on a file card made out when the staff consigned the patient to a hopeless future. Menninger is sure that many of these cases are reversible and that diagnosis is better made by estimating the degree of incompetence. States of mind are not specific. They are not separated in the sense that biological species or physical diseases are.

After diagnosis Menninger traces the history of treatment down through the ages. First there was abuse—whipping, beating, starving, freezing—on the chance that the sick person would be shocked back to normality. The ruthless practitioners of these methods may have been motivated by frustration. After that there was the absence of treatment: the sick person was incarcerated and allowed to deteriorate. Then in the early 19th century, with Pinel and Dorothea Dix, there was an attempt to apply kindness and education, a practice that was in general ridiculed. Medicine had been tried from Greek times and later surgery, of which the latest form is excision of portions of the brain. Psychology did not emerge as treatment until later in the 19th century in France, with A. A. Liébeault and J. M. Charcot. World War I presented psychiatrists with "shell shock," which surprised them by proving to be a reversible incompetence. Psychotherapy came in with Freud and Pierre Janet in the present century, and now, says Menninger, we are equipped with a holistic approach which takes the whole personality into account and which this book is about.

To talk about these matters you need what is called a behavior theory, and Menninger's behavior theory is this business of the individual's need to maintain a vital balance. A person finds himself the seat of a perpetual adaptive effort to maintain the vital balance by the mutual interaction of himself and his environment. Since the environment is always in flux, so also must be the person; he changes to meet change, changing the outside world or changing himself in accordance with the capacities of his ego. Menninger cites many famous names as having contributed to this conception of balance, even alluding to Henry Louis Le Châtelier's conception of chemical equilibrium. He thinks that the evolution of psychiatry from classification to function is an abandonment of Aristotelian thinking in favor of the functional conceptions of Galileo (an argument put forward by the psychologist Kurt Lewin). Menninger accepts from Freud an ego theory: the notion that there is an ego constantly bothering about the vital balance, choosing modes of adaptation, striving always for autonomy, perceiving reality in order to maintain mental organization and also acting as conscience—Menninger does not take over the superego.

The chief activity of the ego is coping, which it does pretty well at the competent end of this particular stretch of human variability. At the other end the ego keeps trying to cope but may fail. "Coping" is a good word to add to psychiatric jargon; everyone knows what it means and recognizes it as his principal activity. In some ways this chapter resembles Freud's *Psychopathology of Everyday Life*, showing how we manage the day's stream of problems but slip up now and then. The idea that coping is living is not new, however, and Menninger quotes Samuel Butler on the topic: "All our lives long, every day and every hour, we are engaged in the process of accommodating our changed and unchanged selves to changed and unchanged surroundings; living, in fact, is nothing else than this process of accommodation.... In quiet, uneventful lives the changes internal and external are so small that there is little or no strain in the process of fusion and accommodation; in other lives there is great strain, but there is also great fusing and accommodating power; in others great strain with little accommodating power. A life will be successful or not, according as the power of accommodation is equal to or unequal to the strain of fusing and adjusting internal and external changes." So coping is normal. Coping is living.

So far, so good, but coping is not always successful. There are failures of adaptation, and they can be permanent, even though they can sometimes be reversed. In other words, there is such a thing as mental illness. You need some way of labeling it without separating it from the adaptive process or pigeonholing it as hopeless. Menninger asks you, therefore, to consider five orders of dysfunction, of dysorganization and dyscontrol. *Dys* is not *dis*. It means bad, bad organization, bad control. All five "dysorders" are bad: they belong in the series that runs beyond normal coping toward incompetence.

The first order of dysorganization and dyscontrol is mere "nervousness." The person is taken off guard and normal coping fails. There is increased tension. Some thoughts are shut out—automatically repressed. There may be a good deal of repetitive thinking. Menninger gives a list of eight exaggerated symptoms, but you don't call the doctor yet. At this level reversibility is taken for granted. Wait.

The second order means some withdrawal from reality. There is personality change toward a simpler level of maturity. There is a great deal of anxiety. The person tries to escape from reality

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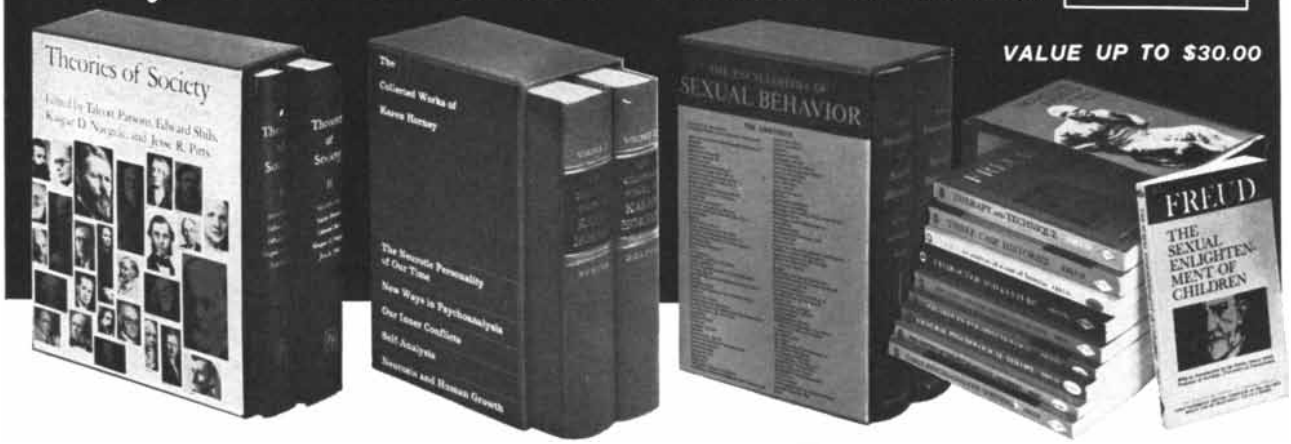

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by forgetting, falling asleep, moving into a world of fantasy, "sleepwalking." Aggressive tendencies develop; the ego tries to control them, sometimes by directing them against the person's own body, as in self-mutilation or the use of drugs. The ego may turn to exaggerated religiosity or magical formulas and rituals such as food faddism. This level represents a broad span of the *dys* continuum. We can name it neurosis, and it may be time to call in the doctor.

The third order is plain aggression, active but obscured in the second order and now out in the open. Physical attacks and social offenses can now get by the increasingly ineffectual ego. The person never really knows "why I did it," although he may manufacture a reason, often a silly one. Nowadays, with overt aggression out of style, aggression is no longer considered manly and courageous; the *Zeitgeist* moves on toward the values of Socrates, Jesus and Gandhi. Only a few sanctions for attack on one's fellow man are left, for example war, hunting, capital punishment and prizefighting. So it is that the ego more often fails to curb hostility than it once did—the demands on restraint are greater. Much of this battle goes on at an unconscious level, and evidence of cognitive dissonance is likely to be buried under rationalization. At the conscious level Hitler must have been sincere about his feelings toward the Jews, and today there are many whose aggressions are directed against entire groups such as capitalists, Negroes and Democrats. Impulsive violence may be felt and exercised, even when it is entirely out of keeping with the habitual personality. The individual may ask to be locked up so that he cannot commit a physical attack, and if he commits an attack it may be erased from his memory. All these dyscontrols have psychological bases, the discovery of which is not easy. The failure of the ego expresses some other failure that is the basis of aggression.

The individual usually manages to present a façade of propriety, but at the fourth level of dyscontrol the façade may no longer be maintained. Now we are on the edge of what used to be called a psychosis. The patient seems to talk perpetually and senselessly, since the hidden meaning of what he says is not clear. He is given over to depression, sadness, hopelessness and feelings of inadequacy, incompetence, worthlessness or wickedness. Elation and irascibility may occur in alternation. He may escape into a private world of delusional preoccupation, or his delusions may reveal themselves as in paranoia, or he may lapse into a confused delirium. Menninger tells us that these extreme deteriorations are usually reversible. The crisis, having come, may recede.

A few people, Menninger says, may move on to the fifth stage of dysorganization and dyscontrol and may even pass beyond hope. This is the living death, where the subject lives on without activity or interest. Sometimes he is able to mount an effort of self-destruction. In either case the ego has surrendered, and death—biological or psychological—is all that is left.

Menninger's book concludes with chapters on the physician's role in treatment. He stresses the reversibility of the course of dysfunction, but there is no sure route to cure. One difficulty is that the retreat from reality can be the ego's solution of a problem. Security may be gained by escape, as the herbivorous members of the animal world know. Illness removes responsibility. Menninger cites the case of "Mary Smith," hospitalized, lonely, with the delusion that a beloved son was trying to see her, spells of shaking the bars of her window and calling out to this son who was not there. A new doctor started by showing interest in her, sitting and listening to her. Soon she began to get better, and this sympathetic understanding on his part set her off toward recovery. After 13 years in the hospital with no improvement, she now changed rapidly. The doctor had begun with the listening treatment in March, and by October Mary Smith was paroled to a job of practical nursing. She was then 76. She returned once more to the hospital, but for the most part she lived outside, reestablishing old social contacts, engaging in many useful activities, and finally retired to a nursing home at 90.

Does this mean that listening is the best treatment? Not always. There was another case in which all effort at treatment failed, and a young woman was finally transferred from a mental hospital to a private sanitarium where it was thought she would live out her thwarted life without change. Less than a year later Menninger, waiting at the station to be picked up by the young woman's father and driven home, was astonished to be met by the daughter herself in the family car. She laughed at his amazement and thanked him for helping to move her to a place where she had "no one but myself to depend on." This particular ego had not found escape the solution to its problem.

What does the physician do? Should he be permissive or employ discipline? Menninger thinks that he needs to be wise and to remember that, if his wisdom fails, the fault is still not his when so many factors are at work. The important thing is to love these people who have lost control, says Menninger, expressing not so much a contribution to science as a conviction firmly set at his threescore years and ten. The remedial role of the physician, he urges, depends on the use of the "intangibles," which are first love, then faith and then also hope, and the greatest of these, as St. Paul said, is love. Let the patient know that the physician loves him, that the physician has inexhaustible faith in his recovery and keeps on hoping and hoping for his improvement. That is Karl Menninger's evangel.

Is an evangel enough? It is less than the truth. Menninger brings faith and hope to his theory as well as to his patients. Here you have a kind personality administering a kind therapy, and in what other way could you get a kind therapy administered? Surely not by a tough cynic. And is Menninger wrong in his faith because he does not always succeed? No, the test would lie in whether a more successful therapy is known to exist. Here it may be that in abandoning the old classifications (as other up-to-date psychiatrists also do) Menninger has been in error in limiting himself to variation along a single dimension of dysfunction. Mental illness may eventually be found to vary along several different courses of dysfunction, with movement more readily reversible on some courses than on others. The experimental control would be to see if a tough-minded, cynical Menninger would come up at 70 with a similar kind of St. Paul therapy. Has the psychiatrist's faith been wrought by facts, by his own personality or—as is almost inevitable—by both? For this question the reviewer has no answer; yet he too has a faith. It is that civilization is carried forward on the shoulders of many dissenters. It is more important that Menninger be clear than that he be right. Being clear, he becomes a usable model of his conviction. Those who dissent from his faith in the therapy of love or from his linear conception of dysfunction are now challenged by him to set up equally clear models. Then clinical experience can ultimately decide.

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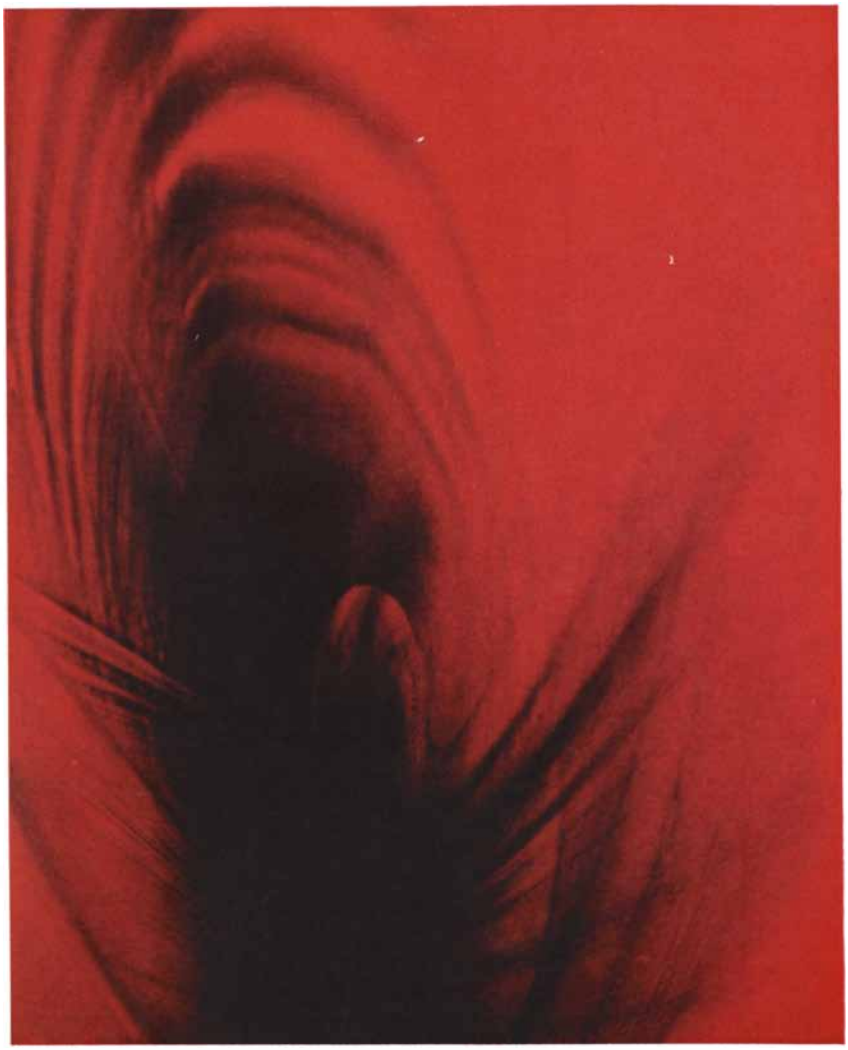

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Since 1944, when Los Alamos scientists developed the world's first homogeneous reactor as a research tool, they have maintained a lively interest in special purpose reactors. Interest now centers on novel fuel systems, such as use of molten plutonium in high-temperature, high-efficiency devices. Other objectives are the development of low-cost nuclear fuel for high-temperature gas-cooled reactors, and thermionic converters for space applications.

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which is to say a nonbook, than a disciplined treatment of a coherent theme. It consists of papers, commentaries on them and discussions at a symposium held at the University of Oxford in 1961 on the "intellectual, social and technical conditions for scientific discovery and technical invention, from antiquity to the present." There are, to be sure, some competent—and even a few highly interesting—studies of specialized subjects, which have intrinsic merit and are worth reading. But anyone who anticipates that this collection will appreciably enlarge his understanding of the reasons for, the nature of and the circumstances critical to scientific change is headed for disappointment. The scope of the symposium is so grandiose that it is almost meaningless. And no two participants seem to be in agreement as to just what is meant by scientific change, let alone what promotes it. One is struck by the fact that most of the participants rode their hobbyhorses through what are by now thoroughly familiar and otiose routines. A few examples are in order.

The distinguished mathematician B. L. van der Waerden, describing and contrasting the basic methods of Babylonian and Greek astronomy, can find no better explanation for the achievements of the Greeks than that they were "born geometers and engineers." For this felicitous insight he was acclaimed by some and jumped on by others. His critics also had an easy time attacking the evidence he marshals for such hoary assertions as that Thales was a geometer and that he predicted a solar eclipse. Joseph Needham's paper on the Chinese scientific tradition is in many respects a masterly performance, but it has its share of special pleading, of precarious, not to say strained, inferences. The peculiar arrested development of Chinese science after the Middle Ages, he tells us, was due in part to social and economic circumstances, in part to the fact that "Chinese conceptions of law did not develop the idea of laws of nature." He seeks to establish for Asian cultures the rightful place too long denied them in the West, yet he frequently weakens the effectiveness of his critique by excessive claims vulnerable to the skepticism of other Sinologists.

Thomas S. Kuhn's paper on the function of dogma in scientific research, with its contrived and, as Stephen E. Toulmin observed, unnecessarily paradoxical concept of the "paradigm," gave joy to Michael Polanyi and irritated other commentators. Whether or not Kuhn is saying anything more original than that it is as hard for scientists as for others to break the cake of custom is open to doubt. The epitome of the academic minuet is the discussion between C. C. Gillispie and Mary B. Hesse. Gillispie gave a paper entitled "Intellectual Factors in the Background of Analysis by Probabilities," which seeks to show the effect of earlier uses of statistics in measuring social phenomena on James Clerk Maxwell in his work on gases and statistical mechanics. Miss Hesse in her commentary began by praising the paper and its "penetrating analysis," then trounced it for its serious weakness and "confusion," particularly for its failure to recognize what Maxwell owed to the theoretical work of Rudolf Clausius, a debt Maxwell himself explicitly acknowledged. Gillispie in reply thanked Miss Hesse for her valuable criticism, admitted his errors and then reasserted the basic validity of his argument. A happy ending for all except the reader.

TUTANKHAMEN, by Christiane Desroches-Noblecourt. New York Graphic Society ($15). The pharaoh Tutankhamen, after a reign of nine years, died about 1350 B.C. at the age of 18. He is remembered primarily for his funeral. His tomb, discovered by Howard Carter in 1922, had, unlike other Egyptian tombs, been robbed only imperfectly. The bulk of its incredible treasure remained intact some 3,300 years until the Carter archaeological party uncovered it. This book by the chief curator of the National Museums of France, a respected Egyptologist, tells the story of the find, describes at length and in detail the objects that were intended to assure the young pharaoh as luxurious and elegant a life in his tomb as he had known in his palace, and it attempts to reconstruct the ceremony of his coronation and the years of his reign on the basis of his baggage. The account is too thick with facts to make it the easiest kind of reading, but it is made more palatable by a wealth of illustrations, some of which are in color and almost too stunning to be believed.

THE MATHEMATICAL WORKS OF J. H. C. WHITEHEAD, edited by I. M. James. The Macmillan Company ($45). A collection of all the known published papers of the eminent British mathematician who died suddenly in Princeton in 1960 at the age of 55. His earliest interest was geometry, from which he moved to the classification problem for manifolds; later he turned to topology, both algebraic and classical, to which he made contributions of a high order.

He is remembered for these and for his influence as a colleague on other mathematicians, with whom he was always willing to share ideas and in whom he inspired deep affection. There are included a biographical note by M. H. A. Newman and Barbara Whitehead and a mathematical appreciation of Whitehead's work by John W. Milnor.

NICKEL: AN HISTORICAL REVIEW, by F. B. Howard-White. D. Van Nostrand Company, Inc. ($6.95). A comprehensive, ably written account of the discovery, mining, refining and uses of this silvery, corrosion-resistant metal. A small proportion of nickel has been found in tools and weapons dating back to 3100 B.C., and copper-nickel alloys were used in coins, swords and other artifacts for many hundreds of years before the element itself was identified in the 18th century. Like cobalt, nickel came from a troublesome ore that was dangerous to work because of its arsenic content. The root of the word itself—*nick*—is said to stem from the Beowulf saga, in which the word *nicor* appears denoting a sea monster associated with devastation. In Central Europe the word "nickel" was used as early as 1329 to apply to hussies or strumpets, to small and ugly horses, to a disability of goats, and in an adjectival sense it was associated with the Devil, "implying bewitched, illusory, spurious, false or even stubborn." This volume recounts many curious features of the early history of nickel (including such intriguing oddments as that early in the 18th century nickel was mined in Litchfield, Conn., and then shipped to China for the production of *pai-thung*, or white copper) and also describes in considerable detail the modern metallurgy of the substance and the rise of the world-wide nickel industry. Many fine illustrations.

AFFECT — IMAGERY — CONSCIOUSNESS: VOLUME I, THE POSITIVE AFFECTS; VOLUME II, THE NEGATIVE AFFECTS, by Silvan S. Tomkins. Springer Publishing Company, Inc. ($18). A third volume on cognition and ideology is to follow. The three together will constitute the author's psychodynamics of personality, put together in a little fewer than 700,000 words it took 20 years to get far enough beyond constant revision to let the printer go ahead. The work is thus eight years and 100,000 words longer than William James's classic *Principles of Psychology*. The talk is about the interaction of drives (such as hunger, thirst, sex and the need for air) with affects. The outstanding affects, as de-

fined by the author, are Interest-Excitement, Enjoyment-Joy, Surprise-Startle, Distress-Anguish, Fear-Terror, Shame-Humiliation, Contempt-Disgust and Anger-Rage. The first two are positive (we like them), the last five are negative (we don't like them), and Surprise-Startle is a transitional affect. All these become conscious. They all have bodily attitudes associated with them, of which the facial expressions such as the smile, the sneer, the raised brow and the lowered eyelid are most important, numerous and complex; there are also sobbing, panting and the hung head. Large parts of the books are about the face, the chief organ of the expression of personality. There is a wonderful chapter about the taboo of people's not looking each other directly in the face and never in the eyes, unless, of course, they are in love or are children. The books are packed with facts and with probable facts and are clearly and discriminatively written, but they show the author to be more concerned with his own thoughts than with being the eager teacher who leads his students to understand him. The reading just isn't easy.

THE ART OF WARFARE IN BIBLICAL LANDS, by Yigael Yadin. McGraw-Hill Book Company ($25). A description, in the light of archaeological evidence, of the art of warfare—vehicles, weapons, fortifications, major battles—from Neolithic times down to the seventh century B.C. The author, who is professor of archaeology at Hebrew University and a major-general (former Chief of the General Staff) in the Israel Defense Forces, supports his text with a large number of illustrations, many of them in color.

QUANTA AND REALITY. American Research Council ($3.95). A symposium on the physical and philosophical implications of quantum mechanics, first presented as a radio series in the 1961 Third Programme of the British Broadcasting Corporation. The contributors discuss the evolution of modern physics, which has carried us to a new summit of understanding and at the same time of uncertainty and uneasiness (Stephen E. Toulmin); the particle-wave dilemma that has forced the mature physicist to "forsake his self-appointed status of near-divinity" and to admit himself "a mere man, with all a man's limitations and ignorances" (A. B. Pippard); the curious conceptual relation between waves and probability (Nicholas Kemmer), and the controversies over intuitive models, which touch on the possibility that nature need not confine itself, as Joseph Glanvill put it in 1661, to our shallow models (Mary B. Hesse). There is a windup dialogue between Maurice Pryce and David Bohm, representing opposite camps, concerning attempts to throw light on what is meant by physical reality. They are certainly two gifted investigators, but the light they manage to produce on this occasion makes that of the glowworm seem dazzling by comparison.

GENETICS AND MODERN BIOLOGY, by George W. Beadle. American Philosophical Society ($2). In the Jayne Lectures for 1962 George Beadle, president of the University of Chicago and corecipient in 1958 of the Nobel Prize for Physiology and Medicine, gives a brilliant sketch of the development of the science of genetics from Mendel to Watson and Crick. In addition to the historical review, he describes the structure of the genetic material, the manner in which it carries information, its replication and the mechanism of mutation. Beadle is as gifted a popularizer as he is an investigator, and some of his analogies in discussing the origins of life and human genetics are memorably enlightening.

WASP FARM, by Howard Ensign Evans. The Natural History Press—Doubleday ($3.95). A relaxed, agreeable and knowledgeable account of the fascinating ways of several different kinds of wasps: spider, digger, mason, paper. The author, associate curator of insects at the Harvard University Museum of Comparative Zoology, has made many field excursions to study these single-minded insects and, in particular, has watched them for hundreds of hours practicing their labors and civilities on his eight-acre farm in Upper New York State. Reading his story, one comes to admire his perceptiveness, devotion and imaginative quest and also the marvelous fitness for life of these tiny creatures that first appeared some 60 million years ago, gave rise at one point in their history to the ants and at another point to the bees and, without having made as much of a splash as either of these insects, have nevertheless managed to achieve a remarkable harmony with many different kinds of environment. Good photographs by the author.

MATHEMATICAL PROBLEMS IN THE BIOLOGICAL SCIENCES: PROCEEDINGS OF SYMPOSIA IN APPLIED MATHEMATICS, VOLUME XIV, edited by R. E. Bellman. American Mathematical Society ($6.50). What one usually gets in

this field are rather meaningless capers on the mathematical high wire—and not very high at that. But this symposium, which offers some fruitful (as well as exotic) suggestions, is altogether refreshing. Among the more stimulating papers are "Machine Models of Self-Reproduction" (Edward F. Moore), "Problems of Formulation for Artificial Intelligence" (Marvin L. Minsky), "Knotting Problems in Biology" (Max Delbrück), "Biochemistry: Sterile or Virgin for Mathematicians?" (Arthur B. Pardee), "Efficient Coding for the Desoxyribonucleic Channel" (S. W. Golomb), "The Mathematics of Pattern Recognition for the Electrocardiogram" (Max A. Woodbury and Lee D. Cady, Jr.), "Enzymology and Kinetics" (Irwin W. Sizer), "On Some Mathematical Problems Connected with Patterns of Growth of Figures" (Stanislaw M. Ulam).

BIRDS OF THE ATLANTIC ISLANDS: VOLUME I, by David Armitage Bannerman. Oliver & Boyd Ltd (84 shillings). This volume, the first of two dealing with the birds of the Atlantic islands, embraces the Canary Archipelago and the Salvage Islands. Among the resident and migratory birds that are fully discussed on the basis of Bannerman's own field notes and the observations of many other prominent ornithologists are the herring gull, Kentish plover, black oyster catcher, frigate petrel, red kite, Egyptian vulture, Barbary falcon, Canarian courser, Meade-Waldo's chat, gray shrike, Berthelot's pipit, chaffinch, chiffchaff, Tenerifean goldcrest, shearwater, Laurel pigeon, thick-knee, peregrine, buzzard titmouse, red-billed chough, great spotted woodpecker and hoopoe. The text is consistently readable; the colored illustrations by D. M. Reid-Henry are vivid and well reproduced. A second volume, in which Mrs. Bannerman joins her husband as collaborator, will cover Madeira, the Desertas, Porto Santo and the Azores.

A HISTORY OF GEOMETRICAL METHODS, by Julian Lowell Coolidge. Dover Publications, Inc. ($2.25). THE MATHEMATICS OF GREAT AMATEURS, by Julian Lowell Coolidge. Dover Publications, Inc. ($1.50). Soft-cover reprints of two of the late Professor Coolidge's attractive and authoritative studies in the history of mathematics. The book on geometrical methods, first published in 1940, covers every aspect of geometry, from its Babylonian, Egyptian, Indian, Oriental and Greek beginnings through the modern developments including algebraic and differential geometry. The

other volume describes the work of such amateurs as Plato, Omar Khayyám, da Vinci, Dürer, Pascal, Buffon, Lhopital, Diderot and Bolzano.

ELECTRICITY WITHOUT DYNAMOS, by John W. Gardner. Penguin Books Inc. (95 cents). An explanation of methods that might be used in the future to tap electricity directly from the fuel instead of through the roundabout of steam plants, turbines and dynamos—whose efficiency is limited to about 40 per cent. The fuel cell, magnetohydrodynamic generation and thermoelectric processes are among the approaches considered. Illustrations.

TREASURES OF VENICE, text by Michelangelo Muraro and André Grabar. Skira: The World Publishing Company ($29.50). A lavishly illustrated survey of Venetian art—paintings, sculpture, architecture, frescoes, mosaics, drawings, manuscripts, art objects, goldwork, tapestries. Eighty-five of the plates are printed in six colors by letterpress, 40 are reproduced in black-and-white heliogravure, and all are separately printed and mounted on the book pages. The text seeks to relate the art forms to the circumstances of Venetian history.

SYMBIOTIC ASSOCIATIONS, edited by P. S. Nutman and Barbara Mosse. Cambridge University Press ($9.50). The term "symbiosis" was defined some 80 years ago by the biologist A. De Bary as an association in which two different species live together in a close spatial and physiological relation. The species may be reciprocally dependent, or one may profit at the expense of the other, or again one member may benefit without affecting the other. Much research has been done on this subject, which not only is of considerable intrinsic scientific interest but also attracts man's attention as a symbol and reminder of his own problems of coexistence. This volume is a symposium of the Society for General Microbiology held in London in 1963 and is primarily concerned with mutually beneficial relations between dissimilar organisms, or at least nonpathogenic partnerships. Many bizarre examples are discussed of associations between microorganisms, between microorganisms and higher plants, between bacteria and animals such as protozoa, beetles, sheep, cows and other vertebrates. Illustrations.

THE SECOND CAREER, by Wilder Penfield. Little, Brown and Company ($5). The author, famous as a neurosurgeon, has in later life devoted himself increasingly to writing—novels as well as essays. This "second career" is here represented by a collection of essays and addresses, all of which mirror his humanity, his broad sympathies and his elevated outlook.

Notes

LAMINAR BOUNDARY LAYERS, edited by L. Rosenhead. Oxford University Press ($14.40). This volume, one of the publisher's "Fluid Motion Memoirs," gives an account of the development, structure and stability of laminar boundary layers in incompressible fluids.

TECHNICS AND CIVILIZATION, by Lewis Mumford. Harcourt, Brace & World, Inc. ($2.95). A soft-cover reprint of a pioneering book on the interplay during the past 1,000 years of Western civilization between the social milieu and invention. Illustrations.

THE SEA SHORE, by C. M. Yonge. Atheneum ($1.95). A paperback reprint of an exemplary sketch of the natural history of the water's edge by an outstanding marine biologist. Many illustrations.

MODERN DEVELOPMENTS IN AUDIOLOGY, edited by James Jerger. Academic Press ($12). For researchers, teachers and graduate students, a collection of papers dealing with progress during the past decade in the investigation of different problems of hearing, in particular of impaired hearing.

THE ENCYCLOPEDIA OF ENGINEERING MATERIALS AND PROCESSES. Reinhold Publishing Corp. ($25). Some 300 articles averaging approximately 2,500 words in length present reference material for design engineers, chemists, metallurgists, production engineers and other technical men in manufacturing.

KIRK-OTHMER ENCYCLOPEDIA OF CHEMICAL TECHNOLOGY. John Wiley & Sons, Inc. ($45). The second volume of the second edition of this encyclopedia covers topics from aluminum compounds to azo dyes.

BIOGRAPHY OF PHYSICS, by George Gamow. Harper Torchbooks ($1.95). A paperback reprint of a diverting and informative popularization that deals with physics and the men who made it. Illustrations by the author.

THE SCIENCE OF LIFE, by Gordon Rattray Taylor. McGraw-Hill Book Company ($9.95). A picture history of biology, with a lively and dependable accompanying text, that is a fine introduction to the subject for young people and grownups alike.

INTERNATIONAL AURORAL ATLAS. Aldine Publishing Company ($8.75). This atlas published for the International Union of Geodesy and Geophysics classifies the auroral forms and presents several dozen photographs of auroral displays, some in color.

MAN AND THE CONQUEST OF THE POLES, by Paul-Émile Victor. Simon and Schuster, Inc. ($6.95). From the Vikings to the International Geophysical Year, an ably written account by an experienced polar explorer of man's gradual penetration of the Arctic and Antarctic and of the enlargement of scientific knowledge about these forbidding and beautiful regions. Illustrations.

ELECTROMAGNETIC SCATTERING, edited by Milton Kerker. The Macmillan Company ($19.75). A collection of papers presented at an interdisciplinary conference on scattering properties and phenomena held at the Clarkson College of Technology in 1962.

METHODS OF QUANTUM FIELD THEORY IN STATISTICAL PHYSICS, by A. A. Abrikosov, L. P. Gorkov and I. E. Dzyaloshinski. Prentice-Hall, Inc. ($16). This volume, translated from the Russian by Richard A. Silverman, is an introduction to many-body theory and its ramifications, a sphere of study in which methods borrowed from quantum field theory have led to remarkable advances in statistical physics.

BASIC ASTRONOMICAL DATA, edited by K. Aa. Strand. The University of Chicago Press ($12.50). This third volume of the series "Stars and Stellar Systems," a compendium of astronomy and astrophysics, describes the chief classes of astronomical data that are available from ground-based observatories and discusses the reliability and completeness of these data. Illustrations.

THE CAMBRIDGE ECONOMIC HISTORY OF EUROPE: VOLUME III, edited by M. M. Postan, E. E. Rich and Edward Miller. Cambridge University Press ($13.50). This volume, continuing the justly admired *Cambridge Economic History of Europe,* consists of essays dealing with economic organization and policies in the Middle Ages.

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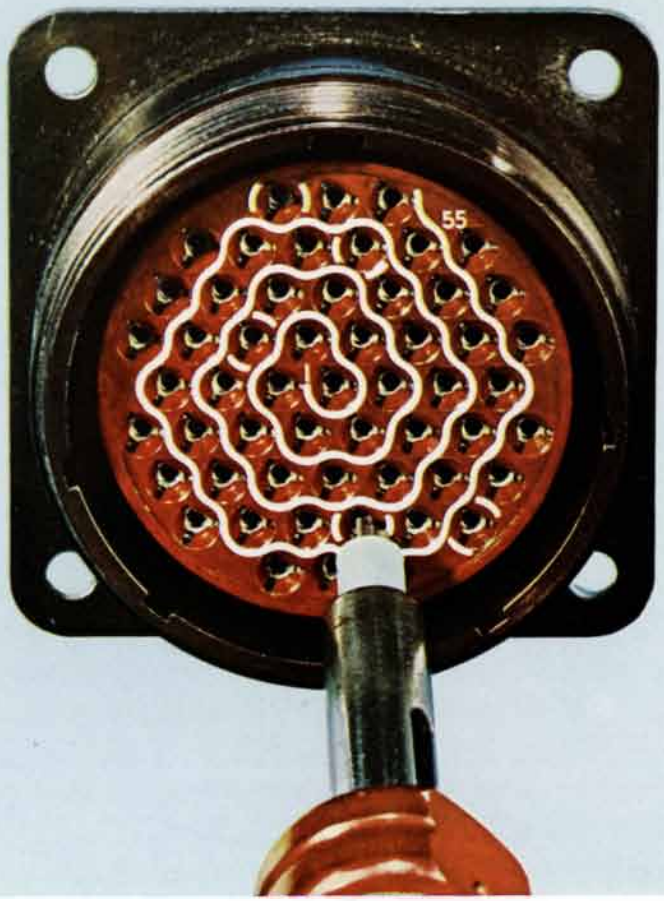

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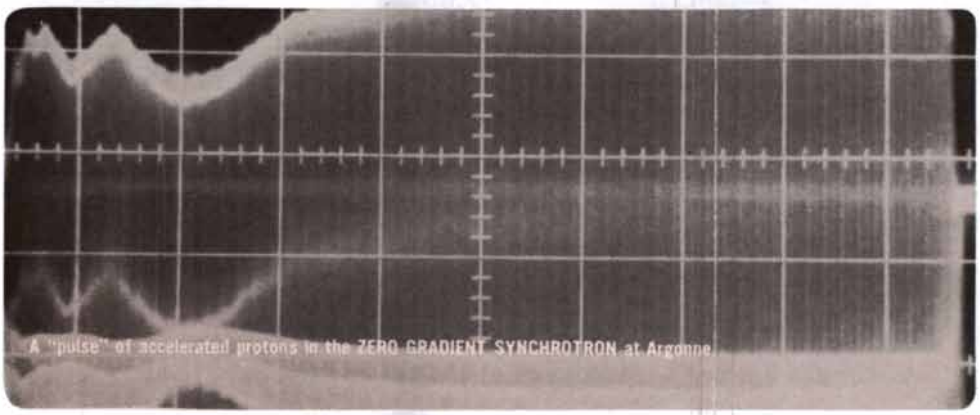

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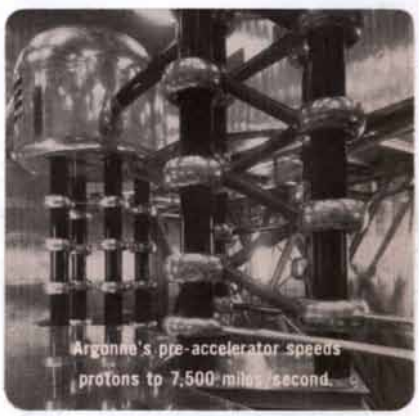

Argonne's pre-accelerator speeds protons to 7,500 miles/second.

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