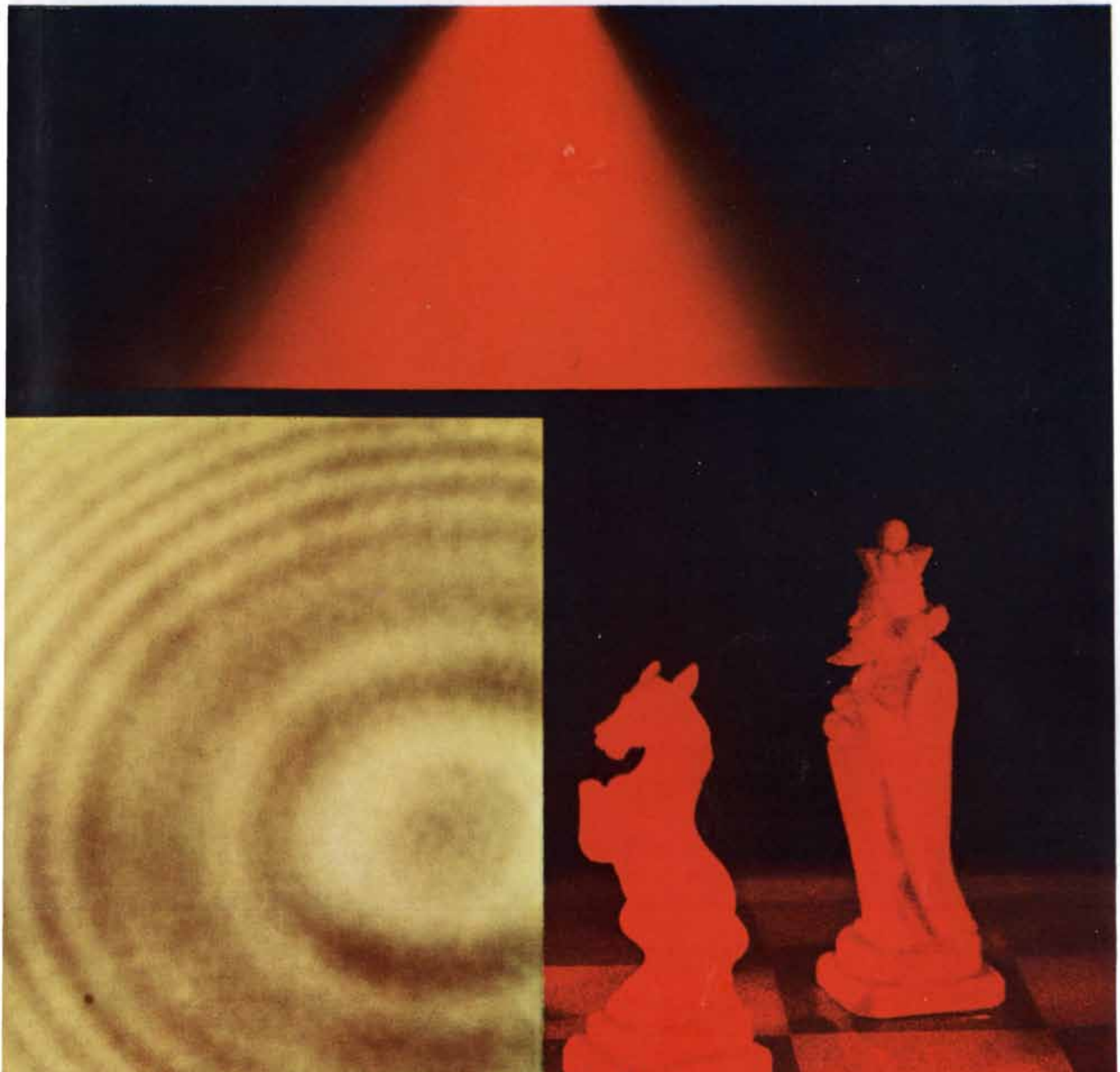
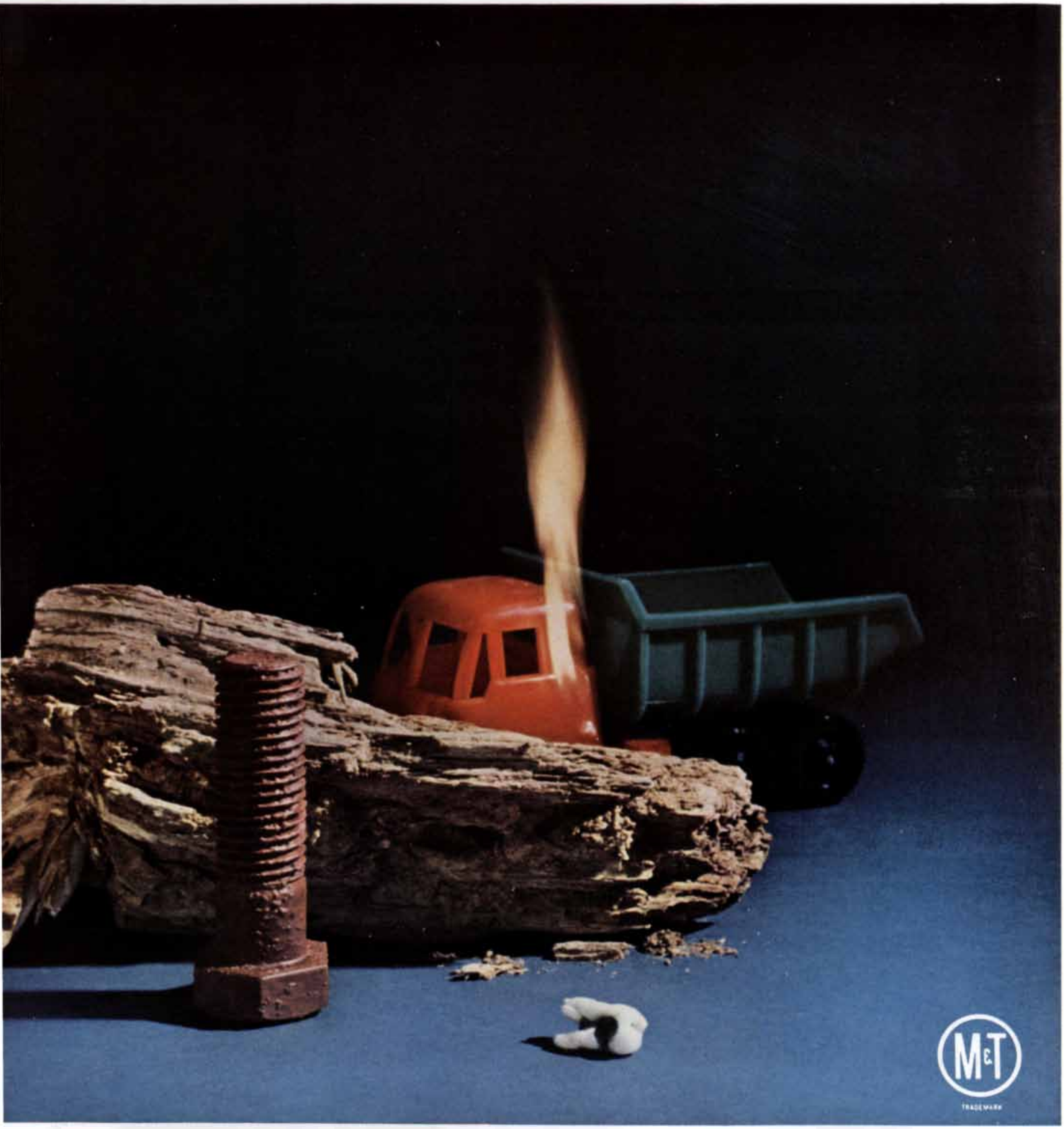
SCIENTIFIC AMERICAN



LASER PHOTOGRAPH

SIXTY CENTS

June 1965


M&T

Established 1845 **SCIENTIFIC AMERICAN** June 1965 Volume 212 Number 6

ARTICLES

DEPARTMENTS

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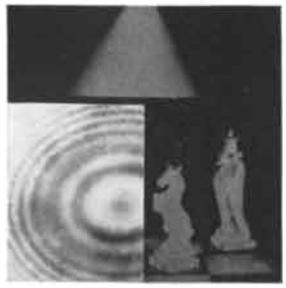

THE COVER

The photograph on the cover shows a hologram: a photographic record of a scene that bears no resemblance to the original objects in the scene but nevertheless contains—in a kind of optical code—all the information about the scene that would be contained in an ordinary photograph and much additional information that cannot be recorded by any other photographic process (see "Photography by Laser," page 24). The cover photograph was made by first masking the top and lower right portions of the photographic plate inside the camera and exposing the lower left portion, which contains a part of the hologram that has been illuminated from behind with ordinary incoherent light. The concentric rings are characteristic of holograms but are purely extraneous: they arise from dust particles and other scatterers in the optical system used to make the hologram. This portion of the photographic plate was then masked and the rest of the plate was exposed. A beam of coherent red light from a laser (*top*) was directed at the hologram from behind and interacted with the microscopic interference fringes in the exposed part of the hologram to produce an image of the original scene (*lower right*). The scene is a group of antique chessmen on a chessboard.

THE ILLUSTRATIONS

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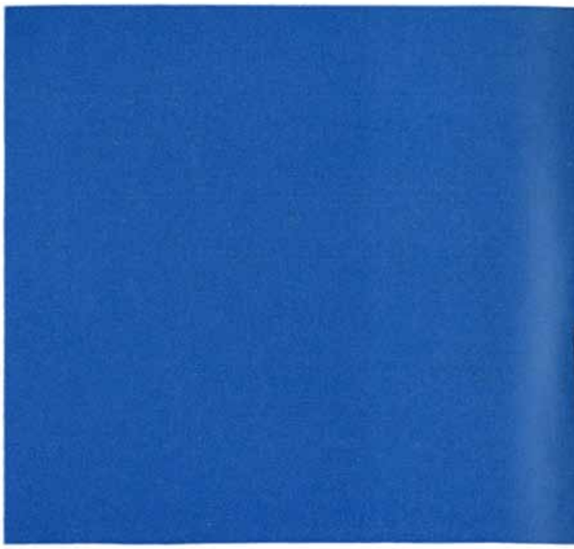

Turning commutators

Natural-diamond tools turn commutators for fractional-hp. motors at the Singer Co. Conventional tool (right) contains a shaped and polished diamond with 60-degree angle. New "skiving" tool (left) contains shaped diamond with 120-degree angle and 6-degree front clearance. This has advantages in an interrupted cut, encountered in commutator turning.

LOOK WHAT THEY'RE DOING WITH DIAMONDS

People with imagination are using natural and synthetic industrial diamonds for an astonishing variety of jobs—everything from straight "muscle" work like cutting quartz to sectioning biological specimens as thin as 50 angstroms.

Every operation shown on these pages couldn't be performed without diamonds. Because with diamonds, you get the unique combination of excellent cutting or grinding ability linked with fantastic endurance. Your diamond tools therefore last longer than any other cutting tool you can use. Your people spend more time in actual production, less time changing tools.

If you cut, sharpen or smooth anything in your business, you can probably use diamonds. Test natural or synthetic diamonds against the method you're now using. You'll learn how efficient—and economical—diamonds can be.

Your wheel and tool manufacturer can prove it. Or write to this magazine for more information.

De Beers, backed by the facilities of the Diamond Research Laboratory in Johannesburg, offers a full range of both natural and De Beers-made synthetic diamonds for industry. The laboratory is constantly engaged in finding new and better uses for industrial diamonds.

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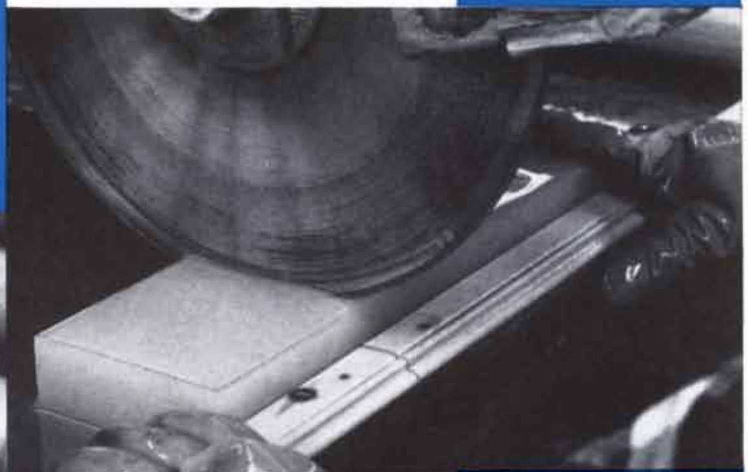
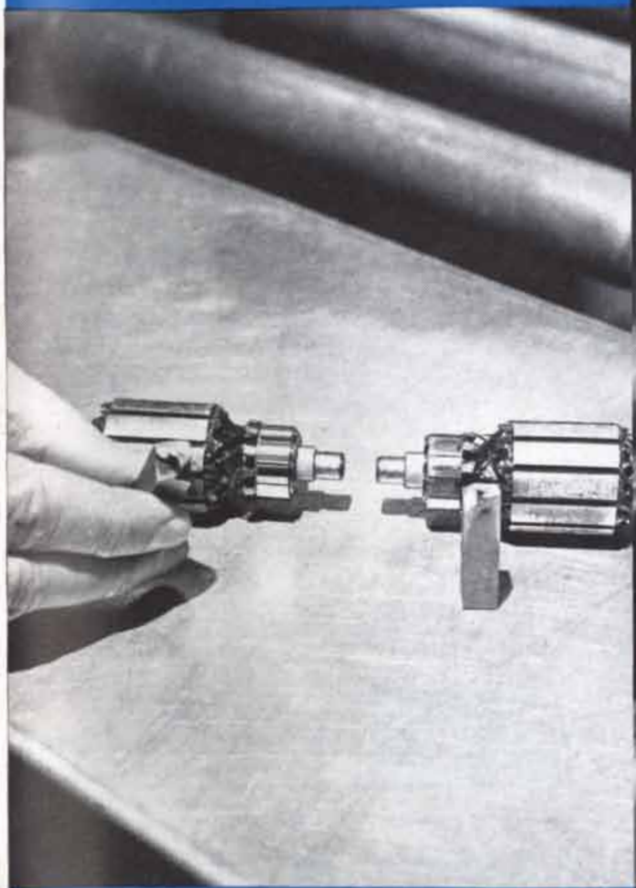
World's leading supplier of diamonds for industry

Industrial Grit Distributors (Shannon), Ltd., Shannon, Ireland

Sawing quartz

Flat quartz blocks are sawed with 14-inch metal-bond diamond saw at Amersil Quartz, Hillside, N. J., a division of Engelhard Industries, Inc. Saw contains 60/80-mesh natural-diamond grit, operates at 5000-7000 sfpm.





Sectioning biological specimens

Diamond knife can cut any known substance into sections as thin as 50-100 angstroms. In addition to sectioning biological specimens, the knife is also used to section such metals as germanium and uranium for the study of their atomic and molecular structure.

LETTERS

Sirs:

I must take exception to your item " 'Eyeless Vision' Unmasked" ["Science and the Citizen," SCIENTIFIC AMERICAN, March], in which the implication is that I used only a blindfold on Mrs. Stanley and did not take adequate precautions to exclude visual stimuli. As I have reported (Psychonomic Society, 1963, 1964), because blindfolds are notoriously ineffective Mrs. Stanley put her arms through holes into a plywood box. She also had double-thickness heavy black sleeves tight around each arm. She also wore a sleep-mask blindfold. The "absolute darkness" your item refers to was inside the box where Mrs. Stanley's hands were. Outside the box there was plenty of light for the experimenters to observe Mrs. Stanley and see whether she was peeking. In later experiments with Barnard students, in addition to a blindfold each subject used a "bib-screen." In this device, developed here, each subject wears a double-thickness heavy black bib that is extended to cover a plywood screen under which she can put her arms.

I share your distrust of the blindfold. I have investigated two instances of people who were reported to be able to identify colors with their fingers. Both were mistaken. I was also present as an observer when a person was investigated who was reported to be able to read print with her nose or cheek at a distance of a foot or more. This was demonstrated to be an instance of (probably inadvertent) peeking around a blindfold. (See J. Zubin's letter in *Science,* February 26.)

Incidentally, your account refers to people who "read" print or have "skin vision" with their fingers. I have never found anyone who could "read" print with his fingers. Also, the word "vision" seems to me too strong a term. My work has been in color sensing and discrimination.

There are certainly several problems not yet solved, but I do not believe the peeking hypothesis is necessarily the solution. For more than 50 hours of work during the summer of 1963 Mrs. Stanley did highly reliable discriminations of colors. On two later occasions she did less well, once reliably above chance and once at chance. Approximately 10 percent of the students tested did consistently and reliably a little above chance on discriminating colors with their fingers. On grounds of parsimony such explanations as "ESP" have been rejected. "Telepathy" was excluded by double-blind experiments. My interest is in finding the dimensions of the physical stimuli.

My current working hypothesis is in terms of temperature discrimination, as described most recently in a report to the Psychonomic Society (1964). Certainly more heat (from such sources as lights and human hands) is absorbed by dark-colored objects than by light-colored objects of similar composition. On this assumption, the Barnard students successful in discriminating colors were those with the best abilities in temperature discrimination. Perhaps Mrs. Stanley also has excellent discrimination, particularly in and around the near infrared areas of the electromagnetic spectrum.

But there is a further question that needs answering. It is: By what physical stimuli could people *identify* the colors of objects with the skin of their fingers? In this connection I invite your attention to a few of the findings in the literature.

As Barnes reported (*Science,* 1963, Vol. 140, pages 870–877), human skin at about 88 degrees Fahrenheit emits heat in wavelengths from four to 14 microns with a peak at about eight microns. Also, dark-colored materials ab-

Scientific American, June, 1965; Vol. 212, No. 6. Published monthly by Scientific American, Inc., 415 Madison Avenue, New York, N.Y. 10017; Gerard Piel, president; Dennis Flanagan, vice-president; Donald H. Miller, Jr., vice-president and treasurer.

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

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

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Subscription rates: one year, $7; two years, $13; three years, $18. These rates apply throughout the world. Subscribers in the United Kingdom may remit to Midland Bank Limited, 69 Pall Mall, London SW 1, England, for the account of Scientific American, Inc.: one year, two pounds 11 shillings; two years, four pounds 14 shillings; three years, six pounds 10 shillings.

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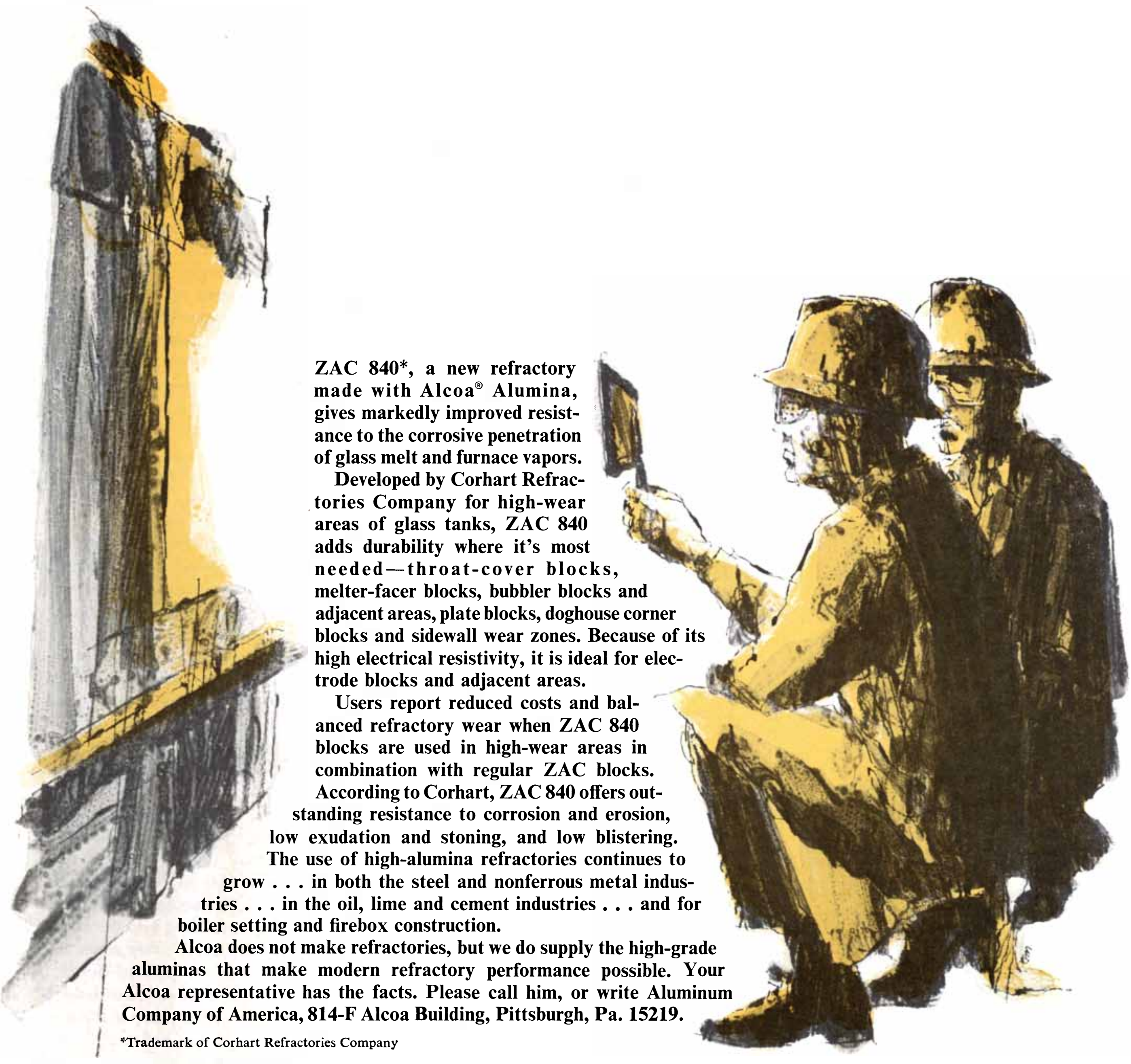
Corhart develops ZAC 840 for high-wear areas in your glass furnace



ZAC 840*, a new refractory made with Alcoa® Alumina, gives markedly improved resistance to the corrosive penetration of glass melt and furnace vapors.

Developed by Corhart Refractories Company for high-wear areas of glass tanks, ZAC 840 adds durability where it's most needed—throat-cover blocks, melter-facer blocks, bubbler blocks and adjacent areas, plate blocks, doghouse corner blocks and sidewall wear zones. Because of its high electrical resistivity, it is ideal for electrode blocks and adjacent areas.

Users report reduced costs and balanced refractory wear when ZAC 840 blocks are used in high-wear areas in combination with regular ZAC blocks. According to Corhart, ZAC 840 offers outstanding resistance to corrosion and erosion, low exudation and stoning, and low blistering.

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CERAMIC ENGINEERS AT CORHART MIX IMAGINATION WITH ALCOA ALUMINAS

ALCOA

sorb heat more rapidly than light-colored materials. Or, more generally, the physics of emission, reflection, absorption and reemission in the electromagnetic wavelengths indicates that objects at a lower temperature than some other object absorb radiation in a manner related to their color and reemit it at wavelengths and with patterns of intensities characteristic of their temperature, composition and color. In the dark box the hands emit heat and the test materials absorb some wavelengths and reemit characteristic wavelengths. (Mrs. Stanley's judgments were at chance when her finger temperature was lowered to 75 degrees F. or less.)

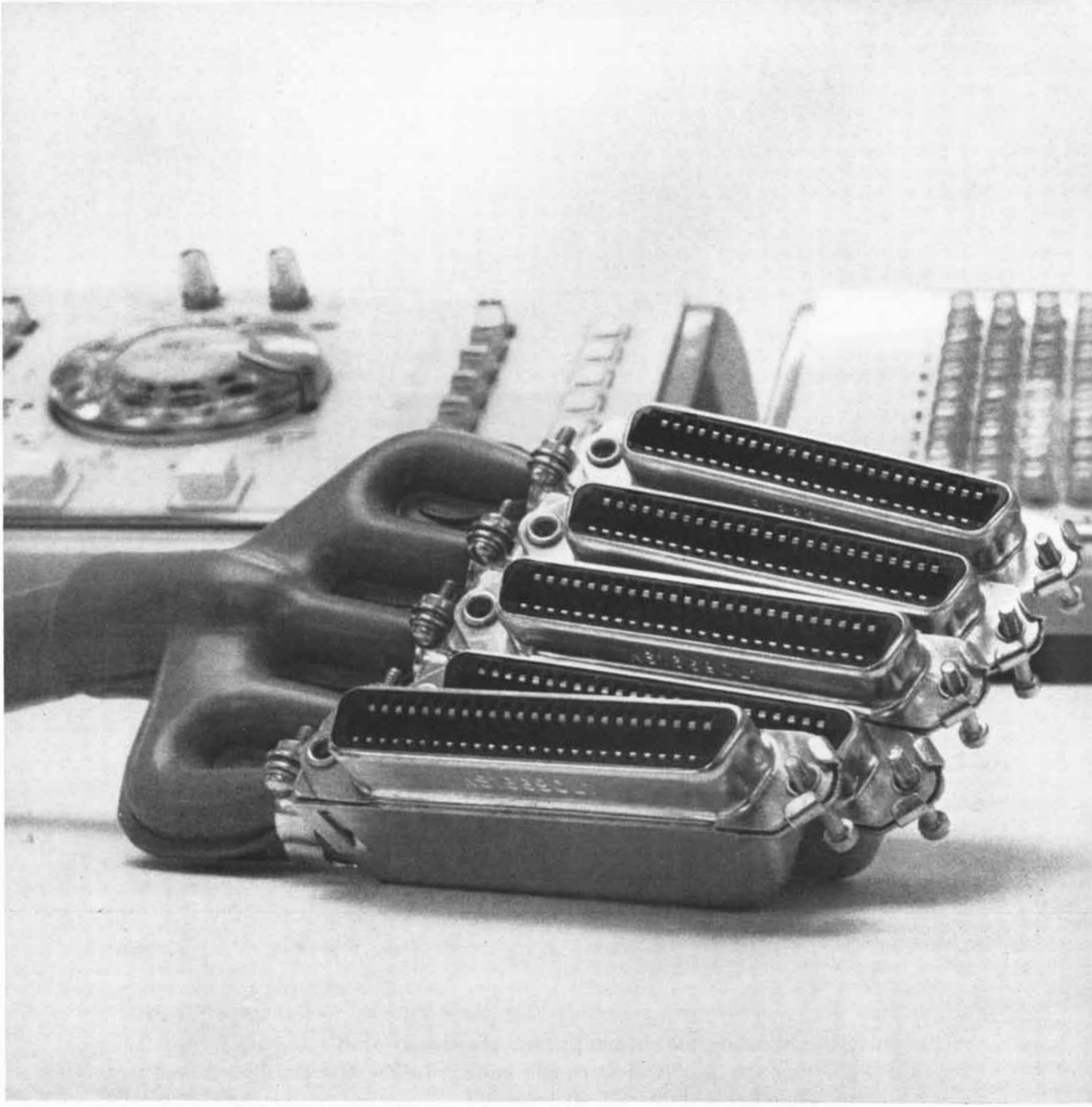
How, then, can the skin be sensitive to these wavelengths? A number of reports are relevant to this problem. That a wide range of electromagnetic wavelengths, including the visible and infrared, do penetrate mammalian skin to a significant depth is shown by various investigations. (Garcia *et al.*, *Science*, 1964, Vol. 144, pages 1470–1472; Ganong *et al.*, *Journal of Endocrinology*, 1963, Vol. 72, pages 962–963; Hardy and Muschenheim, *Journal of Clinical Investigation*, 1936, Vol. 15, pages 1–9.)

An extremely important study has shown that human skin has different sensitivity thresholds for different ranges of electromagnetic wavelengths. As shown by Oppel and Hardy (*Journal of Clinical Investigation*, 1937, Vol. 16, pages 517–540), the sensitivity threshold, apparently in terms of subjective "temperature," is lowest for wavelengths longer than three microns, as measured in gram calories per square centimeter per second. For wavelengths .8 micron to three microns the threshold in the same terms is 50 percent higher. And for wavelengths of .4 to .7 micron, the visible wavelengths, the threshold in the same terms is still higher, being 2.2 times the threshold value for three microns or greater.

All the above results suggest a working hypothesis, capable of experimental test, that human skin, at least in some people, may be able to discriminate different parts of the electromagnetic spectrum, possibly extending into the visible range. There are many other aspects of this problem, but my present desire is to measure the difference threshold of human skin for various parts of the electromagnetic spectrum between .4 micron and five microns.

RICHARD P. YOUTZ

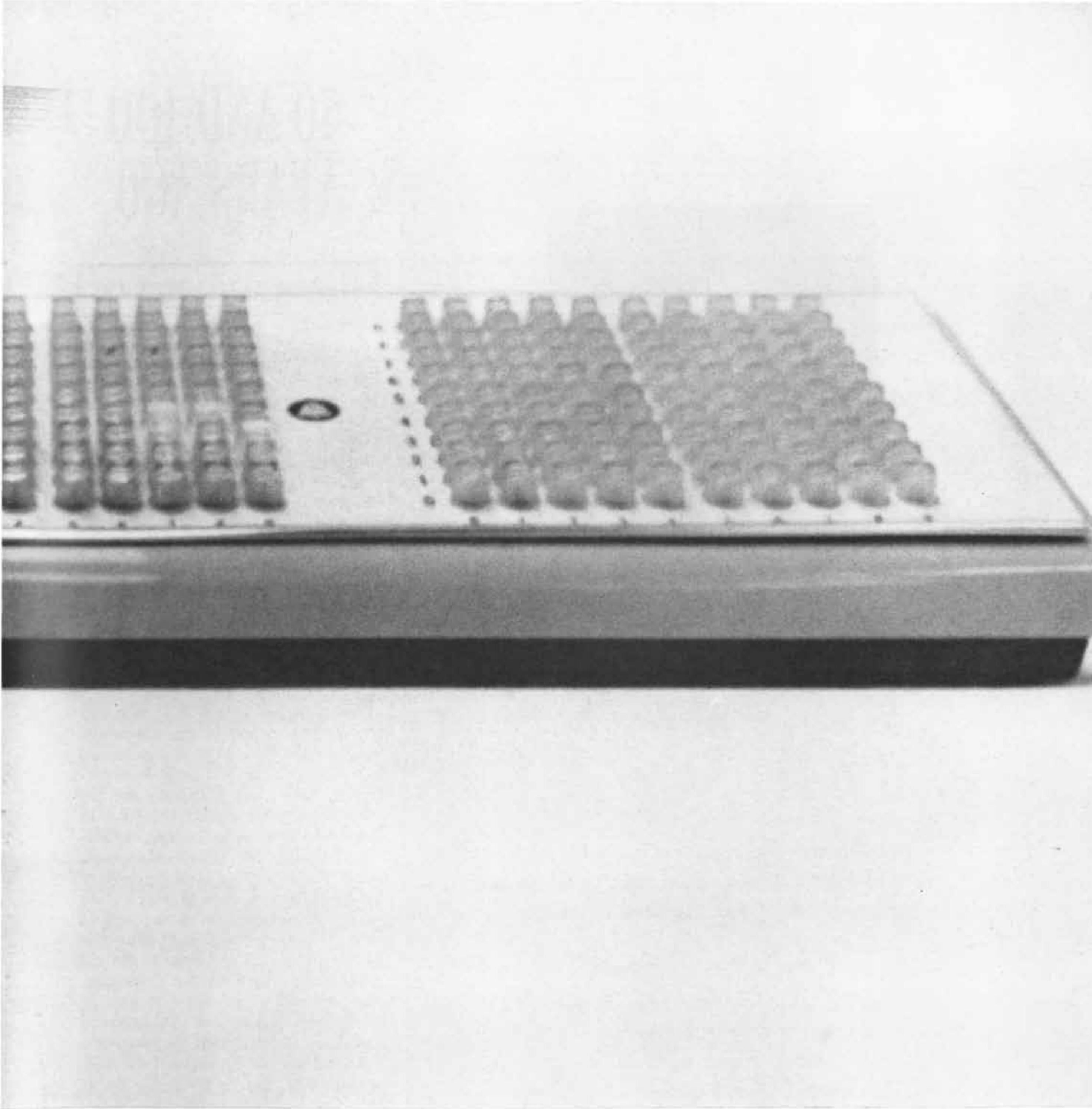
Barnard College
New York, N.Y.



How Amphenol helps put a 200-phone switchboard on a desk top

The Bell System reduced the switchboard to a tenth of its usual size, then called on Micro-Ribbon® connectors to simplify desk-top installations.

Five Micro-Ribbon connectors route the 250 circuits Bell needs for the two-console, 200-phone board—plus they offer these three important advantages:



1. SIZE. Each 50-contact Micro-Ribbon connector takes little more space for the connection than the cable itself.

If your application calls for fewer circuits, you can gain similar miniaturization advantages with Amphenol 14, 24 or 36-contact Micro-Ribbons.

2. RELIABILITY. Bell demands long service life from its equipment . . . usually 25 years. To date, Amphenol Micro-Ribbon connectors with self-cleaning, self-wiping contacts have been equal to the task. Not one failure has been reported in over 500 million contacts.

3. COST REDUCTION. Competitive in initial price, Amphenol Micro-Ribbon connectors helped cut installation time and maintenance costs. Estimates on Bell's savings range from 20% to 30%. Equipment replacement is more simple for Bell, too. Unplug the old; plug in the new.

For complete information about Micro-Ribbon or any of the other 36,000 connectors Amphenol makes, call your Sales Engineer. Or write *Amphenol Connector Division, 1830 S. 54th Ave., Chicago, Illinois 60650.*

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50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

JUNE, 1915: "A deposition by Capt. Bertram of the Eighth Canadian Battalion states: 'On Thursday, April 22nd, he was in a support trench, about 600 yards from the German lines, when he saw, first of all, a white smoke rising from the German trenches to a height of about three feet. Then in front of the white smoke appeared a greenish cloud, which drifted along the ground to our trenches, not rising more than about seven feet from the ground when it reached our first trenches. Men in these trenches were obliged to leave, and a number of them were killed by the effects of the gas.' "

"Dr. J. S. Haldane, F.R.S., who was sent out to France to investigate the effects of the German poison gases and to report upon the best methods of protection, states: 'The symptoms and the other facts so far ascertained point to the use by the German troops of chlorine or bromine for purposes of asphyxiation. There are also facts pointing to the use in German shells of other irritant substances, although in some cases at least these agents are not of the same brutally barbarous character as the gas used in the attack on the Canadians. The effects are not those of any of the ordinary products of combustion of explosives. On this point the symptoms described left not the slightest doubt in my mind.' "

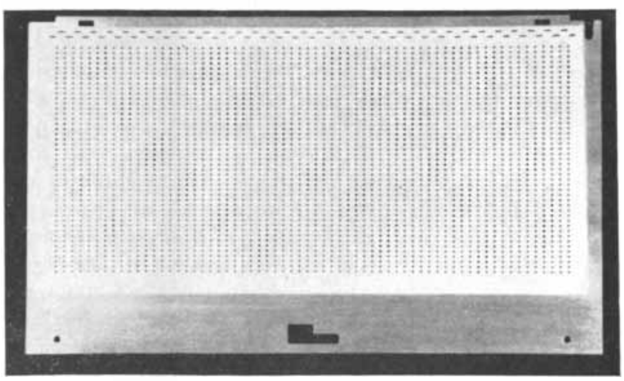
"Thomas A. Edison in a patent No. 1,138,360 presents a method of producing the illusion of scenes in colors in moving pictures. An image of all the elements of a scene of one fundamental color in that color is momentarily projected on the screen and thereafter successively projecting images which are superposed upon or registered with the first image on the retina of the beholder of those elements of the scene of different fundamental colors in their proper colors respectively. The successive projections are at such a rate that, in accordance with persistence of vision, Report from

BELL LABORATORIES

B. G. Hemmendinger examines one of the digital circuit packages used in the central control unit of the new Electronic Switching System developed at Bell Laboratories. In these circuits, logic functions such as AND, OR, and AND-OR are built up with various combinations of a basic AND-NOT gate. About 27,000 transistors and 90,000 diodes are used in two duplicated central control units for one electronic central office.

Stored-program control— flexibility for telephone switching systems

Modern systems that switch your telephone calls use complex control equipment to operate the switches that make telephone connections. Such "common control" equipment is time-shared by many telephone lines. In electromechanical systems, common control apparatus consists of hardware—an array of hundreds of relays wired together to do the switching jobs of a particular telephone exchange.



Memory card, 6½ by 10½ inches, used for storing the ESS control program. Useful information (64 forty-four-bit words) is carried by the card in the form of magnetized spots ("zero") and unmagnetized spots ("one"). The random-access memory stores the control program and other data on 2048 such cards (131,072 words). The control instructions themselves require a minimum of 100,000 words.

By contrast, common control in the new Electronic Switching System (ESS) developed at Bell Laboratories is exercised by a multitude of general-purpose digital circuits whose actions are directed by "software"—programmed sequences of instructions stored in memory. The operation of ESS, including the specific telephone services provided, can thus be changed merely by changing the magnetization pattern of memory cards like that shown at left, with little or no hardware rearrangement or rewiring.

More specifically, ESS common control consists of an electronic data processor with a large memory. The memory contains instructions for processing all of the different kinds of calls handled by a central office. Guided by this stored program, the data processor receives and interprets dialed digits, sends signals to appropriate switches, and at the same time detects and diagnoses circuit malfunctions.

With this flexible common control, combining hardware and software, ESS can efficiently provide the various telephone services available today as well as any new services needed for the future.

BELL SYSTEM

Bell Telephone Laboratories

Research and Development Unit of the Bell System

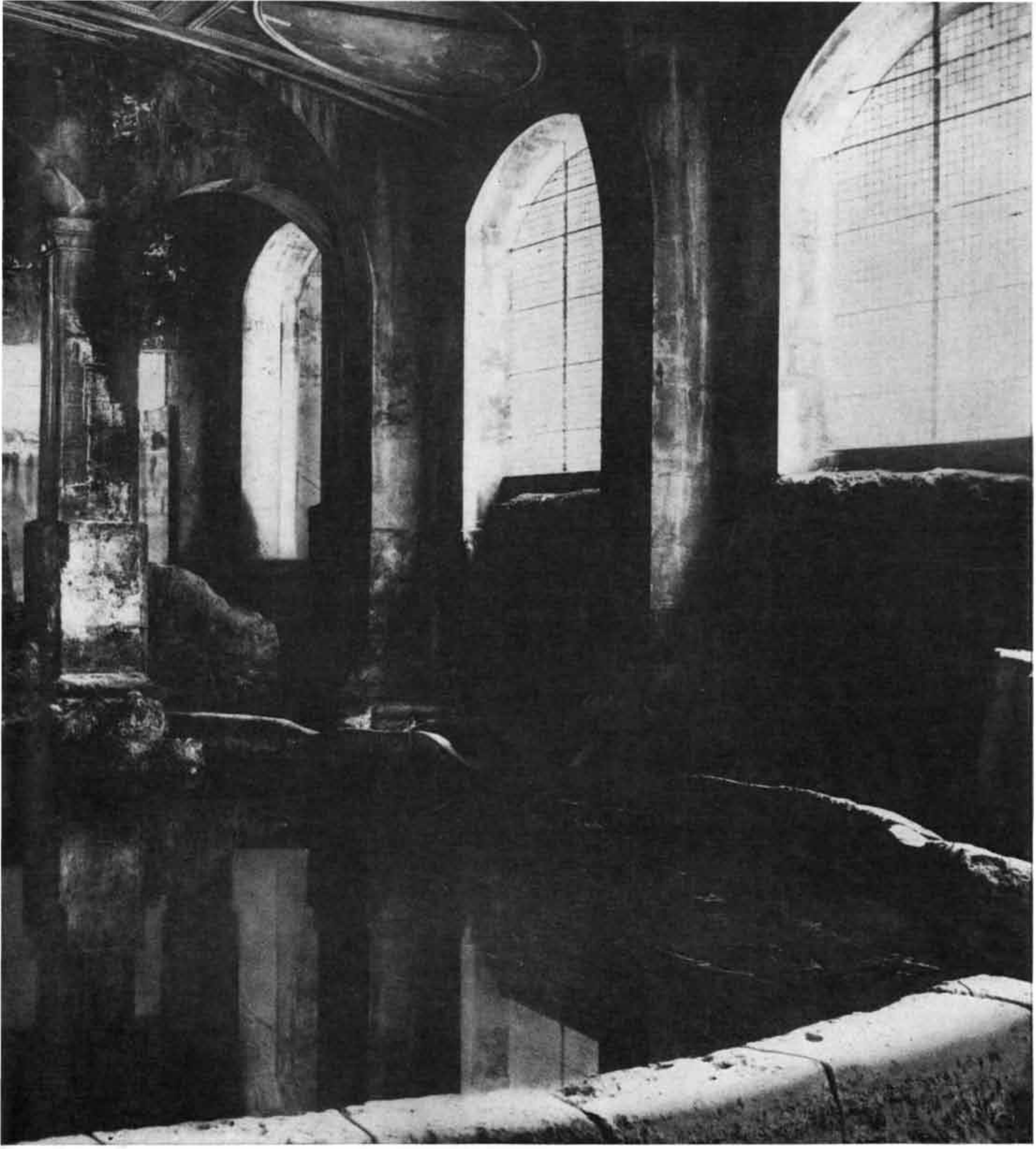
the preceding images will still be seen by the beholder until after the last image of the series has been projected upon the screen."

Scientific American.

JUNE, 1865: "Buckle, in his learned *History of Civilization,* says that all the great reforms have been the removal of some obstruction to human freedom. Such a reform, more radical and thorough in the scope of its operation and wider in extent than any which preceded it, has swept over our Southern states, converting four million of the inhabitants from simple chattels into freemen. The most important effect of this stupendous reform will be experienced by the mass of white inhabitants of the South, in bestowing upon them and their children the priceless boon of education. Among all the inhabitants of the country those who will be most benefited by the suppression of the rebellion are the rank and file of the Southern armies, who have been fighting with such blind desperation to prevent this result, for they will now enter upon that path of forethought, economy, advancement and prosperity which is the inevitable accompaniment of popular education. One of the necessary consequences of the extension of education will be a far greater variety of industrial pursuits. Ignorance was essential to the existence of slavery, and this ignorance was incompatible with the skill and intelligence requisite in the construction and management of machinery, and in all the mechanical operations. Hence the devotion of Southern labor to the raising of rice, tobacco, cotton, hemp and other agricultural products. To these pursuits the whites as well as the blacks were mainly devoted. No pretension could be more ridiculous than that the white men of the South have scorned to labor; there, as elsewhere, the great mass of people are poor and must work or starve. Now all the obstructions that slavery and its concomitants offered to even the rudest mechanical pursuits are removed, and no man can estimate the results; he whose imagination is capable of the boldest flight will come nearest to the truth. A vast horde of skilled laborers from the Northern states and Europe will pour into the South, and mining, manufacturing and mechanical industry will spring at once into life and vigor; the ribs of the mountains will be blasted asunder; the streams will be turned into millcourses; cities, canals and railroads will be constructed, and wealth will be accumulated with a rapidity unparalleled in the entire history of mankind."

"The great canal connecting the Red Sea with the Mediterranean is so far advanced as to be navigable for small barges through its whole length, with the exception of one point where a large lock is in the process of construction; a transshipment is required at this place. The canal when completed will be about 100 miles long and 330 feet wide at the waterline, with its bottom 20 feet below the level of the Mediterranean. The projector of the enterprise is M. F. de Lesseps, a Frenchman, who obtained a grant in 1854 from the Egyptian government of the right of way for 99 years, on condition of paying 15 percent of the net profits to that government. It is stated that contracts have been made for the completion of the several parts of the work by the first of July, 1868. The distance from New York to Bombay in India is now, by the Cape of Good Hope, 18,600 miles; by the way of the Suez Canal it will be 11,283 miles, the new route thus shortening the voyage more than 7,000 miles."

"We do not often transfer to our columns the complimentary notices which are so freely bestowed on this journal, but we cannot forbear to insert the following, which we clip from the *Buffalo Advocate:*—'Of late we have received papers which appear to have been set afloat to rival SCIENTIFIC AMERICAN, published in New York by Messrs. Munn and Company. We have no disposition to discourage any lawful enterprise, especially in the making of papers, but it does appear to us as weak as it is foolish for any one to attempt or even think of bringing out a paper which will at all compare with the one noticed above. The proprietors of SCIENTIFIC AMERICAN are working, enterprising men and are in possession of facilities for making a first-class paper which others could not attain in a score of years. Besides, the polish, beauty and exquisite taste which mark the appearance of each successive issue of the paper must be attended with a great outlay, which no new enterprise could afford to expend. To our citizens and to all we recommend SCIENTIFIC AMERICAN.'"



We're Boosters of an Old Roman Idea.

Heating with circulated hot water is as old as the ancient Roman baths.

Maybe older.

People still use circulated hot water for heating; only now, it heats entire buildings, with the help of circulating pumps.

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And they also can circulate water for cooling. An idea which the Romans did not have.

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And a third, ITT Direct Fired Equipment Division, heats and cools commercial and industrial establishments.

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Whether it's heating, cooling or ventilating, chances are that one of these ITT divisions can do the job.

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ITT

IBM announces three new programming support packages for scientists and engineers who will use SYSTEM/360

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Subroutines we know will be useful to you.

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You can add to it or modify it to suit your needs. You can consider it a collection of input/output-free computational building blocks which can be combined with your own input to produce the exact programs you want.

With the individual subroutines or with combinations of them, you can carry out functions like the following:

In statistics:

• analysis of variance (factorial design)
• correlation analysis
• multiple linear regression
• polynomial regression
• canonical correlation
• factor analysis (principal components, varimax)
• discriminant analysis (many groups)
• time series analysis
• data screening and analysis
• non-parametric tests
• random number generation (uniform, normal)

In matrix manipulation:

• inversion
• eigenvalues and eigenvectors (real symmetric case)
• simultaneous linear algebraic equations
• transposition
• matrix arithmetic (addition, product, etc.)
• partitioning
• tabulation and sorting of rows or columns
• elementary operations on rows or columns

In other mathematical areas:

• integration of given or tabulated functions (Runga-Kutta)
• integration of up to six first order differential equations (Runga-Kutta)
• Fourier analysis of given or tabulated functions
• Bessel and modified Bessel function evaluation
• gamma function evaluation
• Legendre polynominal evaluation
• elliptic, exponential, sine, cosine, Fresnel integrals
• finding real roots of a given function
• finding real and complex roots of real polynomial equations
• polynomial arithmetic (addition, division, etc.)
• polynomial evaluation, integration, differentiation

These new subroutines will help in every area of industry and science.

Correlation analysis, multiple regression, factor analysis, and data screening and analysis are standard tools for research in medicine, biology, psychology and like fields.

In colleges and universities, faculty members and students will get better use of their computation center with a minimum of programming time.

In the process industries, these new subroutines will speed up analysis of operating data, quality control, design of petroleum and chemical units, simulation of units, plants and processes, and laboratory analysis.

In the aerospace industry, the programs will help in system design and analysis, data reduction and analysis, data acquisition and control, and system simulation and evaluation.

Whatever industry you're in, your job becomes a little easier.

...Mathematical Programming System/360 gives you powerful mathematical optimization capabilities

This new system combines the best features of current IBM linear programming systems with significant new capabilities including MARVEL, a new language processor for matrix generation, solution analysis, management reporting and file maintenance. Modular design makes it easy to incorporate new optimization techniques, as they are developed, hence the name Mathematical Programming System/360.

• Maximum problem size of 4,095 rows.

• The system utilizes the Revised Simplex (product form of inverse) Method with bounded variables and range constraints.

• A highly efficient inversion technique using a triangularization method permits inversion to be made frequently, thus increasing the speed of succeeding iterations and maintaining a high degree of accuracy.

• Multiple pricing method, adjusted for problem size and amount of available storage, reduces the amount of file processing and increases solution speed.

• A "cycle" facility which reduces solution time for problems containing many more columns than rows.

• Dynamic storage allocation provides for maximum use of available storage.

• The control language includes conditional control statements which permit alternate solution strategies to be implemented depending upon the conditions which arise during solution.

• Interrupt facilities provide the means for preplanning alternate strategies in the event of off-normal conditions.

• Simultaneous parametric programming on both the right-hand side and the objective function may be used.

• A single language (MARVEL) is used to specify the file processing functions needed for mathematical programming applications.

• Specialized matrix generators and report writers can be written in the MARVEL language.

• Modular design makes it easy to add, modify, replace or delete functions as new requirements develop.

The MARVEL language allows you to prepare printed reports in final form with easily written programs which may perform mathematical operations, reordering, selection and analysis while the report is being prepared. The flexible input and output facilities coupled with the capacity to communicate directly with the mathematical programming procedures provide the user with a powerful management report writing system.

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THE AUTHORS

EMMETT N. LEITH and JURIS UPATNIEKS ("Photography by Laser") are members of the staff of the Institute of Science and Technology at the University of Michigan. Leith is a research engineer and head of the optics group of the radar laboratory; Upatnieks is a graduate research assistant. Leith was born in Detroit; in 1950 he was graduated from Wayne State University, obtaining a master's degree in physics at the same institution two years later. Since then he has been at Michigan, working in radar, microwaves, communication theory, data processing and coherent optical systems. Upatnieks was graduated from the University of Akron in 1960 with a degree in electrical engineering. From 1957 to 1959 he was an engineer with the Goodyear Aircraft Corporation; he went to the University of Michigan in 1960.

ERIC H. DAVIDSON ("Hormones and Genes") is a research associate at the Rockefeller Institute, working in cell biology. As a high school student in Nyack, N.Y., he worked summers at the Marine Biological Laboratory in Woods Hole, Mass., and was one of the national winners of the Westinghouse Science Talent Search. Davidson was graduated from the University of Pennsylvania in 1958, having majored in zoology. For the next five years he was a graduate fellow at the Rockefeller Institute, obtaining a doctor's degree there in 1963. He writes that as a research fellow at the Institute he is "collaborating with Alfred E. Mirsky in the study of gene action in the initiation and control of embryological development."

GLENN L. BERGE and GEORGE A. SEIELSTAD ("The Magnetic Field of the Galaxy") are research fellows at the California Institute of Technology. Berge is an Iowan who did his undergraduate work at Luther College and went to Cal Tech in 1960 as a graduate student in astronomy. "Since then," he writes, "I have worked mainly on two projects in radio astronomy: the polarization of discrete radio sources and the nature of Jupiter's radio emission." Seielstad was graduated from Dartmouth College in 1959 and obtained a Ph.D. in physics at Cal Tech four years later. He spent a year on the faculty of the University of Alaska before returning to Cal Tech as a research fellow. He writes: "My research interests have been in the neutral hydrogen emission of external galaxies and the polarization of radio sources."

CHRISTOPHER J. PRATT ("Chemical Fertilizers") is manager of international agricultural chemical development for the Mobil Chemical Company. He was born and educated in England, studying industrial chemistry at the Rutherford College of Technology and psychology and music at Goldsmiths' College. For several years before coming to the U.S. in 1953 he was a management consultant to British companies in the field of heavy chemical processing. In his spare time he is a free-lance writer, in which capacity he has written several articles (including the present one) on heavy chemicals and on fertilizer production, and he indulges an interest in baroque music by playing the contrabass—he did so professionally for several years in England—and the organ.

DAVID S. SMITH ("The Flight Muscles of Insects") is assistant professor of biology at the University of Virginia. He is a native of London and was graduated from the University of Cambridge in 1955, obtaining a Ph.D. in zoology there in 1958. His interest in insect flight began when he set out to test a hypothesis of Charles Darwin's that beetles on some small oceanic islands had lost the ability to fly as an evolutionary development designed to keep them from being blown to sea. Smith spent three years at the Rockefeller Institute and two back at Cambridge as a research fellow before going to the University of Virginia in 1963 to set up an electron microscope unit. "I relieve this work, when possible," he writes, "with observing and collecting insects in the field."

JOHN A. COFFMAN and WILLIAM R. BROWNE ("Corona Chemistry") are technical managers in the Advanced Technology Laboratories of the General Electric Company in Schenectady, N.Y. Coffman is a native of Virginia who was graduated from Juniata College in 1939 and took a master's degree at Trinity College in Hartford two years later. He has been with General Electric since then, except for a year with the Manhattan Engineer District during World War II. Browne is a native of Massachusetts and obtained bachelor's, master's and doctor's degrees at Boston University. He has been with General Electric since 1956. The authors write that after extensive work

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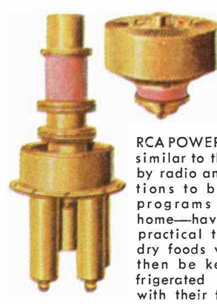

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with electricity they concluded that "it would be fun and perhaps profitable to try to shape corona, a form of electrical breakdown, into a versatile chemical-process tool."

TARO TAKAHASHI and WILLIAM A. BASSETT ("The Composition of the Earth's Interior") are assistant professors in the department of geology and geography at the University of Rochester. Takahashi was graduated from the University of Tokyo in 1953, taking a Ph.D. in geology at Columbia University four years later. He was on the staff of Columbia's Lamont Geological Observatory and was a member of the faculty of the New York State College of Ceramics before going to the University of Rochester in 1962. Bassett was graduated from Amherst College in 1954 and obtained master's and doctor's degrees at Columbia. In addition to his work at Rochester he is involved in research at Columbia and at the Brookhaven National Laboratory.

J. WORTH ESTES and PAUL DUDLEY WHITE ("William Withering and the Purple Foxglove") are respectively an intern in pathology at the Massachusetts General Hospital and the well-known heart specialist. Their collaboration came about because Estes wrote a paper on digitalis during the summer of his freshman year at Harvard College and White, who many years earlier had done experiments with digitalis and had written about them, proposed a joint paper on the history of the plant as a medicine. Estes, after being graduated from Harvard in 1955, went to Boston University, where he obtained a master's degree in pharmacology and a medical degree. In July he will begin a clinical fellowship in hematology at the Massachusetts Memorial Hospitals. White was graduated from Harvard College in 1908 and the Harvard Medical School in 1911. He writes: "In 1916 I persuaded several of my young colleagues who were interns and residents at the Massachusetts General Hospital to take large doses of digitalis to see what the drug would do to the electrocardiogram." The experiments showed that the drug can have a toxic effect. White adds: "I can still taste the digitalis that poisoned me, without any permanent harm, nearly 50 years ago."

PAUL BOHANNAN, who in this issue reviews *A Profile of the Negro American*, by Thomas F. Pettigrew, is professor of anthropology at Northwestern University.

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Photography by Laser

The highly coherent light produced by the laser is used in a novel photographic process, in which the light-sensitive film, instead of recording an image, in effect records the light waves themselves

by Emmett N. Leith and Juris Upatnieks

In spite of the steady refinement of photographic techniques and the invention of new photographic materials, the optical aspects of photography have changed little over the past 100 years. Reduced to its essential elements the photographic process consists of recording an illuminated three-dimensional scene as a two-dimensional image on a light-sensitive surface. The light reflected from the objects in the scene is focused on the sensitive surface by some kind of image-forming device, which can be a complex series of lenses or simply a pinhole in an opaque screen [*see upper illustration on page 28*].

This article deals with a radically different concept in photographic optics. Invented less than 20 years ago, this process, which can be called photography by wave-front reconstruction, does *not* record an image of the object being photographed but rather records the reflected light waves themselves. The photographic record, a hodgepodge of specks, blobs and whorls, is called a hologram; it bears no resemblance to the original object but nevertheless contains—in a kind of optical code—all the information about the object that would be contained in an ordinary photograph and much additional information that cannot be recorded by any other photographic process.

The creation of an intelligible image from the hologram is known as the reconstruction process. In this stage the captured waves are in effect released from the hologram record, whereupon they proceed onward, oblivious to the time lapse in their history. The reconstructed waves are indistinguishable from the original waves and are capable of all the phenomena that characterize the original waves. For example, they can be passed through a lens and brought to a focus, thereby forming an image of the original object—even though the object has long since been removed! If the reconstructed waves are intercepted by the eye of an observer, the effect is exactly as if the original waves had been observed: the observer sees what to all appearances is the original object itself in full three-dimensional form, complete with parallax (the apparent displacement of an object when seen from different directions) and many other effects that occur in the normal "seeing" process.

The wave-front reconstruction process was discovered in 1947 by Dennis Gabor of the Imperial College of Science and Technology in London. During the next few years Gabor developed the method systematically, emphasizing particularly its applications to electron microscopy. Many other workers throughout the world have since made significant contributions—notably Hussein M. A. El-Sum and Paul Kirkpatrick of Stanford University—but their efforts were hampered by the lack of an adequate source of coherent light, that is, light whose waves are all in phase. The invention of the laser in 1960 opened the way to new advances in wave-front reconstruction photography. Using a gas laser as a source of coherent light, as well as several other previously untried techniques, we have been able to obtain high-quality, three-dimensional hologram images in our laboratory at the University of Michigan. Partly as a result of our work and partly as a result of the largely unexplored potential of the laser as a source of coherent light, there has been a widespread resurgence of interest in the possible uses of this intriguing photographic process.

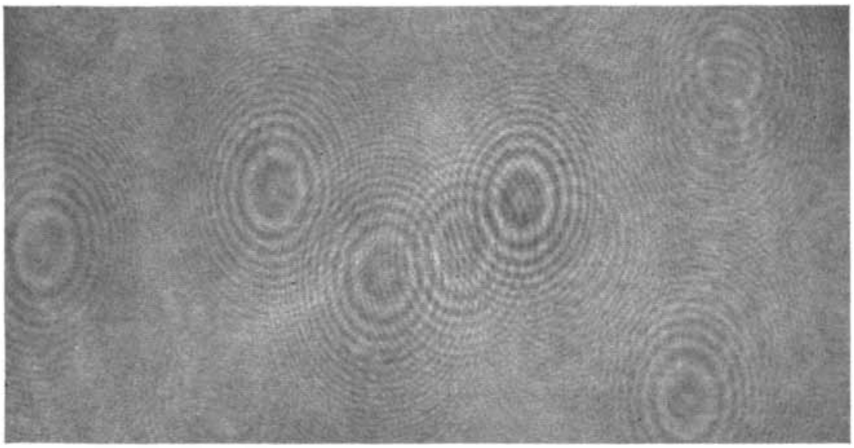
The basic optics of wave-front reconstruction photography differ from those of ordinary photography in three main respects. As in ordinary photography, the object is illuminated and a photographic plate is positioned so as to receive light reflected from the object. Unlike ordinary photography, however, no lens or other image-forming device is used and consequently no image is formed. Instead each point on the object reflects light to the entire photographic plate; conversely, each point on the plate receives light from the entire object [*see top illustration on page 29*]. The second departure from ordinary photography is the use of coherent light for illuminating the object, and the third is the use of a mirror to beam a portion of the coherent light directly to the plate, bypassing the object. This beam is called the reference beam, and it produces, by means of interference effects, a visible display of the wave pattern of the light impinging on the plate from the object; what is recorded on the plate is the resulting interference pattern.

Reflected light waves, like any other waves, are described by their amplitude (or intensity) and by their phase (or frequency). In the case of a point scatterer of light, the reflected waves travel outward from their origin in a series of ever expanding spherical shells, called wave fronts, that are concentric around the point of origin. These spherical waves are the three-dimensional analogue of the circular waves that appear on the surface of a still pond when a stone is dropped into the water. If the reflecting object is not a single point but a complex object, it can then be regarded as a collection of a large number of points, and the resulting wave pattern reflected from the surface of the object can be regarded as the sum of many such sets of spherical waves, each set concentric about its point of origin [*see top illustration on page 30*]. The exact form of the wave pattern reflected from an extended and irregular object is highly complex and cannot be described in detail here.

The central problem of wave-front reconstruction photography is to record this complex, signal-bearing pattern as it exists at a given plane at some instant of time. Such a record can be thought of as a "freezing" of the wave pattern; the pattern remains frozen until such time as one chooses to reactivate the process, whereupon the waves are "read out" of the recording medium. To capture the wave pattern completely both the amplitude and the phase of the waves must be recorded at each point on the recording surface. Recording the amplitude portion of the waves poses no serious problem: ordinary photographic film records amplitude by converting it to corresponding variations in the opacity of the photographic emulsion. The emulsion is entirely insensitive to phase relations, however, and one must assemble some appropriate apparatus that can convert these phase relations into a form in which they can be recorded photographically.

In wave-front reconstruction photography the phase relations are rendered visible to the photographic plate through the technique of interferometry, a standard and long-established way of converting phase relations into corresponding amplitude relations. We shall first consider how this is done in the comparatively simple case in which two

ORDINARY PHOTOGRAPH was made by illuminating a chessboard and a group of chessmen with normally incoherent light and recording a two-dimensional image of the scene on photographic film. Light reflected from chessmen is focused on film by camera lens.



HOLOGRAM RECORDING of the scene shown in photograph at top of page was made in the first stage of the process of wave-front reconstruction photography. The visible structure of the hologram bears no resemblance to the original scene but nevertheless contains more information about the scene than would be contained in an ordinary photograph. The holograms used in this article were made by Albert Friesen of the University of Michigan.

RECONSTRUCTED IMAGE was made by directing a laser beam through the hologram. The reconstructed waves were then passed through a lens and brought to a focus, thereby forming an image of original scene, even though chessmen had long since been removed.

PHOTOGRAPHIC EQUIPMENT used in the first stage of the wave-front reconstruction process was photographed in the authors' laboratory at the University of Michigan. The laser beam enters from right at top and immediately passes through two partially reflecting and partially transmitting glass plates. The reflected parts of the beam are again reflected from two mirrors (*bottom left and right*) before being used to illuminate the chessboard (*center*). The transmitted part of the beam, called the reference beam, is reflected from another mirror (*top left*) and then impinges directly on the hologram plate (*sandwich-like object at bottom center*). Each beam passes through a microscope lens, which broadens the beam but has no effect on its valuable coherence properties.

collimated light beams, whose wave fronts are successive planes perpendicular to the direction of the beams, interact to form a characteristic interference pattern; in terms of the shape of their wave fronts such waves are referred to as plane waves.

If two plane waves derived from a common source impinge at different angles of obliquity on an opaque surface, they will produce a set of uniform, parallel interference fringes on the surface. The spacing of the fringes will depend solely on the angle between the waves. At some places on the surface the waves will arrive in phase and their amplitudes will add to produce a resultant light intensity greater than would be produced by either wave acting alone. This process is called constructive interference and is responsible for the light fringes in the interference pattern. At other places the waves will arrive out of phase and will tend to cancel each other, the cancellation being complete if the two waves are of equal amplitude. This process is called destructive interference and is responsible for the dark fringes in the interference pattern. Where the waves are neither in nor out of phase, the resultant light intensity and corresponding fringe tone are intermediate between these two extremes.

A photographic recording of such a fringe pattern will yield a grating-like structure that can be regarded as a two-dimensional analogue of the sinusoidal wave produced by an electric oscillator. The important point of this analogy is that just as an electric wave can be modulated to serve as a carrier of information (about sound, say), so can the interferometrically produced wave pattern be modulated to serve as a carrier of information about the light waves that produced it.

Modulation of any kind of carrier wave can be accomplished in various ways, but the best-known and most commonly used methods are amplitude modulation (AM) and frequency modulation (FM). In amplitude modulation information is imposed on the carrier wave by causing the wave's amplitude to vary in accordance with some lower-frequency wave [*see illustration on page 31*]. In frequency modulation the amplitude of the carrier wave remains constant but the spacing between the various cycles is altered. The effect can be described as a change in frequency: at some positions the cycles are compressed and the frequency is correspondingly increased, whereas at other positions the cycles are expanded and the frequency is decreased. This kind of modulation can alternatively be described as phase modulation, since at any given time the phase, or the relative positions of the wave crests and troughs with respect to some stationary point, is different from what it would be in the absence of the modulation. (Although frequency modulation and phase modulation are not quite identical, the technical distinctions are not important here and will be disregarded.)

When the irregular wave pattern reflected from a complex object is made to interfere with a plane wave, the resulting interference pattern, instead of being uniform, has an irregularity that is related to the irregularity of the impinging wave fronts. At places where the signal-bearing waves have their greatest amplitude the interference fringes have the greatest contrast, whereas at places of low signal-wave amplitude the fringe contrast is low. Thus variations in the amplitude of the waves reflected from the object produce corresponding variations in the contrast of the recorded fringe pattern.

As we have noted, the spacing of the fringes is related to the angle between the signal-bearing waves and the reference waves. At places where the signal-bearing waves make a large angle with the reference waves the resulting fringe pattern is comparatively fine; at places where the waves meet at lesser angles the fringe pattern is coarser. Therefore the variations in the phase of the signal-bearing waves produce corresponding variations in the spacing of the fringes on the photographic record.

In brief, we have made two significant observations: both the amplitude and the phase of the signal-bearing waves can be preserved respectively as modulations in the contrast and spacing of the recorded interference fringes. All the information that can be carried by the light waves reflected from the object can be recorded on the interference grating produced by making these waves interfere with an obliquely impinging plane wave.

A hologram made in the manner just described has many of the properties of a grating produced on a ruling engine, but there are several important differences, the most important of which is the nonuniformity of the hologram grating slits as opposed to the precise uniformity attained in high-quality ruled gratings. Whereas the inadvertently produced irregularities in an imperfectly ruled grating give rise to false spectral lines, called "ghosts," the deliberately induced irregularities in a hologram give rise, in the reconstruction process, to a complete, well-defined image.

When a grating consisting of uniformly spaced opaque and transparent slits is illuminated with a collimated beam of monochromatic light, a number of plane waves are generated by the interaction of the light with the grating structure [*see right side of top illustration on page 32*]. These plane waves are radiated at various angles, which are determined by the spacing of the slits in the grating. The "zero order" wave propagates in the same direction as the incident wave and can be regarded as an attenuated version of the incident wave. In addition, there are the two "first order" diffracted waves, one on each side of the zero-order wave. Beyond these occur the second-, third- and higher-order diffracted waves.

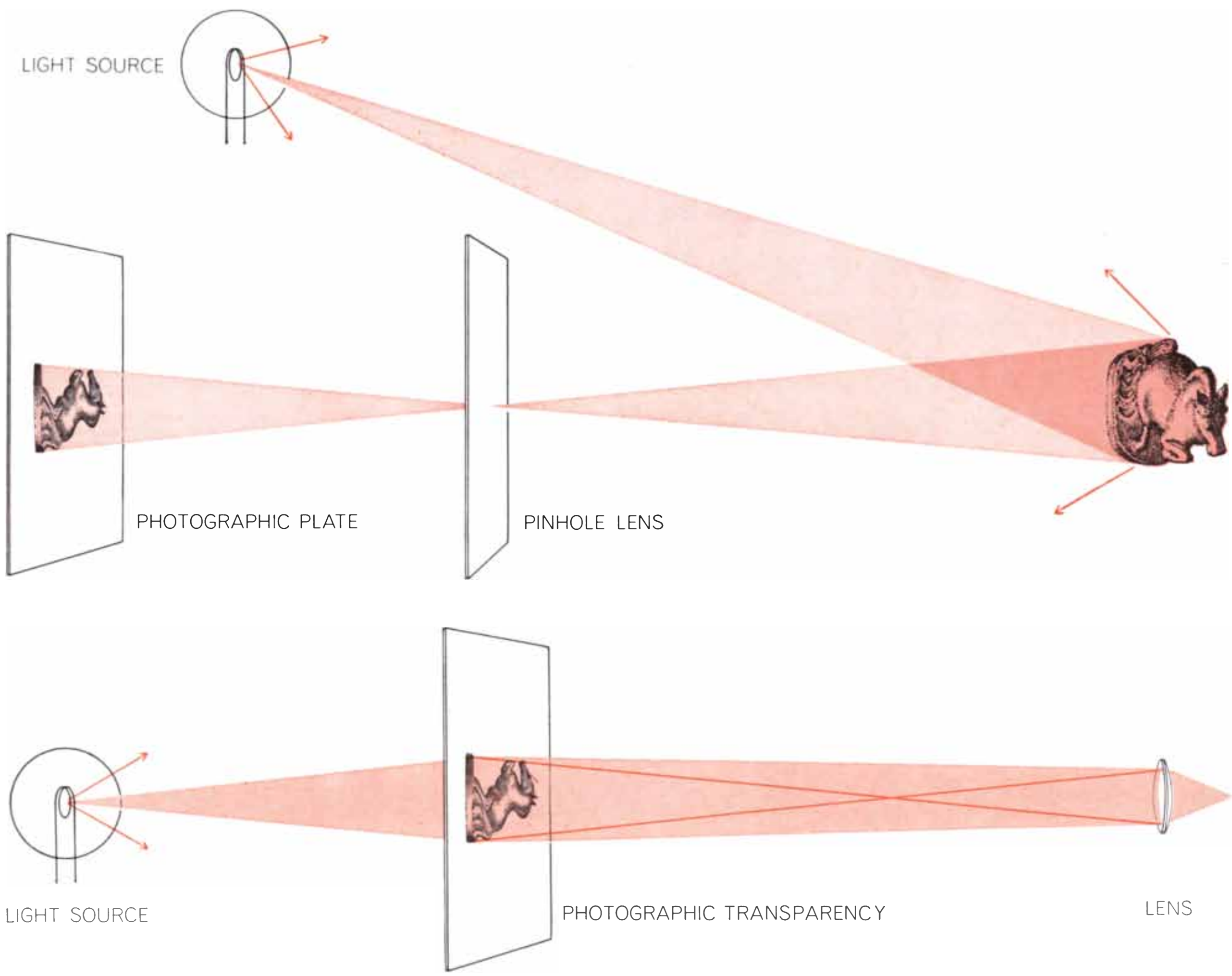
The generation of these diffracted waves can readily be explained by regarding the transparent slits as original sources, each radiating cylindrical waves. These elemental waves reinforce each other in certain directions, thereby giving rise to the various diffracted orders. The directions of reinforcement are obtained by drawing tangent lines to the various elemental wave fronts. The zero-order wave is formed by combining all the wave fronts that originated from the slits at the same time and are therefore all equidistant from the surface of the grating. By drawing a line tangent to all these corresponding cylindrical wave fronts the zero-order wave is obtained. This wave is parallel to the grating surface. One of the first-order diffracted waves is constructed by combining an elemental wave front from one slit with the previous wave front from the adjacent slit, then combining that with a still more previous wave front from the next adjacent slit, and so on. The other first-order diffracted wave is constructed in a similar way but in the opposite direction. The second-order diffracted waves are constructed by combining, from adjacent slits, wave fronts that are two wavelengths apart, and so on. From this construction method it is apparent that the closer the spacing of the grating lines, the greater the angle of diffraction.

When the spacing, or phase, of the grating slits is irregular, with some regions having closer line spacings than other regions, the localized variations in spacing give rise to corresponding local variations in the direction of the diffracted waves. Similarly, local variations in the contrast, or amplitude, of the fringes produce local variations in the amplitude, or intensity, of the diffracted wave. Thus the diffracted wave front is perturbed in a way that is related in a simple and predictable manner to the irregularities, both in spacing and contrast, of the hologram fringe pattern.

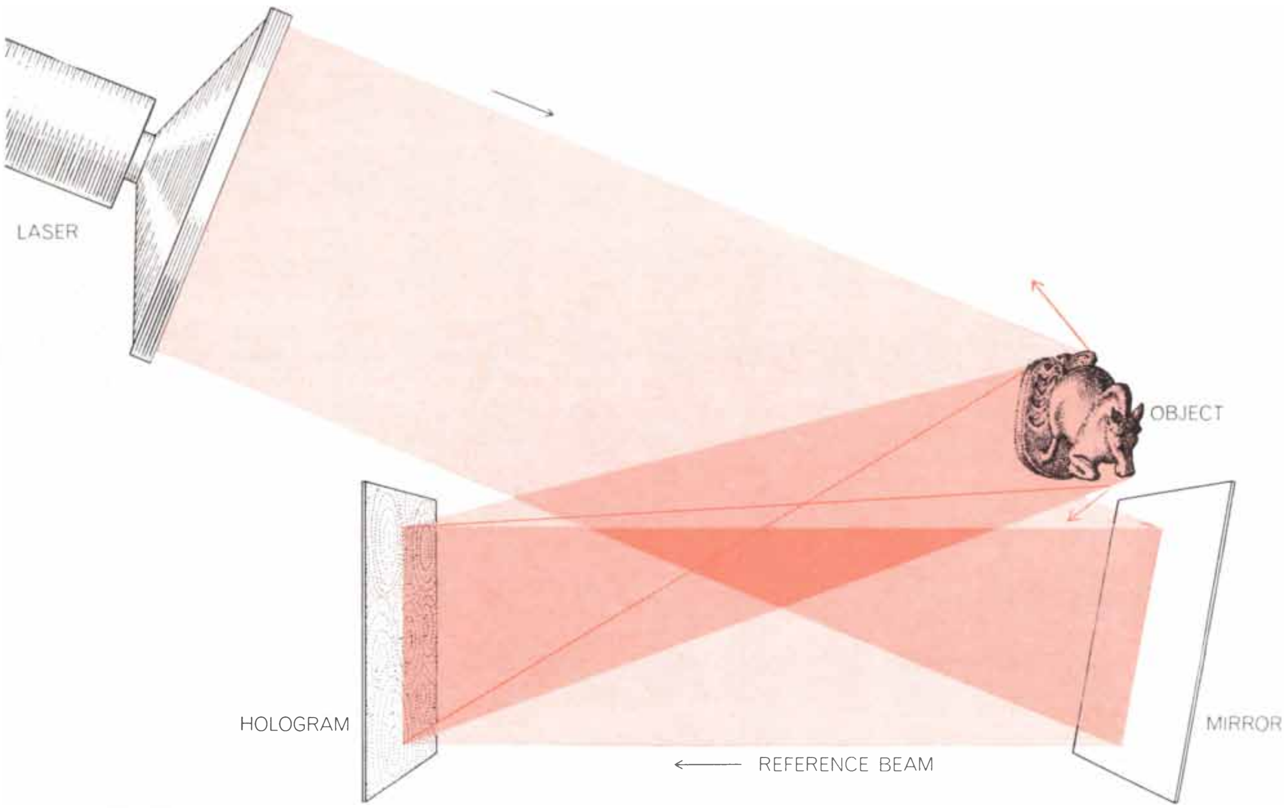
The reader will recall, however, that these fringe irregularities were produced by local variations in the amplitude and direction of the signal-bearing wave fronts that impinged on the hologram plate when the hologram was recorded. There is a kind of reversibility here: the distortions of the diffracted wave fronts by the fringe irregularities are precisely those distortions on the original wave front that gave rise to the fringe irregularities. For example, it was pointed out in the discussion of hologram construction that places where the signal-bearing wave fronts made the greatest angle with the reference wave front corresponded to the most closely spaced fringes. These areas of the hologram grating in turn diffract light at greater angles.

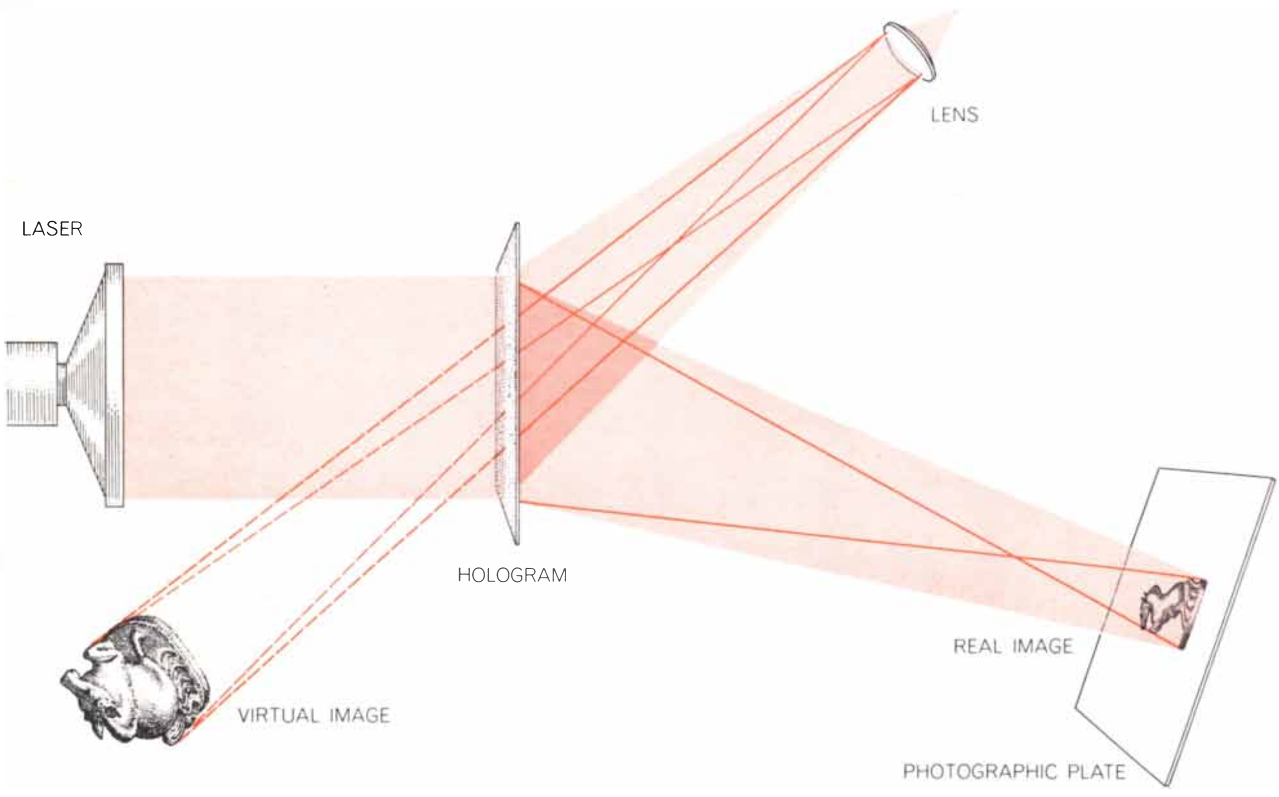
Indeed, the manner of constructing the diffracted orders from the hologram diffraction grating is essentially the inverse of the process of constructing the interference pattern that is recorded on the hologram. The similarity of the two processes is true on a much more rigorous basis than we have described here and is the key concept underlying the wave-front reconstruction process. The two sets of first-order diffracted waves produced by the hologram are each an exact replica of the waves that issued from the original object. These waves propagate outward from the hologram, behaving in all respects as the original waves would have done had they not been interrupted by the photographic plate placed in their path. A lens placed in the path of the diffracted waves can bring them to a focus, thereby forming an image of the original object, even though the original object is no longer present.

The two first-order waves differ from each other in one important respect. One diffracted order consists of waves that, when projected back toward the illuminating source, seem to emanate from an apparent object located where the original object was located. We say that these waves produce a virtual image, similar to the virtual images seen in a mirror. The other first-order diffracted waves are also accurate replicas

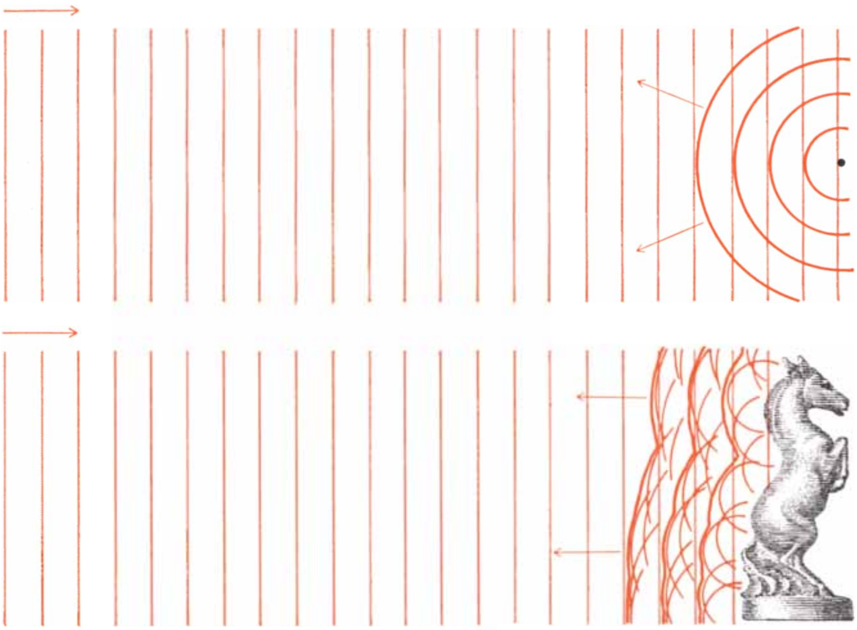


DIFFERENCES between ordinary photography and photography by wave-front reconstruction are illustrated schematically on these two pages. Ordinary photography consists of recording an illuminated three-dimensional object as a two-dimensional image on a light-sensitive surface (*top left*). The light reflected from the object is focused on the surface by some kind of image-forming device, which may be simply a pinhole in an opaque screen. When ordinary incoherent light is shone through the photographic transparency (*bottom left*), the eye sees only a static, two-dimensional image of the original object. In the recording stage of wave-front reconstruction photography (*top right*) no lens or other image-forming device is used and consequently no image is formed. Instead each point on the object reflects light to the entire hologram; conversely, each point of the hologram receives light from the en-

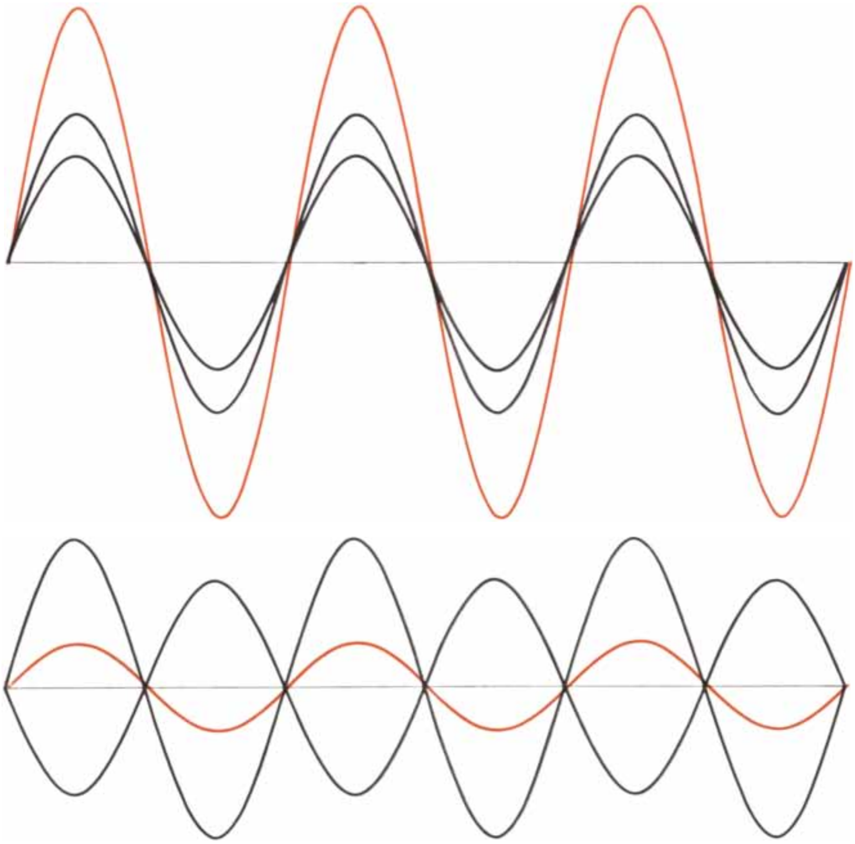




tire object. The reference beam produces, by means of interference effects, a visible display of the wave pattern of the light impinging on the hologram from the object. In the reproduction stage (*bottom right*) the hologram is illuminated with a collimated beam of monochromatic light and two images are produced by the "first order" diffracted waves emerging from the hologram interference grating. One diffracted order consists of waves that, when projected back toward the illuminating source, seem to emanate from an apparent object located at the position where the original object was located. These waves are said to produce a virtual image. The other first-order diffracted waves have conjugate, or reversed, curvature. These waves produce a real image, which can be photographed directly, without the need for a lens, by simply placing a photographic plate at the position of the image.



LIGHT WAVES ARE REFLECTED from a point scatterer (*top*) in a series of ever expanding spherical shells, called wave fronts, that are concentric about the point of origin. If the reflecting object is complex (*bottom*), it can then be regarded as a collection of a large number of points, and the resulting wave pattern reflected from the surface of the object can be regarded as the sum of many such sets of spherical waves, each set concentric about its point of origin. The central problem of wave-front reconstruction photography is to record this pattern as it exists at a given plane at some instant of time.



TWO KINDS OF INTERFERENCE of light waves are depicted. If two light waves of different amplitudes arrive at the recording surface in phase (*top*), their amplitudes will add to produce a resultant light intensity (*colored curve at top*) greater than would be produced by either wave acting alone. This process is called constructive interference and is responsible for the light fringes in the interference pattern. If the light waves arrive out of phase (*bottom*), their amplitudes will tend to cancel one another. This process is called destructive interference and is responsible for the dark fringes in the interference pattern.

of the original waves, except that they have conjugate, or reversed, curvature: originally diverging spherical waves from an object point are converted into converging spherical waves. These waves produce a real image, which can be photographed directly, without a lens, by placing a photographic plate at the image position.

Holograms and the images they produce have many curious and fascinating properties. The hologram on page 25, for example, is quite unintelligible and gives no hint of the image embodied within it. A cursory examination of it tempts one to identify the visible structures (concentric rings, specks and the like) with portions of the subject. Such an identification would be quite incorrect. The visible structure is purely extraneous and arises from dust particles and other scatterers on the mirror that supplies the reference beam. The pertinent information recorded on the hologram film can be seen only under magnification and consists of highly irregular fringes that bear no apparent relation to the subject. It is quite unlikely that one could learn to interpret a hologram visually without actually reconstructing the image.

When the hologram is placed in a beam of coherent light, however, the images embodied in it are suddenly revealed. The identity between the reconstructed waves and the original waves that impinged on the plate when the hologram was made implies that the image produced by the hologram should be indistinguishable in appearance from the original object. This identity is in fact realized. The virtual image, for instance, which is seen by looking through the hologram as if it were a window, appears in complete, three-dimensional form, and this three-dimensional effect is achieved entirely without the use of stereo pairs of photographs and without the need for such devices as stereo viewers.

The image has additional features of realism that do not even occur in conventional stereo-photographic imaging. For example, as the observer changes his viewing position the perspective of the picture changes, just as it would if the observer were viewing the original scene. Parallax effects are evident between near and far objects in the scene: if an object in the foreground lies in front of something else, the observer can move his head and look around the obstructing object, thereby seeing the previously hidden object. Moreover, one must refocus one's eyes when the observation is changed from a near to a more distant object in the scene. In short, the reconstruction has all the visual properties of the original scene, and we know of no visual test one can make to distinguish the two.

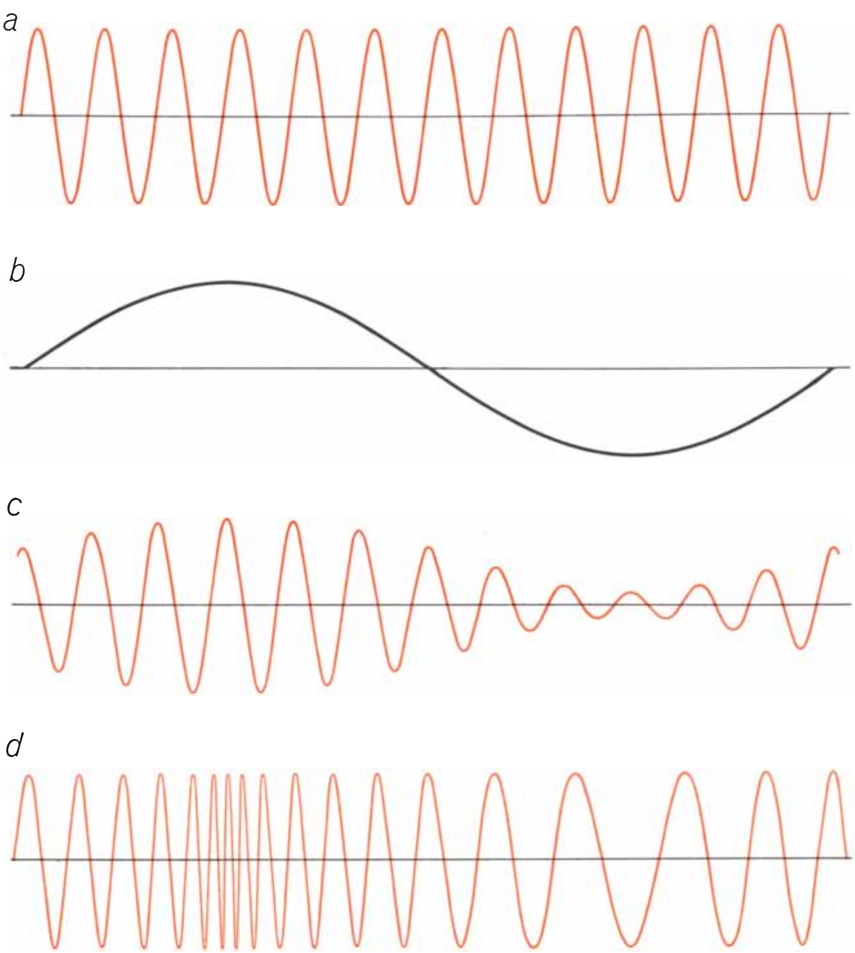
Similarly, the real image can be viewed by an observer, who will find it suspended in space between himself and the plate. This image has all the aforementioned properties, but it is somewhat more difficult to view, for reasons we shall not discuss here.

A hologram made in the manner just described has several interesting properties in addition to those having to do with the three-dimensional nature of its reconstruction. As an example, each part of the hologram, no matter how small, can reproduce the entire image; thus the hologram can be broken into small fragments, each of which can be used to construct a complete image. As the pieces become smaller, resolution is lost, since resolution is a function of the aperture of the imaging system. This curious property is explained on the basis of an observation made above: each point on the hologram receives light from all parts of the subject and therefore contains, in an encoded form, the entire image.

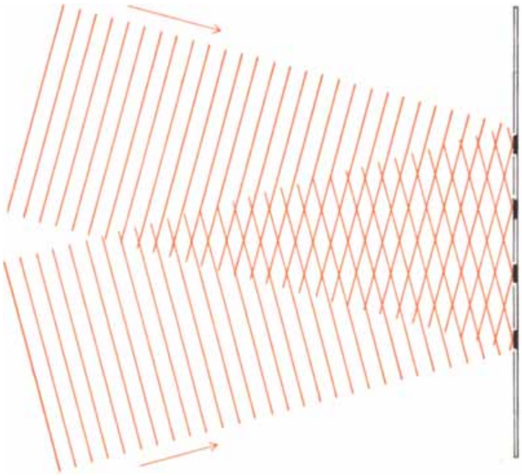
A second curious property of the wave-front reconstruction process is that it does not produce negatives. The hologram itself would normally be regarded as a negative, but the image it produces is a positive. If the hologram were copied by contact printing, the hologram would be reversed in the sense that opaque areas would now become transparent and vice versa. The image reconstructed from the copy, however, would remain a positive and would be indistinguishable from the image produced by the original except for the small degradation in quality that normally occurs in photographic copying. This curious property arises because the information is recorded on the film in the form of a modulated spatial carrier. Contact printing of the film results in only a reversal in the polarity of the carrier, and polarity reversals of a carrier do not affect the signal data contained on the carrier, a fact well known to electronic engineers. The reason for this insensitivity to polarity can be understood by recalling that the information on the grating carrier is embodied in the fringe contrast and in the fringe spacings; neither of these is altered by the reversal of polarity.

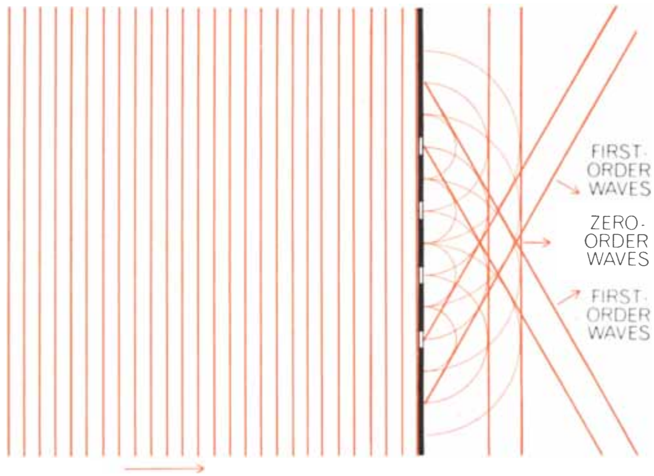
Another interesting property of wave-front reconstruction photography is that the reconstructed image has very nearly the same contrast rendition as the original object, regardless of the contrast properties of the photographic emulsion. Thus high-contrast plates, which in ordinary photography would be useful only for such objects as line drawings, can be used without losing any of the tonal properties of the object. The photographic plate containing the hologram may be capable of registering only two levels of density—transparent and opaque—but the tonal rendition of the reconstruction does not suffer. This mysterious property of wave-front reconstruction photography is not easily explained, but it is again related to the use of a carrier and also to the fact that each point on the object is recorded not on a single point of the hologram but on the entire hologram. Under these circumstances it can be shown that the failure to preserve a proper gray scale produces, as its main effect, higher-order diffracted waves. The first-order diffracted waves, which produce the reconstructed images, are to a first approximation unaffected by the distortion of the gray scale.

Still another interesting property of holograms is that several images can be superimposed on a single plate on successive exposures, and each image can be recovered without being affected by the other images. This is done by using a different spatial-frequency carrier for each picture, just as many radio messages can be transmitted between two sites simultaneously by the use of different carrier frequencies. The grating carriers can be of different frequencies, as in radio communication; moreover, since the film is two-dimensional there is still another degree of freedom, that of angle. Thus the grating carrier is specified both by the fringe spacing and by the fringe orientation. The fringe pattern can be vertical for one exposure, for example, and horizontal for another. In the reconstruction process the various

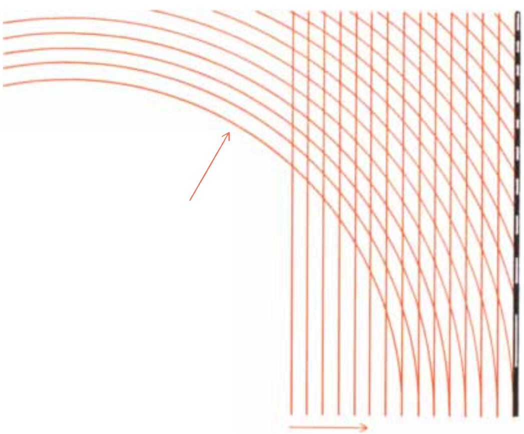


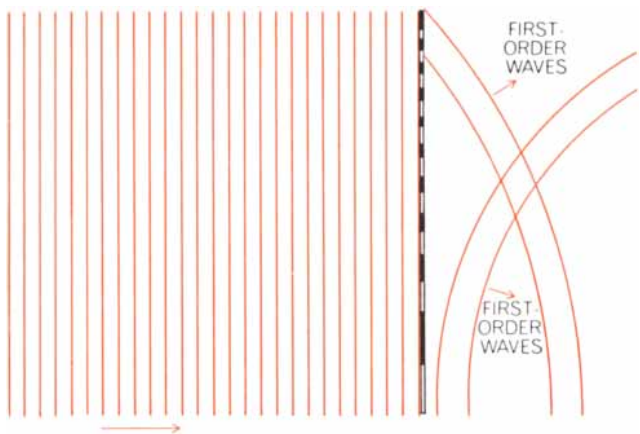
WAVES CARRY INFORMATION in various ways, but the best-known and most commonly used methods are amplitude modulation (AM) and frequency, or phase, modulation (FM). In amplitude modulation (*c*) information is modulated onto the carrier wave (*a*) by causing its amplitude to vary according to some lower-frequency wave (*b*). In frequency modulation (*d*) the amplitude of carrier wave remains constant but spacing between cycles is altered.





UNIFORM, PARALLEL FRINGES are produced by the interference of two plane waves derived from a common source and impinging at different angles of obliquity on an opaque surface (*left*). The spacing of the fringes depends solely on the angle between the waves. When the grating is illuminated with a beam of coherent light (*right*), a number of plane waves are generated by the interaction of the light with the grating. The "zero order" wave propagates in the same direction as the incident wave and can be regarded as an attenuated version of the incident wave. Beyond the two first-order waves occur second-, third- and higher-order waves.





MODULATED FRINGES are produced by the interference of a plane wave and an irregular wave, in this case a cylindrical wave (*left*). Where the angle between the plane and the distorted wave fronts is large the fringe pattern is fine; where the angle is small the fringe pattern is coarse. When illuminated with a beam of coherent light, the modulated fringe pattern acts like an imperfect diffraction grating, producing diffracted waves that are distorted (*right*). The diverging first-order diffracted wave is responsible for the virtual image of the original object; the converging first-order diffracted wave is responsible for the real image of the object.

reconstructed waves will be diffracted in different directions and the reconstructed images will form in different locations.

Wave-front reconstruction photography, although appearing to offer exciting possibilities, has in the past been confined to the laboratory and for some time at least will remain so. The major reason for this is the strict coherence requirements for the light source used in the process. Ordinary light lacks this coherence property, and sources of coherent light are comparatively expensive and inconvenient to use.

There are two kinds of coherence—temporal and spatial—both of which are required for wave-front reconstruction photography. Temporal coherence, or monochromaticity, is required because the fringe pattern generated by the interference process is a function of the wavelength of the illumination. If the spectrum of the light is broad, each wavelength component produces its own separate pattern, and the resultant of all the wavelength components acting at once is to average out the fringes to a smooth distribution. A limited number of spectral components can be superimposed, however, as when three monochromatic waves, comprising the three primary colors, are used to achieve wave-front reconstruction imaging in color. The relaxation of the monochromaticity requirement cannot be carried very far, and each of the three color components must cover a quite narrow spectral band.

The other coherence requirement—spatial coherence—means that the light has been derived from a point source or that the light is capable of being imaged to a small spot or point. If the source lacks spatial coherence (that is, if it is broad), then each element of the source produces interference fringes that are displaced from those of other elements; the sum of many such sets of fringes averages to some very nearly uniform value, and the fringe pattern is absent.

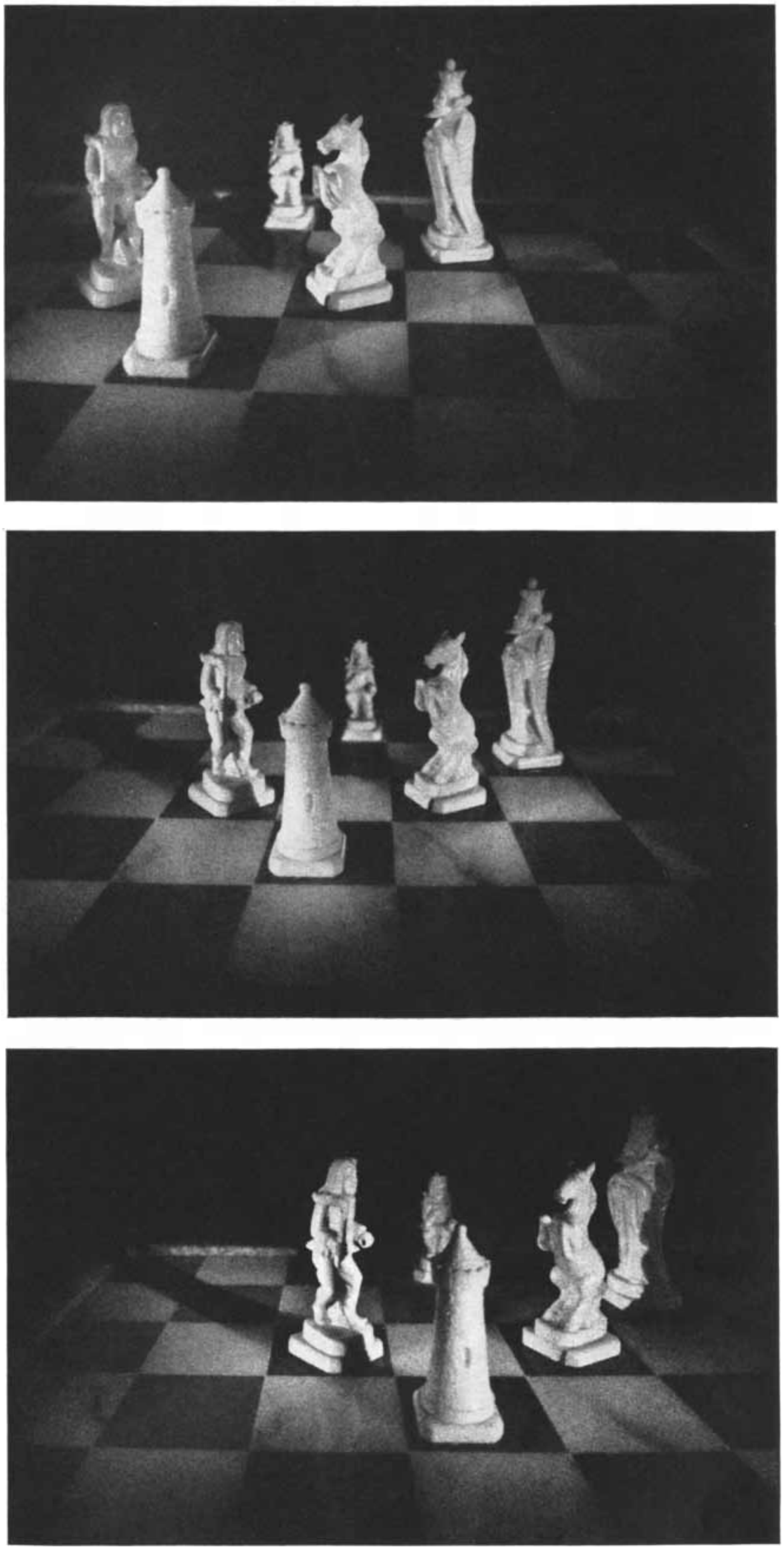
It is possible to meet both coherence requirements using traditional sources, such as a mercury-arc lamp. Monochromaticity is obtained by passing the light through an optical device, such as a monochromator or a narrow-band color filter. This process discards all spectral components except those in a narrow band. Spatial coherence is obtained by focusing the light onto a pinhole. Since only a small fraction of the total light output of the lamp can be focused onto the pinhole, the traditional source is quite inefficient, and only an extremely small fraction of the total light emission is available for illumination of the object.

The light produced by a laser, on the other hand, is highly monochromatic and has extraordinary spatial coherence, thus making the wasteful processes described above unnecessary. The available light is several orders of magnitude greater than the monochromatic, spatially coherent light available from other sources. Hence the laser is greatly superior to all other known sources for wave-front reconstruction photography and is certainly in large part responsible for the interesting results that have already been achieved.

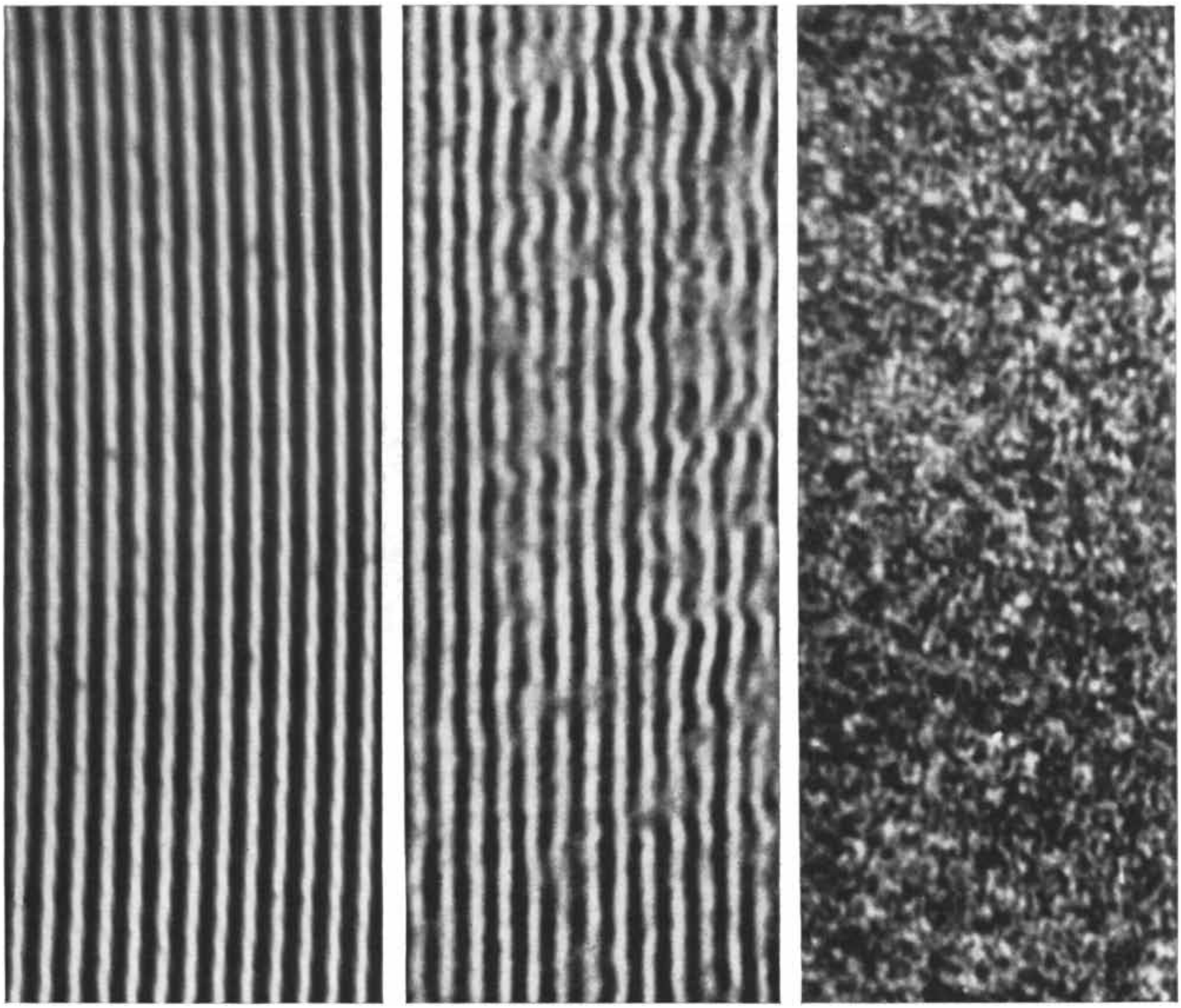
With a high-quality technique for producing fascinating and unusual images fully demonstrated, questions naturally arise as to what applications are to be found for it. Since its discovery by Gabor, many uses for the wave-front reconstruction process have been suggested, and more recently the number of proposed applications has grown rapidly.

Two applications that come to mind immediately are in television and motion pictures. It is possible in principle to produce a hologram television system, since a hologram can be recorded on the photosensitive surface of a television camera just as readily as on a photographic emulsion. Moreover, the hologram data can be transmitted and reconstructed in a receiver. Such a system would produce virtually the ultimate realism.

When the required system and component specifications are examined, however, it is found that they greatly exceed the present state of the art. Transmission bandwidths exceeding present television bandwidths by factors of several hundred are required, unless design compromises are made that result in a partial loss of the dramatic results attainable from holograms. Cam-



PARALLAX EFFECT is evident in these three virtual-image photographs, all made from the same hologram. The apparent displacement of the chessmen resulted from moving the hologram slightly. The same effect could have been obtained by keeping the hologram stationary and moving the camera or by keeping both stationary and moving the laser.



THREE INTERFERENCE PATTERNS show the effects of amplitude and phase modulation of a spatial carrier wave. The fringe pattern at left was formed by two plane waves impinging on a photographic plate at a slight angle to each other. One of the waves responsible for the pattern at center has been modulated to a small degree, producing slight variations in fringe contrast and irregularities in the shape of the fringe contours; the pattern is an enlarged section of a hologram of a comparatively simple photographic transparency. The interference pattern at right is an enlargement of section of a hologram of a diffusely reflecting, three-dimensional object. The degree of modulation is so great that the interference fringes have lost continuity and are no longer identifiable as fringes.

eras, picture tubes and associated components must also be much better than present-day equipment. In addition, the objects would have to be illuminated by laser light, and the receiver similarly would have to contain a laser; present lasers are inadequate for these tasks and would require improvement. The potential is great but the price is still quite high. Methods are being sought for reducing the stringent requirements on system bandwidths, with some initial success, but much remains to be done. For hologram motion pictures the problems are similar and even more severe.

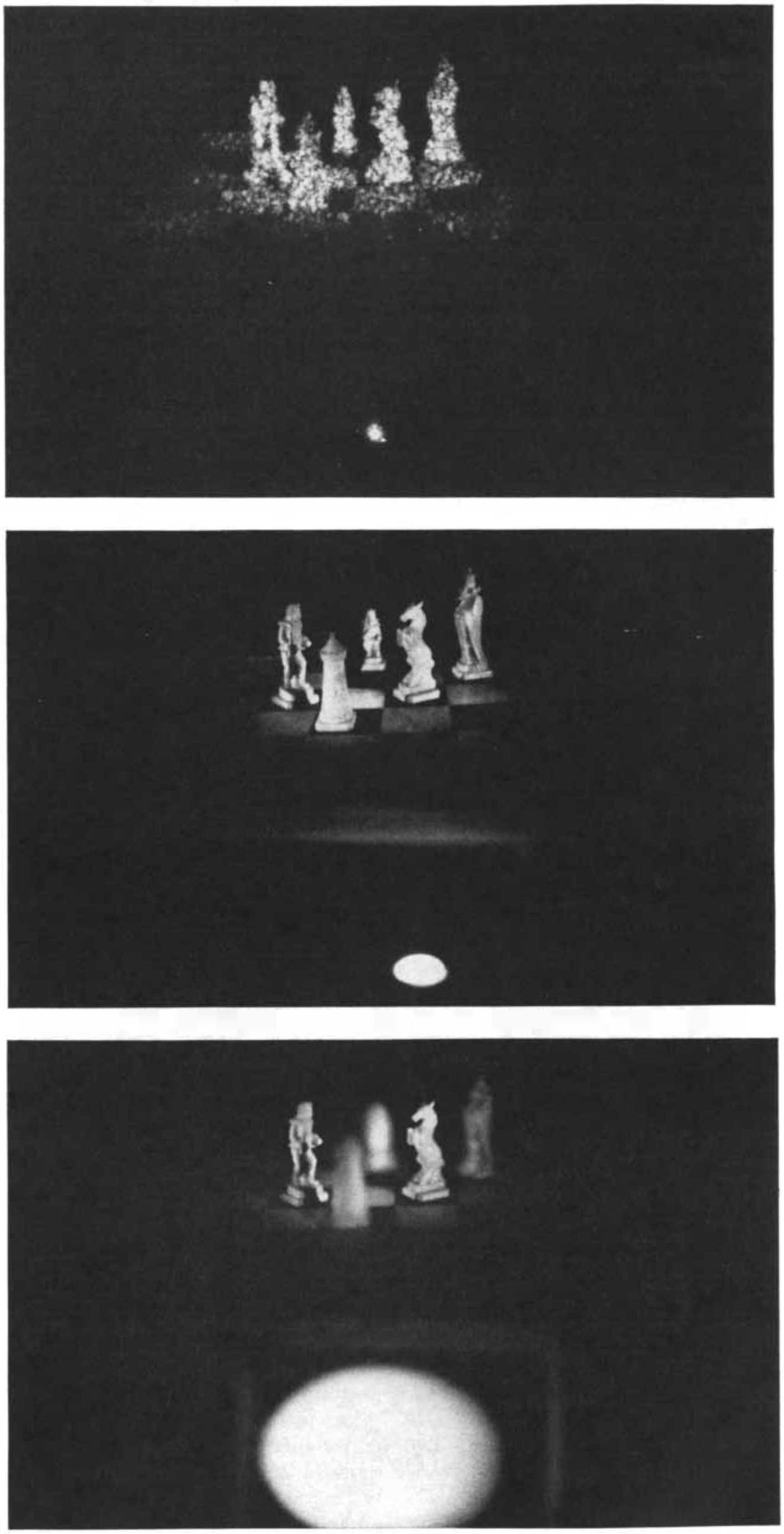
As laser sources improve, wave-front reconstruction photography may emerge from the laboratory and become, through its remarkable three-dimensional imaging properties, an important photographic method for simulation and training devices and for applications in which a highly exact reproduction of the object is required.

Historically microscopy has been the primary area of application for the wave-front reconstruction method; Gabor's original applications were in this area. By the use of divergent beams of radiation Gabor, as well as El-Sum and Albert V. Baez at Stanford, have demonstrated that great magnification can be achieved with wave-front reconstruction, entirely without the use of lenses. Moreover, the hologram can be made with radiation of one wavelength and the reconstruction with another. Gabor proposed to produce a hologram with electron waves in an electron microscope and to make the reconstruction using visible light. By this means the highly developed methods of optical imagery can be applied to image formation in the domain of electron waves, where lens technique is less perfectly developed. Similarly, El-Sum and Baez have made holograms with an X-ray microscope and the reconstructions in visible light. This application holds much promise, because X rays can be focused only crudely and with extreme difficulty. The resolution achieved in X-ray microscopy falls several orders of magnitude short of what is theoretically possible, a condition that can be remedied by wave-front reconstruction methods. Technical difficulties have hampered progress in this area, but the difficulties—primarily the lack of X-ray sources of suitable intensity, monochromaticity and spatial coherence—do not appear insurmountable.

In an application developed by two of the authors' colleagues, Robert Powell and Karl Stetson, the vibratory motion of a complicated object can be measured with ease by the wave-front reconstruction method. The light reflected from such a vibrating object loses its coherence in a predictable manner. Consequently the image reconstructed from a hologram has superimposed on it a contour pattern of the vibrational amplitude; from this reconstruction the amplitude of vibration for each point on the object can be obtained at once by simple inspection of the hologram image.

Brian Thompson, George Parrent and their co-workers at Technical Operations, Inc., have developed an application that has a remarkable simplicity. They were faced with the problem of measuring the distribution by size and other properties of floating, foglike particles in a sample volume. Such particles generally do not remain stationary long enough for the observer to focus on them. In addition, it is often desirable to photograph all the particles in the volume at a given time. The wave-front reconstruction method offers an ideal solution to the problem. A hologram is made by illuminating the volume with a pulsed laser and photographically recording the transmitted light. A short-pulse laser is used to "freeze" the motion of the particles. In the reconstruction an image of the entire volume is produced, and the particle size, distribution and cross-sectional geometry can be measured by microscopic examination. (Although Thompson and Parrent have exploited both the three-dimensional imaging capabilities of the hologram process and the extraordinary coherence properties of the laser, their efforts are unrelated to ours and have developed the original ideas of Gabor along quite different lines.)

Additional applications should develop in time, particularly as advancing technology provides new devices that can facilitate the wave-front reconstruction method. In particular, high-power pulsed lasers with excellent coherence properties should bring about significant advances. It seems safe to predict that most future applications will center on the three-dimensional, highly realistic imagery that the method produces and that is unmatched in this respect by other photographic methods.



ENTIRE IMAGE of the original scene is reproduced by any part of the hologram, however small. At top the unbroadened laser beam, about a half-millimeter in diameter, is directed at the hologram (*faint rectangle in foreground of each photograph*). Since photographic resolution is a function of the aperture of the imaging system, the image appears blotchy and ill-defined at this aperture. As successively larger parts of the hologram are illuminated (*middle and bottom*) resolution is improved, but the depth of field of the image decreases.

HORMONES AND GENES

One of the traditional questions of biology is: How do hormones exert their powerful effects on cells? Evidence is accumulating that many of these effects are due to the activation of genes

by Eric H. Davidson

In the living cell the activities of life proceed under the direction of the genes. In a many-celled organism the cells are marshaled in tissues, and in order for each tissue to perform its role its cells must function in a cooperative manner. For more than a century biologists have studied the ways in which tissue functions are controlled, providing the organism with the flexibility it needs to adapt to a changing environment. Gradually it has become clear that among the primary controllers are the hormones. Thus whereas the genes control the activities of individual cells, these same cells constitute the tissues that respond to the influence of hormones.

New experimental evidence is now making it possible to complete this syllogism: it is being found that hormones can affect the activity of genes. Hormones of the most diverse sources, molecular structure and physiological influence appear able to rapidly alter the pattern of genetic activity in the cells responsive to them. The establishment of a link between hormones and gene action completes a conceptual bridge stretching from the molecular level to ecology and animal behavior.

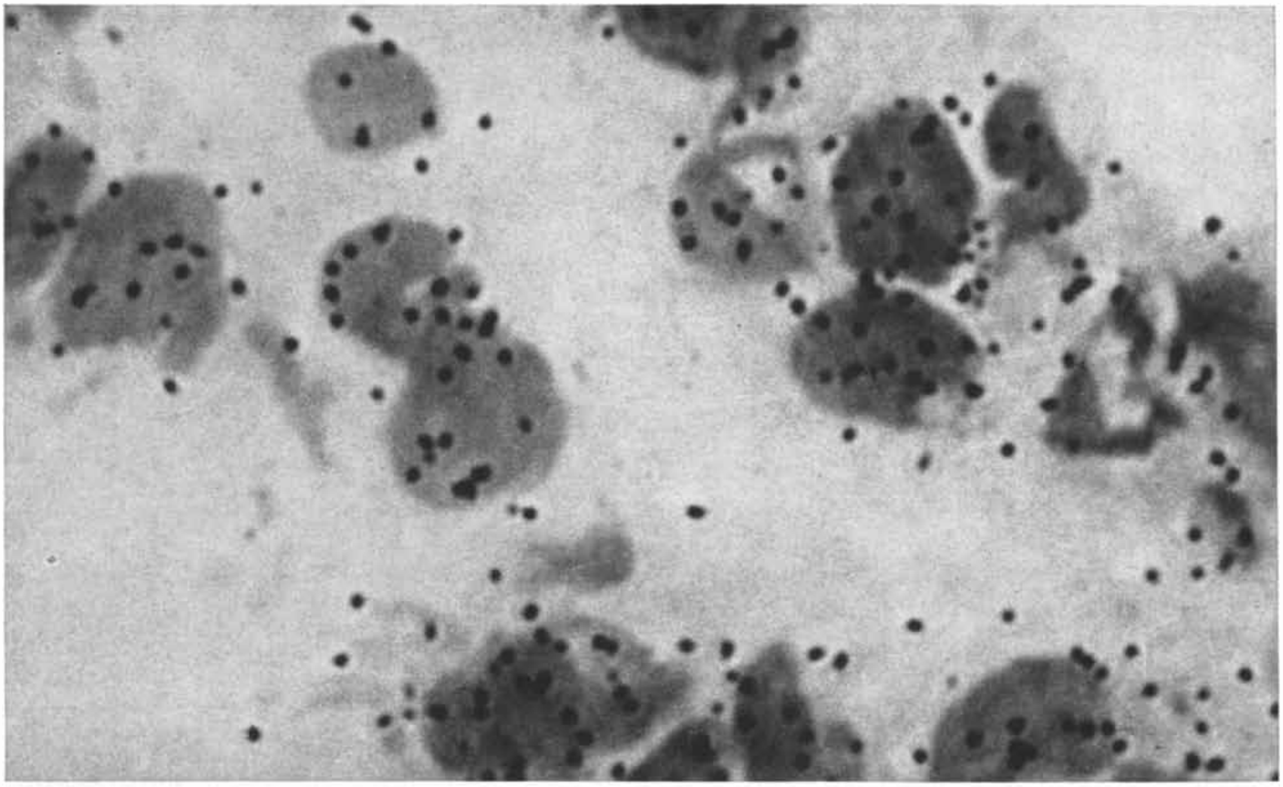
In order to understand the nature of the link between hormones and genes it will be useful to review briefly what is known of how genes function in differentiated, or specialized, cells. One of the most striking examples of cell specialization in animals is the red blood cell, the protein content of which can be more than 90 percent hemoglobin. It has been shown that in man the ability to manufacture a given type of hemoglobin is inherited; this provides a clear case of a differentiated-cell function under genetic control. Hemoglobin also furnishes an example of another principle that is fundamental to the study of differentiation: the specialized character of a cell depends on the type and quantity of proteins in it, and therefore the process of differentiation is basically the process of developing a specific pattern of protein synthesis. Some cells, such as red blood cells and the cells of the pancreas that produce digestive enzymes, specialize in synthesizing one kind of protein; other cells specialize in synthesizing an entire set of protein enzymes to manufacture nonprotein end products, for example glycogen, or animal starch (which is made by liver cells), and steroid hormones (which are made by cells of the adrenal cortex).

If one understood the means by which the type and quantity of protein made by cells was controlled, one would have taken a long step toward understanding the nature of the differentiated cell. Part of this objective has been attained: we now know something of how genes act and how proteins are synthesized. A protein owes its properties to the sequence of amino acid subunits in its chainlike molecule. The genes of most organisms consist of deoxyribonucleic acid (DNA), the chainlike molecules of which are made up of nucleotide subunits. The sequence of nucleotides in a single gene determines the sequence of amino acids in a single protein.

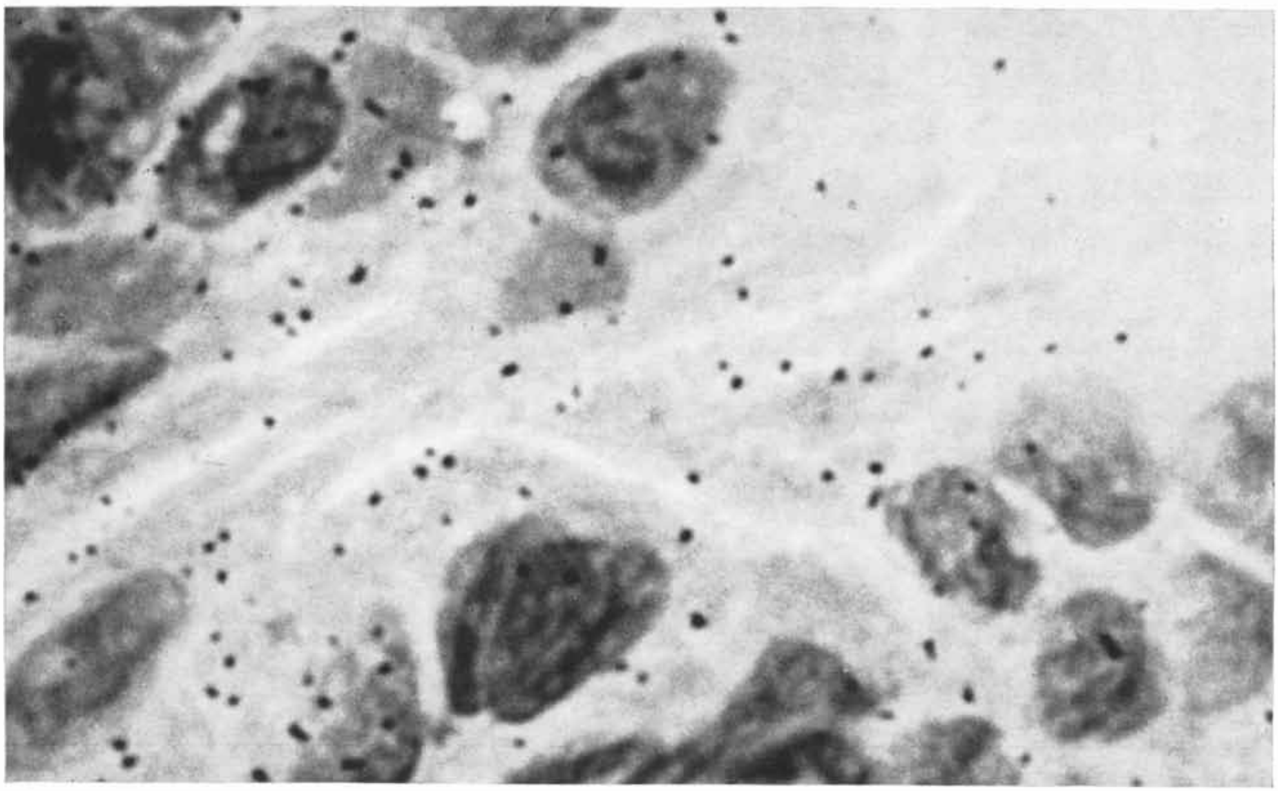
The protein is not assembled directly on the gene; instead the cell copies the sequence of nucleotides in the gene by synthesizing a molecule of ribonucleic acid (RNA). This "messenger" RNA moves away from the gene to the small bodies called ribosomes. On the ribosomes, which contain their own unique kind of RNA, the amino acids are assembled into protein. In the assembly process each molecule of amino acid is identified and moved into position through its attachment to a specific molecule of a third kind of RNA: "transfer" RNA. It can therefore be said that the characteristics of the cell are determined at the level of "gene transcription"—the synthesis of messenger and ribosomal RNA.

Each differentiated cell in a many-celled organism contains a complete set of the organism's genes. It is obvious, however, that in such a cell only a small fraction of the genes are actually functioning; the gene for hemoglobin is not active in a skin cell and the assortment of genes active in a liver cell is not the same as the assortment active in an adrenal cell. The active genes release their information in the form of messenger RNA and the inactive genes do not. Exactly how the inactive genes are repressed is not clearly understood, but the repression seems to involve a chemical combination between DNA and the proteins called histones; it has been shown that histones inhibit the synthesis of messenger RNA in the isolated nuclei of calf-thymus cells, and similar results have been obtained with the nuclei of other kinds of cell. In any case it is clear that the characteristics of the cell are the result of variable gene activity. The prime question becomes: How are the genes selectively turned on or selectively repressed during the life of the cell?

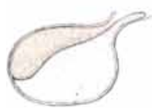
Gene action is often closely linked to cell function in terms of time. It has been demonstrated that genes can exercise immediate control over the activities of differentiated cells—particularly very active or growing cells—and over cells that are going through some change of state. In many specialized cells at least part of the messenger RNA



HORMONE IS LOCALIZED IN NUCLEI of cells in this radioautograph made by George A. Porter, Rita Bogoroch and Isidore S. Edelman of the University of California School of Medicine (San Francisco). The hormone aldosterone was radioactively labeled and administered to a preparation of toad bladder tissue. When the tissue was radioautographed, the hormone revealed its presence by black dots. The dots appear predominantly in the nuclei (*dark gray areas*) of the cells rather than in the cytoplasm (*light gray areas*).



ANOTHER HORMONE IS NOT LOCALIZED in the nuclei in this radioautograph made by the same investigators. Here the hormone was progesterone, and it too was labeled and administered to toad bladder tissue. The dots are distributed more or less at random.

HORMONE	SOURCE	CHEMICAL NATURE	FUNCTION
ECDYSONE	INSECT PROTHORACIC GLAND 	STEROID	Causes molting, initiation of adult development and puparium formation.
GLUCOCORTICOIDS (CORTISONE)	ADRENAL CORTEX 	STEROID	Causes glycogen synthesis in liver. Causes redistribution of fat throughout organism. Alters nitrogen balance. Causes complete revision of white blood cell type frequencies. Is required for muscle function. Alters central nervous system excitation threshold. Affects connective tissue differentiation. Promotes healing. Induces appearance of new enzymes in liver. Affects almost all tissues.
INSULIN	PANCREAS (ISLETS OF LANGERHANS) 	POLYPEPTIDE	Affects entry rate of carbohydrates, amino acids, cations and fatty acids into cells. Promotes protein synthesis. Affects glycogen synthetic activity. Stimulates fat synthesis. Stimulates acid mucopolysaccharide synthesis. Affects almost all tissues.
ESTROGEN	OVARY 	STEROID	Promotes appearance of secondary sexual characteristics. Increases synthesis of contractile and other proteins in uterus. Increases synthesis of yolk proteins in fowl liver. Increases synthesis of polysaccharides. Affects rates of glycolysis, respiration and substrate uptake into cells. Probably affects almost all tissues.
ALDOSTERONE	ADRENAL CORTEX 	STEROID	Controls sodium and potassium excretion and cation flux across many internal body membranes.
PITUITARY ACTH	ANTERIOR PITUITARY 	POLYPEPTIDE	Stimulates glucocorticoid synthesis by adrenal cortex. Stimulates adrenal protein synthesis and glucose uptake. Inhibits protein synthesis in adipose tissue. Stimulates fat breakdown.
PITUITARY GH	ANTERIOR PITUITARY 	PROTEIN	Stimulates all anabolic processes. Affects nitrogen balance, water balance, growth rate and all aspects of protein metabolism. Stimulates amino acid uptake and acid mucopolysaccharide synthesis. Affects fat metabolism. Probably affects all tissues.
THYROXIN	THYROID 	THYRONINE DERIVATIVE	Affects metabolic rate, growth, water and ion excretion. Promotes protein synthesis. Is required for normal muscle function Affects carbohydrate levels, transport and synthesis. Probably affects all tissues.

HORMONES DISCUSSED IN THIS ARTICLE are listed according to their source, their chemical nature and their effects, which are usually quite diverse. Pituitary GH is the pituitary growth hormone. The steroid hormones share a basic molecular skeleton consisting of adjoining four-ring structures. The polypeptide hormones and the protein hormones consist of chains of amino acid subunits.

produced by the active genes decays in a matter of hours, and therefore the genes must be continuously active for protein synthesis to continue normally. Other differentiated cells display the opposite characteristic, in that gene activity occurs at a time relatively remote from the time at which the messenger RNA acts. The very existence of this time element in gene control of cell function indicates how extensive that control is. Furthermore, certain genes can be alternately active and inactive over a short period; for example, if a leaf is bleached by being kept in the dark and is then exposed to light, it immediately begins to manufacture messenger RNA for the synthesis of chlorophyll.

The sum of such observations is that the patterns of gene activity in the living cell are in a state of continuous flux. For a cell in a many-celled organism, however, it is essential that the genetic apparatus be responsive to external conditions. The cell must be able to meet changing situations with altered metabolism, and if all the cells in a tissue are to alter their metabolism in a coordinated way, some kind of organized external control is needed. Evidence obtained from experiments with a number of biological systems suggests that such control is obtained by externally modulating the highly variable activity of the cellular genetic apparatus. The studies that will be reviewed here are cases of this general proposition; in these cases the external agents that alter the pattern of gene activity are hormones.

Many efforts have been made to explain the basis of hormone action. It has been suggested that hormones are coenzymes (that is, cofactors in enzymatic reactions), that they activate key enzymes, that they modify the outer membrane of cells and that they directly affect the physical state of structures within the cell. For each hypothesis there is evidence from studies of one or several hormones. As an example, experiments with the pituitary hormone vasopressin, which causes blood vessels to constrict and decreases the excretion of urine by the kidney, strongly support the conclusion that the hormone attaches itself to the outer membrane of the cells on which it acts.

To these hypotheses has been added the new one that hormones act by regulating the genetic apparatus, and many investigators have undertaken to study the effects of hormones on gene activity. It turns out that the gene-regulation hypothesis is more successful than the others in explaining some of the most puzzling features of hormone activity, such as the time lag between the administration of some hormones and the initial appearance of their effects, and also the astonishing variety of these effects [*see illustration on opposite page*]. There can be no doubt that some hormone action is independent of gene activity, but it has now been shown that a wide variety of hormones can affect such activity. This conclusion is strongly supported by the fact that each of these same hormones is powerless to exert some or all of its characteristic effects when the genes of the cells on which it acts are prevented from functioning.

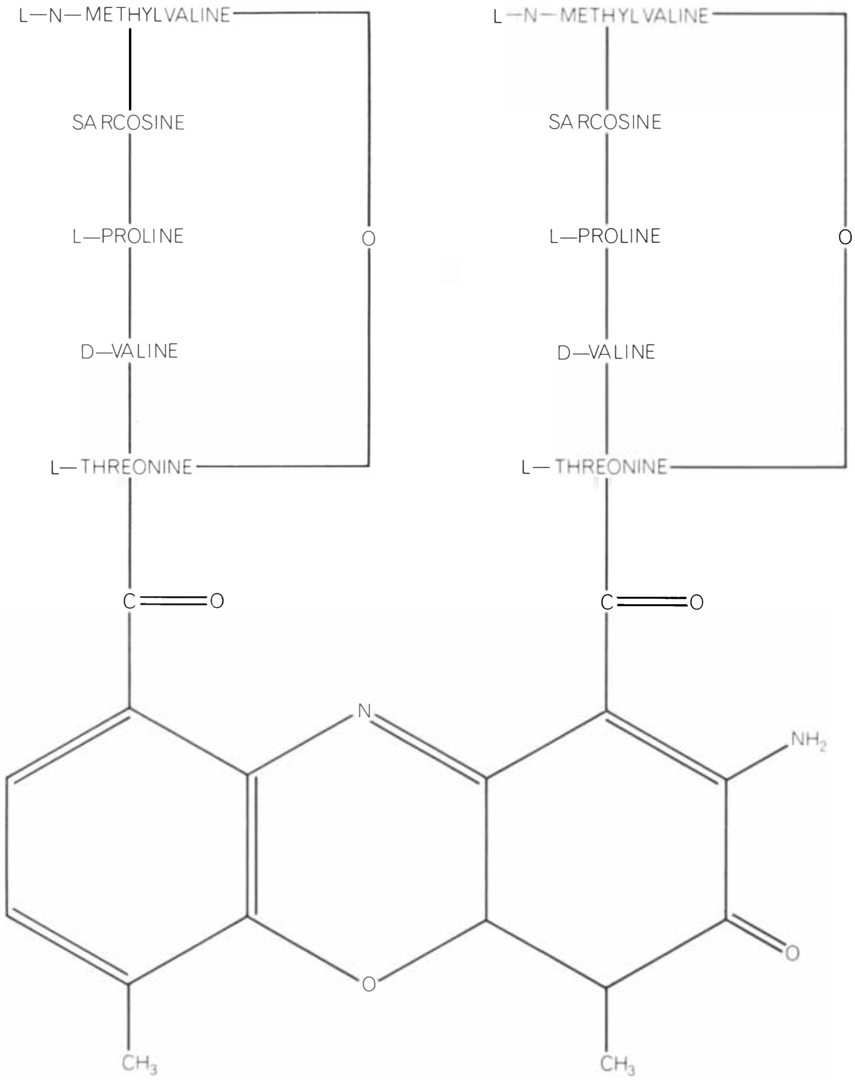
The genes can be blocked by the remarkably specific action of the antibiotic actinomycin D. The antibiotic penetrates the cell and forms a complex with the cell's DNA; once this has happened the DNA cannot participate in the synthesis of messenger RNA. The specificity of actinomycin is indicated by the fact that it does not affect other activities of the cell: protein synthesis, respiration and so on. These activities continue until the cellular machinery stops because it is starved for messenger RNA. In high concentrations actinomycin totally suppresses the synthesis of messenger RNA; in lower concentrations it depresses this synthesis and appears to prevent it from developing at new sites.

So far the greatest number of studies of the effects of hormones on genes have been concerned with the steroid hormones, particularly the estrogens produced by the ovaries. This work has been carried forward by many investigators in many laboratories. It has been found that when the ovaries are removed from an experimental animal and then estrogen is administered to the animal at a later date, the synthesis of protein by cells in the uterus of the animal increases by as much as 300 percent. The increase is detected by measuring the incorporation of radioactively labeled amino acids into uterine protein, or by testing the capacity for protein synthesis of homogenized uterine tissue removed from the animal at various times after the administration of estrogen. Added proof that these observations have to do with the synthesis of protein is provided by the fact that the stimulating effects of estrogen are blocked by the antibiotic puromycin, which specifically inhibits protein synthesis.

In these experiments the principal rise in protein synthesis is first observed between two and four hours after estrogen treatment. Less than 30 minutes after the treatment, however, there is a dramatic increase in the rate of RNA synthesis. When actinomycin is used to block the rise in RNA synthesis, the administration of estrogen has no effect on protein synthesis! What this means is that since the diverse metabolic changes brought about in uterine cells by estrogen are all mediated by protein enzymes, none of the changes can occur unless the estrogen has induced gene action. Among the changes are the increased synthesis of amino acids from glucose, the increased evolution of carbon dioxide and the increased synthesis of the fatty lipids and phospholipids. It is not surprising to find that none of these metabolic changes in uterine cells can be detected when estrogen is administered to an animal that has first been treated with actinomycin.

The effect of estrogen on the synthesis of RNA is not limited to messenger RNA. There is also an increase in the manufacture of the other two kinds of RNA: transfer RNA and ribosomal RNA. The administration of estrogen first stimulates the production of messenger RNA and transfer RNA. The genes responsible for the synthesis of ribosomal RNA become active somewhat later, and the number of ribosomes per cell increases. One of the earliest changes brought about by estrogen, however, is an increase in the activity of the enzyme RNA-DNA polymerase. This enzyme appears to be responsible for all RNA synthesis in such cells.

Two main conclusions can be drawn from these various observations. First, there can be no reasonable doubt that treatment with estrogenic hormones results in activation at the gene level, and that many of the well-known effects of estrogen on uterine cells result from this gene activation. Second, it is clear that a considerable number of genes must be activated in order to account for the many different responses of the cells to estrogen. Consider only the fact that estrogen stimulates the production of three different kinds of RNA. At least two different genes are known to be associated with the synthesis of ribosomal RNA, and each cell needs to manufacture perhaps as many as 60 species of transfer RNA. As for messenger RNA, the variety of the changes induced by estrogen implies that under such influences it too must be produced



ANTIBIOTIC ACTINOMYCIN D has a complex chemical structure. The antibiotic blocks the participation of the genetic material in the synthesis of ribonucleic acid (RNA); thus it can be used in studies to determine whether or not a given hormone stimulates gene activity.

in a number of molecular species. We are therefore confronted with a major mystery of gene regulation: How can a single hormone activate an entire set of functionally related but otherwise quite separate genes, and activate them in a specific sequence and to a specific degree?

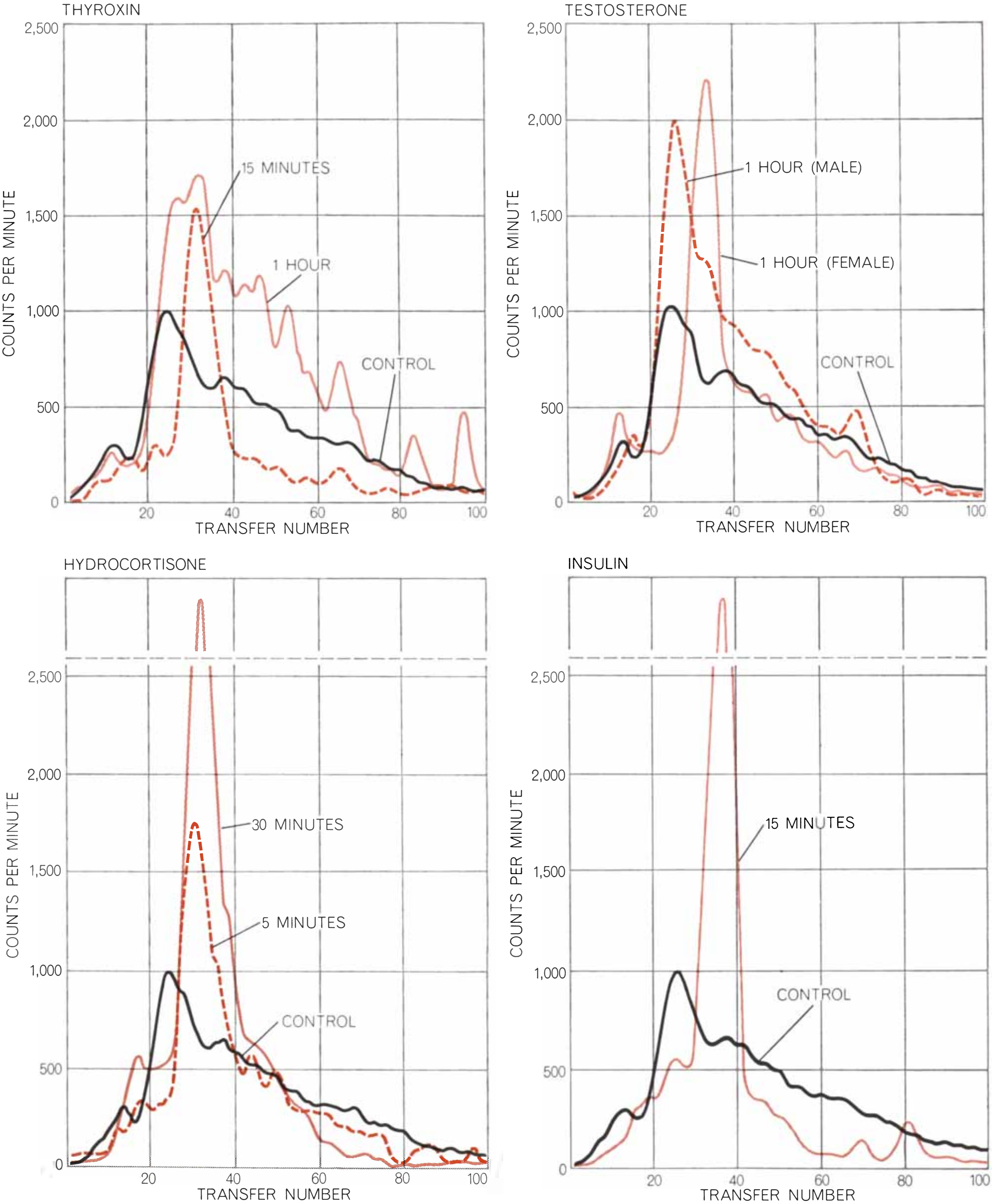
The question can be sharpened somewhat by considering the effect of estrogen not on uterine cells but on the cells of the liver. When an egg is being formed in a hen, the estrogen produced by the hen's ovaries stimulates its liver to produce the yolk proteins lipovitellin and phosvitin. Obviously a rooster does not need to synthesize these proteins, but if it is treated with estrogen, its liver will make them in large amounts! A more unequivocal example of the selective activation of repressed genes by a hormone could scarcely be imagined. What is more, experiments by E. N. Carlsen and his co-workers at the University of California School of Medicine (Los Angeles) have demonstrated that this gene-activating effect of estrogen is remarkably specific. Phosvitin is an unusual protein in that nearly half of its subunits are of one kind: they are residues of the amino acid serine. Carlsen and his colleagues found that estrogen most strongly stimulates liver cells to produce the particular species of transfer RNA that is associated with the incorporation of this amino acid into protein.

The effect of estrogen on liver cells is thus quite different from its effect on uterine cells. Indeed, it has long been recognized that hormonal specificity resides less in the hormone than in the "target" cell. We are now, however, able to ask new questions: How are the sets of genes that are activated by a given hormone selected? Are these genes somehow preset for hormonal activation? How does the hormone interact not only with the gene itself but also with the cell's entire system of genetic regulation?

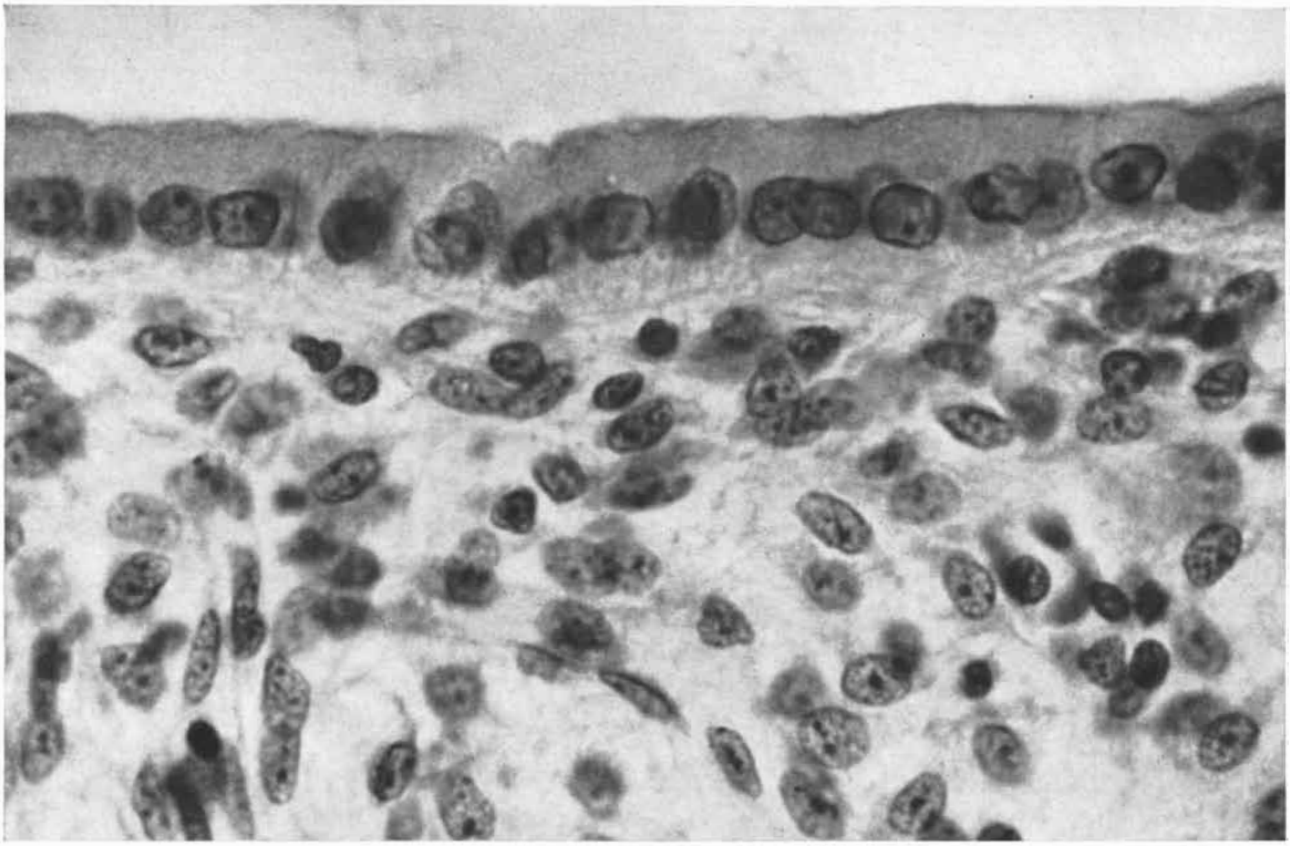
The male hormone testosterone has also been shown to operate by gene activation. Like the estrogens, the male sex hormones can give rise to dramatic increases of RNA synthesis in various cells. In experiments on male and female rats it has been found that the effect of testosterone on the liver cells of a female is somewhat different from that on the liver cells of a castrated male. In both cases the hormone causes an increase in the *amount* of messenger RNA produced, but in the female it also brings about the synthesis of a new *variety* of messenger RNA. This effect, like the ability of estrogen to stimulate a rooster's liver cells to produce egg-yolk proteins, provides a new approach for examining the whole question of sexual differentiation.

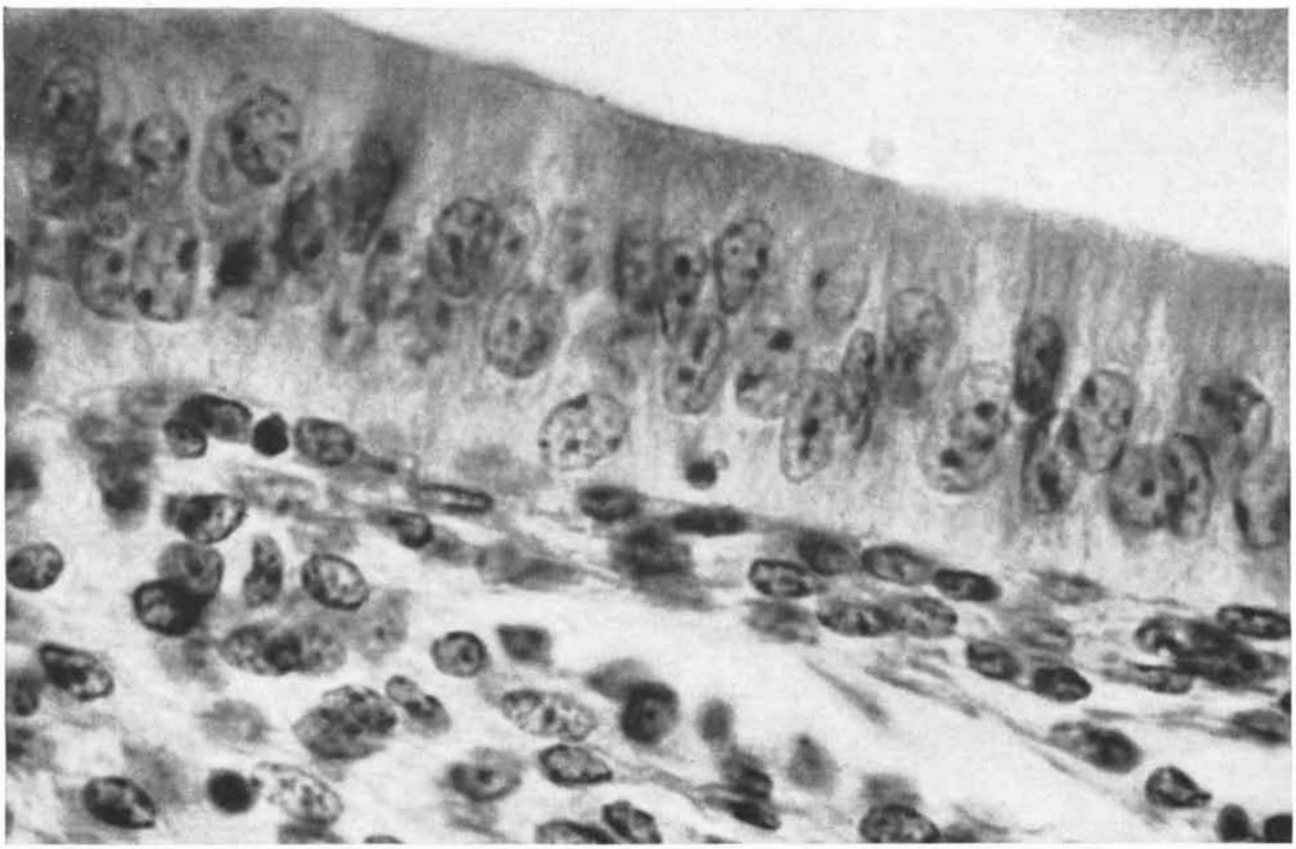
Apart from the sex hormones, the principal steroids in mammals are those secreted by the adrenal cortex. One group of adrenocortical hormones is typified by cortisone; this hormone and its relatives are known for their quite different effects in different tissues. Only a fraction of these effects have been studied from the standpoint of gene activation, and there is much evidence to indicate that some of them are not mediated by the genes. Some responses to cortisone, however, do appear to be the consequence of gene activation.

If the adrenal glands are removed from an experimental animal and cortisone is administered later, the hormone induces in the liver cells of the animal the production of a number of new proteins. Among these proteins are enzymes required for the synthesis of glucose (but not the breakdown of glucose) and enzymes involved in the metabolism of amino acids. Moreover, cortisone steps up the total production of protein by the liver cells. The effect of cortisone on the synthesis of messenger RNA is apparent as soon as five minutes after the hormone has been administered; within 30 minutes the amount of RNA produced has increased two to three times and probably includes not



GENETIC ACTIVITY OF SEVERAL HORMONES is indicated by measurements made by Chev Kidson and K. S. Kirby of the Chester Beatty Research Institute in London. Their basic technique was first to administer to rats radioactively labeled orotic acid, which is a precursor of RNA. The tissues of the rat then incorporated the radioactive label into new RNA. Next liver tissue was removed from the rat and the species of RNA called "messenger" RNA was extracted from its cells. When the messenger RNA was analyzed by the method of countercurrent distribution, it gave rise to a characteristic curve (*black "Control" curve in each graph*); "Transfer number" refers to a stage of transfer in the countercurrent-distribution process and "Counts per minute" to the radioactivity of the solution at that point. Then, in separate measurements, rats were first given one of a number of hormones (*top left of each graph*) and shortly thereafter radioactively labeled orotic acid. The curves (*color*) of the messenger RNA obtained from such rats were entirely different, depending on the time that had elapsed before the administration of the orotic acid or on the sex of the animal (*top right*).



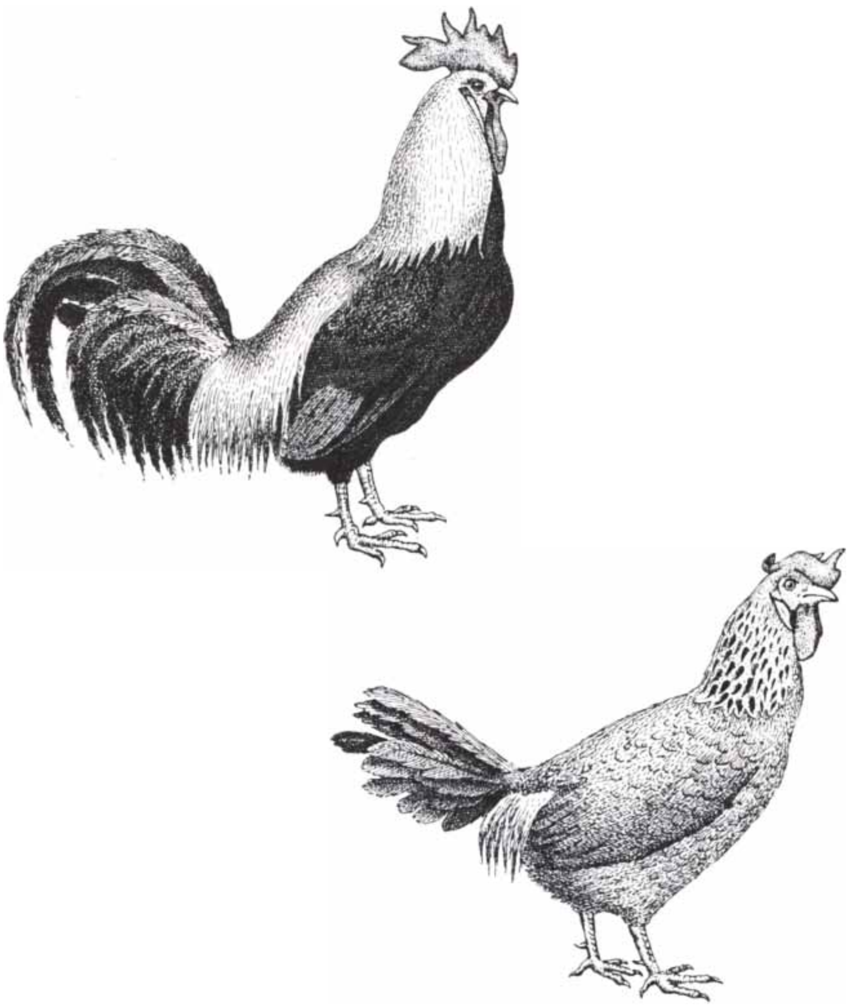


EFFECT OF ESTROGEN ON CELLS in the uterus of rats is demonstrated in these photomicrographs made by Sheldon J. Segal and G. P. Talwar of the Rockefeller Institute. The photomicrograph at top shows uterine cells from a rat that had not been treated with estrogen; the layer of cells at the surface of the tissue is relatively thin. The photomicrograph at bottom shows uterine cells from a rat that had been treated with the hormone; the layer of cells is much thicker. The effect involves enhanced synthesis of protein.

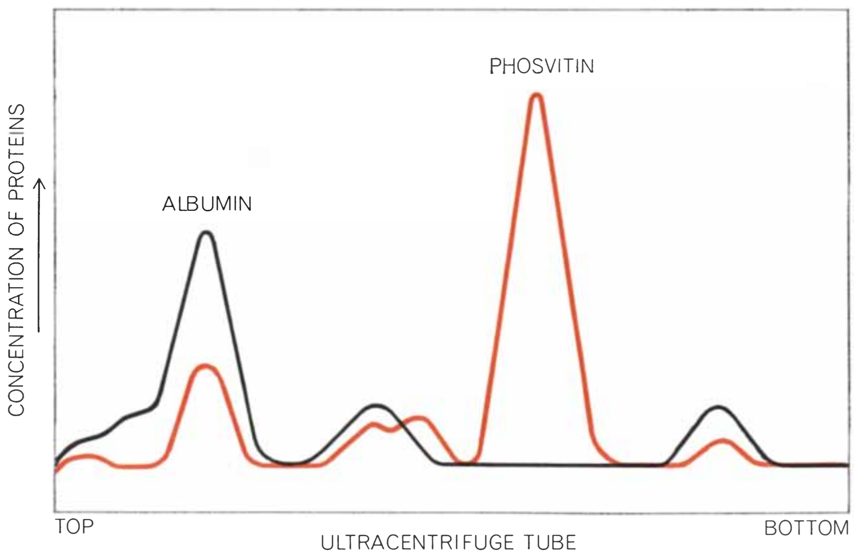
only messenger RNA but also ribosomal RNA. These events are followed by the increase in enzyme activity. Olga Greengard and George Acs of the Institute for Muscle Disease in New York have shown that if the animal is treated with actinomycin before cortisone is administered, the new enzymes fail to appear in its liver cells.

Another clear case of the activation of genes by an adrenocortical hormone has been demonstrated by Isidore S. Edelman, Rita Bogoroch and George A. Porter of the University of California School of Medicine (San Francisco). They employed the hormone aldosterone, which regulates the passage through the cell membrane of sodium and potassium ions. Tracer studies with radioactively labeled aldosterone showed that when the bladder cells of a toad were exposed to the hormone, the molecules of hormone penetrated all the way into the nuclei of the cells [*see illustrations on page* 37]. About an hour and a half after the aldosterone has reached its peak concentration within the cells the movement of sodium ions across the cell membrane increases. It appears that this facilitation of sodium transport is brought about by proteins the cell is induced to make, because it will not occur if the cells have been treated beforehand with puromycin, the drug that blocks the synthesis of protein. Moreover, treatment of the cells with actinomycin will block the aldosterone-induced increase in sodium transport through the membrane. Thus the experiments indicate that aldosterone activates genes in the nucleus and gives rise to proteins—that is, enzymes—that speed up the passage of sodium ions across the membrane.

Ecdysone, a steroid hormone of insects, is also believed to be a gene activator. The evidence for this conclusion has been provided by Wolfgang Beermann and his colleagues at the Max Planck Institute for Biology in Tübingen [see "Chromosome Puffs," by Wolfgang Beermann and Ulrich Clever; Scientific American, April, 1964]. If the larva of an insect lacks ecdysone, the development of the larva is indefinitely arrested at a stage preceding its metamorphosis into a pupa. Only when, in the course of normal development, the concentration of ecdysone in the tissues of the larva begins to rise does further differentiation take place; the larva then advances to metamorphosis. Ecdysone has been of especial interest to cell biologists because it has been observed



ROOSTER TREATED WITH ESTROGEN (*bottom*) is compared with a normal rooster (*top*). The signs of femaleness induced by estrogen include changes in comb and plumage.



ULTRACENTRIFUGE PATTERNS show that phosvitin, a yolk protein found only in hens, is present in serum extracted from a bird that had been injected with estrogen (*colored curve*) but not in serum from a bird used as a control (*black curve*). Each curve gives the concentration of proteins as they are separated out of a mixture by an ultracentrifuge.

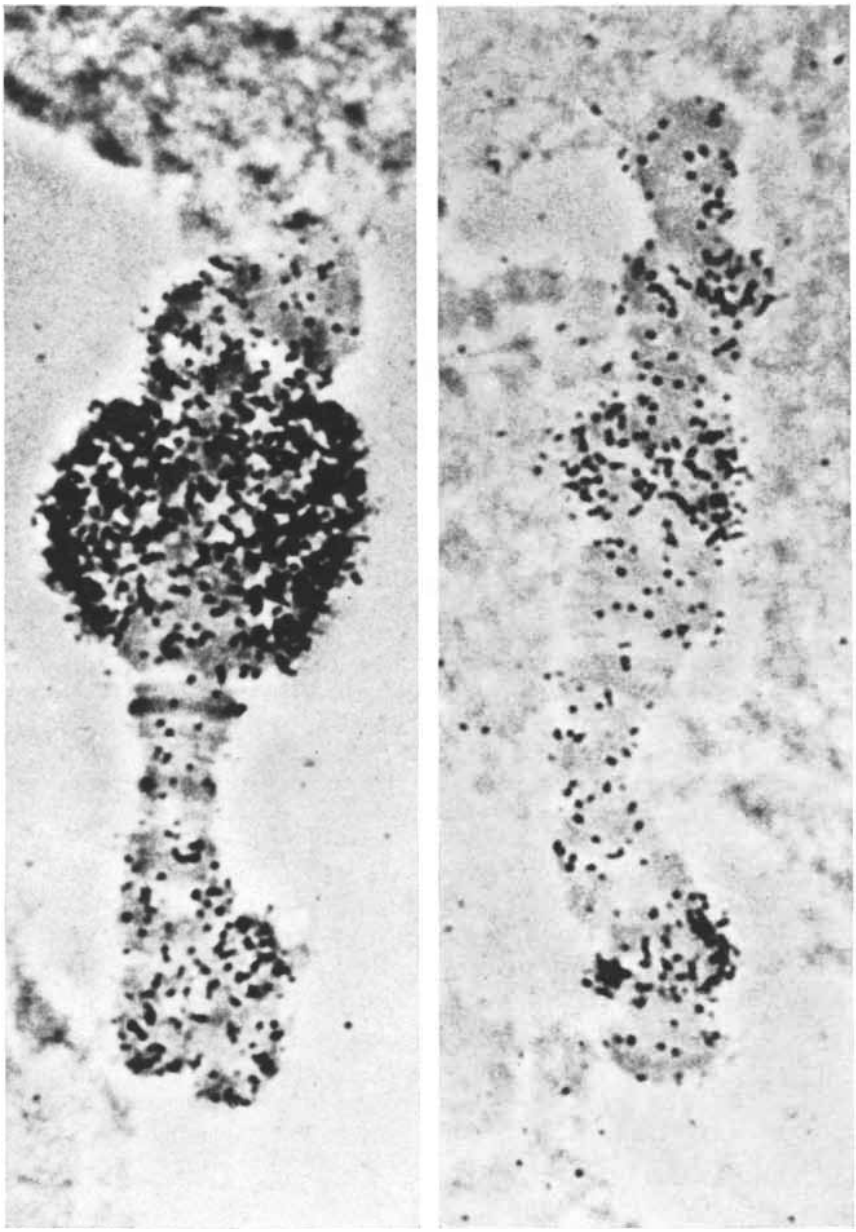
to cause startling changes in the chromosomes within the nuclei of the cells affected by it. Studies of this kind are possible in insects because the cells of certain insect tissues have giant chromosomes that can easily be examined in the microscope. These "polytene" chromosomes develop in many kinds of differentiated cell by means of a process in which the chromosomes repeatedly replicate but do not separate.

In some polytene chromosomes genetic loci, or specific regions, have a distended, diffuse appearance [*see illustration below*]. Biologists regard these regions, which have been named "puffs," as sites of intense gene activity. Evidence for this conclusion is provided by radioautograph studies, which show that the puffs are localized sites of intense RNA synthesis. In such studies a molecular precursor of RNA is radioactively labeled and after it has been incorporated into RNA reveals its presence as a black dot in the emulsion of the radioautograph. According to the view of differentiation presented in this article, different genes should be active in different types of cell, and this appears to be the case in insect cells with polytene chromosomes. In many different kinds of cell—salivary-gland cells, rectal-gland cells and excretory-tubule cells—the giant chromosomes have a different constellation of puffs; this suggests that different sets of genes are active, a given gene being active in one cell and quiescent in another.

On the polytene chromosomes of insect salivary-gland cells new puffs develop as metamorphosis begins. This is where ecdysone comes into the picture: the hormone seems to be capable of inducing the appearance of specific new puffs. When a minute amount of ecdysone is injected into an insect larva, a specific puff appears on one of its salivary-gland chromosomes; when a slightly larger amount of ecdysone is injected, a second puff materializes at a different chromosomal location. In the normal course of events the concentration of ecdysone increases as the larva nears metamorphosis; therefore there exists a mechanism whereby the more sensitive genetic locus can be aroused first. This example of hormone action at the gene level, which is directly visible to the investigator, seems to have provided some of the strongest evidence for the regulation of gene action by hormones. The effect of ecdysone, which is clearly needed for differentiation, appears to be to arouse quiescent genes to visible states of activity. In this way the specific patterns of gene activity required for differentiation are provided.

What about nonsteroid hormones? Here the overall picture is not as clearcut. The effects of some hormones are quite evidently due to gene activation, and yet other effects of the same hormones are not blocked by the administration of actinomycin; a small sample of these effects is listed in the illustration on the opposite page. As for the hormonal effects that are quite definitely not genetic, they fall into one of the following categories.

(1) Some hormones act on specific enzymes; for example, the thyroid hormone thyroxin promotes the dissociation of the enzyme glutamic dehydrogenase. (2) Other hormones, for instance insulin and vasopressin, act on systems that transport things through cell mem-



"PUFF" ON A GIANT CHROMOSOME from the salivary gland of the midge *Chironomus tentans* appears after administration of the insect hormone ecdysone. In the radioautograph at left the round area at top center is a puff. The black dots result from the fact that the midge was given radioactively labeled uridine, which is a precursor of RNA. The concentration of dots in the puff indicates that it is actively synthesizing RNA. In the radioautograph at right is a chromosome from a fly that had been treated with actinomycin before receiving ecdysone. No puff has occurred and RNA synthesis appears to be muted. The radioautographs were made by Claus Pelling of the Max Planck Institute for Biology in Tübingen.

HORMONE	EVIDENCE FOR HORMONAL ACTION BY GENE ACTIVATION.	EVIDENCE THAT HORMONAL ACTION IS CLEARLY INDEPENDENT OF IMMEDIATE GENE ACTIVATION.
PITUITARY GROWTH HORMONE	General stimulation of protein synthesis. Stimulation of rates of synthesis of ribosomal RNA, transfer RNA and messenger RNA within 90 minutes in liver. Effect blocked with actinomycin.	
PITUITARY ACTH	Stimulates adrenal protein synthesis. Messenger RNA and total RNA synthesis stimulated.	Steroid synthesis in isolated adrenal sections is independent of RNA synthesis and is insensitive to actinomycin D.
THYROXIN	Promotes new messenger RNA synthesis within 10 to 15 minutes of administration, promotes stimulation of all classes of RNA by 60 minutes. Promotes increase in RNA–DNA polymerase at 10 hours, later promotes general increase in protein synthesis.	Causes isolated, purified glutamic dehydrogenase to dissociate to the inactive form. Affects isolated mitochondria in vitro.
INSULIN	Promotes 100 percent increase in rate of RNA synthesis. Causes striking change in messenger RNA profile within 15 minutes of administration to rat diaphragm; effect blocked with actinomycin. Actinomycin-sensitive induction of glucokinase activity.	Actinomycin-insensitive increase in ATP synthesis and in glucose transport into cells; mechanism appears to involve insulin binding to cell membrane, occurs at 0 degrees C.
VASOPRESSIN		Actinomycin-insensitive promotion of water transport in isolated bladder preparation under same conditions in which aldosterone action is blocked by actinomycin.

SUMMARY OF EXPERIMENTAL EVIDENCE is given in table. Facts indicating that hormones activate the genes (*middle column*) are compared with facts suggesting that hormonal action does not entail the immediate activation of the genes (*column at right*).

branes; indeed, it is believed that both of these hormones attach themselves directly to the membranes whose function they affect. (3) Still other hormones rapidly activate a particular enzyme; phosphorylase, a key enzyme in determining the overall rate at which glycogen is broken down, is converted from an inactive form by several hormones, including epinephrine, glucagon and ACTH.

This does not alter the fact that many nonsteroid hormones operate at the gene level. Some of the best evidence for this statement is provided by studies of several hormones made by Chev Kidson and K. S. Kirby of the Chester Beatty Research Institute of the Royal Cancer Hospital in London. They separately injected rats with thyroxin, testosterone, cortisone and insulin and then measured the synthesis of messenger RNA by the rats' liver cells [*see illustration on page 41*]. The most striking aspect of their measurements is the extremely short time lag between the administration of the hormone and the change in the pattern of gene activity. The activation of genes in the nuclei of the affected cells occurs so quickly that one is tempted to assume that it is an initial effect of the hormone.

Here, however, we come face to face with a basic problem that must be solved in any attempt to explain the exact molecular mechanism of hormone action. The problem is simply that of identifying the initial site of reaction in a cell exposed to a hormone. Does a hormone move directly to the chromosome and exert its effect, so to speak, "in person"? As we have seen, aldosterone does appear to enter the nucleus, but there is little real evidence that other hormones do so.

For many years biologists have been looking for the "receptor" substance of various hormones. The discovery that hormones ultimately act on genes makes this search all the more interesting. The evidence presented here only goes as far as to prove that an early stage in the operation of many hormones is the selective stimulation of genetic activity in the target cell. The molecules of the hormones range in size and structure from the tiny molecule of thyroxin to the unique multi-ring molecule of a steroid and the giant molecule of a protein; how these various molecules similarly affect the genetic apparatus of their target cells remains an intriguing mystery.

The Magnetic Field of the Galaxy

Its role may be to stiffen the arms of the galaxy and hold them in place. By determining the polarization of incoming radiation radio telescopes have shown how the field is oriented in space

by Glenn L. Berge and George A. Seielstad

Astronomers have recently begun to suspect that large-scale magnetic fields play a major role in determining the structure and evolution of galaxies. Although these fields are exceedingly weak by terrestrial standards, their presence may explain how the arms of a spiral galaxy such as our own can remain extended in space through billions of years while the galaxy as a whole makes many revolutions—perhaps 50 in the 10 billion years since it was formed. Without the support of magnetic fields, or some other force, to make them somewhat stiff the spiral arms would be wrapped into a tight knot after only a few revolutions of the galaxy. Following clues first provided more than a decade ago by optical telescopes, radio telescopes have recently traced out a highly oriented magnetic field in our galactic neighborhood that may provide the "backbone" of the spiral arm in which the sun and its planets are embedded.

The sun is situated about 30,000 light-years from the center of a galaxy that has a radius of some 50,000 light-years. If the sun had happened to be located in the galactic nucleus, astronomers might have faced a difficult task in trying to decipher the galaxy's structure. As it is the difficulties are great enough. Vast clouds of interstellar dust make it impossible to use optical telescopes to map the detailed structure in the plane of the galaxy much beyond a few thousand light-years. Radio waves, however, are not blocked by dust; hence radio instruments have made it possible to obtain a rather good general picture of the galaxy's structure. From these studies and from photographs of other galaxies that undoubtedly resemble our own, our galaxy appears to be a fairly typical "open" spiral with arms that curve gently outward from the nucleus and make two or three turns before they trail off into intergalactic space.

The first definite evidence for a galactic magnetic field was presented in 1949 by W. A. Hiltner of the Yerkes and McDonald observatories and John S. Hall of the U.S. Naval Observatory. They reported independently that the light from a number of stars exhibits a high degree of linear polarization. This means that if these stars are observed through a polarizing filter—not unlike the polarizing material in some sunglasses—the light will dim when the filter is rotated to a certain angle. Hiltner and Hall observed that the light from stars near the plane of the galaxy was usually polarized in a direction parallel to this plane. (Electromagnetic radiation consists of two mutually perpendicular components, represented by an electric vector and a magnetic vector, and is propagated at right angles to these components. In discussions of polarization the direction of the electric vector is used to specify the plane of polarization.) Hiltner and Hall made one other important observation. They found that whenever they detected stars with highly polarized light, the light in the blue portion of the spectrum had invariably been filtered out by interstellar dust. It was therefore almost certain that the polarization they were observing was due not to some property of the stars themselves but to something lying in the path taken by the light in reaching the earth.

Two hypotheses were soon proposed to explain the observations, one by Lyman Spitzer, Jr., and John W. Tukey of Princeton University and the other by Leverett Davis, Jr., and Jesse L. Greenstein of the California Institute of Technology. Both hypotheses suggested that the starlight is absorbed and scattered by tiny but elongated interstellar particles that are aligned by a magnetic field. The mechanism of alignment and the final results, however, are different in the two hypotheses. In the Davis-Greenstein picture, which is now generally favored, each particle (containing a few percent of iron) spins rapidly around its short axis, which is aligned parallel to the lines of force in the magnetic field by the mechanism called paramagnetic relaxation.

Before reaching these spinning particles the starlight is presumably unpolarized. For purposes of visualizing what happens, one can imagine that the light consists of two independent and equal components that are linearly polarized at right angles to each other. A spinning elongated particle scatters and absorbs the incident light in such a way that it weakens the component of the light whose electric vector is parallel to the particle's long axis. Hence the light is polarized with its electric vector parallel to the lines of force in the magnetic field [*see top illustration on page 48*]. Davis and Greenstein concluded that the lines of force in the magnetic field in the vicinity of the sun are parallel to the galactic plane and have a fairly uniform direction that might agree roughly with the direction of the local spiral arm. They estimated that the observed amount of polarization would require a magnetic-field strength of perhaps 10 to 100 microgauss in the vicinity of the sun. A microgauss is a millionth of a gauss, or about a millionth of the earth's magnetic-field strength near the magnetic poles.

In 1953 Subrahmanyan Chandrasekhar and Enrico Fermi of the University of Chicago tried to determine the strength of the galactic magnetic field by two different methods. One method, previously suggested by Davis, was to find the field strength that would be consistent with the observed differences in the direction of polarization for stars near the galactic plane. The other method involved a calculation of the magnetic-field strength needed to maintain a spiral arm against the forces tending to dissipate it. Both methods gave a field strength that was slightly less than 10 microgauss, or just under the range given by Davis and Greenstein.

Some further measurements of starlight polarization were made, but no important new results were provided by optical methods. It was now up to the newly emerging discipline of radio astronomy to make its contribution to the understanding of the galaxy's magnetic field.

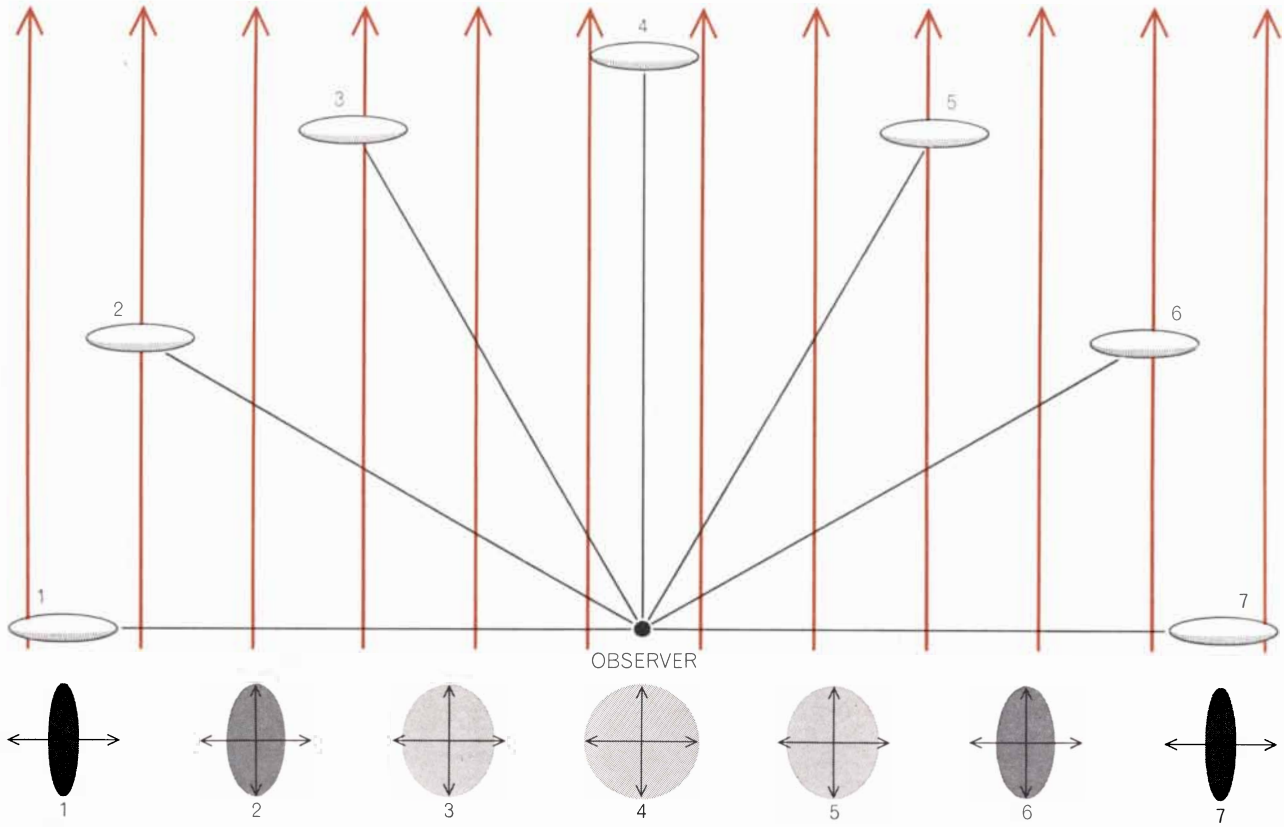
Radio astronomy offers one method of directly measuring a magnetic field as small as that expected for the galaxy. The method involves the Zeeman effect, which occurs when a single emission line or absorption line of the electromagnetic spectrum is produced in the presence of a magnetic field. The Zeeman effect will usually split the line into three components: one unshifted in frequency, one shifted slightly higher in frequency and one shifted slightly lower. If the line originates in a magnetic field whose lines of force are directed toward or away from the observer, the line is split into two components whose electric vectors rotate in opposite senses. Such components are said to be circularly polarized.

In 1957 John G. Bolton and J. P. Wild, then working at Cal Tech, suggested that Zeeman splitting might be observed in the radio waves emitted by hydrogen atoms in the interstellar gas. This emission takes the form of a narrow line with a frequency of 1,420 megacycles per second, equivalent to a wavelength of 21 centimeters. The amount of Zeeman splitting is proportional to the strength of the magnetic field. If the hydrogen line were emitted in a field of 10 microgauss, the two shifted components would differ in frequency by about 30 cycles per second, or one part in 50 million of the natural line frequency.

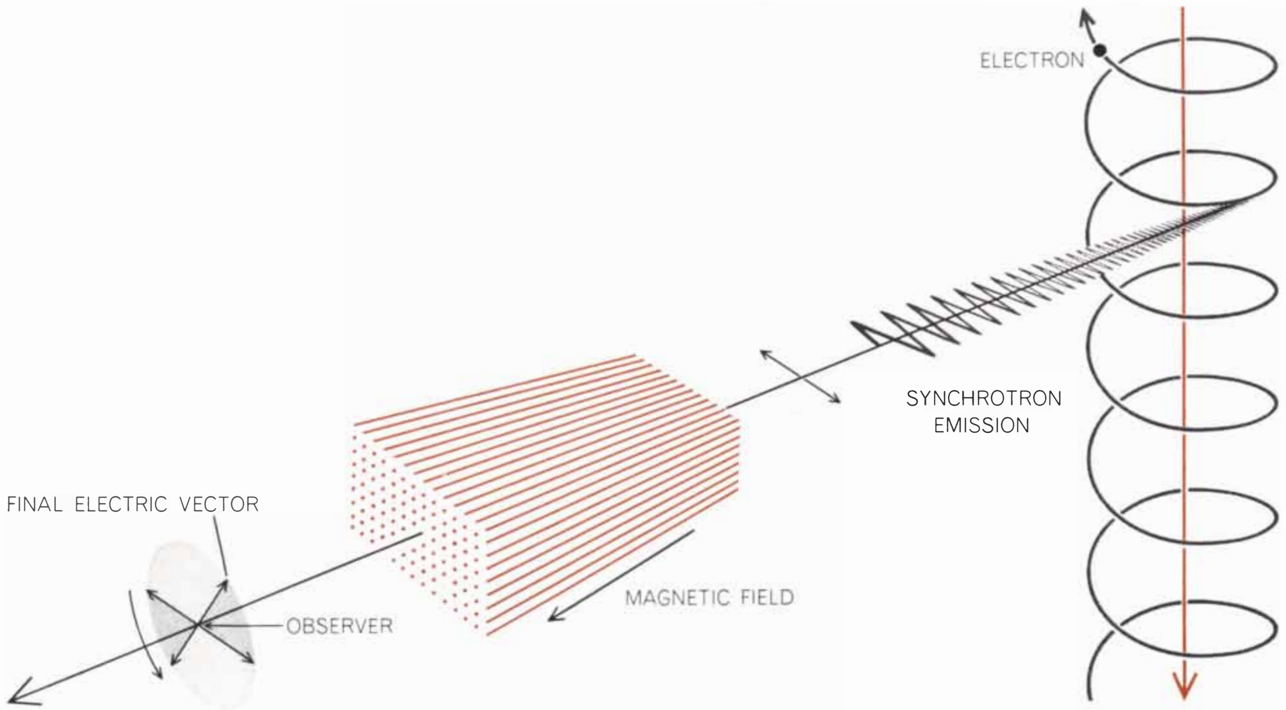
The line emitted by interstellar hydrogen is usually far too broad for Zeeman splitting to be detected. The reason is that interstellar gas is generally in disorderly motion, with the result that the Doppler effect shifts the frequency of emitted radiation upward and downward far more than the amount of Zeeman splitting. Some hydrogen clouds, however, that stand between us and certain strong celestial radio sources have relatively small internal motions. The hydrogen atoms in these clouds absorb 21-centimeter waves and give rise to absorption lines that have a width as narrow as 10,000 cycles per second. This is still about 300 times greater than the shift that would be produced by a 10-microgauss magnetic field, but a useful measurement of the Zeeman effect can just barely be made. The technique is to compare the radiation in each of the two states of circular polarization at the edge of an absorption line. If there is any difference between the amount of radiation polarized clockwise and that polarized counterclockwise, it can be interpreted as Zeeman splitting.

The experiment has now been carried out in the U.S. and Britain with somewhat inconclusive results. The work suggests that the general galactic field has a strength of no more than a few microgauss. It is possible, however, that the magnetic field in the particular gas clouds studied is not representative of the general field in our local galactic arm. Be that as it may, Zeeman splitting

TWIN RADIO TELESCOPES, 90 feet in diameter, are the chief instruments of the Owens Valley Radio Observatory operated by the California Institute of Technology. The telescopes can be moved on tracks to provide a variable-spacing interferometer. They have been used by the authors to study the polarization of cosmic radio waves and to obtain evidence on magnetic fields in the galaxy.



POLARIZATION OF STARLIGHT is believed to occur because stellar radiation impinges on tiny elongated particles that are aligned by an interstellar magnetic field. The top illustration shows the particles spinning with their short axes parallel to the field. The bottom illustration shows the average orientation of the grains as viewed by the observer. The plane of polarization of starlight, assumed to be random initially, is represented by two electric vectors (*black arrows*) at right angles to each other. When the observer looks parallel to the magnetic lines of force, both vectors are equally dimmed. When he looks at right angles to the field, the particles dim the vertical component preferentially so that the starlight appears to be polarized in a horizontal plane.



FARADAY ROTATION is produced when polarized radiation passes through a medium containing a magnetic field and an ionized gas (a gas containing electrically charged particles). Faraday rotation will occur to some extent whenever the lines of magnetic force and the radiation intersect at any angle except a right angle. If the field is directed away from the observer, the rotation is clockwise. Here the polarized radiation is synchrotron emission, which is created when an electron spirals around a magnetic line of force.

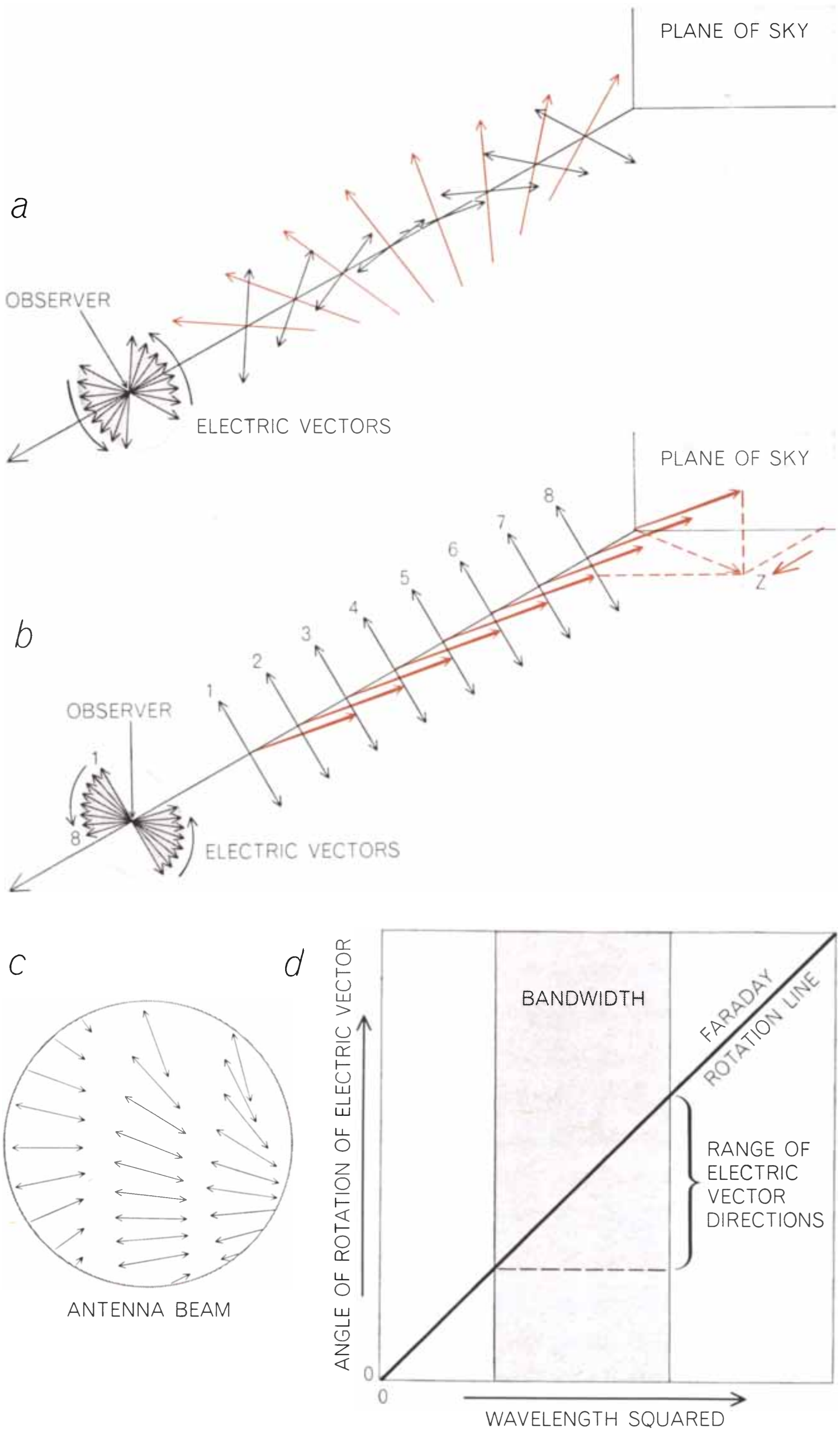
offers the only direct means of measuring the strength of the magnetic field. The other techniques for studying the magnetic field, which we shall describe, require certain special assumptions in order to determine its strength.

Much of the radiation observed by radio astronomers is generated by the synchrotron mechanism. When an electron traveling at a speed close to the speed of light describes its characteristic helical motion around a line of force in a magnetic field, it emits synchrotron radiation. The radiation is sharply beamed in the direction of the electron's motion, and it has a high degree of linear polarization: the electric vector is perpendicular to the magnetic line of force [*see bottom illustration on opposite page*]. The frequency spectrum of the radiation depends on the field strength and the electron's energy. The synchrotron process is thought to be responsible for the phenomenal amount of power emitted by radio galaxies; it is also believed to account for radio emission by the remnants of supernovae in our own galaxy and for much of the background radiation of the galaxy as a whole.

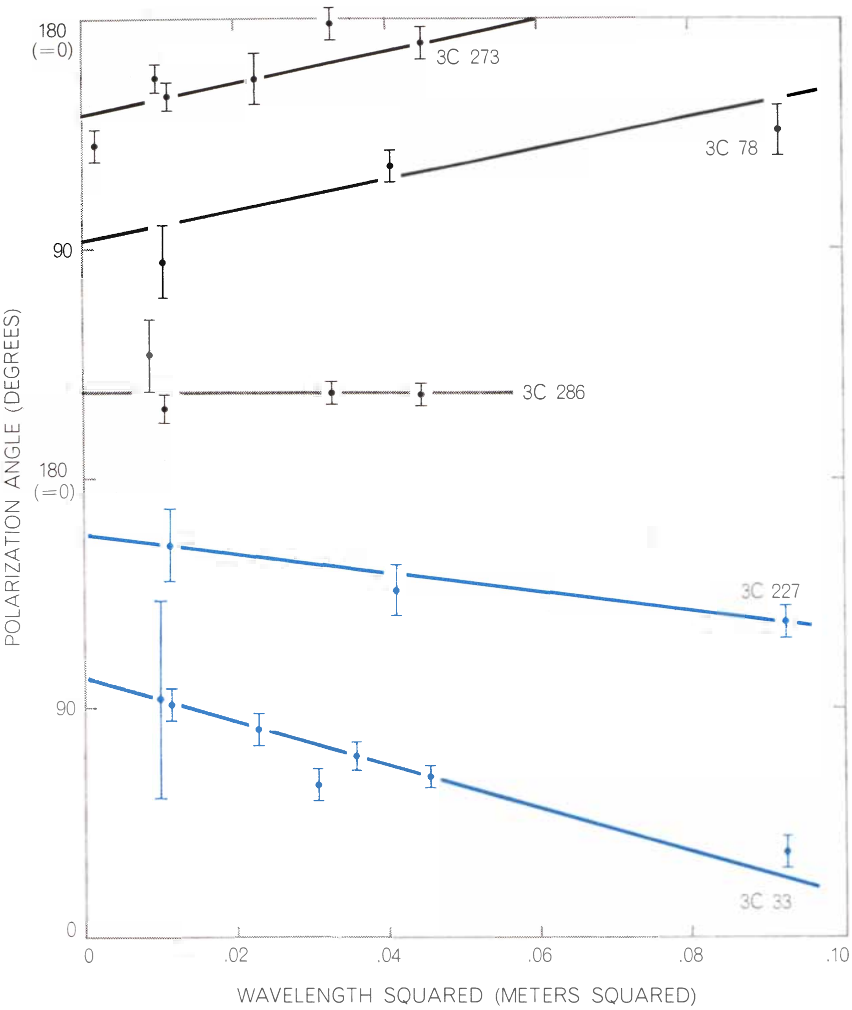
It has now been established by radio surveys that our galaxy has a large "halo" in which synchrotron radiation is generated, and that synchrotron radiation is strongest in the plane of the galactic disk. By using a rough estimate of the energies of galactic electrons (based on the energies of cosmic rays impinging on the earth) it is possible to calculate the magnetic-field strength necessary to produce the observed radiation. The calculated values are a few microgauss for the radiation from the halo and a few tens of microgauss for the radiation from the disk. This method does not yield much information, however, about the orientation of the field.

The remaining methods we shall describe for studying the galactic magnetic field depend on the polarization of synchrotron radiation and what happens to it between the time the radiation is generated and the time it reaches radio telescopes on earth. It is known that when certain materials are placed in the path of an electromagnetic wave, the polarization characteristics of the wave are altered. The particular case that concerns us here is the Faraday effect.

When a wave polarized in a given plane passes through a region containing both an ionized gas (a gas containing electrically charged particles) and a



DEPOLARIZING MECHANISMS reduce the amount of polarization that might otherwise be observed in radiation produced by synchrotron emission. All involve the addition of several electric vectors of different orientations. Synchrotron emission is characteristically polarized with its electric vector (*black arrows*) perpendicular to the magnetic field (*red arrows*) at its origin. In *a* the orientation of this magnetic field varies along the observer's line of sight. There is no Faraday rotation, however, because the fields are parallel to the plane of the sky, hence perpendicular to the direction in which the radiation is traveling. In *b* the magnetic-field direction, although constant, is not parallel to the plane of the sky, so that there is a longitudinal component (*Z*) that produces more Faraday rotation in the far emission than in the near emission. Diagram *c* illustrates that the electric vectors may differ across the small patch of sky that is included within the beam of the antenna. Finally, if the angle of rotation increases with wavelength, as in *d*, a receiver of wide bandwidth will add together electric vectors of different orientations. Nothing can be done about the depolarization represented by *a* and *b*, but the effects represented by *c* and *d* can be mitigated.



VARIATION IN POLARIZATION WITH WAVELENGTH is shown for five strong radio sources, as designated in the Third Cambridge Catalogue. *3C* 273 and *3C* 286 are powerful emitters known as quasars. Since the measurements refer to the rotation of a line the maximum rotation that can be observed is 180 degrees. Rotations that increase with wavelength in the counterclockwise direction are positive and are shown in black; negative rotations are shown in color. The slope of the line in each case is the "rotation measure."

magnetic field in which the lines of force are parallel to the direction in which the wave is traveling, the plane of polarization is rotated. The angle through which the electric vector is rotated is equal to the square of the wavelength times a quantity that depends on the medium that is causing the rotation. This quantity is called the rotation measure; it is expressed in units of radians per meter squared. If the magnetic field and the density of negative electric charges (electrons) are uniform along the line of sight within the medium, then the rotation measure is proportional to the product of the line-of-sight component of the field, the density of electrons and the distance through the medium. The rotation is positive when the lines of force in the field are pointed toward the observer and negative when they are pointed away from the observer.

One expects the Faraday effect to occur in interstellar space because, as we have seen, this space contains a magnetic field and ionized gas (mainly ionized hydrogen). In fact, the observations verify this expectation [*see illustration above*].

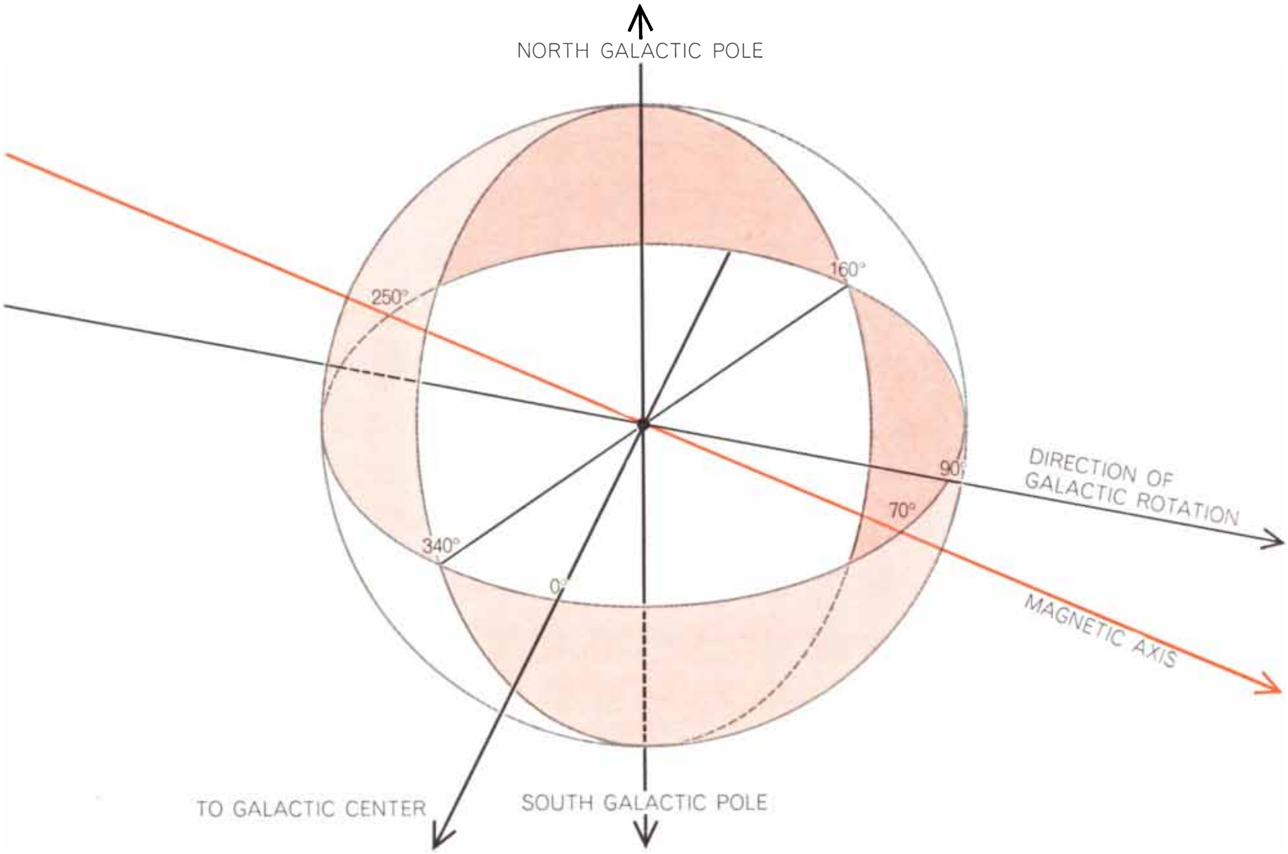
Since most of the galactic background radiation, up to a frequency of at least 1,000 megacycles per second, is due to the synchrotron mechanism, it was no great surprise when attempts to measure the polarization of the radiation in the late 1950's met with some success. What is surprising, on first consideration, is that the degree of polarization is so low. Whereas one would expect synchrotron radiation to be generated with a linear polarization of 60 or 70 percent, the observations at a few hundred megacycles per second indicate no more than about 8 percent and much less in most regions of the galaxy. The explanation is that there are several effects that tend to depolarize the radiation.

The illustration on the preceding page shows four ways in which depolarization can take place. In each case it occurs because the observer adds together samples of radiation that differ in the orientation of their electric vectors. In general, astronomical radio signals are depolarized by a combination of all these effects. In considering the linear polarization of the galactic background radiation it is the second effect—Faraday depolarization—that is of principal interest.

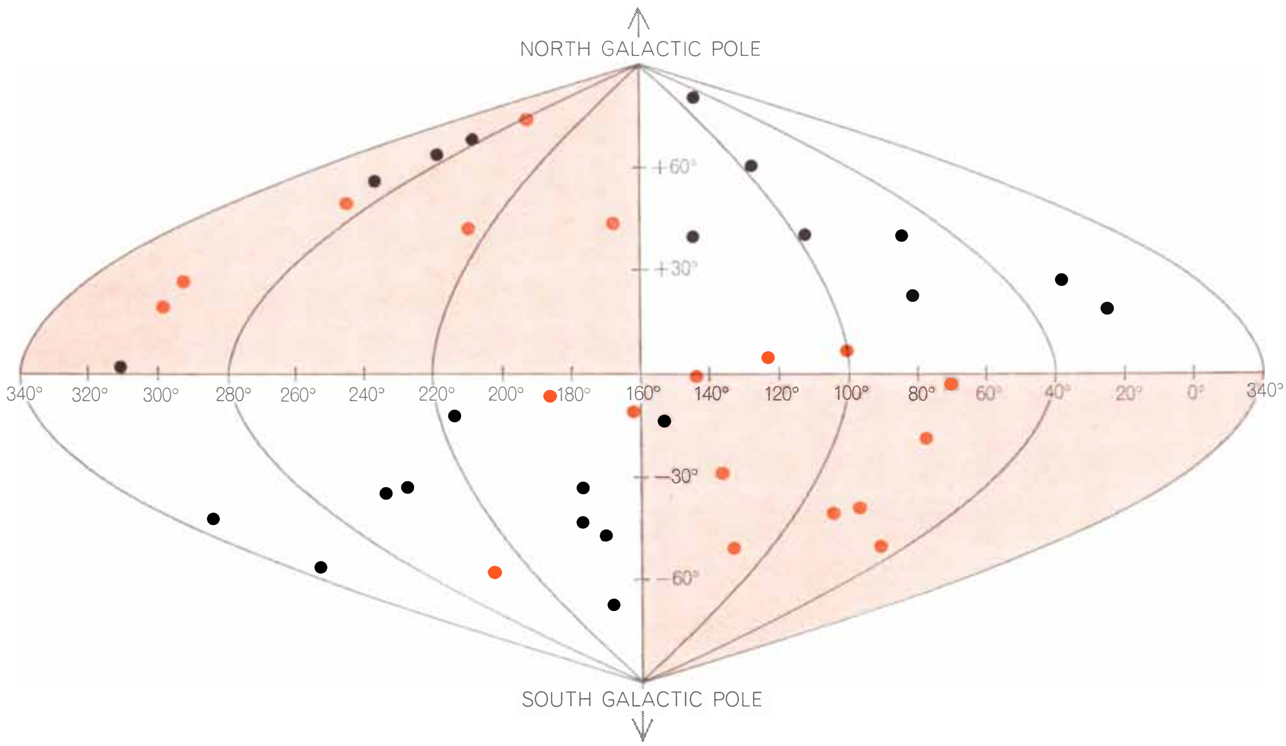
Large-scale surveys of the galactic background polarization have been conducted by three groups of radio astronomers: the first at Leiden in the Netherlands, the second at the University of Cambridge in England and the third at the Radiophysics Laboratory in Australia. Most of their observations have been at a wavelength of 75 centimeters. They have found that over most of the galaxy there is little polarized radiation, and that the plane of polarization is seemingly random. There are, however, a few spots where this is not true, indicating less Faraday depolarization.

The Australian group, whose survey includes parts of the galaxy not accessible to northern observatories, has combined the results of the various surveys and finds that 90 percent of the polarized radiation comes from within 25 degrees of the great circle that passes through the galactic poles and cuts the galactic plane at longitudes of 160 degrees and 340 degrees. They conclude that there is a large-scale magnetic field perpendicular to this great circle; the field therefore cuts the galactic plane at longitudes of 70 degrees and 250 degrees [*see top illustration on opposite page*]. This is in striking agreement with the results obtained by examining the polarization of starlight with optical telescopes.

The orientation of this magnetic axis coincides very closely with the orientation of the spiral arm in which our sun and solar system are presumed to be embedded. In the coordinate system used by astronomers the center of the galaxy lies at zero degrees longitude. If the galactic arm containing the sun were not a spiral but simply a tube concentric with the center of the galaxy, it would form a 90-degree angle with the line of zero longitude. Since the arm is presumably spiraling outward from the center, however, it would be



SYSTEM OF GALACTIC COORDINATES places the sun at the center of a sphere. The direction to the center of the galaxy is taken to be zero degrees longitude. Here the sphere is divided into four quadrants keyed to the sense of rotation measures observed for distant radio sources. Color indicates the directions in which the measures are predominantly negative; absence of color signifies that the rotation measures are positive. The same color scheme is repeated below in a flat representation of the galactic sphere.



SENSE OF ROTATION MEASURES for 41 distant radio sources is plotted with black dots to show positive rotation measures and colored dots to show negative measures. Although not all the dots in each quadrant exhibit the same sense of rotation, the deviants are generally near the boundaries. Most of the measurements were made by David Morris, V. Radhakrishnan and the authors.

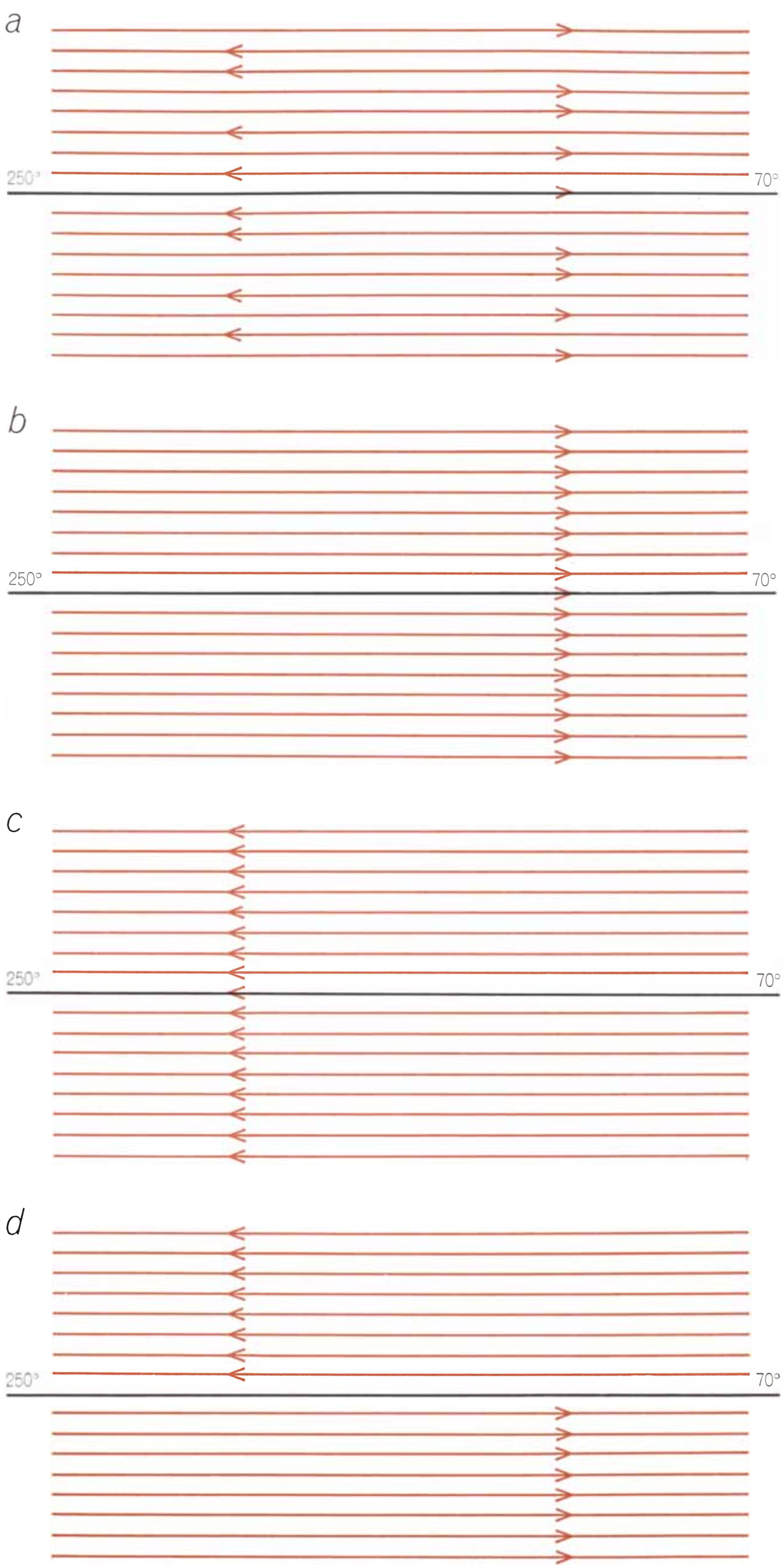
expected to cut the zero-longitude line at something less than a 90-degree angle, and this agrees nicely with the 70-degree figure observed for the magnetic axis.

We shall now describe the method that we have employed at Cal Tech for examining the galactic magnetic field. This method confirms the existence of a 70-to-250-degree magnetic axis and provides additional—and surprising—information about the polarity of the field. One would like to know, for example, whether the field is "pointing" toward the 250-degree end of the magnetic axis or toward the 70-degree end.

In our studies, which have been conducted in collaboration with David Morris and V. Radhakrishnan, we have used the twin 90-foot parabolic antennas at the Cal Tech Owens Valley Radio Observatory. Our objective has been to measure the polarization of distant radio sources—chiefly extragalactic sources—and to determine the Faraday rotation produced when their radiation passes through the medium of our own galaxy. The observations are made at wavelengths ranging from a few centimeters to a few tens of centimeters.

There is, of course, no way to determine where Faraday rotation, if it is detected, actually takes place. It can occur in the source itself, in the region between the galaxies, within our galaxy or in all three places. The relative importance of the first two possibilities is almost unknown. Some rotation is certain to occur in the source, but its magnitude and sense may well vary from point to point over the surface of the source, so that there is little rotation for the source as a whole. The effect of the intergalactic medium is uncertain because no one knows if it contains either electrons or magnetic fields. There is good reason to believe, however, that the Faraday rotation observed in our studies is produced almost entirely within our own galaxy, and chiefly within a few thousand light-years of the sun.

In 1962 F. F. Gardner and J. B. Whiteoak of the Radiophysics Laboratory in Australia reported an apparent correlation between galactic latitude and the Faraday-rotation measures of strong radio sources. In general, sources at high latitudes exhibit a lower rotation measure than sources at low latitudes. The Cal Tech results show a similar correlation. This was the first evidence that our galaxy might be producing a Faraday rotation in the radia-



MAGNETIC-FIELD CONFIGURATIONS that are consistent with a magnetic axis that intercepts the galactic longitudes of 70 and 250 degrees might take any of these forms. The view is a cross section through the galactic plane. In *a* the lines of force run in both directions at random. In *b* and *c* all the lines run one way. In the configuration actually observed (*d*) the field above the plane runs predominantly opposite to that below the plane.

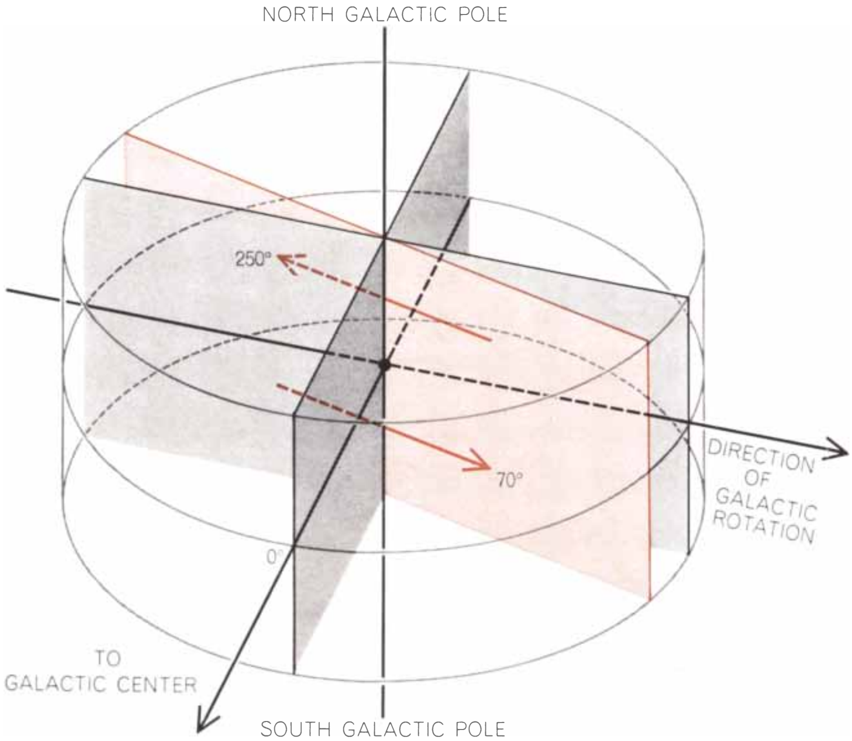
tion arriving from distant sources. At the time the number of sources observed was not large enough to determine if there was also a correlation with galactic longitude.

Early last year, on the basis of a much larger sample of rotation measures, our colleague Morris noted that there was indeed a convincing correlation with galactic longitude as well as with latitude. Let us first consider the sense (positive or negative) of the rotation measures. The bottom illustration on page 51 is a plot, in galactic coordinates, of the sense of the available measures. The most important feature is that the sign of the rotation measures changes at the galactic plane and also at the longitudes of 160 degrees and 340 degrees. Thus the galactic sphere is divided into four regions, two with positive rotations and two with negative. Most of the sources whose sense of rotation does not follow this rule are near the boundaries of the regions.

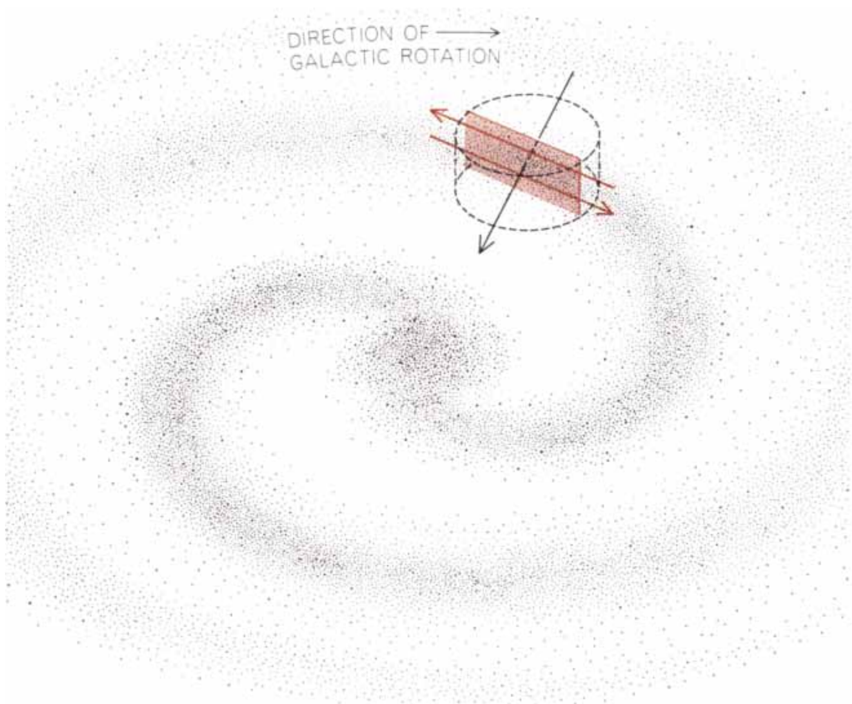
The fact that the sense of Faraday rotation changes at the great circle that passes through longitudes 160 degrees and 340 degrees coincides nicely with the earlier observation that polarized galactic radiation reaches a maximum along such a circle. The change in direction implies that the magnetic field itself runs along a 70-to-250-degree axis (as previously surmised) and that the line-of-sight component of the field changes its apparent direction at the great circle that cuts 160 degrees and 340 degrees.

The change of sign at the galactic plane is a completely unexpected result and indicates that the field points in one direction above the plane and in the opposite direction below the plane. Before this finding one might have expected the field to point the same way both above and below the plane. Or one might have imagined a tangled field consisting of a mixture of lines pointing in opposite directions [*see illustration on opposite page*].

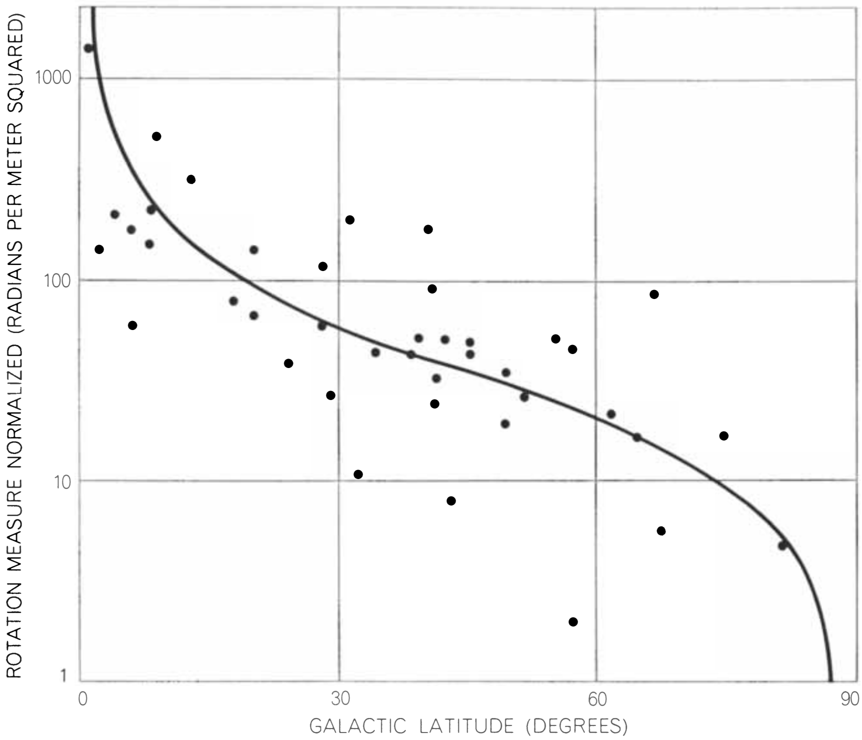
We have sought to develop a simple model for the structure of the magnetic field in the vicinity of the sun to see if it would yield the rotation measures we have observed. In this model all the Faraday rotation is assumed to take place within two flat unbounded disks, one above the other, whose top and bottom surfaces are parallel to the plane of the galaxy [*see top illustration on this page*]. The region of contact between the two disks is near the galactic plane but does not necessarily coincide with it, nor with the plane



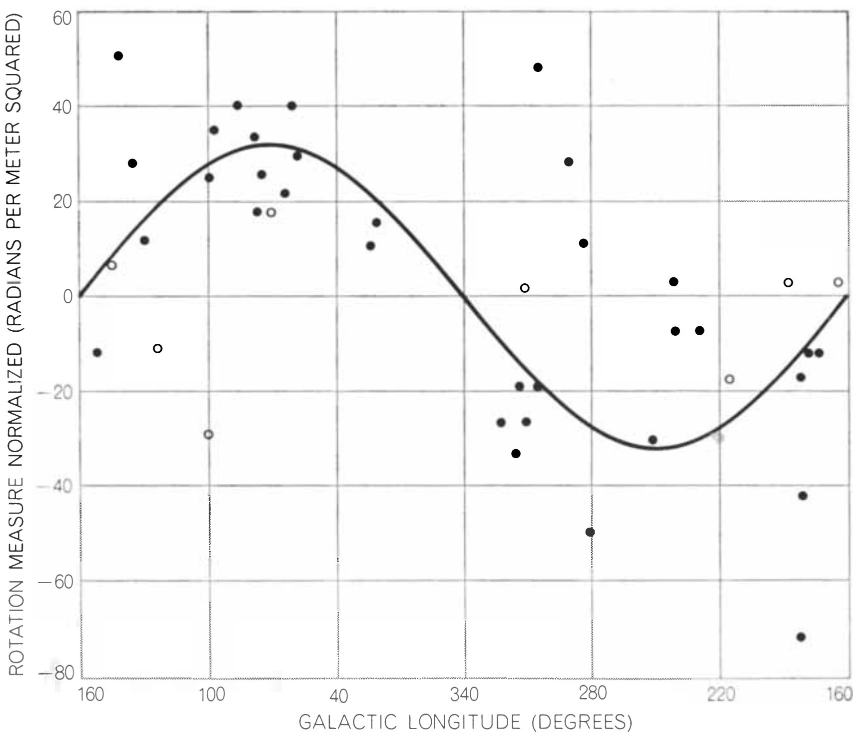
GALACTIC DEPENDENCE OF ROTATION MEASURES can be represented by a model consisting of two unbounded disks whose flat surfaces are parallel to the galactic plane. The sun is located on the vertical axis at or near the center of the model. Within each disk the magnetic field and electron density are assumed to be constant; rotation measures thus conform to the geometry of the disks and the direction of the magnetic field (*colored arrows*).



LOCATION OF THE SUN IN THE GALAXY is indicated in this highly schematic diagram. The flattened cylinder represents the model shown in the illustration above. Since it is unbounded the diameter shown here is arbitrary. The sun, which is contained within the model, is approximately 30,000 light-years from the galactic center. It is thought that the magnetic field (*colored arrows*) follows spiral arms of galaxy and helps to keep them rigid.



DEPENDENCE OF ROTATION MEASURES ON GALACTIC LATITUDE is plotted for 41 strong radio sources. The values have been adjusted to eliminate a consistent difference in the amount of rotation exhibited by sources in the northern galactic hemisphere compared with those in the southern hemisphere and to eliminate the predicted dependence on longitude. The continuous curve is the latitude dependence predicted by the authors' model.



DEPENDENCE OF ROTATION MEASURES ON GALACTIC LONGITUDE is plotted for the same 41 radio sources shown in the illustration at the top of the page. Again the values have been adjusted to account for a consistent difference between rotation measures in the northern and southern hemispheres and, in this case, to eliminate the predicted dependence on latitude. The continuous curve is the dependence on longitude predicted by the authors' model. Open circles represent radio sources within 10 degrees of the galactic plane; solid dots represent sources that are more than 10 degrees away from the galactic plane.

containing the sun. Within each disk the magnetic field and electron density are assumed to be constant. In the upper disk the field is directed toward longitude 250 degrees; in the lower disk it is directed toward longitude 70 degrees. The model must ultimately take into account the fact that rotation measures at negative latitudes are systematically about 1.2 times larger than those at positive latitudes. It is not expected that the model will be valid at low galactic latitudes, where the radiation passes through other spiral arms before reaching our telescopes.

With this model one can show that the rotation experienced by linearly polarized radiation depends on the path it takes in reaching the earth. According to the model the line-of-sight component of the magnetic field depends in a simple way on both galactic coordinates; the path length through the disk depends in a simple way on the galactic latitude. Therefore the rotation measure for a given source will have a direct dependence on both its latitude and longitude. The two illustrations at the left show separately the latitude and longitude dependence of the rotation measures for 41 radio sources. The solid curve in each plot is based on predictions made by the model.

How successful are the model's predictions? In general one sees that the rotation measures exhibit the directional dependence expected for the model. In particular the first plot indicates that the rotation does occur in a flattened structure. If the structure were spherical, for example, the latitude dependence would be much less pronounced. It is obvious, however, that there is a large scatter in the plotted points. Some of it is no doubt due to observational errors, and some of it may be due to Faraday rotation in the sources themselves and perhaps in intergalactic space. Some of the discrepancies, on the other hand, must be real and must represent the failure of a simple model to include small-scale deviations in the magnetic field.

We see, then, how a variety of techniques have helped to demonstrate the reality of a magnetic field within a few thousand light-years of the sun. Although there is uncertainty about the strength of the field, its general configuration is reasonably well established. The configuration is consistent with a galactic structure in which the spiral arms contain—and perhaps are supported by—a magnetic field that runs parallel to their axes.

Kodak reports on:

an informative view in the viewfinder . . . autoradiographic emulsions for biology . . . the proper way to make connections . . . magnetic advertising

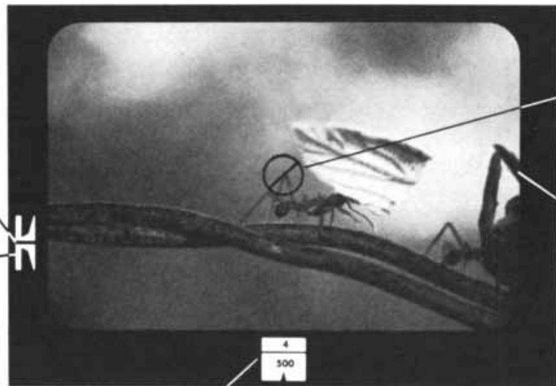
For communication by color slides

There are many millions of amateur photographers, many thousands of professional photographers, and ever-growing numbers of other persons who need to use a camera professionally for communication with assemblies of colleagues. Best current choice for the latter category is the KODAK RETINA Reflex IV Camera. It's a pretty camera, but since you are not likely to admit even to yourself that you could be interested in it for its looks, we shall let you wait to see it and manipulate it at your camera shop. Instead we devote the illustration here to what is seen through the viewfinder.[1]

You see this needle center itself between the brackets to indicate when your finger has twirled exposure-setting ring to right place for the light and the film.

Red signal appears here if you try to set lens and shutter for combination that does not fit exposure conditions.

Beneath the view you read what lens aperture and shutter speed you are using. If at the last moment you change setting for either depth-of-field or stop-motion considerations, the other parameter is automatically compensated and you see the new light-equivalent combination in the little window.



Diagonally split rangefinder field lets you focus on either vertical or horizontal macroscopic object without rotating camera.

Over entire area of bright ground glass you see focus of everything that will be included in final mounted transparency—no more, no less. (Focuses to 2 feet unadorned, 6 inches with close-up lenses, and as close as the limits of optical microscopy with microscope adapter kit.)

[1] Assuming you are in the Chiriquí Province of the Republic of Panama and have just spotted on a barbed wire fence man's fellow-farmer, the mycophagous ant *Acromyrmex octospinosus* going about its business of preparing the medium in which it grows pure cultures of the vegetative stage of a presumed basidiomycete. The little beast was moving fast enough to call for all the speed resources of the shutter.

Too perishable, too steep, too essential

Some products we are more pleased to sell than other products. The pitifully perishable character and steep price per cubic centimeter of liquid KODAK Nuclear Track Emulsions make a wicked combination. Too bad they have turned out so essential to the conduct of fundamental research in the life sciences. Originally, some decades ago, we thought the physicists were going to be the principal customers for photographic materials designed to pick up tracks of ionizing particles, but we were wrong. Turned out that bubble chambers of liquid hydrogen and spark chambers are much, much better for particle physics. Sheer joy it is for us to furnish the film on which these bubble tracks and sparks are imaged by lenses.

But biological scientists, who have a bit less need than high-energy physicists to cluster together in huge establishments with huge budgets and huge, highly specialized purchasing departments, are invited to speak right up on their own for their requirements in autoradiographic emulsions to Eastman Kodak Company, Special Applications, Rochester, N. Y. 14650. We even have a new pamphlet for them.

Artwork for electronics

The following information will strike some as dull, some as confusing, and some as useful enough to make partial amends for often afflicting the reader with windy pseudo-intellectual irrelevancies:

We have worked out the proper way to prepare "artwork" economically for printed circuits connecting pad locations on some standardized grid configuration. It employs KODAGRAPH AUTOPOSITIVE Film, ESTAR Thick Base, EA7, a product which disposes for good and all of any lingering question about dimensional stability.

First you prepare a single master negative that carries the circuit-board outline, terminals, register and identification marks, and all possible circuit pads. From this, working in ordinary room light, you print photographically a stock of artwork blanks. Whenever you want to make a new set of connections, you take one of your blanks and lay down in tape or ink on the matte back of the film blank whatever connections you want. You see all the circuit pads as light blue, but the camera that will reduce the circuit to its real size will see only the pads you color red. No light table required. No register problem because the whole layout, including the grid of pads, is on the same piece of film.

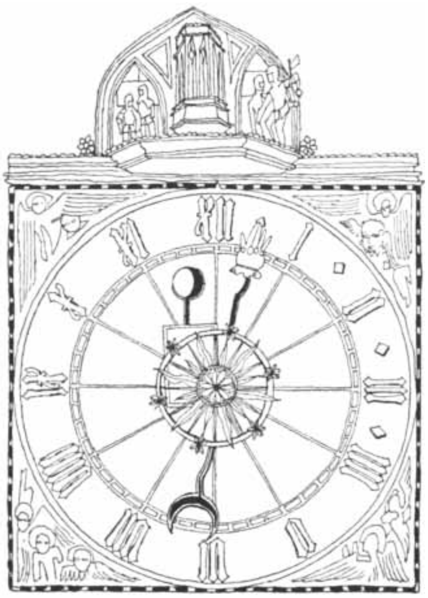
All is spelled out in fine detail—even the formula for making up the etch bath that leaves emulsion on the film base only where wanted—in a pamphlet we call "Instant Artwork." Free from Eastman Kodak Company, Reprography Products Division, Rochester, N. Y. 14650. Actually the method is not limited to printed circuits. It is useful for all kinds of standardized charts. "Imagination is the main factor in its versatility," says our pamphlet. Whoever wishes to lift this unexceptionable sentiment and apply it to his own product should feel free.

Truth on tape

"Some plain talk from Kodak about sound recording tape" is the title of an item of propaganda obtainable free of charge from Department 8, Eastman Kodak Company, Rochester, N. Y. 14650. Learned readers who have dedicated more than their leisure to magnetic tape may find the talk even a little too plain. Others of a less critical disposition will learn much about tape they didn't know before, all of it true.

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

SCIENCE AND



End of the Explosion?

A major "demographic transition" to lower birthrates is under way in some high-fertility countries, according to Ronald Freedman of the University of Michigan Population Studies Center. In his presidential address in April to the Population Association of America, Freedman went so far as to predict that "a majority of the world's population will be living in countries with declining fertility within the next five to 10 years." He said the decline would not occur without "organized and vigorous efforts" but suggested that "fundamental social conditions will bring forth the necessary effort." He also pointed out that none of the previous fertility declines in the West or Japan were studied in detail as they occurred, nor has there ever been an opportunity to learn how large-scale planned programs can accelerate the decline of the birthrate. He urged his colleagues to enter on a broad program of research to "study the conditions and processes of the decline with all the tools of modern social science."

Reviewing the assumptions on which his predictions were based, Freedman said he would expect birthrates to decline most rapidly in those high-fertility areas where significant social changes have occurred, where mortality has decreased, where people are trying to limit the size of their families, where there are social networks through which new ideas can be disseminated, where there are organized efforts to promote family planning and where new contraceptive methods are available. In Taiwan, Korea and Hong Kong, he said, these conditions are reasonably well fulfilled; all three are experiencing fertility declines of major proportions accelerated by organized social efforts, and he predicted large declines for each in the near future (see "A Study in Fertility Control," by Bernard Berelson and Ronald Freedman; SCIENTIFIC AMERICAN, May, 1964).

As for other high-fertility parts of the world, Freedman said that in Africa conditions are not yet favorable and the outlook for an overall decline is poor. In Latin America as a whole a moderate decline seems likely. In at least parts of India and Pakistan conditions are favorable, making moderate national declines foreseeable within 10 years. In the case of mainland China, Freedman said, speculation is "perilous, foolhardy and necessary," since "we are talking about 20 to 25 percent of the world's population"; evidence of an improved public health network and of government interest in family limitation indicates a moderate decline there too.

Whether or not his predictions turn out to be correct in every particular, Freedman said, it is clear that significant changes in fertility will be occurring within the next generation under varying conditions in different countries. It is important to study the social and demographic processes of fertility changes. In fertility control, he noted, large-scale experimental studies are both feasible and ethical, and he called for cooperation between social demographers and family-planning "activists" to combine research with action programs.

The Three-Base Code Confirmed

For the first time synthetic molecules of deoxyribonucleic acid (DNA) have been employed to guide the test-tube synthesis of polypeptide molecules. In the living cell polypeptides, which are built up from amino acid molecules, form the principal chains in the structure of proteins. The plan of each polypeptide chain is embodied in a linear sequence of the units known as bases in a giant molecule of DNA. Each of the 20 kinds of amino acid molecule is represented in DNA by a specific sequence of bases. The cell-free test-tube experiments were carried out by H. Gobind

THE CITIZEN

Khorana and his associates at the University of Wisconsin; the results were reported at the recent annual meeting of the Federation of American Societies for Experimental Biology.

The work of Khorana's group supplies definitive answers to three questions about the way the DNA code is translated into a polypeptide chain. It is now shown that each amino acid is represented in DNA by a sequence of three bases, that the three-base code is strictly sequential and does not overlap and finally that there is no "punctuation" between three-base code "words." There was considerable evidence prior to the Wisconsin work that the code had this form, but other possibilities had not been ruled out. For example, one could imagine a complex coding system made up of a mixture of two-base and three-base code words, or even systems in which the last base of one code word was the first base of the next. Khorana's experiments do not bar the possibility, however, that the code includes some kind of "period," or full stop, to indicate the completion of one polypeptide chain and the beginning of another. Some such punctuation would seem to be needed, because each DNA molecule in a living cell normally embodies the instructions for many different polypeptide chains.

Khorana's associates in developing the experimental techniques were David S. Jones, T. M. Jacob, Susuma Nishimura and R. D. Wells. In studies of polypeptide synthesis this group was augmented by Rolf Lohman, Dieter Soell, Eiko Ohtsuka and Hikoya Hayatsu.

Ultimate Prohibition

A belief widely held and frequently put into medical practice is that a modest dose of ethyl alcohol ("grain" alcohol) will cause the blood vessels to dilate, thus lowering the work load of the heart. On investigation this comforting idea appears to be totally untrue. Within the past few months two separate studies have been completed that indicate that the effect of ethyl alcohol is to increase the work load of the heart.

The first to draw this unhappy conclusion were Watts R. Webb of the University of Texas Southwestern Medical

School and I. U. Degerli of the University of Mississippi School of Medicine. They had tested the effect of ordinary laboratory ethyl alcohol and bonded bourbon on the circulatory systems of a group of dogs. They found that in all the dogs, even those receiving slight doses of alcohol, coronary flow decreased. In those animals receiving large doses, blood pressure increased significantly and the work involved in each heartbeat almost doubled. The type of ethyl alcohol administered did not alter the effects.

The results of a similar study made with human subjects were reported at a recent meeting of the American Association of Physicians. Timothy J. Regan, spokesman for a group of investigators at the New Jersey College of Medicine in Jersey City, described experiments in which the consumption of six or seven shots of whisky over a period of two hours resulted in a 25 percent decrease in the force of contraction of the heart. Regan also described evidence indicating that the hearts of human alcoholics tend to pump less forcefully and adjust to extra work loads less efficiently than the hearts of nonalcoholics.

Last Whales

The whaling industry's inability to attain its own quota of kills in the current season lends ominous weight to predictions by marine biologists that the whale populations of the world are in danger of imminent extinction. The blue whale, largest of all animals and long the mainstay of the whaling fleets, has greatly diminished in numbers in recent years; it is now nominally under full protection, but the annual catch of the world's three whaling nations is still reported in "blue whale units." One such unit is made up of smaller whales, for example two fin whales or six sei whales.

Last year, ignoring the recommendation of scientific advisers to the United Nations' International Whaling Commission that the season's catch be cut to 4,000 blue whale units, Norway, the U.S.S.R. and Japan instead set themselves a combined quota of "not more than" 8,000 units. Although their 15 fleets combed the southern oceans from December, 1964, to April, 1965, the total kill was no more than 7,065 units, consisting of 7,000 fin whales and more than 20,000 sei whales. In comparison the kill in 1960–1961 had included 27,000 fin whales and 4,000 of the less desirable sei whales.

It is estimated that only 36,000 fin whales and 47,000 sei whales now remain; the number of surviving blue whales is unknown. Marine biologists predict that, unless an annual quota of no more than 2,000 units is promptly established, these declining whale populations will soon follow the overhunted passenger pigeon along the irreversible road to extinction. They also agree that the whaling industry will not be influenced by their prediction.

The Spin of Mercury

Radio astronomy continues not only to explore the far reaches of the universe but also to provide new information about objects near at hand. Recent observations with the 1,000-foot fixed radio telescope in Puerto Rico show that, contrary to what had been thought, the planet Mercury rotates at a rate different from its rate of revolution around the sun. When both rates are synchronous—as in the case of the moon's 28-day rotation and revolution around the earth—a smaller body orbiting around a larger one always presents the same side to the larger body.

Measuring Doppler shifts in radio echoes from Mercury, Gordon H. Pettingill and Rolf H. Dyce of Cornell University found that the planet rotates once every 59 (plus or minus five) days. Mercury orbits the sun once every 88 days; a full day on the planet—corresponding to 24 hours on earth—is therefore completed every 180 days or in a little more than two of its years. Mercury's rotation, like that of most planets in the solar system, is counterclockwise with respect to a view from above its north pole; the exception, as other radio astronomy studies have shown, is Venus, which rotates slowly in a clockwise direction.

Still-earlier Life

Two hydrocarbon molecules that are synthesized only by living organisms have been identified in rock specimens from a geological formation no less than 2.5 billion and possibly three billion years old. The discovery, involving the use of refined microchemical techniques by a group headed by Melvin Calvin at the Lawrence Radiation Laboratory of the University of California at Berkeley, extends the history of life on earth by at least half a billion years.

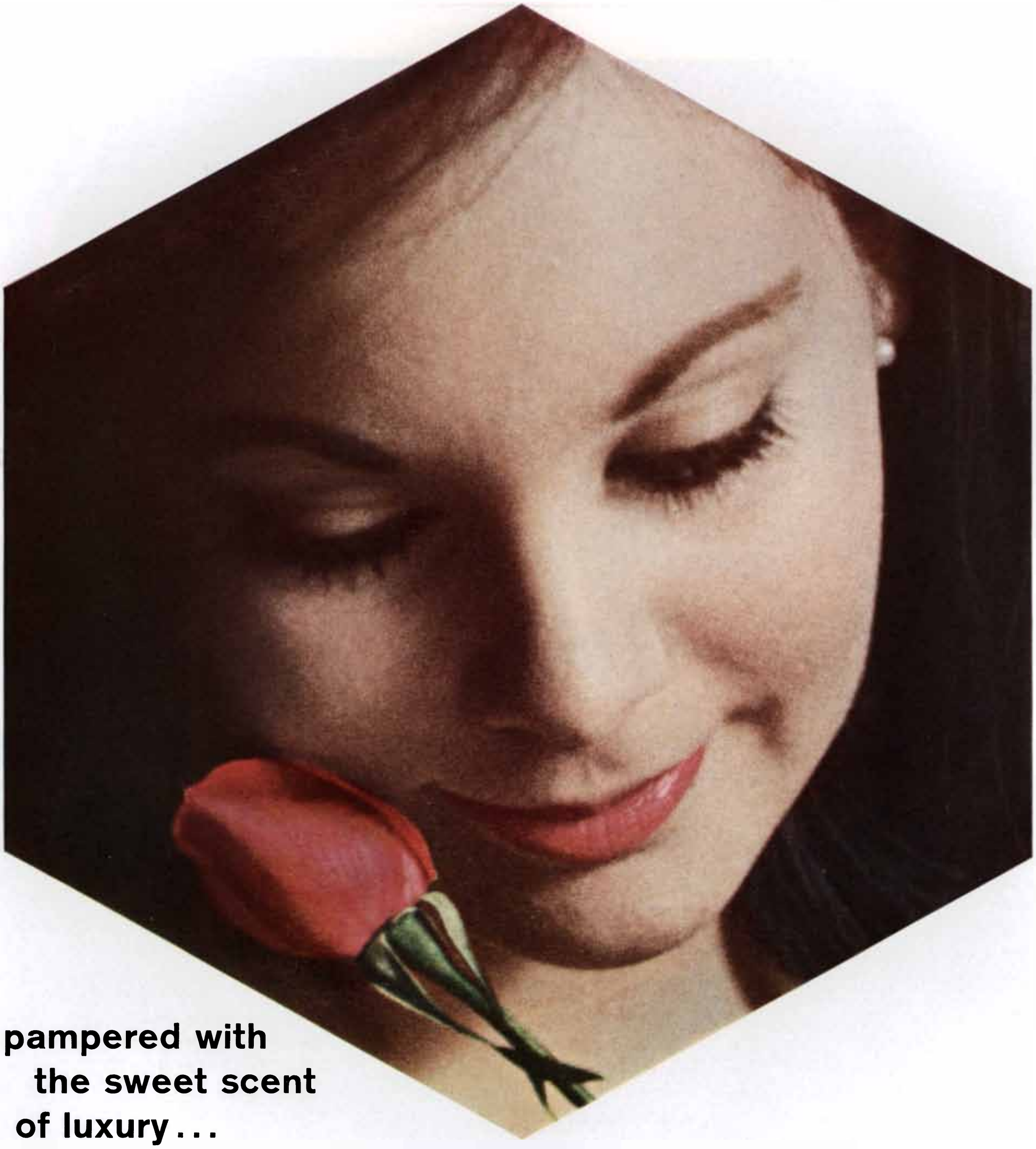
The members of the Berkeley group report in *Nature* that they have extracted pristane and phytane, two hydrocarbons that retain their characteristic chemical structure even after prolonged exposure to heat and pressure, from the carbon-rich rock of the Soudan Formation in Minnesota. Phytane is a derivative of phytol, one of the components of chlorophyll. The history of pristane is less clear-cut: it is a common constituent of modern marine organisms but may also be a breakdown product of chlorophyll. Although none of the organisms that produced these hydrocarbons are preserved as fossils in the rock, the Berkeley investigators speculate that they may have been plants rather like today's primitive blue-green aquatic algae. The earth's earliest known fossils are similar alga-like organisms preserved in the two-billion-year-old Gunflint cherts of Ontario.

The same pair of biological markers may soon prove that life arose on earth in the even more distant past: Calvin and his associates plan to search for pristane and phytane in South African rocks that were formed 3.4 billion years ago.

Death by Radiation

The first known industrial accident involving lethal exposure to a burst of ionizing radiation occurred in a Rhode Island uranium-recovery plant in July of last year; clinical details were published recently in *The New England Journal of Medicine* by Joseph S. Karas and John B. Stanbury. A worker who had improvised a batch method for precipitating small amounts of uranium from atomic-plant waste solutions unwittingly emptied a solution of uranium highly enriched with U-235 into a tank two feet in diameter. As the tank filled, the configuration necessary for a self-sustaining fission reaction was reached; the solution boiled up violently, emitting a massive shower of neutrons and gamma radiation and also splashing the worker. He received an instantaneous whole-body dose of radiation estimated at 8,800 rads (one rad equals 100 ergs of radiation energy per gram of tissue), or from 10 to 20 times lethal dosage.

On arriving at a hospital two hours later the victim was running a low fever and complained of severe abdominal cramps, headache and thirst. Gamma-ray spectrometer analyses of blood and urine specimens showed that the neutrons had induced radioactivity in some of the sodium and phosphorus content of his body. Blood pressure, vision and reflexes were normal. Four hours after admission the patient's blood pressure dropped severely and medication was required to restore it to a functional level. At the end of eight hours, al-



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though his temperature had reached 102 degrees Fahrenheit and his left hand and forearm—the parts of his body that had been nearest the tank—were swollen and red, the patient was alert and reported that he felt well.

Thirty-six hours after the accident redness and swelling had extended to the patient's upper left arm and face, his pulse rate had risen and medication to maintain blood pressure was proving decreasingly effective. A specimen of bone marrow taken at this time showed disruption of the cells; a rise in uric acid and decay products in the blood provided evidence of additional cell destruction in the body. Eight hours later the patient's blood pressure could no longer be maintained; he died 49 hours after the accident. The immediate cause of death was failure of circulation, apparently induced by the toxic by-products of radiation-destroyed cells throughout the body. The victim was the fifth known peacetime casualty from massive exposure to radiation; three of the first four accidents occurred in Atomic Energy Commission facilities and the fourth in a Yugoslavian laboratory.

The Cable of Collagen

The detailed three-dimensional architecture of collagen, the most abundant protein in the human body, has been mapped in the laboratory of Alan J. Hodge of the California Institute of Technology. The results of this study help to explain why collagen fibers are so strong. Collagen forms a tough mesh in skin, provides resilient cables in tendons and acts as reinforcing rods in bone.

The Cal Tech work reveals that the collagen molecule resembles a three-strand rope in which each strand consists of a polypeptide chain, a structure whose building blocks are amino acid molecules. Each strand is in the form of a left-handed helix, and the three together are wrapped into a right-handed superhelix. The strands are held side by side along their length by hydrogen bonds.

The polypeptide chains in the collagen molecule are of two types. Two of the chains consist of five subunits linked end to end; the third consists of seven shorter subunits. The lengths of the subunits are such that seven of the shorter subunits have the same total length as five of the longer subunits. In fact, the molecule is defined as a stretch of collagen fiber that embodies this five-seven module in a helix of 35 turns. The shorter subunits are built up from about 150 amino acid molecules and the longer subunits from about 210. The sequence of specific amino acid units in each kind of subunit has not been determined, but the longer subunits are chemically very similar, if not identical; the shorter subunit is distinctly different. In both kinds of subunit, however, glycine—the smallest of the 20 varieties of amino acid molecule—appears in every third position. As a result of this periodicity the three strands of the molecule fit snugly together.

The precision of architecture extends to the way in which individual collagen fibers, consisting of many molecules joined end to end, are aligned side by side in skin or in other connective tissue. The neighboring fibers are systematically displaced to form an offset pattern like that in a brick wall. In addition there is a small space (about a seventh of the length of a collagen molecule) between adjacent fibers. In bone this space is filled with calcium phosphate, which acts like the concrete in reinforced concrete.

An important technique in unraveling the molecule's architecture was devised several years ago in the laboratory of Francis O. Schmitt of the Massachusetts Institute of Technology. Schmitt and Hodge, who was then at M.I.T., discovered that if a tissue made up of collagen fibers was dissociated, the fibers could be induced to re-form in alignment rather than in overlapped fashion. When they are so aligned, the molecular features are in register and show up clearly as cross-striations in electron micrographs. In his recent work Hodge was assisted by Allen J. Bailey, John H. Fessler and John A. Petruska.

Coherent Matter Waves

An ingenious but simple experiment has recently confirmed in a new way what physicists have long suspected: there is a basic similarity between the superconductivity observed in certain metals near absolute zero and the superfluidity that occurs in liquid helium below 2.19 degrees Kelvin (degrees centigrade above absolute zero). Superconductivity represents the frictionless flow of electric charge; superfluidity represents the frictionless flow of matter. Both are thought to be macroscopic evidence for the existence of matter waves, which are postulated by quantum mechanics to explain the behavior of matter on the atomic and subatomic scale. Recent theories suggest that in a superconducting metal and in superfluid helium these matter waves become coherent in a large volume of material, that is, they have the same frequency, amplitude, phase relation and direction. Thus they produce effects observable on a comparatively large scale.

In 1962 B. D. Josephson of the University of Cambridge pointed out that the matter waves in a superconductor should oscillate at a frequency related to the voltage of the direct current it carried. This could be tested, he proposed, if two superconductors held at different voltages were connected by a weakly superconducting bridge, in which case there should appear in the bridge an oscillating current whose frequency was related to the oscillations in the adjoining superconductors. Since the effect would be weak, Josephson proposed that it might be observed by a trick: if an oscillating electromagnetic signal were applied to the bridge, the properties of the bridge would change abruptly when the frequency of the impressed signal exactly matched the frequency created by the matter waves in the two superconductors. Using this stratagem, S. Shapiro, who was then working at Arthur D. Little, Incorporated, was able to observe the Josephson effect.

The analogue of the Josephson effect in superfluid helium has now been observed at the Bell Telephone Laboratories by Paul L. Richards and Philip W. Anderson. In their experiment liquid helium is allowed to flow from a high-level reservoir into a low-level reservoir through a pinhole orifice in the bottom of the second reservoir. Theory predicts that the matter waves in the two reservoirs will oscillate at different frequencies proportional to the head of liquid helium in each. It is further predicted, in analogy with the Josephson effect, that the flow through the orifice will contain an alternating component related to the difference in heads.

In order to detect the alternating component, Richards and Anderson placed a small ultrasonic vibrator below the orifice in the low-head reservoir. The vibrator generated another alternating flow of liquid helium through the orifice. This impressed oscillation could be expected to interfere in a predictable way with the superfluid flow through the orifice. In fulfillment of this prediction the flow through the orifice was observed to halt at intervals, producing a flow curve with a series of regularly spaced steps. Richards and Anderson interpret this result as showing that the matter-wave fields in the two reservoirs are coupled in phase and are therefore coherent.

CHEMICAL FERTILIZERS

In a world that is obliged to produce more food, enriching the soil with elements that are needed for plant growth is a major concern. What are these elements and how can they be artificially supplied?

by Christopher J. Pratt

Whatever estimate one accepts of the increase of the human population in the finite future, or whatever estimate of how long it will take to bring this increase under control, it is clear that the present rate of increase is alarmingly high. Three centuries ago the number of people in the world was probably about 500 million; now it is more than three billion, and if the current rate of increase holds, it will be six billion by the end of the century and millennium. In some underdeveloped areas, where the rate is highest, the Malthusian prediction that population would eventually outrun food supplies seems close to reality.

Clearly mankind faces a formidable problem in making certain that future populations have enough to eat. Doubtless a partial solution lies in improved technology, which has already done so much to keep the food supply abreast of population, and in the spread of existing technology from the developed to the underdeveloped countries. It should also be possible to bring some new areas under cultivation or grazing, but the opportunities in that direction appear to be limited. Even though only about 2.4 billion acres, or approximately 7 percent of the earth's land area, are used for crop production in any one year, most of the unused land is too dry or too cold for agriculture or is in some other way unsuitable. Neither extensive clearing of forests nor large-scale cultivation of tropical lands offers as much promise as one might think, because much of the soil in such regions is lateritic and turns hard as the result of an oxidizing effect when it is put to the plow [see "Lateritic Soils," by Mary McNeil; Scientific American, November, 1964].

With huge amounts of capital and carefully planned projects it would be possible to create much new cropland by vast undertakings of irrigation, drainage and other kinds of reclamation. Even if such projects were launched, however, they would take decades to complete. It seems more feasible to look to shorter-range ventures, particularly in those developing areas where famine is an imminent threat.

Of all the short-range factors capable of increasing agricultural production readily—factors including pesticides, improved plant varieties and mechanization—the largest yields and the most substantial returns on invested capital come from chemical fertilizers. The application of these substances to underfertilized soils can have dramatic results. In a typical situation the ratio of the extra weight of grain produced per unit weight of nutrients applied can be as high as 10 to 1. To put it another way, an investment of this kind alone can quickly produce increases in crop yields of 100 to 200 percent.

Today some 30 million tons of the so-called primary nutrients—nitrogen, phosphorus and potassium—are annually supplied to world agriculture by chemical fertilizers. This amount is hardly adequate, for reasons I shall discuss. Moreover, crop yields diminish in proportion to the amount of fertilizer applied. Therefore it can be estimated that a population of six billion in the year 2000 will require at least 120 million tons of primary nutrients. An increase of 90 million tons of nutrients for three billion more people means that 60 pounds of primary nutrients will be needed to help sustain each additional person for a year. This is equivalent to about one 100-pound bag of modern high-analysis chemical fertilizer.

Stated in such a way, the amount of effort required to supply the additional fertilizer may seem modest. Actually the expansion of capacity required is enormous; achieving it may well become a major preoccupation of technology. Fortunately processes for manufacturing the needed substances are already well established on a large scale and are capable of rapid expansion, provided

CHEMICAL FERTILIZER is meticulously placed on a field in Oklahoma by a spreader

that enough capital is made available and the necessary priorities are given. Considering all these factors, it is appropriate to review briefly the fertilizer situation: how plants utilize nutrients, how chemical fertilizers came into use, how they are manufactured, how they are best applied and how the increasing demand for them can be met by chemical technology.

Plants and Nutrients

A growing plant requires most or all of 16 nutrients, nine in large amounts and seven in small. The former are sometimes called macronutrients, the latter micronutrients. Most plants obtain three of the macronutrients—carbon, hydrogen and oxygen—from the air and all the other nutrients from the soil. (A few species, such as clover, are able to fill their nitrogen needs from the air.) The primary soil macronutrients—nitrogen, phosphorus and potassium—are the *N*, *P* and *K* often seen on bags of fertilizer; they are also the substances represented by the set of three figures, such as 10-12-8, that normally designates the nutrient content of a fertilizer. Usually these figures respectively denote the percentage in the fertilizer of total nitrogen (N), of phosphorus pentoxide (P_2O_5, often called phosphoric acid or phosphate) in a form available for use by plants and of water-soluble potassium oxide (K_2O, usually called potash).

The three other soil macronutrients—calcium, magnesium and sulfur—are often called secondary. Agricultural lime, limestone and dolomite, which are used to correct soil acidity, also serve as sources of calcium and magnesium. Sulfur deficiencies can be remedied by certain commercial fertilizers. The seven micronutrients, which are sometimes added in traces to fertilizers providing one or more of the primary nutrients, are boron, copper, iron, manganese, zinc, molybdenum and chlorine.

The growth of plants is a highly complicated process that is far from fully understood. For the purposes of this article it is enough to say that the usual path of mineral nutrients from the soil to the plant is from the solid particles of soil to the water in the soil and thence into the root. The actual transfer of nutrients from soil to root involves the movement of mineral ions. These ions are contained mostly in the soil water, but some of them are adsorbed on solid soil particles.

It follows that nutrients must be in ionic form or capable of transformation to ionic form by soil processes if they are to be of any value to the plant. Hence it is not necessarily a lack of minerals in a soil that causes plants to show signs of nutrient deficiency; the problem can also be that the nutrients are not in a form readily available to the plant. For example, it is quite possible for crops to starve in soils that are amply supplied with phosphorus and potassium if these nutrients are insoluble in water or plant juices. Essentially what the chemical fertilizer industry

34 feet wide. The spreader is of the "drill" type, meaning that it lays fertilizer in precise rows instead of broadcasting it generally over the field as would be done by other types of spreaders. Careful placing is often important for economic or nutritional reasons.

does, in addition to converting inert nitrogen from the air into soluble salts, is employ processes to "open" the molecules containing the vital nutrients so that these molecules form soluble salts that plants can assimilate readily.

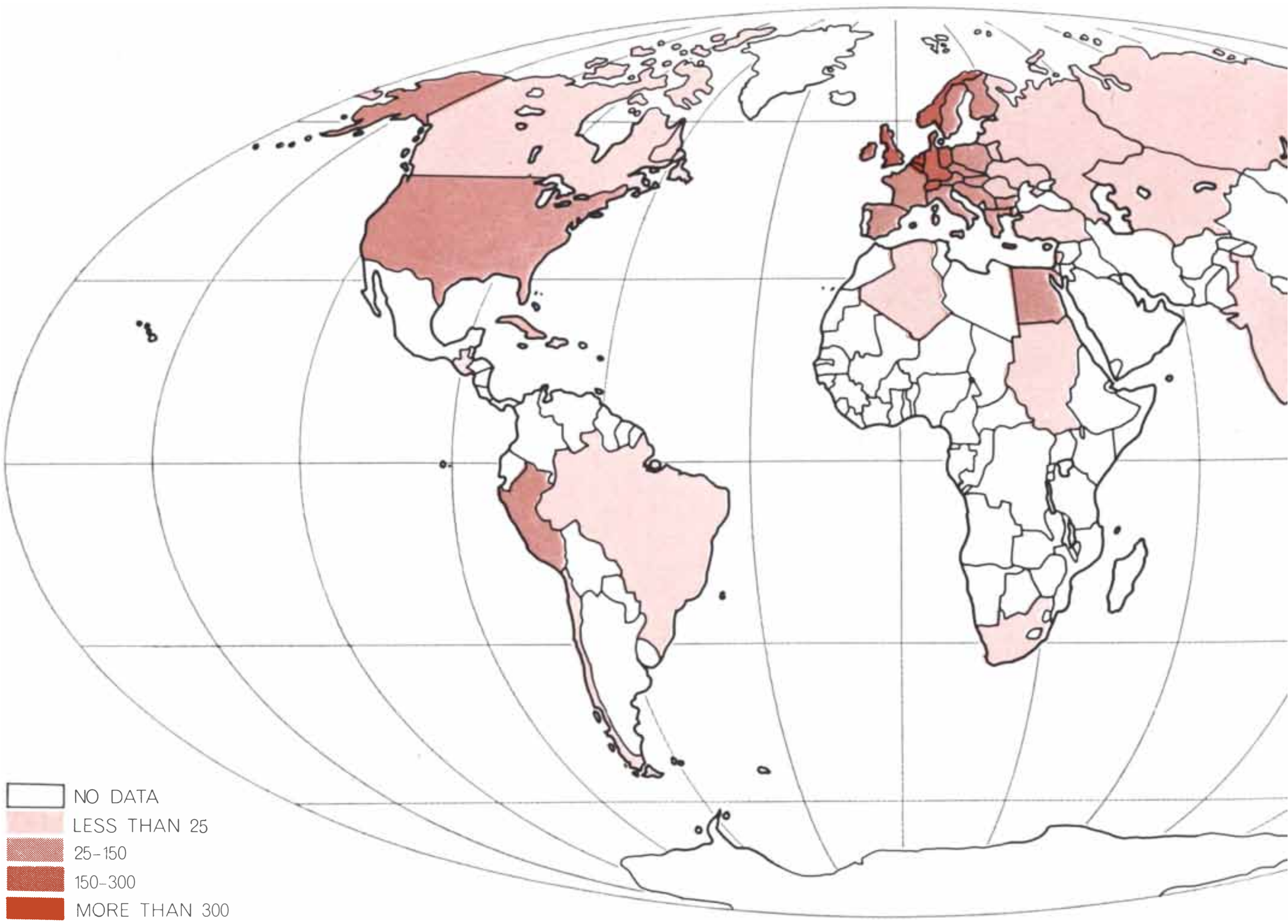
One can best grasp the need for mineral nutrients in agriculture by taking account of the nutrients that are removed from the soil by cropping and grazing. A ton of wheat grain is equivalent to about 40 pounds of nitrogen, eight pounds of phosphorus and nine pounds of potassium. If the straw, husks, roots and other agricultural wastes of such a crop are not returned to the soil, they represent additional large losses of nutrients. A ton of fat cattle corresponds to a depletion of about 54 pounds of nitrogen, 15 pounds of phosphorus, three pounds of potassium and 26 pounds of calcium. Such rates of removal will quickly exhaust a typical soil unless the losses are made up by regular additions of suitable fertilizer.

Equivalent additions of fertilizer, however, are not really enough. There are other factors to be taken into account, and they explain why the present consumption of fertilizers is barely adequate. Nutrients are leached from soils by the flow of water; moreover, they are fixed in forms not readily available to plants. As a result of such losses the proportion of soil nitrogen and phosphorus utilized by a crop is rarely more than 75 percent. In some instances the utilization of phosphorus is as low as 10 percent.

Even allowing for losses, the increased crop value resulting from the proper application of fertilizer can be substantial. On a poor soil the gain can approach 10 times the cost of the material applied. Where the soil is good and the crop yields are high the gain from fertilizing is more likely to be three to five times the cost of the fertilizer. Because of this diminishing return there eventually comes a point at which the additional yield no longer justifies the cost of the corresponding extra fertilizer. There is also an agronomic reason for avoiding the overapplication of fertilizer: ultimately a point can be reached at which the high concentration of nutrient salts in the soil can damage the plants.

The Evolution of Fertilizers

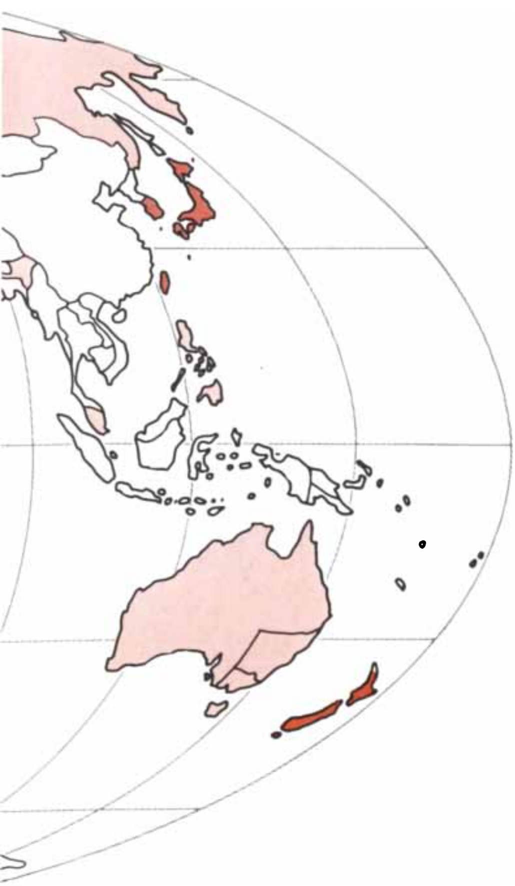
Long before men began to write history they knew about the effects of organic, or natural, fertilizers on growing plants. The effects must surely have been evident in the relatively lush growth induced by animal droppings and carcasses. Eventually farmers began to collect dung and apply it to crops. The first English settlers in North America reported that the Indians substantially increased their yield of maize by burying a fish with each seed they planted. In medieval times farmers in Europe had commonly undertaken to grow nitrogen-converting legumes such as clover and to rotate crops in order to



USE OF CHEMICAL FERTILIZERS is shown according to data assembled by the Food and Agriculture Organization of the United Nations. Figures give average consumption of fertilizer in metric tons per 1,000 hectares of arable land, defined as land planted to

maintain soil fertility. By the early 19th century the use of farm manure, blood, bones, animal wastes and Peruvian guano became widespread, particularly in England, where the Industrial Revolution had brought about a rapid expansion of population and a simultaneous movement of workers from the land to the manufacturing towns. For a time it appeared that the limited supply of organic fertilizer would be insufficient to meet the rising demand for food in the industrializing countries; it is said that even human bones from the battlefields of Europe were recovered, crushed and used as plant foods.

Although the use of organic fertilizers was well established by the 19th century, the basic reasons for their effectiveness were not understood. This lack of knowledge hampered the discovery of alternative substances that could relieve the pressure on the limited supply of organic matter. Another obstacle was the passionate belief held by many that organic materials had special fertilizing properties not shared by inorganic substances. Even after the Swiss chemist Nicolas de Saussure demonstrated in 1804 that plants can grow luxuriantly on carbon and oxygen from the air and mineral nutrients from the soil, strong feelings about organic fertilizers persisted. (Today the view is still sometimes expressed that organic fertilizers possess inexplicable virtues unrelated to their content of primary nutrient. Such materials—manure, sewage sludge, compost and the like—are indeed valuable as conditioners of soil and as minor contributors of plant nutrients, but there is not nearly enough organic material to meet present needs, let alone those of the future.)



crops, in temporary use as meadow for mowing or pasture, or temporarily lying fallow.

Gradually the advances of chemistry revealed the processes of plant nutrition and pointed the way toward the substitution of chemical fertilizers for organic fertilizers. In some instances the process was very slow. Nitrogen, for example, was recognized as an important plant nutrient in manures and other organic matter long before anybody understood the complex cycle by which unreactive atmospheric nitrogen is converted by legumes and soil bacteria into ammonia and soluble nitrogen salts. By the time the process was understood, early in this century, conditions were ripe for a rapid evolution of industrial replacements for organic nitrogen in fertilizer. For one thing, ammonia in the form of ammonium sulfate had become available as a by-product of coal-gas works. For another, mine operators in Chile had begun large-scale production and export of sodium nitrate for use in explosives and other chemicals. As a result of their availability these salts rapidly overtook organic nitrogen as an ingredient of fertilizer. The speed of the transformation is indicated by the fact that the proportion of organic nitrogen materials in fertilizers used in the U.S. fell from 91 percent in 1900 to 40 percent in 1913.

Chilean nitrate was not to hold its position for long. A prolonged effort to synthesize ammonia by combining nitrogen with hydrogen succeeded at last in 1910, when the German chemist Fritz Haber found that the reaction would proceed at high pressure (at least 3,000 pounds per square inch) and in the presence of osmium as a catalyst. The achievement gave rise to a revolution in chemical fertilizer technology. In 1913 Haber and Karl Bosch, having worked out many difficult engineering problems, designed a commercial plant that soon produced 20 tons of ammonia a day. The requirements of the two world wars made ammonia available on a large scale, together with such derivatives as ammonium nitrate and urea. These compounds in time largely replaced Chilean nitrate as a source of nitrogen and also reduced the proportion of fertilizers containing organic nitrogen to a few percent of total fertilizer consumption.

Phosphorus moved from the organic to the chemical stage in fertilizer sooner than nitrogen but by a similarly slow process. The first association of phosphorus with bones was made by the Swedish mineralogist and chemist Johan Gottlieb Gahn in 1769. It took until 1840, however, for chemistry to advance to the stage where it was possible to recognize that phosphorus was the key ingredient in the bone manure that had come into wide use. In that same year the great German chemist Justus von Liebig, who is regarded by many scholars as the founder of agricultural chemistry, put forward the thesis that the action of sulfuric acid on bones would make the phosphorus in the bones more readily available to plants.

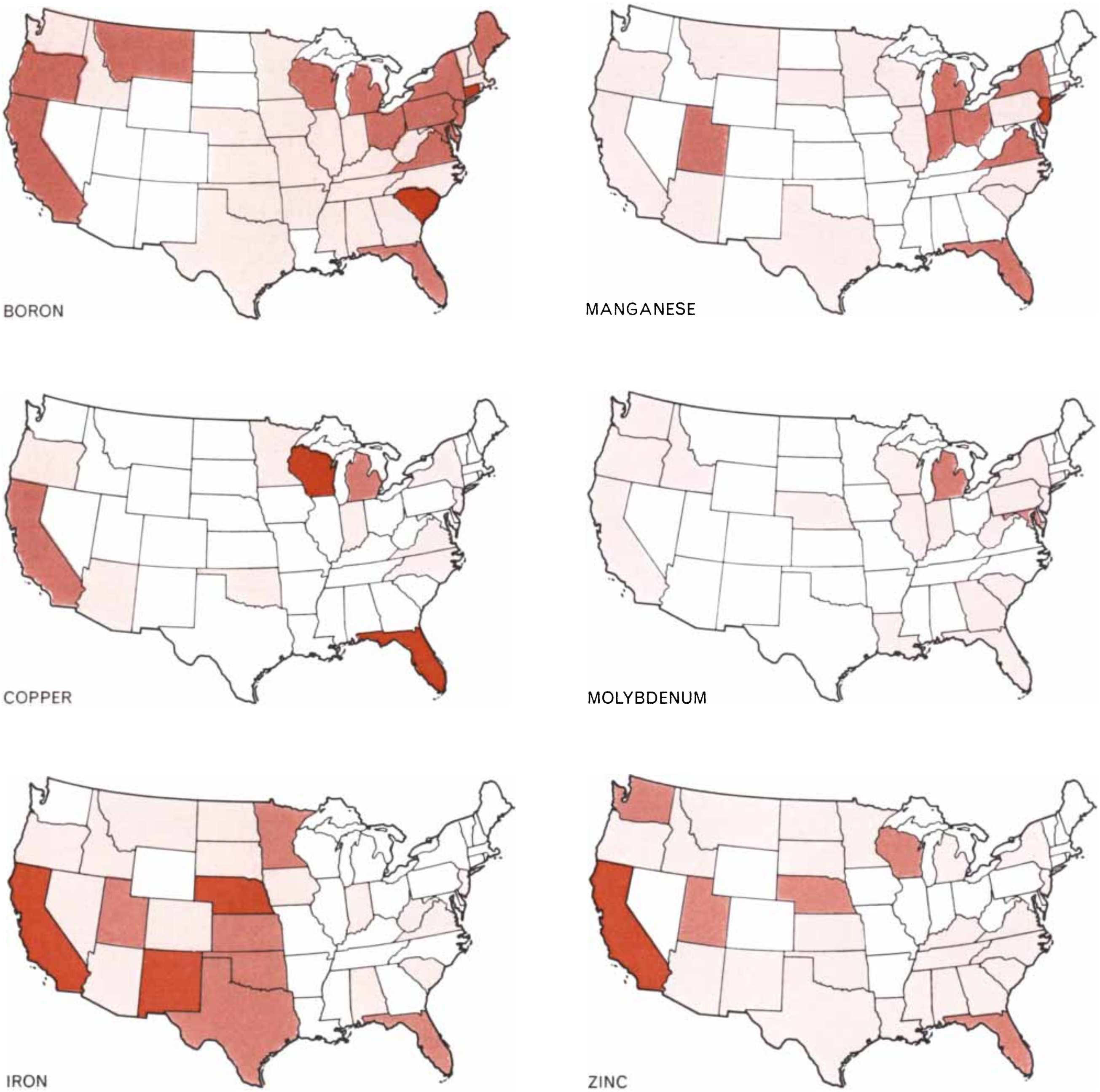
This idea was promptly developed in England, where the need for additional sources of fertilizer was acute. In 1842 John Bennet Lawes, a wealthy farmer and industrialist who spent many years conducting agricultural experiments on his estate at Rothamsted, obtained a patent covering the treatment of bones and bone ash with sulfuric acid to make an improved phosphorus-containing fertilizer. Significantly he included "other phosphoritic substances" in his patent, indicating that he foresaw the role of minerals as sources of phosphate. Within 20 years the production in Britain of "chemical manures" made from sulfuric acid, local coprolites (fossil manures) and various phosphatic minerals had risen to a level of 200,000 tons a year. The phosphate fertilizer industry, thus firmly established, spread rapidly to other countries. Toward the end of the 19th century slag removed during the production of iron and steel from high-phosphate ores became another major source of phosphorus for agricultural purposes in Britain and Europe, where even now several million tons of "basic slag" are used annually as a phosphate fertilizer.

As for potassium, the benefits of adding wood ashes ("pot ash") to the soil must have been recognized in ancient times. By early in the 19th century the progress of chemistry was sufficient for a start to be made in the use of potassium chloride deposits in Germany and France as sources of potassium in fertilizer. The first factory producing potash from these deposits was built in 1861. Germany and France continued to be the principal sources of potash until rather recently, when major deposits were developed in the U.S., Israel, the U.S.S.R. and Canada.

Modern Fertilizer Production

Today a farmer can buy a wide variety of chemical fertilizers. If he wants only one nutrient, he can find a fertilizer that provides it; he can also find fertilizers that contain almost any combination of nitrogen, phosphorus, potassium and the micronutrients. The industry that produces them is enormous, having a worldwide output, according to a recent estimate by the Food and Agriculture Organization, of more than 33 million tons a year. I shall briefly describe the processes now involved in producing the primary nutrients.

Synthetic ammonia is firmly established as the principal source of nitrogen in fertilizer. Ammonia synthesis remains unchanged in principle from the technique developed by Haber and Bosch. Large-scale production often presents additional problems, however, because of the need to obtain huge supplies of pure gaseous nitrogen and hydrogen at low cost. Pure nitrogen can be produced in quantity with relative ease by removing oxygen and other gases from air through liquefaction or combustion. Hy-

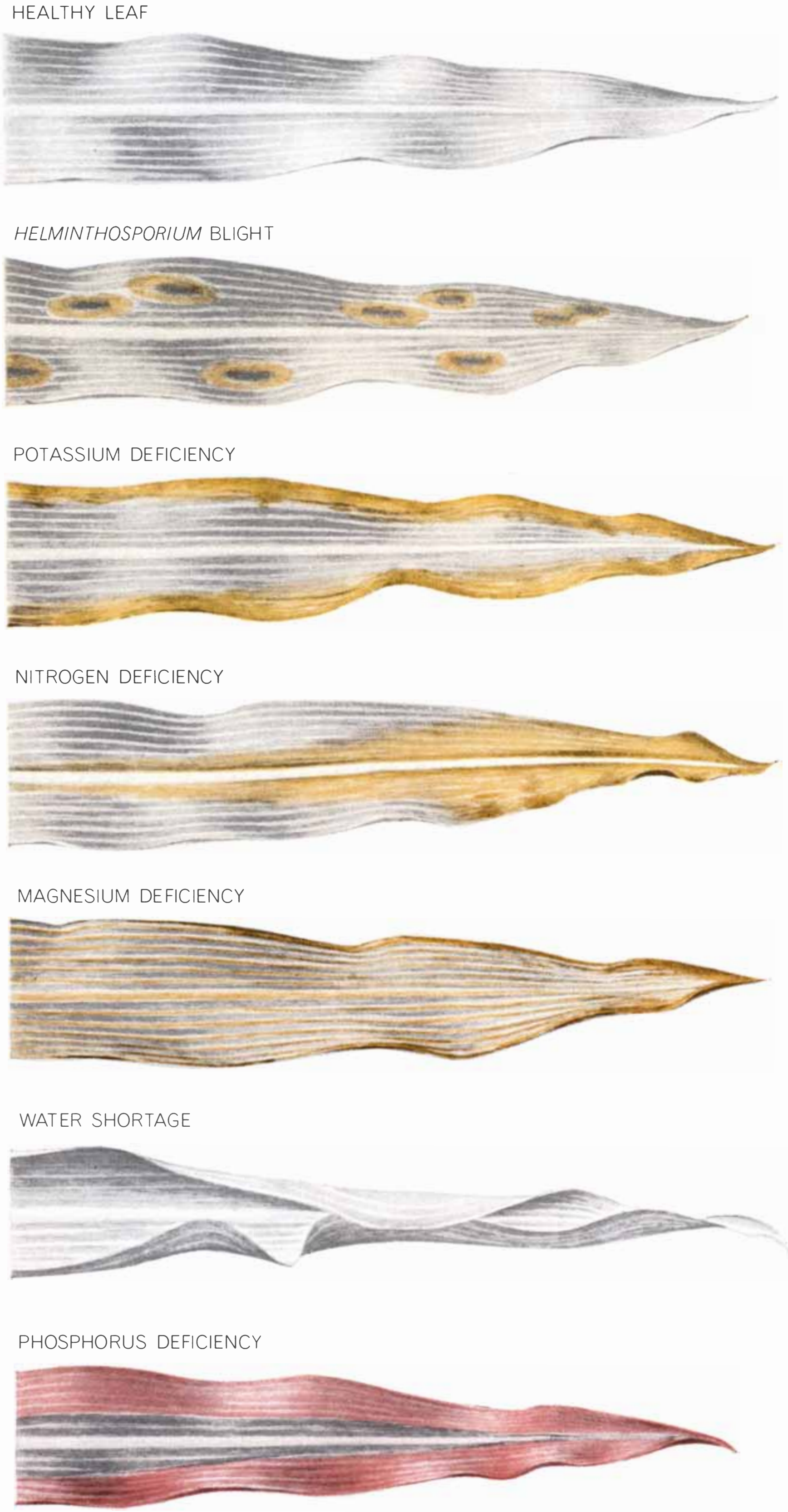


NUTRIENT DEFICIENCIES appearing in various parts of the U.S. mainland are indicated. The findings, based on work done by K. C. Berger of the University of Wisconsin, pertain to several "micronutrients," meaning minerals needed by plants in small but important amounts. "Macronutrients" such as nitrogen, phosphorus and potassium are needed by plants in large amounts and usually must be supplied wherever commercial crops are grown. The colors indicate the degree of deficiency from modest (*light*) to severe (*dark*) as based on reports of the number of crops affected. The absence of color means that the state has not reported a deficiency.

drogen is another matter. Some early ammonia plants used hydrogen made by electrolysis, but the prohibitive cost led to a search for cheaper sources. Methods for producing hydrogen from solid fuels such as coal and lignite were developed in Europe. In the U.S., where natural gas is plentiful, the simpler catalytic re-forming of methane has proved an ideal way of making hydrogen. More recently the catalytic re-forming of light petroleum fractions such as naphtha with the aid of steam and the partial oxidation of heavy oil with oxygen have been widely used in countries that lack natural gas.

Although there is a strong trend, particularly in the U.S., toward injecting ammonia directly into the soil in the form of anhydrous ammonia or aqueous solutions, most agricultural ammonia is still converted into solid derivatives. Ammonium nitrate is a form popular among manufacturers, since the nitric acid needed to produce it is also made from ammonia. Similarly, large amounts of urea are produced by combining ammonia with carbon dioxide derived from oxidation of the raw material used to produce the hydrogen. Ammonium sulfate is also made on a large scale by reacting ammonia with sulfuric acid. In the Far East substantial quantities of ammonium chloride are made from ammonia and salt or hydrochloric acid. Ammonium phosphates and nitrophosphates are additional fertilizers derived from ammonia. A principal advantage of most solid forms of ammonia is the ease with which they can be transported and applied to the soil. The high nitrogen content of urea (46 percent) and ammonium nitrate (33.5 percent) make them particularly advantageous.

Most phosphate fertilizers now come from mineral deposits, chiefly those in Florida, the western U.S., North Africa and parts of the U.S.S.R. Although both igneous and sedimentary phosphate deposits exist, about 90 percent of the world's fertilizer needs are supplied from the sedimentary sources because they are more plentiful than the igneous minerals and also easier to mine and process. The origin of sedimentary phosphates has generated much speculation among geologists. Some of them believe that the minerals were precipitated from seawater after it had been saturated with phosphate and fluorine ions derived from the contact of the water with igneous rocks and gases. It is also possible that these phosphates resulted to some extent from the replacement of calcium carbonate with calcium phos-



CORN-LEAF VARIATIONS directly or indirectly related to the amount of nutrients and water available to the plant are depicted. Gray represents green; the other colors are approximately as they appear in nature. *Helminthosporium* blight is a common fungus disease to which poorly nourished plants are vulnerable. Signs of potassium deficiency usually appear at the tips and along the edges of the lower leaves; of nitrogen deficiency, at the leaf tip, and of phosphorus, on young plants. Water shortage makes leaves a grayish-green.

SOURCES	PROCESS	PRODUCT
PHOSPHATE ROCK	GRIND TO ABOUT .1 MILLIMETER	GROUND PHOSPHATE ROCK (0-35-0)
SULFUR AIR WATER	CATALYTIC OXIDATION AND HYDRATION	SULFURIC ACID
PHOSPHATE ROCK SULFURIC ACID	REACT AND CURE	SINGLE SUPERPHOSPHATE (0-20-0)
PHOSPHATE ROCK SULFURIC ACID	DISSOLVE AND FILTER	PHOSPHORIC ACID GYPSUM
PHOSPHATE ROCK PHOSPHORIC ACID	REACT AND CURE	TRIPLE SUPERPHOSPHATE (0-48-0)
HYDROCARBONS STEAM AIR	RE-FORM TO HYDROGEN NITROGEN FROM AIR SYNTHESIZE	AMMONIA (82-0-0)
AMMONIA SULFURIC ACID	REACT AND CRYSTALLIZE	AMMONIUM SULFATE (21-0-0)
AMMONIA PHOSPHORIC ACID	REACT AND CRYSTALLIZE OR GRANULATE	AMMONIUM PHOSPHATE (18-46-0)
AMMONIA AIR WATER	CATALYTIC OXIDATION ABSORPTION	NITRIC ACID
PHOSPHATE ROCK NITRIC ACID AMMONIA	REACT AMMONIATE FILTER	NITROPHOSPHATES (20-20-0) CALCIUM NITRATE (15-0-0)
AMMONIA NITRIC ACID	REACT AND CRYSTALLIZE OR MAKE INTO PELLETS	AMMONIUM NITRATE (33-0-0)
AMMONIA CARBON DIOXIDE	REACT AND CRYSTALLIZE OR MAKE INTO PELLETS	UREA (46–0–0)
AMMONIA CARBON DIOXIDE SALT	CARBONATE AND FILTER AMMONIATE	SODIUM CARBONATE AMMONIUM CHLORIDE (23-0-0)
COAL LIMESTONE NITROGEN	FUSE IN ARC FURNACE NITRIFY	CALCIUM CYANAMIDE (24-0-0)

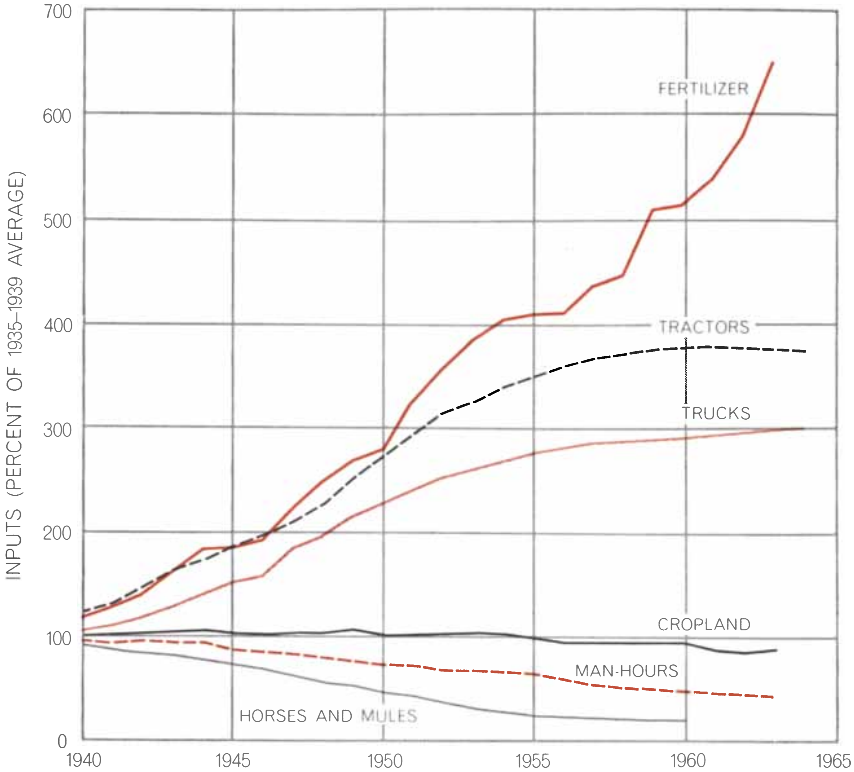
BASIC PROCESSES used in manufacturing the major kinds of chemical fertilizers are charted. Each horizontal line shows the flow of the ingredient listed at left opposite the line. A vertical line shows a combining of ingredients. Numbers in parentheses show respectively the typical percentage of nitrogen, phosphorus and potassium materials used as fertilizer. For example, 0-35-0 means no nitrogen, 35 percent phosphorus pentoxide and no potassium oxide. Figures thus show amounts of primary nutrients.

phate in particles of the mineral aragonite on the ocean floor, a slow process that may still be taking place. Marine deposits of this nature may well become future sources of phosphate.

In any event, most of the primary deposits of sedimentary phosphate were laid down on ocean floor that subsequently became dry land. In time the weathering of such areas removed cementing substances such as calcium carbonate and magnesium carbonate, leaving extensive deposits of phosphate in the form of small pellets. Some of these deposits were later moved by surface water and redeposited elsewhere. Because of this extensive redeposition, and because pellet phosphates are insoluble in water, few minerals are found more widely scattered. By the same token, few have been formed over a longer span of time; phosphate minerals were laid down over the 400 million years from the Ordovician period to the Tertiary period and even later.

Often the phosphate pellets are covered by several feet of sand, clay or leached ore that must be taken off by scrapers or draglines before the phosphate matrix can be removed. In the extensive operations in Florida the matrix is excavated, dropped into sumps, slurried with powerful jets of water and then pumped to the processing plants. The material thus obtained may be only about 15 percent phosphate because of the large amounts of sand and clay in the matrix. Much of the sand and clay is removed by various processes to yield concentrates containing 30 to 36 percent phosphate. These concentrates are then blended and dried before further processing or shipment. Somewhat different methods are used in North Africa; there large tonnages of high-grade phosphate rock are mined by underground methods. Often they are only crushed, screened and dried before shipment.

Several types of fertilizer are made from the phosphate rock processed by the methods I have described. The simplest type consists of high-grade rock ground to particles less than .1 millimeter in size. This type is used directly on acid soils, which slowly attack the water-insoluble phosphate to make it available to plants. Next in simplicity is superphosphate, made by mixing ground phosphate rock with sulfuric acid to form a slurry that quickly hardens in a curing pile. After several weeks the hardened superphosphate is excavated and pulverized; often the powder is formed into granules. The pulverized or granulated material is marketed either alone, as a phosphate fertilizer containing about 18 percent water-soluble phosphorus pentoxide, or in conjunction with other fertilizer materials. The various processing steps convert insoluble tricalcium phosphate to water-soluble monocalcium phosphate and gypsum.



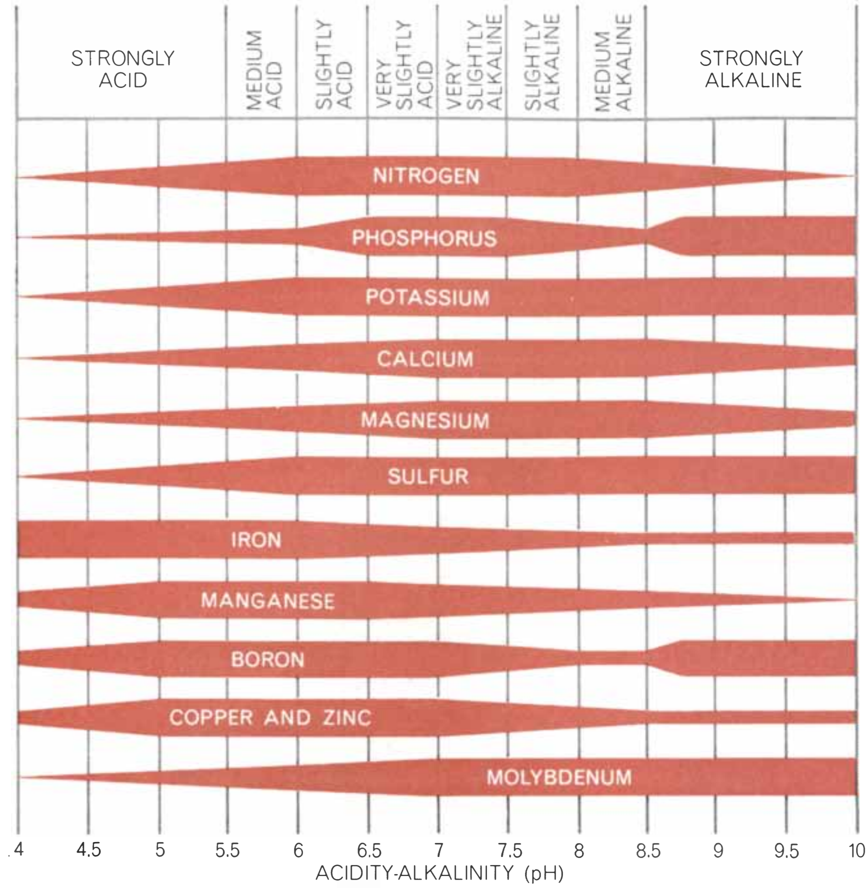
CHANGED TECHNOLOGY of U.S. agriculture over the past 30 years is reflected in a comparison of current inputs with those of 1935 through 1939. The changes are expressed as percentages of the average input in each category for the five-year base period. Concurrent with these changes of input has been a steady rise in the nation's agricultural output.

Gypsum, however, is of little use in soil except when deficiencies in calcium or sulfur exist or when salinity is excessive. It also has a diluting effect on the phosphorus pentoxide content. Therefore it was a substantial advance when methods were devised for producing monocalcium phosphate without gypsum. The technique is to dissolve phosphate rock in a mixture of sulfuric and phosphoric acid to form gypsum and additional phosphoric acid, which can be separated by filtration. Thereafter the gypsum is usually discarded; the phosphoric acid is concentrated and mixed with finely ground phosphate rock to form a slurry that soon hardens into a product known as triple superphosphate. Its content of water-soluble phosphorus pentoxide is about 48 percent. Moreover, the product is cheaper to transport and to apply per unit of phosphorus pentoxide than ordinary superphosphate.

Substantial tonnages of phosphate fertilizers are also made by treating phosphate rock with nitric acid and ammonia to yield a range of materials that contain nitrogen as well as phosphorus. Potash can be added to form high-analysis fertilizers with a content of primary nutrients as high as 60 percent, as for example in a 20-20-20 grade. Another popular fertilizer is diammonium phosphate, which is made by neutralizing phosphoric acid with ammonia to yield a material containing about 20 percent nitrogen and 50 percent water-soluble phosphorus pentoxide. Potash can be added to this product to make another high-analysis mixture containing all the primary nutrients.

Potassium exists in enormous quantities in the rocks and soils of the world. Often, however, it is in the form of insoluble minerals unsuitable for agriculture. Fortunately large deposits of soluble potassium chloride are available, mostly as sylvite and sylvinite or, in conjunction with magnesium, as carnallite and langbeinite. Such deposits are often mixed with sodium chloride in the form of halite, which is toxic to many crops and must be removed.

Extensive supplies of sylvite and



AVAILABILITY OF NUTRIENTS to plants is affected by the condition of the soil. The more soluble a nutrient is under a particular condition of soil acidity or alkalinity, the thicker is the horizontal band representing the nutrient. Solubility in turn is directly related to the availability of the nutrient in an ionic form that is assimilable by the plant.

carnallite were found first in Germany and later in France, the western U.S. and many other countries. Most of these deposits resulted from the evaporation of ancient seas during the Permian period (about 230 to 280 million years ago). In the Canadian province of Saskatchewan huge quantities of sylvite and carnallite were more recently found at depths of 3,000 to 4,000 feet, in the upper portion of a Devonian halite formation. Although these deposits are considerably deeper than U.S. and European potash sources, mining difficulties have now been overcome and the production of several million tons annually of Canadian potash will be of great benefit to world agriculture. Another Canadian development of growing importance is the large-scale production of potash by solution mining, which involves pumping water into the potash beds and bringing the resulting solution to the surface for evaporation and the recovery of potash in solid form.

After solid potash minerals are mined they are sometimes crushed and separated from their impurities by washing and froth-flotation, in which treatment with amine salts and air causes the sylvite particles to float away from the unwanted substances. In other cases potash is recovered by solution and crystallization. The relatively pure product is dried, treated with an amine anticaking agent and sold for agricultural purposes as muriate of potash containing 60 to 62 percent of potassium oxide. Most potash is used in conjunction with nitrogen and phosphorus compounds. Potassium sulfate and potassium nitrate are also used to a limited extent in agricultural situations where the chloride ions of potash would be harmful, as they are to tobacco.

Agronomic Considerations

It is appropriate now to consider the role of nutrients in plant growth, together with some other factors that must be taken into account in the use of fertilizers. As anyone experienced in agronomy or gardening knows, it is wasteful and sometimes even harmful to broadcast fertilizer indiscriminately. The grower must know the condition of his soil and treat it accordingly. In most cases he must apply the bulk of the treatment before sowing, because as a rule most of the nutrient needed by a plant is taken up in the early stages of its growth. The correct nutrient balance is additionally important because a deficiency of any one plant food in the soil will reduce the effect of others, even if they are in oversupply.

A deficiency of nitrogen usually appears in plants as a yellowing of the leaves, accompanied by shriveling that proceeds upward from the lower leaves. The principal effects of nitrogen on plants include accelerated growth and increased yield of leaf, fruit and seed. Nitrogen also promotes the activity of soil bacteria. Nitrate nitrogen is quickly available to root systems, but it may therefore make the plants grow too rapidly. Moreover, nitrate is easily lost by leaching. Ammoniacal nitrogen, on the other hand, is immediately fixed in the soil by ion-exchange reactions and is released to the plants over a longer period than nitrate nitrogen. For these reasons it is sometimes the practice to inject free ammonia in anhydrous or aqueous form a few inches below the surface of a moist soil. With many crops optimum results are obtained by the proper combination of nitrate nitrogen and ammoniacal nitrogen in either solid or liquid form.

Phosphorus deficiency is often represented by purplish leaves and stems, slow growth and low yields. Phosphorus stimulates the germination of seedlings and encourages early root formation. Since these results are less evident than those induced by applications of nitrogen, many farmers, particularly in the Far East, use insufficient quantities of phosphate fertilizer.

Potassium deficiency can often be detected by a spotting or curling of lower leaves. Additional symptoms are weak stalks and stems, a condition that can cause heavy crop losses in strong winds and heavy rains. The application of potassium improves the yield of grain and seed, and it enhances the formation of starches, sugars and plant oils. It also contributes to the plant's vigor and its resistance to frost and disease.

As for deficiencies of secondary nutrients, a lack of magnesium may cause a general loss of color, weak stalks and white bands across the leaves in corn and certain other plants. A calcium deficiency may give rise to the premature death of young leaves and poor formation of seed. An inadequate supply of sulfur frequently leads to pale leaves, stunted growth and immature fruit.

Typical examples of micronutrient deficiency are heart rot in vegetables and fruits as a result of a shortage of boron and stunted growth of vegetables and citrus plants resulting from insufficient manganese and molybdenum. Micronutrient deficiencies may be hard to detect and even harder to rectify, because the balance between enough of a micronutrient and a toxic oversupply can be delicate.

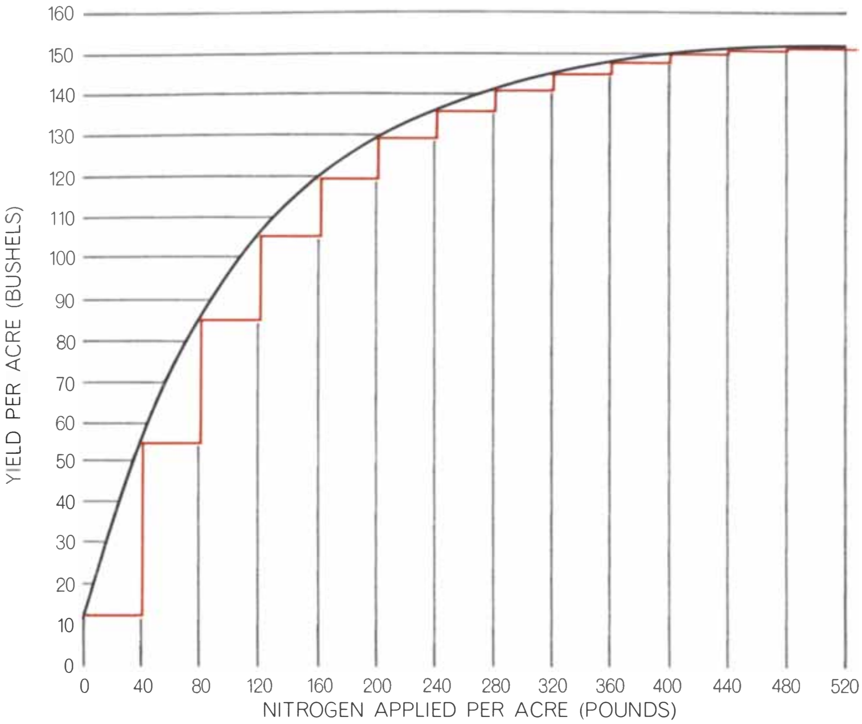
An important consideration in the use of fertilizers is the acidity of the soil, which considerably influences the availability of many nutrients to the plant [*see illustration on opposite page*]. To complicate matters, nitrogen fertilizers such as ammonia, urea ammonium nitrate and other ammonia derivatives can themselves raise the acidity of soils, by means of complex ion-exchange reactions. In most cases the acidity of a soil can be controlled by adding appropriate amounts of lime, ground limestone or other forms of calcium carbonate.

Soil tilth, or structure, is also important. For example, the richer chernozem soils found in the middle of the North American continent and in the Ukraine are in many cases well supplied with organic humus and lime salts and need only regular supplies of plant nutrients to replace those removed by agriculture and leaching. On the other hand, the podzol soils that cover the northeastern U.S., most of Britain and much of central Europe have been intensively leached by centuries of farming and exposure; they need not only liberal supplies of plant nutrients but also lime and organic humus. Desert soils may be rich in certain minerals and yet lacking in available nutrients and in the organic matter usually necessary to retain moisture and to provide good tilth. Such soils can be made productive, however, as has been amply demonstrated in Israel.

Prospective Developments

In spite of the many improvements made in chemical fertilizers during the past 50 years, several problems still confront the fertilizer industry. One major concern is achieving the controlled release of nutrients so that waste and also damage to young plants can be avoided. Methods now being tested in-

TREATMENT PLANT of the V-C Chemical Company in Florida removes organic material and some carbon dioxide from phosphate rock to provide a raw material for making phosphoric acid, which is used in the manufacture of such chemical fertilizers as triple superphosphate and diammonium phosphate. Piles of phosphate rock as brought from the mine are at top right. Horizontal tube in foreground is a calcine kiln in which rock is given thermal treatment. Treated rock is stored in tanks behind kiln until shipped.



FERTILIZER ECONOMICS are indicated by the curve of yield compared with applications of fertilizer. This curve is based on a crop of irrigated corn grown in the state of Washington. With nitrogen as with other fertilizers, crop yields diminish with increasing applications of nutrients. In time additional increments of fertilizer become uneconomical.

SUBSTANCE	APPROXIMATE POUNDS PER ACRE	SUPPLIED BY
NITROGEN	310	1,200 POUNDS OF 25-10-20 FERTILIZER
PHOSPHORUS	120 (PHOSPHATE) 52 (PHOSPHORUS)	
POTASSIUM	245 (POTASH) 205 (POTASSIUM)	
CALCIUM	58	APPROXIMATELY 150 POUNDS OF AGRICULTURAL LIMESTONE
MAGNESIUM	50	APPROXIMATELY 275 POUNDS OF EPSOM SALT, OR 550 POUNDS SULFATE OF POTASH-MAGNESIA
SULFUR	33	33 POUNDS OF SULFUR
IRON	3	15 POUNDS OF IRON SULFATE
MANGANESE	.45	APPROXIMATELY 1.3 POUNDS OF MANGANESE SULFATE
BORON	.10	APPROXIMATELY 1 POUND OF BORAX
ZINC	TRACE	SMALL AMOUNT OF ZINC SULFATE
COPPER	TRACE	SMALL AMOUNT OF COPPER SULFATE OR OXIDE
MOLYBDENUM	TRACE	VERY SMALL AMOUNT OF SODIUM OR AMMONIUM MOLYBDATE
OXYGEN	10,200	AIR
CARBON	7,800	AIR
WATER	3,225 TO 4,175 TONS	29 TO 36 INCHES OF RAIN

NUTRIENTS REQUIRED to produce 150 bushels of corn are indicated. Most plants take all their nutrients from the soil except carbon, oxygen and hydrogen, obtained from the air.

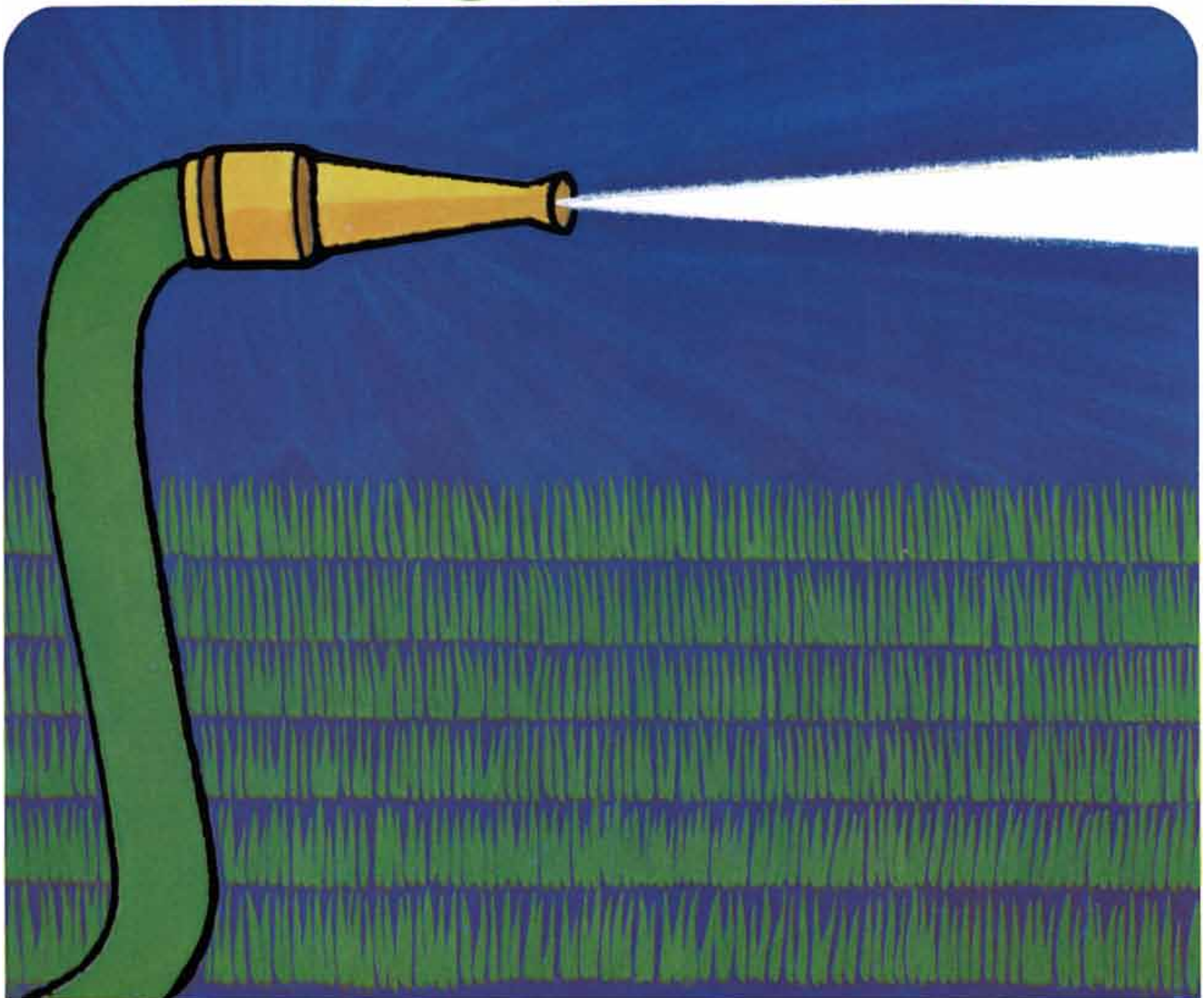
clude the use of slowly decomposing inorganic materials such as magnesium ammonium phosphate and synthetic organic compounds such as formamide and oxamide. Another technique being studied is the encapsulation of fertilizer particles with sulfur or plastic. Investigators are also exploring the possibilities of producing chemical fertilizers in which a plant nutrient would be "sequestered" in molecules of the chelate type. Chelation involves a tight molecular bonding that would protect the nutrient against rapid attack. In this way the desired plant food would be released slowly and in a prescribed manner by chemical reactions in the soil. An ultimate possibility is the production of "packaged" granules, each containing a seed and whatever substances are needed during the lifetime of the plant. They would be released in the proper amounts and sequence.

A new agricultural technique already in use on a small scale is "chemical plowing." Instead of turning stubble and cover crops into the ground mechanically, the farmer kills them by spraying them with the appropriate herbicides. Eventually the dead plant materials become sources of humus and plant nutrient. Any excess of herbicide is rendered harmless by the action of soil colloids. New seeds and fertilizer are drilled directly through the dead cover material, which also gives protection against erosion, frost and drought.

Efforts are also under way to reduce the cost of transporting fertilizers and their raw materials. The approach here is to try to produce them in highly concentrated liquid or solid form. They are then appropriately diluted or combined at the point of use.

Perhaps the most vital work is the education of farmers—particularly farmers in the developing countries—in modern agricultural methods, including the use of chemical fertilizers. In addition the developing nations must establish low-cost credit plans so that impoverished farmers can buy adequate supplies of fertilizer. Similarly, credit must be extended by the developed nations to the less developed ones on an even bigger scale than at present in order to help the less developed nations obtain the materials, equipment and expert advice they need to build their own chemical fertilizer plants. Until these steps are taken to spread modern agricultural technology, the developing nations will fall far short of the contribution they could make to the intensifying problem of producing enough food for the world's growing population.

INNOVATION!



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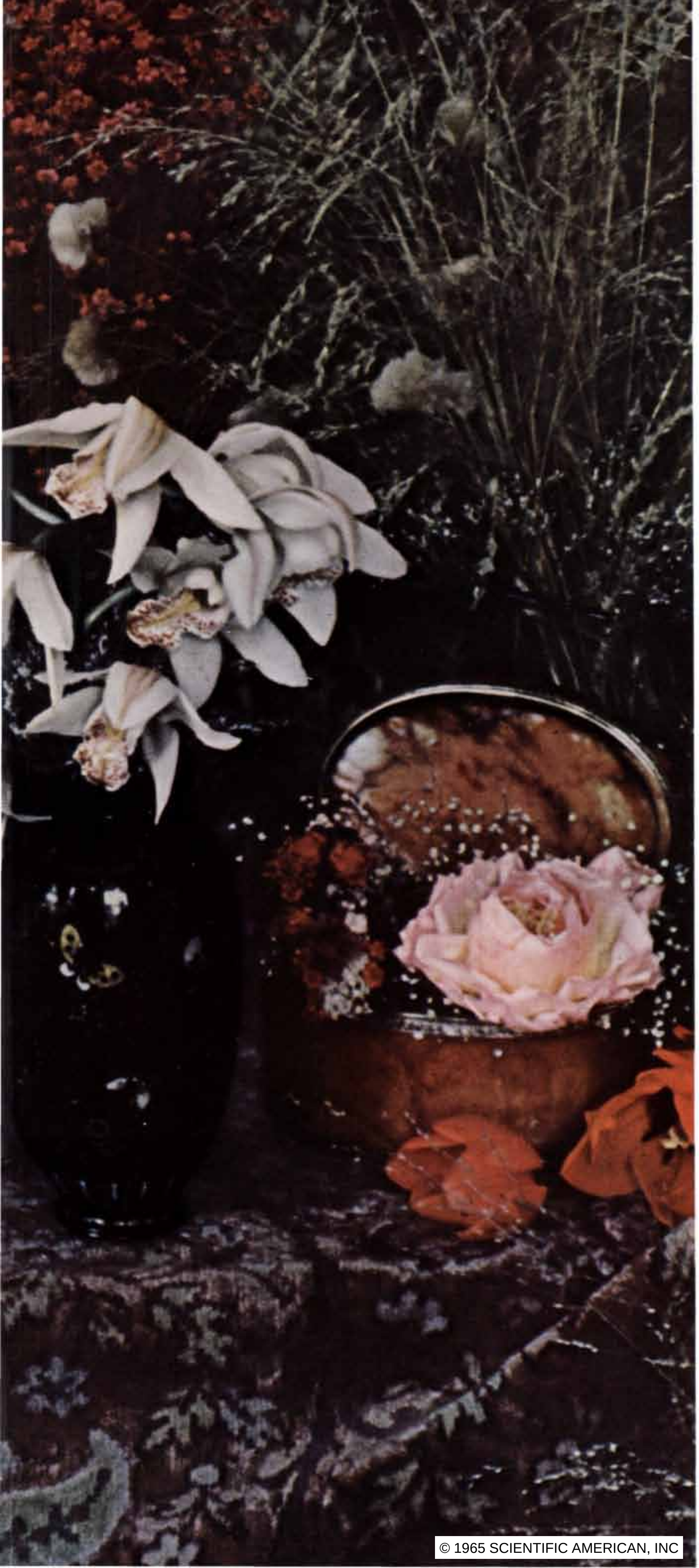
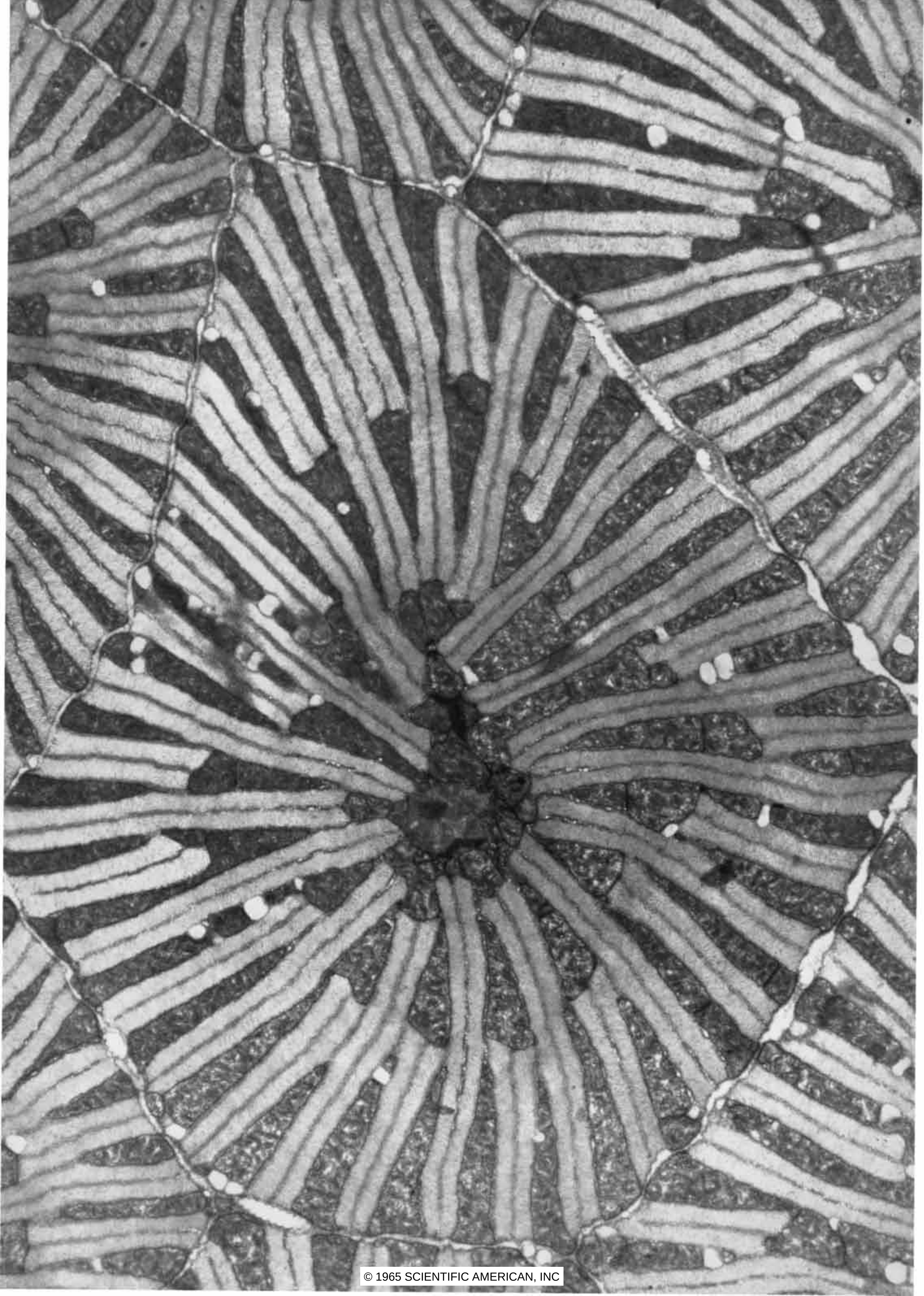




The Flight Muscles of Insects

The wings of some insects beat hundreds of times per second. The two kinds of muscle that power insect flight give clues to the operation of muscle throughout the animal kingdom

by David S. Smith

The voluntary muscles of almost all animals have an important feature in common: a single nerve impulse gives rise to a single response from a muscle. A significant exception is apparent in the flight of certain insects: their wings can beat many times faster than the most rapid rate at which a muscle responding to a series of nerve impulses can alternately contract and relax. Weight for weight the flight muscle of such insects generates more energy than any other tissue in the animal kingdom, and numerous investigators have attempted to find out how it does so. Before I relate some recent developments in the field the reader may find it helpful to have a few pertinent facts about the evolution of insects and about the study of muscle in general.

Some 350 million years ago—during the Devonian period or perhaps the early Carboniferous—the distant ancestors of today's insects made their first evolutionary experiments with flight. So far the fossil record has not revealed what type of insects these were nor what they looked like, but most students of the matter agree that the first advance was probably the appearance in some insects of stationary horizontal fins that enabled them to glide through the air. These gliding insects were superseded by the true winged insects, whose fins were larger and could be moved up and down around the point at which they joined the body.

FLIGHT MUSCLE of a damselfly is shown enlarged 9,000 diameters in the electron micrograph on the opposite page. The cells are seen end on; the individual fibrils in which contraction takes place form a radial array (*light areas*). Between them are mitochondria (*dark areas*) that furnish the required power. Oblong fibrils are typical of primitive synchronous muscle, the less energetic of the two kinds of flight muscle.

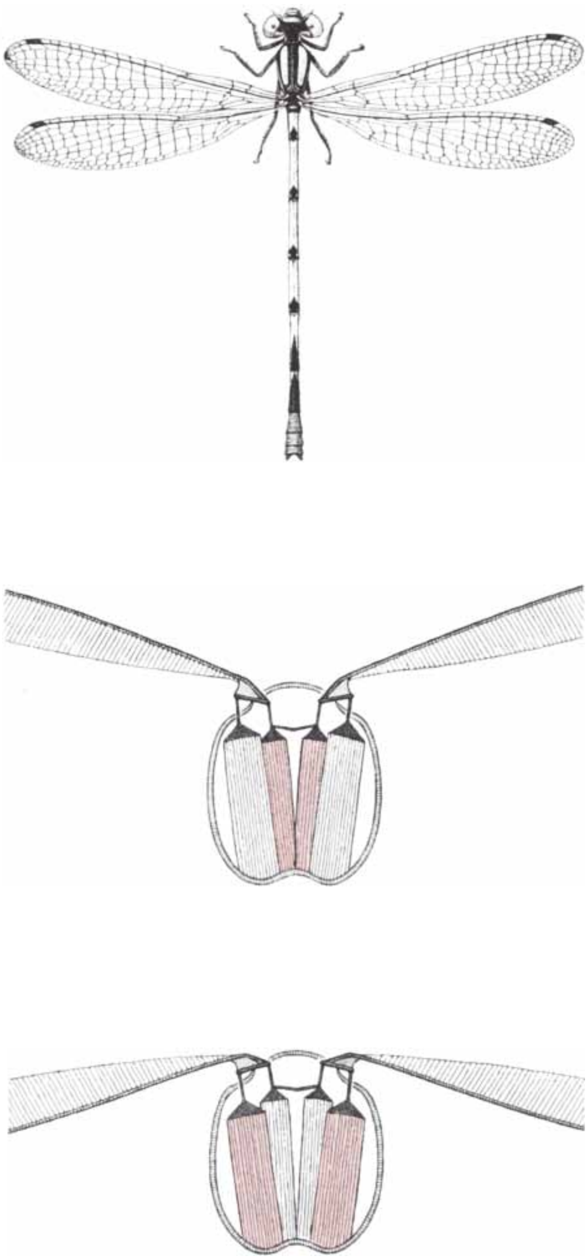
Insects of course have an external skeleton, and they move by means of muscles that act on jointed parts of this more or less rigid shell. As insects evolved movable wings they also had to develop muscles to power them; it is believed that at first certain muscles of the legs and body wall were called into service. Insects, however, are highly diversified, and the various orders of flying insects exhibit many different mechanisms of flight. Everyone is familiar with the differences represented by the dancing flight of a butterfly, the hovering flight of a dragonfly and the remarkably maneuverable flight of the housefly and the honeybee.

It is insects of the last kind—the housefly and the honeybee—that are among those whose wings beat at a high rate. This can readily be perceived, but it was not until 1949 that the flight muscle of such insects was recognized as being physiologically unique. In that year J. W. S. Pringle, who was then at the University of Cambridge, was studying the main flight muscles of the blowfly. He observed that nerve impulses arrived in the muscles at a rate that was similar to the rate of nerve impulses arriving in other muscles, but that this rate was much slower than the rate at which the insect's wings beat. Earlier workers had found that cutting off portions of flies' wings had the effect of speeding up the beat; Pringle suggested that the rate of beat was determined not by the nerve impulses but by the load—in terms of wing area—imposed on a natural rhythm that was produced within the flight muscles themselves.

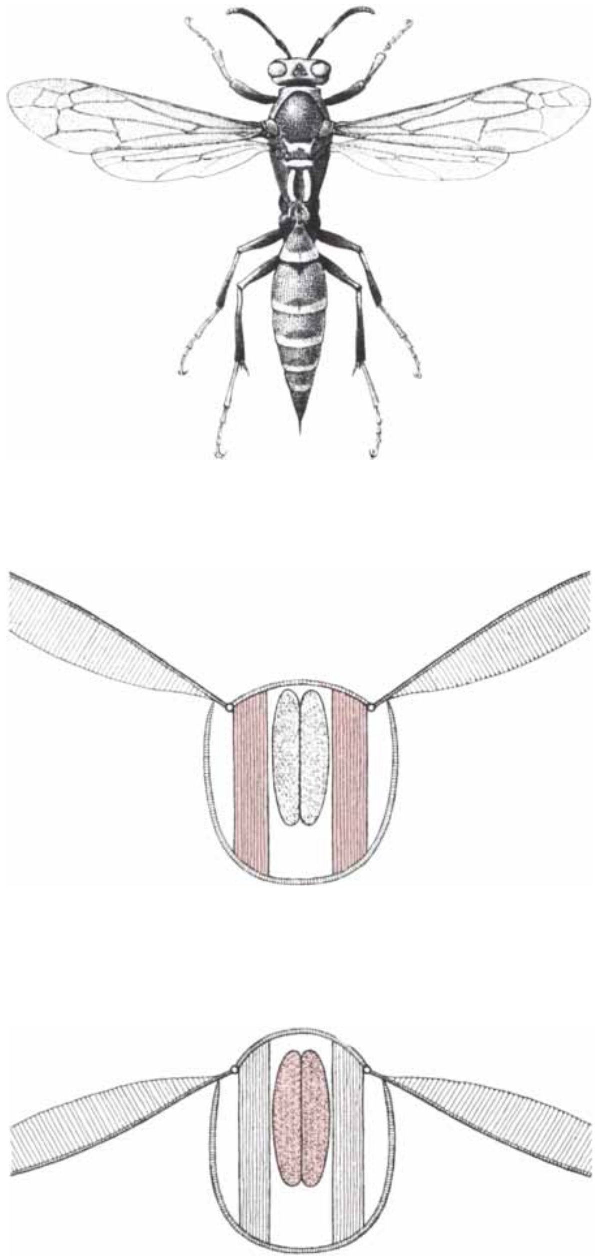
Later studies by Pringle, by Edward G. Boettiger of the University of Connecticut and by Kenneth D. Roeder of Tufts University showed that flight muscles of this kind are found in insects of only four of the 30 or so recognized insect orders: the beetles (Coleoptera); the wasps and bees (Hymenoptera); the flies, mosquitoes and similar forms (Diptera), and certain true bugs (Hemiptera), including the aphids. Because such muscle contracts and relaxes at a much higher rate than the nerve signals it receives it is called asynchronous muscle; the flight muscle of other insects contracts and relaxes in exact response to nerve signals (as do the skeletal muscles of vertebrates) and is therefore called synchronous.

A few examples will make clear just how extraordinary the performance of asynchronous muscle is. O. Sotavalta of the University of Helsinki has measured the wingbeats of many insects; the wings of the swallowtail butterfly, for instance, oscillate through five cycles per second and those of the dragonfly through 35 cycles per second. Both insects have synchronous flight muscles; indeed, these frequencies are within the range of performance of vertebrate skeletal muscles. Among the insects with asynchronous flight muscles, beetles beat their wings at frequencies between 55 and 175 cycles per second, the honeybee at frequencies between 208 and 247 cycles and the mosquito at frequencies as high as 587 cycles. One midge (*Forcipomyia*) attains the almost incredible rate of 1,046 cycles per second. The special tissue that powers this sort of performance has been of great importance in the evolution of body shape and wing size in the insects that possess it; synchronous muscle can drive the large, lightly loaded wings of the butterfly but would be quite unable to lift the relatively bulky, small-winged body of a fly or bee.

Toward the end of the 19th century,



SYNCHRONOUS FLIGHT MUSCLE distinguishes all but four orders of insects; illustrated is a damselfly of the genus *Enallagma*. As the first thorax section shows (*middle*), contraction of an inner pair of muscles, applying force to a lever-like portion of the wing base, raises the wings. Then a more robust outer pair of muscles contracts to provide the downward power stroke (*bottom*). The muscles are called synchronous because each contraction is in response to a separate stimulus from the central nervous system.



ASYNCHRONOUS FLIGHT MUSCLE has evolved among bees and wasps, flies and mosquitoes, beetles and some bugs; shown here is a wasp of the genus *Polistes*. The muscle arrangement is antagonistic: the outer bundles contract vertically and the inner ones horizontally. Both do so alternately and in an oscillatory fashion. The contractions deform the wasp's thorax so that the wings are driven up (*middle*) and then down (*bottom*). This cycle is much faster than the nerve-signal rate, hence the muscle is called asynchronous.

when ideas about the structure of muscle almost equaled the number of investigators interested in the matter, it was realized that vertebrate skeletal muscle, in contrast to "smooth" muscle such as that of the vertebrate intestine, is "striated." This is to say that each of the many fibers, or cylindrical cells, comprising such muscle appears regularly striped or banded when it is viewed in the light microscope. These striations are present whether the fiber is living or has been fixed and sectioned; moreover, their pattern changes during the cycle of contraction and relaxation. There were various interpretations of what the striations meant. Some investigators thought they were part of a contractile network embedded in a gelatinous ground substance; others held that the ground substance alone was able to contract.

At that time insect muscles were widely examined in the microscope as a convenient tissue for the study of muscle. The German anatomist Anton Kölliker showed in 1888 that the individual cells of some insect flight muscles could be teased apart into tiny fibrils, or cylindrical subunits, each with a diameter of about two microns (.002 millimeter). The fibrils too were banded; when they were lined up side by side, they presented the characteristic striped appearance of the whole fiber. Kölliker also observed small spherical objects in the sarcoplasm: the fluid-filled space between the individual fibrils of the muscle cell. These spherical bodies, named sarcosomes, took up stains and dyes in the same way another cellular subunit did; this was the rodlike mitochondrion, which microscopists were then discovering in many types of cells. The two later proved to be identical.

These early observations with light microscopes go a fair way toward providing a basic model of striated muscle. Whether the muscle is vertebrate or invertebrate, each cell is a cylinder containing contractile fibrils in a sarcoplasmic matrix. In recent years, however—particularly during the past decade—biologists have been able to refine the model by using the electron microscope, which of course provides far higher magnification and resolution than the light microscope. Electron microscopy has made it possible to describe the structures within the muscle cell in considerable detail and has contributed much to modern theories of muscle contraction and relaxation and of the processes by which energy is supplied to the contractile mechanism.

On the basis of electron-micrograph studies H. E. Huxley of the University of Cambridge and Jean Hanson of King's College have developed the now generally accepted model of vertebrate muscle-fibril structure and function [see "The Contraction of Muscle," by H. E. Huxley; Scientific American, November, 1958]. They found that the fibril subunit was itself composed of subunits; cross-sectional micrographs looking, as it were, at the fibrils from the side reveal that each fibril is made up of two overlapping sets of filaments. The filaments of one set are thick and those of the other are thin; cross-sectional micrographs looking at the filaments from the end show that they lie together in a hexagonal array [*see illustration on this page*]. The thick filaments are made up of the protein myosin; the thin ones, of the protein actin. Huxley and Hanson propose that a muscle fibril contracts and relaxes not by any change in the length of its constituent filaments but by the fact that two sets of filaments slide past each other. The energy required for the sliding process is provided by adenosine triphosphate (ATP), and the utilization of this molecule within the fibrils during contraction requires the presence of calcium ions.

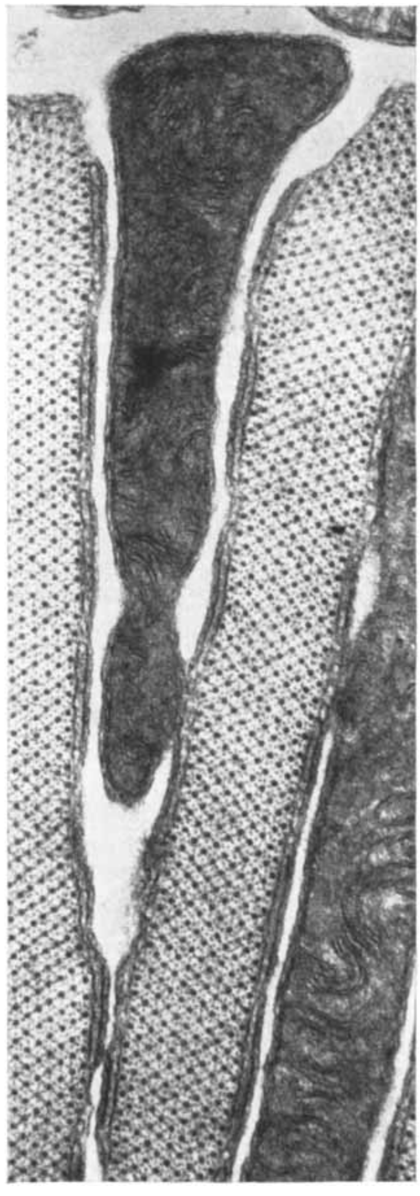
The contraction of a muscle cell is preceded by a chain of events, the first of which is the arrival of a nerve impulse at one or more localized regions where the endings of motor nerves are quite close to the muscle cell's thin surface membrane. A transmitter substance is released from the nerve ending into the narrow gap between the membranes of nerve and muscle; it initiates a wave of electrical activity—a loss of electrical polarity by the muscle membrane—that spreads over the whole fiber. A few milliseconds after the nerve impulse has arrived at the surface of the muscle cell the cell starts to contract.

This is only part of the story, and yet even this part presents an acute problem. Some 15 years ago A. V. Hill of the University of Cambridge pointed out a paradox: the response to electrical depolarization is so swift that even the fibrils farthest from the surface of the muscle cell begin to contract before it seems possible for any substance to have diffused inward from the depolarized surface membrane. The solution to this paradox was to remain unknown for more than a decade.

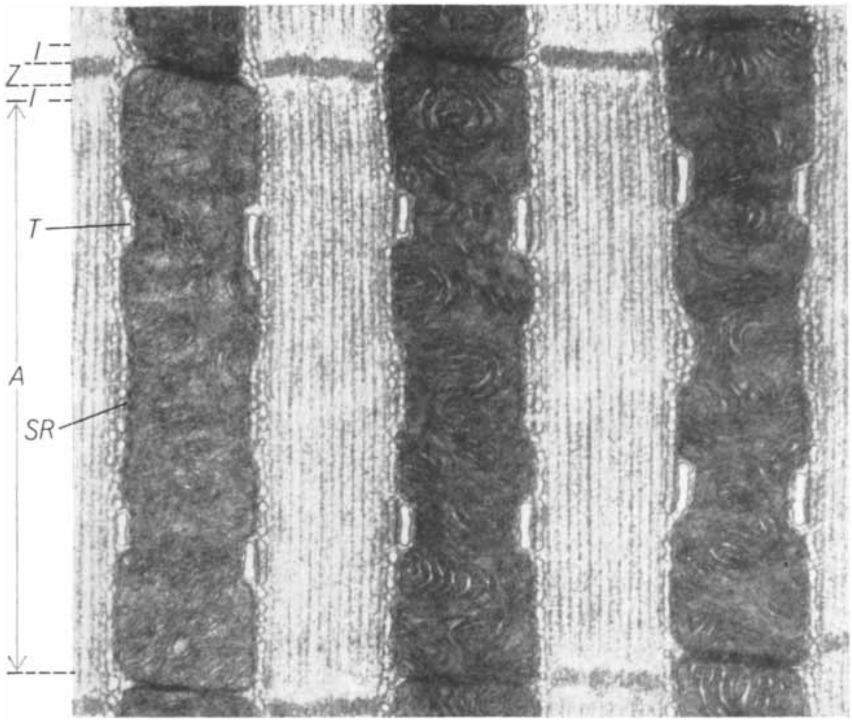
As I have indicated, in vertebrate muscle each nerve impulse gives rise to a single contractile event. In "fast" muscles (muscles that are able to contract and relax quickly) the event is a discrete twitch; in "slow" muscles successive impulses advance the contraction in a stepwise manner. A fast-muscle cell has only one junction with a nerve fiber; a slow-muscle cell has several junctions.

With these facts as background, the similarities and differences between vertebrate and insect muscle can now be examined. All insect muscle fibers resemble the "slow" fibers of vertebrates in having several nerve-muscle junctions rather than one. Electron micrographs of insect muscle show that the structure of these synapses between nerve and muscle is similar to that in vertebrates: the end of the axon—the elongated portion of the nerve cell—is in close contact with the membrane of the muscle cell and contains concentrations of vesicles, or minute sacs. Bernhard Katz of University College London and his co-workers have advanced the hypothesis that these synaptic vesicles hold "packets" of a transmitter substance that in the case of vertebrate synapses has been identified as acetylcholine. Although it is not definitely known what the insect transmitter substance is, it seems safe to infer that insect and vertebrate nerve endings have a common mechanism of transmitter-substance release.

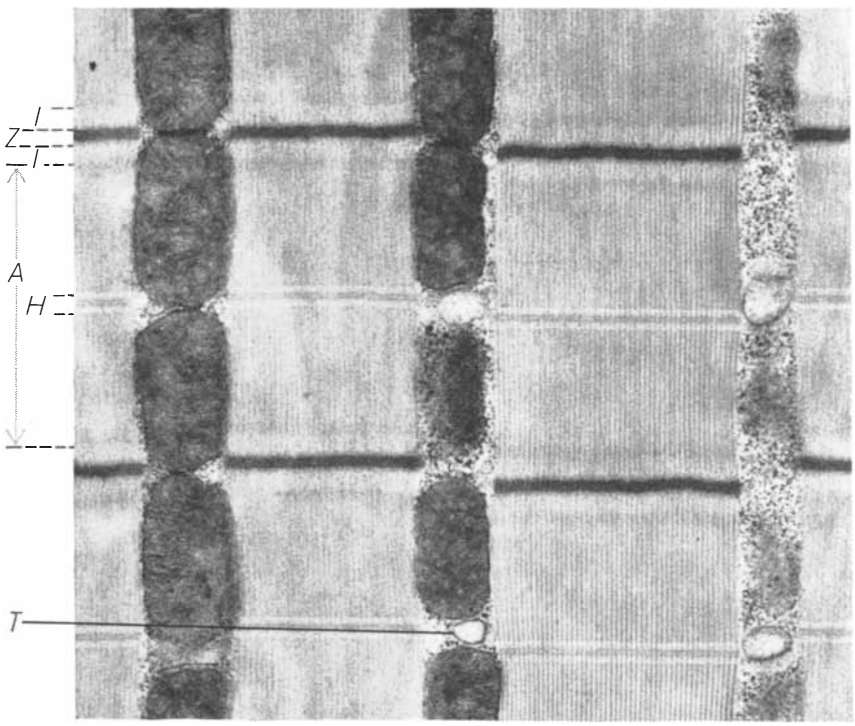
The damselfly *Enallagma*—a familiar fluttering insect of streams and lakesides—provides an example of synchronous insect flight muscle in action. The insect's thorax, or mid-body, is divided into three segments; its flight apparatus consists of two pairs of wings, one pair mounted on the middle thoracic segment and the other on the rear segment. The segments are almost completely filled with the muscles that beat the wings [*see illustration at left on opposite page*]. Each muscle is made up of many separate fibers packed tightly together; each fiber is between 20 and 30 microns in diameter, a size common in vertebrate muscle. A low-power electron



FIBRIL SUBUNITS lie in a geometric array; the large dots are filaments of the protein myosin, the small are actin. These fibrils, seen end on and enlarged 50,000 diameters, are from dragonfly flight muscle.



SYNCHRONOUS MUSCLE, seen in longitudinal section enlarged 40,000 diameters, shows the subunits of muscle cells along their long axes, bounded at each end by dark transverse "*Z* lines." These lines are flanked on both sides by narrow, light "*I* zones," whereas the bulk of each subunit is composed of a wide, medium-density "*A* band." One of the tubules comprising the "transverse" system of ducts is labeled *T; SR* identifies the chains of vesicles making up the sarcoplasmic reticulum that separates fibril from adjacent mitochondrion.

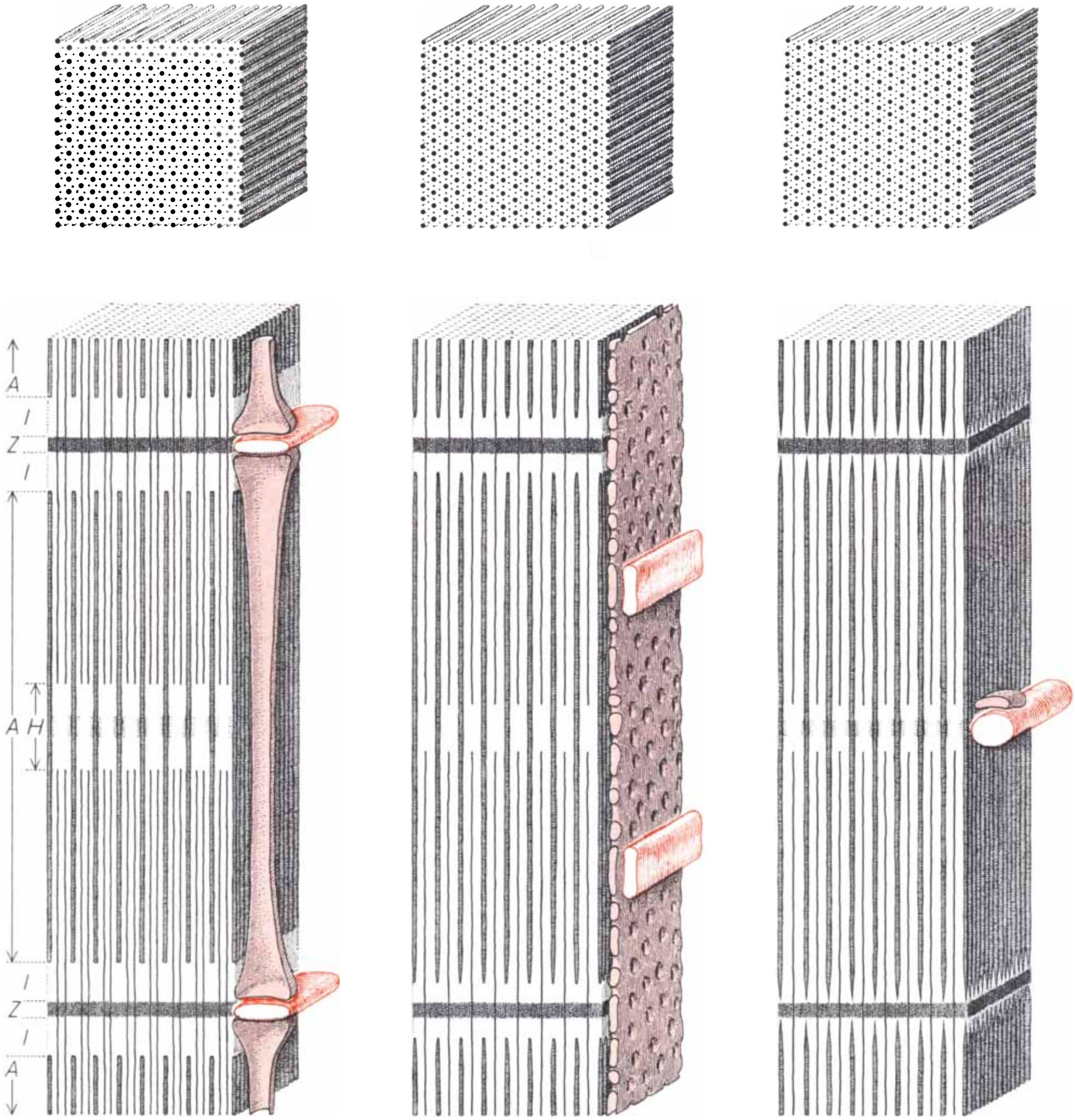


ASYNCHRONOUS MUSCLE, also in longitudinal section but enlarged only 16,000 diameters, contains subunits similarly bounded by dark *Z* lines flanked by narrow *I* zones. Each broad *A* band, however, is bisected by an "*H* zone" that is precisely aligned with the tubules of the transverse duct system (*most clearly visible among the mitochondria at center and right*). One major difference between this and synchronous flight muscle is the virtual absence of sarcoplasmic reticulum vesicles (*see illustration on opposite page*).

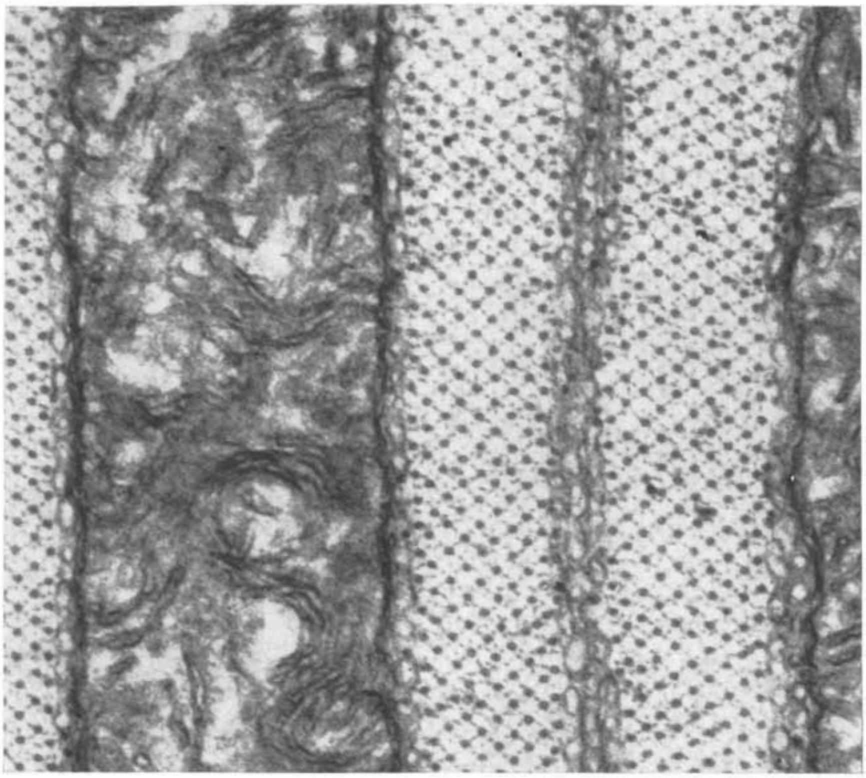
micrograph of these fibers in transverse section shows the striking arrangement of their contents: the sheetlike contractile fibrils form a radial array and alternate with dense mitochondria [*see illustration on page 76*]. At higher magnification the fibril structure is further resolved into its thick and thin filaments of myosin and actin, arranged in a hexagonal lattice. The radial arrangement of the sheetlike fibrils in damselfly flight muscle is typical of the leg and body muscles of insects in general, which are also synchronous.

There is a correlation between the metabolic activity of a muscle fiber and the number of mitochondria within it; these bodies house the enzymes that manufacture the ATP molecules necessary for muscular contraction [see "The Mitochondrion," by David E. Green; SCIENTIFIC AMERICAN, January, 1964]. One of the characteristic features of insect flight muscle, which is metabolically the most active insect tissue, is that it contains large numbers of mitochondria. As an example, although the damselfly has preserved in its flight muscle the primitive radial pattern of fibrils evolved in leg and body muscle, there is a great difference between the two kinds of tissue: to cope with higher metabolic demand the flight muscles have been much more abundantly endowed with mitochondria. Whether synchronous or asynchronous, however, most insect flight muscle has departed from the radial pattern of fibril organization; instead the contractile part of the fiber is divided into fibrils that are circular when seen in transverse section. Butterfly flight muscle, for example, contains cylindrical fibrils about which large mitochondria are wrapped [*see bottom illustration on page 82*].

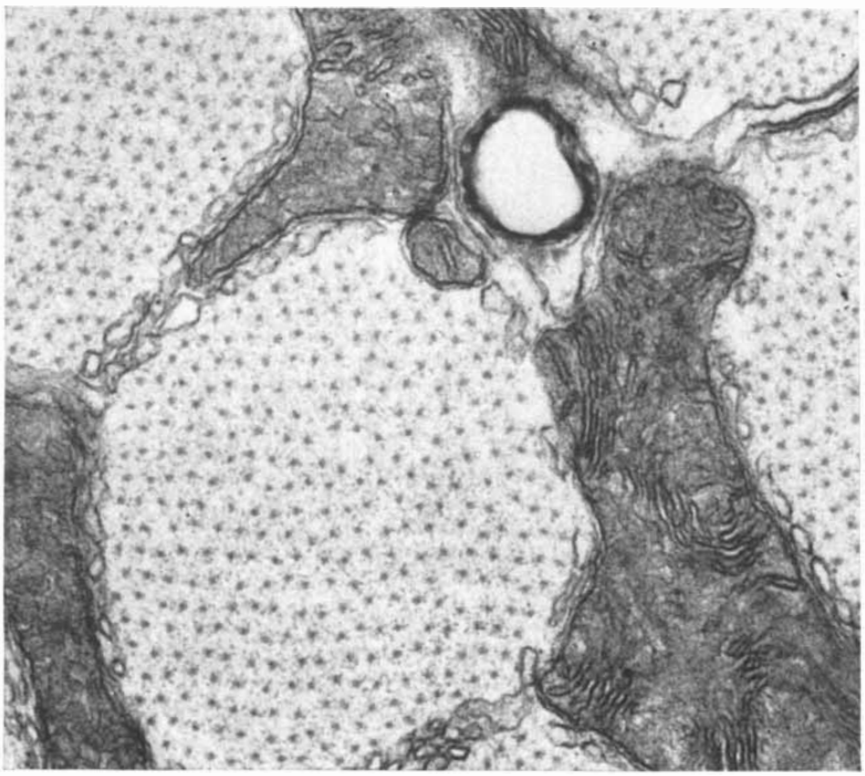
One of the contrasts between insect and vertebrate muscle involves their provision for the supply of oxygen (and the removal of carbon dioxide). In vertebrates oxygen reaches all the organs in chemical combination with hemoglobin, the respiratory pigment of the red blood cells; in vertebrate muscles blood capillaries are located between the fibers. In insects the situation is different: the fluid hemolymph in the insect's body cavity contains no respiratory pigment. Instead atmospheric oxygen diffuses to the cells throughout the insect's body by way of a branching system of tubes—the tracheae—that are open to the exterior. The finest branches of this ramifying system are called tracheoles; they are present most abundantly in the organs that have the highest oxygen requirement—notably the flight muscles. Insect leg muscles (and flight muscles such as those of the damselfly, in which the diameter of the muscle fiber is rather small) are equipped with tracheoles that pass between the fibers as the capillaries in vertebrate muscle do; the oxygen simply diffuses inward from the surface of the fiber. In most insect flight muscles, however, the tracheolar system brings the oxygen much closer to the mitochondria by passing deep into the fibers, rather like fingers pushed into a toy balloon. (The tracheoles do not actually penetrate the muscle fiber; they are sheathed in the muscle cell's thin external membrane.) The result of this arrangement is that oxygen does not have to diffuse across the entire radius of the flight muscle



THREE KINDS OF MUSCLE are compared schematically at the level of fibril structure. At left is a vertebrate fibril; in center, an insect synchronous fibril; at right, an insect asynchronous fibril. The forward face of the cube above each of the longitudinal sections shows the hexagonal pattern formed by the filaments of myosin and actin when viewed in transverse section. The zones and lines that give muscle fiber its characteristic striated appearance are labeled at left. Asynchronous muscle is structurally different from the other kinds in two major respects. The tapering ends of its myosin filaments appear to reach almost to the *Z* line; actin filaments alone occupy the *I* zones bordering the *Z* line in other relaxed muscles. Although asynchronous muscle contains *T*-system tubules (*color*) as do other muscles, the membrane linked to fibril relaxation, the sarcoplasmic reticulum (*tint*), is greatly reduced.



PRIMITIVE SYNCHRONOUS MUSCLE is characteristic of the dragonfly and damselfly; the platelike fibril structure is very much like that of insect leg and body muscle in general but the flight muscles are far more abundantly equipped with energy-supplying mitochondria. This is a transverse section of a damselfly flight muscle, enlarged 70,000 diameters.



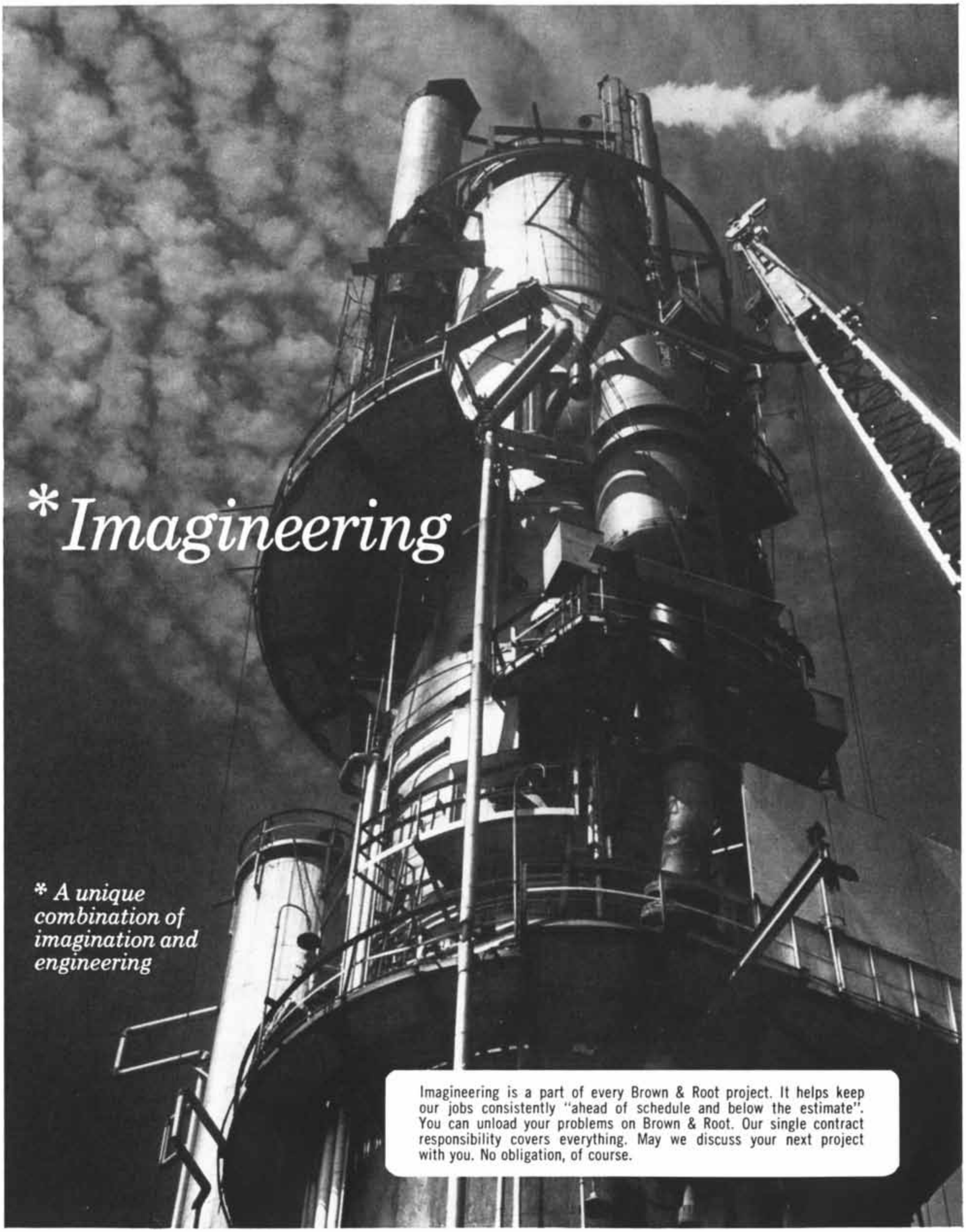
ADVANCED SYNCHRONOUS MUSCLE has its fibrils distributed in cylindrical rather than platelike structures; the mitochondria are wrapped around these cylinders. This is butterfly flight muscle in transverse section, enlarged 70,000 diameters. The tube at the top is a tracheole, part of the system that carries oxygen to and carbon dioxide from the tissues.

fiber but only across a much shorter distance—on the average about five microns.

The existence of this network for oxygen supply hints at the solution to Hill's paradox concerning surface excitation and interior response. Could there not be some structure, similar to the structure for oxygen transport, that would channel excitatory signals deep into the muscle cell? If so, the signal would have to travel only a micron or so to influence the innermost fibrils. As has only recently been made clear, such a structure does exist. Called the *T* (for transverse) system, it extends deep into muscle fiber in association with a separate system of ducts and cavities known as the sarcoplasmic reticulum [see "The Sarcoplasmic Reticulum," by Keith R. Porter and Clara Franzini-Armstrong; SCIENTIFIC AMERICAN, March].

Even after electron microscopy had revealed the *T* system of vertebrate muscle in detail, it was uncertain that its component tubules actually communicated with the exterior of the muscle cell. By means of a simple but elegant experiment Huxley has shown that the system is indeed open to the exterior. He soaked fibers of frog muscle in a solution of ferritin, a protein that contains iron particles .011 micron in diameter. These particles are readily recognized in electron micrographs, and in examining thin sections of soaked muscle Huxley found the iron in the tubules of the *T* system. The particles were never found in any of the cavities of the sarcoplasmic reticulum. Clearly the *T* system is an extension of extracellular space throughout the muscle cell. If very large molecules such as ferritin can diffuse freely through this system, it scarcely presents a barrier to the diffusion of ions and of molecules of a transmitter substance. Thus Hill's paradox is solved; a path is open so that excitation both at the surface and in the interior of the muscle fiber can be virtually simultaneous.

In insect muscle—except for asynchronous muscle—the organization of the *T* system is quite as clear-cut as it is in vertebrate muscle. The two systems are not identical, however. The striations of striated muscle consist of a repeating pattern of "*Z* lines" and "*A* bands." The light region between each *Z* line and *A* band is the "*I* zone"; the *A* band is also bisected by an "*H* zone." In vertebrate muscle the *T* system lies at right angles to the long axis of the muscle fiber, either in the plane of the *Z*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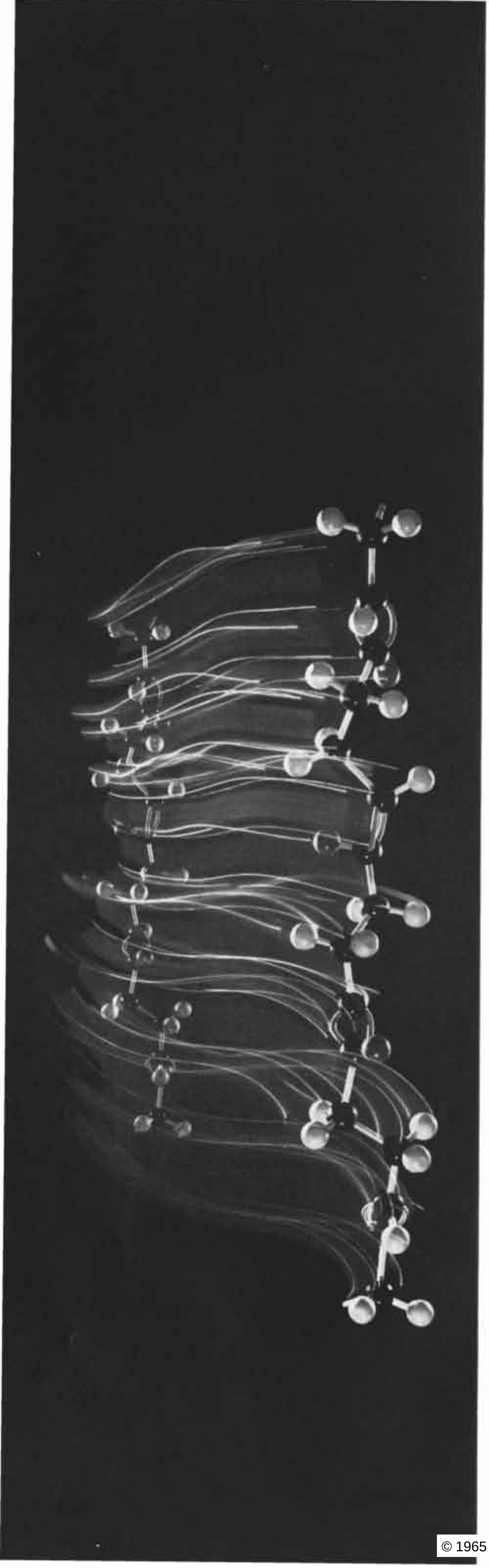

One of a series briefly describing GM's research in depth

Tales of Restless Nuclei

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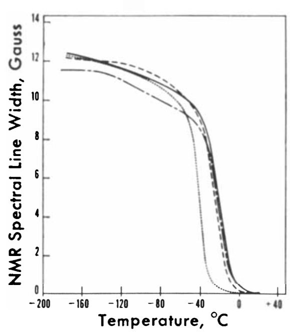
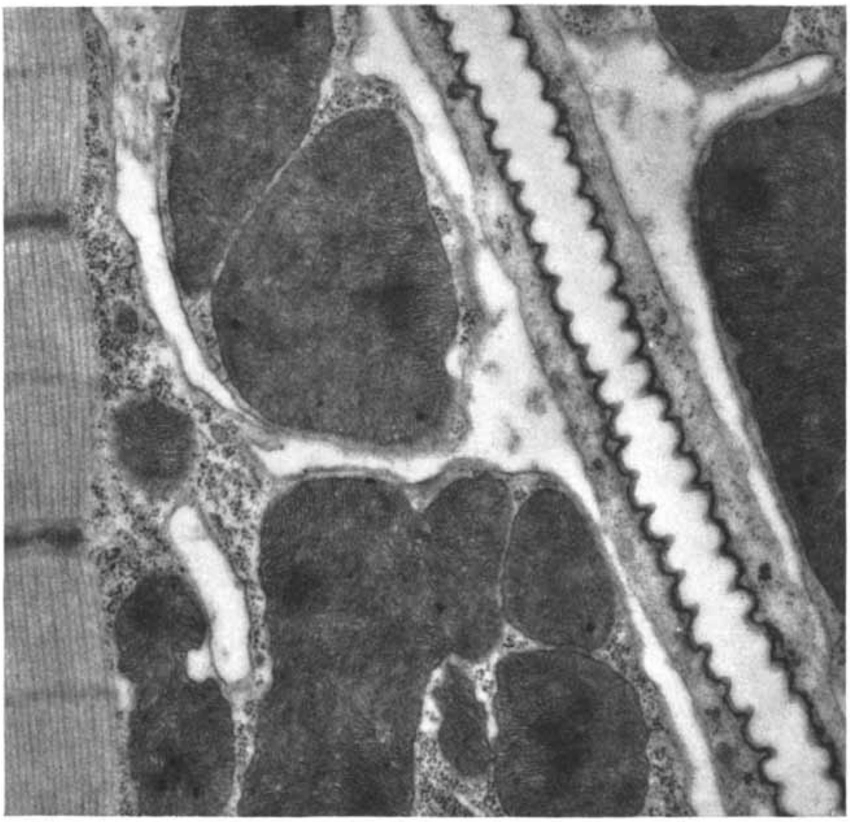


Effects of plasticizers on NMR spectrum of neoprene. The best plasticizer produces spectral line narrowing (due to increased molecular motion) at lowest temperature.
—From a recently published GMR paper.



APHID FLIGHT MUSCLE, seen in longitudinal section and enlarged 16,000 diameters, is somewhat less regularly organized than the flight muscle of a wasp, although it is also asynchronous. The fibril (*left*) shows orderly banding, but the tubules of the *T* system (*light areas at top left, center and top right*) are neither uniform in shape nor aligned with the fibril bands. The indented diagonal structure is one of the tubes of the tracheolar system.

line or in the plane at the junction of the *A* band and the *I* zone [*see illustration on page 81*]. In insect muscle the *T* system lies instead in a plane midway between the Z line and the *H* zone. This arrangement is shown in longitudinal section in the top illustration on page 80 and in transverse section in the illustration on page 79.

The sarcoplasmic reticulum is at right angles to the *T* system; that is, it is oriented along the long axis of the muscle fiber. Its function is probably to provide regions of concentration for calcium ions in resting muscle fiber; the arrival of an excitation in the tubules of the *T* system evidently triggers the release of these ions from the sarcoplasmic reticulum, thus initiating the breakdown of ATP that powers the contraction of the fibrils. The sarcoplasmic reticulum then recaptures the activating ions, thereby halting the breakdown of ATP within the fibrils and allowing them to relax.

Although this picture of calcium ions being rapidly shuttled into and out of the fibrils has been put together on the strength of experiments with vertebrate muscle, the synchronous flight muscles of insects have an equally well-developed sarcoplasmic reticulum. In damselfly muscle fibers the sarcoplasmic reticulum almost fills the sarcoplasm between the elements of the *T* system; in butterfly muscle the sarcoplasmic reticulum is seen as chains of vesicles around transversely sectioned fibrils. Hence it appears that physiologically similar muscles in organisms as widely separated in the evolutionary scheme of things as insects and mammals are constructed on the same plan. The muscles contain not only the specialized array of protein filaments whose movements enable the muscle to do work but also the intricately related internal membranes that ensure that the muscle fibers give correctly timed responses to the directions issuing from the central nervous system.

In what ways has insect evolution modified normal synchronous striated muscle and enabled it to work in asynchronous fashion? The paper wasp *Polistes* will serve as an example of an insect whose wing mechanism is driven by these evolutionarily advanced fibers. Its bulky middle thoracic segment is almost filled with horizontal and vertical blocks of flight muscle. They serve to drive both pairs of wings, which are coupled together and work as one. The two sets of muscles, aligned at right angles to each other, contract alternately; each action slightly deforms the shape of the thorax, and this in turn operates a delicate lever mechanism at the base of each wing. Contraction of the horizontal fibers lowers the wings and contraction of the vertical fibers raises them; they click up and down in time with the oscillatory shortening of the two antagonistic sets of muscles.

Electron micrographs immediately reveal one structural difference between asynchronous and synchronous muscle. This is in the way the myosin and actin filaments are fitted together at the ends of each repeating unit of striations. In relaxed synchronous muscle the *I* zones contain only filaments of actin; during contraction the ends of the myosin filaments are thought to slide into this region. In asynchronous muscle, however, the myosin filaments have tapered ends that seem to reach the central Z line. There they meet the actin filaments in a complicated arrangement; this has been shown by the work of J. Auber and R. Couteaux of the University of Paris.

When an asynchronous muscle contracts, it shortens much less than a synchronous one, but this fact has shed no light on how the myosin filaments of asynchronous muscle move in the vicinity of the Z line. Although the sliding of overlapping filaments—along the lines of Huxley and Hanson's proposed model—may well occur here, there are still only a few hints as to how these muscles achieve their characteristic high-frequency oscillation. In any case it is certain that the fibrils of asynchronous muscle are able to utilize ATP. Experiments I have carried out in collaboration with Lois Tice of Columbia University show that a calcium-activated enzyme that splits ATP is present in the *A* bands of blowfly flight muscle and that the sites of this enzymatic activity are at the periphery of the myosin filaments.

The most striking difference of all between synchronous and asynchronous muscle fiber is found in the arrangement of the membranes situated between the fibrils. Electron micrographs make it clear that *T*-system tubules are present throughout asynchronous fiber just as they are in other muscle. In the wasp

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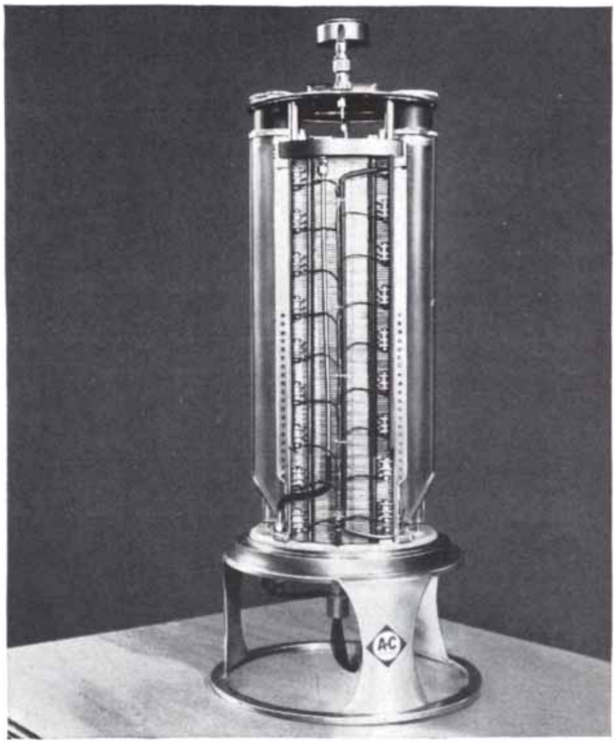

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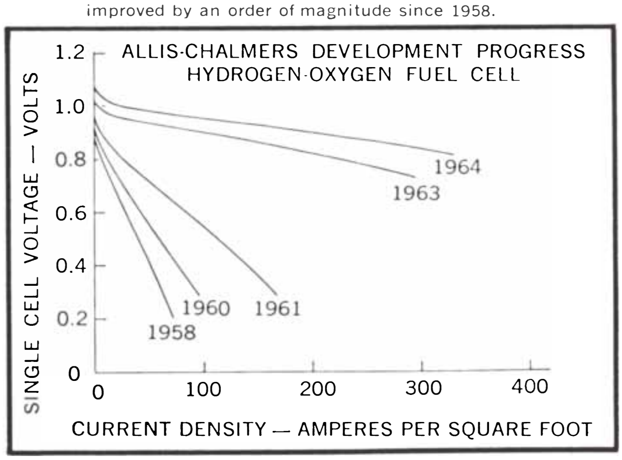
Chart shows Allis-Chalmers fuel-cell technology has improved by an order of magnitude since 1958.



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they are aligned with the *H* zone, in register with the middle of each repeating unit of striation [*see bottom illustration on page 80*]. Presumably the *T* system in asynchronous muscle fulfills the same role of transmitting excitatory signals that it does in other muscles. Although the frequency of oscillation in asynchronous muscle is much higher than the frequency of nerve impulses, a succession of excitations is necessary to maintain activity. In asynchronous muscle, however, there is almost no trace of the other membranous system so evident in synchronous muscle—the sarcoplasmic reticulum.

It is most interesting that the very structure that is believed to control the contraction-relaxation sequence in synchronous insect and vertebrate muscle is virtually absent from asynchronous muscle. Rather than alter our interpretation of the role of the sarcoplasmic reticulum, it is tempting to conclude that the flies, wasps, beetles and bugs have evolved a variety of muscle exceptional enough to prove the rule. Quite recently, however, Pringle and two of his colleagues at the University of Oxford, B. R. Jewell and J. C. Rüegg, have conducted experiments that may help to clarify at least one aspect of the function of asynchronous muscle. They took muscle cells of this type from two species of giant water bug and treated them with glycerine, a process that leaves the filaments of the fibrils intact but removes the sarcoplasm. When the treated muscle cells were placed in a medium containing calcium and ATP, they contracted and relaxed in an oscillatory fashion!

This result makes it clear that the mechanism that enables asynchronous muscle to oscillate resides within the contractile system of protein filaments that compose the fibrils. This being the case, perhaps it is no longer surprising to find that asynchronous muscle is poorly supplied with sarcoplasmic reticulum; the calcium ion give-and-take that operates synchronous muscle may not even occur in these specialized cells. In any case, when the details are fully elucidated of how the filaments in these muscles are organized, how they move with respect to one another and what chemical events are involved in their movement, we shall have not only an overall picture of the function of the most spectacularly active tissue that animals have evolved but also further insight into the mechanism of muscle in general.

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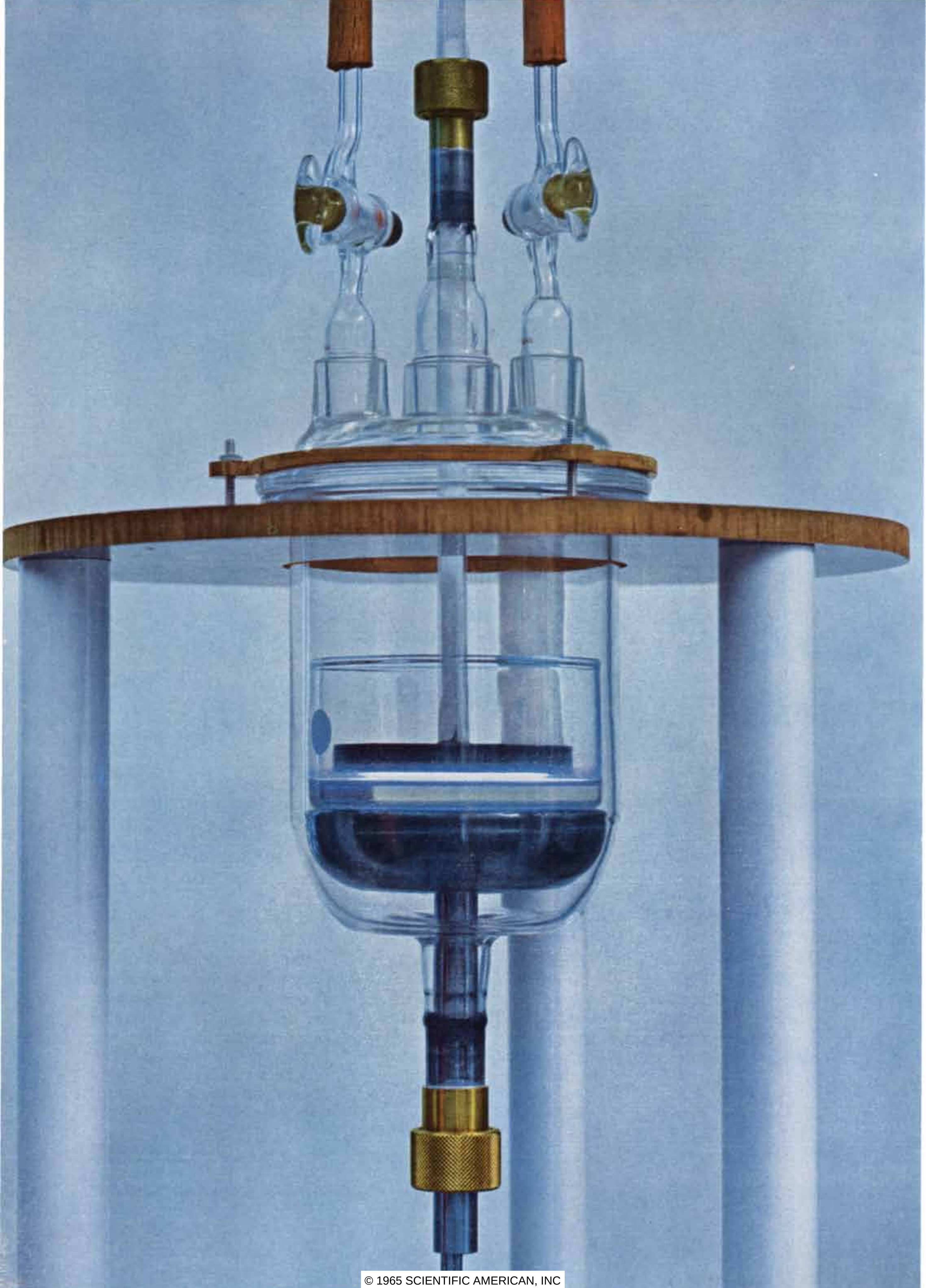


CORONA CHEMISTRY

The electric discharge that results from the incomplete breakdown of a gas can be put to work as a chemical catalyst. The corona acts by creating numerous free radicals that mediate chemical reactions

by John A. Coffman and William R. Browne

Gases are ordinarily good electrical insulators, but in a strong enough electric field a gas "breaks down"; that is, its molecules become ionized and it conducts electricity. There is a sudden electric discharge, which usually develops into an arc: lightning strikes from a thundercloud to earth or a spark flashes between two electrodes in the laboratory. If a solid dielectric, or insulating, barrier is placed between the electrodes, however, no arc develops. The barrier interrupts the conductive path and allows only an incomplete breakdown of the gas; instead of a hot, localized arc there is a cooler, diffuse glow between the electrodes.

This soft, bluish discharge indicating the incomplete breakdown of a gas at or near atmospheric pressure is called corona. In electrical technology corona is usually a sign of trouble; for example, when a glow appears along a high-voltage power line in bad weather, it means that power is being lost. Corona also has its uses. At the Advanced Technology Laboratories of the General Electric Company we are learning how to employ it as a versatile chemical catalyst.

Associated with any electrical breakdown of a gas there is intense chemical activity. A thunderstorm dumps on the ground tons of nitric acid—the product of a reaction involving nitrogen, oxygen and water vapor in the air. The reaction is brought about by lightning; in other words, electricity can be a chemical catalyst. It is hardly surprising that this should be so, since the bonds that tie atoms together are electrical in nature.

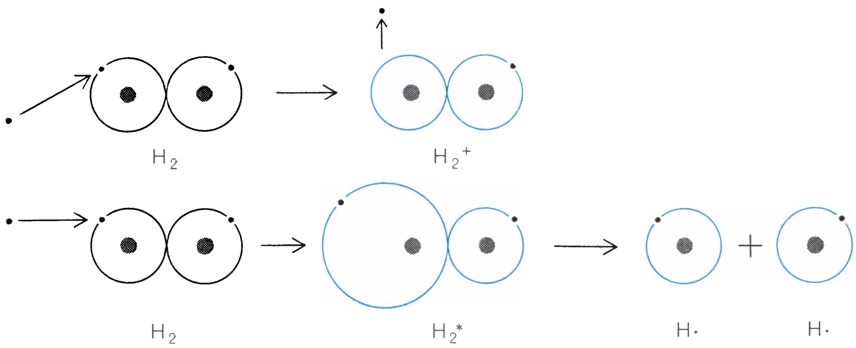
CORONA is visible as a deep-blue band in a liquid-gas corona research reactor (*opposite page*) in the authors' laboratory. The liquid, a vegetable oil that is being hydrogenated, is in a shallow beaker between two electrodes. The corona is established in hydrogen just above the surface of the oil (*see bottom illustration on page 94*).

In an inorganic salt the bonds are ionic: the atoms of the substance either lack one or more electrons or have an excess of electrons, and these oppositely charged atoms attract one another. Such salts can be dissociated by electrolysis, which transports the ions to different electrodes. In most other compounds the bonds are covalent: adjacent atoms in a molecule "share" two orbiting electrons. In quantum-mechanical terms the waves associated with two electrons of opposite spin "spread" themselves over two nuclei; it is as if the electrons wrapped the two nuclei together. Covalent bonds join two hydrogen or two oxygen atoms to make molecules of hydrogen (H_2) or oxygen (O_2); they also bind the organic molecules with which the industrial chemist usually deals. It takes more energy to break most covalent bonds than to break an ionic bond, but the energy required is still low in electrical terms; a few electron volts will do. Reactions that seem quite hard to bring off with conventional chemical methods may yield readily to a few electrons delivered at the right place at the right energy level.

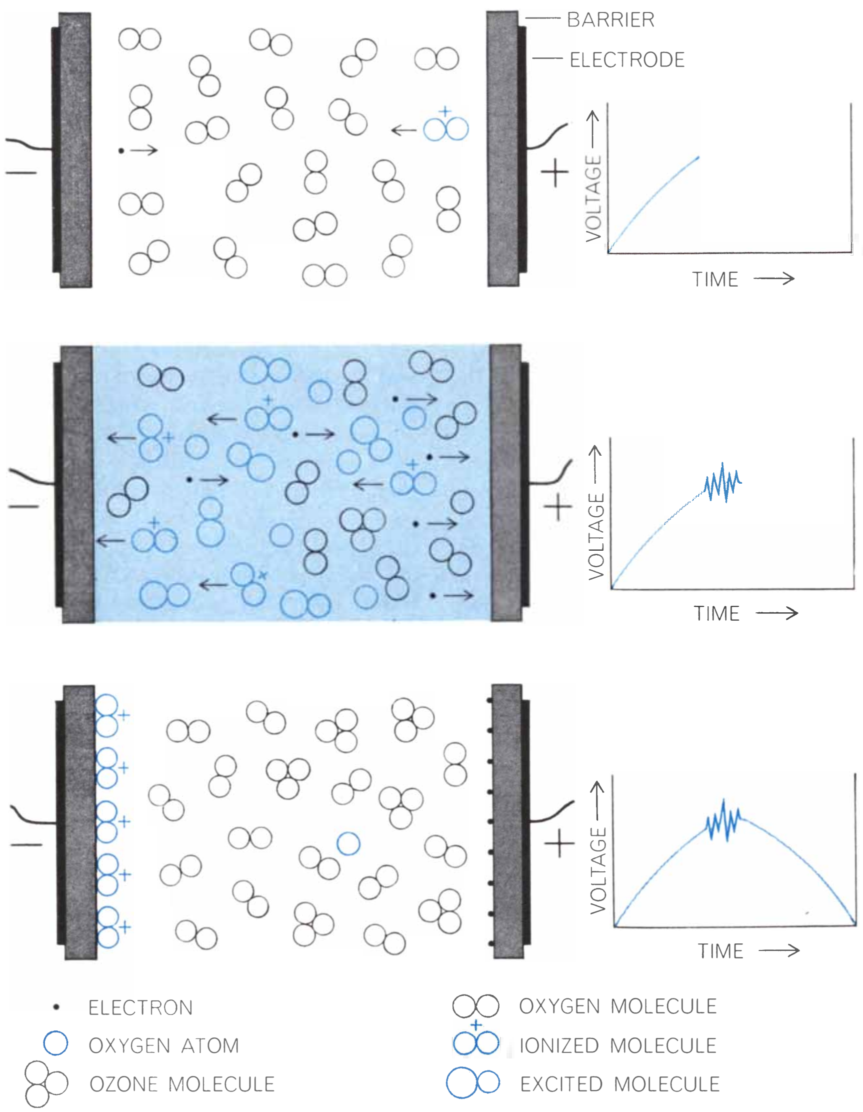
The idea of utilizing corona discharges for chemical catalysis goes back some 100 years. Early experimenters with high-voltage electricity learned how to establish a corona in a chemical reactor, preventing the development of an arc by placing a glass or other insulating barrier in the path of the gas breakdown. Corona was not an easy tool to master, however. The interaction of high-voltage electricity with matter seemed baffling; there were widely fluctuating yields; electrical equipment was undependable. The only commercially significant development of the early corona work was the process for making ozone (O_3) by subjecting oxygen to corona in an "ozonizer."

After World War II advances in technology made corona chemistry a more promising field. High-frequency power could be generated at a reasonable cost. Improved electronic components and circuitry made it easier to tune, control and measure corona power. Materials such as fused quartz, alumina and mica mat became available as dielectrics. Still, most people who might have worked with corona directed their attention instead to such exciting new tools of chemical activation as electron beams, electrical plasmas and nuclear radiation. Only within the past few years have a number of laboratories turned again to corona chemistry, armed with new information on the mechanisms of corona reactions. This information had flowed largely from postwar research in radiation chemistry: the effects of radiation on chemical reactions.

The knowledge of radiation chemistry is relevant to corona research because both deal with "free radicals" formed by electron impact. A radical is a molecular fragment that functions as a unit. A single hydrogen atom is a radical; so are a methyl group (CH_3), an amino group (NH_2) and an acetyl group (CH_3CO). Ordinarily radicals are linked to other atoms by covalent bonds to form molecules. When a bond is broken, the radical is left with one or more unshared electrons. In this condition it is very ready to combine with another atom or group of atoms; it is so extremely re-



EFFECT OF CORONA on hydrogen is to create positive ions and free radicals. An impacting electron can knock out of a hydrogen molecule one of the two electrons orbiting the two nuclei (*top*), producing a free electron and an electron-deficient, or positive, ion. Or the impacting electron can raise the energy level of an orbiting electron (*bottom*), creating an excited molecule (H_2*) that dissociates to form two atoms, or free radicals (*H·*).



OZONE SYNTHESIS is a simple corona process. In the top drawing, as indicated by the oscilloscope trace (*right*), a voltage half-cycle is beginning. An electron and an ion from the previous corona burst move through the oxygen molecules toward the positive and negative electrodes respectively. In the middle drawing the corona is established. There are electrons and ions and also excited molecules that dissociate to form "free radicals" (the oxygen atoms). In the bottom drawing the electrons and ions at the electrodes have damped the corona. Most of the atoms have combined with O_2 molecules to form ozone (O_3).

active that it usually exists as a free radical for a fraction of a second at most. The business of both radiation and corona chemistry is to create free radicals in an environment in which they have a good chance of reacting to form some desired product.

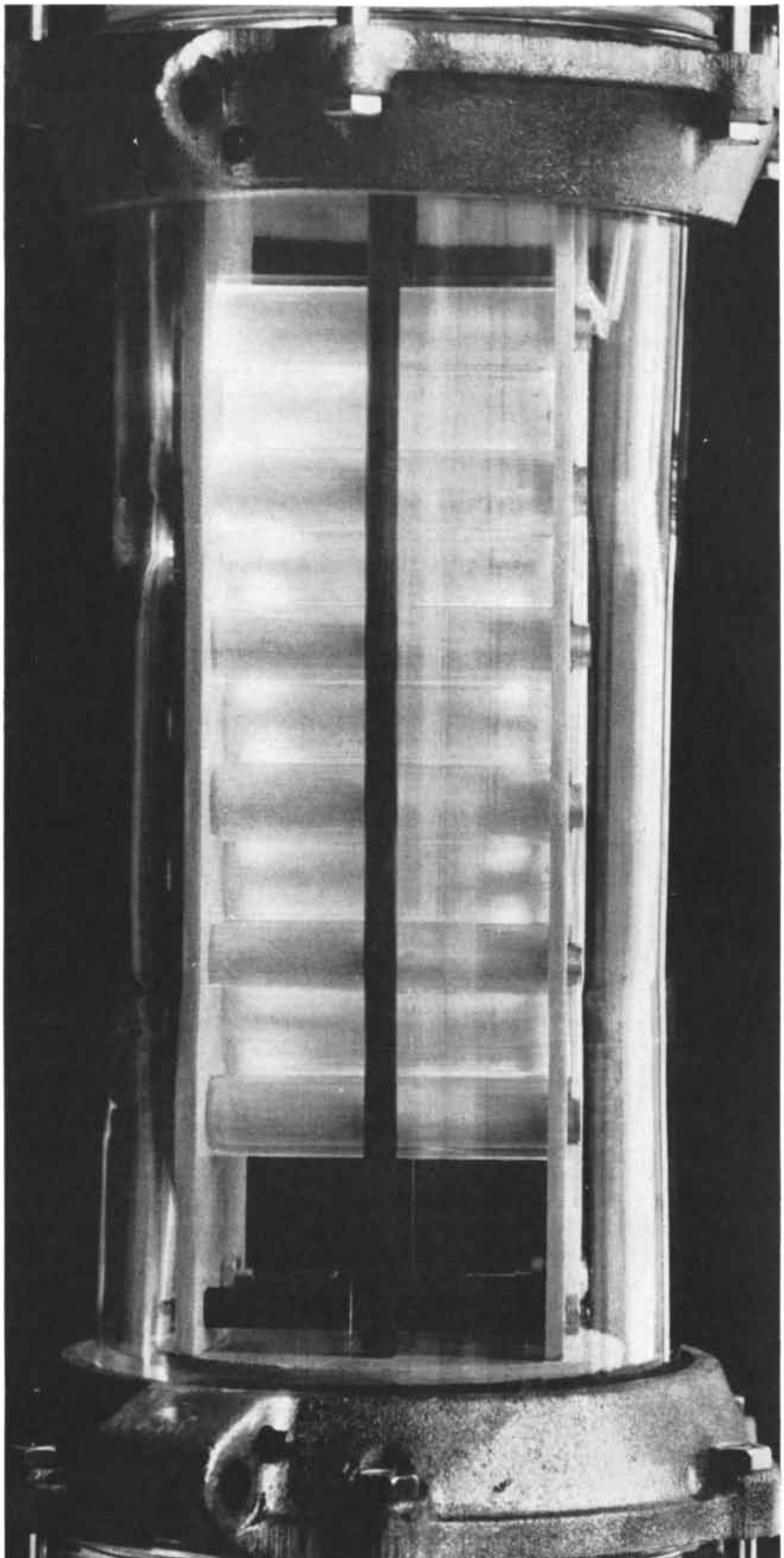
The difference between radiation chemistry and corona chemistry is one of electron energy. The radiation chemist starts with high-energy radiation—gamma rays from radioisotopes, X rays or an electron beam—with energies on the order of a million electron volts; the actual chemical work, however, is done by "secondary" electrons with energies of 10 to 25 electron volts, formed from the primary radiation by a series of energy-damping steps. Corona electrons, on the other hand, are accelerated by the applied voltage up to the required 10 to 25 electron volts; in other words, they are given no more energy than they need to do the job. This makes corona energy less expensive than any other form of electron activation now available. It can be delivered to the reaction site for one to three cents per kilowatt-hour. Comparable costs for high-energy electron beams range upward from 35 cents per kilowatt-hour; for nuclear radiation from isotopes the cost is $1 to $10 per kilowatt-hour. High-energy radiation does have the property, which is sometimes advantageous, of penetrating deep into liquids or solids. Corona is purely a gas-phase phenomenon and it produces free radicals only in a gas or mixture of gases. In addition to reacting in the gas phase, however, the radicals can interact with molecules of a liquid or of a finely divided solid that is subsequently exposed to them.

The phenomenon of corona starts with the few stray electrons that are always present in a gas because of cosmic rays or other background radiation. If a high voltage (some 10,000 to 15,000 volts) is applied, creating a strong electric field, the electrons are accelerated toward the positive electrode. They strike gas molecules in their path, from which they rebound with little loss of energy because of the great disparity in mass—like a ping-pong ball rebounding from a bowling ball. Then they accelerate again. Occasionally, by chance, a long enough path opens up for an electron so that when it finally hits a gas molecule it has acquired enough energy to penetrate the molecule's shield of orbiting electrons. Then one of two things can happen. The impacting electron may knock an orbital electron out of the molecule, leaving a positive ion and another free electron that can go on to strike another molecule. More often the impacting electron lifts an orbiting electron to an unstable, higher-energy orbit, creating an "excited" molecule. Soon the gas is full of electrons, positive ions, excited molecules, heat and light—in other words, corona. The excited molecules are unstable; they decompose spontaneously into free radicals. The whole process of corona buildup takes only about a ten-millionth of a second, and it is repeated every time the electric field reverses.

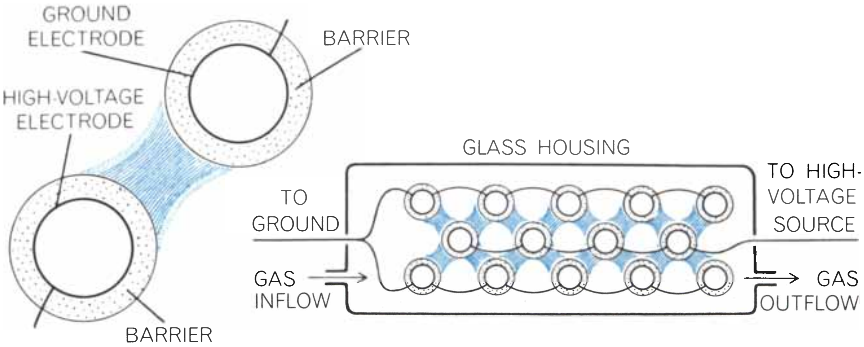
The synthesis of ozone from oxygen is a typical three-step corona reaction [*see bottom illustration on opposite page*]. Impacting electrons create positive ions and excited molecules of oxygen. Excited molecules dissociate to form free radicals: oxygen atoms. The highly reactive oxygen atoms combine with the remaining oxygen molecules to form the desired product, ozone.

There are several generalizations about corona processes that can be made on the basis of ozone synthesis. First, ozone is "uphill" energetically from oxygen; it is more reactive, a stronger oxidizer, even explosive at times. Products of higher energy, greater reactivity and less stability than the starting materials are often made with corona—something contrary to the usual course of chemical reactions. Second, the efficiency of ozone production drops rapidly as ozone accumulates, because ozone is more susceptible to corona attack than oxygen is. The same thing is true of many corona products compared with starting materials, so the product must be removed quickly from the reaction zone. Finally, the oxygen or air fed into an ozonizer must be dry; if water vapor is present, the electrons and radicals will attack water molecules rather than oxygen molecules. In general, because corona attacks the most vulnerable molecules, starting materials must be kept quite pure so that corona energy is not soaked up in wasteful side reactions.

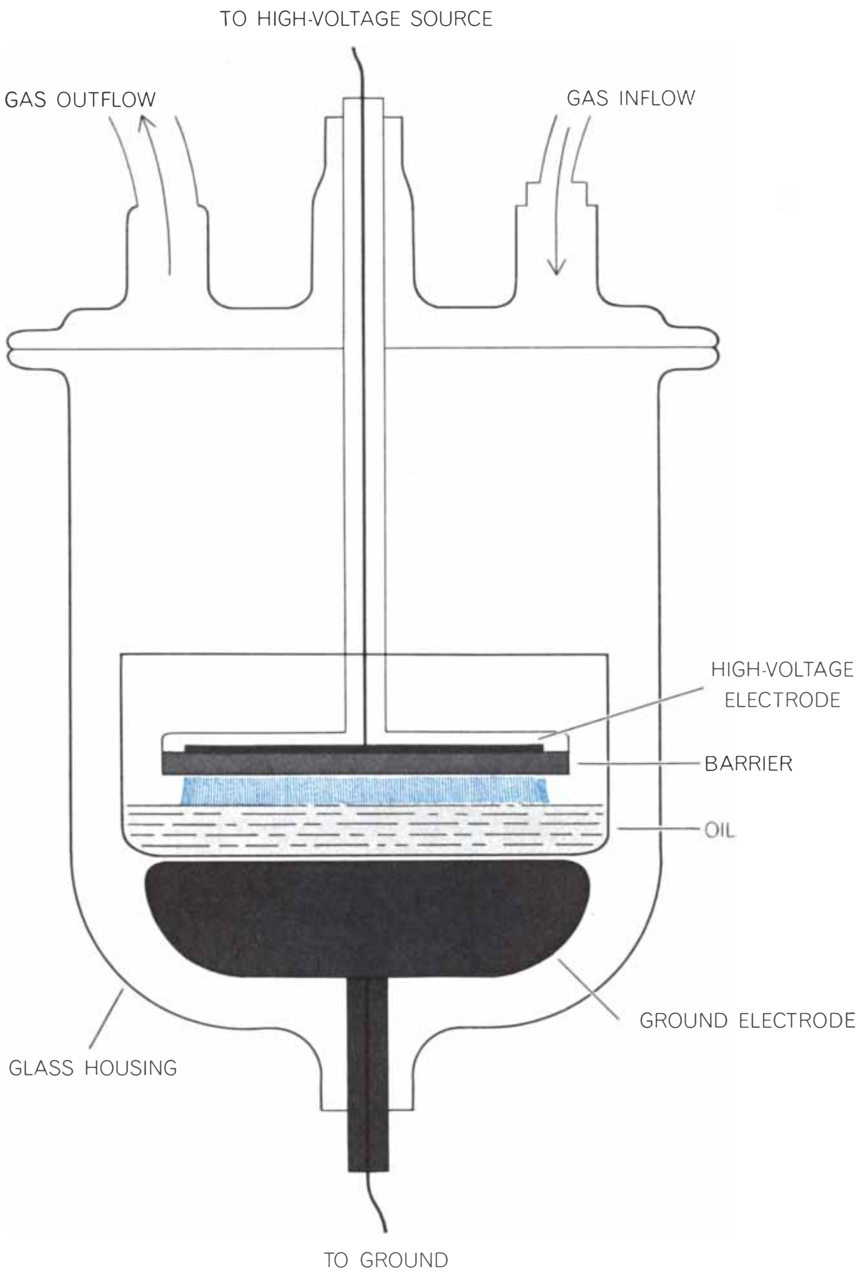
Having described what corona is and what it does chemically, let us now see how it is applied to practical chemical processes. One of the primary tasks in corona technology is the designing of corona cells, or reactors. The simplest situation is one in which both the starting materials and the products are gases. In this case the reactor can consist simply of an assembly of closely spaced



GLOW OF CORONA illuminates an all-gas reactor composed of a bank of tube electrodes inside a glass cylinder. Oxygen fed into one end of the cylinder passes among the electrodes and emerges enriched in ozone. This reactor is diagrammed at the top of the next page.



TUBE ELECTRODES of a gas reactor, seen from the side in the photograph on the preceding page, are shown end on in detail (*left*) and arrayed in a reactor (*right*). Conductive coatings inside the glass tubes are the actual electrodes; tubing forms dielectric barriers.



LIQUID-GAS REACTOR shown in the photograph on page 90 delivers corona power at the surface of a liquid that is held in a beaker placed between two electrodes. The dielectric barrier of quartz covers the face of the high-voltage electrode and prevents arc formation.

insulated-plate or insulated-tube electrodes, between which the corona is generated and the gases pass [*see illustrations on preceding page and at left*]. The product molecules are continuously removed from the mixture of gases that flows out of the reactor and the starting gas is recycled so that further conversion can take place.

When one of the reactants is a liquid, provision must be made for maintaining a two-phase system between the electrodes so that the radicals generated in the gas can reach molecules in the liquid. In one design, appropriate for research but probably inefficient for production, the corona is established directly above a pool of the liquid into which the radicals diffuse [*see bottom illustration on this page*]. For efficiency it is better to stir things up a bit. One way to do this is to make one of the electrodes a rotating disk that carries a thin film of the liquid into the corona region [*see illustration on opposite page*]. It should be possible also to churn the liquid with a blade-shaped electrode or even to establish a corona discharge in bubbles of the reactant gas moving through the liquid.

Finely divided solids can be exposed to corona either by making a slurry that can be handled in a liquid reactor, by stirring or tumbling the particles between electrodes along with the reactant gas or by allowing the gas passing between the electrodes to entrain and "fluidize" the particles. At the Advanced Technology Laboratories we have devised techniques for generating corona in all-gas systems, liquid-gas systems and reactors handling powdered solids and gas. We generally work with a potential of 10,000 to 15,000 volts. The current is on the order of 50 or 100 milliamperes per square foot of corona area and the power level is about one kilowatt per square foot. These values apply when the frequency of the alternating voltage is 10,000 cycles per second, and they are proportionately higher or lower for other frequencies.

The importance of frequency stems from the mechanism of corona formation. The burst of corona activity begins as the voltage rises on each half-cycle [*see bottom illustration on page 92*]. As the electrons and positive ions become concentrated at the opposite electrodes they build up a space charge that neutralizes the electric field and chokes off the corona. When the field is reversed, the space charge is dissipated and another corona burst can occur. The number of bursts, the current drawn, the power level and the rate of chemical reaction are all therefore approximately proportional to the frequency. Although the amount of chemical product does increase with frequency, higher frequencies are more expensive to generate. The best compromise between low productivity and high cost seems to be 10,000 cycles, and that is the frequency we generally use.

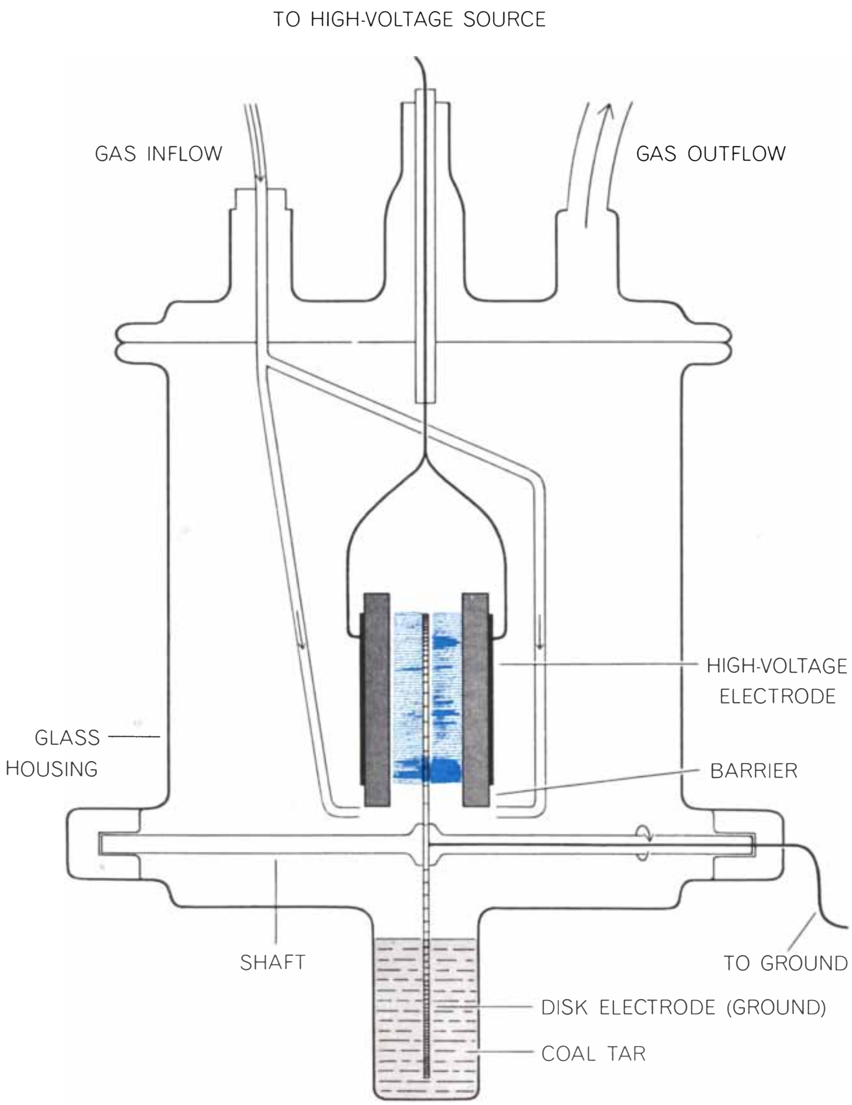
A number of investigators have compiled data indicating that certain frequencies are "preferred" for certain reactions, and some of them have evolved rather elaborate theories relating these preferred frequencies to such characteristics of the particular molecules involved as bond length and molecular vibration. We are skeptical of such results; we attribute the reported variations in efficiency with frequency to technical difficulties or to the standard chemical laws governing reaction rates. We may be quite wrong, however; it is dangerous to be dogmatic about an unfolding technology.

Corona is effective in a wide variety of chemical reactions. The longstanding example of ozone synthesis immediately suggests a number of similar reactions in which simple molecules are converted into more complex ones with higher energy. Hydrogen peroxide, which is generally made by low-voltage electrolysis, is a likely candidate for corona synthesis; German chemists almost perfected a commercially feasible process before World War II. The reaction is straightforward: in a water-vapor corona a molecule of water decomposes into a free hydroxyl (OH) radical and a hydrogen atom; two hydroxyls combine to form hydrogen peroxide (H_2O_2). Another likely product is hydrazine, the nitrogen analogue of hydrogen peroxide, which is an important rocket fuel and might have other applications if it could be manufactured more inexpensively. In our laboratory we establish a corona discharge in ammonia gas; an excited ammonia molecule (NH_3) is dissociated into an amino radical (NH_2) and a hydrogen radical; the latter makes another amino radical by pulling a hydrogen atom out of a second ammonia molecule; two amino radicals then combine to form hydrazine (N_2H_4). Corona can also mimic in the laboratory the synthesis of nitric acid by lightning.

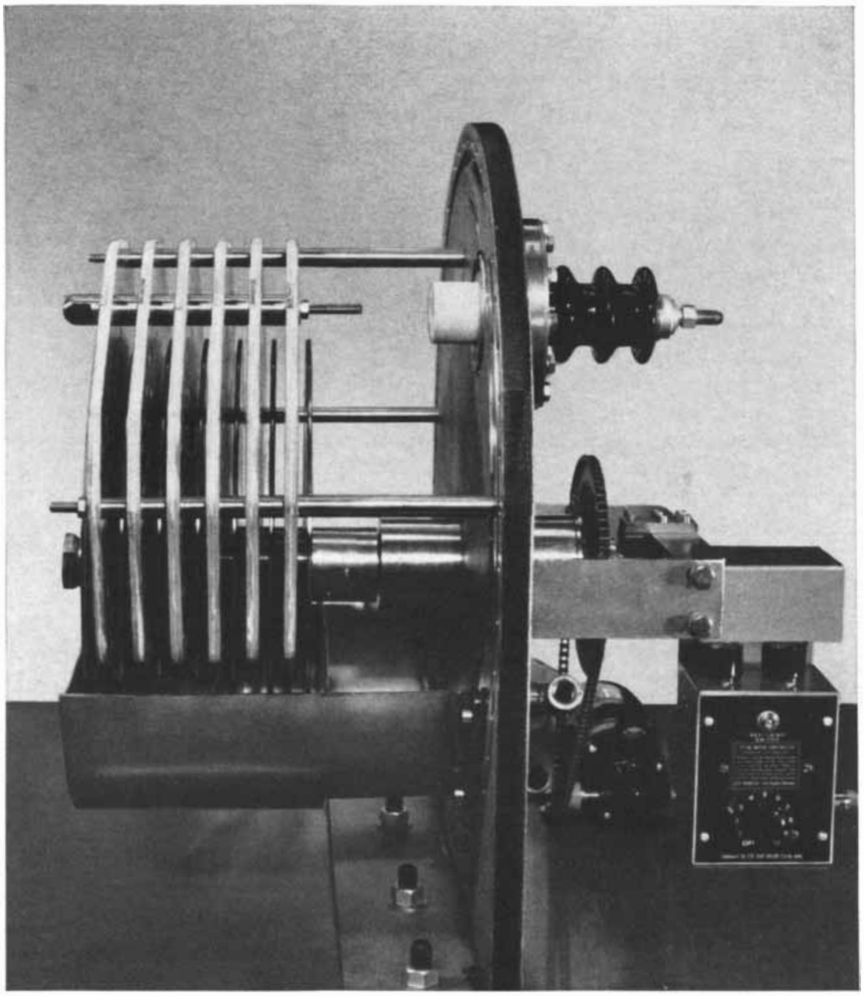
Corona has special virtues as the synthesizer of highly reactive compounds. There are a number of oxygen fluorides, for example, that are so unstable that they break down at the very temperatures required for their synthesis by conventional methods. A research group at Temple University was able to synthesize such fluorides with corona by operating at low temperatures; this does not inhibit corona formation or the creation of free radicals but does prevent the breakdown of the products formed when the radicals couple. Recently the Temple workers have accomplished corona synthesis of even more unusual compounds, in which the noble gases xenon and krypton are linked with fluorine or oxygen difluoride.

Although these exotic compounds are interesting, the low cost of corona power suggests that it should have its widest application in the processing of large volumes of material. We have investigated a number of such potential applications, including water purification, polymerization and the cracking of petroleum and coal.

Corona has been playing an indirect role in water purification for some time because ozone synthesized by corona has long been used, particularly in Europe, to treat drinking water. Ozone's effectiveness stems from its power as an oxidizer; the direct action of corona on water apparently brings about many of the same chemical and bacteriological changes as ozone but seems to be even more potent. Corona playing on water forms hydroxyl and hydroperoxy (HOO) radicals at the surface. These diffuse into the water, where they kill bacteria by interfering with metabolic processes. The radicals also react with any organic impurities they meet, start-



ROTATING-DISK CELL is another liquid-gas reactor. The ground electrode is a metal disk that transports a film of liquid or suspended solids from a sump into the corona. The reactant gas enters at top left and leaves at top right, carrying product molecules with it.



SCALED-UP VERSION of the rotating-disk reactor has six ground electrodes. They rotate between parallel high-voltage electrodes made of stainless sheet steel insulated by laminated mica mat. The photograph shows the inner elements of the reactor; the containing vessel for the gas has been removed. This reactor developed five kilowatts of power.

ing a process of oxidation that continues until the organic material—including the dead bacteria and the most refractory pesticides and detergents—is converted entirely into innocuous molecules such as carbon dioxide and water.

In behalf of the Taft Sanitary Engineering Center in Cincinnati we are currently investigating the effectiveness of corona in reducing what is called the biochemical oxygen demand of the effluent from sewage-treatment plants, that is, the extent to which organic wastes in the effluent will deplete the dissolved-oxygen content of the river or bay into which the effluent flows and so reduce the water's ability to support aquatic life. The hope is that corona can provide a "polishing" treatment for waste water just before it is discharged, or even purify the effluent enough to permit its reentry into the municipal water supply. We have found several corona reactors suitable for water treatment, including the rotating-disk model and a tube-shaped reactor in which water and air or oxygen are swirled turbulently between concentric electrodes. Much development work remains to be done in order to find the reactor design and conditions that will most efficiently transport radicals from corona to water, but judging by what we have seen to date water treatment is one of the most promising fields for corona technology. Corona should be effective not only for purifying municipal water supplies but also for very different purposes; it may, for example, be a good substitute for pasteurization in the case of bottled beer, with a less detrimental effect on the taste of the beer.

Many early corona researchers were bothered by unexpected semisolid deposits that encrusted their equipment. Before the era of plastics the goals of organic chemistry were clean, easily characterizable compounds, and the formation of such residues was something to be avoided. Now it is clear that those gummy deposits were polymers: substances composed of long-chain molecules made by the repetitive linking of free-radical monomers created by the corona. Polymerization is one of the basic operations of industrial chemistry and it seems likely to be one of the most successful applications of corona technology. One attractive prospect is the use of corona to lay down a thin film of polymer as a coating on sheets of metal, plastic or cloth.

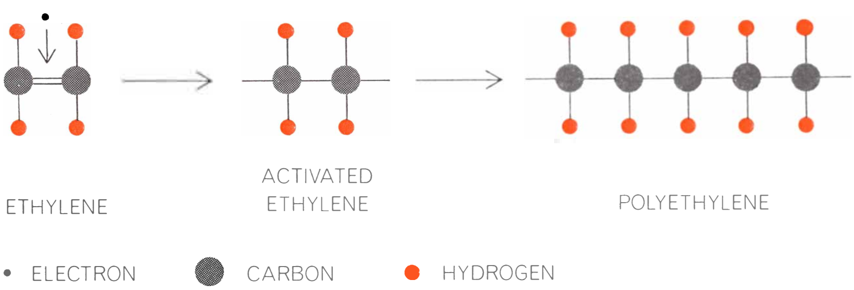
We feed the material to be coated into a corona reactor along with the appropriate monomer in the form of a gas or vapor. Radicals and ions formed by the corona start to polymerize, condense on the material and continue to polymerize there under the influence of their own radical content and further bombardment by corona electrons. The coating that is formed adheres well and is uniform in thickness. Its properties can be controlled, since they are functions of the particular monomer chosen, the rate of flow of the gas, the corona power level, temperature and other variables. The coatings may be tacky or, if the molecules are cross-linked by numerous bonds, they may be hard, insoluble and practically impermeable. The great advantage of corona polymerization is its ability to produce a finished coating from an inexpensive monomer in one step. It is also possible to apply such coatings with a "glow discharge," an electrical breakdown that occurs at lower voltages in gases at low pressure. The British Iron and Steel Research Association, for example, has developed coating processes for sheet steel based on low-pressure glow discharges. We have concentrated on the corona method at atmospheric pressure because it makes the problem of feeding the material to be coated through the reactor so much simpler.

One of the basic operations in petroleum refining and petrochemistry is cracking, by which large molecules in coal or oil are broken into smaller, more volatile molecules. Cracking is based on free-radical chemistry and would seem to be made to order for corona. The trouble is that gasoline is so cheap (before taxes!) that the cost of production must be kept low; corona has not yet become economical for petroleum refining. The situation may be very different in the case of specific petrochemical processes that turn out to be susceptible to corona. Under contract to the U.S.

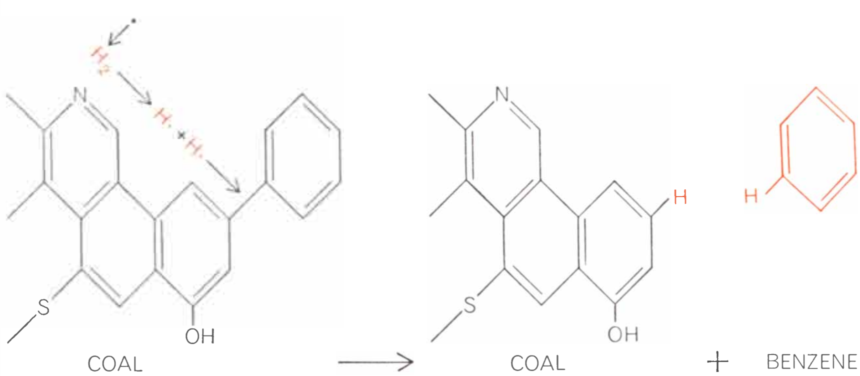
Public Health Service we are currently attempting to "desulfurize" heavy fuel oil with corona, since sulfur in fuel oil is a serious source of air pollution. In the course of a previous investigation into corona processing of coal we had found that hydrogen sulfide was always one of the early products of corona attack on coal. In coal (and, we expect, in oil) the sulfur bonds appear to be cleaved by corona more readily than any other bonds.

The original objective of the coal project, which was sponsored by the U.S. Department of the Interior's Office of Coal Research, was to convert a substantial part of the coal molecule into liquid and gaseous fuel, at the same time putting the residual charcoal to work as a fuel to generate the corona power. German chemists had managed to make gasoline and oil from coal by hydrogenation (adding hydrogen to crack molecules) during both world wars, but the process was not economical in peacetime. We set out to reduce the cost by working at atmospheric pressure with corona and at the same time to increase the value of the product by generating higher-octane gasoline. We used the rotating-disk reactor, among others; the disk carried a film of coal slurry or tar up into the corona zone, where it was cracked by electrons and radicals from a stream of hydrogen or methane gas.

The products we obtained included a wide range of volatile hydrocarbons, including valuable "aromatic," or ring-shaped, molecules such as benzene, xylene and toluene. The electrical efficiency was not satisfactory, however. The condensed-ring molecular structure of coal seems to be able to soak up great quantities of electrical energy and, instead of cracking, to "shimmy" a little and then give the energy back as heat. (Indeed, the oils used as moderators in some nuclear reactors are effective in absorbing energy because they have a similar molecular structure.) We concluded that although corona processing may be appropriate for deriving chemicals from coal, it is not now an economical technique for converting coal to liquid fuel. Further research could very well change that assessment, however. As a matter of fact, at this early stage in corona research no such judgment can be considered final.



POLYMERIZATION of monomers is catalyzed by corona. An electron striking the double bond in ethylene (*left*) opens the bond to form activated ethylene, a "diradical" with two free bonds. The radicals link to form the long-chain polyethylene molecule (*right*).



MOLECULES OF COAL can be cracked by corona. Hydrogen atoms formed in a corona strike a bond in a typical coal molecule, a corner of which is illustrated. One atom combines with the coal molecule; the other binds to the split-off ring to form a benzene molecule.

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The Composition of the Earth's Interior

There is little likelihood that the core of the earth will ever be examined at first hand, but recent studies of solids at high pressures support the idea that it is made of iron and nickel

by Taro Takahashi and William A. Bassett

Geophysicists have inferred from seismic (earthquake) waves that the solid earth consists of three principal concentric zones: (1) a thin crust varying from five to 50 kilometers in thickness; (2) a mantle about 2,900 kilometers thick and (3) a large core, divided into an inner and outer region, that accounts for about half of the earth's diameter and nearly a third (31.5 percent) of its mass. The composition of the crust varies from granite in continental areas to basalt in ocean basins. It is generally accepted that the mantle is made up of denser silicate minerals, which are rich in magnesium and iron.

Although it seems quite unlikely that a sample of the core can ever be examined at first hand, there is considerable evidence that it is composed chiefly of iron. Whether or not any other elements are present, and if present which elements they are, is a much debated subject. We believe experiments in our laboratory at the University of Rochester have cast some fresh light on the matter.

Heretofore hypotheses about the composition of the earth's core have been based primarily on two lines of reasoning. The first involves seismic and other geophysical measurements that indicate that the core has a density consistent with that of metallic iron. The second involves an appeal to the composition of certain kinds of meteorites that are believed to be fragments of a shattered planet. Since these objects consist mostly of iron-nickel alloys, they suggest that the earth's core may have a similar composition.

Within the past 15 years still another approach to the understanding of the earth's interior has been actively explored. In this approach one attempts to reproduce conditions of temperature and pressure resembling those inside the earth and to observe under these conditions the changes that take place in the properties of various substances. One means of achieving such conditions is to use explosives; this method has recently been employed by workers at the Los Alamos Scientific Laboratory, who have devised ingenious recording instruments to measure fleeting changes in the properties of samples subjected to explosive shock waves.

In our laboratory we have chosen to study samples that have been placed in a small but powerful press. This press is so designed that we can use X-ray diffraction to determine the effects of pressure and temperature on the arrangement of atoms and the density of the material under examination. From our measurements it has been possible to obtain information that is pertinent to questions about the composition of the core.

Our investigations grew out of some interesting findings made by the Los Alamos group on the effects of pressure on the density of iron. They found that at pressures comparable to those in the earth's interior the density of pure iron is 10 to 15 percent greater than the density of the earth's core as determined by geophysical measurements. This implied that the core could not be composed of pure iron; if it were, the core should be 10 to 15 percent denser than it is found to be.

Could the discrepancy be explained by supposing lighter elements, such as silicon, are alloyed with iron in the core? That seemed unlikely, because no such alloys have been found in iron-nickel meteorites. Nickel itself should presumably make the alloy denser, since it is heavier than iron. These problems led us to initiate a series of studies of iron and its alloys with our high-pressure equipment.

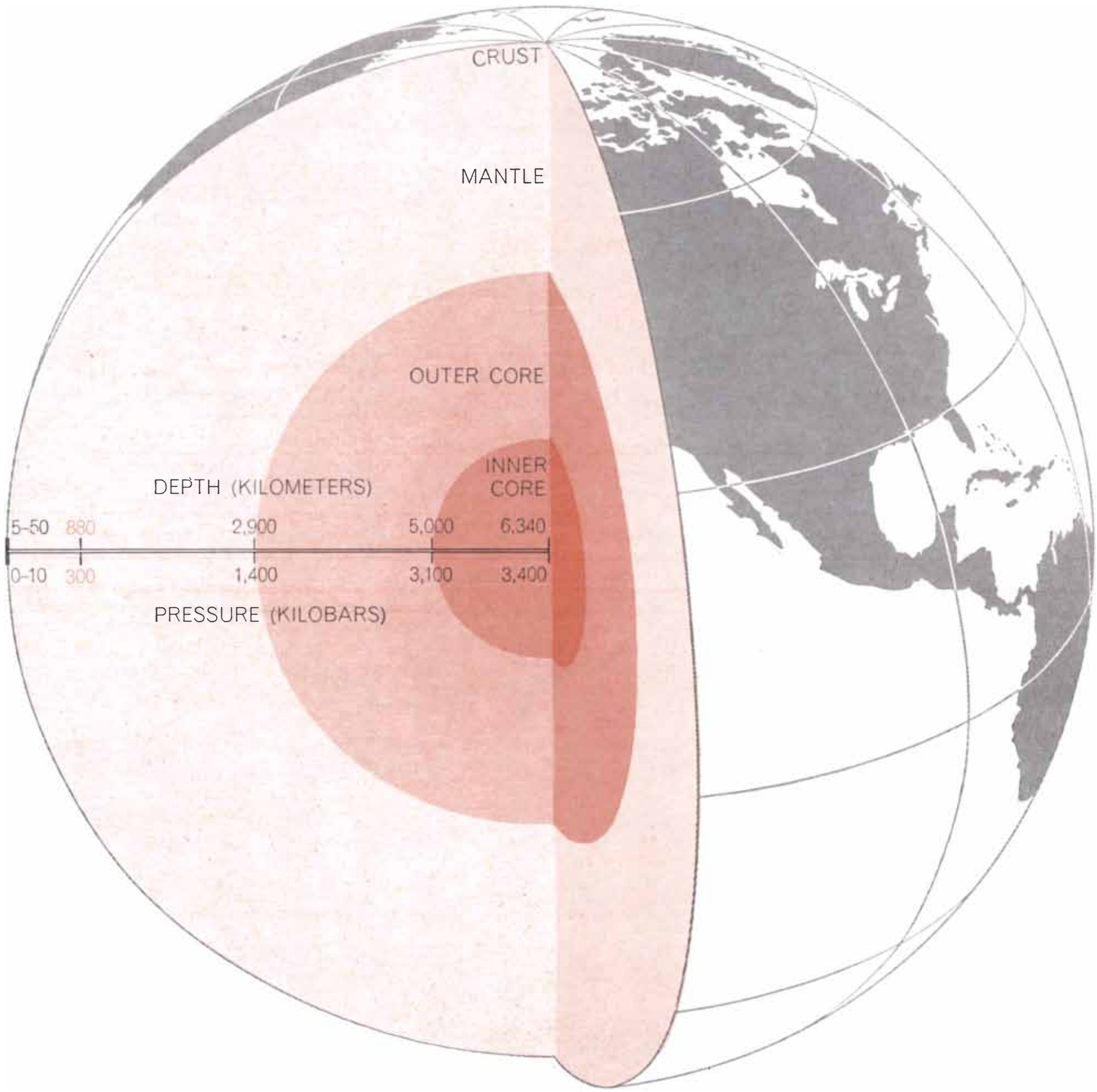
The father of all modern high-pressure studies was the late Percy W. Bridgman of Harvard University. He developed equipment that was capable of subjecting small samples of matter to very high pressures—up to 100 kilobars. (One bar is approximately one atmosphere; a kilobar is about 1,000 atmospheres, or 14,500 pounds per square inch, and 100 kilobars is 1,450,000 pounds per square inch.) Bridgman investigated the effects of high pressure on many elements and compounds, measuring particularly the changes in density and in electrical resistance of the compressed samples.

Two kinds of change in density take place with increasing pressure. One is simple compression, which gradually reduces the distance between atoms and thereby increases the density of the solid. The other type of change, called polymorphism, is an abrupt transformation, through either a sharp decrease in the size of atoms or a radical rearrangement of their geometry. The effect of temperature, on the other hand, is usually to increase the distance between atoms, resulting in expansion. A change in temperature, however, can also give rise to polymorphism. In other words, the atoms of a substance always tend to arrange themselves in the configuration that will be most stable under given conditions of pressure and temperature.

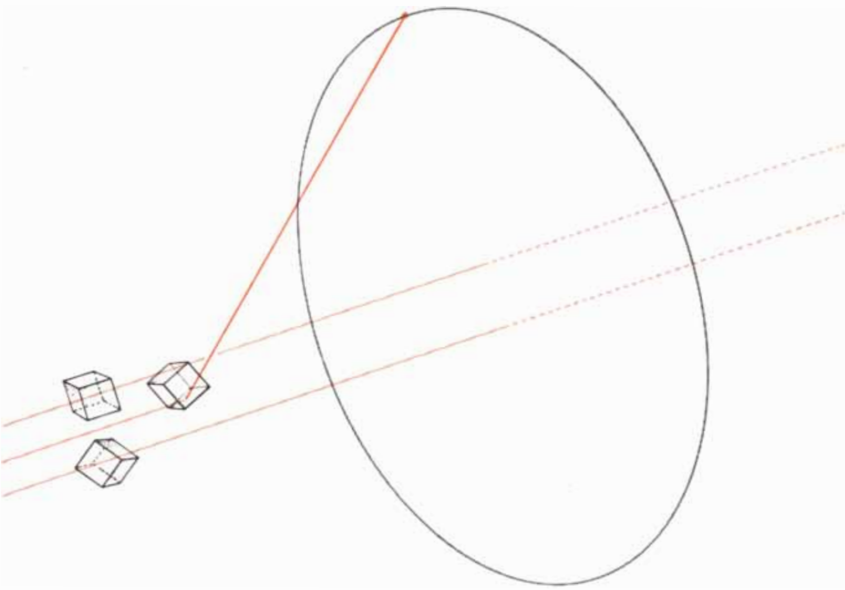
It is such changes in configuration that can be examined by X-ray diffraction. When a beam of X rays is directed through a crystal, the rays are reflected from the layers of atoms, and these rays form a pattern that indicates the spacing and arrangement of the atoms [*see illustration on page 102*]. Caught on photographic film, the reflected rays form a set of diffraction rings; from the diameter of the rings one can calculate the distance between the layers of atoms in the crystal. With simple crystals this is usually enough information for obtaining the arrangement of the atoms as well as the distances between them.

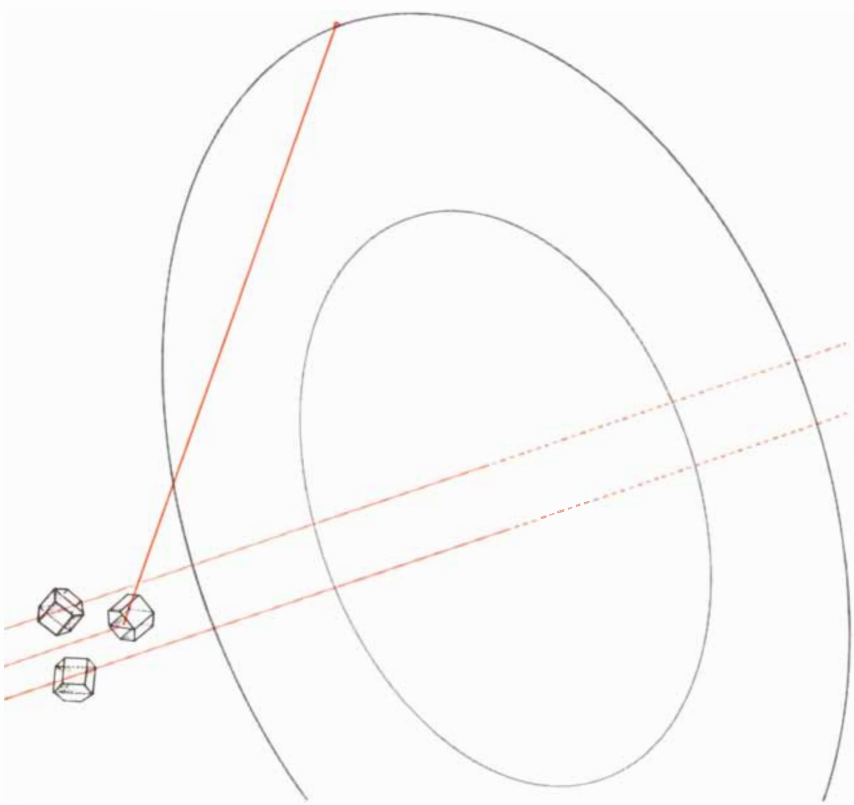
The use of X rays to examine substances under pressure was first successfully introduced in 1937 by R. B. Jacobs, who was then working at Harvard University. To admit the X-ray beam into the pressure chamber Jacobs used a window of beryllium. There are materials other than beryllium that are transparent to X rays and also strong enough to serve as windows of a high-pressure chamber; among them are diamond, boron and lithium hydride. In recent years a number of workers have developed effective designs for studying samples under extremely high pressure, both by X-ray diffraction and with the microscope; with the aid of a grant from the National Science Foundation we have built such an instrument [*see top illustration on page 103*]. A. Van Valkenburg and C. E. Weir of the National Bureau of Standards provided valuable technical advice.

Our instrument employs as anvils for



INTERIOR OF THE EARTH is divided into crust, mantle, outer core and inner core. The illustration shows how pressure increases with depth. A kilobar is 14,500 pounds per square inch; thus the pressure of 3,400 kilobars at the center of the earth is equivalent to almost 50 million pounds per square inch. The diamond-anvil press used by the authors can exert a pressure of 300 kilobars, equal to that found at a depth of 880 kilometers in the earth's interior. The temperature of the mantle probably ranges from 600 to 2,500 degrees centigrade; the core, from 2,500 to 3,500 degrees. The outer core is believed to be liquid; the inner core may be solid.



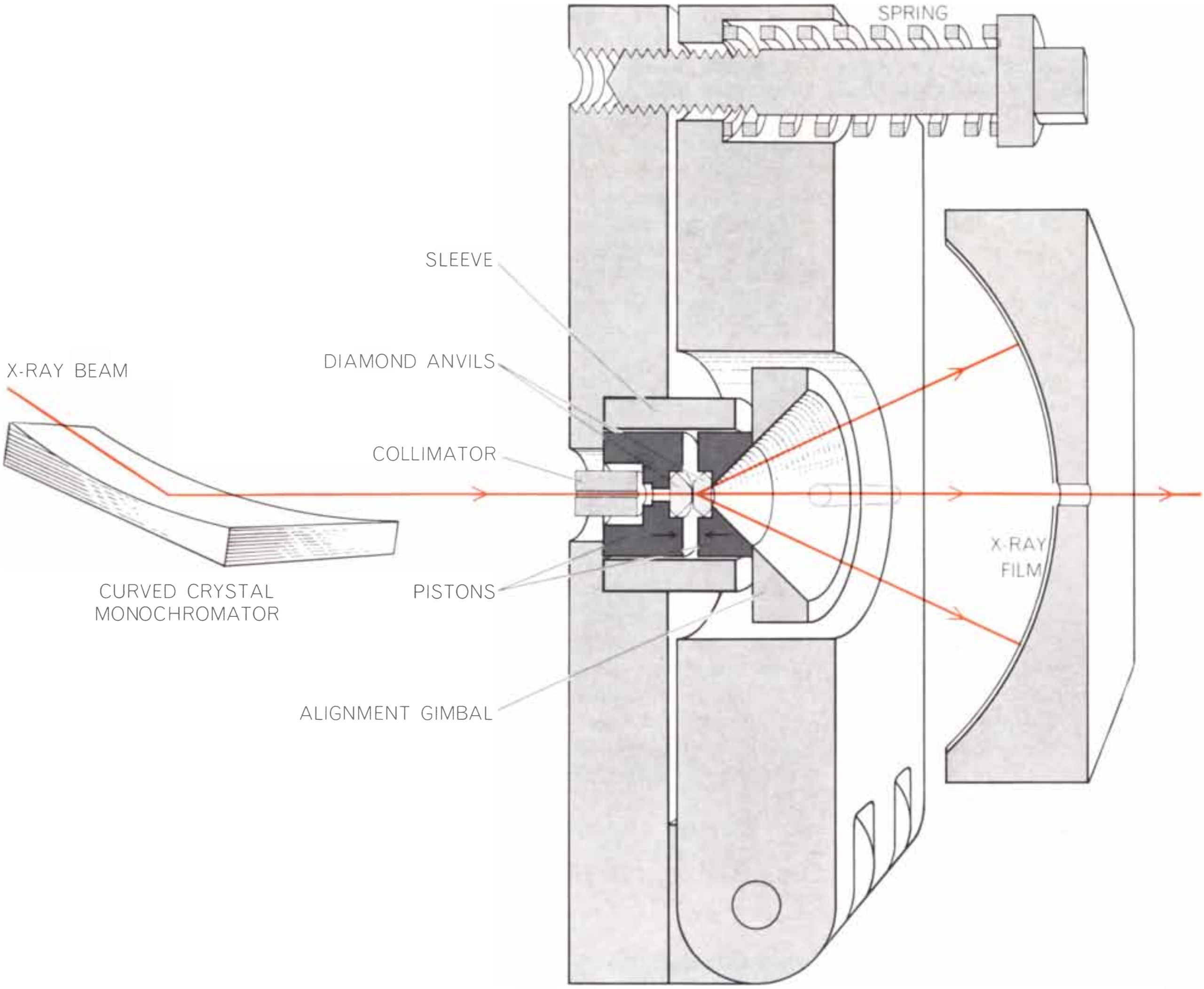


STRUCTURE OF CRYSTALS can be studied by sending a beam of X rays of uniform wavelength through a powdered crystalline sample. When the X rays are diffracted by the planes of atoms in the crystals, the waves of radiation reinforce each other in certain directions and cancel in others. Thus crystals produce an X-ray "glitter" only if they are properly oriented with respect to the X-ray beam. The glitter from a randomly oriented sample of crystals produces one or more concentric rings on a photographic plate. The size of the rings varies inversely with the spacing between the atomic planes in the crystal. Here the crystals at the bottom have the narrower spacing and therefore produce the larger rings.

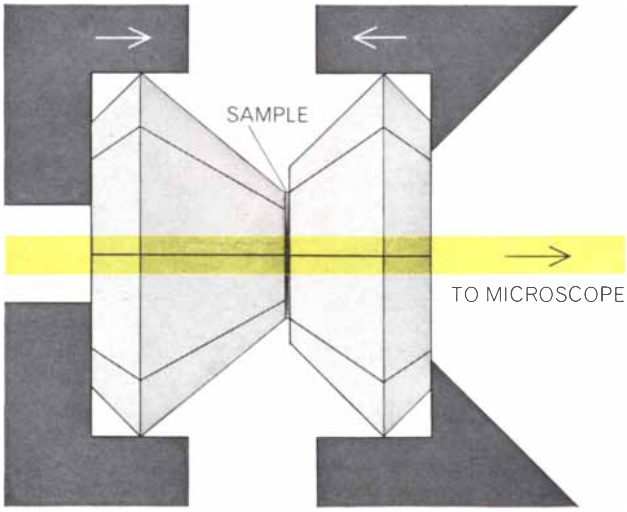
compressing the sample two gem diamonds with working faces half a millimeter (a fiftieth of an inch) in diameter. The diamonds are mounted at the ends of two pistons, which are driven together by a lever-and-spring arrangement that can exert pressures up to 300 kilobars (4,350,000 pounds per square inch). As the sample, which is originally in the form of a powder, is squeezed, part of it is extruded at the edges of the diamond faces, but its escape is limited by friction and some of it is retained between the faces. The pressure is greatest at the center and falls off rapidly toward the edges, where it may be no more than one bar. If the sample undergoes a change of phase at a particular pressure, the transformation will appear first in the central area as a different color or brightness. As the pressure is increased there may be successive phase transformations; these will reveal themselves as a series of concentric rings, each of which represents a phase change at a particular pressure.

Such changes can be observed both by X-ray diffraction and with the light microscope. A thin beam of X rays of a single wavelength is directed through one of the diamond anvils to the sample. Rays reflected from the sample pass out through the other diamond and are recorded on photographic film. The apparatus also allows us to look at the sample through holes in the pistons with a microscope employing either transmitted or reflected light [*see illustration at bottom left on opposite page*]. Among other things, the microscope enables us to pick out particular areas of the sample for X-ray examination.

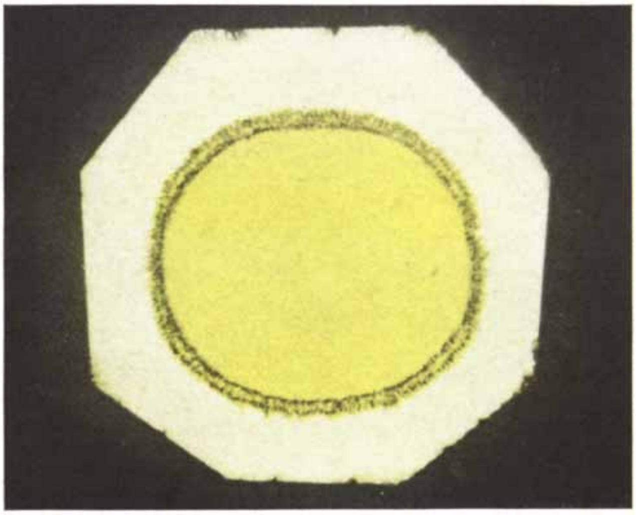
With this apparatus we have studied the changes in various materials at pressures up to 300 kilobars and temperatures up to 300 degrees centigrade. A substance that nicely exemplifies the phase changes that can be brought about by pressure is silver iodide. At ordinary atmospheric pressure and room temperature silver iodide is a lemon-yellow powder. Under a pressure of three kilobars it changes to a different phase; at four kilobars it undergoes a second transformation, and above 100 kilobars it has still another form. The three polymorphs, or phases, are distinctly visible in photomicrographs of a sample in the pressure apparatus [*see illustration at bottom right on opposite page*]. Thus silver iodide dramatically demonstrates that, depending on pressure and temperature, a single substance can exist in various structural forms,



HIGH-PRESSURE X-RAY CAMERA built by the authors can make X-ray diffraction photographs of crystalline samples under pressures as high as 300 kilobars (4.5 million pounds per square inch). The sample is compressed between diamond anvils (*see detail at left below*), with force being applied by a lever-and-spring arrangement. The curved surface in the X-ray beam serves the same purpose as a prism in a light beam: it fans out rays of different wavelengths so that a narrow band of wavelengths can be selected.



DIAMOND ANVILS of gem quality are mounted so that X rays or an ordinary light beam can be passed through the compressed sample. If light is used, the sample can be examined by microscope.



PHOTOMICROGRAPH OF SILVER IODIDE shows three crystalline phases. The center is at about 10 kilobars, the ring is at three to four kilobars, the outer portion is at less than three kilobars.

each possessing characteristic physical and chemical properties.

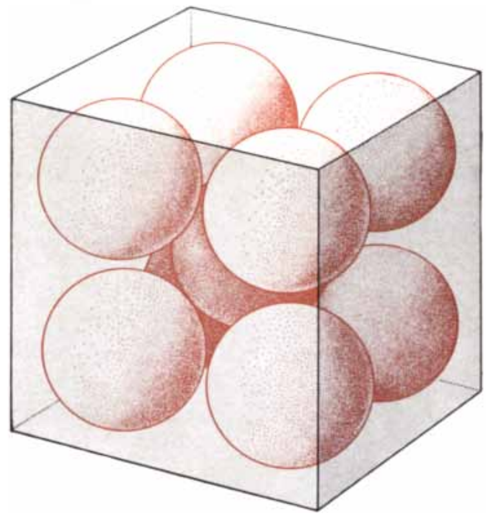
Now let us proceed to the experiments with iron and iron-nickel alloys. It was known that at ordinary pressure iron has three phases depending on temperature. At temperatures up to 906 degrees C. it has the form called alpha, in which the atoms in the crystal are arranged in a "body-centered" cubic structure; between 906 and 1,401 degrees it favors the gamma phase, characterized by a "face-centered" cubic structure, and between 1,401 and 1,530 degrees (the melting point of iron) it returns to a phase called delta, in which the structure is again body-centered cubic [*see illustration at top of these two pages*].

In order to explore the effects of pressure alone, we subjected iron samples to various pressures while keeping the temperature constant at 25 degrees C. (77 degrees Fahrenheit). When the pressure reached 130 kilobars, the iron began to exhibit a visible change of phase from the normal alpha form: it became brighter [*see illustration at bottom left on this page*]. When we examined our compressed samples by X-ray diffraction, we found that the iron had indeed been transformed into a new structure: a more compact hexagonal arrangement. We named this new phase epsilon.

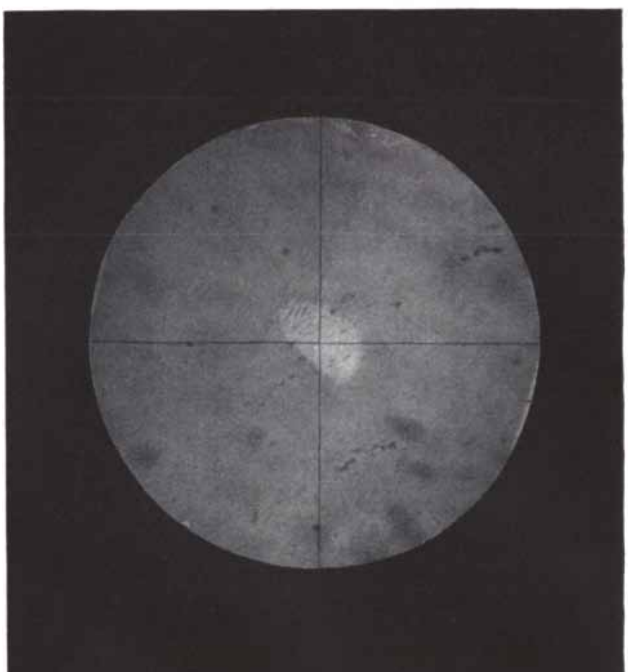
From the X-ray studies we were able to calculate how the density of iron responded to increasing pressure [*see top illustration on page 106*]. At ordinary temperature and pressure the density of iron is 7.86 grams per cubic centimeter. At pressures up to 130 kilobars compression reduced the distances between atoms, so that the density rose steadily to 8.46 grams per cubic centimeter. But at 130 kilobars, where the iron changed to the epsilon phase, the density abruptly jumped to 8.81 grams per cubic centimeter. Thereafter, as the pressure was increased further, the density increased at a uniform rate. At 300 kilobars, the limit of our equipment, the density of pure iron was 9.49 grams per cubic centimeter.

We then tested an alloy consisting of 95 percent iron and 5 percent nickel. Like iron itself, the alloy normally crystallizes in the alpha phase, or body-centered cubic arrangement. Up to 115 kilobars it increased in density at almost the same rate as iron. Then it changed to the epsilon phase and its density jumped from 8.40 grams per cubic centimeter to 8.87. As we raised the pressure higher, however, the alloy behaved differently from pure iron. To our surprise it showed substantially lower compressibility at high pressure than pure iron did; that is, its density rose at a slower rate. Whereas the alloy was denser than pure iron at a pressure of 115 kilobars, at 230 kilobars the density of both became equal, and at 300 kilobars the iron-nickel alloy was actually 1 percent lighter than pure iron!

The final experiment was performed

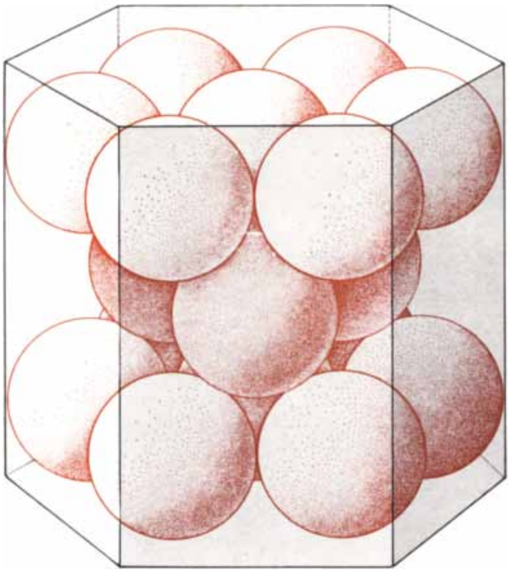


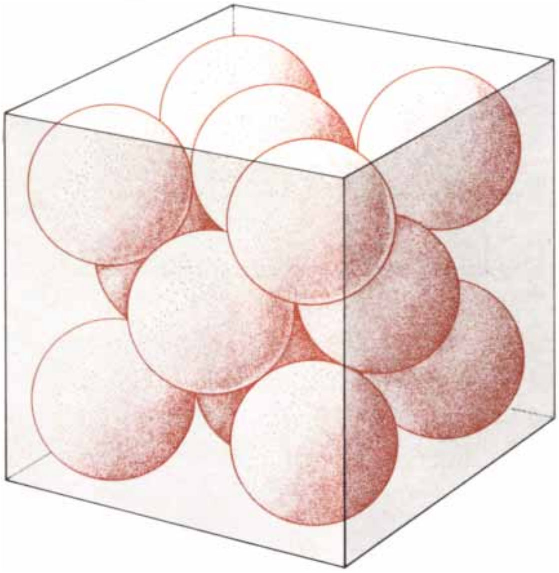
IRON CRYSTALS assume different atomic arrangements at different pressures and temperatures. The common low-temperature



PHOTOMICROGRAPH OF IRON shows the epsilon phase formed at pressures above 130 kilobars as a bright region in the center. This region is surrounded by iron in the less dense alpha phase.

X-RAY PATTERNS OF IRON show how the crystal structure of iron varies with pressure. To provide a means for estimating pressure sodium chloride is mixed with the iron powder. At room

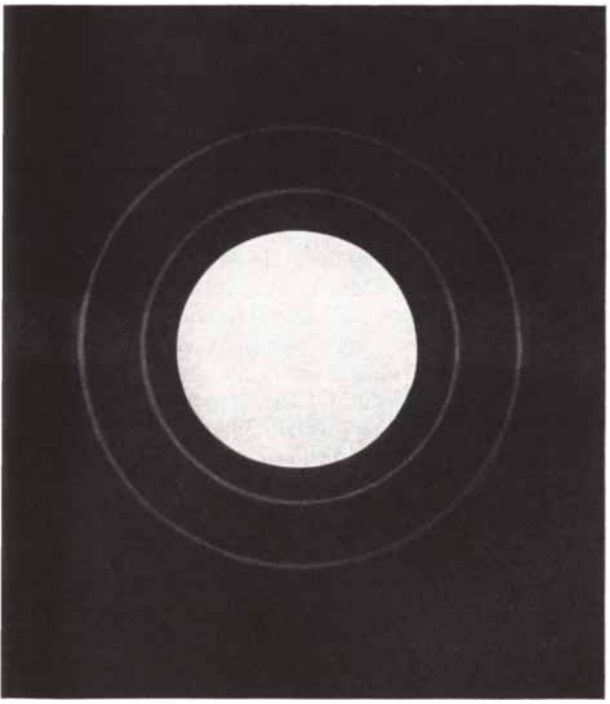


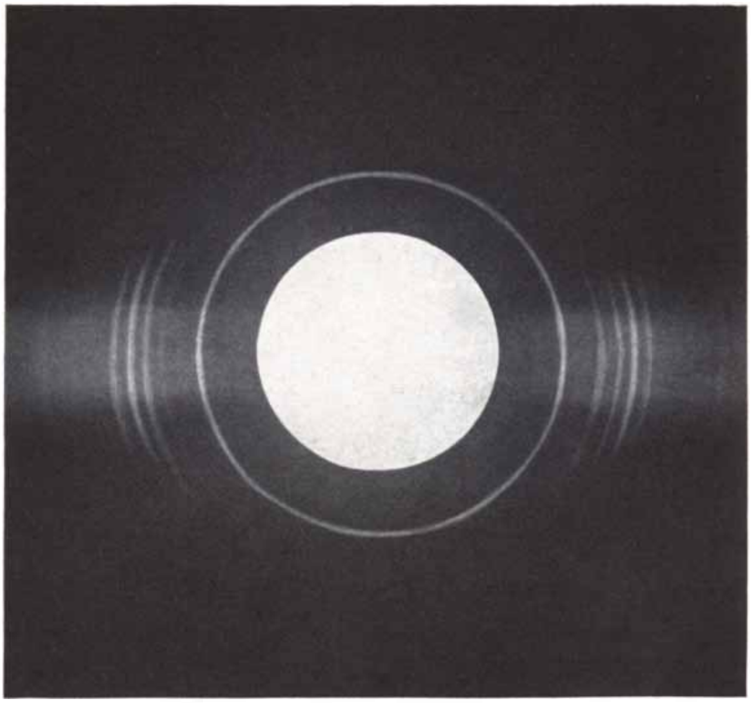


form is a "body-centered" cubic crystal (*left*) called alpha iron. One high-temperature form, delta iron, has the same structure. A form found at intermediate temperatures, gamma iron, has a "face-centered" cubic structure (*middle*). Epsilon iron (*right*), which appears only at pressures above 130 kilobars, exhibits hexagonal close-packing. It was discovered in the authors' laboratory.

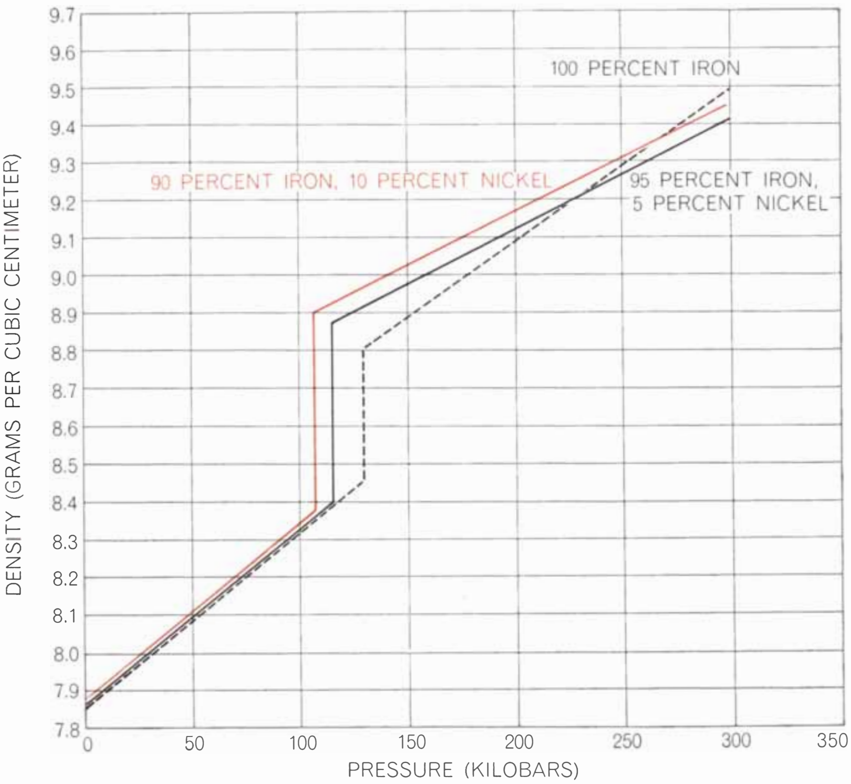
with an alloy of 90 percent iron and 10 percent nickel. This is the composition of the average iron-nickel meteorite. The 90:10 alloy again showed the same property of being less compressible than pure iron at high pressures. Extrapolating to pressures above the limit attainable with our instrument, we calculated that under the conditions in the earth's core (1,500 to 3,500 kilobars and 3,000 degrees C.) the iron-nickel alloy would be approximately 10 percent lighter than pure iron.

On the basis of various experiments it is possible to plot the joint effects of temperature and pressure within the limits of conditions attainable in the laboratory [*see bottom illustration on next page*]. The iron or iron-nickel alloy in the core cannot be in the alpha phase, because that phase cannot exist at a temperature higher than 906 degrees or a pressure higher than 130 kilobars. Under the conditions in the core,

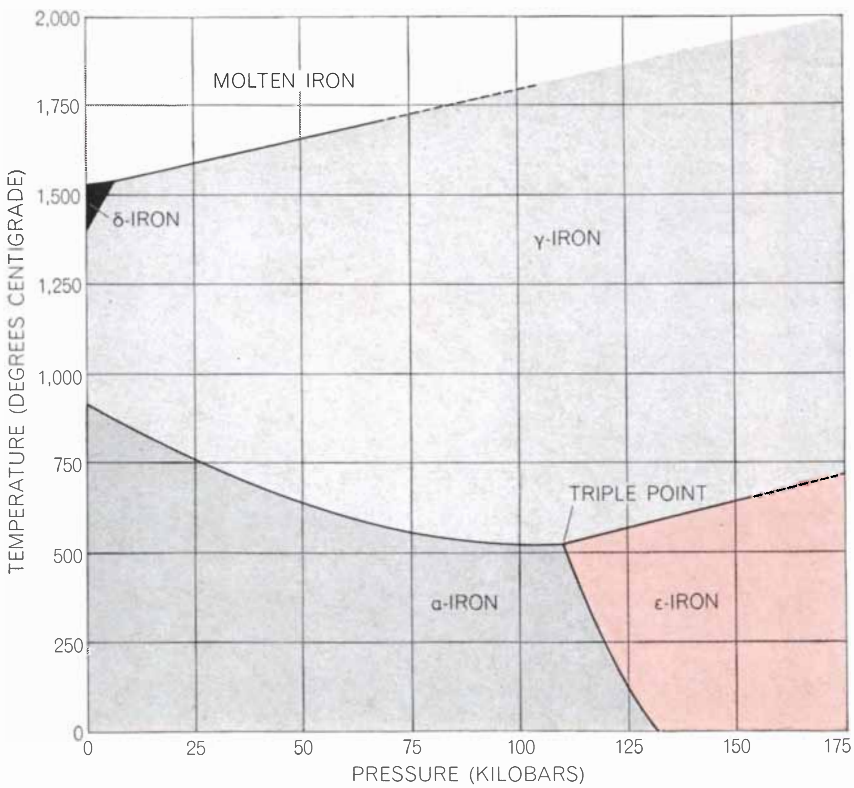




pressure and temperature (*left*) iron is in the alpha form. At 130 kilobars and room temperature (*middle*) a new line just outside the strongest alpha line signals the first appearance of the epsilon phase. At 200 kilobars and room temperature (*right*) the diffraction lines of the alpha phase have entirely disappeared and only those of the epsilon phase remain. Sodium chloride lines are also present.



EFFECT OF PRESSURE ON DENSITY of pure iron and iron-nickel alloys has been determined with the authors' high-pressure X-ray camera. In all three samples the density increases smoothly until there is an abrupt change in crystal structure between 110 and 130 kilobars, after which the density again increases smoothly. The significant finding here is that the two nickel alloys are less dense than pure iron at 300 kilobars. It is proposed that these alloys may resemble the material in the earth's core, which is less dense than pure iron.



PRESSURE-TEMPERATURE DIAGRAM shows where the various forms of iron are stable. Alpha, gamma, delta and epsilon iron are identified by the Greek letters α, γ, δ and ε.

therefore, the metal must be in either the gamma phase or the epsilon phase. Which is more likely? One can only try to extrapolate from the laboratory results to higher levels of the pressure-temperature curve governing the transition from the gamma to the epsilon phase.

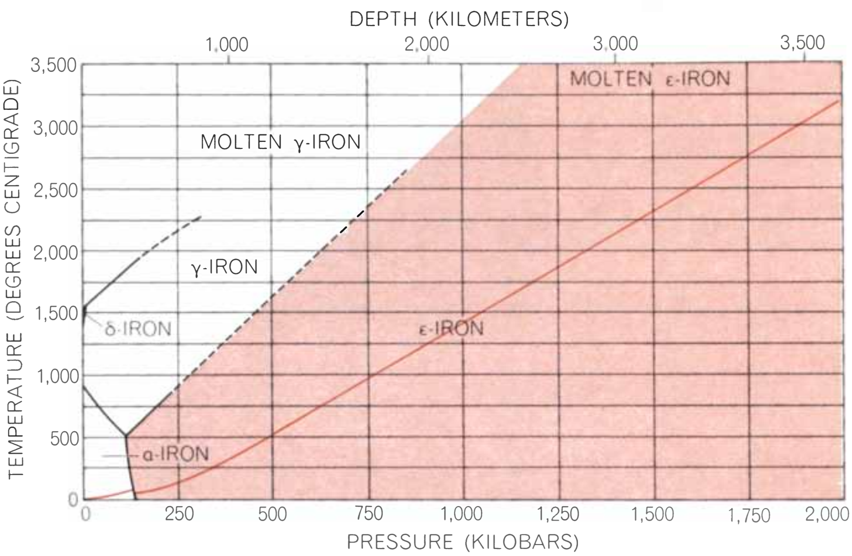
F. P. Bundy of the General Electric Research Laboratory has experimentally determined that the temperature required for the transformation of iron from the gamma to the epsilon phase goes up by 2.8 degrees C. with each increase of one kilobar in pressure. Our calculations indicate that for a 90:10 iron-nickel alloy the requirement is 7 degrees per kilobar. An extrapolation to the temperature-pressure conditions in the earth's core leads to the conclusion that the metal there is most likely in the epsilon phase. The conclusion is supported by the studies that have subjected iron to high temperatures and pressures by means of explosives [*see upper illustration on page 108*].

Observations of seismic waves that have traveled through the core suggest that the outer portion of the core—between 2,900 and 5,000 kilometers below the earth's surface—is fluid, because that region does not transmit shear waves as a solid usually does. Reflections from a surface within the core have led geophysicists to conclude, however, that there may be a solid inner core. In any case we can reasonably assume that, whether the metal of the core is in the molten or the solid state, its atoms are arranged in closely packed configurations; molten or solid, the density of the metal is about the same.

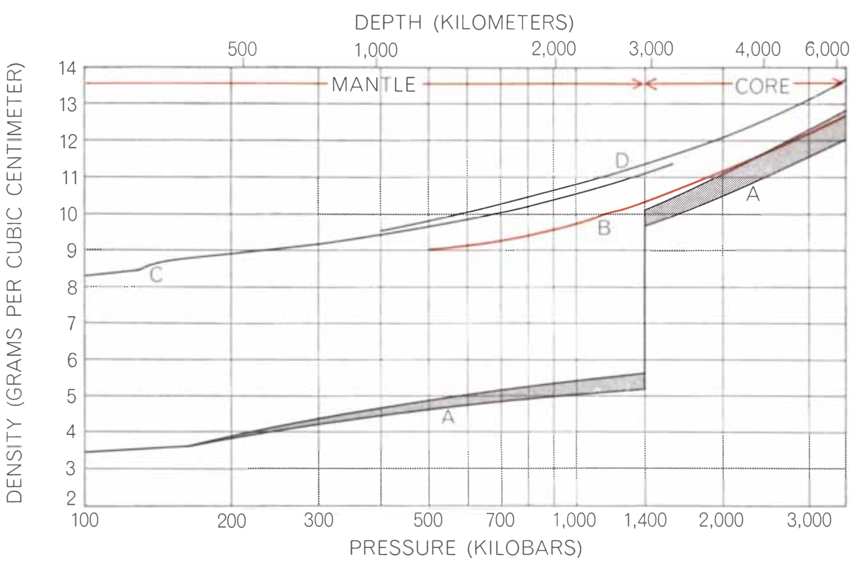
The present information on the probable composition of the earth's core can be summed up in a single chart [*see lower illustration on page 108*]. This shows first of all the density of pure iron at very high pressures, as determined in independent shock-wave experiments by R. G. McQueen and S. P. Marsh at Los Alamos and by L. V. Al'tschuler and his associates at the Institute of High Pressure Physics in the U.S.S.R. The chart also shows the results of our experiments with the 90:10 iron-nickel alloy and extrapolations from these results that indicate that under the assumed high pressures and temperatures of the earth's core the density of the alloy is about 10 percent less than that of pure iron. Our density values for this alloy agree with the density of the core, as estimated by K. E. Bullen of the University of Sydney and Francis Birch of Harvard University on the

basis of seismic data, the moment of inertia and the earth's mass.

We conclude, therefore, that the earth's core probably consists of iron-nickel alloys and is similar in composition to the iron-nickel meteorites. In all likelihood the inner core is solid and crystalline, with the atoms of the alloy packed in a hexagonal arrangement, and the outer part of the core is fluid, with the atoms closely packed but in a less orderly configuration.



EXTENSION OF PRESSURE-TEMPERATURE DIAGRAM shows the type of iron alloy that may exist in the earth's core. The colored curve shows pressure-temperature conditions produced by shock waves in iron samples subjected to explosive blasts. The break in slope at 130 kilobars is produced by the transition from alpha iron to epsilon iron. The absence of further breaks in the curve shows that the epsilon phase is probably the stable phase of solid iron up to pressures of at least 2,000 kilobars, or well into the earth's core.



DENSITY OF MATERIAL WITHIN THE EARTH as inferred from geophysical measurements (*A*) can be compared with extrapolations from laboratory experiments (*B*, *C*, *D*). Values plotted in *A* are those calculated by Francis Birch of Harvard University and Sir Edward Bullard of the University of Cambridge; shaded areas represent uncertainty. Line *B* shows the density of a 90-percent-iron-10-percent-nickel alloy extrapolated to 3,500 kilobars and 3,500 degrees C. from the authors' data. Line *C* shows the densities of pure iron as determined by the shock-wave technique developed by R. G. McQueen and S. P. Marsh of the Los Alamos Scientific Laboratory. Line *D* shows the density of pure iron as determined by L. V. Al'tschuler of the U.S.S.R., who also used a shock-wave technique. The agreement between *A* and *B* speaks for a core composed of 90 percent iron and 10 percent nickel.

WHO'S AFRAID OF THE ONE-EYED JACK?

THIS JACKRABBIT is a small part of an NUS program at San Onofre, California. He is one of the fauna and flora examined in a program developed by NUS to establish base levels of radioactivity before initial operation of the reactor plant under construction there for the Southern California Edison Company. ¶ He contributes, willy-nilly, to one of NUS's varied complex of programs—test facility planning and design, the NERVA Nuclear Rocket tests at Jackass Flats, Nevada, SNAP projects, the Surveyor Lunar Roving Vehicle, and others. ¶ But NUS *habitually* stretches far beyond its basic nuclear disciplines as a leading consultant-engineering firm—into applied research, operations research, systems analysis and design, and other fields. The question is apt and answerable: NUS's multi-discipline staff does *not* fear the one-eyed jack (-ass, -rabbit, or card), the unexpected variable, in problems of many diverse kinds.

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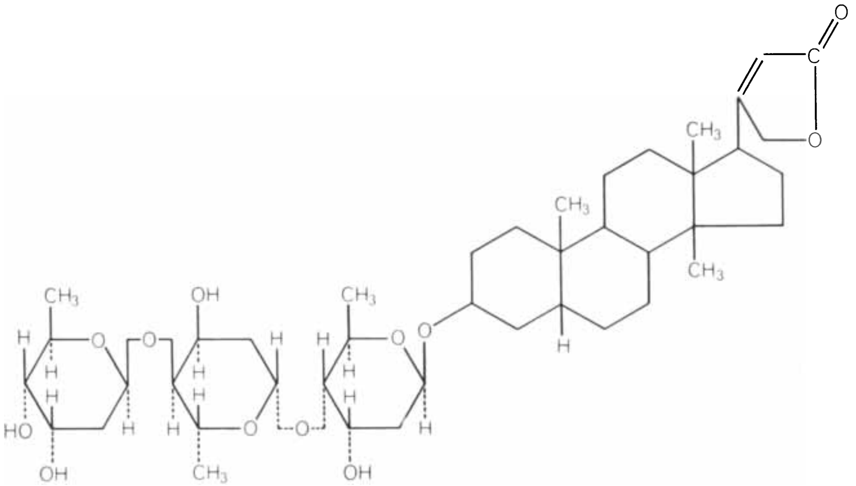
William Withering and the Purple Foxglove

The foxglove yields the invaluable heart drug digitalis. Discovered at least as early as the 16th century, the drug fell into disrepute but was reinstated by the careful studies of an English physician

by J. Worth Estes and Paul Dudley White

Digitalis, an extract of the leaves of the plant called the purple foxglove, is currently used to treat almost every type of heart disease. It causes heart muscle to contract quickly and forcefully and thus works against cardiac insufficiency. In speeding up contraction it gives the heart more time to rest between beats. In strengthening contraction it enables the heart to deliver blood to the rest of the body at higher pressure; this tends to keep fluid from leaking out of the capillaries and to encourage the kidney to excrete it. The most active constituent of digitalis is the glycoside digitoxin, the molecular structure of which was determined a decade ago. Exactly how digitalis produces its effects in the heart muscle, however, remains unclear.

Men have been interested in digitalis and its effects for centuries; even the discovery of its medical usefulness was a historical process rather than a single event. Written records indicate that as early as the 16th century physicians were praising the medicinal properties of the purple foxglove. As so often happened in past epochs of medical practice, however, the practitioners did not systematically compile or transmit their clinical experience. Foxglove would be used successfully in one case and then unsuccessfully—even fatally—in another. Apparently by 1745 the failures of the drug had come to outweigh the successes; in that year it was dropped from the influential London *Pharmacopoeia.* It was not readmitted to the *Pharmacopoeia* until the end of the 18th century, when an English physician named William Withering published his *Account of the Foxglove and some of its Medical Uses: with Practical Remarks on Dropsy and Other Diseases.* This book described extensive tests of the applicability of digitalis in treating various ailments. If we consider Withering's contribution in the context of several centuries of discussion of digitalis, we begin to see that rigorous and systematic observation can do more to advance medicine than the most accurate insight that is not accompanied by experimentation.



DIGITOXIN, the principal active constituent of digitalis, was isolated more than 100 years ago, but its molecular structure was determined only about a decade ago. Its glycoside molecule has two components: a sugar (*three rings at left*) and a steroid (*five rings at right*).

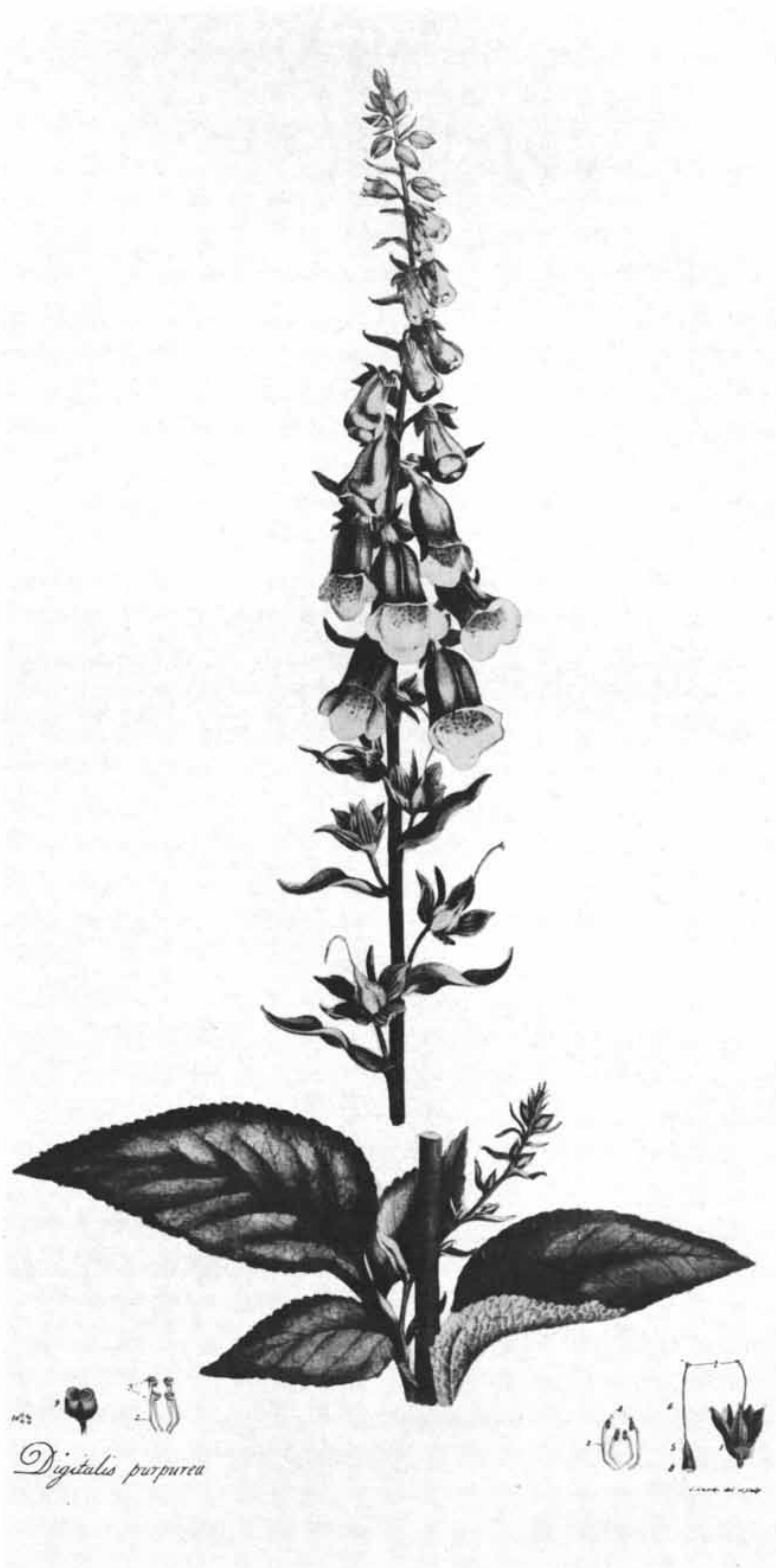
Few aspects of the history of digitalis can be set forth simply and unambiguously. It is difficult to determine who first wrote about the medical uses of the foxglove, and there are even two versions of how the word originated. It has been suggested that "foxglove" is a corruption of "folk glove"; "folk" here refers to "little folk," or fairies. The second version is that the word derives from the Anglo-Saxon *foxes-glew,* or "fox music," which refers to an ancient musical instrument that consisted of bells hung on an arched support. When we examine equivalents of the word in other languages, we find that they support both notions; for example, the Norwegian *revlecka* means "fox music," whereas the Welsh *menygellydon* means "elves' gloves." The synonymous term in Latin—*Digitalis purpurea*—is less troublesome because it was explained by its originator, a 16th-century Bavarian physician named Leonhard Fuchs. Fuchs derived "digitalis" from the German word for the plant: *fingerhut,* or "thimble," which refers to the shape of the flower.

Foxglove is native to Europe, where

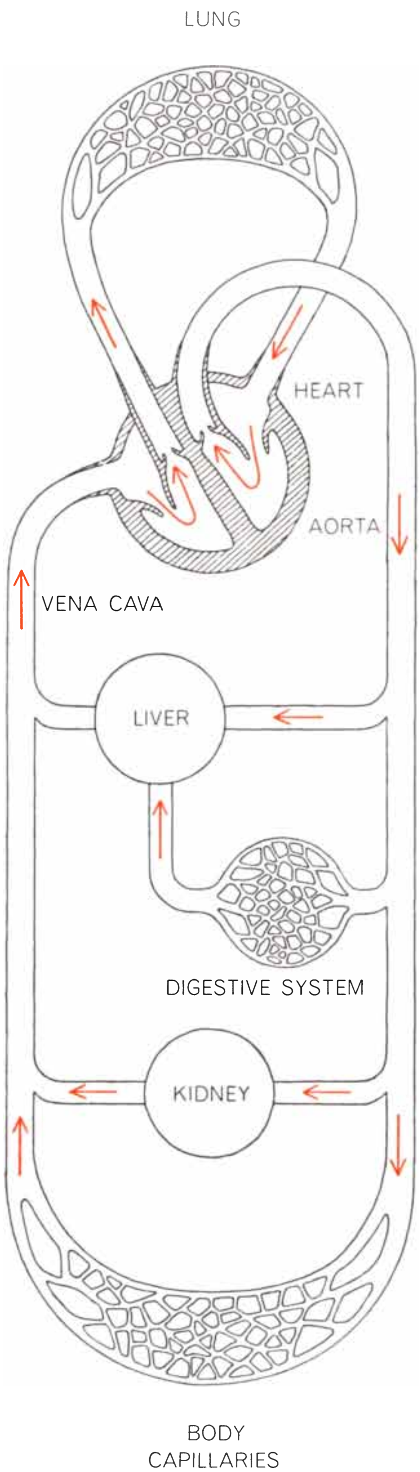
it is widespread and common; it was imported to America. Here it was first used late in the 18th century by Hall Jackson, a physician of Portsmouth, N.H. Jackson obtained foxglove seeds and instructions for administering the drug from Withering himself, who had been an acquaintance of Jackson's student years at the University of Edinburgh. In the U.S. today the foxglove is cultivated as a medicinal herb (a more economical way of producing digitalis than synthesizing it) and frequently as an ornamental flowering plant. Propagated by seed and sown in a hotbed in early spring, it is transplanted to fields after a late frost. The first year's growth is a rosette of oval leaves. In the second year the stem rises a yard or more and bears long, pointed leaves. It is topped by purple flowers that are spotted on the inside and are about an inch and a half long. Although the plant does not flower until its second year, the leaves are collected in both the first and second years. If the leaves are gathered before the plant flowers, they contain maximum amounts of the active digitalis glycosides. After the leaves are dried all that remains to be done is to remove the stalk and midribs; the powdered leaves can be taken orally. Today, however, digitalis is normally administered in solution or by tablet.

The variety of names for the foxglove and its vague resemblance to other plants complicate the task of identifying the first description of its medicinal properties. There is an apparent reference to the foxglove in the *Grete Herball* (*Great Herbal*) published by Peter Treveris in 1526; the book includes a plate showing a plant that resembles the foxglove and that is also recommended for "feebleness of the heart." It has recently been proved, however, that Treveris was discussing another plant.

Just as Treveris, a botanist, commented on the medicinal properties of the plants he described, so his contemporary Fuchs, a professor of medicine at Tübingen, compiled a herbal as his contribution to medical literature. In *De historia stirpium*, published in 1542, Fuchs described digitalis as a purgative and an emetic. He may even have observed that it can cure dropsy, but this hangs on the debatable translation of a sentence. Dropsy is a consequence of many diseases, including certain kinds of heart trouble in which the heart muscle does not contract forcefully enough to propel the blood through the circulatory system and back to the heart; as a result fluid col-



PURPLE FOXGLOVE, the plant whose leaves yield digitalis, is depicted in the frontispiece of William Withering's *Account of the Foxglove*. The plant grows more than three feet high. Its flowers are purple, about an inch and a half long and spotted inside. The leaves of the plant contain a maximum amount of drug's glycoside constituents before the plant flowers.



EFFECT OF DAMAGED HEART is outlined in this highly schematic diagram of the circulatory system. Blood pumped from the damaged heart returns to it at low pressure. The drop in pressure allows fluid to leak out of the capillaries into tissues, which then swell. It also prevents the kidney from functioning at the level of efficiency necessary to excrete the fluid. The retention of fluid resulting from congestive heart failure was at one time customarily termed dropsy.

lects in the lungs, the liver, the legs, the abdomen and even in the pleural cavity, causing edema in these areas. In his herbal Fuchs concludes: "This plant is usually very effective in its action to thin, to dry up, to purge, and to free of obstructions." We interpret this passage as indicating that Fuchs probably knew the drug could remove fluid from people in whom it had accumulated abnormally, including those with dropsy.

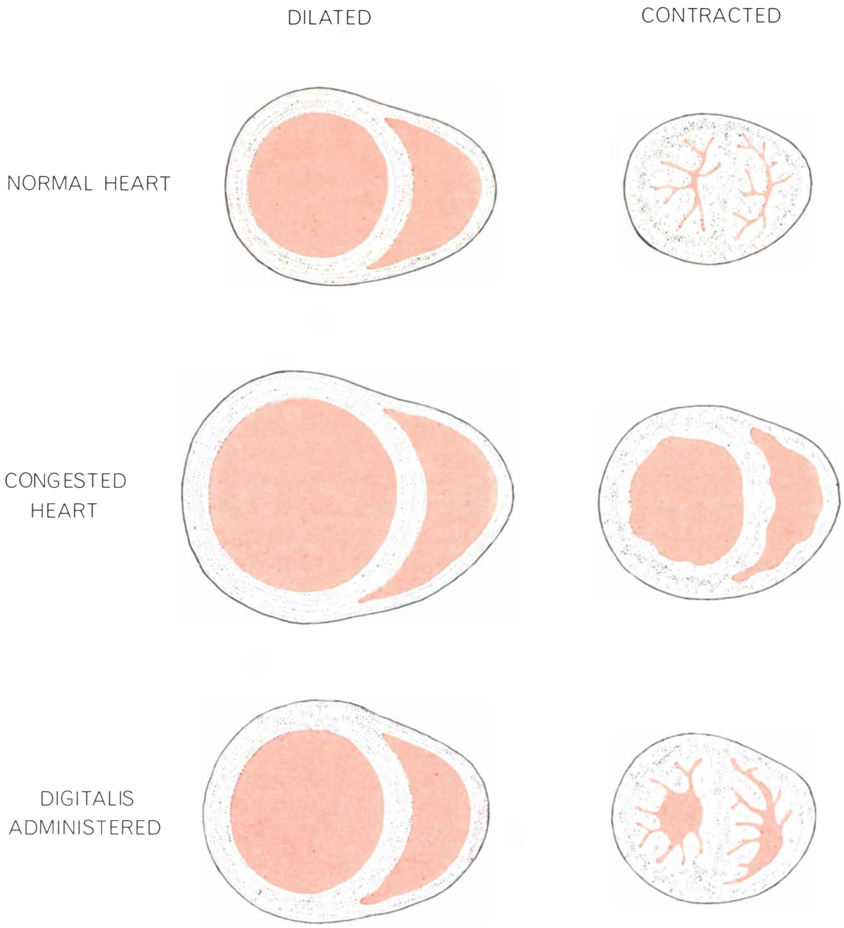
In the medical literature of the 16th century other herbalists mentioned digitalis, usually as an emetic or an ointment for open wounds. Andrea Cesalpino, who first suggested the circulation of the blood, recommended digitalis for the treatment of "malignous tumors." Since the word "tumor" properly refers to any swelling, this may have been a reference to the swelling caused by dropsy. As the reputation of the plant grew it was described in many herbals, and more powers were ascribed to it. By 1661, the year of its first inclusion in the London *Pharmacopoeia*, foxglove was being recommended for epilepsy and as a sedative. It was also administered for consumption, later known as tuberculosis. Here it should be recalled that heart failure frequently affects the lungs, and that it may have been difficult for physicians to distinguish consumption from heart failure. At any rate, digitalis was being recommended as a treatment for a disease it could not alleviate.

The drug had its wise advocates, but even they did not often moderate their tone. William Salmon, an English physician who rarely made exaggerated claims, wrote: "This medicine has restored (where the patient has been past all cure) beyond all Expectation.... It opens the Brest and Lungs, frees them from tough Flegm, cleanses the Ulcer. ... Persons in deep consumption, and given over by all Physicians, have been strangely recovered as to grow fat again. I commend it as a Secret, and it ought to be kept a Treasure. These few lines concerning this Medicament are worth ten times the Price of the whole Book." In one of Salmon's several works on medicinal plants he mentions dropsy as a disease for which digitalis provides therapy. He also made the astute observation that it should be used in small doses because large ones elicit violent reactions.

Such recommendations went unheeded, and digitalis gained a reputation for toxicity. Hermann Boerhaave, who in the 18th century founded physiology as a separate discipline, regarded the drug as a poison and cautioned against its use. Others ceased to recommend it. Such discredit culminated in a widely publicized pseudoscientific experiment. A French physician named Salerne, exhibiting unusual bias and ignorance, stuffed some foxglove leaves down the throats of two turkeys. Both birds became violently ill; one died of the overdose. An autopsy revealed that the birds' intestines were shrunken and dry. Salerne reported his findings to the French Academy of Sciences, arbiter of European medicine at the time, and they were published in the annals of the Academy for 1748. After that no physician dared to use such a toxic drug in treating human beings. What acceptance digitalis had attained during the preceding century was now completely dissipated. The scattered and incidental comments made by many physicians in praise of the drug provided no guidelines for its safe and efficient use and so could not serve to restore its reputation. Digitalis was assumed to be more harmful than helpful—until Withering undertook to study it in exhaustive detail.

The man whom modern physicians should thank for assuring the place of digitalis in medicine was born in Wellington in England in 1741 and received his degree as a doctor of medicine from the University of Edinburgh in 1766. He practiced in Shropshire for a while and then, at the suggestion of Erasmus Darwin (Charles Darwin's grandfather), moved to Birmingham. There he founded a clinic for the poor in which he treated some 3,000 patients a year. In 1776 he published *A Botanical Arrangement of All the Vegetables Naturally Growing in Great Britain According to the System of the Celebrated Linnaeus*, the first complete text on the plants of the British Isles to be written in English. He became interested in this project while gathering flowers to amuse one of his patients, who later became his wife. In his botanical text Withering's only reference to the medicinal properties of the foxglove was: "A dram of it taken inwardly excites violent vomiting. It is certainly a very active medicine and merits more attention than modern practice bestows upon it." Considering that he had already spent a year studying the effects of the foxglove, this understatement indicates the caution that characterizes his work.

Withering had first concerned himself with the foxglove when, as he explained in his *Account*, his opinion was asked "concerning a family receipt for the cure of the dropsy... kept a secret by an old woman in Shropshire." He immediately realized that foxglove was the active component in the woman's mixture of herbs, and he assumed that its effect was to encourage the excretion of excess fluid; today this effect would be called diuresis. For the next 10 years, during which he studied the plant and its curative properties, he continued to think of diuresis as its chief effect and to regard dropsy—rather than the malfunctioning heart often responsible for it—as the disease against which digitalis primarily acts. Withering did comment, in a concluding section of his *Account* entitled "Inferences," that digitalis "has a power over the motion of the heart, to a degree yet unobserved in any other medicine, and that this power may be converted to salutary ends." Withering did not, however, follow up this idea of a primary effect on the heart, and it is not clear whether or not he thought of dropsy as being related in some way to the malfunctioning of the heart. In a few of his case reports he recorded the drop in pulse rate, but that would seem to be the extent of the attention he paid to cardiac function.



EFFECT OF DIGITALIS on the heart is illustrated by cross sections of lower chambers. Contraction of normal heart (*top*) involves a marked change in the size of the left ventricle as it pumps blood to the aorta (and thence to rest of the body). Weak heart (*middle*) is characterized by decreased contraction of the ventricle as blood is pumped. Effect of digitalis (*bottom*) is to increase the force of contraction and raise the pumping pressure.

Digitalis, Withering realized, had no diuretic effect on people who were not suffering from dropsical retention of fluid. He also learned that diuresis need not be accompanied by such side effects as nausea and vomiting, and he controlled these side effects by administering opium along with digitalis. Withering recognized that the chemical techniques of his time were not adequate for further study of digitalis, and so he considered other methods for investigating the drug. He suggested that fruitful results would come from studying its effects on insects and higher animals, from comparing its effects with those of other diuretics and from empirical application to human patients. He favored the last method, which would of course be unacceptable today unless the drug had first been investigated by other means.

Withering's *Account* discusses, in varying degrees of detail, 158 patients who took digitalis on his prescription. Of these, 101 experienced relief following administration of the drug. Analysis of the individual case reports suggests that many of the 57 others—for example those with pulmonary tuberculosis—did not suffer from diseases that are amenable to treatment with digitalis. Withering himself recognized the role such considerations might be playing in his results and warned against generalizing on his cases. He also noted, along with his description of several digitalis preparations and a general formula for determining proper dosage, that schedules of dosage should be varied with individual patients. He warned that "the more we multiply the form of any medicine, the longer we shall be in ascertaining its real dose." The warning is still well taken.

Edward W. Pelikan of the Department of Pharmacology at the Boston University School of Medicine has joined us in analyzing the data represented by Withering's clinical record. The results we obtain [*see illustrations on page 119*] show that for their time Withering's observations were remarkably thorough. He tested the available preparations of the drug and determined that dried and powdered foxglove leaves were significantly more potent than an extract made by soaking the leaves in water. He also found that, although an extract made by soaking the leaves in alcohol was as effective as powdered leaves, it had a larger number of undesirable side effects. These results are consistent with our modern knowledge of the various preparations. We also know that Withering was able to arrive at the optimum quantity of the drug to be administered as a single dose: the amount of digitalis he prescribed had only slightly less activity than the standardized tablet used in contemporary practice. By plotting Withering's data in chronological order, Pelikan has demonstrated that the incidence of side effects declined as the physician gained experience with the drug. It appears that the overall incidence of side effects attributable to digitalis in Withering's patients approximates the incidence recorded by physicians today. One could learn to use digitalis effectively and safely if one had no other text than Withering's *Account*.

A sense of Withering's medical and literary style can best be conveyed by considering an individual case report in his *Account:*

"July 25th (1776). Mrs. H... of A..., near N..., between forty and fifty years of age, a few weeks ago, after some previous indisposition, was attacked by a severe cold shivering fit, succeeded by fever; great pain in her left side, shortness of breath, perpetual cough, and, after some days, copious expectoration. On the 4th of June, Dr. Darwin was called to her. I have heard what was then done for her, but, between the 15th of June, and the 25th of July, the Doctor, at his different visits, gave her various medicines of the deobstruent, tonic, antispasmodic, diuretic, and evacuant kinds. . . .

"She had experienced no relief from any means that had been used.... In this situation I knew of nothing likely to avail us, except the Digitalis: but this I hesitated to propose, from an apprehension that little could be expected from anything; that an unfavourable termination would tend to discredit a medicine which promised to be of great benefit to mankind, and I might be censured for a prescription which could not be countenanced by the experience of any other regular practitioner. But these considerations soon gave way to the desire of preserving the life of this valuable woman, and accordingly I proposed the Digitalis to be tried; adding, that I sometimes had found it to succeed when other, even the most judicious, methods had failed. Dr. Darwin, very politely, acceeded immediately to my proposition, and, as he had never seen it given, left the preparation and the dose to my direction....

"The patient took five of these draughts, which made her very sick, and acted very powerfully upon the kidneys, for within the first twenty-four hours she made upwards of eight quarts of water. The sense of fulness and oppression across her stomach was greatly diminished, her breath was eased, her pulse became more full and more regular, and swellings of her legs subsided....

"It is now almost nine years since the Digitalis was first prescribed for this lady, and notwithstanding I have tried every preventive method I could devise, the dropsy still continues to recur at times; but it is never allowed to increase so as to cause much distress, for she occasionally takes the infusion and relieves herself whenever she chooses. Since the first exhibition of that medicine, very small doses have been always found sufficient....

"I have been more particular in the narrative of this case, partly because Dr. Darwin has related it rather imperfectly...trusting, I imagine, to memory, and partly because it was a case which gave rise to a very general use of the medicine in that part of Shropshire."

When one analyzes the case in the light of current knowledge, it becomes apparent that the primary reason for the success of Withering's use of digitalis lies in the reduction of the heart rate during the irregular and rapid heart action that we now call atrial fibrillation—not only on the first occasion but repeatedly thereafter. Today the continuous administration of digitalis to such a patient would also tend to prevent the recurrence of dropsy.

The last paragraph of the report refers to an embarrassing episode in the history of the foxglove. Erasmus Darwin had publicly taken credit for the introduction of digitalis into the medical repertory, omitting any mention of Withering in a case on which he had sought and successfully applied Withering's advice. Withering was naturally upset

ELECTROCARDIOGRAM of a normal heartbeat is characterized by .16- to .20-second interval between wave *P* and wave *R* (each small square of the grid is .04 second) and the orientation of wave *T*. The interval between *P* and *T* indicates the relationship of activity in the atria, or upper chambers of the heart, to activity in the ventricles, or lower chambers. The three closely spaced waves at right center are for calibrating the electrocardiogram.

ATRIAL FIBRILLATION, a type of heart failure, is recorded in this electrocardiogram. Rapid atrial impulses (*irregular heavy line*) precede ventricular impulses (*sharp peaks*).

EFFECT OF DIGITALIS appears on electrocardiogram in two obvious ways. The interval between *P* and *R* waves is prolonged (.28 second), and the *T* wave goes down instead of up.

about this flagrant omission, but he could not openly rebuke the man who had helped to establish him in practice. When he wrote his *Account,* he inserted a paragraph to set the record straight.

Withering achieved a considerable reputation in his own lifetime. He calculated that in 1785, the year the *Account* was published, he was called on to participate in consultations that entailed 6,300 miles of travel in Britain and on the Continent. He became a member of the Lunar Society of Birmingham, to which the most distinguished intellectuals of 18th-century England belonged, including James Watt, Matthew Boulton and Joseph Priestley. He wrote not only on medicine and botany but also on anthropology and mineralogy; he discovered a mineral later named witherite. He was particularly concerned not only with dropsy but also with sore throat and scarlet fever. His *Account of the Foxglove* ultimately brought him a fellowship in the Royal Society of London. Shortly after the publication of the book his already delicate health had begun to decline; in 1799 he died of consumption, a disease he, like his predecessors, had tried to cure with foxglove.

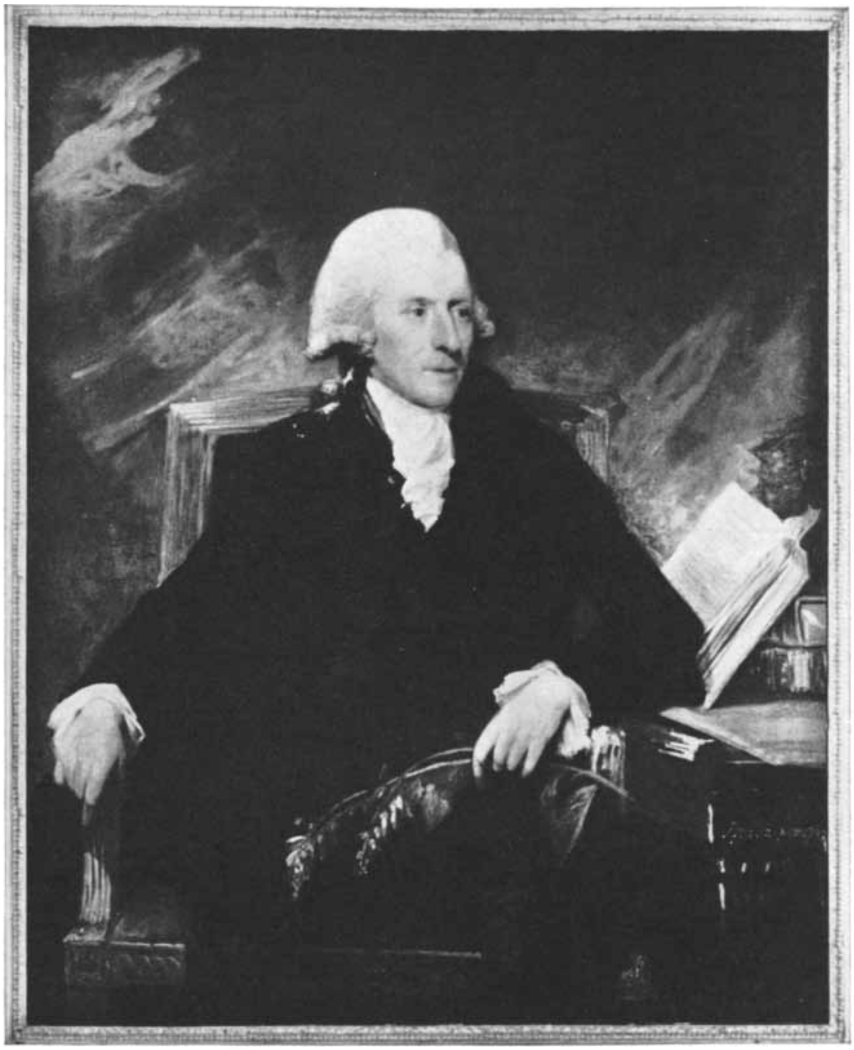
In spite of Withering's illustrious reputation, his advice was ignored or contradicted for some time after the *Account* was published. Digitalis was used almost with abandon; physicians prescribed it for all kinds of diseases, and in extravagant dosages. It appeared that the historical process that had led digitalis into disrepute would repeat itself. Physicians began to notice that digitalis had not cured a single case of consumption. Those who made this observation advanced the idea that the drug actually was dangerous to the patient, since whatever effect it might have was not a helpful one. This hard-headed school finally disappeared and a new generation of medical investigators came to the fore. They revived Withering's work and showed that the drug was not at all dangerous if his directions were followed. They then asked new questions about how digitalis acts, about its chemical constitution and about the heart and its connection with dropsy.

In 1799 John Ferriar suggested that "the power of reducing the pulse is the true characteristic" of digitalis. Because of this comment Ferriar has been credited with the first realization that the primary site of action for digitalis is the heart. It seems to be true that he was the first to recognize that diuresis is not the primary effect of digitalis, but his observation does not mean that he had perceived the site of action. Ferriar probably knew little more than Withering, and he did not pursue his idea.

LEONHARD FUCHS, a professor of medicine at the University of Tübingen in Bavaria, included this self-portrait in his herbal *De historia stirpium*, published in 1542. The book is actually a medical text with comments on the curative properties of various plants; in it the Latin name for foxglove, *Digitalis purpurea*, first appeared. Fuchs accompanied his drawing of the foxglove with a comment suggesting its effectiveness as a cure for dropsy.

In the same year Thomas Beddoes wrote that digitalis "increases the organic action of the contractile fibers," an observation that is essentially in accord with our modern understanding of how the drug acts. Beddoes also found that digitalis gave relief to patients with lung disease only when the disease was not limited to the lung, that is, when it was secondary to heart disease. (Beddoes did not, however, grasp any pathological connection between the two organs.)

The problem of dropsy resulting from the failure of the heart muscle was elucidated at the beginning of the 20th century by Arthur Cushny of the University of London, by the Scottish physician James Mackenzie and by Karl Wenckebach, resident physician at an old people's home (a good place for the study of heart disease) in Holland. They



WILLIAM WITHERING, the English physician whose painstaking research restored digitalis to the medical repertory, was the subject of this portrait painted by Carl Frederick von Breda in 1792. The painting now hangs in the Swedish National Museum in Stockholm. The plant Withering holds is the foxglove; the open volume is his *Account* of its properties.

found that a disturbance of rhythm affects the muscles of the heart and gives rise to atrial fibrillation, a conflict of many waves of contraction originating from various sites in the atria, or auricles. The excessively fast heart rate induced by fibrillation weakens the heart and diminishes its output; the result is a diminished excretion of urine by the kidneys and the leaking of body fluids into the tissues of the thorax and the extremities.

By the time one of us (White) was a medical student and hospital intern in the years 1908 to 1913, the use of digitalis had become almost as rational on the basis of sound physiological knowledge as it is today. One major defect in the use of the drug remained: the practice of giving it in courses lasting only a week or two at a time. Perhaps this practice was related in some way to the earlier reputation of digitalis for toxicity. In any event it was standard procedure to stop administering digitalis as soon as the symptoms of cardiac insufficiency had lessened. The result would almost invariably be that in another few weeks or months the symptoms would all return and the patient would be rehospitalized in more or less of an emergency. The practice of short-term administration of digitalis was finally abandoned at the urging of several astute physicians (including Joseph H. Pratt and Henry Jackson, both of the Harvard Medical School), who established the principle of continued administration of digitalis, if necessary for many years.

The story of digitalis is important to the history of medicine because it exemplifies the value of an able physi-

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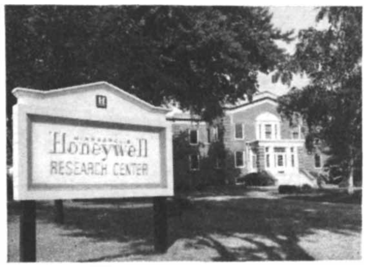


The Problem of Second Breakdown in Transistors

The use of transistors is limited by second breakdown, where there is an abrupt reduction in the collector voltage at levels of current below the rated value. In certain cases this can cause destruction of the transistor. New research indicates there are both thermal and electrical causes and some opportunities to push second breakdown limits considerably higher.

Transistors have a characteristic which is not completely understood and which puts undesirable limits on their use.

In all transistors as the collector-to-emitter voltage (Vce) is increased the transistor will reach a point where the collector current I_c increases rapidly. (See Fig. 1)

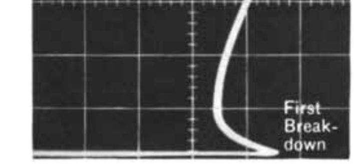


Fig. 1

This occurs at first breakdown and as current increases further, voltage will decrease to a sustaining value. This sustaining value is considered the maximum operating value of the transistor.

As current is further increased, the transistor enters a new mode of operation where voltage decreases rapidly. This is termed the second breakdown region. (See Fig. 1)

Obviously, this phenomenon puts an even lower limit on the device and one that if exceeded is potentially destructive.

Many theories have been proposed to explain this second breakdown but none have been found completely satisfactory.

Honeywell scientists in earlier work on first breakdown developed a technique that is useful in studying second breakdown. They experimentally studied the collector junction, or the interface between the P and N regions, to observe whether breakdown occurs in a uniform manner over the entire collector junction or in localized hot spots at random in the junction.

By introducing a variable transverse base current they literally obtained a "contour map" of the breakdown voltages over the entire collector junction surface. These "maps" show that breakdown voltage is not uniform.

An infrared sensor was used to confirm the non-uniform characteristic. It was observed that the infrared emission was not uniform and in fact at breakdown there was a point of intense local heating.

The results of the mapping technique supported by the infrared observations have led to the development of a model with which to analyze second breakdown.

The model treats a transistor as if it were two discrete devices operated in parallel: one device where second breakdown occurs and one where it has not occurred. It is then possible to compare the devices and come to some conclusions as to what the mechanism is that causes breakdown and triggers the negative resistance phenomena. In general, both electrical and thermal effects are important, with the dominant mechanism determined by the transistor design, mode of operation and imperfections present.

Honeywell scientists have concluded that second breakdown in transistors originates in majority carrier current (electron current in a PNP transistor) from the breakdown spot. These majority carriers are generated by the process of avalanche multiplication. During multiplication at the breakdown spot an equal number of electrons and holes are produced. In a PNP transistor the holes enter the collector and the electrons flow through the base region to recombine with holes lost by the emitter. This electron flow has a transverse component which causes a voltage drop which concentrates the emitter current in the vicinity of the breakdown spot. The higher emitter current to the breakdown spot results in a higher electron current through the base. Thus the cycle is regenerative and if the process continues, it will result in the hot spot mentioned earlier.

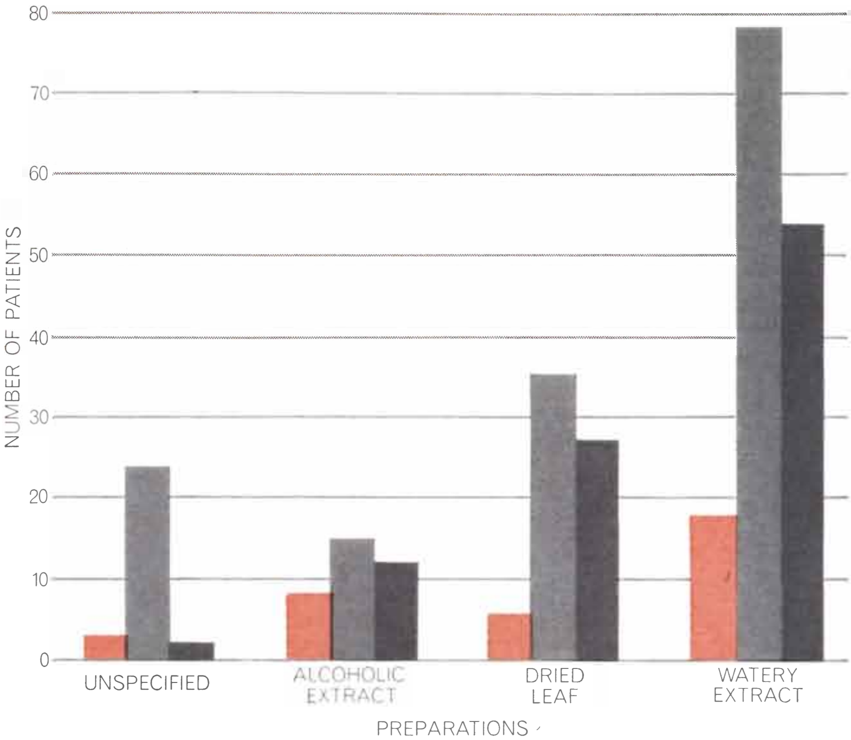
Continuing work should lead to a computer program to solve equations to predict where and when breakdown will occur and whether by electrical or thermal mechanisms.

The result, it is hoped, would be the ability to design transistors to minimize thermal effects and to eliminate or minimize the electrical effects.

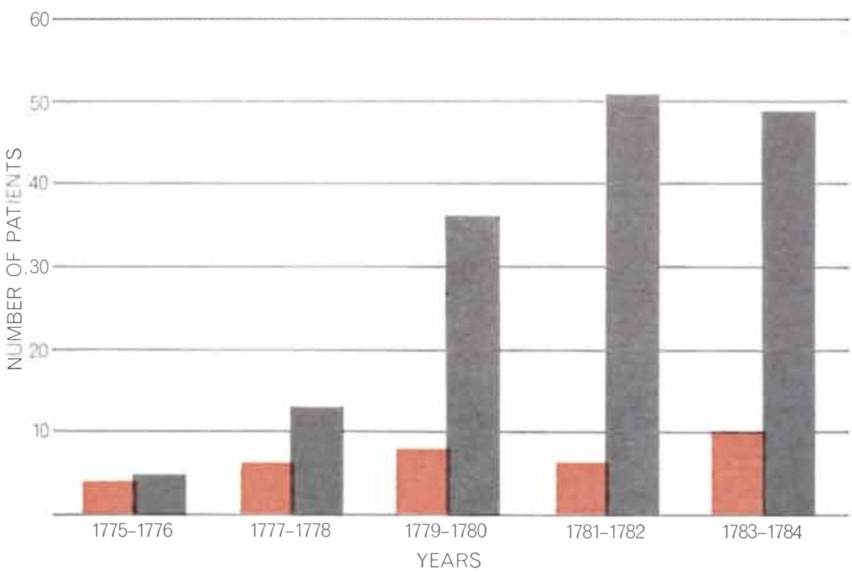
If you are engaged in research on second breakdown you are invited to correspond with Mr. Harold Josephs, Honeywell Research Center, Hopkins, Minnesota. If you are interested in a career at Honeywell's Research Center and hold an advanced degree, write to Dr. John Dempsey, Director of Research at this same address.

Honeywell

cian's experience. We can trace the career of the foxglove through its confused and sometimes mistaken use in the 16th century to its rational prescription in modern times and the quite recent description of its action in physiological terms. We now need a complete chemical explanation of its action on the muscle cells of the heart to provide a satisfying conclusion; we expect that this will come. Even as matters stand we could wish we were as well acquainted with the other drugs on our shelves as we are with foxglove.



WITHERING'S CLINICAL RECORD is tabulated from data in his *Account of the Foxglove*. Four sets of bars distinguish types of digitalis preparations Withering used. Bar in middle of each set gives total number treated as specified. Bar at left gives number of patients manifesting side effects. Bar at right gives number of patients treated successfully.



WITHERING'S INCREASING SKILL in administering digitalis as he gained experience with it is presented in graph. Each set of bars describes a two-year period of his work. Bar at left of each set shows number of patients manifesting side effects; bar at right, the total number treated in that period. The ratio between the two generally shows a decline.

MATHEMATICAL GAMES

Some diversions and problems from Mr. O'Gara, the postman

by Martin Gardner

I'm seen in the country, I'm seen
in the town,
I'm servant of all from pauper
to crown.
Take one letter from me, and still
my good name
In spite of your action continues
the same.
Take from me two letters, then three
and then four,
My name will continue the same
as before.
In fact, you can take all the letters
I've got
And my name you will not have altered
one jot!

I was leafing through a stack of unopened envelopes on my desk, looking for unusual foreign postage stamps, when a bright red sticker caught my eye. It said: "Please notify P. O. immediately if this gummed label has fallen off in transit."

This had such an unmistakable flavor of an "Irish bull" (the essence of which is logical contradiction) that I was not surprised to discover that "P. O." stood not for "Post Office" but for the sender, one Patrick O'Gara of Brooklyn. His letter began with the charade above, which he said a grandfather in Ireland had clipped from an English newspaper half a century ago. O'Gara was a postman by profession but a recreational mathematician by avocation. He entertained himself on his daily rounds, he said, by creating unusual puzzles. Would I be interested in discussing some of them with him?

The intersection set of all people interviewed in this department and the set of all existing individuals is, I must confess, empty. This, however, has never discouraged me from further interviews. Moreover, I was psychologically prepared for meeting a remarkable mailman, having recently reread one of my favorite Father Brown stories, "The Invisible Man." In this G. K. Chesterton murder mystery four witnesses swear that no one has entered or left a certain building because they all take the postman so much for granted that they do not consider him worth mentioning. "Nobody ever notices postmen, somehow," as Father Brown put it, "yet they have passions like other men. . . ."

Although O'Gara's major passion was recreational mathematics, he minored in philately. He turned out to be a young, athletically built chap with sandy hair and a face heavily freckled by the sun. His education had not gone beyond high school, but the small study in his bachelor apartment in Brooklyn Heights overflowed with old and new books on mathematical puzzles, and after a few minutes of conversation it was obvious that he was well informed in the field.

"Are you a stamp collector?" he asked.

"No," I replied, "but my 10-year-old son has just started an album."

"Encourage him to specialize," said O'Gara. "The big thing now, you know, is what is called thematic or topical collecting. Nobody collects miscellaneously anymore. Let me show you some of my topicals."

His largest collection concerned mathematics. I was amazed by the number of eminent mathematicians whose portraits had appeared on these little engravings ever since Germany, in 1926, had issued the first mathematical stamp: a 40-pfennig violet with the head of Leibniz. O'Gara had French stamps honoring Descartes, Pascal, Buffon, Carnot, Laplace, Poincaré and many others; Italian stamps showing scenes from the life of Galileo; Dutch stamps with faces of Huygens, Lorentz and others; Russian stamps honoring such notables as Euler, Chebyshëv and Lobachevski. A striking set of four Norwegian stamps commemorated the centenary in 1929 of Abel's death. Two stamps issued by the Irish Free State in 1943 bore portraits of Hamilton to celebrate the centenary of his discovery of quaternions. Gauss appeared on a German stamp in 1955. A Romanian mathematics journal, *Gazeta Matematica*, was honored on its 50th birthday with a pair of stamps, and in 1955 Greece commemorated the 2,500th anniversary of the Pythagorean school by putting a 3-4-5 right triangle on four stamps.

"Has the United States ever honored a mathematician with a commemorative stamp?" I asked.

O'Gara shook his head. "Neither has England, but of course England has an excuse. She limits her stamp portraits to members of the royal family."

One of O'Gara's most amusing topical collections contained what he called "science goofers"—stamps on which someone had made a whopping scientific mistake. The British colony Saint Kitts-Nevis issued a stamp in 1903 showing Columbus, on deck, searching for land with a telescope, which had not yet been invented. A 1932 Jamaican stamp has a banana tree on which the fruit grows down instead of up. A skier's ears, on a 1934 Austrian stamp, are upside down. The constellation of the Southern Cross somehow got reversed when it appeared on a 1940 Brazilian stamp. A U.S. Transcontinental Railroad commemorative of 1944 shows smoke from a locomotive billowing to one side and a flag blowing the other way.

Another unusual thematic collection consisted of "hidden pictures." In 1904 Serbia issued a famous "death mask" stamp: the profiles of Karageorge and Peter I Karageorgevich, upside down, merge to form a death mask of the

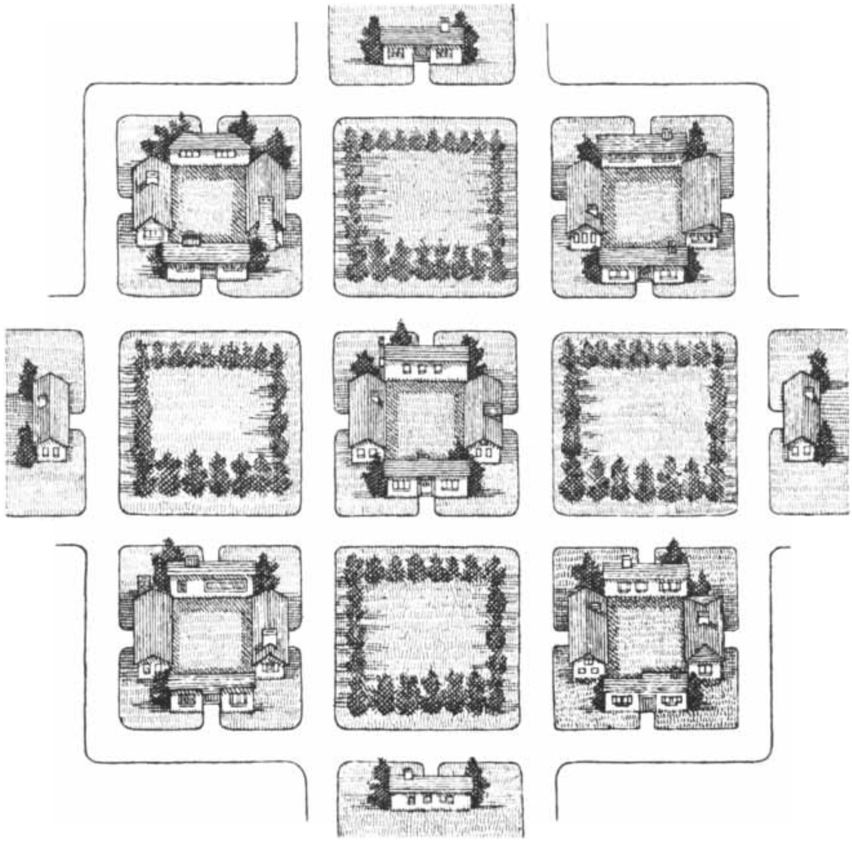
Serbian and U.S. stamps that reveal hidden pictures when turned upside down

Serbian king Alexander I Obrenovich—who had been murdered the year before by Karageorgevich' supporters. On a 1932 U.S. three-cent, the tie and shirt-front of Daniel Webster turn into the face of Fu Manchu when viewed upside down [*see illustration on opposite page*]. A range of mountains on a 1934 U.S. National Parks issue becomes a man's profile when rotated 90 degrees. A 1935 Boulder Dam stamp, inverted, looks like the Liberty Bell. On a West German 50-pfennig of 1964 a tiny face of Hitler is concealed in some tree foliage. O'Gara had scores of others.

When a postman goes on a holiday, the fictional detective Charlie Chan used to say, he takes long walks. During a vacation in Europe a few years ago O'Gara had actually made, he told me, a special trip to the Baltic seaport of Kaliningrad (formerly Königsberg, the capital of East Prussia) for the sole purpose of tramping over the famous seven bridges of Königsberg in one continuous path without going over any bridge twice. He was able to do this, he explained, because an eighth bridge had been built across the Pregel River since Leonhard Euler first proved that the original problem was unsolvable. On a day off last winter, fortified by some Irish whisky, O'Gara had conducted extensive investigations of random-walk problems in a large open field of snow somewhere in Brooklyn.

"I'm very good at visualizing geometric patterns," he told me. "Used to play a lot of blindfold chess as a boy. So I work on my graph puzzles in my head while I'm making my rounds. For instance..."

He paused to sketch for me an aerial view of a housing development where he had at one time delivered mail [*see illustration on this page*]. There were houses in every second block, and each house required a delivery, as shown on the map. "It's easy to apply Euler's rules here," said O'Gara. "They show that it's not possible to make mail deliveries along all eight streets without walking some of the blocks more than once." (To trace a network in an unbroken path, without going over any part twice, there must be either *no* intersections where an odd number of paths meet or *exactly two* such intersections.) "But how *short* can the path be? I soon convinced myself it couldn't be less than 27 blocks. Every day for months I tried to find new 27-block paths that would meet various restraints. For example, I found all sorts of ways to cover the eight streets in a 27-block path without ever making a left turn [*see upper illustration on next page*]. Finally I hit on two pretty problems your readers might like."



What is the best route for delivering to each house?

The first problem, O'Gara explained, is to find a path that covers all the streets in the minimal length of 27 blocks and that also has the minimal number of turns. The path in the upper illustration on the next page, for instance, has 19 turns—far more than necessary. A "turn" occurs at any point where the path changes direction; turns may be left or right, and the path may be open at the ends or "reentrant" (with ends joined). The second problem is to find a 27-block path with the maximum number of turns. In both problems the entire length of each of the eight streets must be traversed. Answers will be given next month.

"When I get bored looking for *best* paths," O'Gara went on, "I like to look for *worst* ones. For example, I used to deliver mail to 10 houses that were spaced at equal distances along one side of a street. What's the *longest* path a postman can take if he starts at any house, walks straight to another, then to a third and so on until he's gone once to each house?"

He made the sketch shown in the lower illustration on the next page to show how he had first tried it: from house 1 to house 6 along a path of 45 unit intervals. "And there are paths worse than that?" I asked.

O'Gara nodded. "You might ask your readers to see if they can find the worst one. If they like this kind of combinatorial puzzle, they can try the harder problem of finding a formula for the longest path as a function of *n* houses."

"Splendid," I said, scribbling in my notebook. "But I don't want to overload this interview with route problems. Have you invented any good puzzles involving other things? House numbers, for instance?"

O'Gara pulled open a drawer in which he seemed to have hundreds of problems neatly recorded on file cards. Here is the best one he showed me.

A long street runs east and west, with houses on both sides. Houses on one side have odd numbers in serial order, starting with 1. Houses on the other side have even numbers starting with 2. On each side there are more than 50 houses and fewer than 500. Smith lives on the odd side. The sum of all the odd house numbers east of him exactly equals the sum of all the odd numbers west of him. The same situation holds for Jones, who lives on the even side:

the house numbers west of him, on his side of the street, have the same sum as all the house numbers east of him. What are the house numbers of Smith and Jones?

"Have you ever mentioned in your department," asked O'Gara, "the old problem of the person who writes n letters, addresses n envelopes and then inserts the letters into the envelopes at random?"

"Yes," I replied, "although I gave it in terms of simultaneously dealing two decks of shuffled cards. As I recall, as n increases, the probability that no letters and envelopes will match approaches the limit of $1/e$."

"Right," said O'Gara. "With only four letters it's easy to show that the probability that one letter or more gets mailed to the right person is 5/8, and the probability that *exactly* one letter goes to the right person is 1/3."

"I'll take your word for it," I said.

"Can you tell me," he continued, smiling faintly, "the probability that exactly one of the four letters is mailed *incorrectly*?"

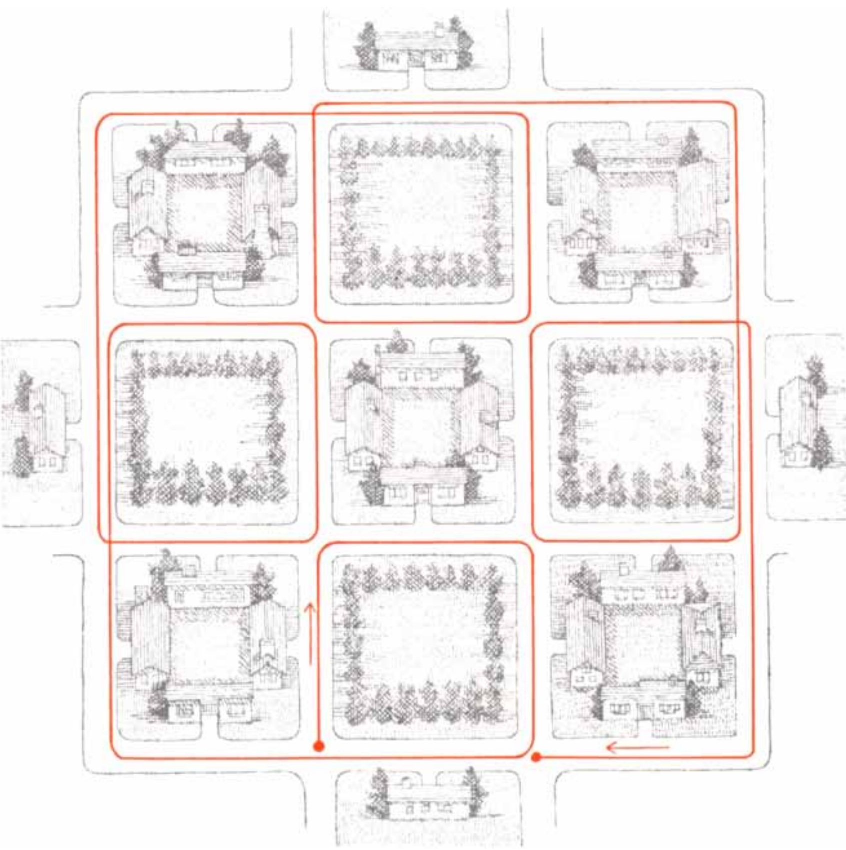
I started to jot down a list of all the permutations of A, B, C, D but O'Gara seized my wrist. "You have to do it in your head," he said, "and in less than 10 seconds."

I was startled for a moment, but then I broke into a laugh. Does the reader see why?

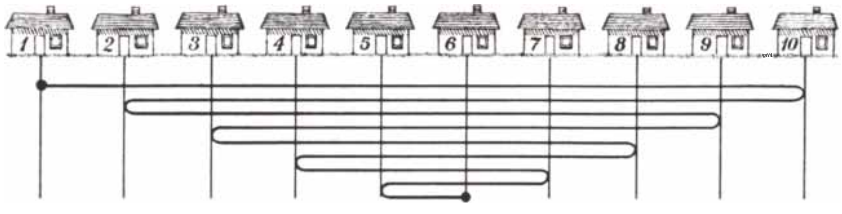
I had walked from the subway to O'Gara's apartment in a heavy downpour. When I took my leave, it was still raining. "Well," I said as we pumped hands, "you'll observe that neither snow nor rain, nor heat, nor night can stay this courier from the swift completion of his appointed rounds."

"Ah, yes," he said, wincing. "Most everybody, I suppose, knows that statement you're paraphrasing so badly. But can you tell me who first said it?"

I could not, and I leave O'Gara's parting remark as my parting question.



A minimum-length route with right turns only



A "worst route" problem

Last month's problems are answered as follows:

A line from 0,0 on the lattice of integers, with a slope of $\sqrt{27}/\sqrt{3}$, will pass through an infinity of lattice points. Because $\sqrt{27} = \sqrt{3 \times 9} = 3\sqrt{3}$, the fraction $\sqrt{27}/\sqrt{3}$ reduces to 3/1, a rational fraction. The first lattice point on this slope is $y = 3$, $x = 1$.

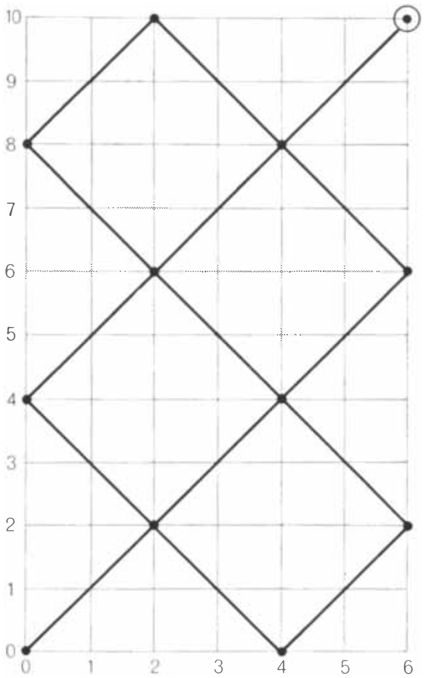
On a rectangular lattice with even sides, a ball leaving the origin at a 45-degree angle will travel through lattice points separated (along coordinate lines) by a distance equal to twice the greatest common divisor (g.c.d.) of the sides. If we mark these points with spots as in the upper illustration at the left on page 124, we see that only one of the three possible terminal corners receives a spot, and it therefore must be the corner the ball will hit. To determine which corner this will be, we divide each side by the g.c.d. If both results are odd, the ball strikes the corner diagonally opposite the origin. If one result is even (both cannot be even), the ball strikes the corner on that side and adjacent to the origin. For rules governing the more general case, when the ball's path may be at any angle with a rational slope, see M. S. Klamkin's solution to his problem No. 116 in the *Pi Mu Epsilon Journal*, Spring, 1963.

Formulas for the length of the ball's path and the number of rebounds are intuitively evident in the lower illustration at the left on page 124, which is adapted from Hugo Steinhaus' *Mathematical Snapshots*. Whatever the integral dimensions of a rectangle, a square can always be formed by placing a finite number of replicas of the rectangle side by side as shown at the top in the illustration. The smallest square formed in this way will have a side that is the lowest common multiple of the rectangle's two sides.

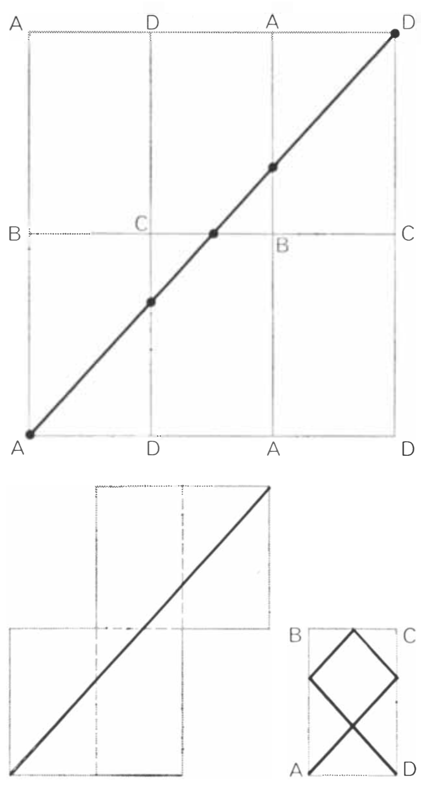
Think of each rectangle as a mirror reflection of each rectangle adjacent to it. The diagonal line from A, where the ball starts its 45-degree path, to the opposite corner will then be the "unfolded" path, so to speak, of the ball as it rebounds from side to side. If we cut out just those rectangles that contain the path (*lower left*), fold them along the broken lines and then hold the

packet up to a strong light, the diagonal line will trace the actual path of the ball around the rectangle (*lower right*).

Since the diagonal line *AD*, on the large square, is the hypotenuse of a right isosceles triangle with a side equal to the lowest common multiple of the sides of the rectangle, we see at once



Solution to the "even-even" problem



Finding the length of the ball's path

that the length of the path is this lowest common multiple times $\sqrt{2}$.

The spots shown along the diagonal, minus the end spots, represent points of rebound. It is easy to see that the number of such rebounds must be

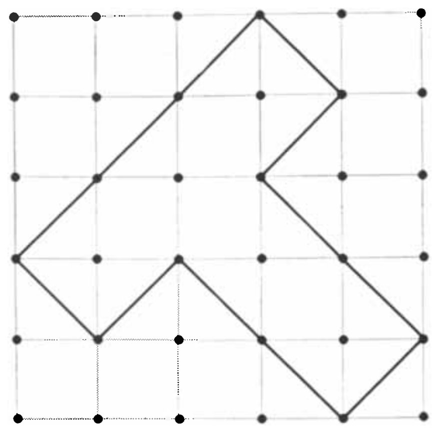
$$\frac{a+b}{\text{g.c.d.}} - 2\,,$$

where a and b are the sides of the original rectangle and g.c.d. is their greatest common divisor.

The upper illustration at the right shows the only way to draw the *T*-polygon on a square lattice so that there are 12 points on the border and five inside: an area of 10 square units.

The sliding-block puzzle given in March can be solved in 30 moves. I had hoped that this month I could list the names of all readers who found a 30-move solution, but the letters kept coming until there were far too many names for the available space. All together readers found 10 different 30-movers. They are shown paired in the lower illustration at the right because, as many readers pointed out, each solution has its inverse, obtained by substituting for each digit its difference from 9 and taking the digits in reverse order. Note that of the four possible two-move openings, only 3,6 does not lead to a minimum-move solution. Solutions *2a* and *3b* proved to be the easiest to find; by April 10, 40 readers had sent the first, 39 readers the second. The most elusive solution, *5a*, was discovered by only eight readers. No one found all 10 without the help of a computer. Norman Taylor came closest, with eight solutions. Frank S. Kmetz of Clarkston, Mich., R. Vincent Kron of La Grange Park, Ill., and Wilfred H. Shepherd of Manchester, England, found six. Fourteen readers each found four solutions.

Donald Michie of the University of Edinburgh has been using this eight-block puzzle in his work on game-learning machines. His colleague Peter Schofield, of the university's computer unit, had written a program for determining minimum solutions for all patterns that begin and end with the hole in the center. With the aid of this program Schofield was able to find all 10 solutions, but this did not rule out the possibility of others, or even of a shorter solution. The matter was first laid to rest by William F. Dempster, a computer programmer at the Lawrence Radiation Laboratory of the University of California at Berkeley, with a pro-



The T*-polygon solution*

1a.	34785	21743	74863	86521	47865	21478
1b.	12587	43125	87431	63152	65287	41256
2a.	34785	21785	21785	64385	64364	21458
2b.	14587	53653	41653	41287	41287	41256
3a.	34521	54354	78214	78638	62147	58658
3b.	14314	25873	16312	58712	54654	87456
4a.	34521	57643	57682	17684	35684	21456
4b.	34587	51346	51328	71324	65324	87456
5a.	12587	48528	31825	74316	31257	41258
5b.	14785	24786	38652	47186	17415	21478

Minimum-move sliding-block solutions

gram for an IBM 7094. It first ran off all solutions of 30 moves or fewer, printing out the 10 solutions in 2½ minutes. A second run, for all solutions of 34 moves or fewer, took 15 minutes. It produced 112 solutions of 32 moves and 512 solutions of 34 moves. There are therefore 634 solutions superior to the 36-mover given by Henry Ernest Dudeney, who first posed the problem. The 10 30-movers were later confirmed by Richard F. Smiley, a senior mathematics student at Carleton College, who used the smaller IBM 1620; by Duncan Ewing of the Illinois Institute of Technology's IIT Research Institute in Chicago, who used a Raytheon 440, and by Jay Emerson Vinton of Chevy Chase, Md., who used a Honeywell 800.

Schofield's program proved that no problem starting and ending with the hole in the center requires more than 26 moves. Since two moves will transfer a corner hole to the center, it follows that 30 moves are enough for any problem that starts and finishes with the hole in the same corner. The problem given by Dudeney is therefore among the "worst" possible problems with the eight-puzzle; that is, it is a problem with the largest minimum solution.

THE AMATEUR SCIENTIST

How to study the genetics of fruit flies with chromatograms viewed by ultraviolet lamp

Conducted by C. L. Stong

In 1951 Ernst Hadorn, who is now rector of the University of Zurich, and Herschel K. Mitchell of the California Institute of Technology conducted an interesting experiment involving the genes responsible for eye color in the fruit fly *Drosophila*. The experiment showed that the genes also control the production of a family of compounds that in effect serve to label the flies by genetic type. The compounds were isolated by the analytical procedure of paper chromatography. Hadorn and Mitchell crushed anesthetized flies on a piece of filter paper, one edge of which was subsequently immersed in a solvent. As the solvent migrated through the fibers of the paper it washed the compounds from the spot made by crushing the flies. When the paper was viewed under an ultraviolet lamp, the compounds appeared as a series of fluorescing bands spaced according to the solubility of the compounds and to differences in their affinity for the paper [see "Fractionating the Fruit Fly," by Ernst Hadorn; SCIENTIFIC AMERICAN, April, 1962]. Subsequently the compounds were identified as pteridines, a name that comes from *pteron*, the Greek word for "wing"; the first compounds of the family were found in the wings of butterflies.

A modified version of the experiment that can be done at home has now been worked out by Richard LaFond of Monson, Mass. Although LaFond's apparatus is largely assembled from scrap materials and presents a deceptively simple appearance, it provides the experimenter with a powerful means for delving into an exciting aspect of genetics. LaFond writes:

"The eye of *Drosophila* has been found to contain two genetically controlled pigment systems, one brown and the other red. These systems were first revealed by their different solubilities. The red pigment is water-soluble but the brown is not. During the fly's early development the brown pigment appears first; the red, some hours later. The normal eye color of flies of the "wild" type, such as Oregon-R, is brick red, caused by the presence of both pigments. This eye color appears when all genes are working normally.

"In the case of mutant flies that have eyes of abnormal color, such as scarlet, a gene suppresses the formation of brown pigment. Accordingly the eyes are red. Mutants with brown eyes, on the other hand, have a gene that suppresses the formation of red pigment. A cross between a mutant with scarlet eyes and one with brown eyes produces a hybrid with white eyes. In effect the pigment systems cancel out.

"It is the red pigments and other brightly fluorescing compounds that comprise the pteridines. These compounds are situated not only in the eyes of the fly but also in the ovaries and testes and in the Malpighian tubules, which act as a kidney. The relative amounts present in a specimen tend to differ at each stage of the life cycle as well as between mutants and their hybrid offspring. For this reason experiments having to do with the pteridines are open to almost limitless variation.

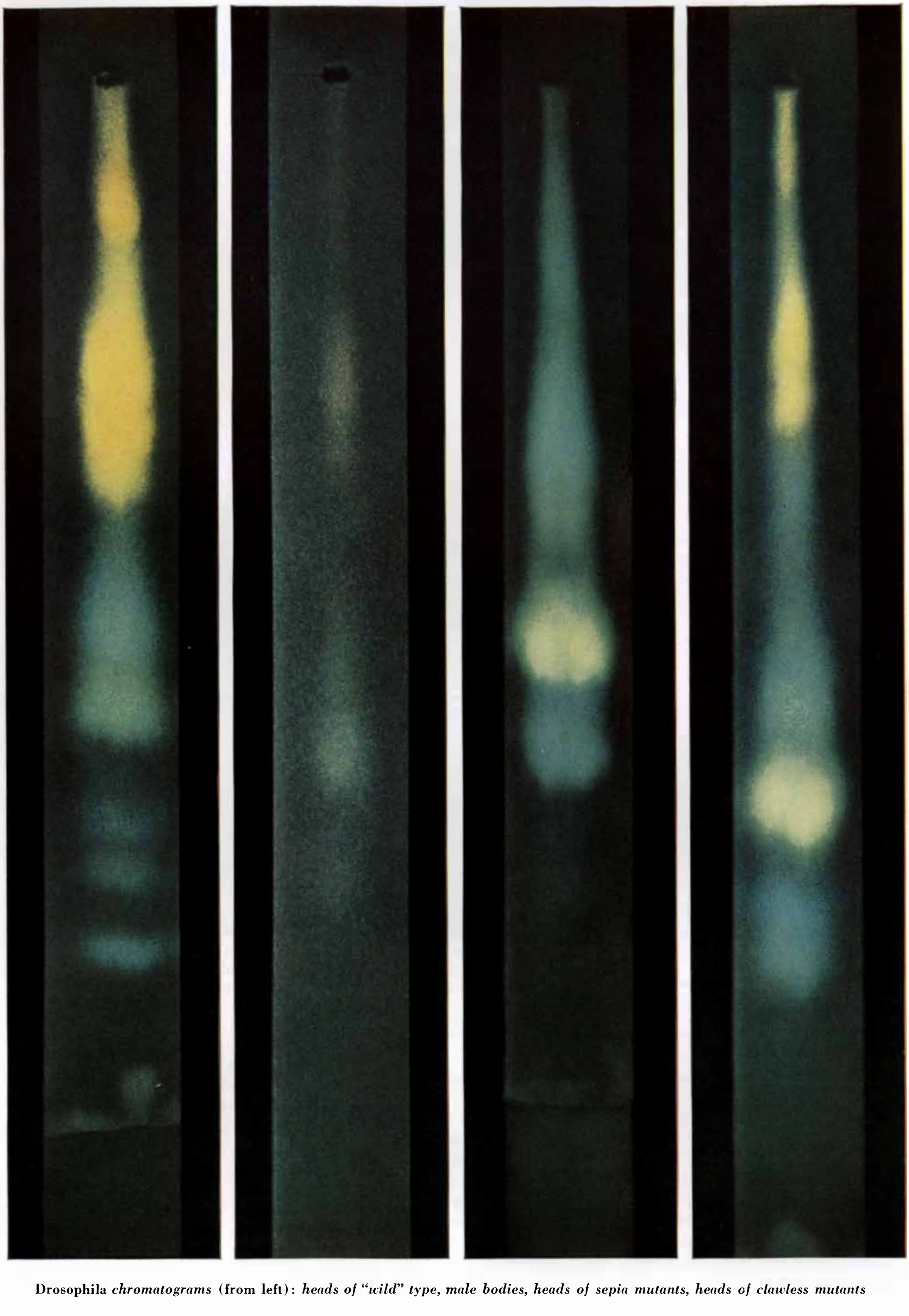
"One must, of course, have a stock of flies in order to conduct experiments. An easy way to collect *Drosophila* is to leave outdoors in a shaded area a culture bottle containing a special food rich in yeast. By careful inbreeding it is possible to develop a number of mutant strains from the wild stock. Specimens of all types also can be bought from suppliers. My initial flies were obtained from the Curator of Stocks, Division of Chemotherapy, The Institute for Cancer Research, 7701 Burholme Avenue, Philadelphia, Pa. 19111.

"Having acquired a small initial stock by capture or purchase, the experimenter then perpetuates the stock by culturing techniques. The live specimens come in small vials. Adults are promptly transferred to a culture bottle, but the vials are not discarded immediately. Eggs have been laid in the food from which young flies will soon hatch.

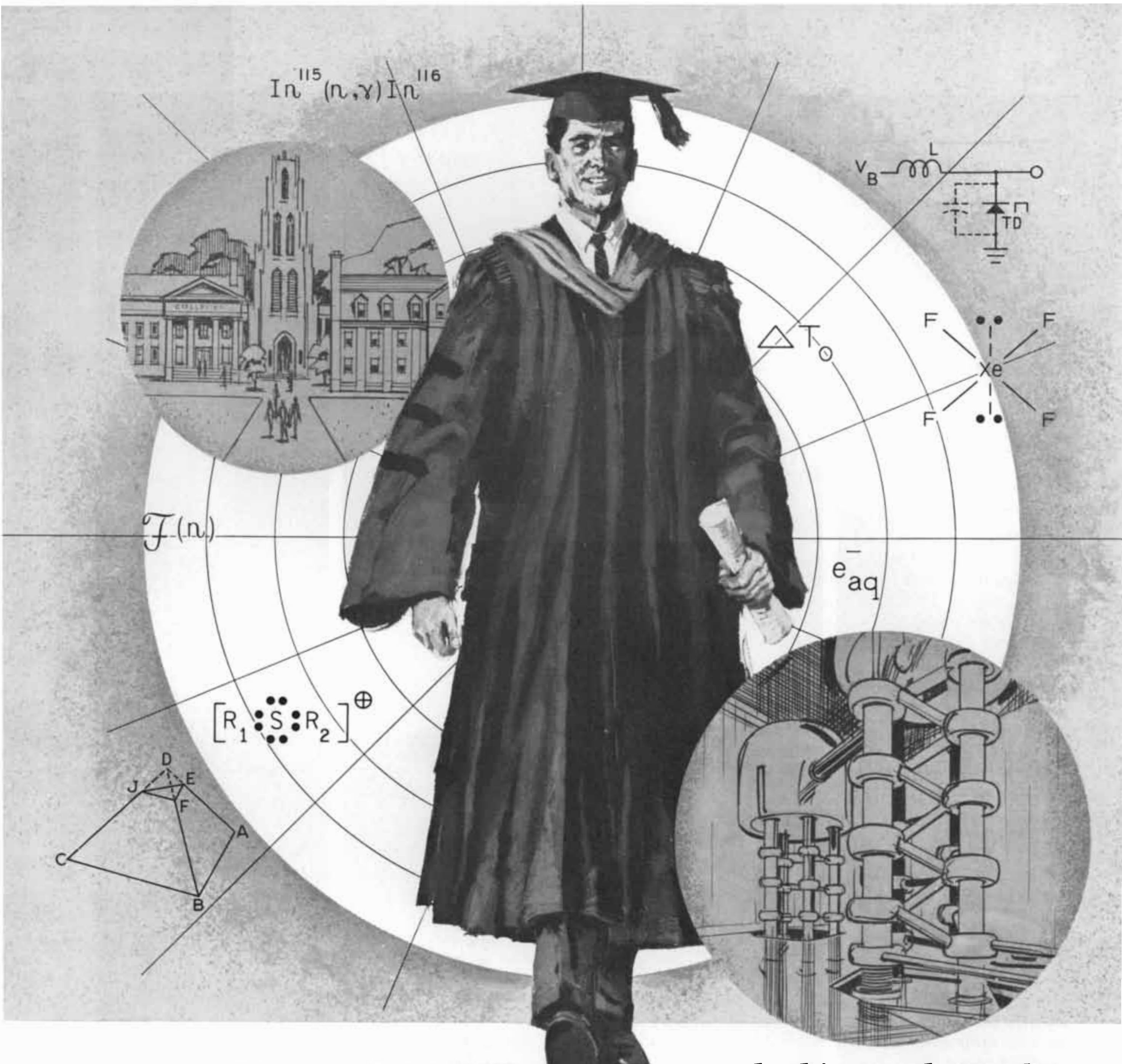
"I use half-pint milk bottles as culture vessels. Before transferring flies to these containers each bottle is sterilized and equipped with a supply of food. A number of food preparations have been developed for culturing *Drosophila*. I use the recipe devised by Boris Spassky of the Rockefeller Institute. This nutrient is made by adding 194 milliliters of tap water to 29 milliliters of unsulfured molasses (Grandma's brand) and bringing the mixture to a boil in a pan. To the boiling solution are added 26 grams of regular Cream of Wheat and two grams of uniodized salt. The mixture must be stirred constantly and cooked for about five minutes. The pan is then removed from the stove. Two milliliters of a 10 percent solution of Tegosept M, a brand of methyl-p-hydroxybenzoate, are stirred into the mixture as a preservative. The 10 percent solution is made by diluting 10 grams of the compound in 100 milliliters of 95 percent ethyl alcohol.

"To milk bottles that have been thoroughly washed and boiled in water add the food mixture to a depth of about half an inch by means of a funnel that prevents food from spattering on the glass. Wipe any condensed water from the inner wall of the bottle. Plug the opening of each bottle with an unwaxed paper cap or a tuft of cotton covered with a piece of cheesecloth. Place the bottles in a pressure cooker containing about 100 milliliters of water and boil for 30 minutes at a pressure of 15 pounds per square inch.

"After sterilization stand the capped bottles on a convenient wooden shelf or table until any large drops of water adhering to the inner wall evaporate. This step is important because in an excessively moist bottle the flies may get stuck in the food medium and drown. Excessive moisture can be removed with a sterilized paper towel. When the interior of the bottle is dry, fold a piece of sterilized paper toweling



Drosophila *chromatograms* (from left): *heads of "wild" type, male bodies, heads of sepia mutants, heads of clawless mutants*



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11 inches long and 2½ inches wide into quarters, so that the folded sheet measures 2¾ by 2½ inches, and push one end below the surface of the food medium. The paper strip provides a place on which *Drosophila* larvae can pupate. *Drosophila* thrive on a fermenting medium. This is provided by sprinkling a pinch of Fleischmann's active dry yeast over the surface of the food. Each bottle is then carefully labeled with the name of the type of fly it will house and the date.

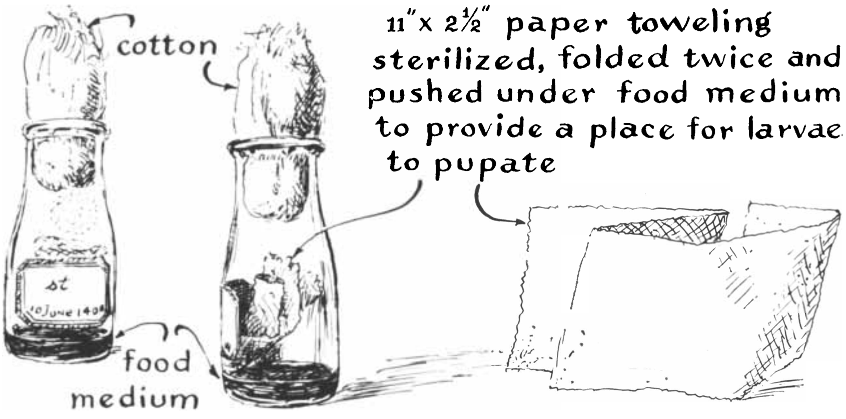
"Cultures of *Drosophila* should not be kept more than 20 days because they may become infected with mites, which markedly decreases their abundance. Mites are minute members of the class Arachnida; an effective agent against them is benzyl benzoate. Make up a solution of this compound and mineral oil in equal proportions. Shake the solution well and spread it on the shelves supporting the culture bottles. Maintain a temperature of 72 degrees Fahrenheit in the storage room. A new generation of flies will appear in 12 to 14 days. When discarding an old culture, always wash the used bottles thoroughly in hot water and any convenient detergent and then boil them in fresh water to destroy mold spores.

"Before you count or handle individual flies you must anesthetize them. The anesthetizing apparatus consists of a peanut butter jar closed with a large cork through which the spout of a small funnel is inserted. A small sponge in the bottom of the jar is moistened with a few drops of ether. A miniature cage for holding the flies is made from the larger section of a No. 000 gelatin capsule (manufactured by Eli Lilly and Company) by perforating the gelatin about six times with a hot sewing needle. The open end of the capsule is slipped partway into or over the end of the funnel and, if it does not make a snug fit, taped in place. Flies are transferred to the anesthetizing cage by placing the mouth of the open culture bottle tightly against that of the funnel, orienting the assembly so that the bottle containing the ether is on the bottom and tapping the culture bottle. The flies will fall down through the funnel into the anesthetizing cage. I use Merck motor ether. The container in which the ether is stored must be tightly closed when not in use.

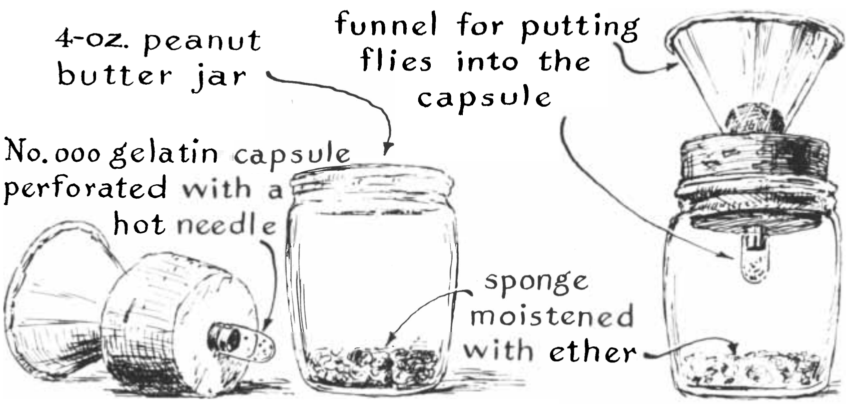
"The flies must be counted as one step in nearly all experiments. It is also often necessary to separate them by sex, type, age and so on. During such steps the anesthetized specimens are manipulated by means of a small camel's-hair brush, preferably on a smooth white surface such as white glass or a sheet of clear glass that rests on white paper. The sex of specimens is easily determined by examining inverted flies under a five-power magnifying glass. The distinguishing sexual features appear in the accompanying illustration [*below*].

"Normally flies remain anesthetized for five to 10 minutes. Some individuals revive sooner than others. These can be anesthetized again by inverting over them a Petri dish or other shallow container into which is fastened a small piece of paper toweling moistened with a few drops of ether. Remove specimens from the ether promptly when they stop moving. Overexposure will kill them.

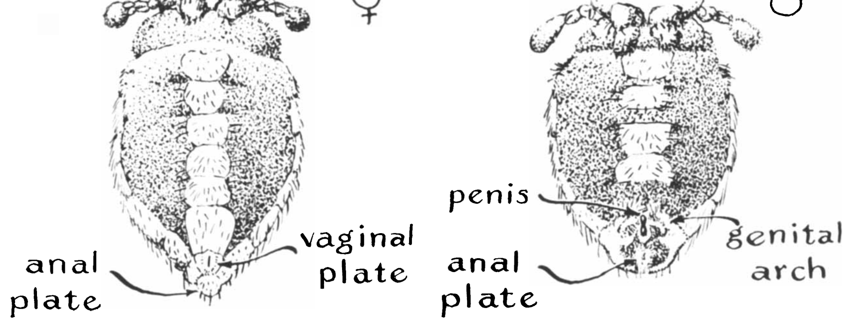
"After a culture has been maintained for 20 days transfer all adults to a fresh culture bottle. Recap the old bottle and 48 hours later transfer the young flies that have hatched during the interval to a fresh culture bottle. The old flies can be used to start new cultures. Develop scrupulously clean work habits



Arrangements for culturing fruit flies



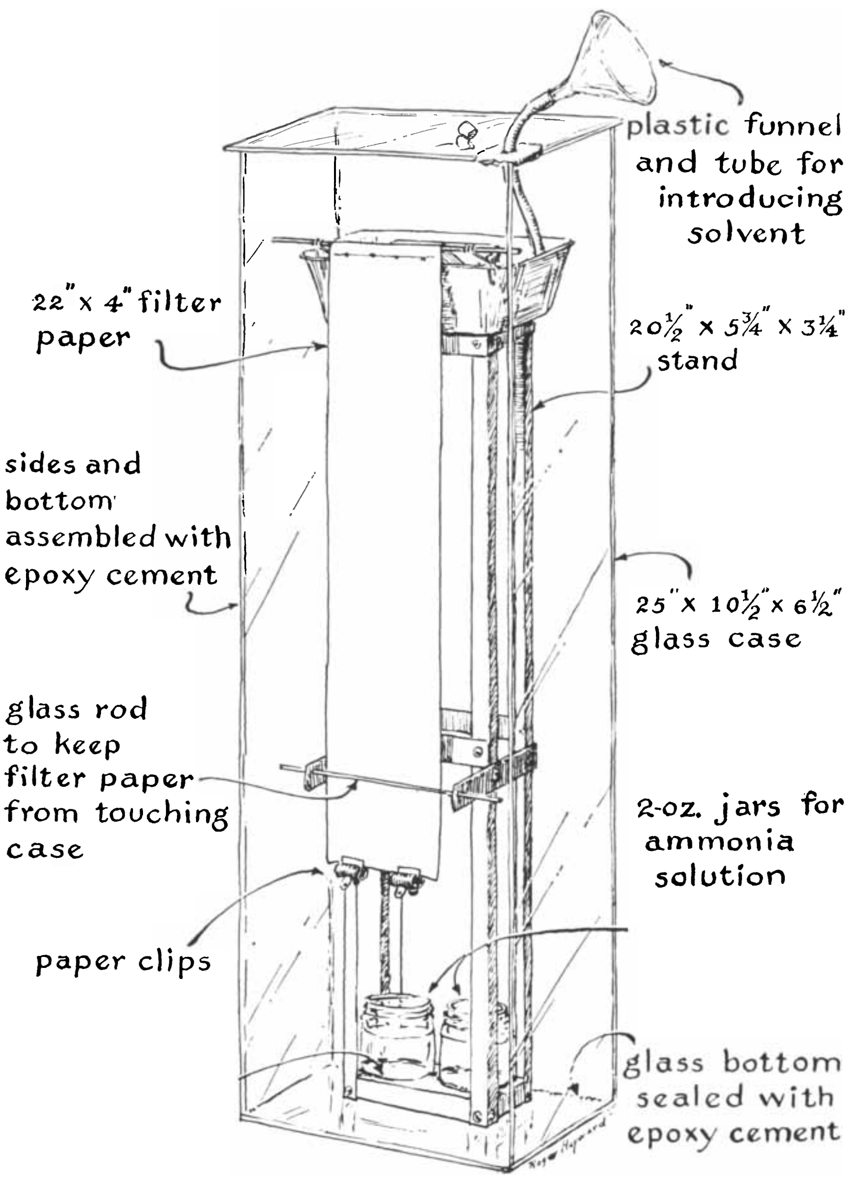
Anesthetizing apparatus



Ventral view of fruit flies: female (left) *and male* (right) in order to avoid contaminating or mixing cultures. Specimen types can be mixed accidentally, for example, by transferring a soiled glass rod or other implement to which an egg adheres from one bottle to another.

"For separating the pteridines I use a chromatographic apparatus of the descending-paper type. Essentially it consists of a closed glass box that houses an elevated container of solvent in which the upper end of the paper is immersed. The dimensions of the apparatus are shown in the accompanying illustration [*below*]. A square inch of glass is cut from one corner of the close-fitting cover to provide access for transferring the solvent to the container. This opening is sealed with a thick sheet of paraffin in which a round hole about half an inch in diameter is made. The hole is then fitted with a removable stopper, which is also made of paraffin. The container for the solvent, which rests on the top platform of a removable framework, can be any convenient shallow vessel about seven inches long and an inch or two deep. I use an aluminum pan that rests on a framework made of parts from an old Erector set.

"Brackets of wire and paraffin, attached to one edge of the pan, support a slender glass rod 10 inches long over which a piece of moist filter paper is draped. In addition to serving as a support for the paper, the rod prevents a siphoning action that would cause the solvent to flow; the only kind of flow should be that due to capillary action. The upper edge of the paper strip is weighted against the bottom of the solvent container by a glass butter dish filled with sand held in place by a layer of melted paraffin. A second glass rod, attached about halfway down the framework, serves as a stop to keep the paper away from the glass housing.



Dimensions and parts of the chromatograph

"Two glass jars of about 50-milliliter capacity are placed on the lower platform of the framework. These each contain 30 milliliters of a solution that by evaporation brings about an equilibrium between the atmosphere of the chamber and the vapor content of the filter paper. One can make a 100-milliliter stock of this solution by diluting 25.9 milliliters of 27 percent ammonium hydroxide with distilled water. The entire apparatus must be carefully leveled before use so that the surface of the solvent in the container makes a right angle with respect to the center line of the paper strip.

"Chromatograms are made on strips of Whatman No. 1 chromatography paper cut four inches wide and 22 inches long. My paper was bought from Howe and French, 99 Broad Street, Boston, Mass. 02110. It comes in sheets 18¼ inches long by 22½ inches wide. As an aid in placing specimens uniformly on the paper I draw a light pencil line squarely across each strip at a distance of 6¾ inches from one end and divide the line into five equal intervals by four light pencil dots. The material to be analyzed is placed on these dots.

"To prepare for the analysis of adult flies first anesthetize selected specimens of the same age. Age is an important factor because the concentration of pteridines in the flies varies during the life cycle. The concentration also differs substantially between the head and the body. Moreover, the chromatograms of males differ from those of females.

"One begins a typical experiment by severing the heads of 10 flies with a razor blade and squashing the material onto the paper with the end of a glass rod. I always reserve the right-hand dot for the control specimen, which is prepared by applying to the dot the heads of 10 Oregon-R wild-type flies. If the control specimen fails to separate as anticipated, the chromatogram is discarded. The control also provides a convenient cross-check for estimating the amounts of pteridines in other specimens in relation to those naturally present in the wild type.

"When one is making chromatograms of fly bodies rather than heads, one must take care to separate all head tissue cleanly. A small amount of head tissue can contain more pteridines than a whole body, hence even a tiny frag-

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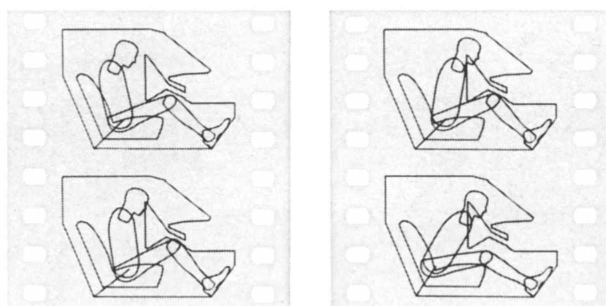
The speed of the resulting motion picture can be controlled by specifying the time interval used in the numerical solution of the differential equations. Thus, any degree of slow motion can be produced. Because a crash into a fixed barrier occurs within 150 milliseconds, it has been found convenient to use problem spacing of one millisecond or less.

Inputs to the system can be deceleration waveforms measured in real crashes or arbitrary waveforms which correspond to different amounts of energy absorption in the structure.

Computerized visual crash simulations make it possible to expedite the interpretation of data. At the same time, they provide insight into crash dynamics since any contact force which affects the motion of the occupant can be observed in the movie as a deceleration. The new system promises to be of considerable value to Ford Motor Company's continuing efforts to develop vehicle designs that will help minimize crash injuries.



This is a segment of the film photographed directly from the oscilloscope of the computer. The position of the driver outline is the solution to equations of motion which describe the time-histories of the displacement of the centers of gravity of each of the body links. These data are used to compute the relative angles between the body links. The simulation also includes plastic-elastic deformation of the steering wheel and instrument panel, which is shown by the degree of driver intrusion into the vehicle structure.
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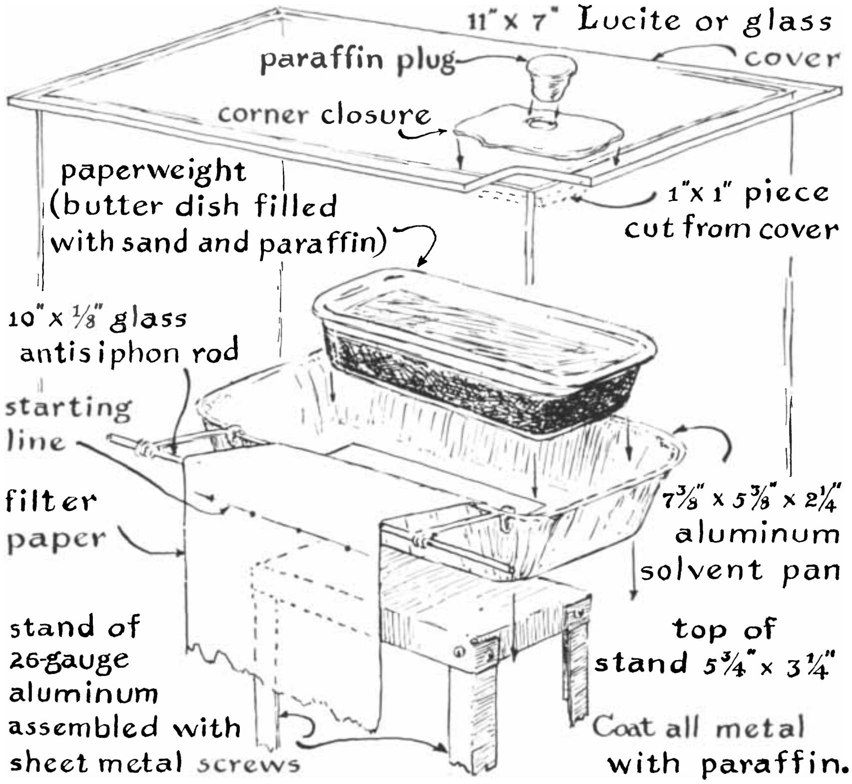

Details of the chromatograph

ment can seriously distort a body chromatogram. The bodies are boiled in water for three minutes to coagulate the protein and thus facilitate the chromatographic separation. After boiling they are placed on paper toweling to remove excess water. Five bodies are applied to each spot. All spots must be dried at room temperature before the chromatographic paper is placed in the apparatus. In addition, a pencil notation is made next to each spot that includes its descriptive initials—such as *p* for plum eye, *st* for scarlet or bright-red eye, *v* for vermilion eye, *w* for white-eye mutants, *bw* for brownish eye, w^a for white-apricot eye—together with the date and time.

"After the paper strip has dried, the solvent pan is placed on the upper platform of the framework. The strip is then draped over the upper glass rod and anchored in place by the butter dish. The loose end of the strip is threaded between the lower glass rod and the framework so that it hangs freely suspended. Paper clips of the pinch type are attached to the bottom edge as weights. The ammonium hydroxide containers are then put on the lower platform. Now the entire assembly is placed in the glass housing, covered by the glass top, draped with a cloth that excludes light and left undisturbed for two hours. During this interval the vapor content of the paper reaches equilibrium with the atmosphere of ammonia released by the ammonium hydroxide. Good separations cannot be expected if the interval of equilibration is stinted.

"When equilibration is complete, remove the cloth cover and the paraffin plug and insert into the solvent container a rubber tube equipped with a small plastic funnel. This is used to transfer 230 milliliters of developing solvent into the tray. The solvent consists of 360 milliliters of 1-propanol (n-propyl alcohol), 45 milliliters of 7 percent aqueous ammonia and 135 milliliters of distilled water. Finally, remove the rubber tubing, reinsert the paraffin plug promptly, cover the apparatus to exclude light and maintain the room temperature at 68 degrees F. for 20 hours. At the end of this interval remove the chromatogram from the apparatus. Handle the paper by its ends and suspend it upside down for drying at room temperature. Return the solvent and equilibrating solutions to their respective storage bottles.

"When the chromatogram has dried, it can be examined under an ultraviolet lamp. If all has gone well, the characteristic fluorescent bands will appear [*see illustration on page 127*]. Caution: Never look directly at the bulb of an ultraviolet lamp. The rays are injurious to the eyes. Protective goggles should always be worn when working with ultraviolet radiation. Dual lamps that emit ultraviolet at wavelengths of 2,537 and 3,660 angstrom units and operate from regular house current are available from the Edmund Scientific Co. of Barrington, N.J. Pteridines that emit blue or violet light glow with greatest brilliance when they are irradiated at a wavelength of 3,660 angstroms; those that emit reds or yellows appear brightest when they are irradiated at a wavelength of 2,537 angstroms.

"Chromatograms should be examined and evaluated as soon as they dry because the fluorescent compounds tend to fade with time. As a convenience in scoring and recording the results I prepare a table in advance. Symbols designating all specimens are listed in a column that extends down the left edge of the page. A similar row across the top of the page lists the several pteridines: DRO for drosopterins that fluoresce orange-red; XAN for xanthopterin, green; SP for sepiapterin, yellow; AHP for 2-amino-4-hydroxypteridine, blue; BIO for biopterin, blue; ISO for isoxanthopterin, violet, and RFL for riboflavin-like compounds mixed with sepiapterin, yellow. The apparent brilliance of each band as judged by eye is then recorded by means of plus and minus symbols, as shown in the accompanying illustration [*bottom of next page*].

"Isoxanthopterin is present in the bodies of both male and female flies but is found in much larger amounts in male bodies because it is concentrated in the testes. This difference in concentration, as disclosed by the chromatogram, immediately identifies the sex of most specimens. Certain mutants, however, such as the rosy-1 (ry^1), rosy-2 (ry^2) and maroon-like (*ma-l*), do not produce detectable quantities of isoxanthopterin. Rosy-2 males can still be distinguished by an abnormally large amount of 2-amino-4-hydroxypteridine, the precursor compound in the formation of isoxanthopterin.

"Interesting changes in the amounts of the pteridines with time can be observed by doing chromatography of larvae, young and old pupae and hatched flies of various ages. Young pupae are brown and translucent, whereas older pupae are opaque. Larvae that have begun to climb onto the paper in the culture bottle and up the wall of the bottle are removed with a glass rod and applied directly to the paper. I chromatographed five larvae,

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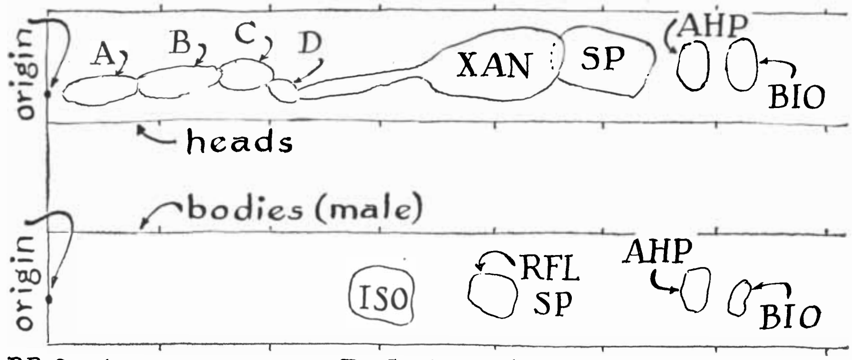

DRO drosopterins A, B, C, D, red eye pigments, red-orange-fluorescing
XAN xanthopterin, green-fluorescing
SP sepiapterin, yellow-fluorescing
AHP 2-amino-4-hydroxypteridine, blue-fluorescing
BIO biopterin, blue-fluorescing
ISO isoxanthopterin, violet-fluorescing
RFL riboflavin-like compounds mixed with sepiapterin, yellow-fluorescing

Diagram of a chromatogram

five pupae and 10 heads of sepia mutants one day old. The larvae show a very weak fluorescence that does not seem to indicate any particular pteridine. Young pupae display xanthopterin, together with a substance I could not identify that fluoresces in the blue portion of the spectrum. There was also a hint of yellow sepiapterin. Xanthopterin and sepiapterin appear in substantial amounts during the late pupal stage.

"The experiments I found most interesting involved crossing different eye-color mutants (and also crossing such mutants with flies of the wild type) and then chromatographing the offspring. Virgin females must be used for making controlled crosses because females can store the sperm from one insemination for a large part of their reproductive lives. To collect virgin females, clear a culture bottle of all flies. Search the paper carefully for adults that may be hidden in its folds. Use a bottle that contains many pupae from which new flies will soon hatch. From this bottle collect females within 10 hours of the time they hatch. (After 10 hours they will mate with males, although they do not lay eggs for two days.) Transfer the virgins to a fresh culture bottle placed on its side so that they will not stick to the food at the bottom. Males of any age and desired type are then anesthetized for transfer. Several pairs of males and females are placed in a fresh culture bottle and labeled with the description of the cross and the date. When larvae begin to climb up the wall of the bottle and onto the paper, the adults are removed.

"Always remember when chromatographing young flies of any type that the relative amounts of the pteridines change with the age of the specimen. Use specimens that are approximately the same age. I usually select flies that are 12 days old. To age specimens, clear a culture bottle of adults, collect the young as they hatch during an interval of an hour or so and then transfer the young to a fresh, dated culture bottle. Chromatograph after 12 days.

"An important consideration in interpreting the chromatograms of the mutants and the crosses is whether the characteristic pattern is the result of the major gene or genes under consideration or merely a reflection of the specimen's genetic background. Genes other than those assumed by the experimenter can modify the amounts of pteridines in the fly. For example, it has been shown that the amount of isoxanthopterin is influenced by many genes because there is less variation in the concentration of this compound in inbred stocks of flies than in flies that have been collected in nature and mass-cultured for maximum heterozygosity, or variation of genes.

"In my experiments I have assumed that the obvious differences between chromatograms of the various mutants are associated with a major gene. Although I chromatographed many flies, I made no attempt to exclude the possibility of background effects by crossing mutants with flies of the wild type and then reisolating the stock after six or seven backcross generations to compare the chromatographic results with those of the original strain. This step would be essential, however, in a quantitative study designed to reveal the influences of genetic background."

Mutant	Drosopterins				XAN	SP	AHP	BIO	ISO	RFL
	A	B	C	D						
p	++	++	++	++	+	++	+	++	+++	++
st	+++	+++	+++	+++	+++	+++	++	++	+++	++
v	+++	+++	+++	+++	++	++	++	++	+++	++
Orc.-R	+++	+++	+++	+++	+++	++	++	++	+++	++
w	–	–	–	–	–	–	–	–	–	–
bw	–	–	–	–	–	–	–	–	–	–
w^a	–	+	+	+	+	+	+	+	++	+
ry	++	++	++	++	++	+++	++++	+++	—	++
wild *	+++++	+++++	+++++	+++++	+++	++	+++	+++	++	++
se x w **	+++	+++	+++	+++	+++	+++	+++	+++	+++	++

*D. willistoni

** Sepia female crossed with white male

– = nothing apparent
+ = trace
++ = small amount
+++ = moderate amount
++++ = large amount
+++++ = very large amount

A method of charting the results of chromatograms

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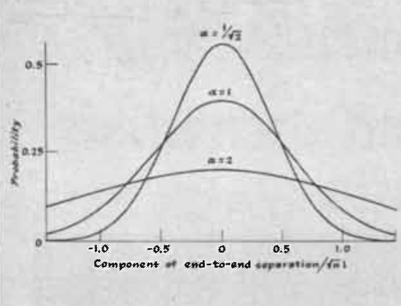

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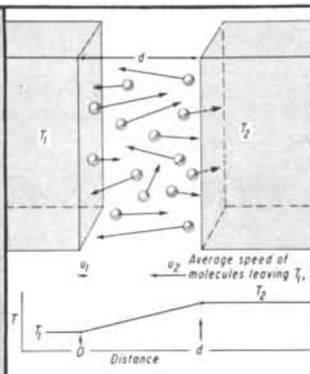

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BOOKS

On the current condition of the Negro American

by Paul Bohannan

A Profile of the Negro American, by Thomas F. Pettigrew. D. Van Nostrand Company, Inc. ($5.95).

The first Negro arrived in the New World, as far as we know, in 1494. There have been Negro Americans ever since. From one era to the next their difficulties and their status in the eyes of whites have changed markedly. The first Negroes were not slaves, but Negro slaves soon followed. American Indians died in slavery; African Negroes—who understood the institution—survived under it. Then, as other forms of institutionalized inequality such as debt bondage disappeared from the American scene, the association between "Negro" and "slave" became firmer. By the beginning of the 19th century Negroes who were not slaves (the ancestors of some never had been slaves) had a difficult time maintaining their position. Ironically as the worldwide antislavery campaign that had begun late in the 18th century proceeded, the stereotyped association of "Negro" and "slave" became increasingly widespread.

With the Emancipation Proclamation a vast social change was both heralded and accomplished in the U.S. A social subsystem based on unequal legal status, and the legal rights inherent in such a system, were changed. In the new system the "status" of slaves was abolished—and with it the rights of slaves. A situation once viewed in terms of legal rights came to be seen in terms of social rights, and the ex-slaves were thrown completely out of the social system. They quickly came to constitute what can best be called a pariah group. The Negroes were "untouchables" in somewhat the same sense as the untouchables in the old Indian caste system. Being for the most part outside the social system, few chose to risk exercising such rights as they might have claimed in the legal system.

Slaves have rights. They may be minimal rights, and the system of slavery practiced in the Americas was a particularly oppressive form of an oppressive institution. Even in the Americas, however, slaves had rights. Pariahs are a different matter. With them the question of legal—even moral—rights becomes irrelevant for most purposes; pariahs are beyond the pale. When Negro Americans became "free," they lost as much ground as they gained.

In our own era, in the years following the Supreme Court decision of 1954, still another social revolution is taking place, and it is well along. It is further along, in fact, than many white and Negro Americans think. The pariahs are being brought back into the system, or are fighting their way back into it, with the full rights of citizens.

A historical fact that is never adequately stressed is that the Emancipation Proclamation was issued only four years after the publication of *The Origin of Species*. Today, a century later, the social revolution of the 1950's and 1960's again overlaps a period of rapid advance in biology, notably in genetics and biochemistry. Social and scientific revolutions have twice converged to complicate the concepts and problems of "race."

On both occasions there has been a spiral of interaction between biology and changing social structure. The position of the Negro American has been almost exactly correlated with progress in biological theory. On the basis of such concepts it has been possible to discover much about human origins and to understand much about genetic variation in human beings. Advances in biology, however (as well as some advances in the social sciences), have at the same time been used to feed notions of racism. In spite of social change and scientific progress racist assumptions—dogmas about the superiority or inferiority of human groups—are still with us.

Eighteenth-century biology inherited a concept known as the "great chain of being," in which living things were ranked from the lowest and least noble to the highest and noblest. It is perhaps needless to add that European members of *Homo sapiens*, who invented the concept, ranked at the top of the chain. A recent book by the historian Philip Curtin (*The Image of Africa*, University of Wisconsin Press, 1964) has traced in fascinating detail the racial attitudes derived from the concept, which was apparently accepted even by Linnaeus. No two varieties of life could occupy the same position on the chain; therefore human beings were divided, on the basis of external characteristics, into several varieties (the number was in dispute, as it is today) and the varieties were ranked.

Curtin has documented the ways in which ethnocentric and uninformed men created hierarchies of physical types based on the chain of being. The late 18th century was also plagued by disputes that swung between biology and theology: whether man had been created in the image of God and had been degenerating ever since (the dark-skinned "races" had degenerated most) or whether by some form of evolution (not yet understood) things—including man—were getting better. A second debate revolved around the supposed origin of living organisms: the argument of monogenesis v. polygenesis. The polygenesist's position was that "savages" were descended from creatures created separately from the progenitors of "civilized" men. As one writer picturesquely put it, the various human groups were "separate thoughts of God."

In the same period there was a tendency, for purposes of classification, to emphasize differences. Human differences were subjected to "scientific" inquiry by such men as Johann Friedrich Blumenbach, who wrote *On the Natural Varieties of Mankind*. It should be noted, however, that although Blumenbach described differences among human groups, he was not a racist. Nonetheless, the word "race" did come to be used by men (such as Joseph Arthur de Gobineau) who fought to maintain the social structure of feudalism in the face of democratic revolutions. The old aristocracy (to which Gobineau himself had been a pretender) was "Teutonic"; the new citizenry was "Mediterranean" and "Alpine." Such groups—all Caucasian—were sorted out by color: the former were called "white" and the latter "black." When the issue of slavery came to a head in the New World, a vocabulary and concepts were ready-made.

The Darwinian revolution destroyed the degeneration argument and stilled the debate over polygenesis. The position of the racists, however, remained unchanged; they simply used the new scientific ideas to back up the beliefs they already held. Now they focused on an alleged lack of potential for the development of "civilization": the "natural inferiority" of non-Europeans was "proved" by the superior technological achievements of Europeans. In our century the same arguments are put in terms of misunderstood and misapplied "genetics" and "personality." The lack of connection between racism and scientific inquiry is in no way shown more clearly than in the fact that advances in knowledge have had little effect on the premises or arguments of racism.

In the middle 1960's the Negro American stands on the divide between being a pariah and being an "ordinary citizen." His position is summarized sparely and clearly in the book reviewed here: *A Profile of the Negro American*. Thomas F. Pettigrew, a social psychologist at Harvard University, has written eight short chapters in which the issues of race and racism, Negro health, Negro intelligence, Negro crime, Negro reactions to oppression, the impact of the Negro role on human personality, and Negro protest movements are succinctly but broadly considered. Seldom does one see so much research summarized so lucidly with such seemingly simple exposition.

Pettigrew's third chapter—"The Concept of Race"—is probably his weakest. In today's world it is anybody's weakest chapter, if for no other reason than that a reader cannot face up to it dispassionately even if a writer were to manage to present it so. Pettigrew's attempted solution to this insoluble problem is to return to very simple beginnings. The human species is a single species, but geographical and (in a few cases) social barriers have given rise to restricted pools of human genes. Genetic "drift" has further emphasized the localization of some genes in some populations. So much is good biology: a race is a population of organisms that share certain genetically determined traits. The question, of course, is: Which traits? Obviously that question must be answered by a qualified student of the matter on the basis of the problem at hand. There is no definition of race that is qualitative rather than quantitative, none that holds up independent of context. "Race" is part of our vocabulary for explaining differences and similarities found in the "real" world.

According to Pettigrew, there are four "recurrent questions" that emerge from the concept of race. The first is the absurd idea of a pure race. The other questions follow: Is interracial mixing harmful? How many races are there? Are some races superior to others?

All these questions are left over from the specters of pre-Darwinian biology. Pettigrew quotes an aphorism from a book by L. C. Dunn and Theodosius Dobzhansky: "Mankind has always been, and still is, a mongrel lot." The notion of pure race is part of the debris left by the destruction of the old theories of polygenesis and degeneration. Today the notion must be considered quite foolish in all situations except those in which biologists or practical breeders laboriously produce pure lines of plants and animals by controlled inbreeding. The difficulty of arriving at an acceptable number of human races is that nobody can decide which characteristics should or should not be included in the definitions. Pettigrew understates when he says that "the biological view of race has been more misused and distorted than perhaps any other scientific conception." He might have added that geneticists themselves find the concept less and less useful.

The chapter on Negro health (in which the author is joined by his wife, Ann Hallman Pettigrew, M.D.) is surely the best available brief statement about the mental and physical health of Negro Americans. It was once thought by physical anthropologists that the biological differences used to devise popular concepts of race were not "adaptive" in the evolutionary sense. Today the same statement is made in a more sophisticated way: All genetic lines of human beings have adaptive advantages and disadvantages. Some are "useful" in one environment, others in another environment or another time. By and large, however, they cancel out. Negroes are far more likely than Caucasians to have sickle-cell anemia; on the other hand, the rate of leukemia among whites is almost twice that among Negroes. Negroes have fewer "blue babies" than whites and far less hemophilia; they have more diabetes. Most of the diseases from which both whites and Negroes suffer, however, are not inherited. The differences in the rates of such diseases are direct reflections of cultural factors: the high rate of pulmonary tuberculosis and venereal disease among Negroes, and the higher mortality rates from childhood diseases, are obviously social in origin and not hereditary.

Negro mental health is a notoriously prickly subject. It is the more so when the American social definition of the Negro is added to the basic difficulty of acquiring data on the subject of mental health in general. The Pettigrews give a sophisticated short discussion of the differences between rates of incidence and rates of prevalence, and they follow it with some broad generalizations. Psychoses, particularly those that involve syphilitic paresis and alcoholism, are disproportionately frequent among Negroes. Most such research, however, is done in hospitals and "obviously underestimates the amount of white psychosis." Moreover, "personality tests confirm a greater tendency among Negroes to report psychotic symptoms." The quantitative data on neurosis are even more difficult to decipher, leading to confusing and contradictory claims. As a guide through such confusion, this chapter is extremely illuminating. Citing comparative examples, the Pettigrews sum up by saying: "The human species reacts to crushing oppression in much the same way the whole world over."

The chapter on the Negro "role" is particularly useful, and its insights can be taken in combination with the material on health. Until recently it has been very difficult for white Americans—at least those who have not lived in the Southeastern states—to be aware of the social role "White" to the same degree that Negro Americans are aware of the role "Negro." Indeed, such awareness may define the "Southern White." The social role "Negro" is as intensely felt—perhaps more so—than the roles of male or female. The number of situations in which an individual can be unaware of sex in evaluating the behavior of himself and others is small indeed. Within the white community the role "White" is not important; presumably the role "Negro" is not important within the Negro community. We all know, however, that Negroes are more aware of being Negroes among themselves than whites are of being whites among *themselves*. Race roles similar in intensity to sex roles are a feature of life that was absent in most of the world a century or two ago. It is another irony of history that as desegregation continues race roles are becoming more overt and more pervasive, and more difficult to play without deep self-consciousness.

The role "Negro" seems, on the basis of some of Pettigrew's quotations from Negroes such as James Baldwin and Richard Wright, to make its players more aware of role-playing than many other roles do. Self-identity presents a serious problem, self-esteem an even greater one. Pettigrew does not merely generalize about these matters but cites the findings of experimental psychologists and other investigators to back up his comments. He is optimistic, however; he assumes that as the stereotypes of Negro Americans are dissipated and Negro Americans are allowed to see themselves without the constant filtering effect of these stereotypes, the "wounds begin to heal."

The few pages Pettigrew can give to family disorganization raise some questions. He seems (to this anthropologist) to have taken the "absent father" as a veritable *deus ex machina* and hence to have oversimplified some of his explanations. Many lower-class Negro families are matricentric families: a woman and her children, with only vague or temporary associations with adult males. It is obviously true that the adult male roles recognized by children who grow up in this kind of family will not be of a "father" sort. This, however, is not the whole story. The point is: Are there any adult males who are vitally interested in the children? It seems that in many cases there are. Such situations are not studied, however, because the absent-father explanation is thought to have covered the matter.

Furthermore, it is well known among social workers that the Aid to Dependent Children programs in the nation have sharpened the trend toward the matricentric family. "A.D.C." is not really enough to live on, and undereducated Negro men often cannot make enough to keep a family. Put the two sources of income together and it is possible to keep everyone's head above water and live a tolerable life. But A.D.C. will be stopped if there is an employed man in the household, particularly if he is the woman's husband. Therefore such women either do not get married or, if they are threatened with the loss of A.D.C. money, have little choice but to throw their "man" out. Many stable marriages have been destroyed by this pressure. Most social workers do not talk about such problems for fear that A.D.C. funds will be cut, resulting in worse poverty than exists already.

Only after such an examination of the Negro role and its many burdens can one consider questions of Negro intelligence and crime. The concept of "intelligence" has changed beyond all recognition since World War II. "Intelligence is," Pettigrew tells us, "a plastic product of inherited structure developed by environmental stimulation and opportunity, an alloy of endowment and experience. It can be measured and studied only by inference, through observing behavior defined as 'intelligent' in terms of particular cultural content and values." In other words, the rug has been pulled from under almost all studies of intelligence done before the war—what had been "measured" did not in fact exist. Pettigrew is at considerable pains to point out that the new outlook in no way denies hereditary influences on intelligence but that none of us has "begun to expand our phenotypic intelligence even close to our genotypic potentials." One might also observe that playing the role "Negro" often demands "stupidity," passivity and lack of ambition. Negroes who take tests often feel threatened and may prefer not to do well if the alternative is overt rejection.

Pettigrew's chapter on crime begins: "Crime *is* prevalent among Negro Americans." On the other hand, "high Negro crime rates may be—like communicable diseases and low I.Q. scores —another handmaiden of oppression." Negro crime rates are made up largely of crimes that display hostility and those that can be termed "crimes of escape." The Negro homicide rate is particularly high in America (African homicide rates are very low), and Negroes are overrepresented in aggravated assault and some kinds of robbery. The rates are also high for such escape crimes as gambling, drug addiction and drunkenness—all veritable indexes of social disorganization. It is well known —and Pettigrew cites relevant data— that many police handle Negroes more nearly in accordance with the letter of the law than they do whites, that a larger proportion of convictions is obtained for Negro defendants than for white ones and that Negroes are given fewer opportunities for parole from prison than whites. "The salient feature of Negro Americans is that they have accepted and internalized American culture but are generally denied the chief rewards and privileges of that culture. High crime rates are but one consequence of this situation."

The last two chapters of Pettigrew's book deal with Negro protest movements. In order to achieve national goals special educational programs for Negroes (and obviously for other undereducated Americans) are needed. If the U.S. really achieves its major economic and social goals, the problem of racial equality will be solved in the process. The book ends with four brief predictions based on what the author has learned, and on social scientists' knowledge of human reactions under intense deprivation: Negro protests will continue to grow both in intensity and depth; the protests will increasingly attract a larger proportion of lower-income Negroes and shift from status goals to economic ones; a more extensive use of local and national boycotts of consumer products will be made; as the revolution proceeds some basic structural changes in American society will have to occur before viable solutions to problems of race relations can be found.

For biology and the social sciences the end of racism means the freedom to investigate biological and cultural problems without the ambiguity in the word "race" providing a *non sequitur* cause-and-effect relation between the individual human being and society. As Pettigrew puts it: "The final, definitive research must await a racially integrated America in which opportunities are the same for both races. But, ironically, by that future time the question of racial differences in intelligence will have lost its salience; scholars will wonder why we generated so much heat over such an irrelevant topic."

Short Reviews

THE FLYING TRAPEZE: THREE CRISES FOR PHYSICISTS, by J. Robert Oppenheimer. Oxford University Press ($2.75). CONTEMPORARY PHYSICS, by David Park. Harcourt, Brace & World, Inc. ($4.95). Modern physics prides itself on having swept away most of the metaphysics that was long considered essential to any scientific discipline. It has, of course, achieved no such emancipation, having simply substituted a new metaphysic for an old one. Indeed, it would probably be impossible to conduct a meaningful physical discourse and to handle the abstractions, symbols and logical transformations that are characteristic of the transactions of physics if certain underlying metaphysical assumptions were not accepted—even if these assumptions are not acknowledged. One has only to look at these two books that attempt to explain the character of modern physics to the nonspecialist to realize what a formidable structure of metaphysical theories forms the underpinning of the discipline. Oppenheimer's three short lectures are concerned with space and time, atom and field, and a somewhat general evaluation of the relation between science and politics. The lectures are more successful in creating a mood, or perhaps one might say a poetic picture, of modern physics than in elucidating its concepts. The performance is not without virtuosity; one can be reasonably sure that the audience experienced intellectual exhilaration even if not complete enlightenment.

Park's book is a fuller, more systematic popularization of such topics as the properties of nuclei, quantum mechanics, gravity, elementary particles, symmetry and the like. He begins his account skillfully and carries the reader a good way in showing how the modern ideas of physics evolved. But after a time the story bogs down in complexities, qualifications, subqualifications, dilemmas, paradoxes and puzzles—all of which are the notorious attendants of this sophisticated, fascinating and infuriatingly difficult science. There is the pretense that the propositions of physics pertain to "real" entities in the physical world, and there is also the pretense that there are propositions of physics so abstract that although one can make use of them one must not inquire too closely into their meaning in terms of physical reality. That both of these pretenses have substance and are necessary to the pursuit of physics is the best evidence of its elaborate metaphysical apparatus.

LIFE IN DESERTS, by J. L. Cloudsley-Thompson and M. J. Chadwick. Dufour Editions ($8.95). DESERT ANIMALS, by Knut Schmidt-Nielsen. Oxford University Press ($7.20). Much of the history and prehistory of man is linked with deserts. Surprising as this may be, the fact is that only a small portion of the arid regions of the world is totally inhospitable to man. The remainder offers a variety of opportunities for raising domesticated animals, the pursuit of agriculture, trade and the establishment of stable communities. A comprehensive definition of "deserts" presents difficulties. Deserts can be cold or hot; they are found in Alaska, Siberia

and Tibet as well as in Africa, Asia, North and South America and Australia. In tropical countries desert conditions are said to prevail where the average precipitation is less than five inches and semidesert conditions where the average precipitation is less than 15 inches. Among other characteristics to be considered are the seasonal distribution of rain, the nature of the soil on which the rain falls, evaporation and the transfer of moisture back to the atmosphere from the earth's surface.

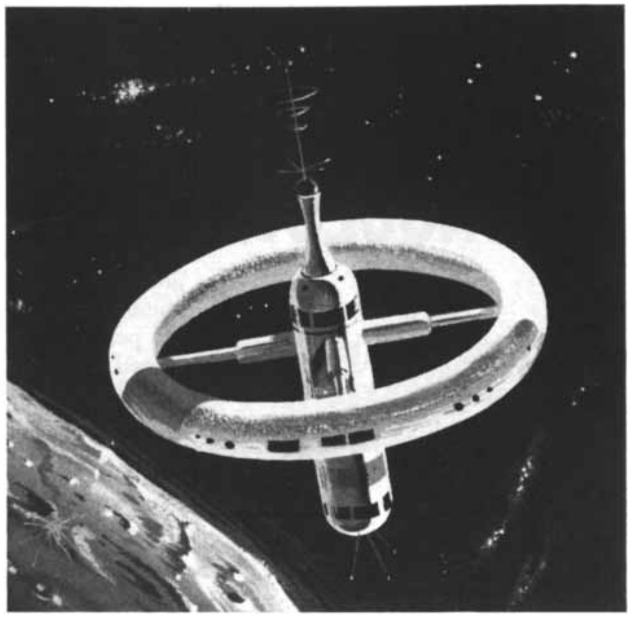
These two books deal with the relation between different forms of life and the desert environment. Cloudsley-Thompson and Chadwick cover a wide field that includes the physical features of deserts and the adaptation of all kinds of animals and plants to arid and semiarid conditions. The monograph is clear, interesting, authoritative and well written and gives an abundance of intriguing facts, from the behavior of scorpions, ticks and mites (many species of which show fantastic powers of water conservation and can live for 10 years or more without food or drink) to the astonishing physiology of ostriches and camels. Schmidt-Nielsen is primarily concerned with the physiological problems of heat and water. He too explains such matters as how the camel can drink as much or as little as it does, how the desert rat survives without water and what purpose is served by the enormous ears of the jackrabbit. (The rabbit often sits quietly in the shade of a surface depression and his ears act as heat radiators, thereby sharply reducing perspiration and the use of water in dissipating the animal's heat.) Both books, although written by specialists, make good reading for anyone interested in natural history. Both are copiously illustrated.

Philosophical Problems of Space and Time, by Adolf Grünbaum. Alfred A. Knopf, Inc. ($10.75). As Einstein repeatedly acknowledged, Henri Poincaré's views on the relation of geometry to space, first published 70 years ago, helped to prepare the ground for the theory of relativity. Poincaré made it clear that the three main types of metric geometry (Euclidean, Lobachevskian and Riemannian) represent different ways of defining spatial congruence. He therefore maintained that these geometries are alternative but intertranslatable languages, so that a choice among them—like a decision to use French instead of English to formulate physical laws—can rest only on considerations of convenience rather than of objective fact. This "conventionalism" with respect to metric geometry (as well as chronometry) has been extensively discussed by leading scientists and philosophers since the beginning of the century, but its precise meaning and validity continue to be actively debated. The first part of Grünbaum's solidly packed book is a careful examination of the various issues that have emerged in this long discussion. Its main burden is a defense of what is said to be Poincaré's real thesis about the conventional status of attributions to space and time of properties (such as the magnitude of the angle sum of a triangle) that depend on definitions of congruence. Grünbaum's conventionalism, however, is limited to the metrical characteristics of space and time and does not extend to their topological traits. The second part of his book tries to show, among other things, that the three-dimensionality of space and the anisotropy (or directionality) of time are objective features of our actual world that cannot be altered by any definitional maneuver. The final part of the book deals with a miscellany of issues in the foundations of relativity theory, such as the question of whether the Lorentz-Fitzgerald contraction hypothesis is falsifiable or whether the notion of absolute space has been made untenable by the general theory of relativity. Grünbaum's analyses are not uniformly convincing, but they are invariably well informed and clarifying. He certainly does not subscribe to the assumption on which so much current philosophical writing appears to be based: that ignorance of relevant scientific findings is an indispensable requirement for philosophizing about a subject matter. It is all the more regrettable that Grünbaum's penchant for polemics has prevented him from writing a more readable book. He is so anxious to settle the controversies over the problems he is seeking to analyze that he rarely has the patience to explain just what the problems are about in their own right, and the details of his arguments frequently obscure the points he is trying to establish.

Ways of Thought of Great Mathematicians, by Herbert Meschkowski. Holden-Day, Inc. ($4.95). Treasury of Mathematics, edited by Henrietta O. Midonick. Philosophical Library ($15). These two books are as disparate in size and price as they are in merit. Meschkowski's volume, a mere 110 pages translated from the German, is the work of a skilled and thoughtful mathematician who knows what he wants to say, has selected good examples of different kinds of mathematical thinking and has put each example in its proper setting, relating it to the development of the subject over a period of 25 centuries. Among his topics are the work of the Pythagoreans (the Pythagorean numbers, the discovery of the Golden Section), Archimedes' proof of the theorem on the surface of the sphere, Nicholas of Cusa's study of the squaring of the circle, Pascal's triangle, Leibniz' researches on series, Gauss's proof of the fundamental theorem of algebra and Georg Cantor's theories of infinite sets. This is an attractive little book that even fledgling mathematicians will find to their taste.

Miss Midonick's book, in contrast, is little more than a swollen hodgepodge. It consists of selections from the writings of some 50-odd mathematicians, among them such inevitable figures as Euclid, Archimedes, Apollonius of Perga, Descartes, Newton and George Boole. It also includes more doubtful discoverers, among them Omar Khayyám, Chaucer and a more than generous sprinkling of Chinese and other Oriental writers whose labors produced only a very dim light in the firmament of mathematical history. Although Miss Midonick refers to a large number of minor innovators, she succeeds entirely in forgetting such outstanding mathematicians as Fermat, Pascal, the Bernoullis, Euler, Lagrange, Laplace, Cauchy, Galois and Riemann.

Selected Papers of Richard von Mises, edited by G. Birkhoff, Philipp Frank, S. Goldstein and others. American Mathematical Society ($35.80). This two-volume collection presents a number of characteristic papers by a versatile, penetrating and imaginative scientist and philosopher: the late Richard von Mises. Von Mises was trained in Vienna at the beginning of the century as an engineer and mathematician. He taught applied mathematics at the University of Strasbourg, then in World War I served as an officer in the newly formed flying corps of the Austro-Hungarian army. During his military service he designed and supervised the construction and testing of the first large airplane of the Austro-Hungarian monarchy, wrote a book on the science of flight (*Fluglehre*, of which the sixth edition appeared in 1958) and made major contributions to the theory of airfoils. In 1919 he became professor of mathematics at the University of Dresden; that same year he published two famous papers on probability the-



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ory embodying his notion of the collective and espousing the relative-frequency concept of probability. Later he taught in Berlin and Istanbul; in 1939 he went to Harvard University, where he became Gordon McKay Professor of Aerodynamics and Applied Mathematics. The first of these volumes contains papers on geometry, mechanics and analysis; the second, papers on probability and statistics and also a number of essays concerned with logical positivism, which Von Mises embraced in the early 1920's. To this philosophy he gave full and mature expression in a treatise published in German in 1939 and in English in 1951. In addition to being an engineer, a mathematician and a philosopher, he was a foremost authority on the German poet Rainer Maria Rilke, wrote a book on his work and left a large Rilke collection to Harvard's Houghton Library. Von Mises' work, as can be judged from these papers as well as from his books, was as sure and as elegant as the man himself, and by its very diversity it reflected the diverse strands of his personality: an aristocratic Jew, a convert to Catholicism, a scientific humanist and a positivist.

THE LIFE OF PLANTS, by E. J. H. Corner; THE LIFE OF INSECTS, by V. B. Wigglesworth. The World Publishing Company (each $12.50). These two natural-history books by leading British specialists are well above average in scientific and literary quality. Corner's story of botany begins with simple plant life in the sea and traces its migration to the shorelines, its spread over the land and its evolution into innumerable forms from fungi to trees. The emphasis of Wigglesworth's book is on the physiology of the living insect: appendages for locomotion and flight, diet, egg-laying, growth and metamorphosis, mating and reproduction, vision, hearing and smell. There are also chapters on the "wisdom of the insect," the organization of insect societies, migration and insects and man. Both of these books are well illustrated.

THE AMERICAN LANDSCAPE, by Ian Nairn. Random House ($5.95). The author of this book, an Englishman trained in town planning and architecture, made a 10,000-mile automobile trip through the U.S. to study roads, cities and towns, housing developments and other features of the "townscape." It is not news that we have squandered our opportunities, misused our resources and made a greedy, abominable mess of most of our urban areas. Nairn, however, not only describes the disease but also diagnoses it. He demonstrates by text and original photographs the deadly gridiron monotony of our city layouts. His acute eye has also detected the wonderful exceptions to be found in the most unlikely places, some in great metropolises, some in obscure waysides and bus stops, some the result of pure accident, some of design and planning. He stresses the value of variety, contrast, adventure and unexpectedness in the urban scene, as well as the importance of making elements that hang together, structural clusters that both fit in with the ecology—man-made and natural—and enhance it. The style is clear and occasionally deliberately *enfant terrible,* but even the brashness is in a good cause.

DISPERSION RELATIONS AND THEIR CONNECTION WITH CAUSALITY, edited by Eugene P. Wigner. Academic Press ($12). This volume, which presents the proceedings of Course 29 of the Enrico Fermi School of International Physics, contains papers on such topics as the proof of dispersion relations and high-energy scattering. There is an interesting and more general paper by Wigner that discusses the nature and development of invariance principles and their role in the framework of the physical sciences.

THE HISTORY OF THE STUDY OF LANDFORMS, by Richard J. Chorley, Antony J. Dunn and Robert P. Beckinsale. John Wiley & Sons, Inc. ($13.50). The first volume of a history of geomorphology, carrying the story from early ideas on erosion and rock strata to studies of the geographical cycle by William Morris Davis. The book includes many excerpts from the writings of James Hutton, John Playfair, Abraham Werner, Charles Lyell, George Greenwood, James Dana, John Wesley Powell and others. Good illustrations and bibliographies.

THE NEW SOCIOLOGY: ESSAYS IN SOCIAL SCIENCE AND SOCIAL THEORY IN HONOR OF C. WRIGHT MILLS, edited by Irving Louis Horowitz. Oxford University Press ($8.50). Twenty-eight essays on important trends of present-day American sociology, some directly concerned with the late C. Wright Mills's work as a social scientist, some with other studies in social science and social theory. A number of the essays are of high quality—much better than those usually found in memorial volumes of this kind—and the book as a whole is more than a gesture.

Notes

HERACLITUS, by Philip Wheelwright. Atheneum ($1.25). A soft-cover reprint of an excellent book that translates the surviving fragments of Heraclitus' writings and analyzes their meaning.

STUDIES IN THE LIFE HISTORY OF THE SONG SPARROW, by Margaret Morse Nice. Dover Publications, Inc. ($3.50). A two-volume soft-cover reissue of a comprehensive study of the song sparrow and other passerine birds that originally appeared some 25 years ago in *Transactions of the Linnaean Society of New York.*

THE AAAS SCIENCE BOOK LIST FOR YOUNG ADULTS, compiled under the direction of Hilary J. Deason. American Association for the Advancement of Science ($2.50). An annotated bibliography of 1,376 science and mathematics titles intended as a guide for "young adult" readers, which is to say any nonspecialist.

INDIAN ART IN MIDDLE AMERICA, by Frederick J. Dockstader. New York Graphic Society ($25). A lavishly illustrated survey of pre-Columbian and contemporary arts and crafts of Mexico, Central America and the Caribbean. Seventy color plates, each separately mounted, 180 black-and-white illustrations, maps and a bibliography.

RUSSIA AND THE SOVIET UNION: A BIBLIOGRAPHIC GUIDE TO WESTERN-LANGUAGE PUBLICATIONS, edited by Paul L. Horecky. The University of Chicago Press ($8.95). Included in this useful cooperative work are reference aids and bibliographies, general and descriptive surveys and titles of books on the lands of the U.S.S.R., the people, the nations, history, economic and social structure, intellectual and cultural life.

THE ORIGINS OF MODERN SCIENCE, 1300–1800, by Herbert Butterfield. The Free Press of Glencoe ($1.95). Butterfield's brilliant survey is reissued as a paperback.

CONTROLLED THERMONUCLEAR REACTIONS, by L. A. Artsimovich. Gordon and Breach Science Publishers ($19.50). A translation from the Russian of a foremost student's review of work done on controlled thermonuclear reactions in the U.S.S.R. and Western countries.

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