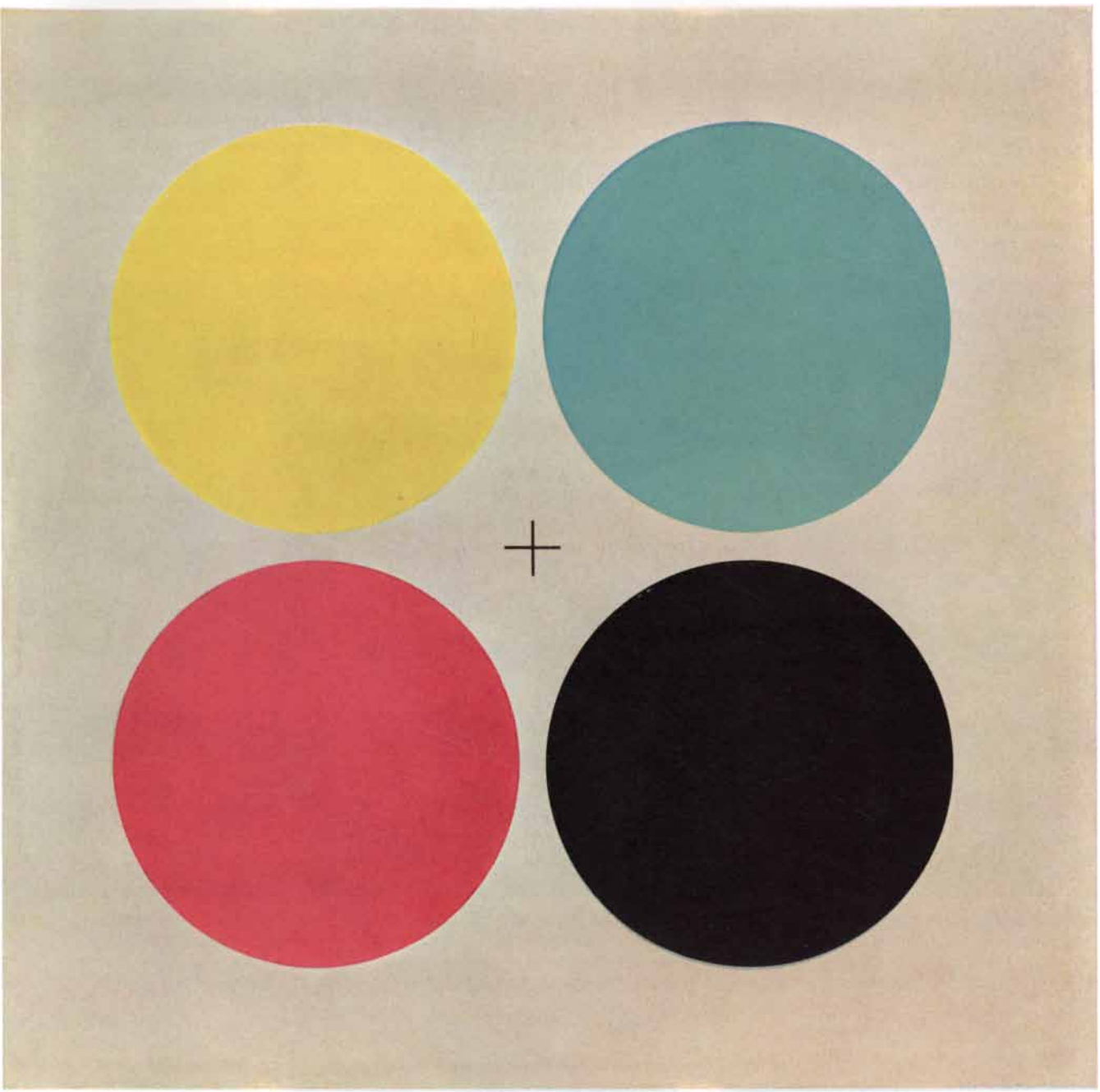
SCIENTIFIC AMERICAN



AFTERIMAGE TEST PATTERN

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October 1963

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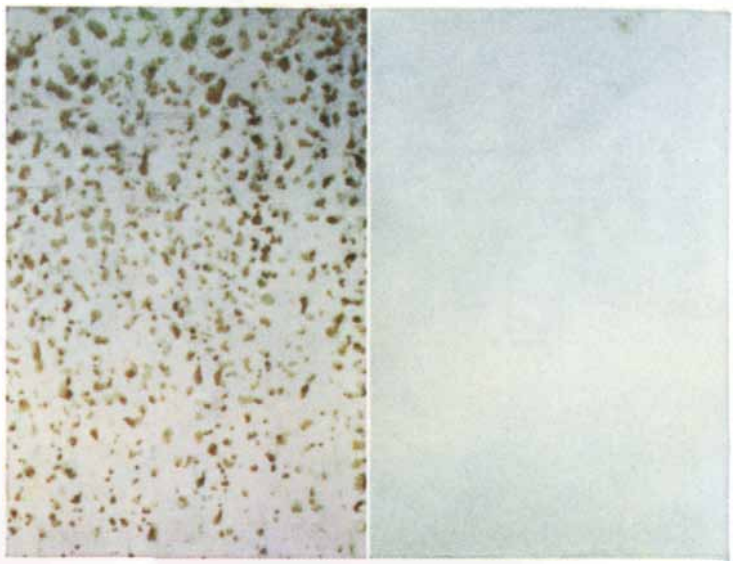

How microscopic cracks retard corrosion of plated metal: Plate more than 20 millionths of an inch of ordinary chromium on auto brightwork and it soon develops relatively gross cracks, some extending right to base metal, inviting corrosive action *(left)*.

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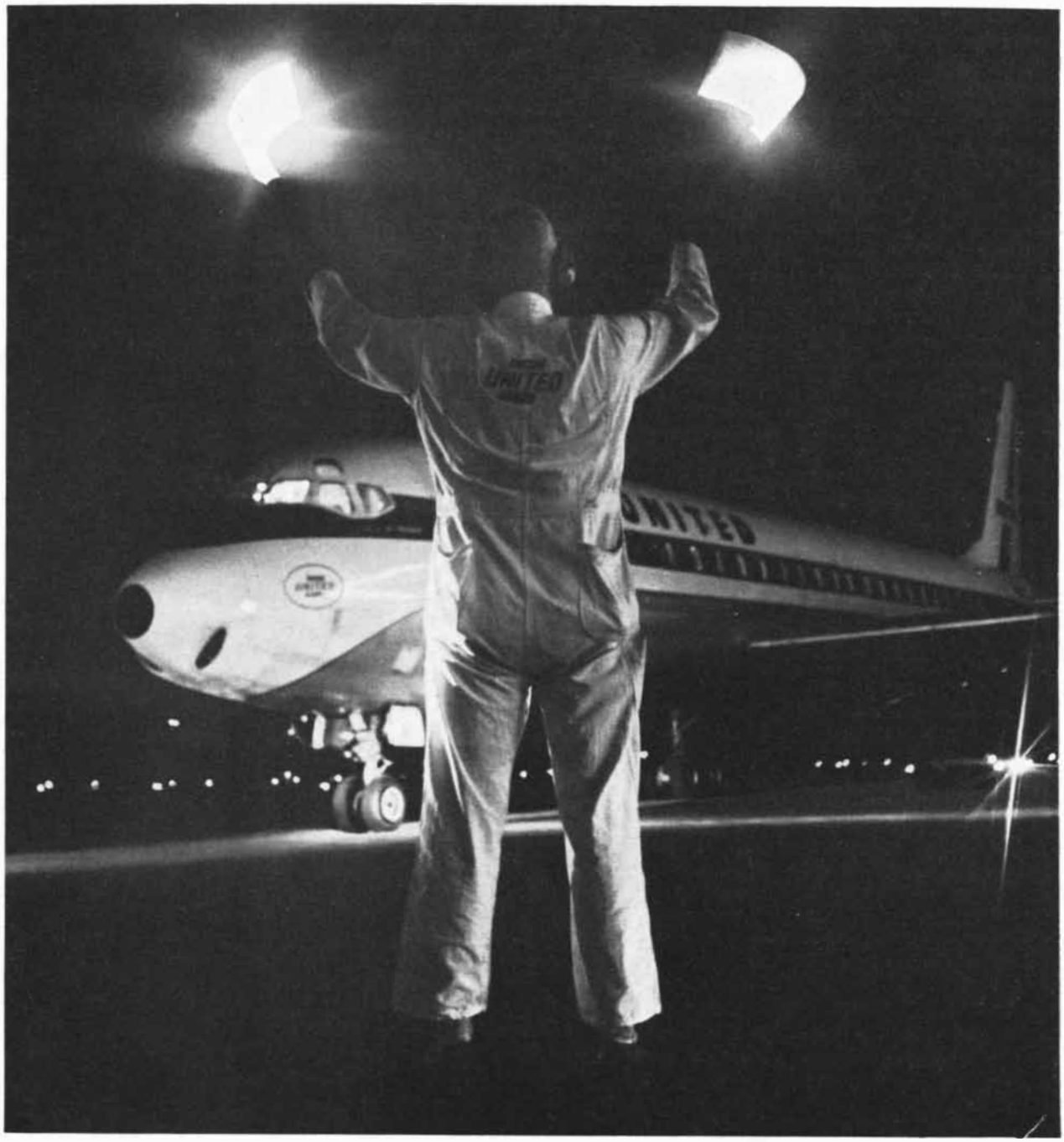

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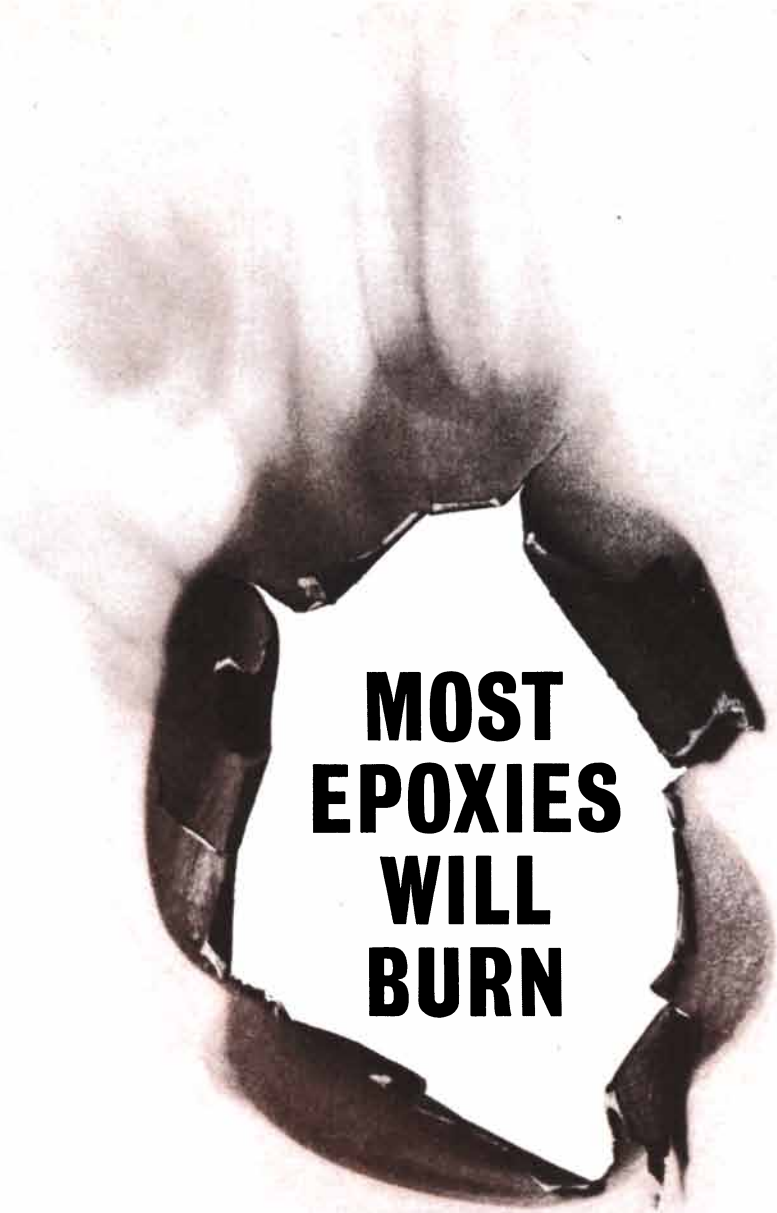

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Established 1845 **SCIENTIFIC AMERICAN** October 1963 Volume 209 Number 4

ARTICLES

DEPARTMENTS

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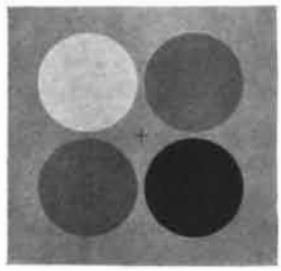

THE COVER

The picture on the cover is a test pattern to demonstrate visual afterimages (*see page 84*). If the viewer looks steadily at the small cross in the center of the pattern for about 10 seconds and then looks at a plain white surface, he should see the four disks emerge in their complementary colors. Such an afterimage is called negative; it is also possible, although more difficult, to produce a positive afterimage, in which the colors are the same as those in the test pattern. To obtain a positive afterimage the viewer should look at the cross in bright sunlight for two or three seconds, then close his eyes and cover them with his hands without pressing on them until the image appears.

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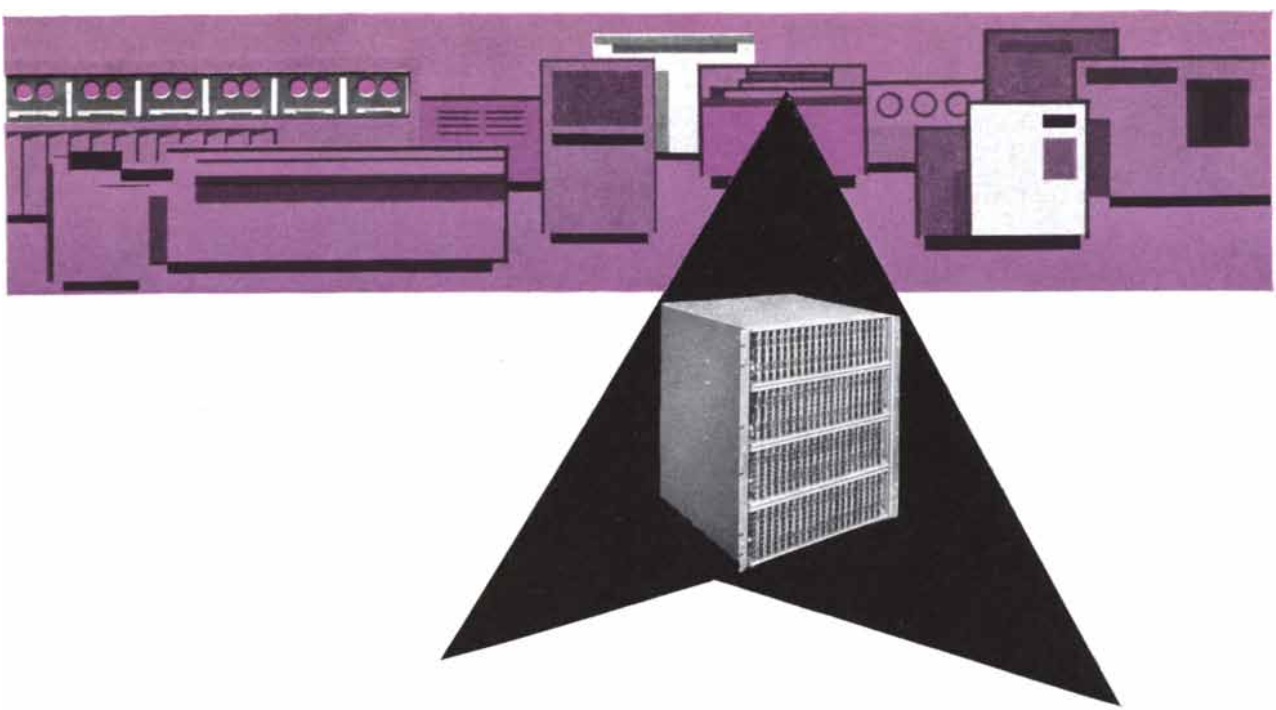

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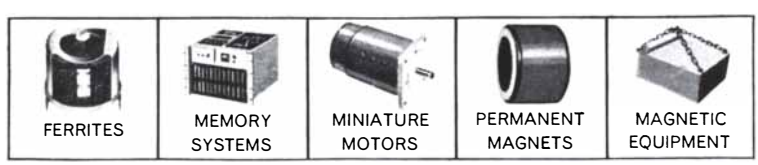

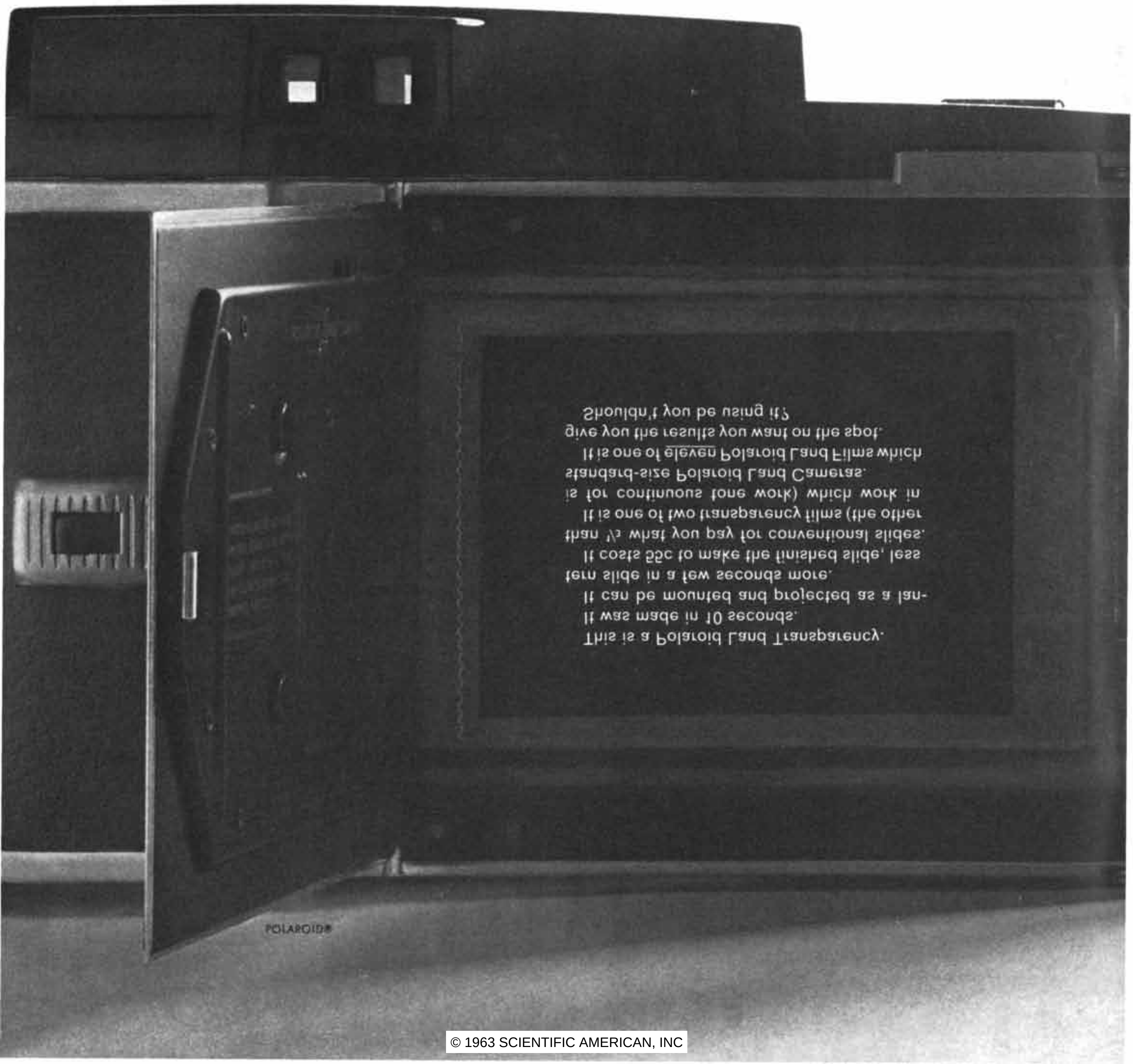

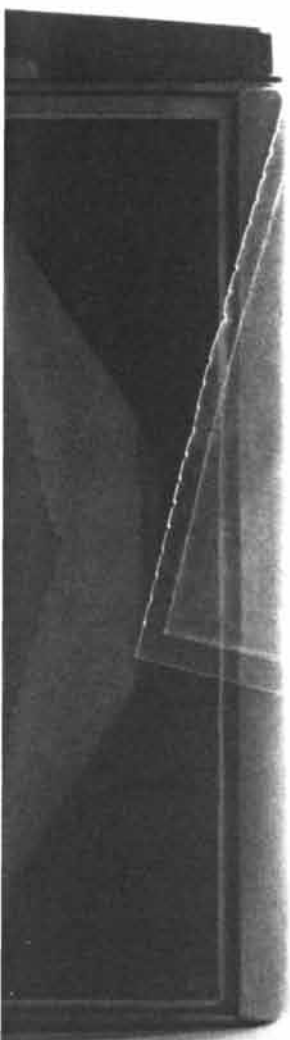

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It can be mounted and projected as a lantern slide in a few seconds more.
It costs 55c to make the finished slide, less than ⅓ what you pay for conventional slides.
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LETTERS

Sirs:

The article by Gilbert W. King and Hsien-Wu Chang ["Machine Translation of Chinese," SCIENTIFIC AMERICAN, June] contains several extremely misleading statements. First, it is claimed that "scientific and technical journals published in Russian are routinely translated by machine." This simply is not true. The system that Dr. King developed while he was at IBM did indeed produce what can only euphemistically be called translations, but in a careful environment in which neither equipment nor procedure could be said to have been employed routinely.

Furthermore, the statement that "the results, although far from perfect, have demonstrated that understandable and useful translations can be made automatically" is misleading. There is no published evidence that any impartial evaluation of the output of this system has been made at all, and only a few months ago this question was a subject for inquiry by the Air Force Scientific Advisory Board, whose conclusions, one gathers, were not as sanguine as represented.

This type of misrepresentation, which has occurred quite frequently over the past decade, has unfortunately led many Government agencies and others to believe that their language-translation problems are already solved. Nothing could be further from the truth, and it would be folly, for example, not to continue emphasizing the training of scientists and engineers in order to enable them to read, by themselves, foreign literature in their fields.

The statement that "it proved impossible to find any fabric of grammatical and syntactical rules that could be reduced to a manageable set of machine instructions" is not true in the world at large. Considerable progress is being made in this area at a number of research centers.

Dr. King has consistently chosen to ignore certain very serious problems. For example, the sample translation of Chinese on page 124 misleadingly suggests that machines can reliably produce a single English correspondent for a single Russian word or combination of Chinese characters. This has indeed been the case in Dr. King's Russian system, but simply because the dictionary included only one English correspondent for each Russian word, and very rarely two. This naturally has the effect of making the "translations" look good, but since most Russian words and most Chinese character combinations are hardly unambiguous, this kind of drastic oversimplification can lead to serious errors. The article similarly gives the impression that tree structures such as those displayed on page 132 can readily be obtained in an unambiguous fashion. This again is hardly the case for Russian or English, and I very much doubt that it would be the case in Chinese. There is, therefore, no guarantee that the structure developed by the machine is at all correct.

Dr. King does admit in his closing paragraph that "this is not to say that all the relevant problems are solved or will soon be solved," but this mild disclaimer is hardly enough to undo the damage caused by the less responsible claims made earlier in the article.

ANTHONY G. OETTINGER

The Computation Laboratory
of Harvard University
Cambridge, Mass.

Sirs:

I would regret as much as Professor Oettinger any interpretation of the article on Chinese translation that would discourage future research and I had no intention of misrepresenting the quality

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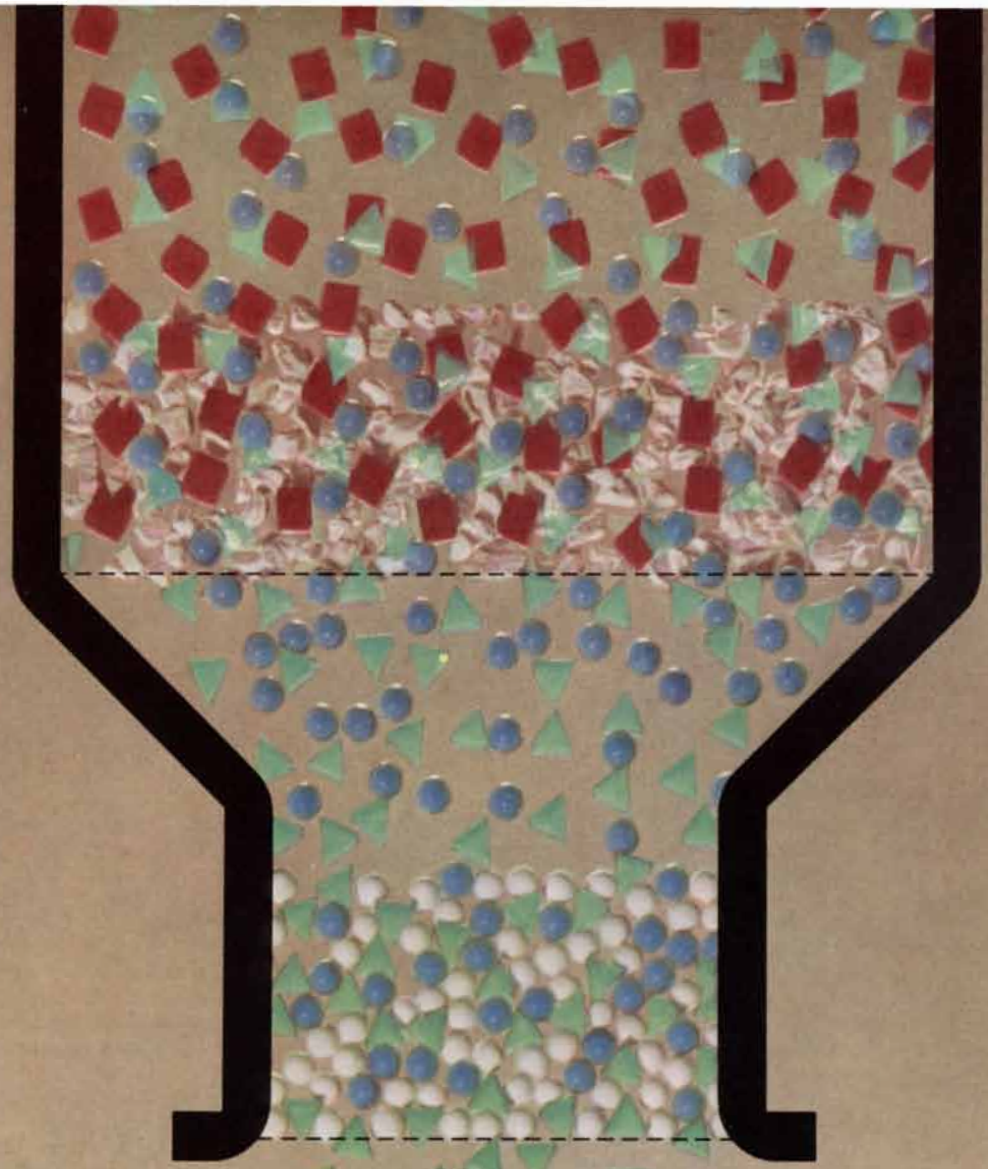

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ALCOA

IBM computers, science and you:

Digital trouble shooter for Titan

At Martin Company, systems engineers help assure success in operational missiles by continually checking product performance with the help of an IBM 7090 system.

Martin engineers have processed 200 miles of paper and 2 million punched cards through the 7090—a complete and continuous case history on the performance of every part in every missile built at Martin's Denver Division.

Take the Titan for example.

Once a month, the manager of systems engineering receives an 8-month record of Titan performance. A curve drawn by the computer pinpoints potential trouble areas, alerts Martin engineers to parts that have started to drop in reliability.

The "trouble" might be just a loose wire, a minor drop in voltage or just a tired resistor. The point is they find and correct trouble before it aborts a mission.

That's pretty important—Titan II will boost Project Gemini into orbit, with a couple of astronauts aboard.

Reliability is pretty important in your product, too. It is to your customers anyway. And you can perform this type of quality control in your products, if you have an IBM computer handy. It doesn't always take a big 7090. Sometimes an inexpensive 1620 system is all you need.

Automatic maps help find oil

Geologists and geophysicists collect core samples and pressure readings and seismic data and dipmeter readings and other technical data.

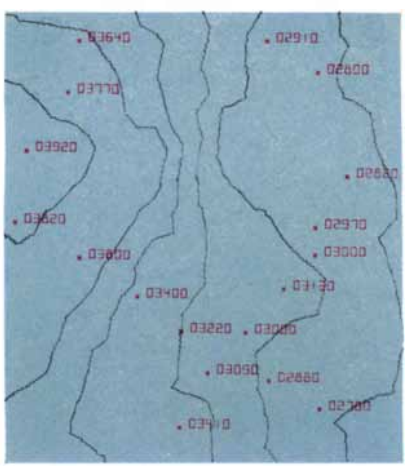
Then what? That's the rub.

Like most scientists, their problem is finding time to sift through it all...analyze it...and make it useful.

But not any more.

Now, a set of new IBM computer programs helps them process and analyze their data. The programs are tailored to oil exploration and production problems and the capabilities of the small, low-cost IBM 1620 computer.

The programs automatically stamp out quick contour maps that help petroleum experts avoid unpromising



fields and concentrate on fields that look like winners.

The new IBM programs also guide economic forecasts, casing design, waterflooding patterns and other activities.

You can handle all these problems on a 1620 with 20K core storage and automatic divide, a card read-punch and a paper tape reader adapter to handle an X-Y plotter (for the contour maps).

The programs, of course, are free. And so is the help of our petroleum industry specialists.

Our programs help cut the cost of operating the computer.

This is worthwhile if it helps geologists and geophysicists eliminate just one million-dollar dry hole a year.

Computer programs speed lens design

If you've ever designed a lens system—even a simple one—you know it's no snap assignment.

It can take several months if you're working on a complex system and doing all the work by hand.

But you can cut this to a few days and increase precision at the same time, with an IBM 1620 computer and a set of four IBM lens design programs.

The first program in this package does two things. First, it traces individual meridional and skew rays and fans of sagittal and tangential rays (up to 99 per fan). It also calculates third order aberrations for the system and for individual surfaces.

The second program computes the vignetted aperture of the lens system, constructs a grid across this area and traces selected light rays through the system from this grid. This enables the designer to check the total usable path of light through the system. He may specify up to 999 rays.

The third program evaluates the output of the second program. It computes the radial distribution of light energy and provides focus and origin shifting, if desired.

The fourth program compares third order aberrations in the system with desired values. It automatically computes changes in system parameters and recalculates third order aberrations until the lens system performs within specified tolerance limits.

These lens design programs improve accuracy, help the designer improve lens system performance and make it possible for him to devise more sophisticated designs.

You can get these easy-to-operate lens design programs through your local IBM branch office.

IBM
DATA PROCESSING

of translation being achieved with machines at present. A real difference of opinion seems to exist on the usefulness of translations of this quality. They were found, in an operational evaluation, to be quite useful by the Government. For the past two years a contract has been in effect under which 10,000 words of Russian are translated daily. Generally these are sent in on a telephone line, processed and sent back to the Government in minutes, in what I at least regard as being a routine manner not requiring a particularly "careful" environment. Our allusion to this Government project was, perhaps, the first in open literature, so that Professor Oettinger's being unaware of it is understandable.

Although Professor Oettinger believes it is possible, "in the world at large," to reduce grammar and syntax to a manageable set of machine instructions, he can only support his belief with the claim that "considerable progress" is being made in this area. The fact is that progress has been slow, and a decided trend to the descriptive, or "table look-up," methods advocated in the Chinese-translation article is developing not only in machine translation but also in the field of nonnumeric processing as a whole.

I would agree with Professor Oettinger that it would be deplorable to have machine translation used as a reason for de-emphasizing the training of scientists and engineers in languages. On the other hand, I think that the ability to process languages by machine is a national requirement and that the support of research in the language-translation field by the Air Force and other Government agencies is, and will continue to be, of immense general value.

GILBERT W. KING

Vice President and
Director of Research
Itek Corporation
Lexington, Mass.

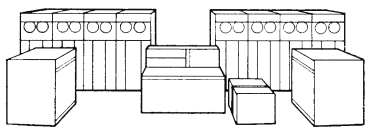
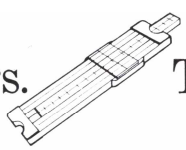
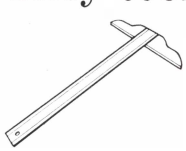
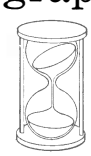
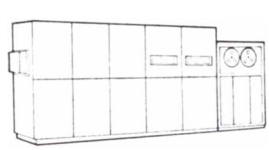
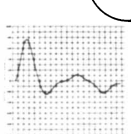
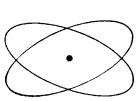
Sirs:

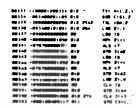
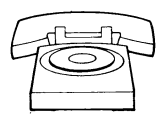
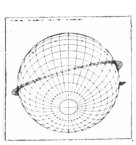
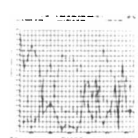
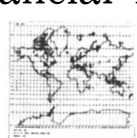
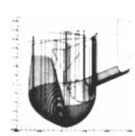
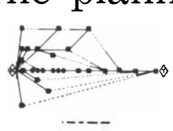
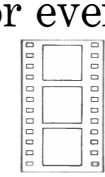
The article on moiré patterns by Gerald Oster and Yasunori Nishijima [SCIENTIFIC AMERICAN, May] was a delightful review of a fascinating optical phenomenon. A curious omission, however, was a mention of that most widely used moiré pattern, the vernier scale—a sort of one-dimensional lensless moiré microscope.

MARK R. DUSBABEK

Whittier, Calif.

The machine that helped a computer work for everybody

Once upon a time, a company bought a large-scale digital computer.  It was very useful but - alas! - expensive. It was hoped all departments would benefit, but because the computer-printer generated only row after row of numbers and symbols,  it was used only by the engineers.  They took their armloads of papers to the drafting department  where an army of draftsmen and clerks converted the figures into charts, graphs and drawings. This was expensive and time consuming,  and some charts were needed immediately. Then a bright engineer learned about a new kind of machine called the S-C 4020  that takes the information  from a computer and converts it into curves, graphs  and pictures.  And this machine keeps up with big computers because it prints with electron beams  instead of a hammer or stylus. Of course,

the S-C 4020 prints words and numbers  too, so they got one. The engineers talked  about their versatile new machine, and soon other company departments were using it to solve their problems by transforming numbers into picture form  that everybody could understand and use. The comptroller used the S-C 4020 to draw graphs and charts  for his financial reports. The marketing manager produced sales maps.  The production man used it for tool path  drawings. The planning people used it to update critical path diagrams  And the S-C 4020 saved space for everybody by storing all kinds of information on microfilm.  (Naturally it prints paper copies, too.) If your computer has a usage barrier, learn how the S-C 4020 can help it to talk in everybody's language. Write to *General Dynamics|Electronics,* Department D-37, P. O. Box 127, San Diego 12, California.

Each of the sample illustrations above were actually produced in less than one-half second on the S-C 4020.

50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

OCTOBER, 1913: "The race for the Gordon Bennett trophy was won this year by Maurice Prevost, who covered the course of 124.77 miles in 59 minutes 45⅘ seconds. His average speed was more than 125 miles an hour—the fastest speed yet attained in a flying machine."

"If the development of the ocean-going submarine in the early years of its existence seemed to be rather slow, no such charge can be made against this interesting craft at the present time. Within a single decade it has developed from an ingenious curiosity into a potent engine of war, the limit to whose future development no intelligent student of naval affairs would care just now definitely to determine."

"The London *Times* correspondent in Munich reports that all Germany is obsessed with the idea of procuring mesothorium for use as a panacea for cancer. This radioactive substance is obtained from the thorium waste in the manufacture of gas-mantles. For therapeutic use a tiny particle is inclosed in a silver covering pierced with minute holes; the box is placed upon the part affected with cancerous growth and is said to slowly but surely eradicate the disease, although leading physicians are disposed to reserve judgment on the subject."

"Dr. H. Geiger of the Reichsanstalt, who four years ago in conjunction with Prof. Rutherford devised a method of counting the number of alpha particles emitted by a radio-active body, has now, according to a communication from the Reichsanstalt, succeeded in perfecting a very simple method which allows both the alpha and the beta particles to be counted."

"On September 23 Roland G. Garros, the famous French aviator, made what may well be regarded as the most perilous over-sea aerial voyage in an aeroplane thus far achieved. He flew across the Mediterranean Sea from Saint Raphaël, France, to Bizerta, Tunis, a distance of 485 miles. This is the longest over-water flight ever made in an aeroplane. The distance was covered in seven hours 53 minutes at an average speed of 61.44 miles an hour."

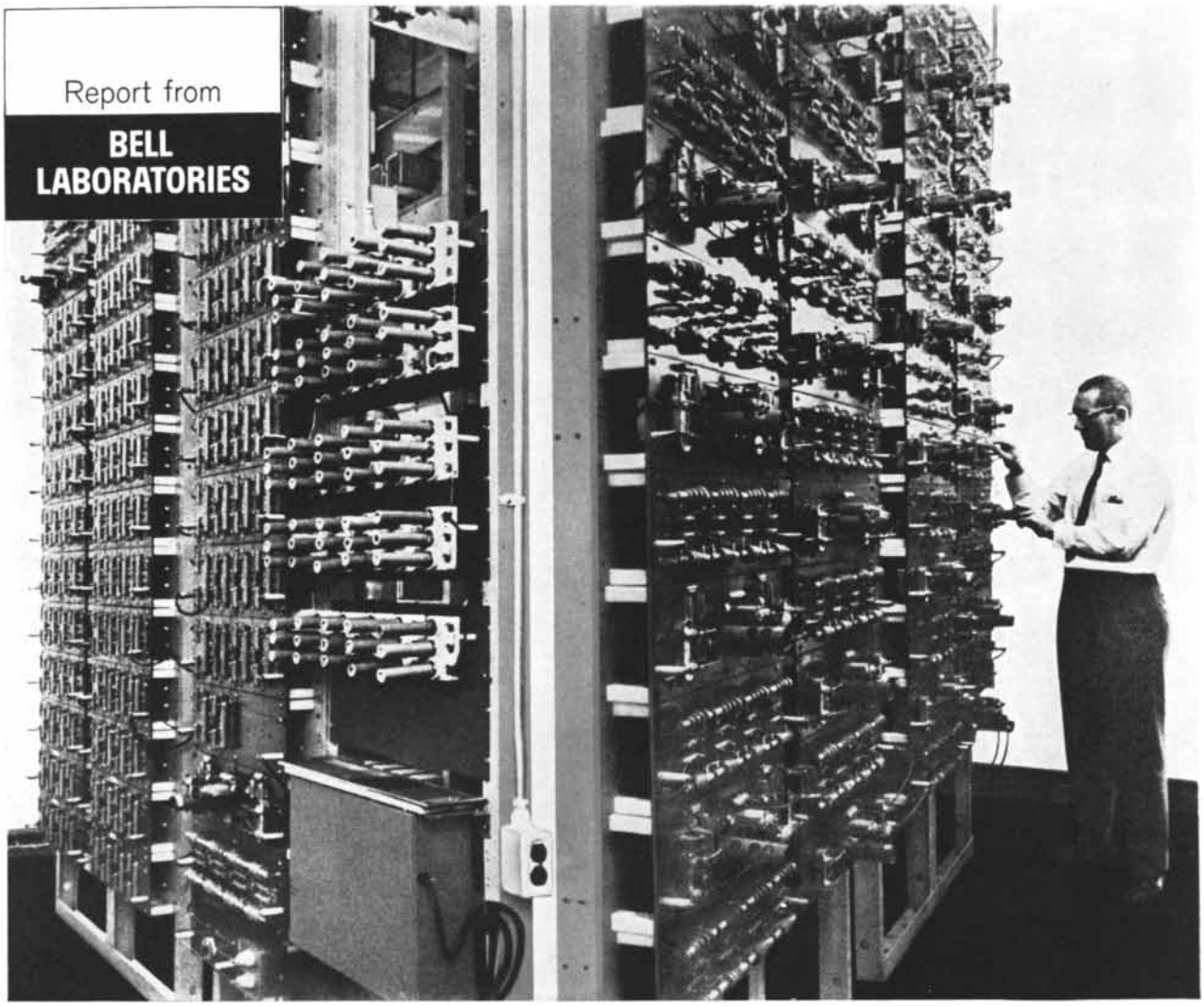
"The report of Col. Gorgas from Panama for the month of July, 1913, shows a lower death rate than for any of the 10 years during which the canal has been under construction. The total death rate per thousand for July was 7.66, and of these deaths only 5.38 were due to disease. These figures may be compared with the death rate per thousand for 1906, which for the month of July was 64.71, of which the death rate due to disease was 62.15."

Scientific American.

OCTOBER, 1863: "President Lincoln has issued a proclamation appointing the last Thursday of November as a day of general thanksgiving to Almighty God for the blessings and favors bestowed upon the land, even amid the havoc and desolation of our sad war. The proclamation is couched in chaste and beautiful language and is pervaded with an humble and devout spirit. We take this opportunity of suggesting that all the governors of the loyal States appoint the same day for the usual States' thanksgiving, so that it may be kept in the spirit of unity and the bonds of fraternal concord by every household in the land."

"The number of prize vessels taken into the port of Philadelphia since the beginning of the war is 85. The most valuable, including the cargo, was the steamer *Bermuda,* which realized more than half a million of dollars. Several of the late prizes, which brought heavy cargoes of cotton, also realized large sums. It is understood that the total prize-money of the navy thus far amounts to $30 million. Most of this sum will come directly or indirectly from British pockets. Of this, few will be disposed to complain. There have been numerous heavy failures in England from this cause, and more will inevitably follow."

"T. C. McKeen of Dunkirk, N.Y., has invented a diving apparatus that enables a diver to carry with him a sufficient supply of fresh air to last for several hours. The invention consists of a reservoir containing compressed air which is strapped to the shoulders or otherwise



Engineer A. H. Evans measures the effect of voltage surges on Bell Laboratories' simulated undersea telephone cable. Simulating 180 amplifiers and 181 cable sections, with a total length of 3600 miles, the arrangement includes over 1100 electrical components. Photo merges two sides of the simulated cable so that both can be viewed at once.

THE UNDERSEA "CABLE" THAT NEVER GOES TO SEA

In undersea cable systems, electric power for the amplifiers is transmitted along the cable itself. To make this possible, precisely engineered circuits and devices must be designed into the system for protecting electron tubes and other components from sudden voltage surges which may result from accidental damage to the cable.

In systems such as these, the computation of the effects of such surges to establish the needed design parameters is extremely complex. Here, as in many other areas of our work, a solution to the problem has been found through electrical simulation.

Full-scale simulation is achieved by means of networks of electrical components. For the new 128-channel cable scheduled for transatlantic service this year, a network (above) was built to simulate the power path of a 3600-mile cable with its 180 amplifiers.

With the aid of this simulator, engineers can study the effects of voltage surges, the operation of electron tube protectors, and the performance of the power supply in the various contingencies that may occur in active service.

This study of unknown factors by means of electrical simulation is an example of how engineers at Bell Laboratories work to assure the performance and reliability of new communications systems before they are committed to service.

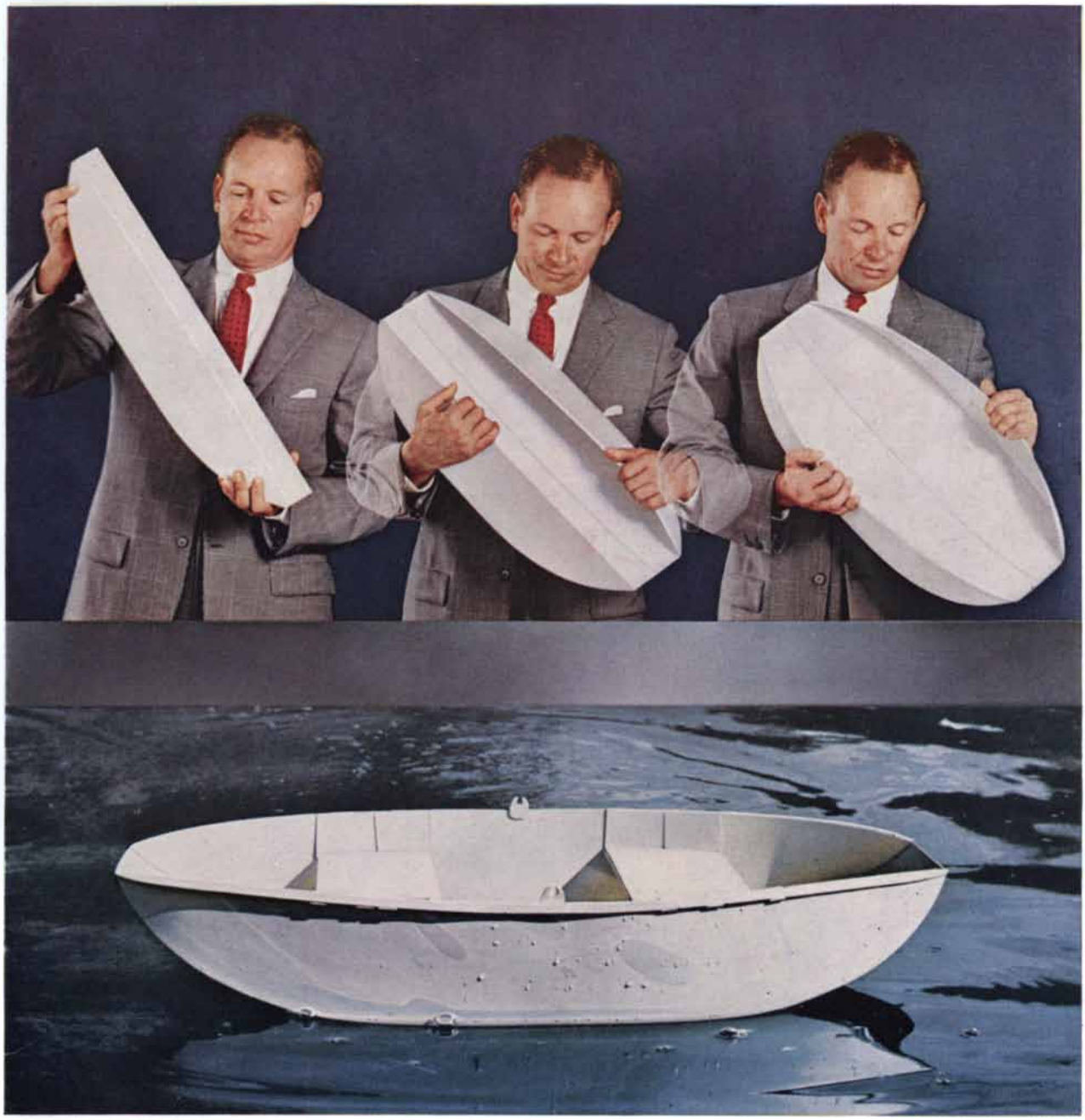
Bell Telephone Laboratories
World center of communications research and development

secured to an ordinary diving dress, communicating with the interior of the same by a pipe provided with a faucet, in such a manner that the supply of air to the interior of the dress can be regulated at any moment and the diver is free to move in any direction."

"The Suez Canal, intended to connect the Mediterranean Sea to the Red Sea, and which has been so long delayed from various causes, has at length been taken up again by parties styling themselves 'the Universal Company of the Suez Maritime Canal.' The exclusive privilege of forming this company was granted by the late Pasha of Egypt to a French engineer; the capital stock amounts to $40,000,000, in shares of $100 each, the Pasha investing to the amount of $18,000,000. The works are to be completed in six years, the Egyptian government to have a claim of 15 per cent on the net profits of each year. The canal itself is to be 90 miles long and 330 feet wide."

"The changes which have recently taken place in the use of fluids for artificial light have been rapid and astounding. Only a few years ago whale and lard oils were the common agents for this purpose; then these were superseded in great measure by that dangerous compound of alcohol and turpentine called 'burning fluid,' and again this agent was displaced by oil called 'kerosene,' distilled from cannel coal. Now this oil too has been superseded by petroleum—the natural product of wells situated in the valley of the Allegheny in Pennsylvania. How this fluid is produced in nature's laboratory is still a subject of speculation; in most respects it is similar to the oil obtained from coal, but it has been supplied so profusely and at such low prices as to have completely annihilated the manufacture of kerosene. In the course of two short years the petroleum trade has attained to gigantic proportions. In 1861 only a few hundred thousand gallons of it were exported; in 1862 about five millions of gallons; while during the past seven months of this year, ending in September, 21 millions of gallons had been exported."

"The greatest single engineering work ever undertaken is the tunnel for a railroad through Mont Cenis between France and Italy. Begun in 1857, the tunnel will be nearly eight miles in length when it is completed. Work now proceeds at the rate of 2,600 feet per annum and 720 men are employed at one end and 900 at the other."



DESIGNER W. DORWIN TEAGUE, JR.

What's a chemical company doing creating a one-piece folding boat?

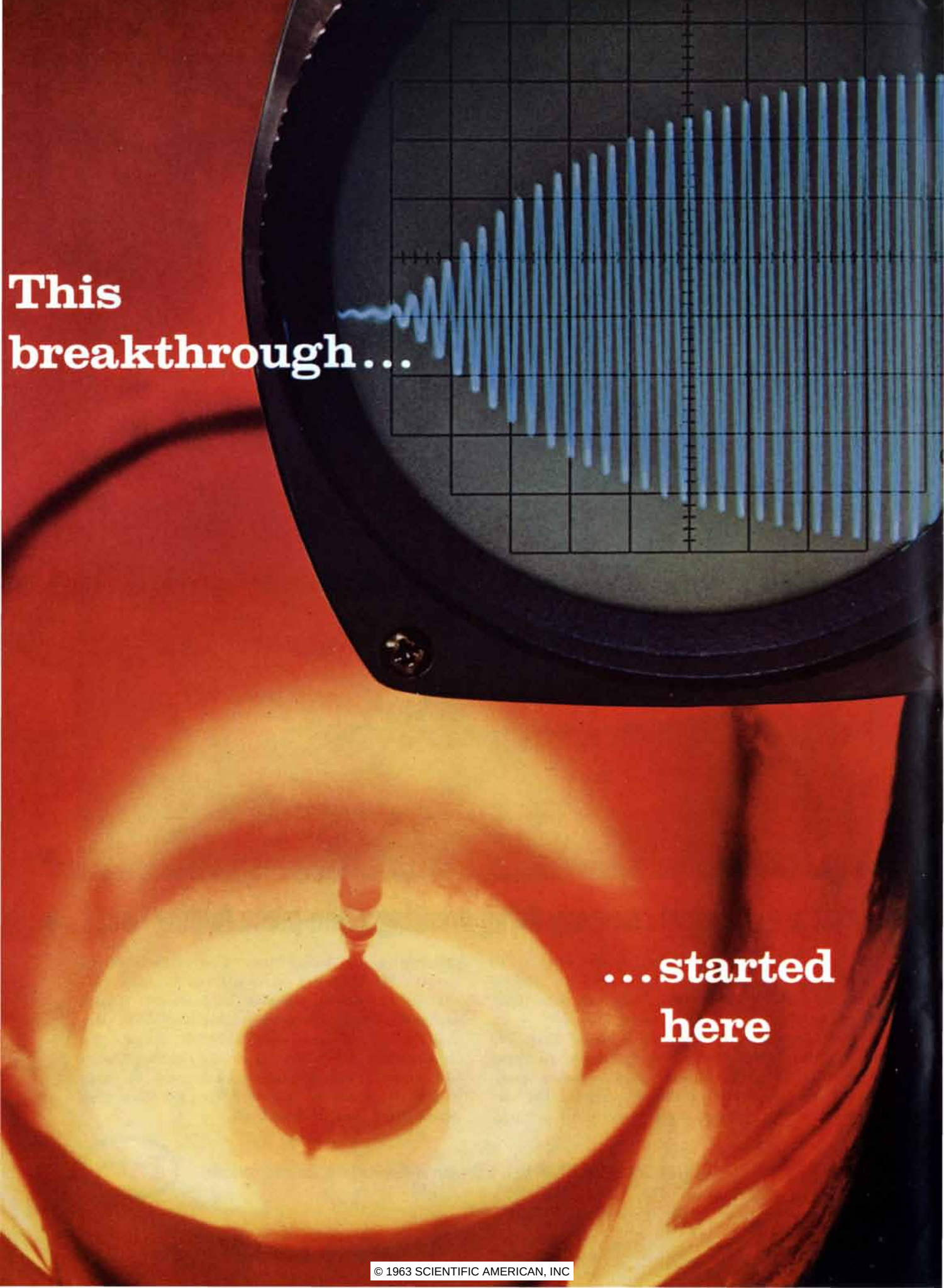
It's part of the unusual design support supplied to users of Enjay products. An Enjay designer, for example, works with manufacturers on everything from lampshades to bread trays for bakeries.

But Enjay design service doesn't stop there. We go to some of America's top designers and ask them to explore the exciting new world of Escon® polypropylene. One result was the one-piece folding boat you see above, a design made possible by polypropylene's unique "living hinge" characteristic, tested for over 3,000,000 flex cycles without a failure.

Enjay has helped many of its customers launch dramatic new products. If you use chemicals, plastics, rubber or petroleum additives, Enjay — the chemical arm of Humble, America's Leading Energy Company—is ready to go to work for you. For help with your problems, contact Enjay, 60 West 49th Street, New York 20, New York.

ENJAY CHEMICAL COMPANY, a division of Humble Oil & Refining Company

ENJAY



PROGRESS

in radio communication depends on continuing improvement in microwave technology. Despite steady advances in the generation and reception of microwave signals, the techniques for modulating these signals have remained relatively undeveloped.

Modulating, or varying the signal so that useful intelligence is carried, has been extremely difficult because of the nature of the klystron oscillator, the usual source of microwave signals.

Under previous conditions, for example, attempts to amplitude modulate the output of a klystron with a sine wave have resulted in major changes in the output signal's frequency. Attempts to pulse modulate klystron output also result in poor frequency stability of the modulated signal.

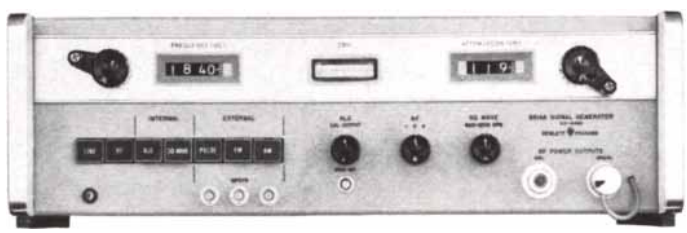
Now Hewlett-Packard, with a four-year research program, has developed a unique proprietary PIN (positive-intrinsic-negative) diode which permits, for the first time, normal amplitude and pulse modulation of high frequency signals without affecting the rf frequency. Where previous attempts to modulate klystrons involved changing the potentials on the klystron itself, the PIN diode affects only the *output* signal; the rf signal source is completely undisturbed during modulation.

The diode consists of a minute chip from a specially diffused silicon wafer in which the diffused P and N surfaces are separated by a layer of intrinsic silicon. At low frequencies this device operates as a typical diode rectifier, but at high frequencies it behaves as a high-speed voltage-programmable absorption-type attenuator, essentially as a linear microwave resistor whose resistance changes according to a bias potential. This bias potential is the modulating signal, the intelligence that varies the effective resistance of the diode. This, in turn, varies the amplitude of the output from the klystron by absorbing varying amounts of the rf energy.

Modulation of carrier signals is important both from the standpoint of transmitted information and from the standpoint of testing the performance of high frequency instruments and systems in the laboratory, to be sure their characteristics are such that they will be useful when finally given the supreme test—that of reaching areas as yet unexplored by man.

Hewlett-Packard's PIN diode, then, is a true contribution to the state of the art. Applications for high frequency modulation challenge the imagination. Incorporated in hp instruments, the PIN diode and its accompanying circuitry provide a practical innovation, a totally new capability in measurement.

The oscilloscope trace shows a 1000 mc uhf signal being pulse modulated by the new Hewlett-Packard PIN diode modulator. The twenty nanosecond rise time shown, completely freed from FM and jitter, has been impossible to achieve until now. The bottom area of the photograph shows one of the first stages in the manufacture of a PIN diode, the "growing" of the silicon wafer.



The Hewlett-Packard 8614A Signal Generator, which employs the PIN diode modulator, delivers precision uhf signals from 800 to 2400 mc and permits amplitude modulation of these signals from dc to 1 mc. Other modulation capabilities include signal leveling across the band, internal square wave, 800 to 1200 cps, and 0.5 μsec rise time. It features an output of at least 10 mw or a leveled output flat within ± 0.5 db. Price, $1650.

HEWLETT-PACKARD COMPANY

1501 Page Mill Road, Palo Alto, California

Divisions and Affiliates: Hewlett-Packard S.A., Geneva; Hewlett-Packard (Canada) Ltd., Montreal, Quebec; Boonton Radio Company, Dymec Division, Harrison Laboratories Division, HP Associates, F. L. Moseley Co., Sanborn Company. **Plants:** California, Colorado, Massachusetts, New Jersey; England, Germany.

THE AUTHORS

CLEMENT A. SMITH ("The First Breath") is associate professor of pediatrics and director of the research project on newborn infants at the Boston Lying-in Hospital. He is also chief of the infants' service at Children's Hospital in Boston. A graduate of the University of Michigan, Smith received an M.D. from that university's medical school in 1928. He also holds two master's degrees, one from Michigan in 1925 and another from Harvard University in 1949. After interning in pediatrics at University Hospital in Ann Arbor, Mich., from 1928 to 1930, Smith spent a year in residency at Children's Hospital in Boston. He returned to Michigan briefly in 1932 as an instructor in pediatrics before joining the faculty of the Harvard Medical School in 1933. From 1943 to 1945 he was professor of pediatrics at Wayne University and medical director of the Children's Hospital of Michigan in Detroit.

GERALD FEINBERG and MAURICE GOLDHABER ("The Conservation Laws of Physics") are respectively associate professor of physics at Columbia University and director of the Brookhaven National Laboratory. Feinberg received a B.A. from Columbia College in 1953 and was a National Science Foundation Fellow at Columbia from 1953 to 1956, obtaining a Ph.D. in physics there in 1957. He spent a year as a member of the School of Mathematics of the Institute for Advanced Study in Princeton, N.J., before becoming a research associate at Brookhaven in 1957. He joined the Columbia faculty in 1959. Goldhaber was born in Lemberg, Austria, in 1911 and received a Ph.D. in physics from the University of Cambridge in 1936. He was a fellow of Magdalene College, Cambridge, from 1936 to 1938, when he came to this country to join the faculty of the University of Illinois. He became a member of the Brookhaven staff in 1950 and was appointed director in 1961.

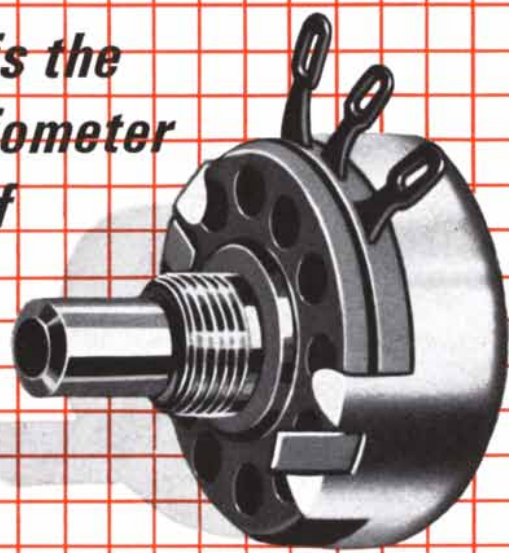
ALICK ISAACS ("Foreign Nucleic Acids") is head of the Bacteriology and Virus Division of the National Institute for Medical Research in London. Born in 1921, Isaacs was graduated with a bachelor's degree in medicine and surgery from the University of Glasgow in 1944. From 1948 to 1950 he worked with Sir Macfarlane Burnet at the Walter and Eliza Hall Institute of Medical Research in Melbourne, Australia. He joined the National Institute in 1950 and has been a member of the staff there ever since. He acquired an M.D. from the University of Glasgow in 1955.

JOHN A. WOOD ("Chondrites and Chondrules") does research at the Enrico Fermi Institute for Nuclear Studies of the University of Chicago. His work is also supported by the Smithsonian Institution Astrophysical Observatory. A native of Virginia, Wood received a B.S. in geology from Virginia Polytechnic Institute in 1954 and a Ph.D., also in geology, from the Massachusetts Institute of Technology in 1958. While at M.I.T., Wood studied astronomy at Harvard University to fulfill the minor requirement for his doctorate. "I soon became interested," he writes, "in the area of overlap between geology and astronomy, namely meteorites. At the encouragement of Fred L. Whipple, director of the Smithsonian Astrophysical Observatory, I began work on meteorites at the observatory in the fall of 1957, during my last year of doctoral work. *Sputnik I* was launched a few weeks after I began, so that I take a certain amount of quiet pride in being one who entered space and solar system research before it achieved its present enormous popularity." Wood spent the academic year 1959–1960 doing research in the Department of Geodesy and Geophysics of the University of Cambridge. Last year he joined the staff of the Fermi Institute.

G. S. BRINDLEY ("Afterimages") is lecturer in physiology at the University of Cambridge. He received a B.A. from Cambridge in 1947 and a medical degree from the University of London in 1950. After a year's residency in ophthalmology at the London Hospital he did research on visual problems of aviation for the Royal Air Force Institute of Aviation Medicine from 1952 to 1954. In 1960 he spent a year doing research at the University of California at Berkeley and in 1962 he worked at the Johns Hopkins Medical School.

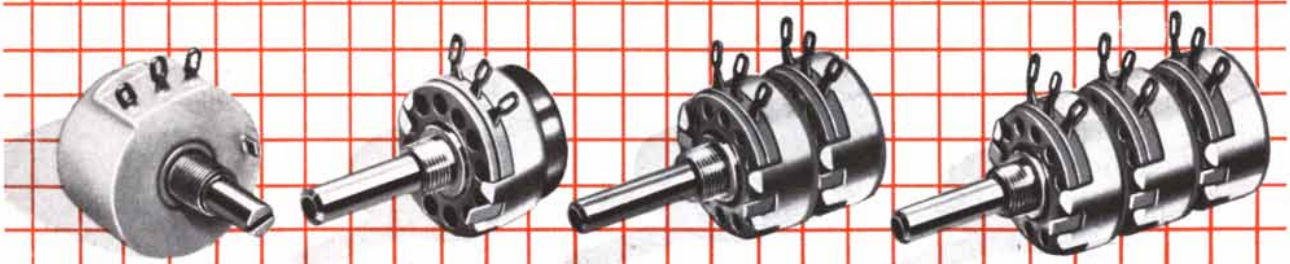
PETER J. PARR ("The Capital of the Nabataeans") is lecturer in Palestinian archaeology at the Institute of Archaeology of the University of London. Born in Minworth, England, in 1929, Parr was graduated from the University of Oxford in 1952. During the next three years he worked at various archaeological sites in North Africa and the Middle East, including Leptis Magna and Bengasi in northern Libya and Jericho and

Allen-Bradley's Type J is the only hot molded Potentiometer with a 25-year record of unfailing service



(Shown twice actual size)

Type J controls are rated 2.25 watts at 70°C and are available in special as well as standard tapers ... and in standard total resistance values up to 5 megohms. Higher resistance values and various mechanical variations can also be furnished to fit your special requirements.



Type J (encapsulated) | Type JS | Type JJ | Type JJJ

Over "25 years" much can go wrong—but no A-B hot molded potentiometer has failed in service to date. And, the A-B potentiometers of today are superior to those built 25 years ago, because continuing improvements have been made over the years to make sure the Type J has no equal for performance.

Today, the Type J hot molded potentiometers can claim: Longest life, yet high wattage rating in a compact structure; stability under the most demanding conditions; extremely low noise level; smooth, stepless control.

And here are the reasons: Type J solid resistance element made by A-B's exclusive hot molding process; and A-B's production control of resistance-rotation characteristics. These reasons account for the fact that the Type J potentiometer provides consistently uniform characteristics . . . that the Type J assures complete freedom from catastrophic failures . . . that the Type J eliminates the incremental steps of wire-wound units, and provides the freedom from inductance which insures excellent high frequency response.

For full details on Type J potentiometers, write for Publication 5200, please: Allen-Bradley Co., 1204 South Third Street, Milwaukee, Wisconsin 53204. In Canada: Allen-Bradley Canada Ltd., Galt, Ontario.

QUALITY ELECTRONIC COMPONENTS

ALLEN-BRADLEY

Dhiban in Jordan. From 1953 to 1954 he was a student at the British School of Archaeology in Jerusalem, where he made a special study of the early Bronze Age; during this period he also conducted his own excavations at an early Bronze Age site, Khirbet Iskander, in eastern Jordan. After a brief return to England, where he worked with the Royal Commission on Historical Monuments, Parr went back to Jerusalem in 1957 to join the staff of the British School of Archaeology, where he became assistant director in 1960. He took up his present post in 1962.

F. C. STEWARD ("The Control of Growth in Plant Cells") is professor of botany and director of the Laboratory for Cell Physiology, Growth and Development at Cornell University. A native of London, Steward was graduated with first-class honors in chemistry from the University of Leeds in 1924. He received a Ph.D. in botany from Leeds in 1926 and was a member of that university's faculty from 1926 to 1933. As a Rockefeller Fellow, Steward came to this country in 1927 and again in 1933 to study at Cornell, the University of California at Berkeley and the Carnegie Institution of Washington. He joined the faculty of the University of London in 1934 and obtained a D.Sc. in botany there in 1936. During World War II Steward served as director of aircraft equipment in the British Ministry of Aircraft Production. Following the war he spent a year doing research at the University of Chicago before becoming visiting professor and chairman of the department of botany at the University of Rochester in 1946. He joined the Cornell faculty in 1950 and was elected a Fellow of the Royal Society of London in 1957.

HENRY GLEITMAN ("Place-Learning") is professor of psychology at Cornell University. Born in Leipzig, Germany, in 1925, Gleitman received a B.S. from the College of the City of New York in 1946 and a Ph.D. in psychology from the University of California at Berkeley in 1949. Shortly thereafter he joined the faculty of Swarthmore College, where he conducted the experiments described in this article. In July of this year he was appointed professor of psychology at Cornell, where he is currently studying memory and forgetting in various laboratory animals.

ERNEST NAGEL, who in this issue reviews W. H. Watson's *Understanding Physics Today*, is John Dewey Professor of Philosophy at Columbia University.

F-12463-A

Can you imagine anything faster than one-billionth of a second?

You're looking at it.

This new Fairchild silicon diode is *twice* that fast. Designed for use in high speed computers, it makes possible much higher calculation rates—and at a lower cost. It is the first mass-produced electronic switch to pass the billionth-of-a-second mark—breaking a barrier comparable to the 4-minute mile. To a computer which uses hundreds of thousands of diodes, it now means that a problem can be solved in less than half the time. And to the electronics industry, it now makes practical a new way of splitting seconds: *into trillionths.*

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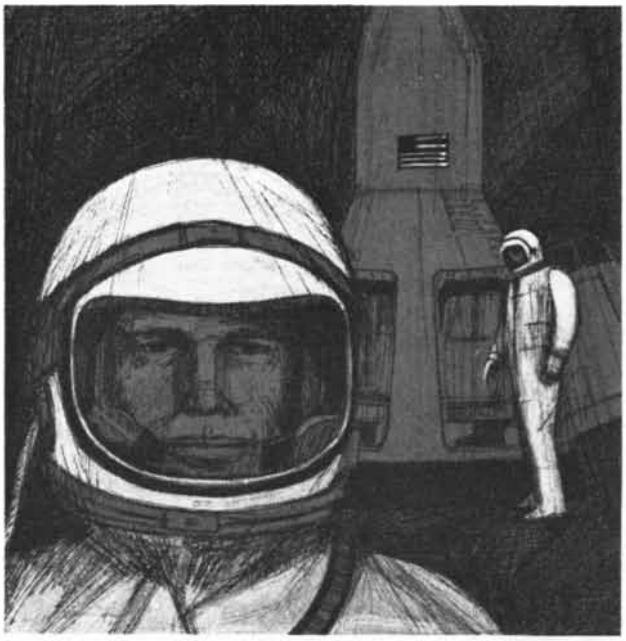

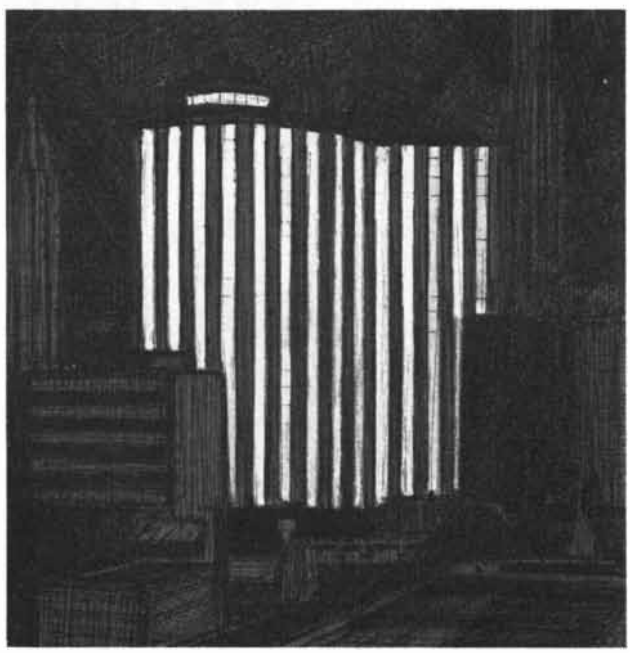

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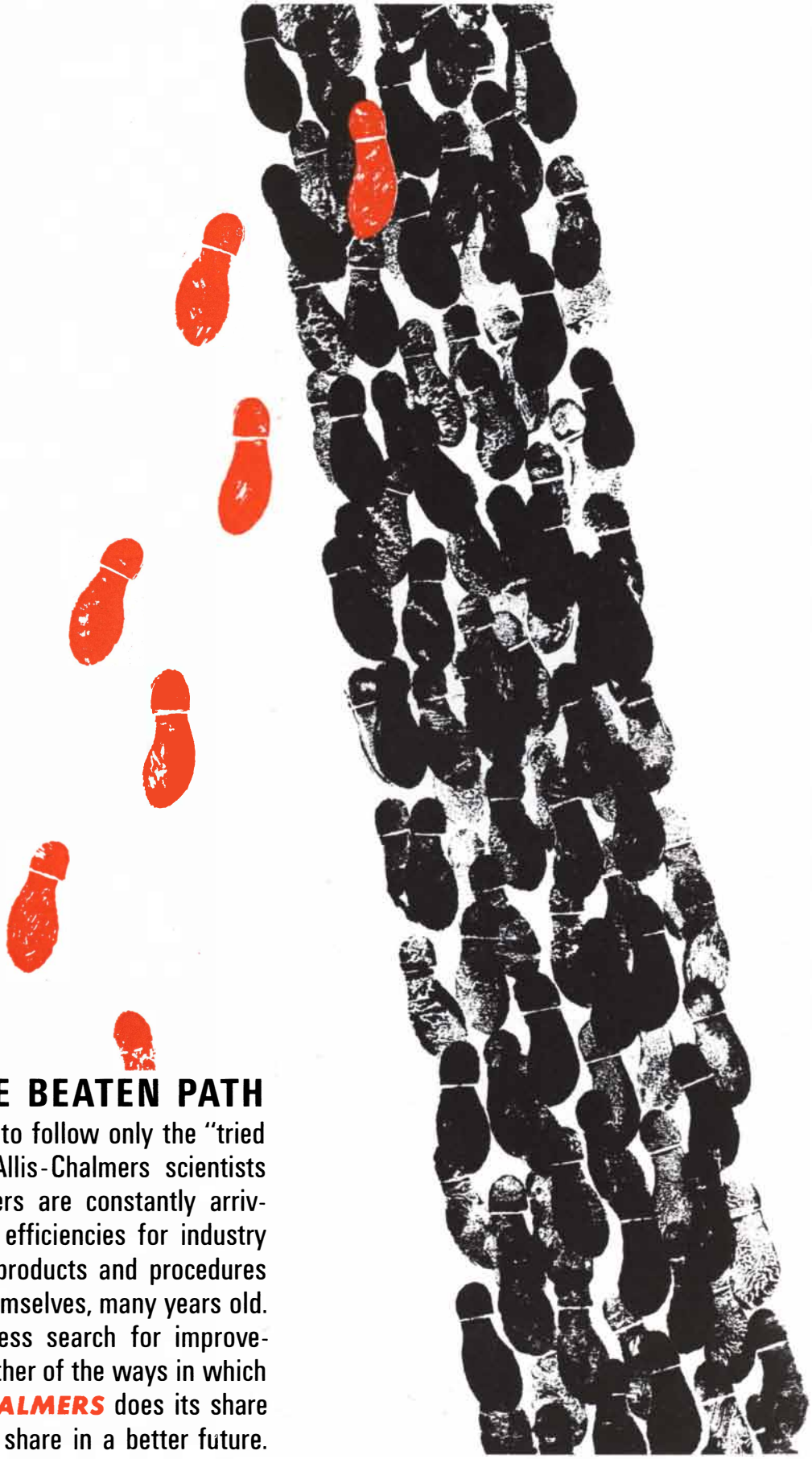

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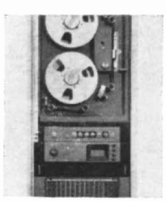

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The First Breath

When a baby is born, it must suddenly change its system of obtaining oxygen and disposing of carbon dioxide. Recent studies have revealed new details of what takes place during this critical episode of life

by Clement A. Smith

The first breath of a newborn baby must give even the most experienced physician a small thrill of excitement. Until that sudden indrawing of air occurs the baby's life is in doubt, even though the heart is beating. In the phrase of Hippocrates, "The occasion is instant." Other problems may be put off for hours, days or weeks, but if the baby is to live, it must begin moving air into and out of its lungs within minutes after emerging from the birth canal.

Once the infant is safely past this major crisis the physician takes a few deep breaths of his own and, if he is worth his intellectual salt, may wonder how the act was accomplished. The baby has suddenly emerged, a physiologically displaced person, into an entirely new medium with such novel physical properties it is astonishing that the infant is able to deal with it so promptly and effectively. The infant is called on, in one sudden moment, to replace the gestational system of oxygen supply and carbon dioxide disposal by the placental circulation with a new system employing the hitherto unused lungs.

Fortunately there is a brief period of grace. Even after the umbilical cord is cut, the oxygenated blood in the baby's circulatory system will continue to nourish the tissues for a few moments. Although a strongly beating heart and good muscle tone will indicate that respiration may safely be delayed for as long as five minutes, the sooner the infant breathes, the better its general condition is likely to be. Commonly it begins breathing within a few seconds after delivery—occasionally even as soon as its head emerges.

Perhaps one baby in a hundred born at full term may have breathing difficulties ("respiratory distress") after starting to breathe. (The rate is higher in premature babies.) The remarkable fact is that failure to begin breathing at all (apnea) is much rarer: better than 99 per cent of the infants whose hearts are beating at delivery do manage to start breathing. How impressive this performance is cannot be appreciated until one examines the obstacles the baby must surmount in drawing its first breath. It is born with its lungs and air passages probably distended by fluid, and against this and other resistances it must inflate the lungs, keep them inflated between breaths and quickly establish a breathing rhythm. As Sidney Farber and James L. Wilson of Children's Hospital and the Harvard Medical School wrote some 30 years ago: "The first breath of a newborn baby may . . . be its most difficult one." Investigation has amply confirmed this view.

How does a baby begin to breathe? What mechanism, we may start by asking, triggers this activity?

It is surprisingly hard to answer the question. There is even a difference of opinion whether breathing activity normally begins only at birth or may occur before. Fetuses delivered prematurely as early as 12 weeks after conception have been observed to make gasping movements, and there is no doubt that a fetus can make respiratory movements in the uterus, drawing some of the amniotic fluid into its lungs in the process. But whether this is normal or occurs only under temporarily unfavorable circumstances cannot be decided with any certainty. Neither experiments on animals nor post-mortem examinations of prematurely delivered fetuses can settle the question, because the experiments and the premature delivery themselves are abnormal situations.

In any case, we must ask what stimulus is responsible for setting off the burst of breathing activity that begins after a baby is born. We know that the breathing of adults is regulated in varying degrees by the levels of oxygen, carbon dioxide and acidity in the blood and the cells it bathes. One or more of these chemical stimuli presumably take part in initiating the infant's breathing. But it is likely that physical stimuli also play a role. They impinge on the newborn baby even before any chemical changes in the body can take effect. The infant is thrust for the first time into an environment that is cooler and in many other ways physically different from its former surroundings. It is assailed by light, sound and the tactile sensation of solid objects in place of the liquid pool in which it has been lying. Its limbs are suddenly heavy instead of weightless. All these sensations bombarding its body

must be violently disturbing. The baby might well respond with a startled gasp and an angry cry.

Nevertheless, physical stimuli may be ineffectual by themselves. Occasionally, after a difficult delivery or one in which the oxygen supply from the mother was temporarily reduced, the baby will lie still without breathing in spite of the application of extra physical stimuli. Then it will suddenly awaken with the sharp intake of breath, as if the body were waiting until chemical changes in the blood or tissues, or both, finally reached a state that triggered the respiratory muscles to contract. Oxygen is usually given by face mask or other apparatus to such infants. Its sudden entry into the lungs and blood will improve the sensitivity of the mechanisms responsible for the rhythmic respiration that should follow.

B. Delisle Burns of McGill University, noting that the activity of the respiratory nerves depends on a background of activity in the central nervous system, points out that the sudden increase in sensory input from the environment at the moment of birth may facilitate the initiation of breathing. "Incidentally," he adds, "it... provides justification for slapping the bottoms of infants who refuse to breathe spontaneously!"

Our next question is: What does the baby have to do to start breathing? What forces act? How much force is required? How much air is moved? How is enough air held and accumulated in the lungs to keep them comfortably air-filled between expiration and inspiration?

Direct observation of the baby taking its first breath tells us tantalizingly little about how these matters are managed. The act is seldom performed in slow motion. At most it lasts no more than a couple of seconds, and a lively baby may be born and start to breathe in one composite flourish of movement. It all takes place too quickly for an observer to see and sort out the details. The process has, however, been recorded and analyzed by means of X-ray photography and other techniques. These studies have been done largely in Sweden, and we are particularly indebted to John Lind of the University of Stockholm and Petter Karlberg, now at the University of Göteborg, for the information they have provided the medical profession and for pictures and records such as some of those illustrating this article.

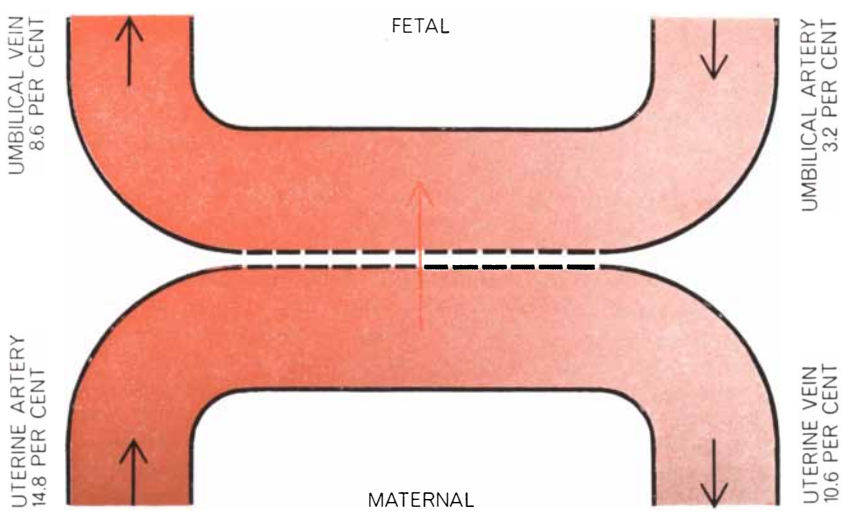
Let us first take a quick orienting look at the human breathing apparatus [*see illustration on opposite page*]. In appearance and functioning it is much like a tree. Looking at it in reverse of the way we usually think of a tree, we start with the alveoli, the tiny air spaces of the lungs, which correspond to the tree's leaves: the alveoli carry out the business of respiration in the animal body, as the leaves perform the essential (although chemically different) breathing functions of the tree. Each alveolus is in intimate contact with capillaries through which it carries on a continuous gas exchange with the blood, giving the blood oxygen and taking away carbon dioxide. Millions of alveoli make up the lungs—about 25 million at birth and some 85 million by the time the baby has grown to the age of three months. The alveoli are connected to bronchioles (twigs), the bronchioles in turn to the two large bronchi (branches), and the bronchi finally meet to form the trunklike trachea, or windpipe, by which air comes into the body from the nose and throat.

This constitutes the air-transport system. What sort of engine moves the air? Essentially it is a kind of bellows composed of the diaphragm, the chest wall and the two-layered linings (the pleura) of the lungs. The "pleural space," a potential rather than an actual space between the two layers, is normally at negative (that is, less than atmospheric) pressure. When the diaphragm and the chest wall expand in the breathing movement, they reduce the pressure in the pleural spaces; as a result the volume of the lungs is increased and the atmospheric pressure outside pushes in more air. In short, the change of pressure in the pleural spaces is the bellows action that moves air in and out of the lungs.

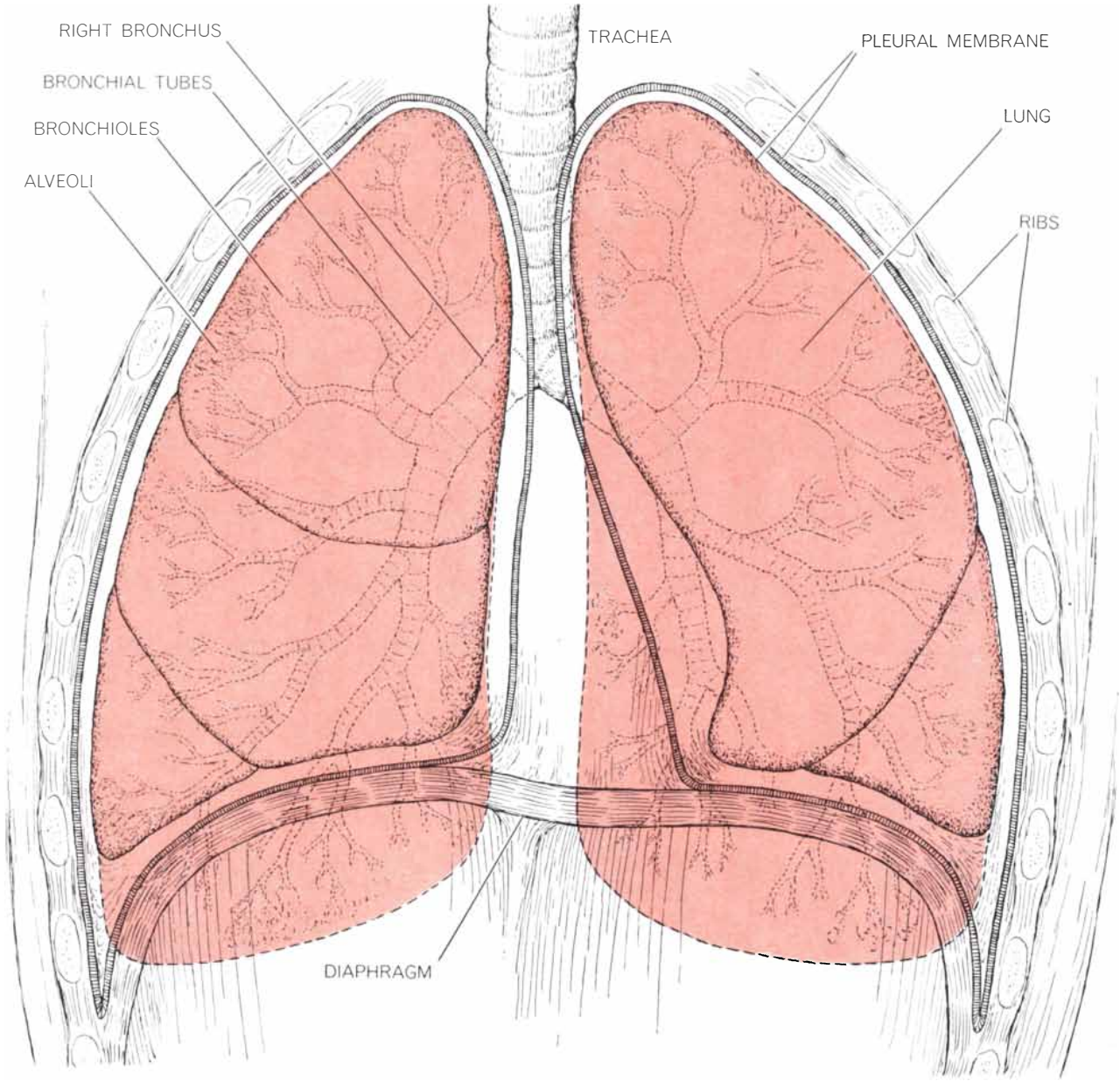
Picture now the situation confronting the newborn baby as it comes into the new air environment and must start taking air into its lungs. There is no helpful negative pressure in the pleural spaces to begin with. Moreover, recent evidence indicates that the airways and alveoli are not merely collapsed like an uninflated balloon, as was formerly thought, but contain some liquid. One of the items of evidence is a study of experimental animals by Mary Ellen Avery and Charles D. Cook of the Harvard Medical School; they found that the lungs of these animals before birth were relatively heavy and that the extra weight must have been due to a considerable amount of liquid in the lungs.

Whatever the source of the liquid—whether it is aspirated from the surrounding amniotic fluid or secreted into the respiratory spaces by the fetus' body—it presents an obstacle to the newborn infant's inflation of its lungs, for two reasons. First, it is hard to move the fluid because of the comparatively high viscosity of any liquid (compared with that of air). The Italian physiologist E. Agostoni and his colleagues have concluded from studies of small animals that the viscous resistance of fluid in the animals' lungs may amount to as much as the pressure of 25 centimeters of water. They note that the viscous resistance must be greatest at the beginning of the first breath, as the air starts to push the liquid down the windpipe.

Second, the incoming air must also contend with the resistance caused by



OXYGENATED BLOOD is supplied to the fetus by the maternal circulatory system. This diagram of the uterine-umbilical connection indicates high oxygen content by darker color. Figures show the average per cent of oxygen in blood flowing to and from the placenta.

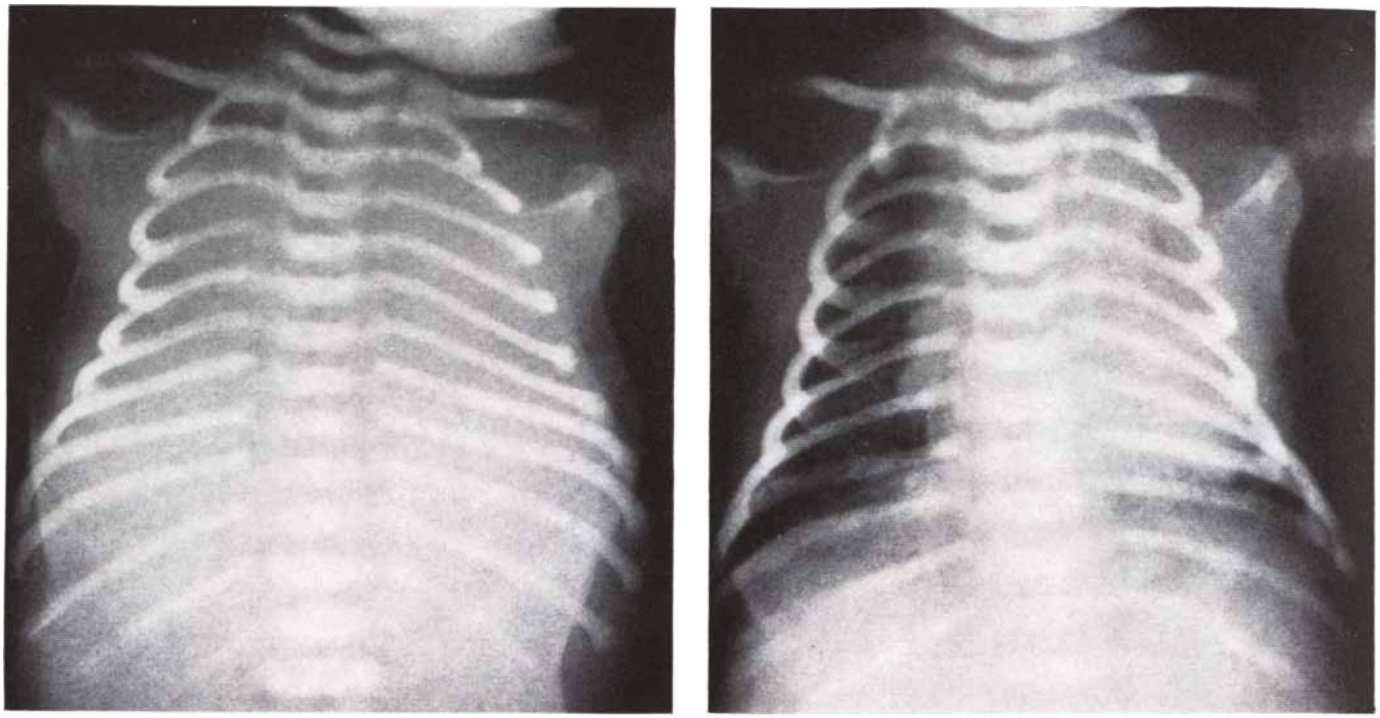


THORACIC CAVITY is shielded by the ribs and muscular wall of the diaphragm. Air enters via the trachea (*top*). The trachea divides into two bronchi, each going to a lung, where it divides further into alveolar ducts. These end in the alveoli, or air sacs.

surface tension at the interface between the air and the liquid. The force of surface tension is responsible not only for the rounding of raindrops in air but also for the contraction and ultimate rupture of bubbles of air in water. The force increases as the radius of curvature becomes smaller. Therefore as the air of the indrawn breath moves into the narrow ducts leading to the alveoli the resistance of the surface tension increases. The presence of liquid in the passages may, however, provide a compensating advantage. By distending the passages the liquid increases the radius of curvature, so that the resistance from surface tension may be less than if the walls of the duct were collapsed. That is to say, the prior filling of the airways with liquid may thus pave the way for the first breath.

In the alveoli themselves the advancing breath encounters other problems. Imagine it blowing little spherical bubbles of air into these pockets. It must inflate each alveolus to its full capacity of expansion before the pressure becomes sufficient to drive air through the connecting duct to inflate the next alveolus. Students of the subject have noted that in an interconnecting system of this sort the smaller chambers will tend to empty their air into the larger ones. Thus an instability of this nature would not only interfere with the initial inflation of the lungs at birth but also would tend at any age to collapse the lungs when they are partly emptied during the exhalation of the breath.

The body contrives a neat answer to this dilemma, as John A. Clements has found and recently reported in *Scientific*



SERIES OF X-RAY PHOTOGRAPHS shows that before first breath an infant's ribs are depressed and its diaphragm raised. Air entering lungs is transparent to X rays and thus appears darker. It is visible in second photograph throughout right lung and at

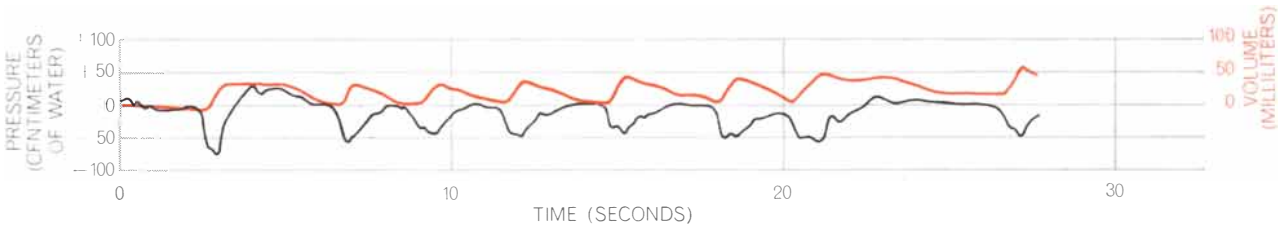
American [see "Surface Tension in the Lungs," by John A. Clements; SCIENTIFIC AMERICAN, December, 1962]. A wetting agent, presumably secreted by certain cells in the walls of the alveoli, decreases the surface tension and "brings about an even distribution of pressure between large and small alveoli." It also "reduces the muscular effort required for respiration." This substance cannot remove the resistance of surface tension to the first breath; rather, it promotes the even distribution of air as the lungs are inflated.

Agostoni believes that the combined resistance of viscosity and surface tension probably prevents the first expansion of the lungs from ever being complete "and that many breaths are necessary in order to aerate the whole lung; during these breaths the liquid ... in the airways can be gradually absorbed by the pulmonary capillaries."

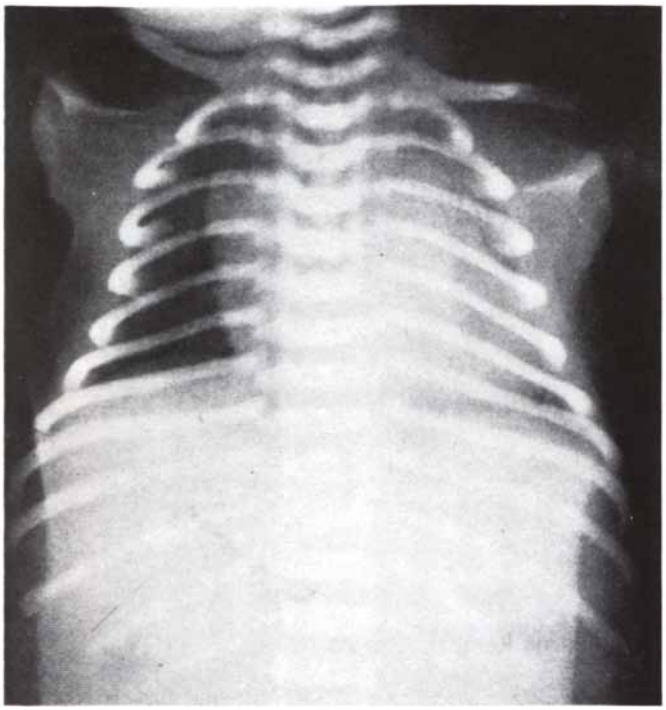
The first breath meets resistance not only from the liquid but also from the tissues of the lungs themselves. In inflating the lung it must stretch—actually deform—the whole organ. The amount of elastic resistance of the lung tissue has been measured; it turns out to be rather small. Avery and Cook found that when the excised lungs of newborn goats were inflated to several times their tissue volume (by filling them with salt water), the elastic recoil amounted to only a few centimeters of water pressure. Measurements of pressure in the pleural space show that the pressure becomes more negative with age; this may reflect changes in the elastic recoil of the lungs or the thorax.

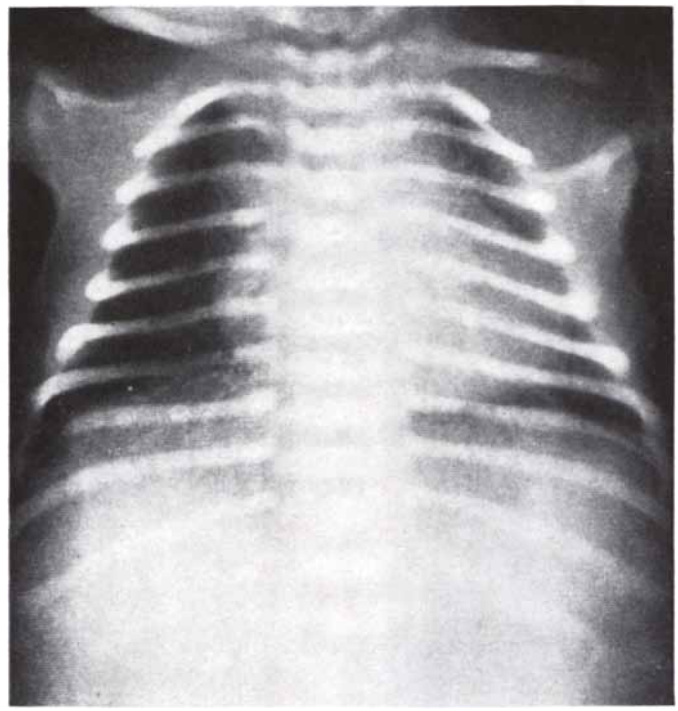
We are now in a position to understand a little better what occurs when a baby takes its first breath. Let us follow the event as the Swedish workers have recorded it by sequences of X-ray pictures made at rapid intervals [*see illustrations at top of these two pages*].

At the outset the baby's chest has a shape rather more like that of a cone than that of a cylinder, with its ribs lowered like the ribs of an incompletely opened umbrella. As the breathing movement begins the chest narrows slightly in transverse diameter, perhaps because of the creation of negative pressure within. The force comes from the contraction of the diaphragm: it flattens, descends and thereby expands the chest volume. Air begins to enter the pharynx. A third of a second later a considerable amount of air has reached the lungs. When they have received all the air that can be forced in by the baby's first inspiration, the diaphragm begins to rise



STEADY RESPIRATION is shown in this tracing of first seven breaths of "Baby A." The horizontal axis represents a span of 30 seconds. Pressure is measured on the vertical axis at left (*black*) and is given in centimeters of water; zero equals atmospheric pressure. The vertical axis at right (*color*) indicates volume of intake in milliliters. Six rhythmic breaths follow the first.





bottom of left. Diaphragm rises in the process of expiration. Third photograph shows rib cage taking on a more cylindrical shape.

Last of this series, prepared by John Lind of the University of Stockholm, shows lungs retaining residual air after first breath.

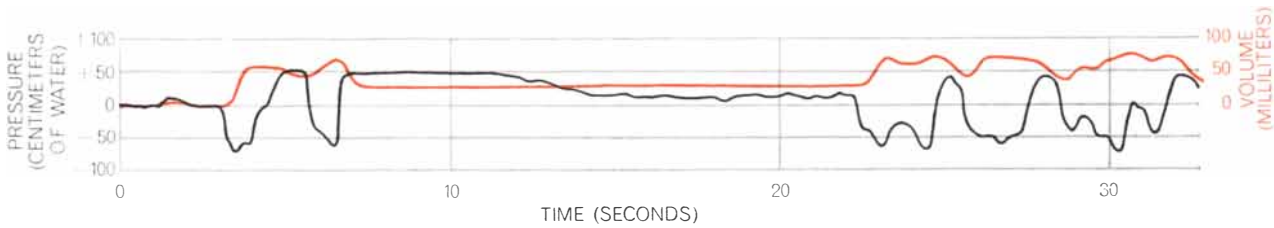
and expel the breath. The pictures show, however, that at the end point of expiration the lungs still contain a large amount of air.

The infant has already begun, with its first breath, to build the highly advantageous reservoir of air in the lungs that is called the "functional residual capacity." Never again will it be obliged to draw air into a closed and resisting space or to do the other special work required of the first breath. After this first installment the infant adds to the residual air with succeeding breaths until it has accumulated a reservoir that nourishes the blood comfortably between breaths. Without this air, eating, drinking, talking and other essential activities would be severely limited by the necessity of continuous breathing.

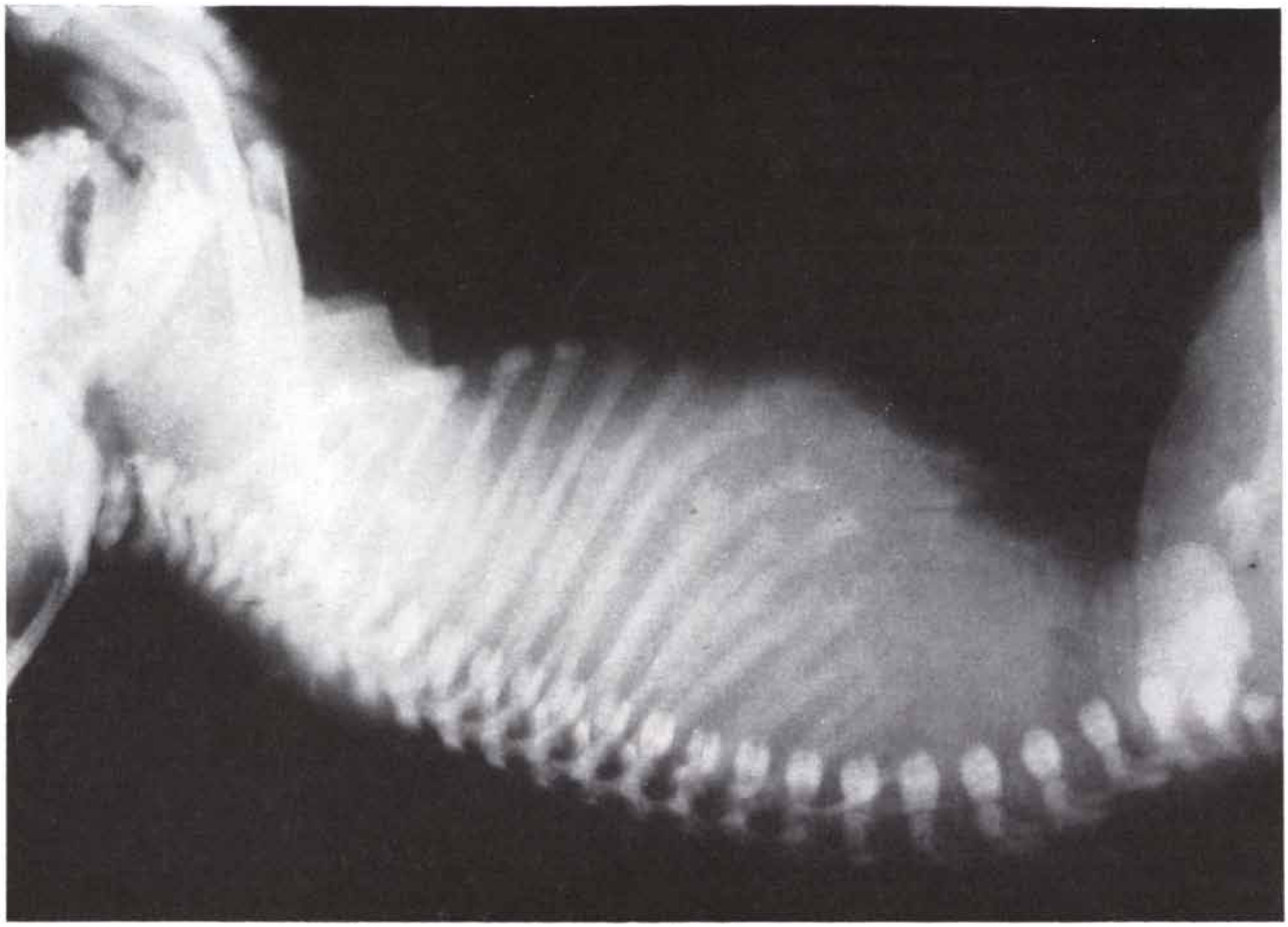
The X-ray photographs indicate that the most important movement in the process of drawing breath is the lowering of the diaphragm, although some upward expansion of the chest by elevation of the ribs may assist in enlarging the thorax. Other pictures studied by the Swedish workers suggest that the tongue and throat may also contribute to the intake of air by a swallowing or "engulfing" action, similar to the "frog-breathing" process by which a patient paralyzed by poliomyelitis learns to push air into the lungs.

X rays cannot tell us anything about the quantitative aspects of the first breath: how much force is required, how much air is moved and so on. Such measurements have been obtained, however, by various ingenious methods. Karlberg has been particularly active and successful in these studies of newborn babies. Indeed, in some cases he was able to begin his measurements of air volume and pressure changes while the baby's chest was being squeezed through the birth canal!

Two items of information are needed: (1) the amount of air moved into the lungs by the breath and (2) the amount of force that is required to draw in this volume of air. The first quantity can be measured in several ways. The most familiar is the one used in the basal metabolism test: the subject breathes through a mask or nosepiece connected to a delicately balanced reservoir of air, and the volume of his indrawn breath is measured by the fall in volume of the air in the reservoir. However careful the balance, the system involves resistance; hence in Karlberg's studies the infants were allowed to breathe through a mask and a large rigid tube into a sealed chamber. A delicate strain gauge measured



UNSTEADY RESPIRATION is exemplified in the pattern made by "Baby B." A long pause of some 15 seconds followed the infant's first two breaths, during which time pressure gradually decreased. The fact that the volume of air in the lungs remained constant during this pause suggests that intrathoracic pressure can alter without causing a change in the amount of air held in the lungs.

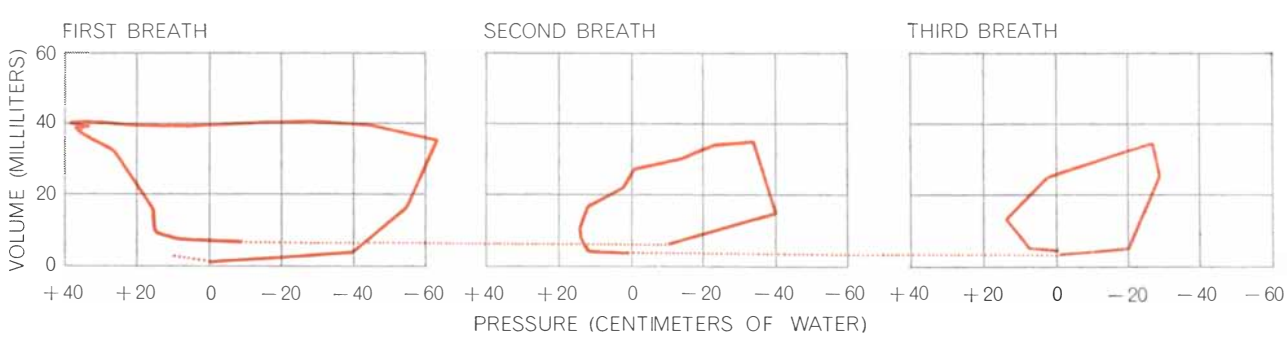


BEFORE FIRST BREATH there is no air in the respiratory system. This chest X ray, made laterally, shows the lungs to be filled with an opaque substance. Some air can be observed beneath the roof of the infant's mouth, but none has entered into the pharynx.

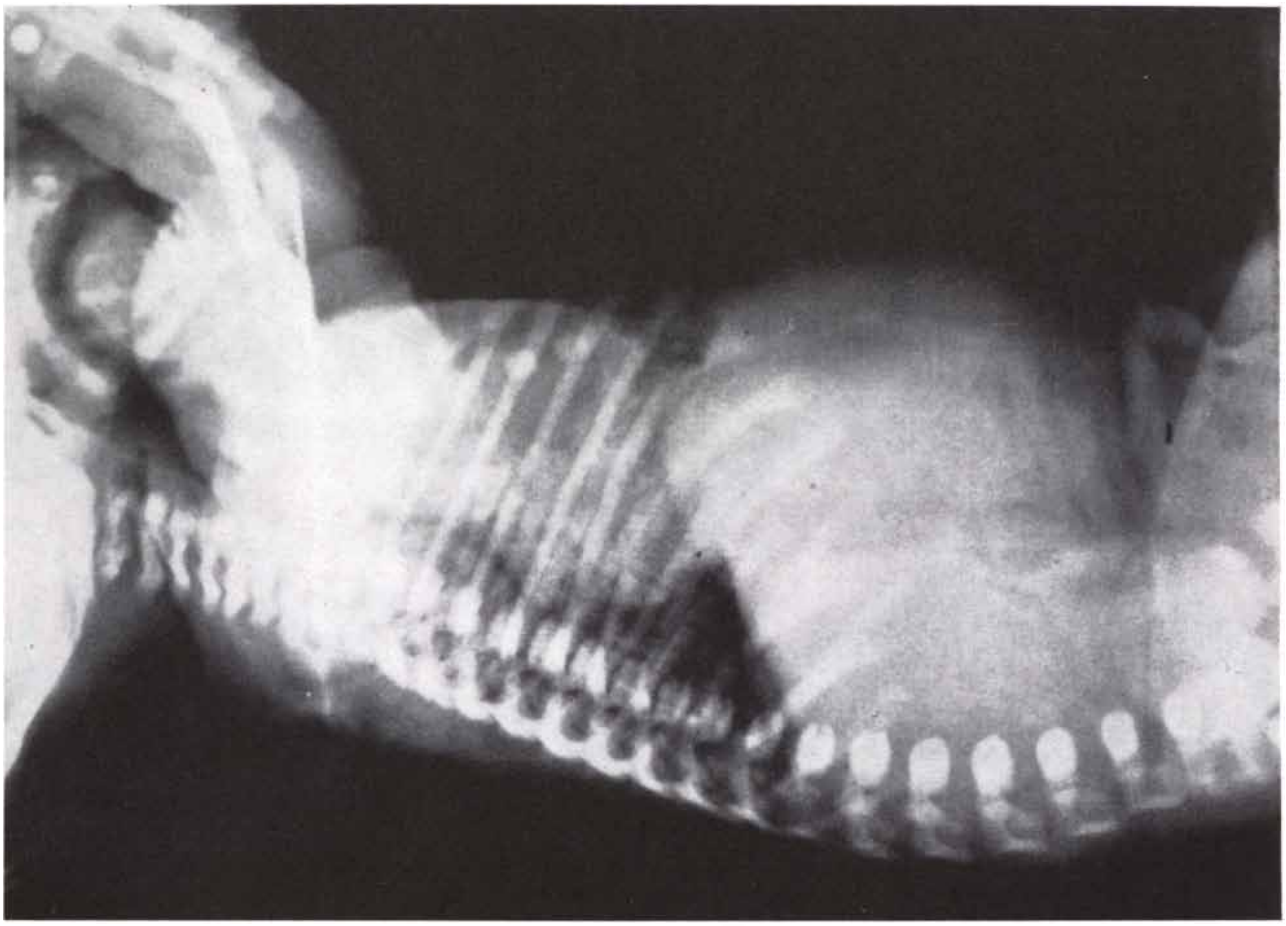
the slight drop in pressure in the chamber when the baby took a breath; this change in pressure was accurately translated into the volume of the breath.

The second quantity—the amount of force applied to draw the breath—is indicated by the change of pressure in the pleural spaces of the lungs. This is usually inaccessible to direct measurement, because one cannot get into the pleural space except by inserting a hollow needle through the chest wall. But the pressure in the esophagus is a reasonable index of the pressure in the nearby pleural space, and the esophageal pressure can readily be measured by means of a water-filled catheter, or thin tube, introduced into the passage. This can be done without much discomfort to the infant; indeed, premature babies are on many occasions fed through such a tube.

Before we consider Karlberg's records of babies' first breaths let us first note, as standards for comparison, the measurements of normal breathing. During the first week after birth the volume of the breath of a normal baby at rest (the "tidal volume") is usually between 15 and 30 milliliters (roughly one to two cubic inches). This is considerably less



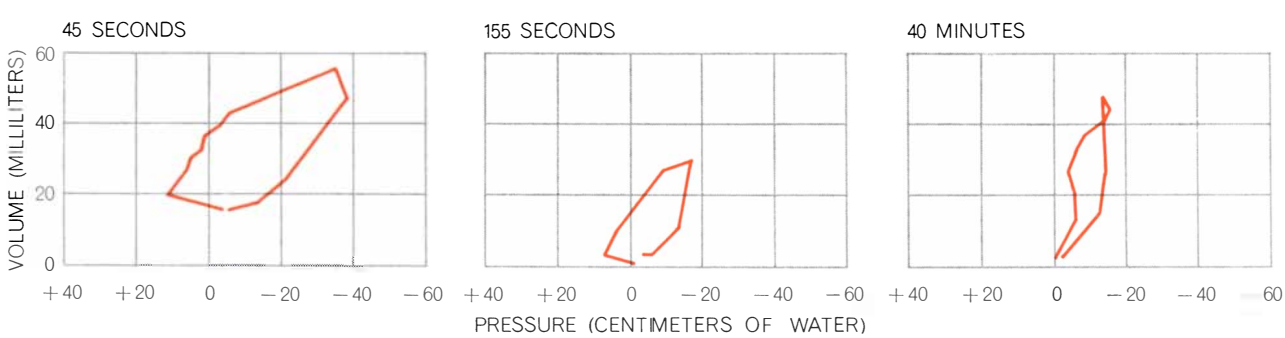
INSPIRATORY EFFORT is traced by plotting negative pressure required to open the lungs (*horizontal axis*) against the volume of air intake (*vertical axis*). Pressure is given in centimeters of water. The base line represents the pressure of one atmosphere. The infant whose respiration is traced here, Baby A, breathed 33 seconds after birth and had to exert — 60 centimeters of pressure to achieve an intake just below 40 milliliters. The second intake, a smaller one, required — 40 centimeters. The third required — 25.



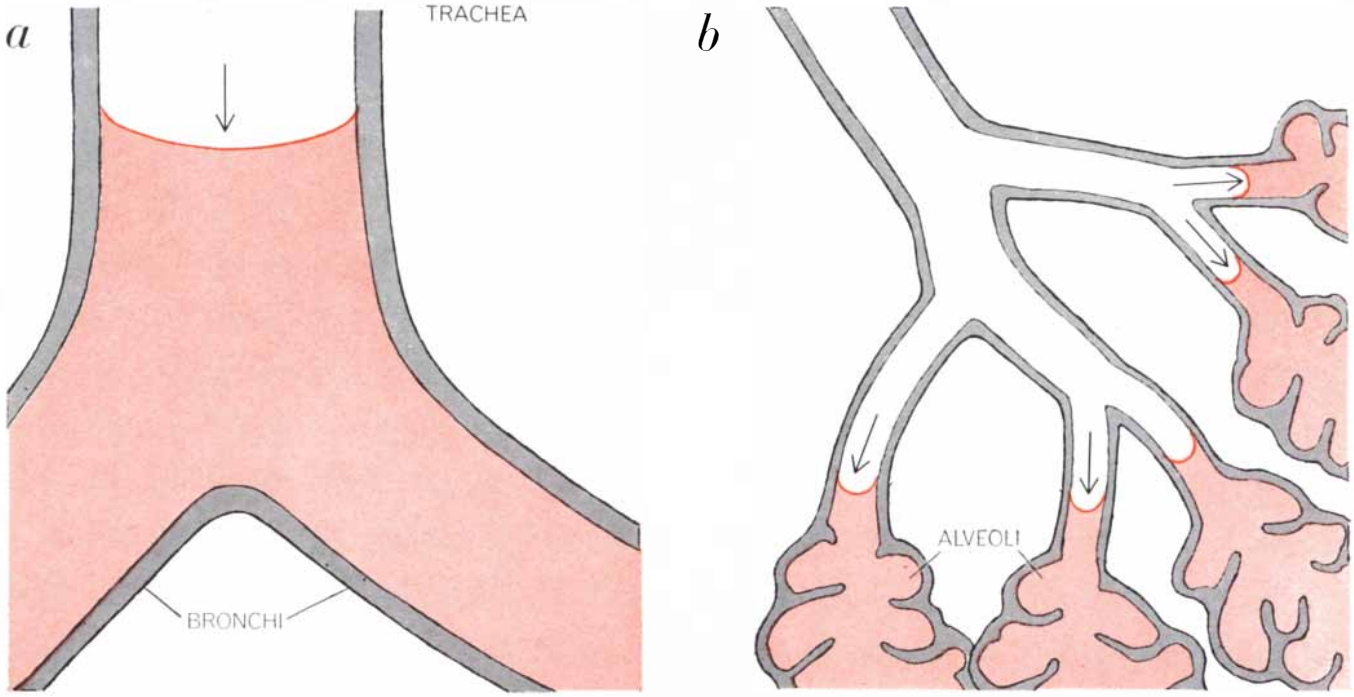
FIRST BREATH is taking place in this photograph, made one-third of a second later. The course of the trachea is obscured but air can be seen entering the lungs via the two main bronchi. During expiration lungs will not empty to their original state.

than the volume of a prolonged cry, which in turn may approach what is called the "vital capacity." A violently crying infant may inhale in one breath as much as 150 milliliters of air (nearly 10 cubic inches). As for force, the amount required once respiration is established is very small: the pressure difference in the esophagus between the beginning and end of a breath in the quiet breathing of a normal baby a few days old is only four to five centimeters of water pressure.

Here, then, are the measurements of the first breaths of two normal babies as recorded by Karlberg [*see illustrations at bottom of pages 30 and 31*]. "Baby A" drew its first breath about half a minute after delivery, and the volume of the breath was 30 milliliters. The esophageal pressure dropped from the base line (set at zero) to a negative, or less than atmospheric, pressure measured as − 60 centimeters of water. This represents the force exerted by the baby in taking its first breath. After the breath was drawn in the pressure began to rise. At first there was no change in the volume of air in the lungs, which indicates that the baby closed its glottis and thereby cut off



EASIER BREATHING of a normal infant is illustrated by these tracings of Baby A's subsequent breaths. First loop shown here was traced 45 seconds after birth. It signifies that pressure of − 40 centimeters was necessary for an intake of about 40 milliliters. The next tracing, made after two minutes 35 seconds, reveals − 15 centimeters of pressure sufficing for a breath of 30 milliliters. The last loop, made 40 minutes after birth, shows that by then − 15 centimeters of pressure could cause a 50-milliliter intake.

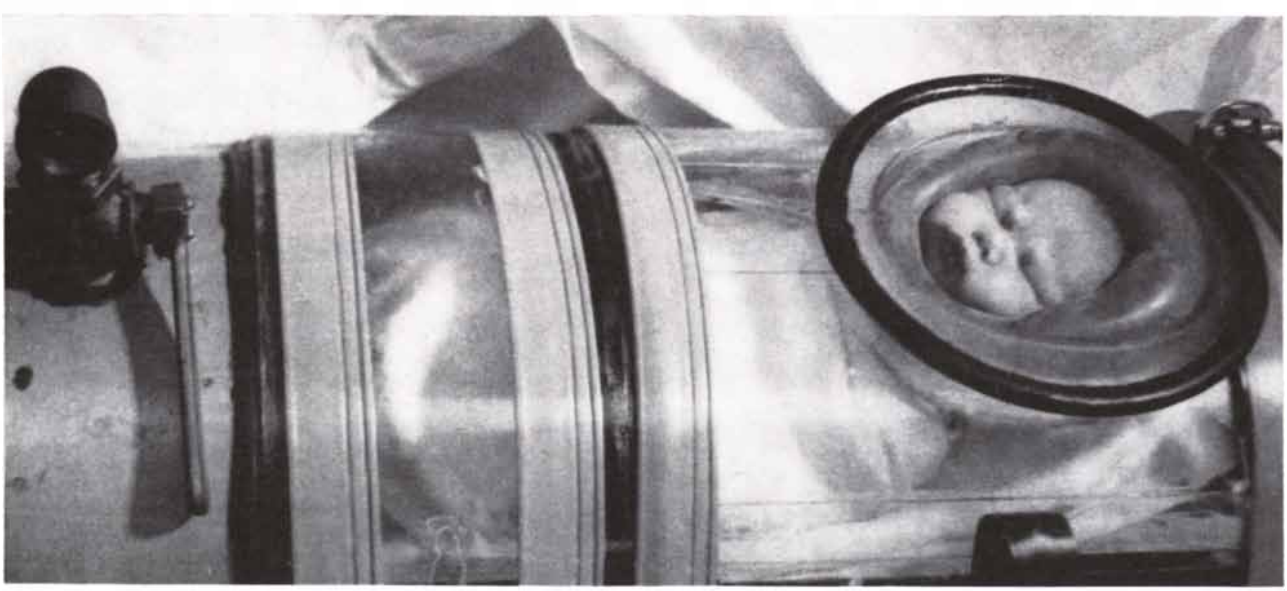


FOUR MAJOR OBSTACLES confront the infant attempting to draw air into organs previously occupied by amniotic fluid. Viscosity of the fluid is shown (*a*) offering resistance as air enters the bronchi. Surface tension causes rounding (*b*) at interface of advancing air and residual fluid. Since surface tension varies inversely with curvature, it is strongest in small airways. Serial

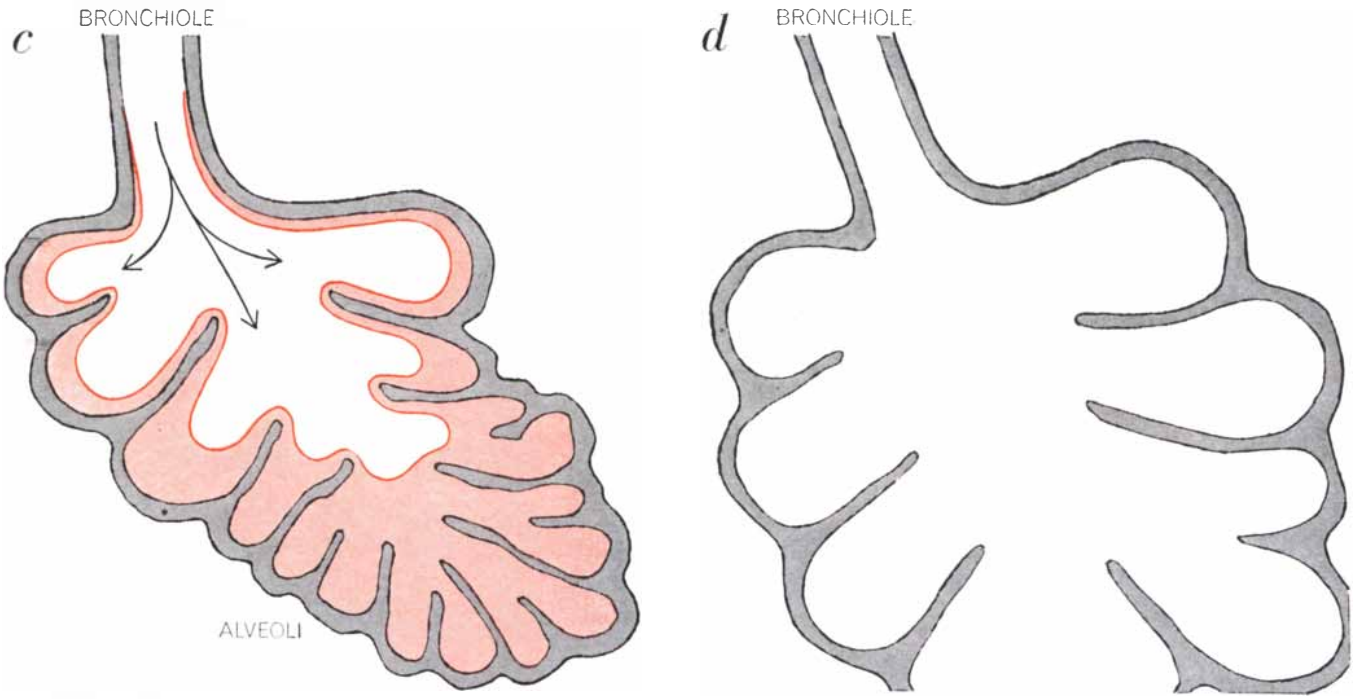
the escape of air from the trachea. The infant then let its breath go, and the esophageal pressure fell back toward a negative value again. The tracing of this cycle shows that the volume of air in the lungs never returned to zero after the first breath, and the residual reservoir rose with each breath during the 30-second time span of this record. Rhythmic breathing followed, and the tracings of subsequent breaths show the increasing efficiency of the inspiratory efforts.

"Baby B," although also normal, had a more irregular beginning. The pressure drop for the first breath was about 70 centimeters of water. This first breath amounted to some 60 milliliters, and so did the second. Then followed a comparatively long pause of some 15 seconds, during which the positive pressure in the esophagus relaxed very gradually. After this the infant resumed breathing with four fairly rhythmic respirations. By the end of the 30-second record it had built up its lungs' residual capacity to 50 milliliters or more.

Examining these records, one is struck immediately by the considerable amount of force, measured as a pressure



PLETHYSMOGRAPH measures an infant's respiration indirectly but accurately. The baby is placed in a chamber with its face outside, as shown here. The amount of air entering and leaving its lungs is indicated by the volume displaced within the chamber.

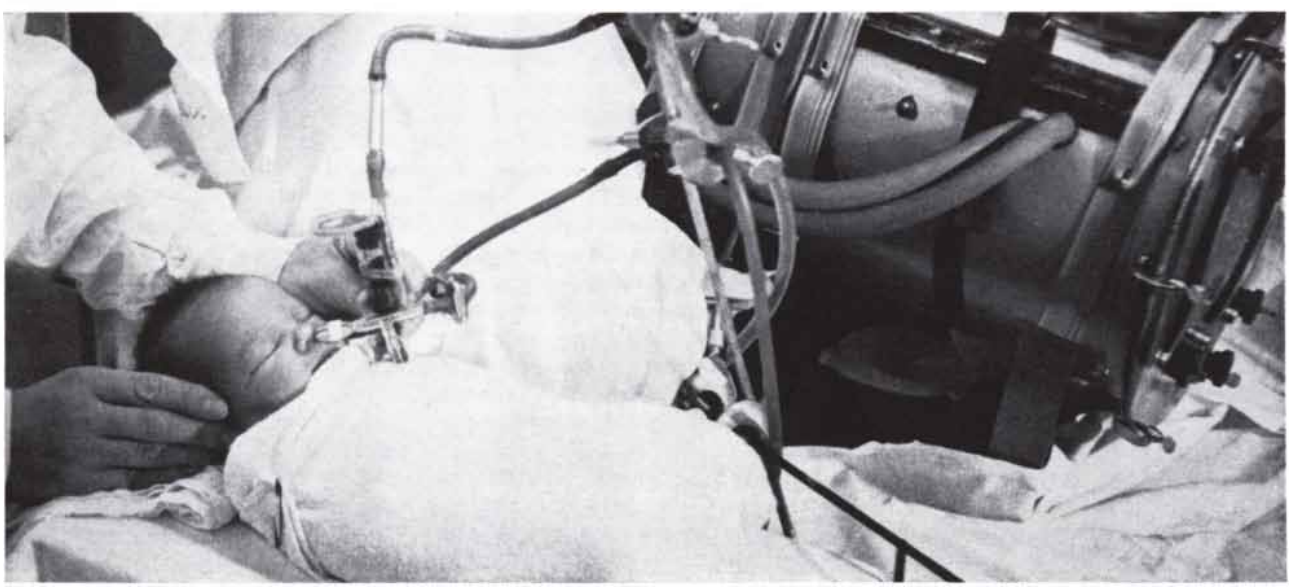


opening of the air spaces is effected (*c*) by an alveolar secretion that reduces surface tension, preventing smaller sacs from emptying their air into larger ones. Expansion of tissue (*d*) must be achieved throughout the lungs. This section of alveoli after the first breath, drawn to same scale as *c*, indicates the extent of physical stretching necessary to accommodate the incoming air.

change, that is available to a normal infant for drawing its first breath. It would appear from other evidence that many infants may require for the first breath a force equivalent to a pressure drop of only 20 to 30 centimeters of water. But obviously the normal baby's powers are considerably greater than that. The explanation lies, of course, in the possibility of circumstances that may call for an extraordinary effort. Certainly Karlberg's records show that some infants require a pressure change of 40 centimeters of water or even more to inflate the lungs with the first breath [*see bottom illustration on page 32*].

Investigations such as those reviewed in this article have added a great deal to our understanding of a newborn baby's first drawing of breath. But no matter how thoroughly the event is studied, some element of mystery remains. We are left with the feeling that was described by Robert Frost in his account of another familiar phenomenon of nature, the sudden thawing of snow on a sunny hillside:

As often as I've seen it done before,
I can't pretend to tell the way it's done.



ALTERNATE METHOD of gauging air intake and pressure change is shown in this photograph, made by the author, of a baby whose respiratory system has been connected to a delicately balanced reservoir of air (*in the chamber at right*) by means of tubing.

The Conservation Laws of Physics

Modern physics rests largely on classical laws of the constancy of such quantities as electric charge. The extension of physics into new realms, however, requires that these laws be re-examined

by Gerald Feinberg and Maurice Goldhaber

The philosopher Heraclitus taught that nothing is eternal; everything is continually in flux. There can be no doubt that over a period of time the objects around us do change in such respects as form and position. How these changes occur is described by certain of the laws of physics. The human mind, however, has always sought to find underlying the changes properties of physical objects that do not change. In the development of physics this search has been profoundly rewarded by the discovery of conservation laws. A conservation law states that the value of some quantity, such as energy or electric charge, does not change with time. The name suggests that although the form in which the quantity appears may vary, some essence is preserved.

The physicist's confidence in the conservation principles rests on long and thoroughgoing experience. The conservation of energy, of momentum and of electric charge have been found to hold, within the limits of accuracy of measurement, in every case that has been studied. An elaborate structure of physical theory has been built on these fundamental concepts, and its predictions have been confirmed without fail. Consequently there has been a tendency to forget that the basis of the conservation laws is, after all, empirical, and that there is always the possibility they may break down when they are extended into a new realm of physical phenomena.

Such a breakdown has come not once but several times in recent explorations of the elementary particles of matter. It turns out that the particles have some properties that are conserved only approximately; that is, the conservation "laws" for these properties hold on one time scale but break down on a longer time scale.

The "natural" period for interactions of elementary particles is about 10^{-23} second. This is the time scale for the "strong" interactions that involve pions (pi mesons) and nucleons (protons or neutrons) and are responsible for the forces between particles in the nucleus of the atom. There is another class of particle processes called weak interactions, of which the best known is beta-decay (radioactive decay involving emission of an electron and a neutrino). The "weak" processes take at least 10^{-10} second to occur, which is obviously much longer than the period of the strong interactions.

One conservation law that was found to break down was the conservation of "strangeness," a property associated with the so-called strange particles, such as the lambda, the sigma and the K. It was found that the total strangeness, obtained by adding the strangeness of the individual particles, does not change in strong interactions but need not be conserved in weak interactions [see "Elementary Particles," by Murray Gell-Mann and E. P. Rosenbaum; SCIENTIFIC AMERICAN, July, 1957].

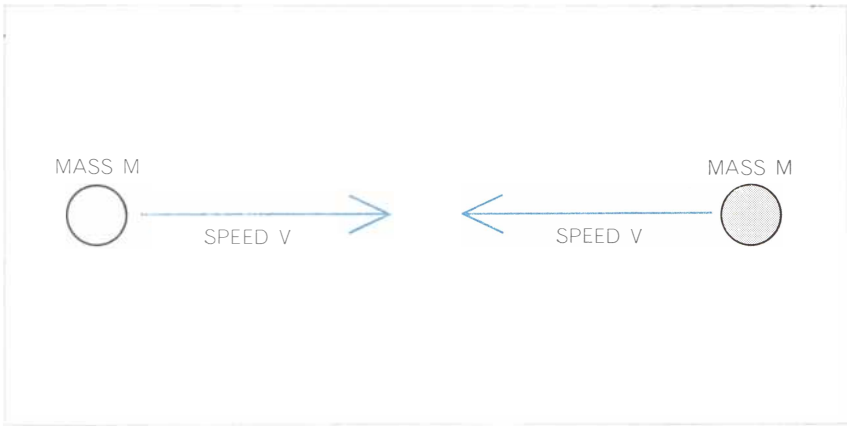
This failure of a conservation law was disconcerting but did not surprise physicists very much, because the discovery of the exceptions came at the same time as the discovery of the law itself. Soon afterward, however, physicists were startled by the breakdown of a conservation law that had been honored for some time.

The event was the collapse of the conservation of parity, brought to light as the result of questions raised in 1956 by T. D. Lee and C. N. Yang. Again it was a case of a conservation law that had passed all its tests in one domain (strong interactions) but failed completely in another (weak interactions). This time physicists were stirred to profound questioning of some of their basic assumptions. Among other things, the parity failure served as a salutary reminder that no scientific belief, not even a well-established conservation law, can be taken for granted in areas where it has not been tested. The reminder has inspired many physicists to rigorous testing of the conservation laws, old and new, in the domain of particle physics. This article is a discussion of these recent tests.

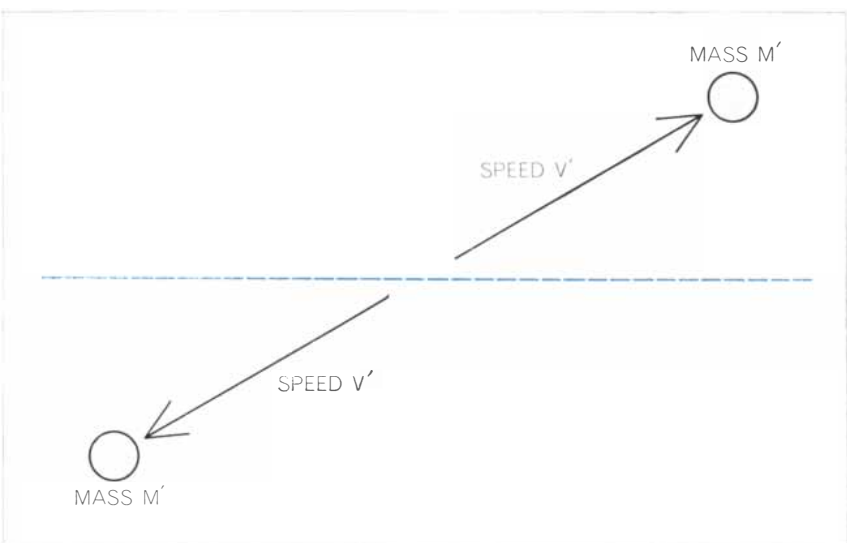
In order to test a conservation law it is in principle necessary only to measure the conserved quantity at two different times. For several reasons the elementary particles lend themselves to more precise tests of conservation laws than do bodies of ordinary or of astronomical size. To begin with, the system to be studied must be isolated—free from any outside addition to or subtraction from the quantity whose conservation is being measured. It is not easy to isolate a large-scale body from all external influences; for example, the earth is bombarded by charged particles and is subject to the gravitational force of other celestial bodies. A system of elementary particles, on the other hand, can be isolated much more easily; it often isolates itself by the very rapidity of its interactions, because they take place much faster than any effect from its surroundings. Second, any violation of a conservation law is more likely to show up in the fundamental particles than in a large body, where the presence of a mixture of many atoms may mask slight discrepancies. Third, by making precise measurements of particle reactions it is often possible to say quantitatively how well we know that the conservation laws are satisfied.

Let us start with tests of the conser-

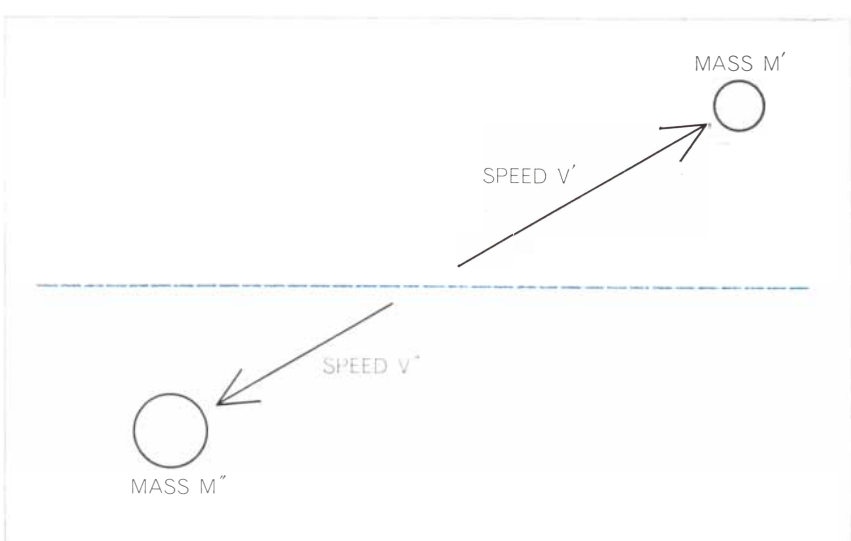
NEW PARTICLE, the anti-xi-zero, was recently discovered when the events shown in the bubble-chamber photograph at left seemed to violate the law of conservation of momentum. The events are outlined in the map at right: track of an antiproton ($\bar{p}$) is shown emerging at bottom of the photograph. It branches after collision with a proton gives rise to a xi-minus (Ξ^-), a positive pion (π^+) and the anti-xi-zero ($\bar{\Xi}^0$). Existence of the anti-xi-zero, which leaves no track, was inferred when physicists analyzed subsequent decay products at upper left: a neutral pion (π^0) and an anti-lambda-zero ($\bar{\lambda}^0$) that decays to an antiproton and a positive pion.



BEFORE COLLISION of fundamental particles of equal mass (M) and speed (V) moving in opposite directions, total momentum is zero. Length of arrows is proportional to speeds.



AFTER COLLISION of particles, masses, speeds and line of motion may have changed but particles rebound in opposite directions. Original line of motion is drawn in color.



UNEQUAL MASS of emerging particles (M' *and* M'') determines unequal speeds of rebound (V' *and* V''). For slow particles ratio of speeds varies inversely with that of masses.

vation of momentum—ordinary momentum in a straight line, not angular momentum. The most convenient experiment for this purpose is a collision (that is, an interaction) of two particles. The law of conservation of momentum states that the total momentum of the two particles will be precisely the same after the collision as it was before they collided.

Consider a head-on collision between two particles that are equal in mass and traveling at equal speeds. The momentum of each particle is its mass multiplied by its velocity. The two momenta are therefore equal, but since they have opposite directions the total momentum of the two particles is zero [*see top illustration at left*]. If the conservation law holds, the total momentum *after* the collision must also be zero, and the two particles must rebound with equal and opposite momenta. They may fly off at angles to their original line of motion, but this does not matter as long as their momenta are equal and opposite. The collision may transform one or both of the particles; again conservation of momentum is not violated as long as the mass times velocity of one equals the mass times velocity of the other.

This is the content of the law of conservation of momentum. But the principle does not tell us anything about the speed of the individual particles after collision compared with its value before collision. For example, it would be possible for the original particles to come out moving much faster than they had come in without violating the law of conservation of momentum. But this does not happen because of an even more famous law: the law of conservation of energy.

In order to describe elementary-particle reactions in which the particle masses can change, it is necessary to use the conservation of energy in its modern form, which includes in the total energy the "rest-energy" of the particles. This rest-energy is given by the celebrated equation of Einstein $E = mc^2$: E is the rest-energy, m the rest-mass of the particle and c^2 the square of the speed of light. Different particles will in general have different rest-masses and hence different rest-energies. The total energy of a particle is the sum of this rest-energy and the kinetic energy of motion, which is a positive quantity also proportional to the rest-mass and which increases as the particle speed increases. For slow speeds the kinetic energy is proportional to the square of the particle's speed. As

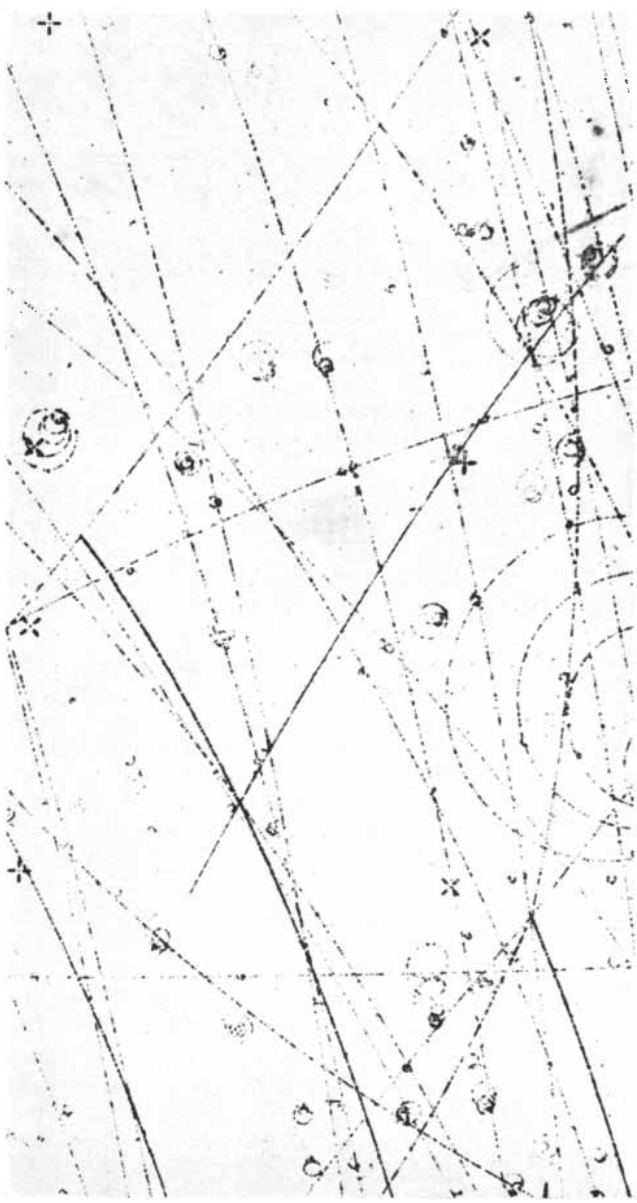
the speed approaches the speed of light, the mass increases and the formula for the energy is changed.

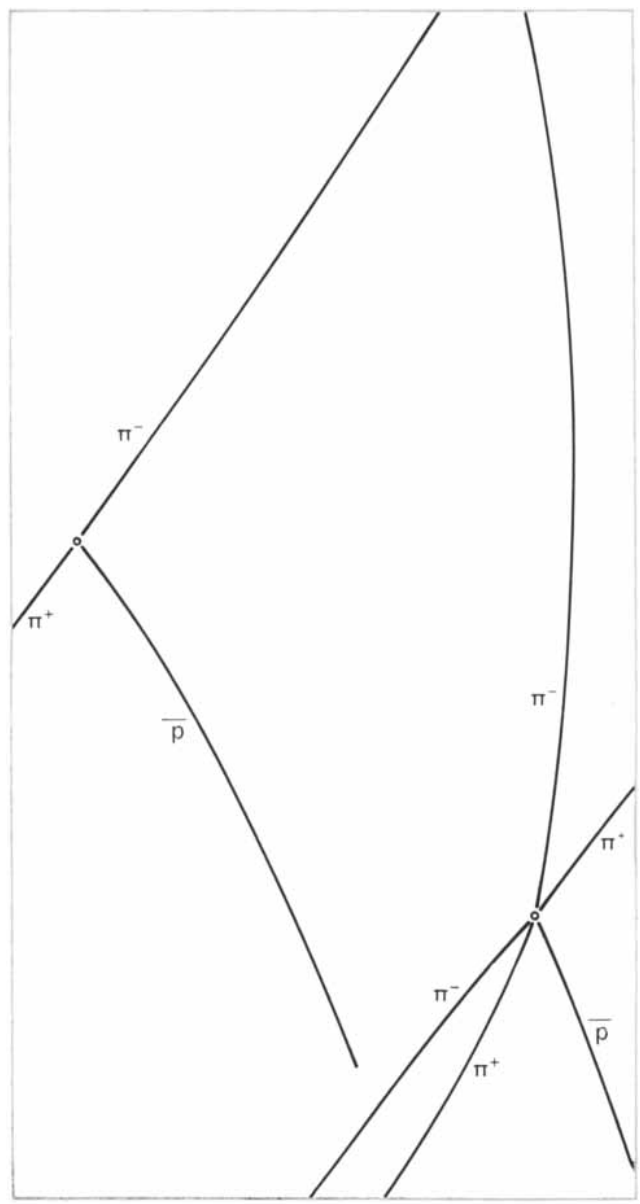
The law of conservation of energy then asserts that in any particle interaction the total energy of all the particles does not change. There are several predictions of the combined laws of energy and momentum conservation. If in a collision between particles of equal and opposite momentum the kind of particle is unchanged by the interaction, then the speeds should also be unchanged. If the particles are transformed into other particles with different masses, then the speeds of these emerging particles must differ from those of the original ones in a definite way.

Thousands of laboratory experiments, performed in different ways and measuring all the quantities involved, have confirmed that the laws of conservation of energy and of momentum do hold true in the domain of elementary particles. They have verified the formula that expresses the energy equivalent of the rest-mass. And some of the experiments have borne out the laws with a high degree of confidence in the accuracy of the results.

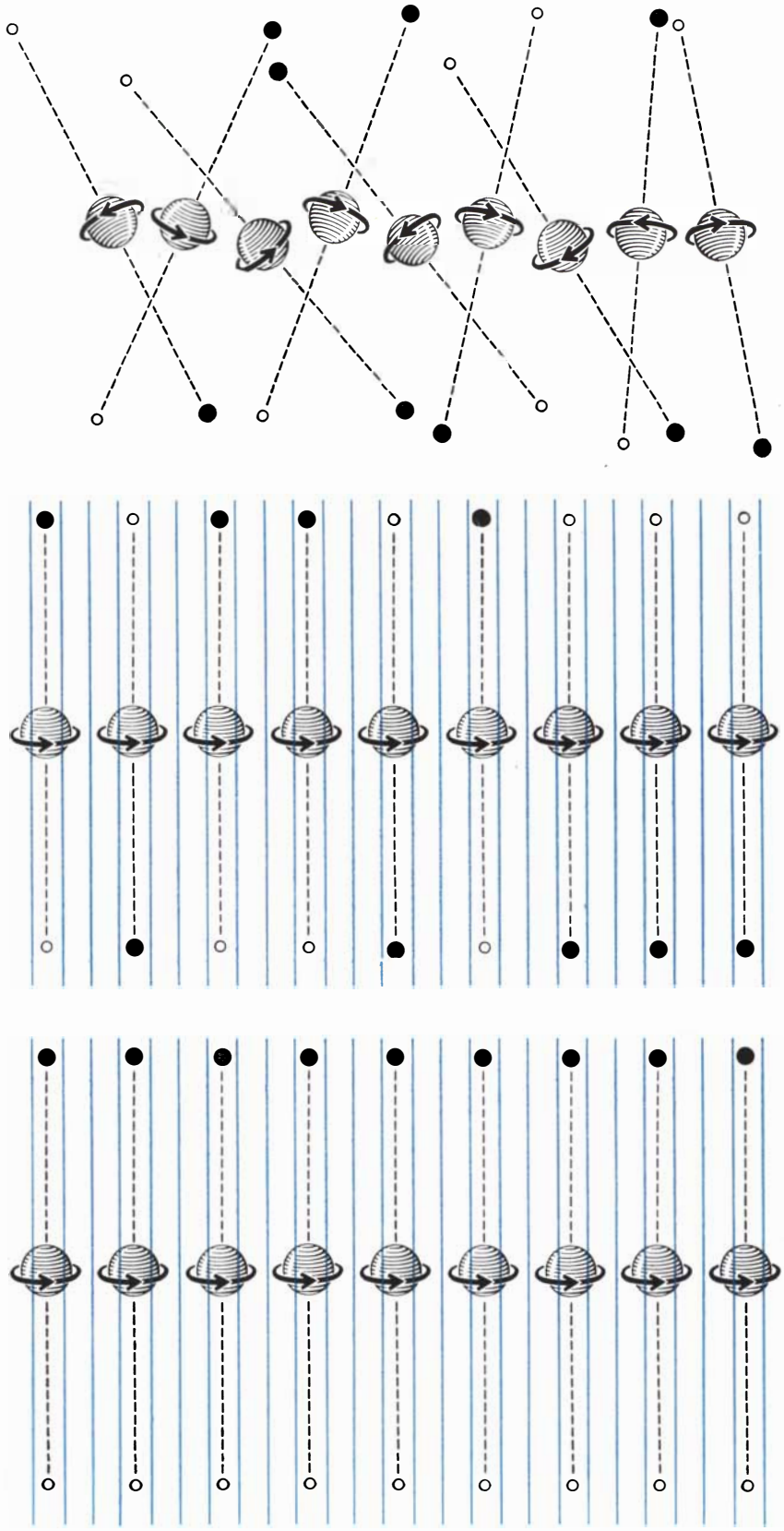
The situation is neatly illustrated by collisions between particles and their antiparticles. In such an encounter the particle and antiparticle annihilate each other and are transformed into photons or other particles that emerge with high energy. A meeting of an electron and its antiparticle the positron, for example, gives rise in less than 10^{-10} second to two highly energetic photons, or gamma rays. When a proton and an antiproton meet, they produce a burst of pions and other particles.

In these annihilations the particle (electron or proton) is essentially at rest, and the antiparticle is often slowed almost to rest by electrical interaction of





ANNIHILATION of a proton-antiproton pair is illustrated twice in this bubble-chamber photograph made by Jack Steinberger of Columbia University and in the map at right. Path of antiproton ($\bar{p}$) is traced to point at which it stops and collides with a proton at rest. Conservation of momentum can be confirmed by analyzing tracks of the pions (π^+ *and* π^-) emerging from point of collision.



PARITY EXPERIMENT is shown in generalized form. The spinning balls at top represent radioactive nuclei in a film of cobalt 60. In decaying they emit a beta particle (*black dot*) and a neutrino (*white dot*). Below is a hypothetical view of this decay if nuclei were placed in a magnetic field (*vertical lines*); conservation of parity implied that particles would be emitted in a direction independent of spin (*arrows*). But in the experiment suggested by C. N. Yang and T. D. Lee, when cobalt 60 was placed in a magnetic field, the direction in which beta particles were emitted proved to be a function of spin, as shown at bottom.

the atoms in the surrounding matter. Consequently the total momentum of the particle-antiparticle system is close to zero. The conservation of momentum then implies that the total momentum of the particles emerging must add up to zero. The rest-energy of the particle and antiparticle is converted into the total energy—kinetic energy plus rest-energy—of the products. A measurement of this energy should then agree with the original rest-energy.

In general the results of such experiments confirm the conservation of energy and momentum. But the accuracy of the measurements is limited. In the case of the electron-positron interaction the electron is never completely at rest, so that it is difficult to determine precisely if the electron and positron have a total momentum of zero when they collide. In the case of the proton-antiproton interaction the momenta of the pions emerging from the collision cannot be measured with an accuracy much better than one part in 1,000. All in all the accuracy of the measurements in the annihilation experiments is limited to the order of one part in 1,000 or one part in 10,000.

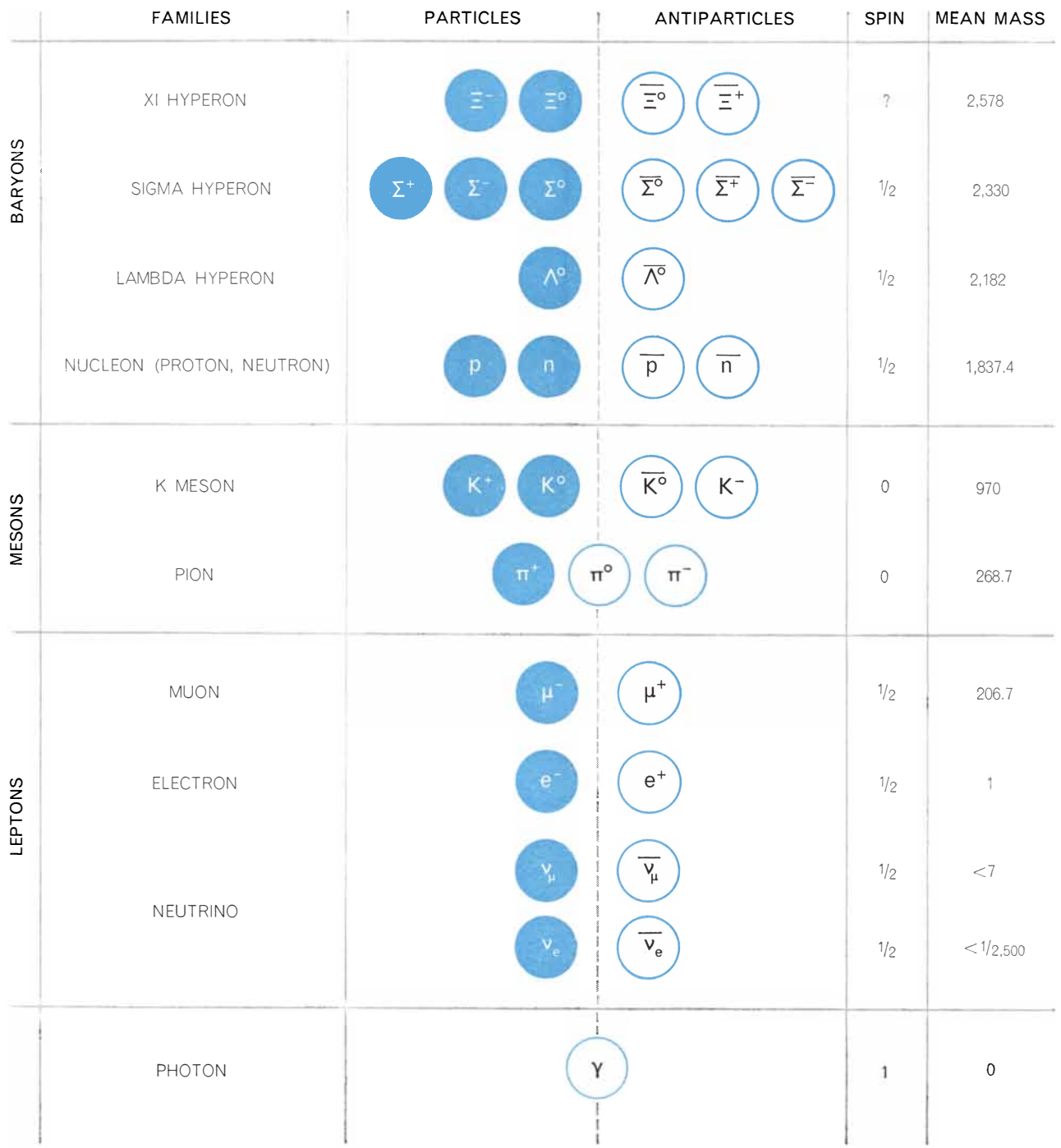
There is another type of experiment, however, in which the conservation of both energy and momentum has been checked to a far higher accuracy. This type of experiment has to do with the emission of gamma rays by "excited" nuclei. Is the total energy conserved when a nucleus emits a gamma ray? A very accurate means of determining this has been provided by the Mössbauer effect, for the discovery of which Rudolf Mössbauer was awarded a share of the 1961 Nobel prize in physics.

When a nucleus emits a gamma ray, the nucleus will normally recoil a bit to conserve momentum, just as a gun recoils when it fires a bullet. The total energy available must be shared between the photon and this recoil, so that the photon has a little less than the total energy. But suppose the nucleus is tightly bound in a crystal lattice, as it is in a metal. The inertia, or weight, of the crystal is so great compared with the photon's push that the bound nucleus does not recoil to any measurable degree. Hence the gamma ray gets essentially all the available energy and momentum.

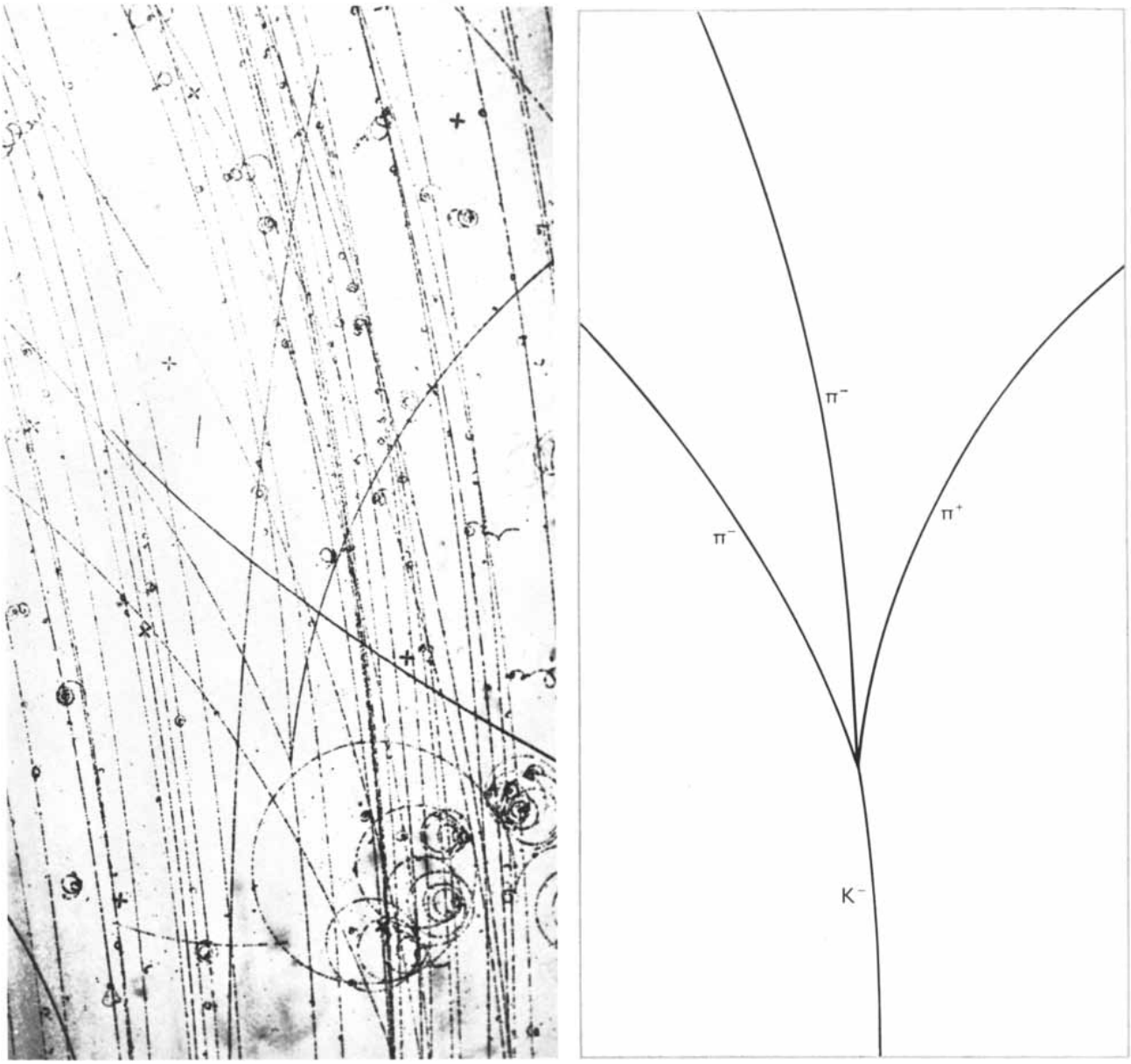
Mössbauer pointed out that such a gamma ray, with unchanged energy, should readily be reabsorbed by a nucleus of the same kind as the one that emitted it. This "resonance absorption" turned out, indeed, to be an extremely sensitive and accurate measure of the

energy of gamma rays. It is so accurate that by using the Mössbauer effect R. V. Pound and Glen A. Rebka of Harvard University were able to measure the very slight changes in a photon's energy that are produced by differences in the earth's gravitational field, thereby confirming a prediction of Einstein's general theory of relativity.

The Mössbauer effect itself is a striking confirmation of the conservation of energy. When the crystal-bound nucleus of an atom of the isotope iron 57, for example, emits a gamma ray photon, the photon can be absorbed by an iron-57 nucleus in another crystal. This means that the photon's frequency (that is, energy) must be in resonance with the frequency of the vibrations of the iron-57 nucleus, which in turn means that it must match the frequency with an accuracy of about one part in 10^{15}! That is a truly remarkable demonstration that the photon lost no energy and that energy is conserved in gamma ray emission. By the same token it also confirms the conservation of momentum; the special theory of relativity states that a photon, although weightless, has a momentum that is proportional to its energy (the momentum is equal to the particle's energy divided by the velocity of light). If the photon's energy remains un-



FUNDAMENTAL PARTICLES are classified symmetrically in this table in order of mass. Mean mass represents a particle's mass divided by the mass of an electron, taken as one. The spin indicates number of possible configurations that particle could occupy if considered at rest. Most recent addition to table, the anti-xi-zero ($\bar{\Xi}^0$), was traced by a matter-antimatter annihilation.



DECAY IN FLIGHT of K-minus particle is shown in bubble-chamber photograph made at the Brookhaven National Laboratory and in the accompanying map at right. The track of the K-minus can be seen giving rise to two negative pions (*branching to left*) and a positive pion (*branching to right*). By measuring curvature of tracks the physicist can determine if momentum is conserved.

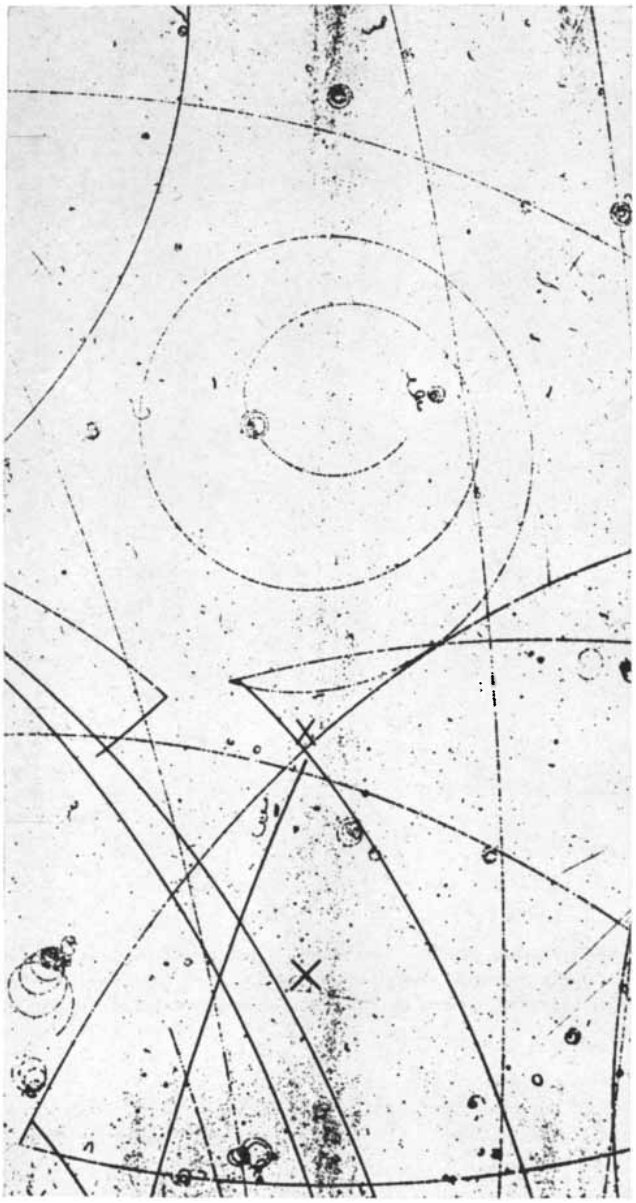
changed, its momentum must be unchanged. It is clear that the laws of conservation of energy and momentum, introduced by Christiaan Huyghens, Daniel Bernoulli and Isaac Newton in the 17th century to describe collisions between macroscopic bodies, also apply with remarkable accuracy to the collisions and interactions of subatomic particles.

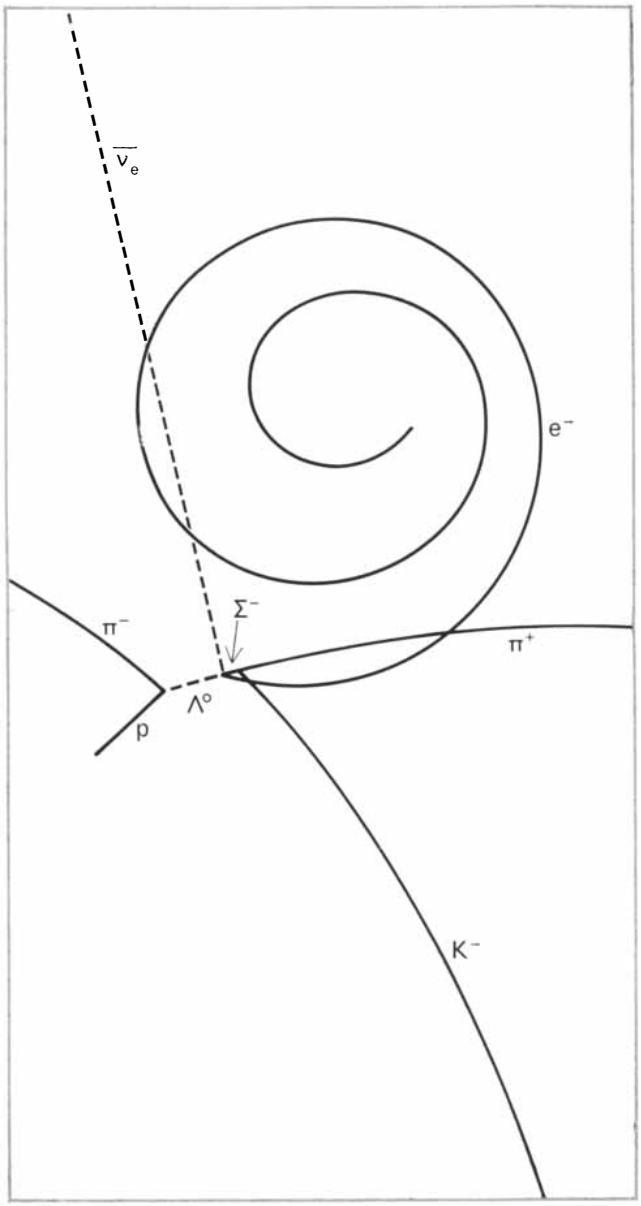
One useful aspect of the conservation formulas is that they enable us to tell which particle transformations or decays are possible and which are forbidden. The total energy of the products of an interaction or a decay must be equal to the rest-energy plus kinetic energy of the original particle or particles; it cannot be more and it cannot be less. It was this inviolable rule of energy conservation that led to the discovery of the neutrino and certain other previously unsuspected particles.

Energy and momentum are not the exclusive criteria of whether or not a given reaction can occur. For example, if we consider only the rest-mass of the electron, we can say that the electron could decay into a neutrino and a gamma ray without violating conservation of energy or momentum. But no such decay has ever been observed, and we believe it is actually forbidden by the law of conservation of electric charge.

This law was discovered in the 18th and 19th centuries by Benjamin Franklin and Michael Faraday. It was found then that electric charge occurs in two forms, positive and negative. The two kinds are never produced separately; they are always produced together and in equal amounts. Furthermore, the two cannot disappear separately, but equal amounts can combine to give neutral, or uncharged, matter.

In experiments with elementary particles a remarkable regularity of the





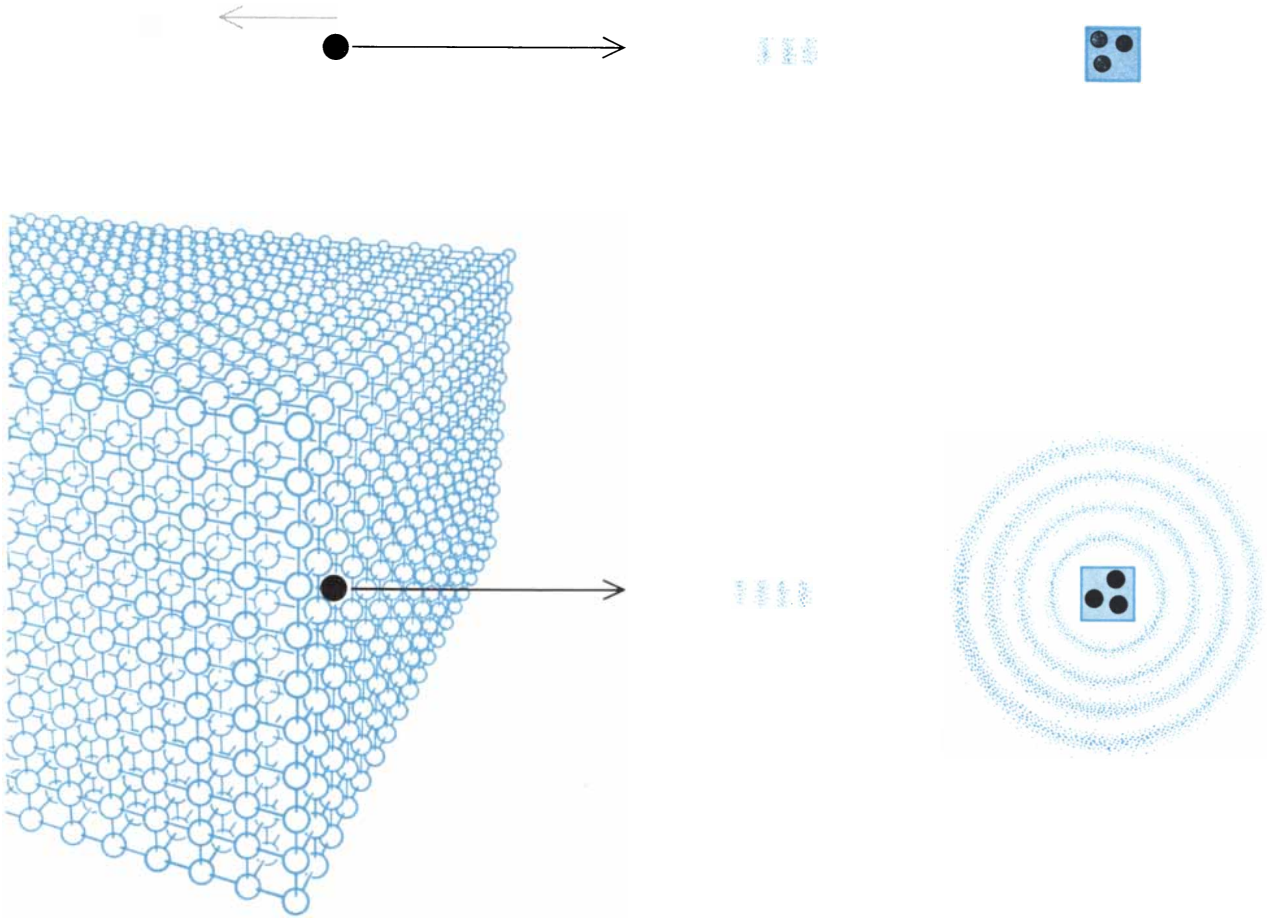
SIGMA-MINUS DECAY is shown in bubble-chamber photograph and map. A K-minus particle decays to a sigma-minus (Σ^-), whose brief track is indicated by arrow. It gives rise to electron (e^-) leaving spiral track, and a lambda-zero (λ^0) that decays further at left. Presence of antineutrino ($\overline{\nu}_e$) was inferred when angle made by electron and lambda-zero tracks violated conservation laws.

electric charges has been found. If the charge is expressed in units in which the electron has one unit of negative charge and the positron one unit of positive charge, then all known particles either have one unit of positive or negative charge or are neutral. It is not known why there should be no particles whose charge differs from this unit, but the equality of charges has been verified to one part in 10^{17}.

When applied to particle reactions, the law of conservation of charge states that the total electric charge at the beginning is equal to the total electric charge at the end. To find the total charge the algebraic sum must be taken; that is, a positive charge counts as one unit, a negative charge as minus one unit and the two together come to zero total charge. It is now easy to see why the law forbids the transformation of an electron into a neutrino and a gamma ray. The last are uncharged; therefore the conversion would call for disappearance of the electron's unit of charge, which is forbidden. If it decays at all, the electron must decay into a charged particle.

In view of this, the law of conservation of energy tells us that in fact an electron cannot decay. There are no known charged particles with a smaller rest-mass, or rest-energy, than that of the electron. Unless and until such a particle is found, one must rule out any possibility of a breakdown of the electron, assuming that the laws of conservation of energy and of charge are valid.

Electric charge is conserved in all the particle reactions we know about. This does not necessarily verify, however, that it never disappears under any circumstances. We would like to have some upper limit for the rate of reactions that would not conserve the electric charge. One such reaction would be the



MÖSSBAUER EFFECT eliminates the recoil of an excited nucleus (*dot at top left*) by anchoring it in a crystal lattice (*bottom left*) while it emits photons. Recoil lowers the frequency at which the nucleus emits photons (*top center*) and prevents resonance between the emitting and absorbing nuclei. Resonance (*indicated at bottom right*) occurs only if emission is at maximum frequency.

decay of an electron; hence an experiment to test the conservation of charge could consist of watching and waiting for an electron to disappear. An experiment of this type was performed a few years ago at the Brookhaven National Laboratory.

The rationale of the experiment was as follows. Consider an electron in the filled, innermost shell (the K shell) of an atom. Suppose the electron were to "decay" in some way. One of the electrons in an outer shell would then drop into the hole left in the K shell and in doing so would release energy in the form of an X ray. In the experiment the electrons under surveillance were in iodine atoms in a crystal of sodium iodide. In this crystal the emergence of even a single X ray could be detected. And since the crystal contains a very large number of atoms, the counter monitoring it was in effect watching an immense population for just one electron decay occurring sometime, somewhere in that vast sea of electrons.

The experiment was set up and the crystal was monitored for several months. On the basis of the number of K electrons in the crystal it was calculated that an electron does not decay—that is, lose its charge—in at least 10^{17} years. This is 10^{24} times longer than the average time for a weak interaction of comparable energy, such as a beta-decay. Therefore we can say that the law of conservation of charge is confirmed with an extremely high degree of probability.

There are still other conservation laws in the domain of particles. An example is the new law required to explain the stability of the particles in the nucleus. Consider the proton. None of the conservation laws we have discussed would prevent it from decaying into a positron and a gamma ray. In contrast to the electron, the proton is not the smallest known charged particle. There are several positively charged particles of smaller mass: the positron and various mesons. The proton could therefore break down without violating conservation of energy or of charge. Similarly, nothing in these conservation laws should forbid the neutron from decaying into a neutrino and one or more gamma rays.

Yet obviously these two particles, which make up the nuclei of atoms, do not decay, at least on any significant scale. If they did, the matter of our universe would have disintegrated into radiation long ago. Some property other than energy and charge must therefore be conserved. E. C. G. Stuckelberg and Eugene P. Wigner have called the new conserved quantity "baryon number."

"Baryon" is the name assigned to the comparatively heavy particles: the proton and all other particles of the same or greater mass. Stuckelberg and Wigner have suggested that just as there is a quantum, or unit, of electric charge, so there is a quantum of the assumed baryon property. This quantum, or baryon number, is carried by the proton. The fact that the proton is the lightest

particle carrying that quantity guarantees it against any decay. All heavier particles that can decay into a proton (for example the lambda particle, which decays into a proton with the emission of a pion) must have the same baryon number. Thus the baryon number is always conserved. The proton must have a positive baryon number and the antiproton a negative number of the same magnitude, so that the total baryon number of the two is zero. In their mutual annihilation there is no change of baryon number: it is still zero. As in the case of electric charge, in any reaction the total baryon number of all the particles after the reaction must be the same as the total before.

How can one find limits within which the law of conservation of baryon number is known to be valid? The most critical test is similar to the one for the conservation of electric charge: watch the proton to see if it ever decays. If a proton decayed, its breakdown would be easy to detect. It has so much more mass (that is, rest-energy) than any particle into which it might decay, such as a pion, that the conversion of the mass difference into energy would give the emerging particle or particles great kinetic energy. The signal of a proton breakdown would therefore be the appearance of a very energetic light particle in the collection of protons that is being watched.

A number of experiments monitoring large samples of material containing great numbers of protons have been carried out by Frederick Reines and Clyde L. Cowan, Jr., by one of us (Goldhaber), by Hans Frauenfelder and others. In none of these samples, each consisting of some 10^{30} protons, was proton decay detected. The experiments showed that a proton does not break down in at least 10^{22} years, which is 10^{43} times longer than the time of other particle decays of comparable energy.

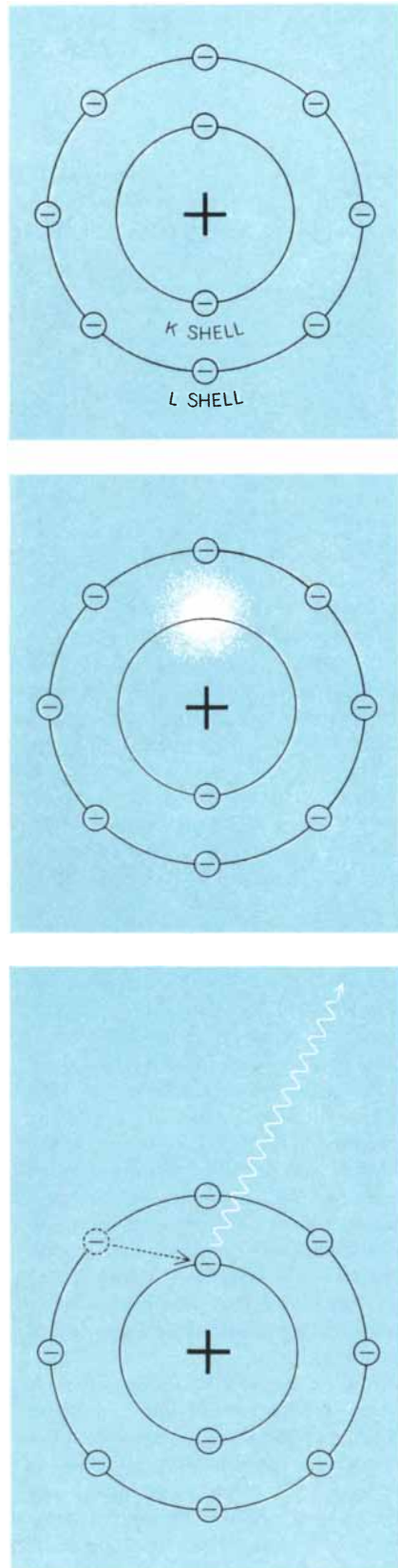
The only problem with the law of conservation of baryon number is that the baryon number has no known properties other than that it satisfies the conservation law. It is not like electric charge, which can be defined and measured independently, for example by measuring the motion of charged particles in an electric field. The lack of such properties of the baryon number is disturbing, and the search for them is sure to continue. Meanwhile, in the absence of a firm theoretical basis for the law, we can only conclude that it is known to be true with great accuracy.

Are there other forms of conservation in the domain of elementary particles? Physicists have noted two that seem to be similar in kind (and in mysteriousness) to the conservation of baryon number. One applies to the leptons, the name given to the light particles (electrons, muons, neutrinos and their antiparticles) to distinguish them from the baryons. It appears that the leptons possess a property called lepton number whose conservation forbids certain reactions the other conservation laws would allow (for example the transformation of a negative pion and a neutron into two electrons and a proton). The conservation of lepton number has been found to hold in all the cases so far studied.

The other new conservation law is connected with the recent discovery of the existence of two different neutrinos, one associated with muons and the other with electrons. Physicists now believe that the muon neutrinos, the muons themselves and their antiparticles have a property, called muon number, that forbids certain processes such as the decay of a muon into an electron and a gamma ray or the combination of a muon neutrino with a neutron to form a proton and an electron. The experimental absence of these reactions is the basis of the belief in the law of muon-number conservation.

Our purpose in this article has been to show the great power of the conservation laws and of the simple experiments that have been carried out to test them in the realm of elementary-particle processes. These laboratory tests have validated the laws to unprecedented limits of accuracy. They leave unanswered the question about the possibility that the conservation laws may not hold true on the cosmic scale, as the proponents of the theory of the continuous creation of matter in the universe contend. It must be said, however, that so far no one has demonstrated that it is necessary to assume such violations of the conservation laws do occur.

Finally, we should like to point out the usefulness of studying the conservation laws in the light of still more fundamental principles of physics. As an example, the law of conservation of momentum can be derived from the more basic concept that physical phenomena do not depend on the place where measurements are made. Such reductions of conservation laws to deeper principles may well lead to important clarifications of the still mysterious forms of conservation observed in the world of elementary particles.



ELECTRON DECAY would result in a hole in the K shell of an iodine atom. K shell, shown filled at top, has one space vacated below. This would be filled by an electron from the outer L shell, as shown at bottom, with the subsequent emission of an X ray.

FOREIGN NUCLEIC ACIDS

In 1957 it was found that the cell defends itself against viruses with a protein called interferon. It now seems that this substance protects the cell against all the nucleic acids other than its own

by Alick Isaacs

The body, it appears, has not one line of defense against virus infection but two. The first—in the chronology of discovery—is the familiar immune reaction. Against the protein that jackets a virus the lymphatic cells manufacture a specific and complementary protein, an antibody, that neutralizes the virus and keeps it from invading the cells of the body to which it is infective. Whether or not the immune reaction plays a decisive role in resisting a first infection by a particular virus, it sets up a more or less enduring immunity against later infection by the same virus. The second line of defense, discovered only recently, looks in some ways more like a first line. Against the nucleic acid of the virus—which encodes the genetic information for the production of more virus and which is contained in the virus-protein jacket—the invaded cell generates a substance that blocks the reproduction of the virus and stops the infection. Just how this substance, called interferon, does its work and how significant it is in the body's resistance to virus disease are questions that remain to be answered. But the promise of this discovery is such that interferon is being intensively investigated in a number of laboratories.

From the outset it had been observed that the action of interferon, in contrast to that of antibodies, is nonspecific. That is, interferon generated in response to one virus will block infection by another. Now it has been found that exposure to foreign nucleic acid of any kind will excite the production of interferon in the cell. Since nucleic acids function as the molecules of heredity in all living organisms, it might be expected that the nucleic acid of the cell would possess some capacity for protecting its integrity from contamination by genetic material from some other organism. At this stage in evolution, however, the occasions for such contamination are rare. The virus embodies one of the few mechanisms by which foreign nucleic acid can be introduced into a cell; in this case it is the highly specific virus protein that facilitates the penetration of a particular virus into a particular cell. Nevertheless, the antiviral action of interferon may constitute a special adaptation of a capacity that was originally designed for, and may yet be serving, a much more general purpose.

The phenomenon of "virus interference" had been known for many years before Jean Lindenmann and I first isolated interferon in 1957 at the National Institute for Medical Research in London [see "Interferon," by Alick Isaacs; SCIENTIFIC AMERICAN, May, 1961]. In 1937, G. M. Findlay and F. O. MacCallum had observed that monkeys infected with Rift Valley fever virus were protected from the fatal effects of yellow fever virus, and had taken note of the fact that antibodies against Rift Valley fever conferred no immunity against yellow fever. Early in our work we obtained suggestive evidence that it is the nucleic acid, not the protein, of the virus that provokes the production of interferon by the cell. In the first isolations of interferon by Derek C. Burke of our laboratory it was found to have a molecular weight of 63,000 (or 63,000 times the weight of a hydrogen atom). More recently my colleagues Zeev Rotem and Peter Charlwood have shown that chick, mouse and monkey interferons all have a molecular weight of about 20,000. George P. Lampson and his co-workers at the laboratories of Merck, Sharpe and Dohme have found a molecular weight of 24,000 in a highly purified preparation of chick interferon, a preparation of such high potency that only .0042 millionth of a gram of this protein protects a sheet of cells in a tissue culture from virus infection.

Interferon does not affect the entry of virus into the cells, but it blocks virus reproduction soon afterward. P. de Somer and his colleagues at the Catholic University of Louvain were able to show that interferon inhibits the replication of the viral nucleic acid. Beyond this general finding, however, the mode of action of interferon remains unknown.

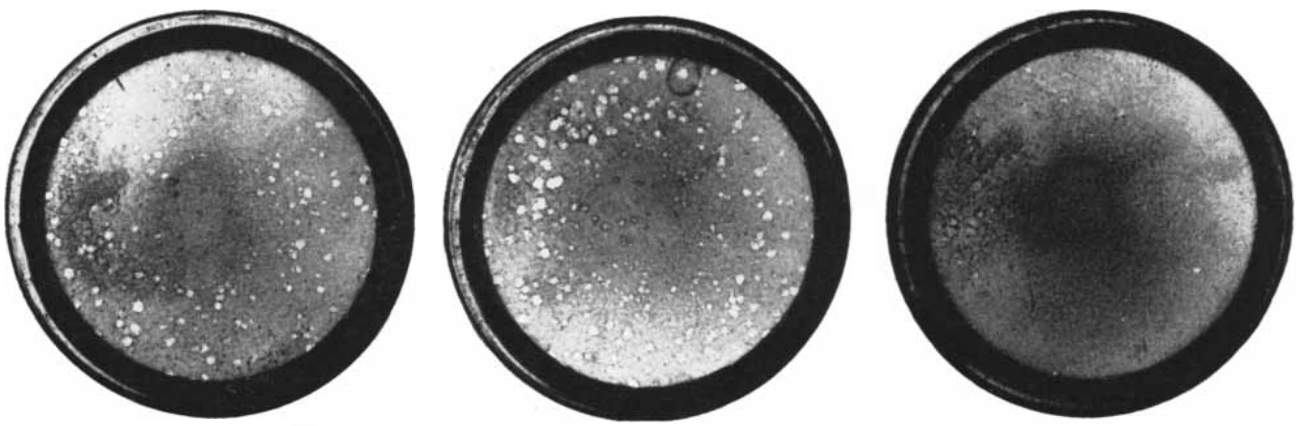
The importance of the substance in the intact living organism is also hard to ascertain. We have observed significant correlation between the production of interferon in the lung tissues of mice and the concentration of influenza virus in the tissues over the course of the infection. Individuals who suffer from the disease agammaglobulinemia lack any protection by antibodies, yet they have been known to incur virus infections and recover according to the schedule of normal experience. The best evidence for the action of interferon in promoting recovery from virus infection comes from tissue cultures. For example, L. A. Glasgow and Karl Habel of the U.S. National Institutes of Health have shown in a clear-cut fashion that in cells infected with virus under test-tube conditions the decision whether the cells will recover, die out or remain chronically infected depends on the amount of interferon the experimenter allows to accumulate in the test tube.

In the living animal the situation is more complex. Some interesting clues have come, however, from studies of the problem of virus virulence. At the Harvard Medical School in 1960 John F. Enders observed that an avirulent strain of measles virus induced the production

of much larger yields of interferon than a virulent strain. This and similar results obtained earlier with polioviruses prompted Enders to speculate that an important clue to the nature of virus virulence might be found in this relation between the virus and the output of interferon from the cell. Later work has supported Enders' idea. Juan Ruiz-Gomes and I studied a group of viruses that varied in virulence for the chick embryo. In general we found that virulent viruses produced less interferon than avirulent viruses and that they were also less sensitive to the antiviral action of interferon. In another suggestive cycle of experiments we found that Newcastle disease virus produced very low yields of interferon in chick cells for which it was highly virulent; yet the same virus produced good yields of interferon in human cells and in mouse cells, in which the virus grows poorly. Thus virus virulence may depend to some extent on the capacity of a virus to avoid this cellular defense mechanism, either by inducing low yields of interferon or by being insensitive to any interferon that is produced.

Still other viruses have yielded similar results in other laboratories. Robert R. Wagner of the Johns Hopkins School of Medicine found that a variant of vesicular stomatitis virus showing low virulence for mice was more sensitive to interferon and gave better yields of interferon in mouse cells than a more virulent virus. Lise Thiry of the University of Brussels has found that when she produced mutants of Newcastle disease virus by chemical modification of the virus particle, those viruses that were least virulent showed the greatest sensitivity to interferon. Frank J. Fenner of the Australian National University, working with myxoma viruses, and Robert Sellers of the Institute of Scientific Investigation in Venezuela, working with hoof-and-mouth-disease viruses, have also observed that the relation between virulence and the amount of interferon induced is an inverse one. It would be most surprising if other quite unrelated factors do not prove to be involved in virus virulence, but it is good to know that something has been found that makes sense to the biologist.

These experiments also demonstrated that the production of interferon is a general response of cells—at least of vertebrate cells—to virus infection. The indirect evidence that the cells are responding to the nucleic acid portion of the virus suggested still another hypothesis: that the nucleic acids of the various viruses provoke the response simply because they are foreign to the cell. In our laboratory, therefore, we undertook



CHICK CELLS were treated with chick RNA (*left*) and mouse RNA (*right*) and then infected with viruses. The success of mouse RNA in blocking virus growth is shown by the relative absence of virus plaques, or holes, in the sheet of cells treated with it. Control was carried out by infecting a sheet of chick cells (*center*) not previously exposed to either foreign or homologous nucleic acid.

MOUSE CELLS were treated with chick RNA (*left*) and mouse RNA (*right*), complementing the experiment in which chick cells were used. A smaller number of plaques can be seen again in the sheet of cells treated with the foreign nucleic acid. Close observation reveals fewer plaques in the mouse cells treated with mouse RNA than in sheet of cells used for control purposes (*center*).

to induce interferon production by exposing cells to foreign nucleic acids of nonviral origin.

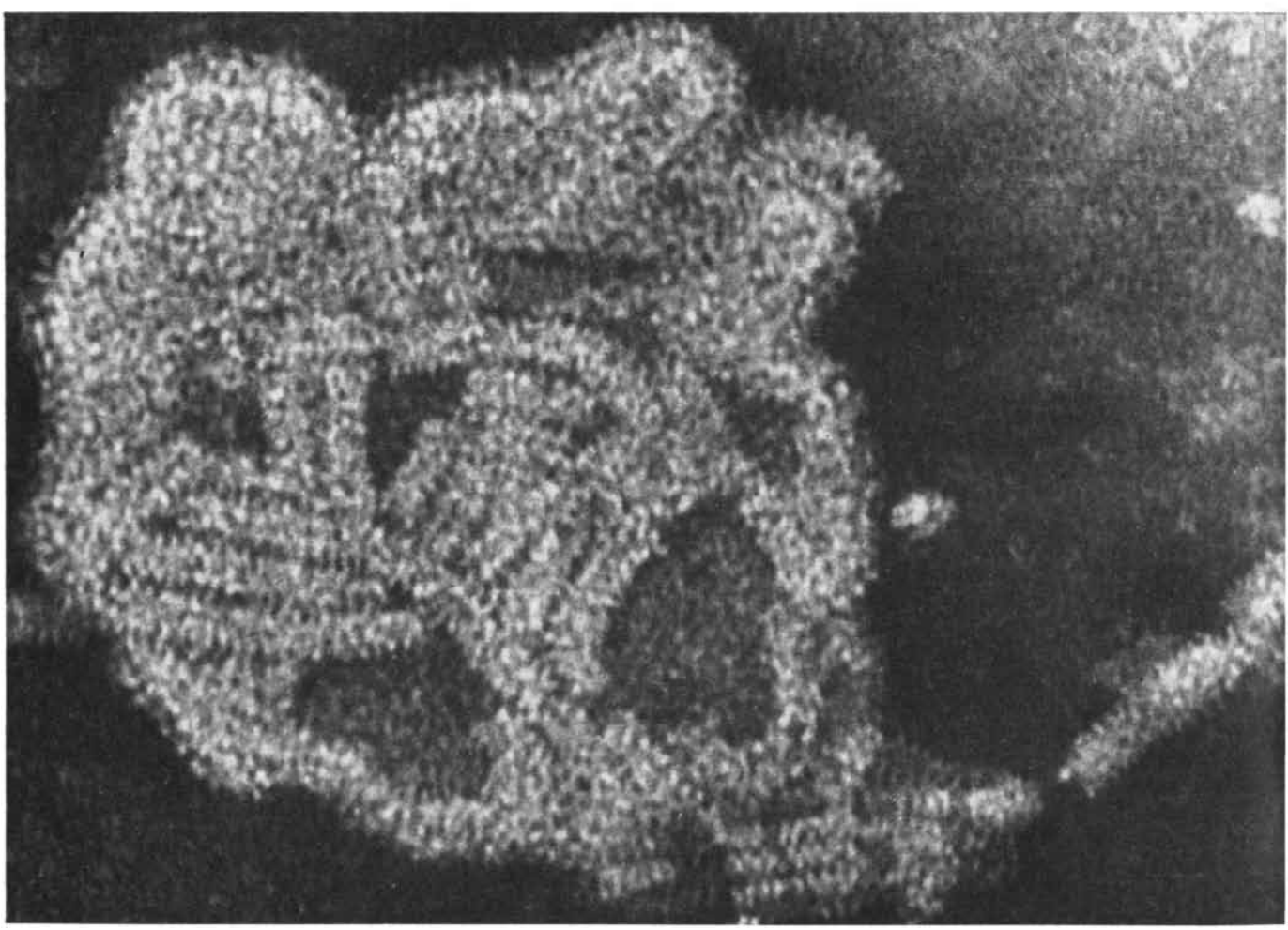
In the first experiments, conducted by Rotem, Robert A. Cox and myself, we prepared ribonucleic acids (RNA) from mouse and chick tissues and then exposed mouse and chick cells to these preparations in a culture medium. After giving the cultures time to react we infected them with viruses and then looked for evidence, or lack of it, of antiviral action. We hoped that we might be able to take direct antiviral action as an index of the interferon induced by exposure of the cells to foreign nucleic acids. It was not only that this technique promised to be less laborious than attempting to isolate and measure the small quantities of interferon we expected the cells to produce; we also hoped that the antiviral activity would prove to be a more sensitive measure of interferon production.

Although we eventually had to abandon the technique, the early results were encouraging. When we introduced mouse RNA into a culture containing chick cells, the foreign nucleic acid caused a striking inhibition of virus growth, as shown by a reduction in the number of plaques, or holes, produced in the sheet of chick cells [*see upper illustration on preceding page*]. Chick RNA introduced into a control culture of chick cells had very little antiviral effect. Conversely, in a culture of mouse cells, the introduction of chick RNA exerted a strong antiviral action and induced the production of small but measurable amounts of interferon. Our results were blurred somewhat, however, by the fact that the homologous nucleic acid—nucleic acid of the cell's own species—also produced a weak antiviral action.

Rotem and Cox showed that this weak antiviral potential of the homologous nucleic acid can be traced to its propensity to combine with virus particles in the culture medium and prevent their adsorption to and penetration of the cells. As a result we were compelled to measure antiviral activity in a more roundabout way. The new technique entailed treating cells with nucleic acid for three hours, then washing them free of the nucleic acid preparation and incubating them overnight in buffered salt solution. The next day the buffer was removed and tested for its content of interferon by measurement of its antiviral activity in fresh cell cultures.

Under these more precise conditions we were able to show that only the foreign nucleic acid induced the production of interferon; the homologous nucleic acid gave rise to none that could be detected.

This experiment also settled the question of whether the interferon is "coded" by the host cell or by the foreign nucleic acid. Chick and mouse interferons differ in their host specificity; chick interferon, induced by exposure of chick cells to mouse nucleic acid, protects chick cells from virus infection but not mouse cells,



NEWCASTLE DISEASE VIRUS is releasing a helical component containing its ribonucleic acid in this micrograph made by R. W. Horne, A. P. Waterson, P. Wildy and A. E. Farnham of the University of Cambridge. Recent studies indicate that exposure to a nu-

and vice versa. The two interferons also differ in their stability when heated. Hence it was found, just as in the case of virus infection, that the composition of the interferon is determined by the organism and not by the nucleic acid introduced.

Having shown that for chick and mouse cells only a foreign nucleic acid would induce the production of interferon, we wondered if a homologous nucleic acid could be modified chemically to a degree of "foreignness" that would induce interferon production. We prepared RNA from the ribosomes of chick liver, mouse liver and rabbit reticulocytes (immature red blood cells). These preparations were treated with nitrous acid for five to six hours, at which point we stopped the reaction by adding urea. For control purposes we mixed RNA with urea before adding nitrous acid. The nitrous acid has the effect of deaminating three of the bases on the nucleic acid chain, with the result that cytosine is changed to uracil, adenine to hypoxanthine and guanine to xanthine [*see illustration on next page*]. In other words, the nitrous acid alters the coding of the nucleic acid without altering the essential structure of the molecule.

When tested for antiviral activity, the control preparations behaved like untreated homologous RNA and gave rise to no interferon. The RNA that had been treated with nitrous acid for five to six hours, however, stimulated the production of interferon. In the chick, mouse and rabbit cells the interferons induced by their no longer homologous RNA's had the same properties as those of interferons induced in these cells by virus infection. Evidently the nitrous acid had made their own RNA foreign for each of these cells.

In order to fortify this conclusion we had to exclude the possibility that the nitrous acid had had some other unknown effect on the RNA molecule to make it behave in this way. We accordingly selected a preparation of chick RNA treated with nitrous acid that stimulated a good yield of interferon in chick cells, and a control preparation of chick RNA that did not give rise to any detectable interferon in chick cells. These two preparations were then tested for their effect on mouse cells. We found that they provoked almost the same amount of interferon output from these cells. Evidently, since chick RNA is already foreign for mouse cells, treatment with nitrous acid did not make the chick RNA any more or less foreign to mouse tissue.

What degree of foreignness is necessary before the RNA will stimulate production of interferon? We treated chick RNA with nitrous acid and stopped the reaction with urea after various intervals of time. Treatment for one hour resulted in no measurable yield of interferon from chick cells, whereas treatment for six hours gave a good yield. Study of the six-hour sample by a spectrophotometer technique devised by Cox indicates that roughly 10 per cent of the cytosine bases are deaminated to uracil in this time. Since nitrous acid acts at a linear rate with respect to time, it seems that deamination of 2 per cent of the cytosine bases makes chick RNA insufficiently foreign to produce a quantity of interferon measurable by our present methods.

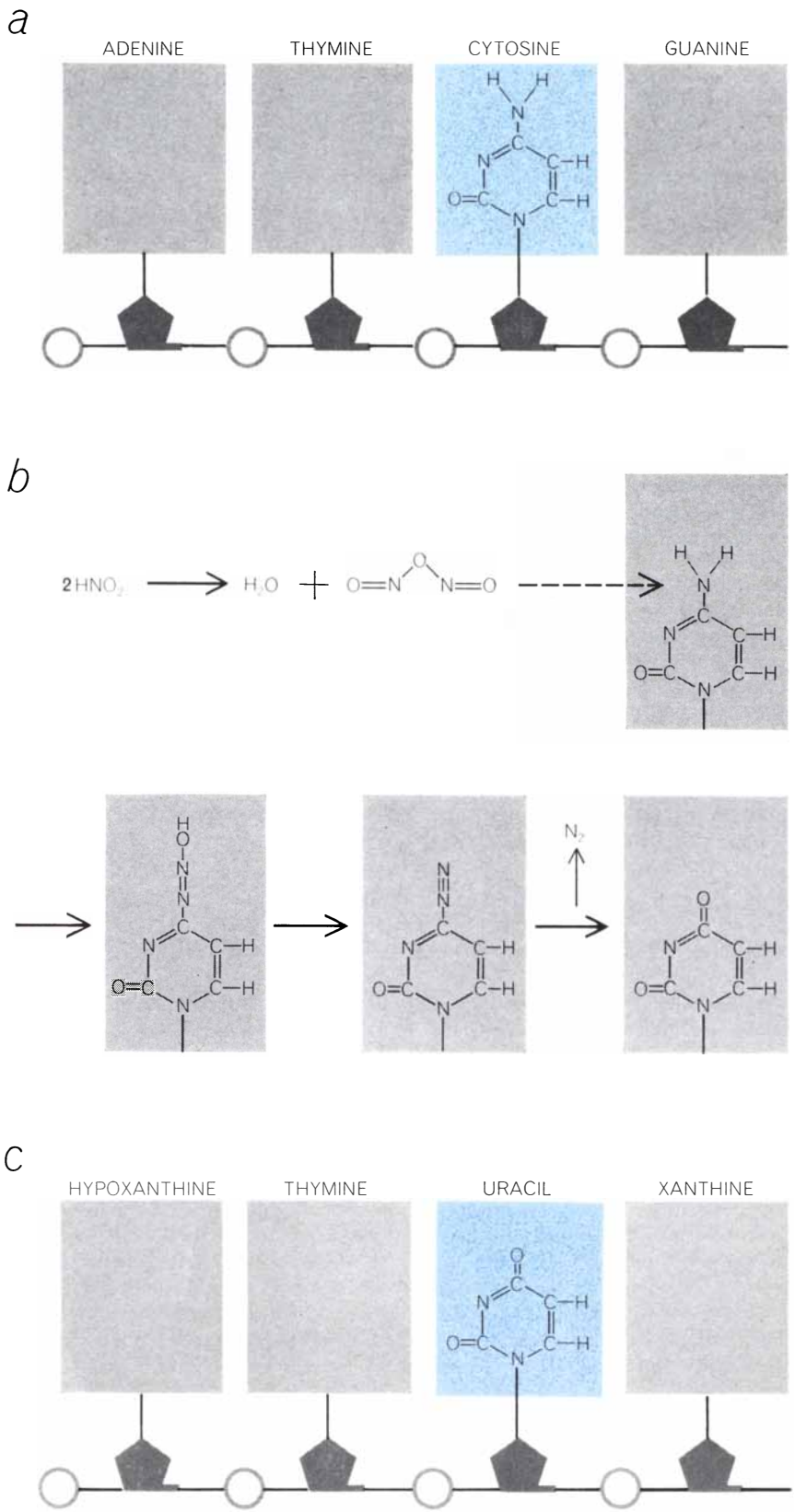
We may conclude, therefore, that the interferon mechanism is able to recognize foreign nucleic acids whether these are present in an infecting virus particle or in the free state. The fact that we find much higher yields of interferon resulting from virus infection than from treatment with nonviral nucleic acids may attest to the efficient job done by the viral protein in delivering the viral nucleic acid safely to the cell.

The interferon mechanism is evidently designed to protect cells against foreign nucleic acids in general rather than the single class carried by viruses. It is easy to understand how important it is for the living cell to be protected against foreign nucleic acids that might alter their genetic structure, but it is difficult to envision in what way the nucleic acids of foreign animal species might become involved in the genetic apparatus of a vertebrate's cells. Bearing in mind, however, that the concept of foreignness includes chemically altered homologous nucleic acids, we might legitimately wonder whether smaller degrees of foreignness can be recognized by the cells of the body without the induction of interferon in an amount sufficient for detection by our present crude methods. Such foreignness might result from mutations caused by chemical damage to the cell's genetic material. Cancer cells, for example, may have nucleic acid that is foreign to the normal cells of the animal, and we are at present looking for such differences in composition.

It has been known for some time that many kinds of cancer cells are relatively resistant to the antiviral action of interferon. If we suppose that some cancer cells contain a nucleic acid foreign to the organism and that neighboring cells react to this foreign nucleic acid by producing interferon, it could be that the survival and proliferation of these cancer cells would be restricted until such time as a mutant appeared that was resistant to the action of interferon. Put another way, resistance to the action of interferon would negate the hostility of the environment and help cancer cells to survive. It has often been suggested that cancer cells occur commonly throughout the body, but that they can flourish only when conditions favor their growth with respect to that of the neighboring healthy cells. Possibly the interferon mechanism, under normal circumstances, acts to keep such isolated cancer cells in check; possibly also, then, it is the mutants resistant to the action of interferon that proliferate into cancers.

Potentially fruitful speculation has been provoked by the question: When does a cell first meet foreign nucleic acid? If we use the term "foreign" to

cleic acid unlike their own can make some cells resistant to the Newcastle disease virus.



ALTERED CODE results when a nucleic acid is treated with nitrous acid ($2HNO_2$). At start of reaction (*top*) the bases adenine, thymine, cytosine and guanine are aligned on a polynucleotide chain. Three of the bases are attacked and changed by nitrous acid, but only the transformation of cytosine (*colored base*) into uracil is detailed in this illustration. In the case of nitrous acid treatment of ribonucleic acid, uracil would replace thymine. Intermediate products (*middle*) of the reaction form rapidly in the presence of water, and evidence for the chemical steps shown here is indirect. In row of end-product bases (*bottom*) guanine has been changed to xanthine and adenine changed to hypoxanthine.

mean any nucleic acid that is different from the cell's own, then the first occasion is the meeting of an ovum and the deoxyribonucleic acid (DNA) of a fertilizing sperm. It is significant that the cells of young embryos are poor producers of interferon and are insensitive to its antiviral action. Samuel Baron and I found in 1960 that production of interferon and sensitivity to its antiviral action increase as the embryo matures. We do not yet know how the ovum behaves with regard to interferon, but it seems reasonable to guess that, since it is younger, it would respond even more poorly than the embryo. This is perhaps fortunate, because if the male DNA were to be rejected effectively by the ovum, the pattern of society might not resemble the one we know.

Somewhere between the ovum's acceptance of a foreign nucleic acid and the maturation of the embryo's capacity to produce interferon against such substances, cells seem to "learn" that certain nucleic acids are foreign. This learning process raises the possibility that an immunological tolerance to foreign nucleic acids could be induced in the living cell. Leslie Brent and I are currently experimenting to see if embryos injected with foreign nucleic acids at a very early age will regard them as foreign when exposed to them later in life. Complementary studies of how a cell can distinguish between its own and foreign nucleic acids are being conducted on the chemical level.

From the biologist's point of view there is much significance in the idea that cells possess a mechanism that enables them to reject foreign nucleic acids and thus helps them to survive with an unchanged genetic structure. The presence of interferon in the cells of so many different animals suggests its appearance early in the evolutionary history, but just how early we cannot say, since there is no firm evidence for the presence of interferon in animals more primitive than birds.

Whatever the original function of interferon was, there is no reason why man should not try to take advantage of it. Foreign nucleic acids could possibly be developed as materials that would stimulate our production of interferon and so help us to resist virus infections. In immunology the use of vaccines that stimulate antibody production has proved more efficient than the direct administration of antibody, and the same could yet be true of what we must pray will never be called interferonology.

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Thoughts to buy tape by

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2. The support is not the super-strength kind but cellulose triacetate, treated to make it stronger than triacetate has any business being. Amateur recordists generally don't realize when they buy super-strength that the low-tension equipment used in the home never requires it, though it costs something in audio uniformity and money. Professionals with their high-tension equipment, on the other hand, have long known that in case of trouble, a clean break is instantly apparent, remediable, and preferable to the treacherous stretch—over 70% before breaking—of the super-strength stuff. (Our treated triacetate stretches no more than 0.5%. We trademark it DUROL Base.)

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Few men have the knack of making a good piece of color film—far fewer than can sew a good overcoat or brew a good glass of beer. As a matter of fact, not a single man in the world knows all by himself how to do it. Only the gigantic organization knows. The people constituting the organization spend their time at small tasks, like broadening the exposure latitude. It was notoriously narrow when color film first became important.

Today on an instrumentation range when the button is pressed that makes the thingamabob go off and simultaneously starts 31 movie cameras that will show afterwards what happened, the thingamabob might be sadly wasted if unanticipated light levels resulted in bad underexposure or overexposure. One 16mm, 35mm, and 70mm color film that we endowed with much tolerance against this risk is now being superseded by another with more tolerance. The new one, KODAK EKTACHROME MS Film, can stand four stops (2^4) of underexposure and two stops of overexposure and provides better resolution of fine detail than the older film.

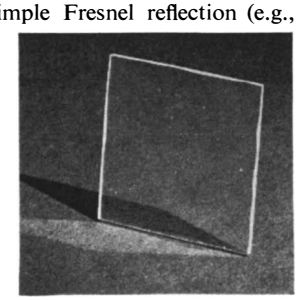
Note that the concept of underexposure and overexposure implies the possibility of a most admirable on-the-nose exposure. As for the two ends of the tolerance curve and how good the results must be to get inside them, one places one's trust in an expert, much as one trusts one's tailor or brewer.

One's consultant on these *matters is Eastman Kodak Company, Photorecording Methods Division, Rochester 4, N. Y.*

Infrared advantageously reflected or refracted

A gnat can fascinate as much as a hippopotamus. Though the polycrystalline infrared media business is considerably smaller than the film business, it continues to yield its own satisfactions. To our four KODAK IRTRAN Optical Materials, we are now able to add IRTRAN 5. The new one commends itself, among other merits, for *reststrahlen.*

Being only a manufacturer instead of an institution of learning, we try to avoid robbing academic circles of too many scholars who can invoke the Fermi surface in discussing ionic crystals that behave like metals in the extent to which they reflect radiation of certain long wavelengths. The monumentally casual and clever oldtimer R. W. Wood simply tells us in his *Physical Optics* that in 1897 Rubens and Nichols worked out a scheme for using several bounces off a crystal to attenuate wavelengths subject to simple Fresnel reflection (e.g., $(4\%)^3 = 0.006\%$), so that only the metallically reflected infrared bands remained; hence, *reststrahlen.* A thin plate of KODAK IRTRAN 5 Optical Material, largely MgO, effectively isolates 15μ - 25μ by one bounce under the right conditions.



On the other hand, the transparency you see here is good from 0.5μ to 8μ, without the water band at 2.8μ. Thermal conductivity exceeds that of any of the other IRTRAN materials by several times. Its dispersion suggests pairing with some of the others to make achromats.

Apparatus and Optical Division, Eastman Kodak Company, Rochester 4, N. Y. can send much data about IRTRAN *materials. If you would rather have real infrared lenses than data and can contrive to avoid the need for achromatism, a purchase order would probably result in shipment within a week of any of the following* IRTRAN *2 f/1 menisci, which transmit 1μ - 14μ and are very rugged thermally, chemically, and mechanically:*

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1. IR-100	25.2 computed at 1.5μ 26.4 computed at 10μ	0.36	$ 77
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4. IR-200	50.6 computed at 1.5μ 53.8 computed at 10μ	0.61	$168
5. IR-201	48.8 computed at 4.26μ 50.9 computed at 10μ	0.20	$325

*diameter of axial image of point source at which measured intensity drops to 5% of center peak intensity, for 2 - 4.5μ range.

**net price each in 1-10 quantities, subject to change without notice.

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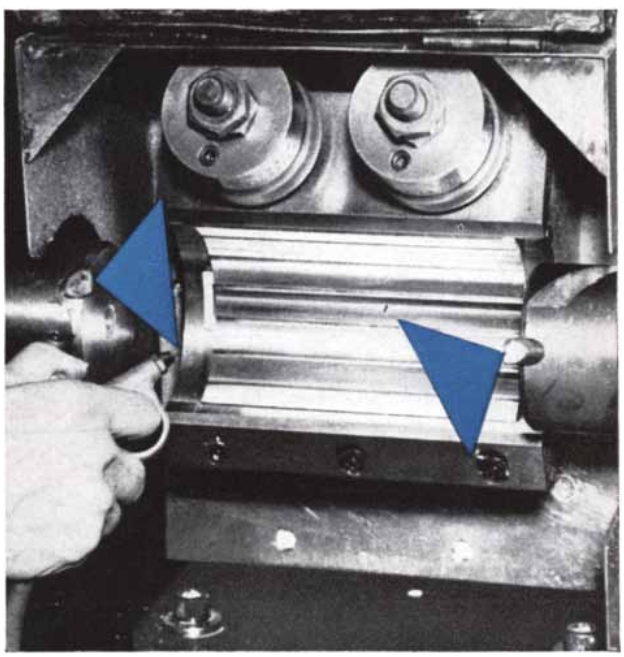
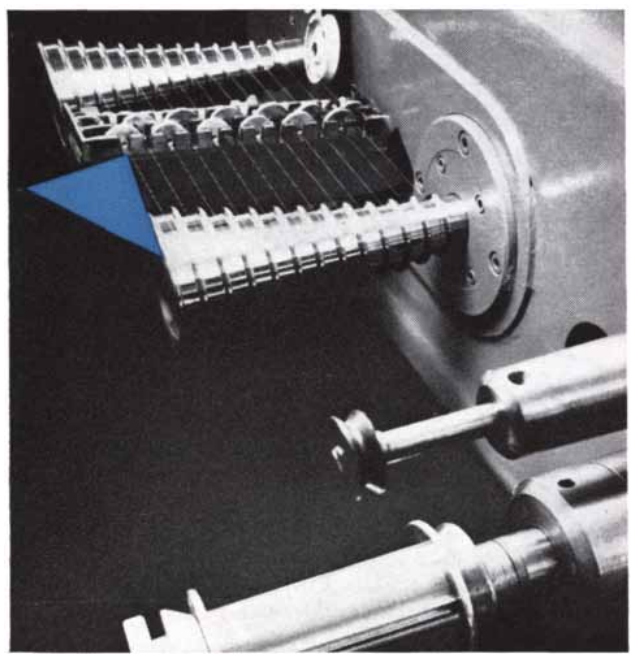


HIGH-SPEED BORING of large, silver-plated steel bearings is now accomplished with precision-shaped and lapped diamond tools by a large aircraft engine manufacturer. Tolerances: ±.00025 inch on the inside diameter, with 25 micro-inch finish. Silver coating on the bearings wore conventional carbide tools rapidly, resulted in frequent shutdowns. Diamond tools were found to hold tool dimensions many times longer than carbide tools.



COPPER WIRE for the electronic circuit in the Accutron® timepiece is drawn to microscopic fineness through natural-diamond dies by the Bulova Watch Company, Inc. The wire passes over a graduated step-cone (top), through a series of 12 diamond dies with diameters calibrated in millionths of an inch (holes in discs), over a second step-cone and onto a take-up spool (bottom). The processed wire on the spool has a diameter of .0006 inch.

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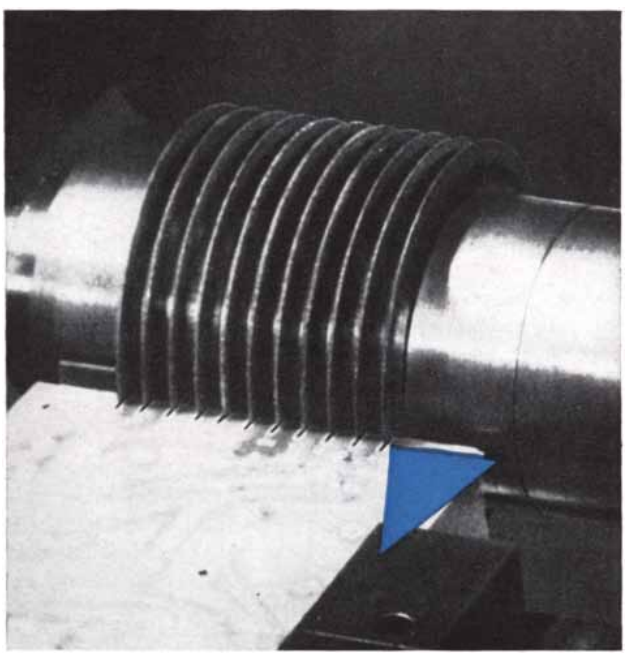
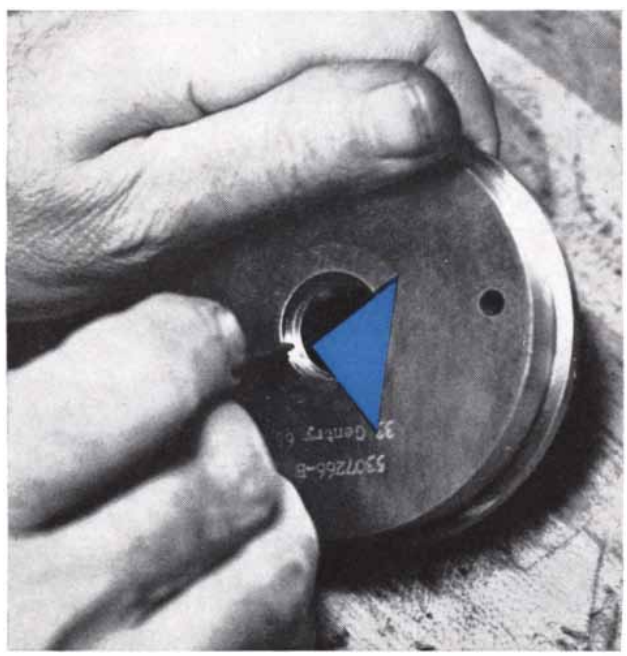


ELEVEN NOTCHES in copper-clad printed circuit boards are cut in two seconds by three-inch slitting saws at Lockheed Electronics Co., Los Angeles. Natural diamonds coat .034-inch-thick cutting edge of each saw. Life expectancy of each metal-bonded blade: 150,000 notches.



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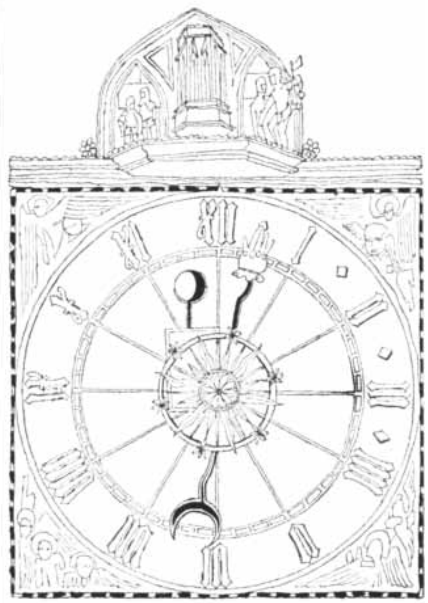

The 34th Particle

Anti-xi-zero, the 34th and last of the "expected" elementary particles of matter, has been discovered. The long-anticipated announcement was made in the August 15 issue of *Physical Review Letters* by a team of 13 physicists from Yale University and the Brookhaven National Laboratory.

The existence of the new particle, predicted on theoretical grounds for several years, was confirmed in an experiment that employed the huge alternating-gradient synchrotron at Brookhaven to generate a beam of antiprotons with an energy of 3.69 billion electron volts. The beam was directed into a 20-inch hydrogen bubble chamber, and the tracks resulting from the collision of the antiprotons with the protons of hydrogen were photographed. Of the 300,000 photographs made since September, 1961, only three showed any evidence of the extremely rare anti-xi-zero. One of these photographs appears on page 37 of this month's issue of SCIENTIFIC AMERICAN.

The new particle was difficult to detect not only because it was rare but also because it has no electric charge and therefore leaves no track in a bubble chamber. Moreover, its immediate decay products, an anti-lambda-zero and a neutral pi meson, are also uncharged. The subsequent decay of the anti-lambda-zero, however, does leave visible tracks, and from these tracks and other considerations the decay of an anti-xi-zero can be deduced. The appearance and configuration of the tracks in the three critical photographs convinced the Yale-Brookhaven group that anti-xi-zero particles had been produced in their bubble chamber and that its lifetime was of the order of 10^{-10} second.

The discovery of anti-xi-zero further confirms the fundamental concept of quantum mechanics that states that for every known elementary particle there must exist a corresponding antiparticle. Anti-xi-zero is the antiparticle of xi-zero, which was discovered in 1959. The complete inventory of elementary particles, each with its antiparticle, now stands as follows: the photon, two kinds of neutrino, the electron, the mu meson, two pi mesons, two K particles, the proton, the neutron, the lambda particle, three sigma particles and two xi particles. (Two particles, the photon and the pi zero, are their own antiparticles.)

Although many physicists regard the new particle as the last in a distinct "family" of elementary particles, the existence of other particles has been conjectured. At Brookhaven and other high-energy research centers around the world work has already begun on the possibility of detecting a hypothetical negative omega particle.

End of Krebiozen?

The Krebiozen controversy appears to be nearing resolution. The Food and Drug Administration reported last month that it had "positively identified" the compound, which has been promoted in the U.S. as a cancer drug since 1951 and administered to some 5,000 patients at up to $9.50 for a .01-milligram dose, as creatine, a common amino acid derivative. The tissues of an adult human being contain about 120 grams of creatine, mostly in the form of creatine phosphate, which plays an essential role in supplying energy for muscle contraction. Creatine is available commercially at 30 cents a gram.

Krebiozen was first put forward as an anticancer drug by Steven Durovic, a Yugoslav physician who had come to the U.S. from Argentina, but its reputation rested largely on the support of Andrew C. Ivy, a well-known physiologist and former head of the University of Illinois Colleges of Medicine, Dentistry and Pharmacy. Ivy did not identify the drug

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beyond calling it a "lipopolysaccharide," and an impasse developed: Krebiozen's sponsors and many lay proponents claimed it was being suppressed by orthodox medical workers and demanded intensive clinical tests; many physicians, the American Medical Association and the National Cancer Institute maintained that available data showed Krebiozen had no effect on cancer and that an unidentified drug should not be given to patients. The National Cancer Institute was unable to identify Krebiozen on the basis of infrared absorption spectrograms and an empirical formula ($C_{25}H_{67}O_{18}N_{19}$) submitted by Durovic and Ivy.

Last July the Food and Drug Administration barred Krebiozen from interstate shipment when its sponsors withdrew an application to continue distribution under new amendments to the Federal drug laws. Studying the data of the National Cancer Institute, the FDA's Division of Pharmaceutical Chemistry spotted a similarity between Krebiozen's infrared spectrogram and the infrared profile of creatine. A curve submitted by Durovic proved to be that of creatine hydrate (creatine bound to a molecule of water). Another National Cancer Institute curve, made from a sample provided by Durovic, matched that of anhydrous creatine with a small amount of adsorbed water. The empirical formula, then, could be explained as a slightly incorrect formula for six molecules of creatine hydrate ($C_4H_9N_3O_2 \cdot H_2O$). Finally the FDA obtained a new sample from Durovic and Ivy. Its infrared curve was that of creatine. Its X-ray diffraction pattern and microscopic crystal structure were those of creatine. Mass spectrography showed that it could only be creatine or creatinine, a creatine derivative. Treated with hydrochloric acid, the sample produced creatinine, as only creatine could.

The National Cancer Institute had tested creatine in routine screening for chemotherapeutic agents and found it to be ineffective even in very large doses. FDA chemists are now trying to determine how much—"if any"—of the supposedly active ingredient (or creatine) is actually dissolved in mineral oil in a one-dose ampoule of Krebiozen. Even if there is as much as the distributors say,

.01 milligram, it would only be a hundred-thousandth as much as the human body synthesizes in one day.

Inhomogeneous Mantle

Over the next few years geophysicists hope to learn much more about the nature of the earth's upper mantle, the little-known region that extends from the base of the earth's crust to a depth of 450 miles. These hopes are largely based on an international collaboration known as the Upper Mantle Project. Although the project is just getting under way, reports at an upper-mantle symposium during the Congress of the International Union of Geodesy and Geophysics, which was held in August in Berkeley, Calif., suggest that the upper mantle may be quite as varied and complex a region as the crust above it.

Explosion-seismology studies, carried out as part of the U.S. Vela Uniform project for finding a means of distinguishing between earthquakes and underground nuclear explosions, have revealed significant differences in the velocity of seismic waves traversing different sections of the upper mantle below the western U.S. Between the California coast and eastern Utah seismic compression waves move through the upper mantle with a velocity of less than eight kilometers per second; off the California coast and in the mountain and Great Plains areas east of Utah the waves have a velocity of more than eight miles per second. According to L. C. Pakiser of the U.S. Geological Survey the difference in velocity probably indicates differences in density and perhaps also in composition within the upper mantle, the high-speed regions consisting of denser rock than the low-speed ones.

Another indication of inhomogeneity in the upper mantle is provided by powerful electric eddy currents flowing near the earth's surface during magnetic storms. Such currents ordinarily flow only at depths of more than 250 miles, where the mantle is hot enough to be a good conductor of electricity. Eddy currents have been detected at depths of 60 to 100 miles, however, in northern Germany, central Japan, Australia, Utah and Ellesmere Island in the Arctic. The anomalous currents are believed to be caused by "hot spots" in the mantle far above their usual depth.

The geophysical congress also heard reports on two drilling projects that will add to knowledge of the mantle. William E. Benson of the National Science Foundation exhibited a model of the floating

platform from which the long-awaited Mohole will be drilled. The drilling rig will rest on a platform supported by what amounts to two remotely controlled submerged submarines. The rig will be able to travel under its own power at a speed of about 10 knots to whatever drilling site is chosen. Meanwhile the U.S.S.R. is pushing plans for five deep holes to be drilled within Soviet borders. Two of the holes, one designed to penetrate 40,000 feet of sediment north of the Caspian Sea and the other to reach an anomalous crustal layer in the Caucasus, will be started next year. The Soviet drilling program will be capped by an effort, in two to four years, to reach the Mohorovičić discontinuity under the Kurile Islands north of Japan, where the crust is believed to be thinner than in other continental areas.

Total Synthesis of ACTH

The complete molecule of the adrenocorticotropic hormone (ACTH) has been synthesized by Robert Schwyzer and P. Sieber of the Swiss firm Ciba, Limited. The hormone, which contains 39 amino acid subunits, is the largest protein-like molecule yet synthesized. (The term "protein" is usually reserved for molecules containing 100 or more amino acid subunits. Smaller molecules such as ACTH are called polypeptides.) The synthesis was reported in *Nature*.

ACTH, which is produced by the anterior part of the pituitary gland, stimulates the adrenal cortex to make a variety of steroid hormones that regulate carbohydrate metabolism and the balance of sodium and potassium in the body fluids. A subsidiary effect of ACTH is to darken the skin by stimulating the activity of the pigment-producing cells called melanocytes.

In 1960 Choh Hao Li and his colleagues at the University of California at Berkeley succeeded in linking together the first 19 amino acids of the ACTH molecule [see "The ACTH Molecule," by Choh Hao Li; SCIENTIFIC AMERICAN, July]. This abbreviated molecule was found in human subjects to have about 80 per cent of the adrenal-stimulating activity of the natural hormone. Later in 1960 synthetic molecules containing 19 to 24 subunits were prepared by Klaus H. Hofmann and his co-workers at the University of Pittsburgh School of Medicine and by Schwyzer and his associates at Ciba. Curiously, these shorter molecules showed a greater skin-darkening action than the natural hormone. The explanation is that the first 13 subunits

in ACTH are almost identical with the 13 subunits found in one form of melanocyte-stimulating hormone (MSH), also produced by the anterior pituitary. The synthesis of the complete ACTH molecule should help to clarify how the skin-darkening action of the first 13 subunits is suppressed by the remaining 26 subunits.

Hydrologic Decade

A large-scale international investigation and assessment of world water resources is to be launched on January 1, 1965. Because of year-to-year variations in rainfall and water flow in different parts of the world the project will be conducted over a 10-year period and has been named the International Hydrologic Decade. Hydrologists and other investigators from more than 50 nations are expected to take part.

Preliminary plans for the water study, which will be jointly sponsored by UNESCO, the World Meteorological Organization and the International Union of Geodesy and Geophysics, were drawn up at a meeting in Paris last spring. Since government agencies are directly involved in water works and water studies in nearly all countries, the committee directing the hydrologic decade will represent both governments and national commissions of experts. A further planning meeting is scheduled for next spring.

Unlike the International Geophysical Year, on which it is partly modeled, the hydrologic decade will have immediate applied objectives as well as long-range scientific ones. It will seek not only to detail on a world-wide scale the movement of water between the earth and the atmosphere and the earth and the sea but also to find ways of increasing the supply of water for agricultural, industrial and domestic purposes, particularly in areas where population growth threatens to outstrip water resources. The specific programs to be undertaken will differ from country to country. In the U.S. and Europe, it was noted by William C. Ackermann, president of the American Geophysical Union's hydrology section and a member of the planning group, the emphasis will be on sophisticated projects such as sediment transportation in relation to the longevity of dams and the movement of rain water into the underground water table. In less developed areas an effort will be made to institute systematic, continuing measurement of stream flow, ground-water levels and the like in order, among other

things, to make it possible to draw up continental water budgets. Particular attention will also be given to the expansion of training facilities for hydrologists and to the establishment of international centers for the development of and training in standardized methods of making observations and forecasts of streams and other hydrologic systems.

Infant Mortality

The U.S. has dropped to 11th place among the nations of the world in infant mortality. It now trails not only the traditional leaders in infant health—the Netherlands and Sweden—but also such countries as Ireland. Even the states with the lowest infant death rates—Utah, Iowa, Massachusetts and Hawaii—have rates a third higher than the Netherlands and Sweden.

The decline is brought out in a recent report of the U.S. Children's Bureau that covers over-all infant mortality rates for 1962 and state-by-state rates for 1961. Since 1950, when it stood sixth among the nations, the U.S. has reduced its death rate for babies younger than a year from 29.2 per 1,000 live births to 25.3 per 1,000, an improvement of 13.4 per cent. During the same years, however, other advanced nations were lowering their infant death rates by 20 to 40 per cent.

In some respects the U.S. has made no progress in reducing infant deaths. In 1959, 1960 and 1961 the U.S. death rate on the first day of life was 10.3 per 1,000, the highest since 1950. Moreover, a number of the nation's largest cities, including New York, Chicago, Philadelphia, Detroit, Baltimore, Cleveland, Washington and St. Louis, have recorded increases of 1.6 to 26.4 per cent in infant mortality over the past 12 years. In most of these cities the increases have affected the white sectors of the population as well as the nonwhite. According to Katherine B. Oettinger, chief of the Children's Bureau, the major factor in the poor U.S. showing is inadequate prenatal care and the resulting increased risk of premature birth.

Distant Supernova Remnant

A radio survey of the Large Cloud of Magellan, the larger of the two galaxies nearest our own, has revealed the remains of a supernova that exploded some 1,500 years ago. The supernova remnant is the first to be discovered in another galaxy; our own galaxy contains a number of such remnants. One of them,

Cassiopeia *A*, is among the strongest celestial radio sources.

Supernovae remnants exhibit a peculiar pattern of radio emission that distinguishes them from other kinds of emission nebulae, which they superficially resemble. Most emission nebulae are bodies of gas that are heated to incandescence by a star embedded in them; in such nebulae the strength of radio emission decreases with increasing wavelength. In supernovae remnants, however, the radio emission increases with wavelength. The supernova remnant in the Large Cloud of Magellan, which is about 180,000 light-years away, carries the designation *N*49 in the catalogue compiled by Karl G. Henize of Northwestern University. In photographs it resembles a slightly distorted smoke ring. It is calculated that the radio emission of *N*49 is 1,000 times more intense than that of Cassiopeia *A* at a comparable age.

The discovery was reported in *Nature* by D. S. Mathewson and J. R. Healey of the Commonwealth Scientific and Industrial Research Organisation in Australia and B. E. Westerlund of the Australian National University.

Stress and the Zulu

A study of high blood pressure among Zulus in the Union of South Africa strongly suggests that stress is a major factor in the condition, and it also sheds some light on the nature of stress itself. Writing in the *American Journal of Public Health*, Norman A. Scotch of the Harvard University School of Public Health reports on a survey conducted in two Zulu communities, one a rural "reserve" and the other an urban "location" near the city of Durban. Hypertension, or high blood pressure, was significantly more prevalent among the urban Zulus. Scotch first attributed this to the greater severity and variety of stress in the location, where the predictable strains of city life and detribalization are complicated by the stressful effects of apartheid, the South African policy of strict separation of the races.

In an effort to define "stress" more specifically, Scotch examined the effect of a number of social variables on the incidence of hypertension in both communities. He found that only four variables were clearly associated with hypertension in both communities: age, sex, obesity and marital status (widowed women and women separated from their husbands were more likely to be hypertensive). But a number of other factors that were correlated with high blood pressure in one community were

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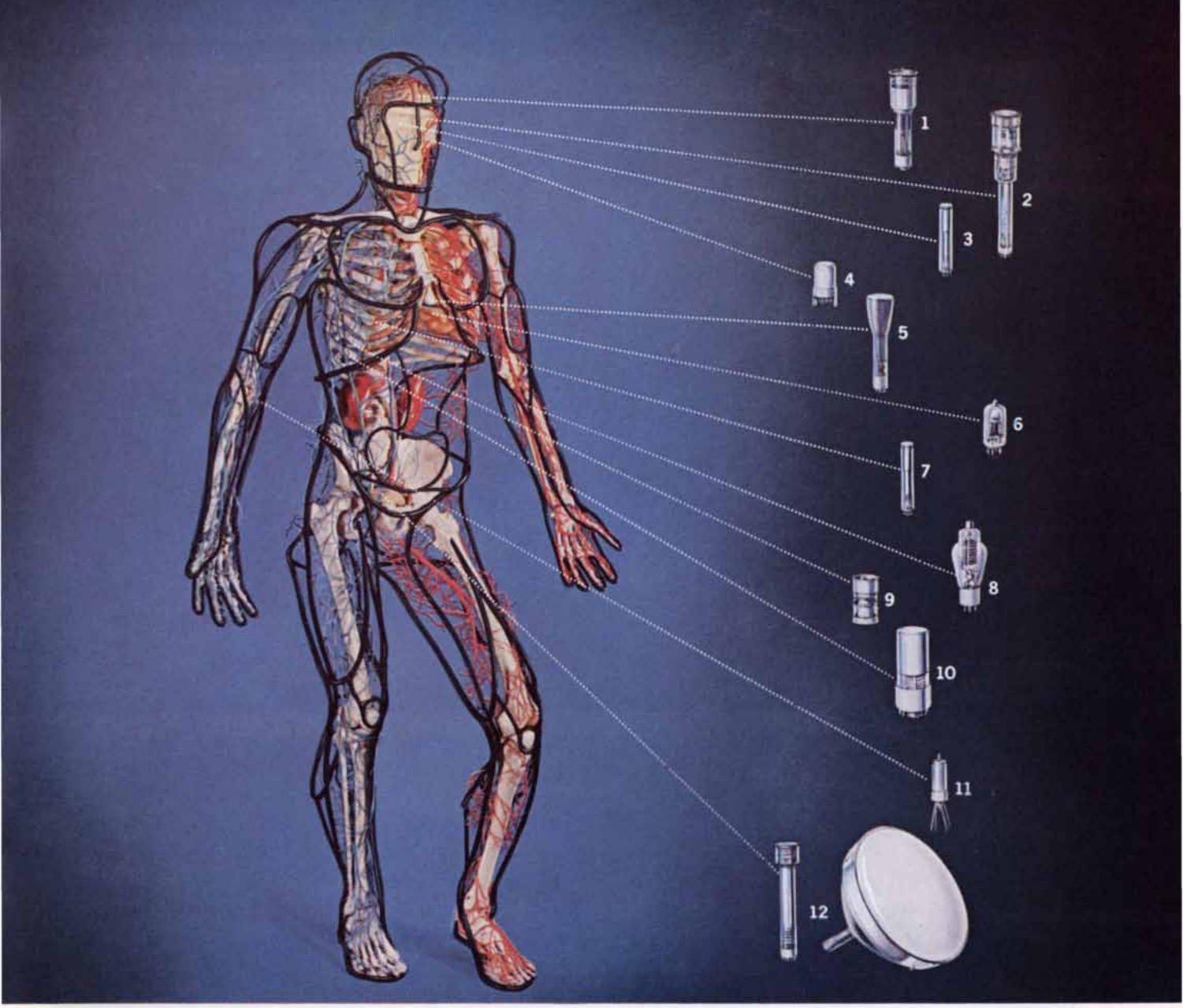
correlated with normal pressures in the other. For example, in the city women with many children were more hypertensive than those with few children; in the rural area there was no such correlation. Country women who had passed the menopause were more likely to be hypertensive than those who were premenopausal, whereas in the city the menopause had no such clear relation to hypertension. Scotch points out that a large number of children is stressful in the city but not in the country. Menopause, on the other hand, is stressful for the rural Zulu woman because it marks the end of her high-status period of childbearing; in the city, however, it frees her for greater productivity as a wage earner and is nonstressful. Scotch concludes that whether or not a variable is stressful depends on the social context in which it arises.

In general, Scotch believes, urbanization may not be stressful in itself. "It is not simply a case of change but rather of success or failure in change." The individuals most likely to be hypertensive were "those who maintained traditional cultural practices and who were thus unable to adapt successfully to the demands of urban living."

Flipped Magnetic Poles

A study of "frozen" magnetism in rocks has shown that the direction of the earth's magnetic field was reversed at least twice in the course of geologic time. In the period between 980,000 and 1.9 million years ago and prior to 3.4 million years ago magnetic north lay deep in the Southern Hemisphere. The present orientation of the field has prevailed for the past 980,000 years and existed once before between 1.9 million and 3.4 million years ago.

These conclusions were drawn from a study of old lava flows in many parts of the world, particularly those in Hawaii and those from Mount Etna in Sicily. The remanent magnetism in the volcanic rocks faithfully records the direction of the earth's magnetic field at the time the lava flows took place. The rocks were dated by measuring the amount of the nonradioactive isotope argon 40 that has accumulated in them from the decay of the radioactive isotope potassium 40. The study was reported by Allan Cox, Richard R. Doell and Brent Dalrymple of the U.S. Geological Survey. They are continuing their investigation to see if any magnetic reversals took place earlier than four million years ago. They offer no hypothesis for the cause of the reversals.



Actual photograph of Vesalius Model, courtesy of Cleveland Health Museum **1** RADECHONS: for studies of nerve impulses in presence of uncorrelated signals **2** IMAGE INTENSIFIER ORTHICONS: for internal eye examination without stimulated pupil dilation **3** VIDICON TUBES: for blood count, ophthalmological examination **4** NUVISTOR TUBES: for unique artificial mastoid **5** OSCILLOGRAPH TUBES: to study heartbeats, brainwaves; for visual diagnostics during surgery **6** RECEIVING TUBES: for electrocardiography, electroencephalography, electronic brain probes, guidance aids for the blind **7** FIBER-OPTIC TV VIDICON TUBES: for internal body examination **8** HIGH-POWER TUBES: for deep-seated heat treatment, general diathermy **9** IMAGE-CONVERTER TUBES: as an aid in cancer research **10** PHOTOMULTIPLIER TUBES: for tracer studies of cell growth, measurement of body fluid content, general diagnostics **11** MECHANO-ELECTRONIC TRANSDUCER TUBES: for measuring phasic blood flow, recording of the peripheral pulse, other physiological applications **12** COLOR IMAGE ORTHICONS AND COLOR PICTURE TUBES: for remote diagnostics, and as a teaching aid through observation of surgical techniques

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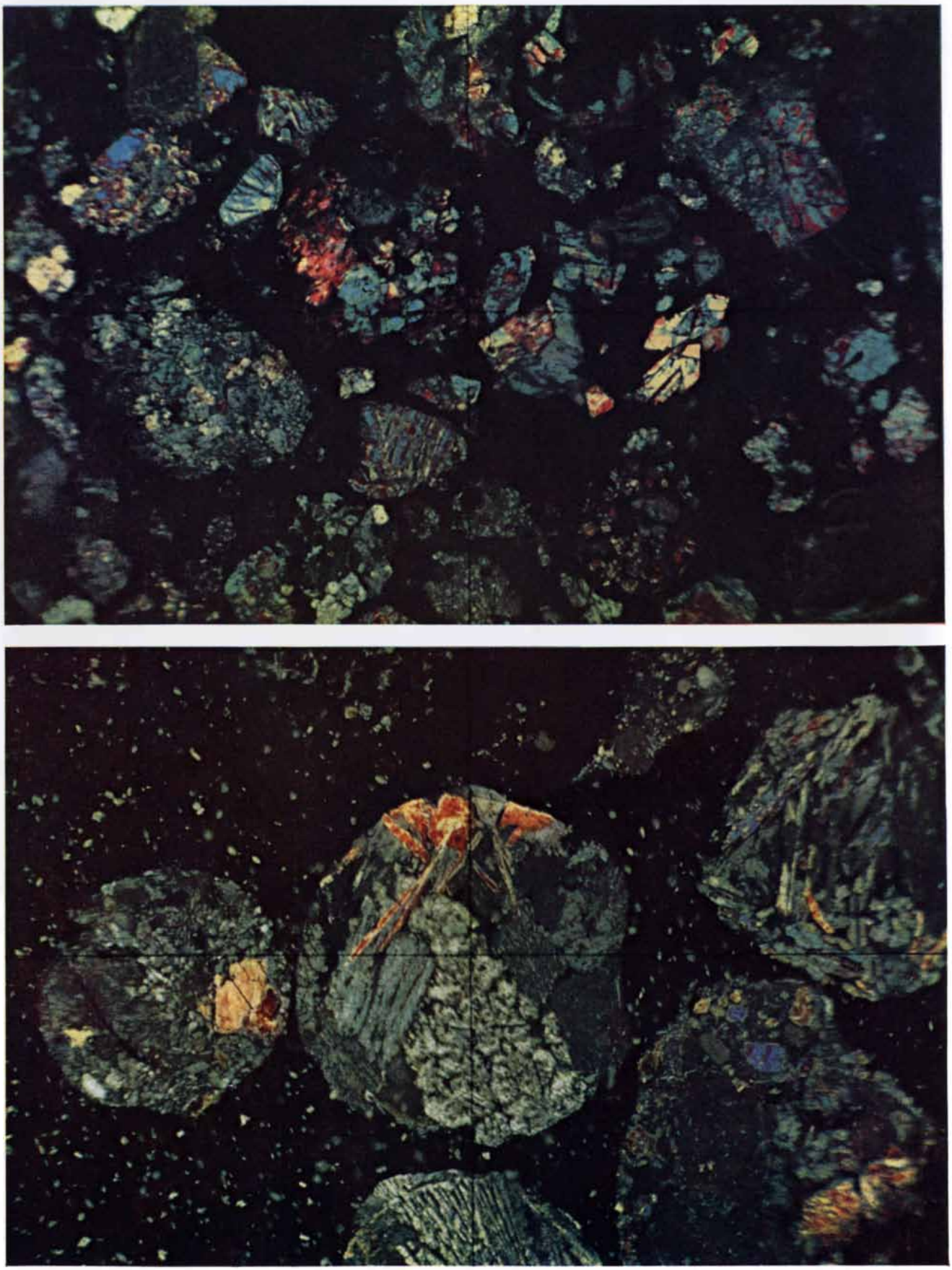


THIN SECTION OF CHONDRITE viewed through the microscope (*top*) is interspersed with chondrules (*colored bodies*). The photomicrograph at bottom shows round chondrules that have been removed from their matrix in a chondrite. The sections were photographed through polarizing filters, which here give the chondrules their color. Chondrules range from size of a pinhead to that of a pea.

Chondrites and Chondrules

The first are stony meteorites; the second, the small spherical bodies they contain. There is evidence that the chondrules date back to the opening stages in the evolution of the solar system

by John A. Wood

In 1802 an English chemist named Edward C. Howard cautiously titled a paper he had written "Observations on certain stony and metallic Substances, which at different Times are said to have fallen on the Earth." Howard seems to have been the first person to examine carefully the internal structure of stony meteorites, and in all four specimens he studied (stones from England, Italy, Bohemia and India) he found "abundant small bodies, some perfectly globular, others rather elongated or elliptical." Their size ranged from that of a pinhead to that of a small pea, and their color from gray to brownish.

At that time the idea that meteorites were of extraterrestrial origin enjoyed roughly the same reputation flying saucers do today. In 1803, however, the French village of L'Aigle was pelted by a shower of falling stones so dense (more than 2,000 were recovered) that the Académie des Sciences was moved to appoint a commission, headed by the eminent physicist Jean Baptiste Biot, to investigate the event. Biot's detailed report eliminated the possibility that the stones were a hoax or a terrestrial phenomenon. Soon the idea that meteorites are fragments of another planet or planets, probably broken up by mutual collisions, won wide acceptance.

After Biot's report museums began to collect meteorites enthusiastically. By 1864 almost 200 meteorites had been studied, and it was evident that the great majority of meteorite falls were stones containing Howard's "small bodies." In that year a classification of meteorites was set up by Gustav Rose, a German mineralogist; he named this majority class of meteorites "chondrites" after their peculiar internal structure. (*Chondros* was the ancient Greek word for "grain of seed.") The small, rounded bodies occurring in chondrites soon came to be called chondrules.

From the beginning investigators have tended to believe that chondrites are pieces of planetary matter in a very primitive state. If this matter is not still in exactly the form it took when the planets first coalesced, it is not many evolutionary steps removed from that form. Recent studies of chondrites and chondrules provide reinforcement for this concept and tell a story about the early history of the solar system.

The Antiquity of Chondrites

At first the belief that chondrites are primitive planetary matter stemmed largely from the mystique that is naturally excited by material from interplanetary space. In 1929, however, the first quantitative evidence appeared. At that time the astrophysicist Henry Norris Russell, working at the Mount Wilson Observatory, used solar spectrograms to make the first crude estimate of the relative abundances of the elements in the sun's atmosphere. He found that the abundance pattern for metallic elements matched the abundances in chondrites fairly well. Later and more precise work on the composition of the solar atmosphere showed the match to be quite striking [*see illustration on page 75*]. Apparently both sun and chondrites were made from the same parent material, and the metal content of both has remained unchanged since. If melting or some other form of material transfer had occurred in the chondrites, it would have segregated the elements and introduced large-scale heterogeneities in metal abundances from one chondrite to another. We know such fractionation occurs in the earth. No type of earth rock has metal abundances similar to those of the solar atmosphere.

In 1930 the German spectroscopists Ida and Walter Noddack pointed out additional evidence. They found that chondrites contain a more generous assortment of trace elements in measurable amounts than any type of earth rock does. In particular chondrites contain, mingled together, lithophile, chalcophile and siderophile elements—elements that respectively tend to associate with silicate and oxide material, sulfide material and metallic iron material. If the chondrites had been melted in the parent meteorite planet, or if any kind of extensive material transfer had occurred, the lithophile, chalcophile and siderophile elements would have tended to segregate themselves as they have in the earth.

Finally, isotopic-dating techniques developed during the past decade have shown that although chondrites are very old—older than any earth rock studied, their ages clustering around 4.6 billion years—they have been cold, inert bodies most of this time. Some chondrites have recently been found to contain excessive amounts of the rare isotope xenon 129 [see "The Age of the Elements in the Solar System," by John H. Reynolds; SCIENTIFIC AMERICAN, November, 1960]. Xenon 129 is produced by the decay of iodine 129, an isotope with a half life that is brief by cosmic standards: 16.4 million years. Those chondrites with excess xenon 129 must have cooled to a low temperature while they still contained some iodine 129, and they must have remained cold ever since, because heat would have driven xenon 129 out of the meteorite as fast as it was created by iodine-129 decay. We conclude that the time interval between the creation of the iodine 129 and final cooling of some chondrites was short—less than

BIRTHPLACE OF STARS is probably in dense clouds of gas and dust such as these nebulae, which contain stars regarded as young. At top is the Horsehead Nebula, part of the Great Nebula in Orion, at bottom the nebula NGC 6611 in Scutum Sobieski. Light of nebulae is emitted by atoms excited by radiation of nearby stars. Photographs were made with 200-inch telescope on Palomar Mountain.

100 million years. Therefore high-temperature evolutionary events could have occurred only during the first 2 per cent or less of the lifetime of these chondrites.

Chondrites fit rather well into the idea astronomers currently have of the nature of primitive planetary matter. For many years it was supposed that each planet condensed directly from a discrete mass of hot gas that had been torn from the sun (the Jeans-Jeffreys hypothesis). This concept was discredited, however, by a theoretical study showing that hot gas would not remain in discrete masses long enough to allow condensation. The view now held by most astronomers is that any condensation that occurred yielded a large number of small granules, or "planetesimals," and that later these particles were brought together to form the planets. According to this picture planetary matter was at first a conglomeration of planetesimals. Can it be that chondrules were the planetesimals? Studies of the intrinsic properties of chondrules and chondrites have given us part of the information needed to answer this question.

Chondrites under the Microscope

Much of this information has come from the study of meteorites with microscopes, a study begun by Rose and his contemporaries. The internal microstructure and mineralogy of a rock can best be disclosed by making a thin section of it. A slice of the rock is cemented to a glass slide and carefully ground down to the thinness of a sheet of paper. Silicate minerals ground this thin are quite transparent, so that a fragment prepared in this way can be viewed through a microscope. Thin-section studies established that the chondrules are unlike any structures occurring in terrestrial rocks but that they are composed mostly of olivine and pyroxenes, iron-magnesium silicate minerals common in the earth. They also contain small amounts of feldspar, iron sulfide and sometimes nickel-iron metal, a natural "alloy" peculiar to meteorites. Moreover, microscopic observations allowed two inferences to be drawn about the history of chondrites.

First, it was noted that chondrules are much more conspicuous in some chondrites than in others. In a few the chondrules are quite sharply defined and occur embedded in an opaque black matrix. In others the chondrules are scarce and hard to distinguish from their surroundings, the entire chondrite being nearly uniform in granularity and mineralogy. All gradations between these conditions were observed among the chondrites. We know that when rocks or metals are held for months or years at high temperatures (but not melted), the textures they had at first are often replaced by systems of new, coarser crystals. This recrystallization, or metamorphism, to use a geological term, occurs entirely in the solid state. Petrographers concluded that all chondrites once had clear-cut chondrules but that many, like the stone from Milena shown in the top illustration on the next page, have been recrystallized by heat. Presumably they were heated in the interior of their parent planet or planets.

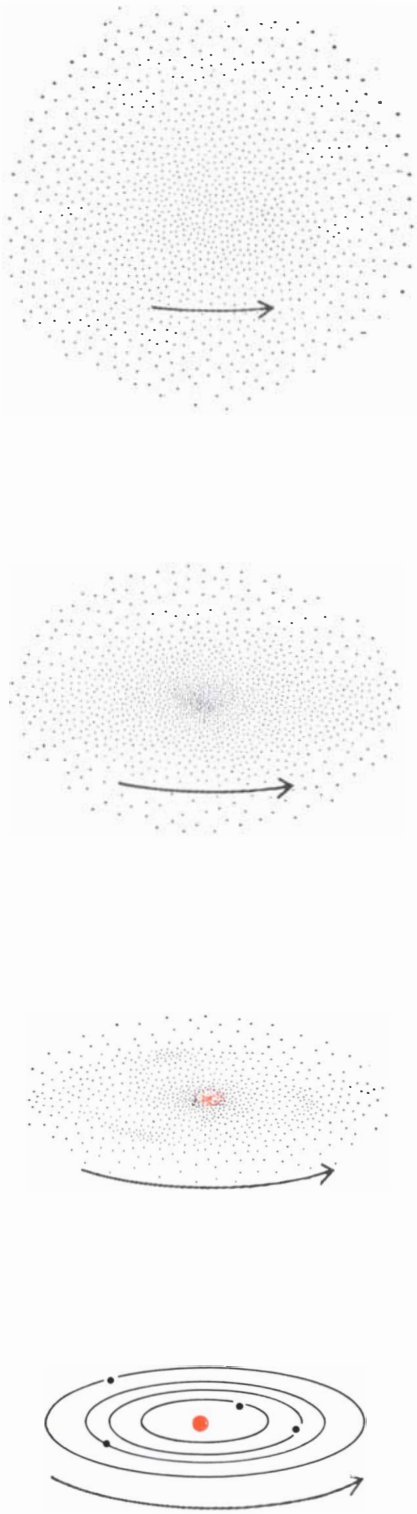
The second inference concerns the chondrules themselves. Some were found to contain glass, evidence that they had been melted and then rapidly chilled. Glassy chondrules occur only in relatively unrecrystallized chondrites, so that the melting cannot be associated with the metamorphic heating just described. The presence of glass, the anhydrous or high-temperature character of chondrule minerals, the igneous texture of some chondrules and their spheroidal shapes—all these distinctive features of the chondrules pointed to the conclusion that they had once been dispersed droplets of hot molten silicate: a "fiery rain," in the words of the 19th-century English microscopist Henry Clifton Sorby. Some or all of the droplets had cooled rapidly on a time scale of minutes or even seconds.

The Formation of Chondrules

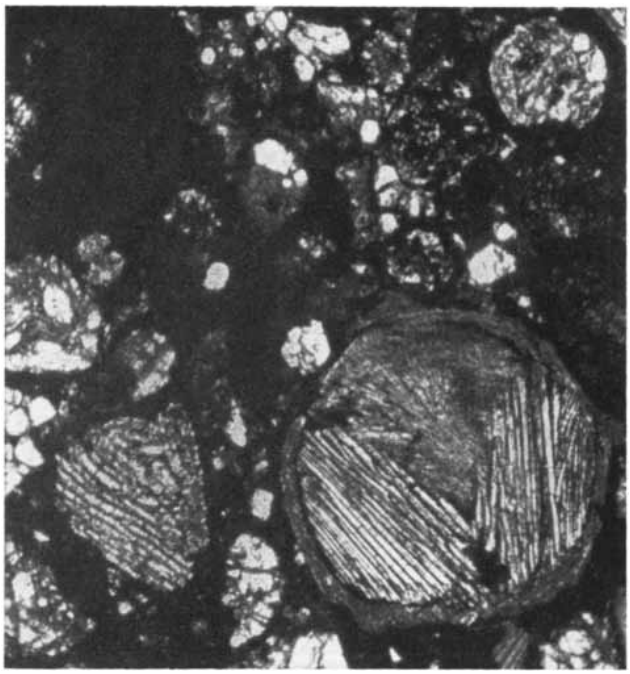
Many investigators have speculated on the origin of these hot droplets. Most have concluded that the droplets were created on or in parent meteorite planets and that truly primitive planetary matter did not contain chondrules. They thought chondrules might be lava droplets that were ejected from volcanoes on the planets, or the molten debris of high-velocity collisions between planets.

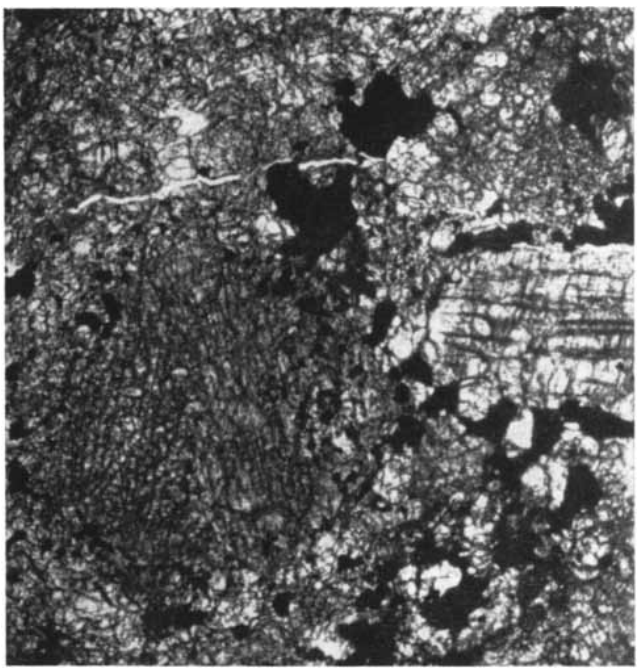
A few workers have suggested, however, that chondrules were actually the first solid particles in the solar system and that these subsequently accreted to form the inner planets, including the earth. Naturally, no traces of chondritic character would be preserved on the earth today. Complex evolutionary processes—weathering, sedimentation, melting—have reworked the earth's crust time after time.

Strong evidence has recently come to hand that this latter hypothesis is probably true. Craig M. Merrihue and Robert



BIRTH OF SOLAR SYSTEM, according to current views, is depicted schematically in four steps. Vast cloud of interstellar gas and dust (*top*), spinning from galactic rotation, had change of density causing start of collapse from self-gravitation (2). As cloud neared size of present solar system, intensifying spin had made it a disk-shaped nebula (3) with dense mass, a protosun, at center. The sun and planets then evolved (4).



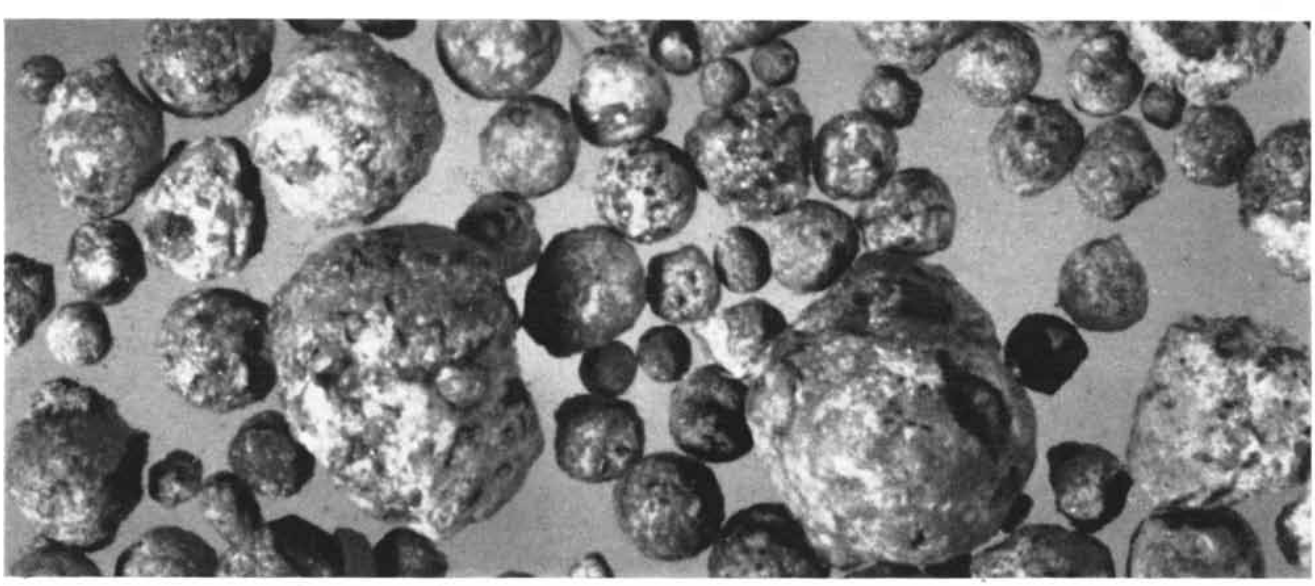


CONSPICUOUSNESS OF CHONDRULES varies among chondrites. At left is microscopic view of a thin section of a chondrite that fell at Tieschitz in Czechoslovakia; its round chondrules are distinct. At right is similar view of chondrite that fell at Milena in Yugoslavia. It has undergone recrystallization, probably from prolonged heating in parent planet; the chondrules are indistinct.

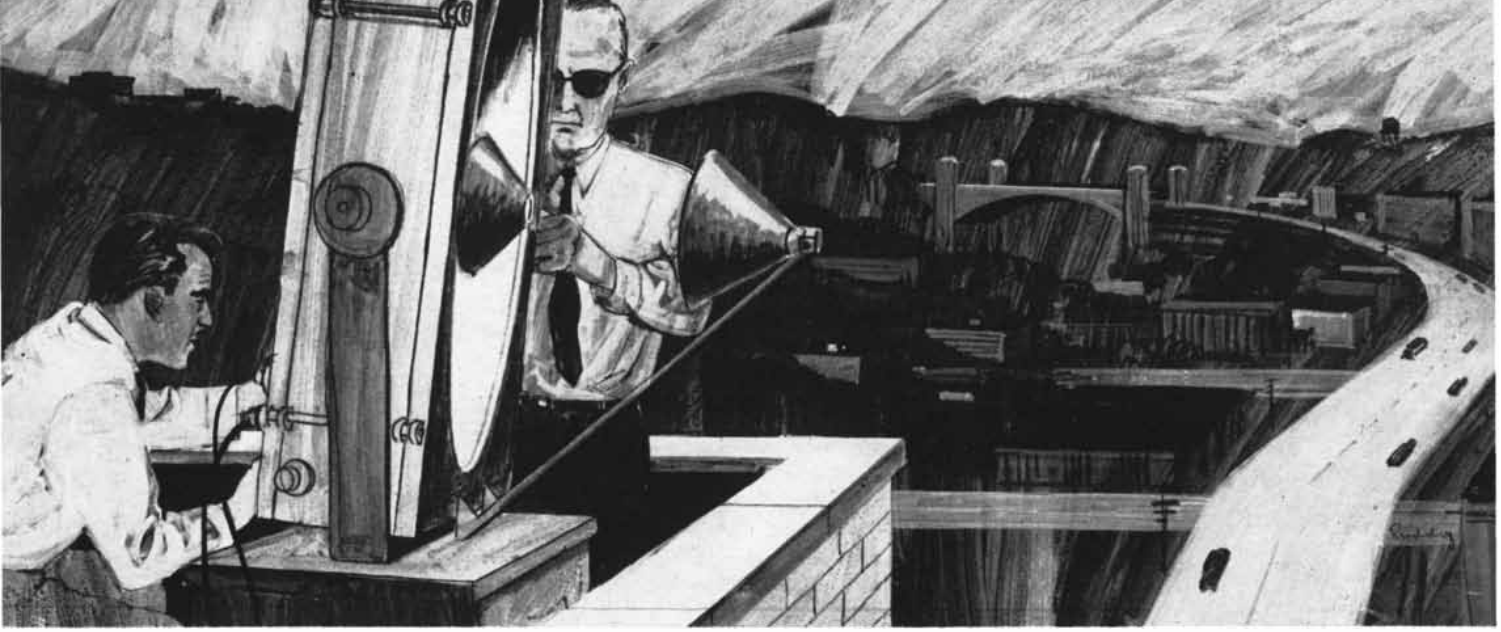
O. Pepin, graduate students working with John H. Reynolds at the University of California at Berkeley, have separated chondrules from chondrites, extracted the xenon from them and measured its mass spectrum. In chondrules from the chondrite that fell at Bruderheim in the Canadian province of Alberta they found the isotopes xenon 124 and xenon 126 to be more abundant than they are in terrestrial xenon by as much as a factor of three. As far as we know this surplus xenon 124 and xenon 126 can only have been made in the proportions observed by the reaction of high-energy protons or alpha particles (helium nuclei) with certain trace elements in the chondrules, particularly tellurium and barium.

Present-day cosmic radiation is not nearly intense enough to produce the effect. There is only one obvious way in which the chondrules might have been exposed to particle bombardment: they were dispersed in space at a time when the sun or protosun was emitting a dense flux of high-energy protons and alpha particles similar to the solar flares we observe today. If the chondrules had not been dispersed, most of them would have been shielded from the bombardment by overlying planetary material, inasmuch as high-energy protons can rarely penetrate more than one meter of rock, and alpha particles are stopped by one millimeter.

There is also evidence of a chemical nature that chondrules were the original solid particles in the solar system. It is



SEPARATED CHONDRULES show the spheroidal shape of these small bodies that characterize chondrite structure. The name of both objects comes from *chondros*, the ancient Greek word for "grain of seed." Largest chondrules yet found are size of a pea.



1933 target: vehicles on a highway

1963 target: vehicles in space

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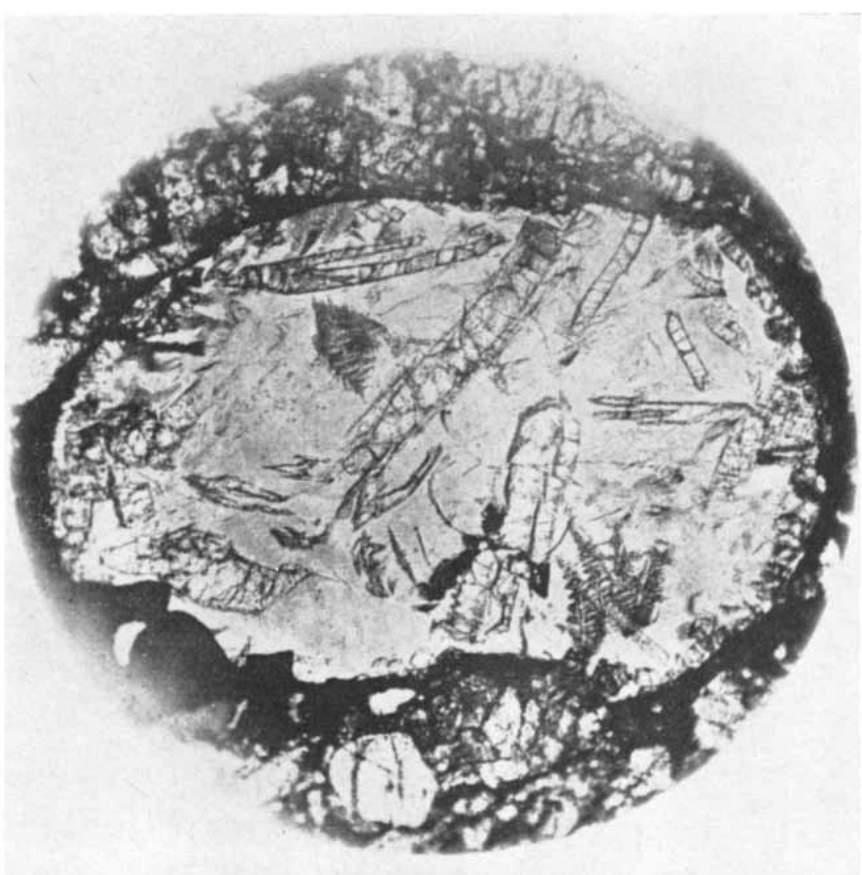
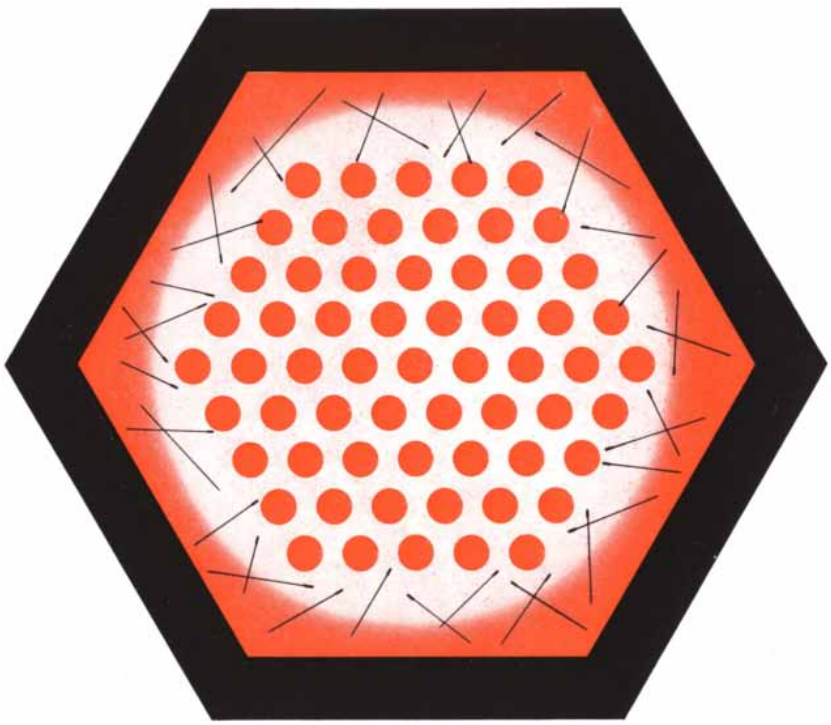
believed that the solar system condensed from hydrogen-rich gases, almost the same in composition as the sun is now. Thermodynamic calculations show that the hydrogen in such a gas would reduce iron oxide, that is, it would react with the oxide, removing oxygen and leaving iron metal. (In the reducing atmosphere of a blast furnace, for example, carbon takes up the oxygen from iron oxide to free the iron.) If the chondrules were once hot molten droplets in the cloud, any iron oxide they contained would have been reduced. We might expect to find iron metal in them after they had cooled, but they should be almost devoid of oxidized iron.

When we analyze the chondrules in unrecrystallized chondrites, such as those found at Renazzo in Italy or at Tieschitz in Czechoslovakia, we find that this is precisely the case. The elemental content of structures as small as chondrules can be measured by optical, X-ray or arc spectrographic techniques. The recently developed electron-probe microanalyzer offers a particularly effective means of measurement. A polished surface of the specimen is placed in the vacuum chamber of the instrument and a beam of electrons, accelerated to about 25,000 electron volts, is made to impinge on it. The beam is focused in a spot a few microns in diameter on the specimen surface. The specimen acts like the target in an X-ray tube; X radiation characteristic of all the various elements present immediately under the bombarded spot is generated. Analysis of the X-ray spectrum yields the elemental composition of that small volume. By such means it has been shown that the Renazzo chondrules contain abundant nickel-iron metal but little iron oxide: only .5 to 2 per cent by weight.

The chondrules in recrystallized chondrites, however, contain substantial amounts of oxidized iron, up to 16 per cent. How can this iron be accounted for if the chondrules once existed under reducing conditions? The question is a fairly crucial one. Perhaps the chondrules after all were never associated with the solar nebula or any other environment that would prevent them from containing abundant oxidized iron. Perhaps they have contained oxidized iron from the time they were formed, and the comparatively few chondrites containing reduced chondrules, like the Renazzo



GLASSY CHONDRULES such as that shown here are evidence that chondrules were once molten bodies that cooled rapidly, since glass can only be formed in this manner. The fern-like, microcrystalline structures visible are characteristically found in quenched glasses.



PROGRESS IN COMPACT NUCLEAR POWER PLANTS

Extensive preliminary studies of advanced mobile and transportable nuclear power plants have been made by Aerojet-General Nucleonics, using proven technology and components derived from America's first mobile nuclear power plant, the ML-1. The ML-1 is being developed by AGN for the Atomic Energy Commission and the Army Corps of Engineers. ■ The AGN studies covered the power range from 100 kw to 3 Mw—with applications ranging from the Antarctic to space, and emphasis on economy, reliability, and safety. ■ Fundamental to these studies: a practical, straight-forward fuel element successfully operated for 10,000 hours at full power, at a coolant temperature of 1200°F . . . with no fission product release . . . and no sign of failure. ■ Based on these results, core lifetimes of several years are clearly feasible. ■ For information on AGN's programs in mobile nuclear power, write for AGN Active File #2.

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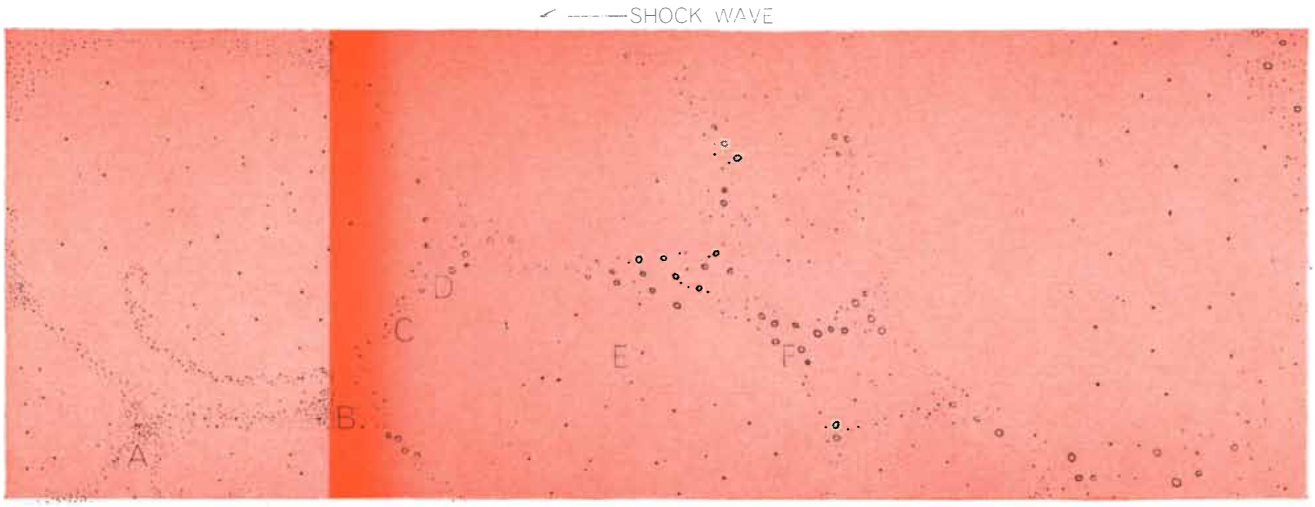
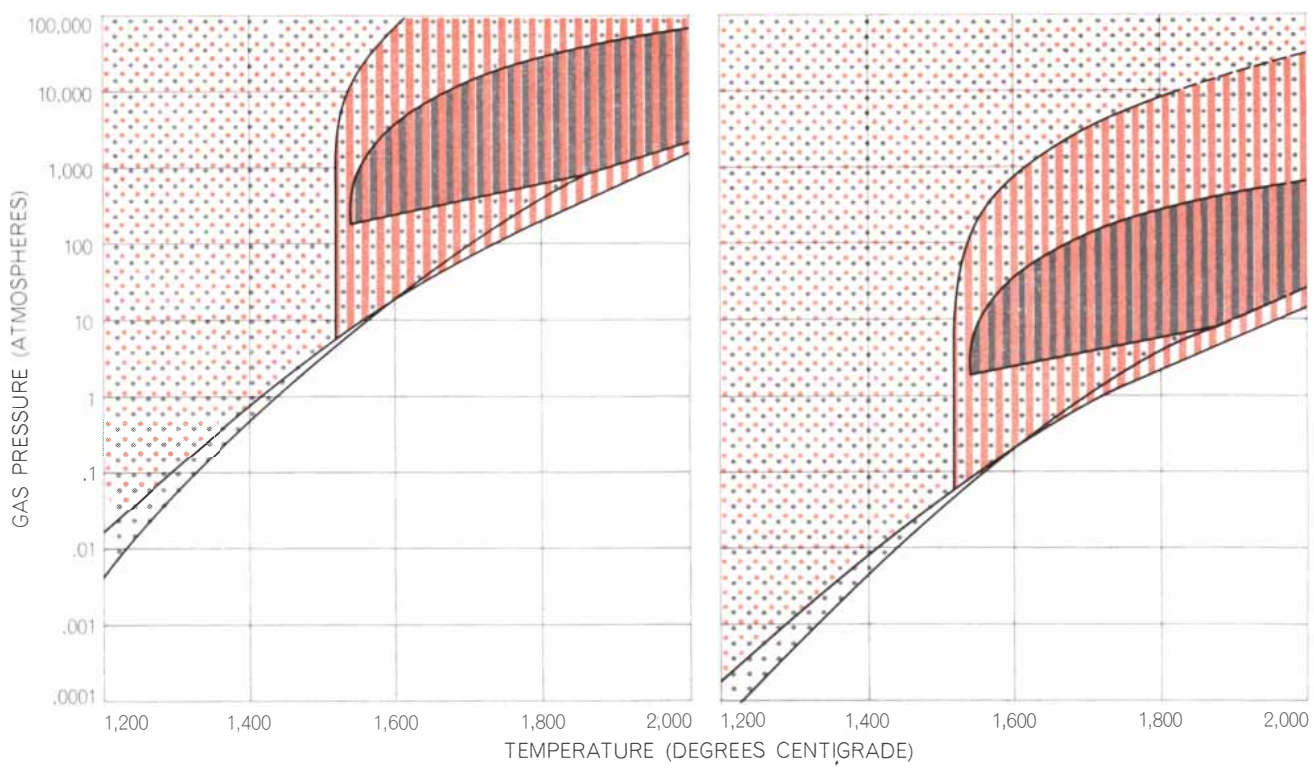


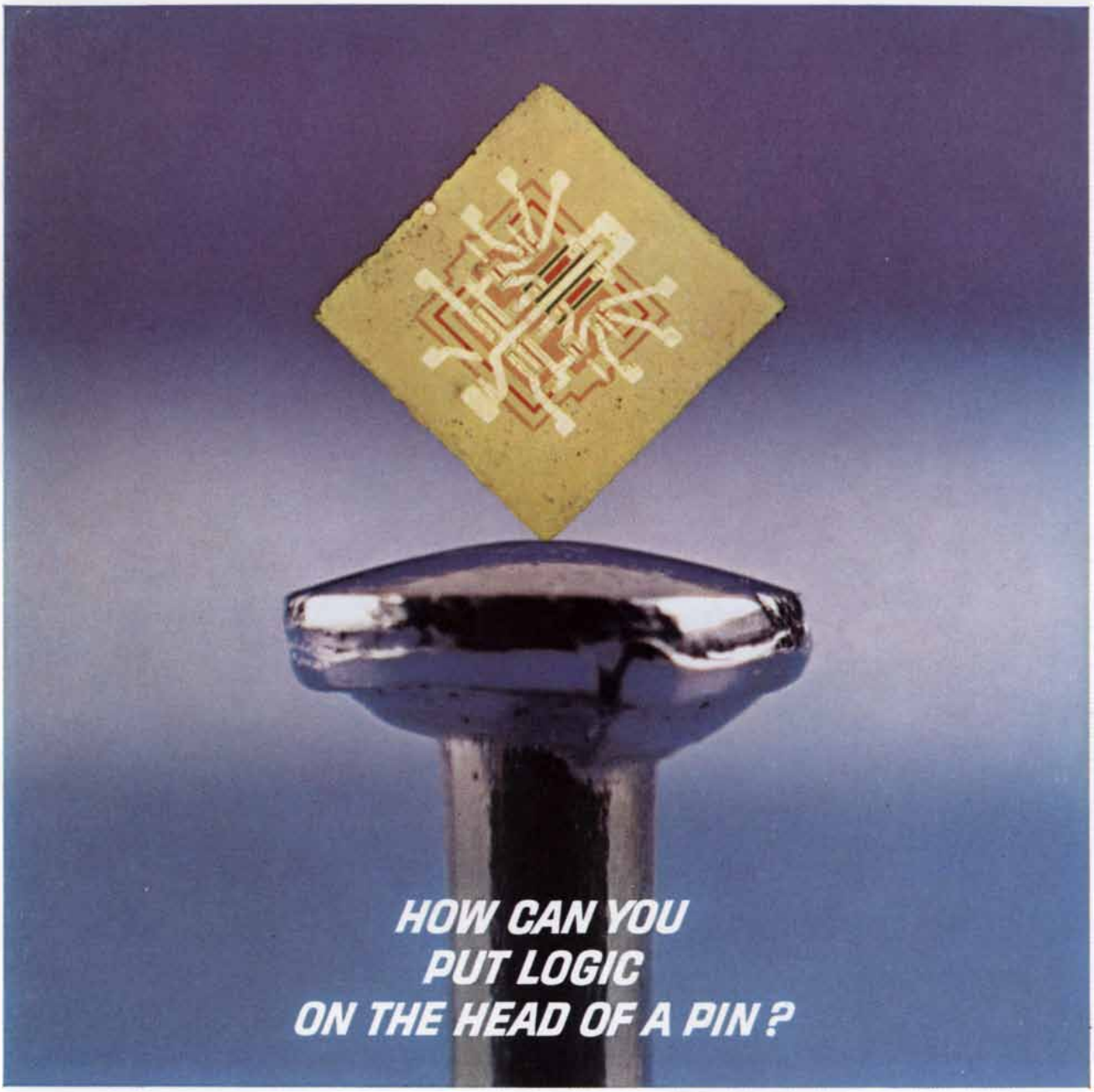
FORMATION OF CHONDRULES may have occurred when a shock wave passed through the solar nebula, as shown in this diagram. Intensity of color reflects gas density at various stages of the process. As wave passed, dust gathered between turbulent eddies (*A*) was vaporized (*B*) by compressional heating. On decompression and cooling, tiny liquid droplets recondensed (*C*) in metal-rich regions and then many of them coalesced through collision (*D*), forming chondrules. After more cooling chondrules became solid (*F*). Meanwhile in metal-poor regions (*E*) product of recondensation was dust grains; they and chondrules accreted as planets.

and Tieschitz stones, were the product of complex and atypical circumstances.

It turns out that the iron-oxide content of chondrules correlates strongly with the degree of recrystallization observed in the chondrules in which they occur. Could the oxidized iron have been introduced into the chondrules during recrystallization? It is possible; the iron would not have to move very far. In unrecrystallized chondrites such as those of Renazzo and Tieschitz the fine-grained black matrix material between the chondrules contains abundant oxidized iron in the form of the mineral magnetite. We know that in such a situation the oxidized iron would "want" to move from the magnetite into the chondrules; magnetite is thermodynamically unstable in a rock of chondritic composition, and the chondrules contain olivine and pyroxenes—stable minerals that can accept oxidized iron in their crystal lattices. Oxidized iron would have been free to



PRESSURE AND TEMPERATURE REQUIRED for liquid droplets and solid particles to exist in the solar nebula are shown in these diagrams. At left gas is assumed to be same as sun's; silicate liquids can exist in gray-striped region and silicate solids in gray-dotted area, iron-metal liquids in colored-bar area and solid iron in area of colored dots. In blank region only vapors are stable. Diagram at right assumes enrichment of metal vapors in gas by factor of 100; liquids could exist at correspondingly lower pressures.



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A HAND IN THINGS TO COME

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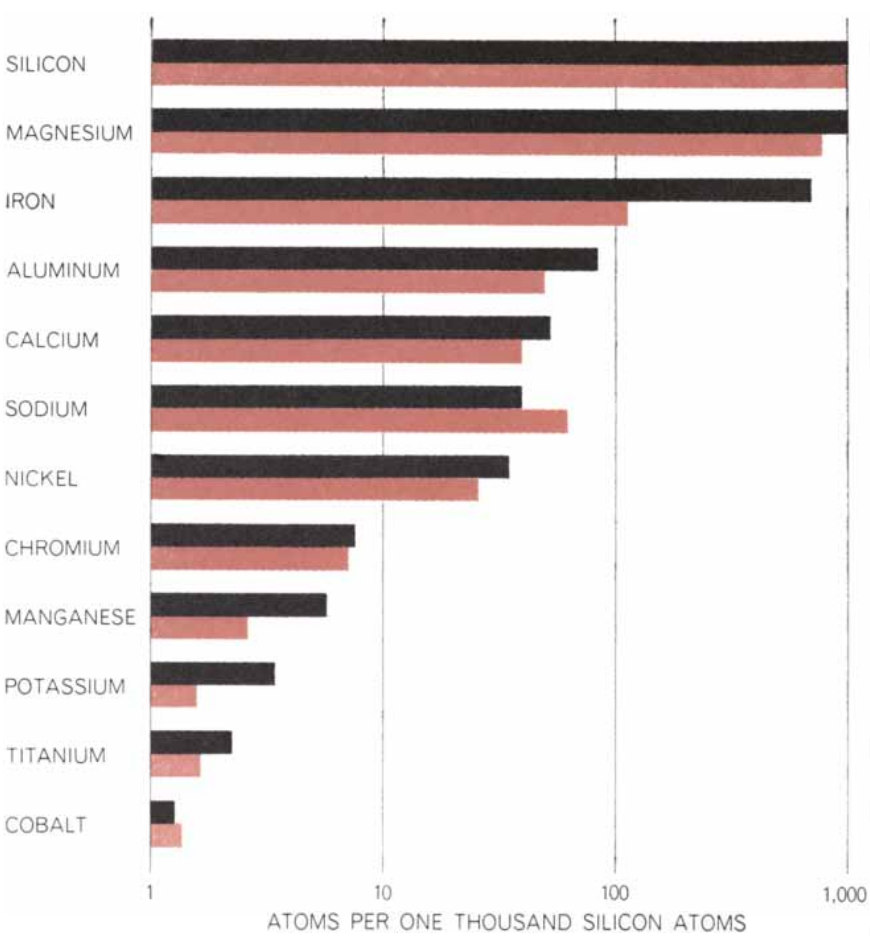
make this move when the thermal recrystallization of most chondrites occurred; high temperatures render atoms mobile, able to diffuse through crystal lattices. The amount of heating necessary to move the oxidized iron from the matrix of the Renazzo and Tieschitz chondrites into their chondrules can be estimated: 10 million years at 500 degrees centigrade, 40,000 years at 700 degrees C. or 1,000 years at 900 degrees C. Evidence of such small-scale chemical migrations is common in metamorphic earth rocks.

It seems that oxidized iron must have moved into the chondrules at some time after they were formed. There is chemical evidence that all chondritic material, including the chondrules, was once in a highly reduced state, with nearly all iron in the form of metal. Chondrites can be divided into several subclasses on the basis of their chemical composition. Among the subclasses the atomic ratio of iron in all forms to silicon varies widely [*see illustration on next page*]. Iron evidently was fractionated in varying degrees with respect to silicon at some stage in the history of chondrites. The ratio of nickel to iron, however, is essentially the same for all the subclasses; the process that fractionated iron also fractionated nickel to the same degree. This could have happened only if all the iron and nickel were once in the metallic state, in the form of an alloy of nearly constant composition.

The fractionation of iron with respect to silicon could have been accomplished simply by mixing the nickel-iron alloy with silicate minerals in different proportions. It is not hard to imagine this happening in a system of dispersed chondrules before they accreted into planets. Chondrules contain varying amounts of nickel-iron metal. The metal-rich chondrules are substantially heavier than the metal-poor ones. If chondrules were dispersed in a turbulent gaseous nebula, some degree of sorting was bound to occur, concentrating denser metal-rich chondrules in one region and lighter ones in another, just as sand and pebble grains are sorted in stream beds.

Both the Merrihue-Pepin findings and the evidence that all chondritic material was once in a reduced state make it seem fairly certain that chondrules were



CHONDRITES AND SUN show close correlation in metals content, indicating origin from common material. Gray bars represent chondrites; colored, sun. Only major variant is iron.

among the planetesimals that conglomerated to form the terrestrial planets. Judging from the composition of chondrites such as the Tieschitz and Renazzo stones, roughly half of the matter that accreted was chondrules. The other half —the black material between chondrules in these chondrites—is ultrafine-grained, so that presumably it was dispersed as a fine dust before accretion. It is similar in over-all composition to the chondrules, except that its iron is oxidized. Later we shall see why the matrix of a chondrite might contain oxidized iron whereas its chondrules do not.

The Primordial Solar System

It is appropriate now to consider how this background of information about chondrites and chondrules contributes to the reconstruction of the origin and early history of the solar system and, in particular, how the "fiery rain" of chondrules fits into the scheme. It is reasonably certain that planetary systems are a normal by-product of the condensation of stars from interstellar clouds of gas and dust. Interstellar clouds such as the Great Nebula in Orion [*see illustration on page 66*] are often populated with stars of the types designated O, B and T Tauri, types thought to be relatively young. Studies have been made of why and how a gas cloud would evolve into a star, based on our knowledge of the influence of gravity, the behavior of gases as temperature and pressure vary and the flow of thermal energy in gas systems. The process is not fully understood, and there are important differences in the models proposed by different astrophysicists; nevertheless, it is possible to sketch the broad outlines.

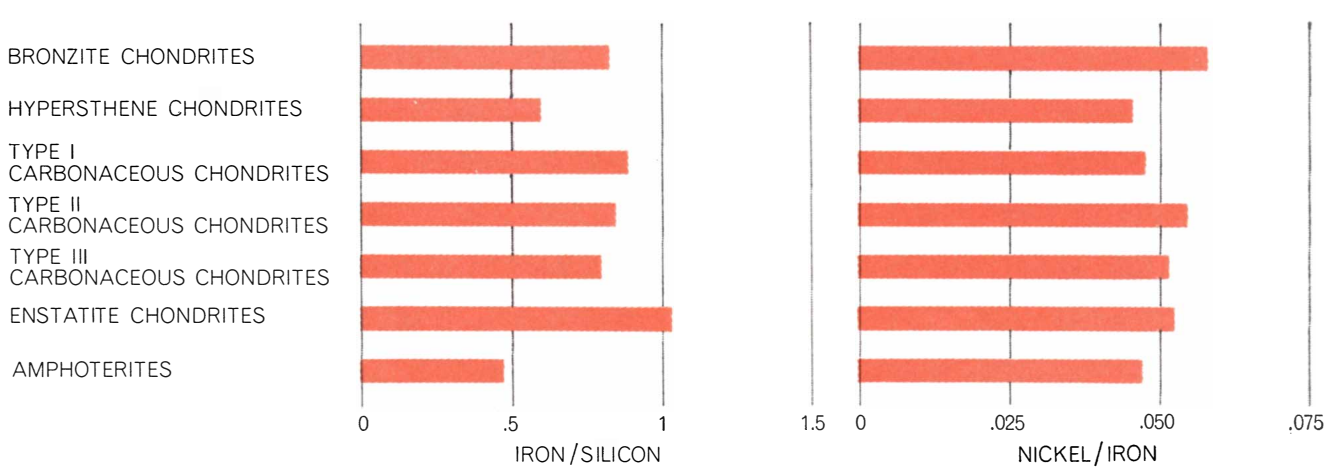
The space between stars in our galaxy is not really empty. It contains thinly dispersed gas (hydrogen, helium and neon) and tiny solid grains, ranging in size from a hundred-thousandth to a ten-thousandth of a centimeter, in which all the other elements are frozen. The density of the interstellar gas is about one atom per cubic centimeter.

The interstellar matter is not uniform in density. There are thin regions and dense regions, and over long periods of time these fluctuate. It is believed that the fluctuations sometimes create a region or cloud so dense and so large that self-gravitation—the attractive force exerted by each portion of the cloud on the rest of the cloud—overwhelms the other forces that act on it and causes the cloud to fall together. As it collapses, its density everywhere increases, and soon particularly dense parts of the cloud probably begin to collapse on themselves. The cloud breaks up into numerous collapsing subsystems, many with masses comparable to that of the sun. It is supposed that the solar system was formed from one such collapsing cloud fragment.

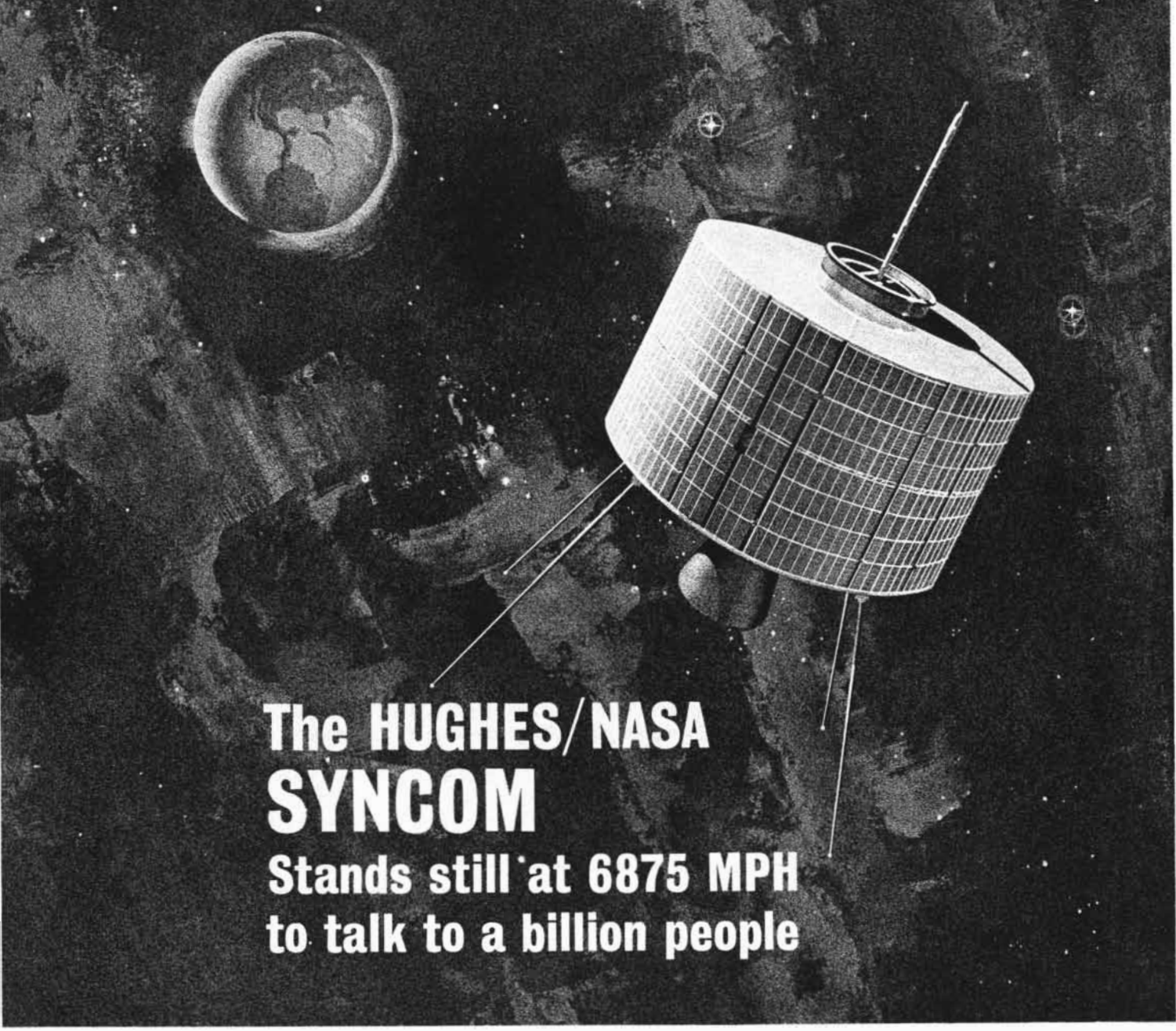
Every cloud would have possessed some angular momentum, or spin, before it began to collapse, if only because it was part of a galaxy that is itself rotating. As the subcloud that was to become the solar system fell together its angular momentum was largely conserved; it rotated faster and faster, as a spinning figure skater rotates faster when he pulls in his arms. By the time it approached the size of the present solar system, rotation had given the cloud the form of a flat disk with a concentration of mass—a protosun—at its center.

The cloud was at first very cold, probably about 50 degrees Kelvin (degrees centigrade above absolute zero). Collapse caused its gas to be compressed, and this generated heat. At first the heat was radiated into space as fast as it was created. Then, as the cloud continued to contract, the dust grains in it came closer together, causing it to become less transparent to radiation. Heat generated by compression began to accumulate and the temperature rose. At higher temperatures hydrogen molecules absorbed increasing amounts of radiation, storing the energy in the form of the rotation and vibration of molecules. This further decreased transparency. According to a recent theoretical study made by A. G. W. Cameron and Dilhan Ezer of the National Aeronautics and Space Administration's Institute for Space Studies, by the time the protosun had collapsed to 50 times the radius of the present sun its average temperature was more than 3,000 degrees Kelvin, its central temperature was nearly 200,000 degrees K. and it was almost completely opaque to its own radiation. Previously the collapse of the system had been unchecked, but now mounting temperature brought about gas pressures high enough to balance the force of gravity that was trying to pull the system together. Collapse ceased.

A sphere of gas in which gravity is everywhere balanced by pressure, and in which radiative heat transfer from one region to another is prohibited, is said to be in polytropic equilibrium. The protosun was now in this state. Heat moved comparatively slowly in gas convection



METALLIC ELEMENTS in chondrites indicate that chondritic material was once in reducing atmosphere, such as solar nebula. Iron was fractionated in relation to silicon, as shown by bars at left giving atomic ratio of iron to silicon by chondrite subclasses. But the process that fractionated iron also fractionated nickel, since the nickel-iron ratio is almost identical (*right*). The close association of nickel and iron indicates that all the iron was in a metallic state, alloyed with nickel, at the time of fractionation.



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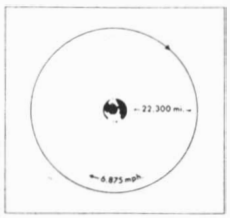

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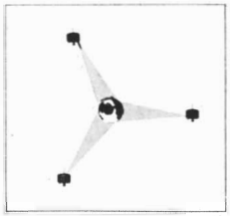

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currents from its interior to its surface, there to be radiated away. Heat lost at the surface had to be balanced by the generation of new compressional heat, so that the protosun slowly contracted. By the time it had shrunk to nearly the size of the present sun, its central temperature had increased to about 20 million degrees K., giving rise to thermonuclear reactions. A temperature was finally reached at which thermonuclear reactions generated exactly as much heat as the sun radiated from its surface. There contraction halted, and since then the sun has remained in essentially the same steady state.

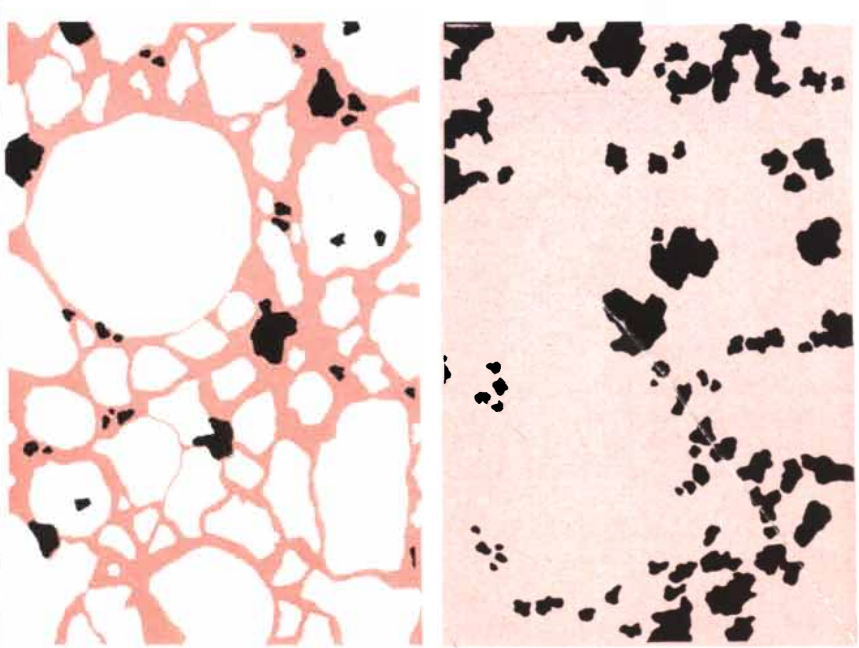
The Evolution of Chondrules

The solid grains that were included in the collapsing cloud fragment would have been evaporated at an early stage by increasing temperature. The metal vapor they yielded, however, would have had a chance to recondense near the surface of the protosun as convection currents continuously moved the gas upward into regions of lower pressure and temperature. Could chondrules be the product of this condensation?

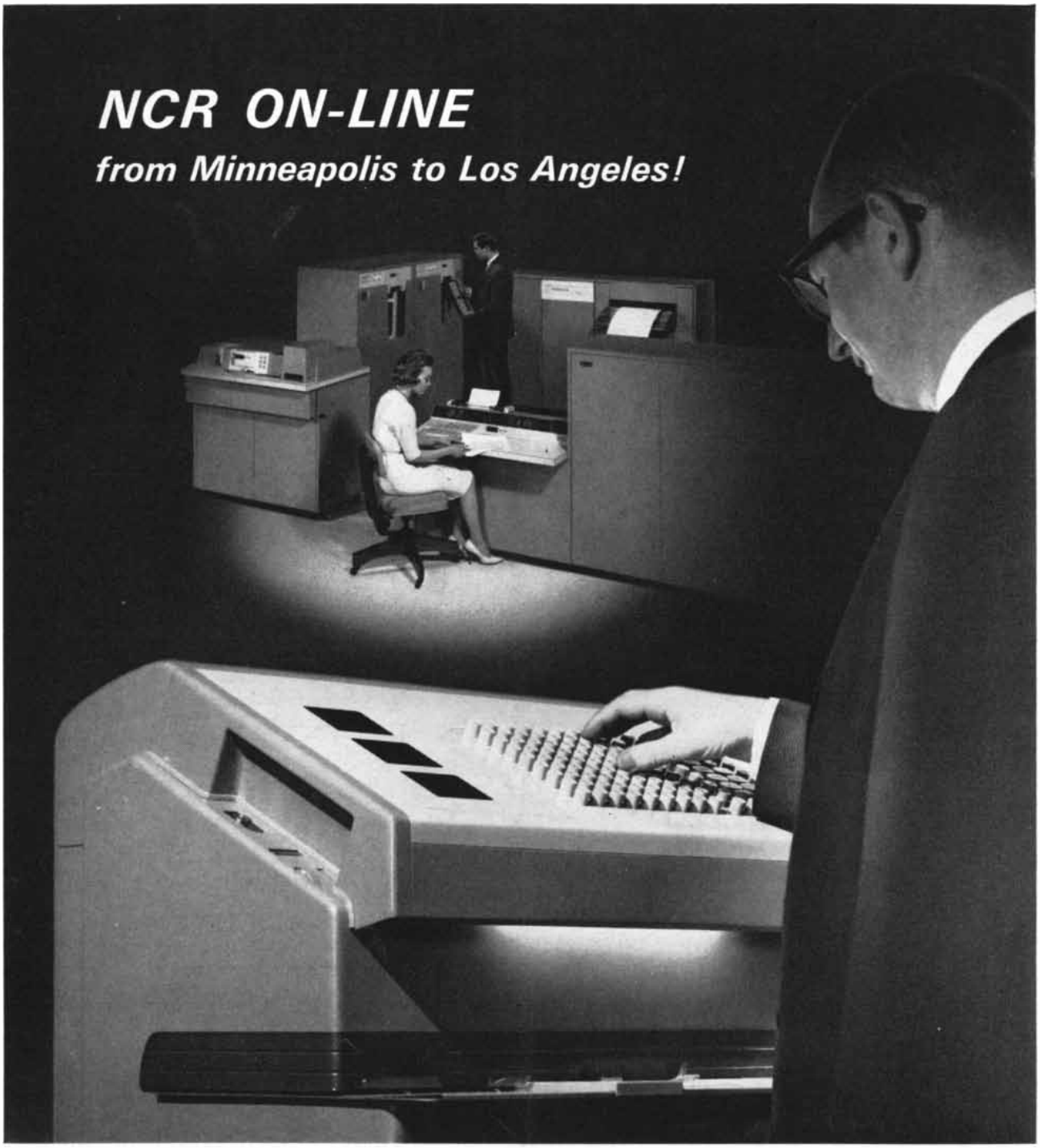
Apparently not. The difficulty lies in the stringent physical conditions that have to be satisfied in order to have silicate liquids coexist with a gas of solar composition. A diagram showing the conditions for stability of magnesium silicate liquids and iron-metal liquid (the two principal constituents of chondrules) in a solar gas can be constructed [*see bottom illustration on page 72*] by taking into account the thermodynamic properties and abundances of the substances in the gas phase and the properties of potential condensed material (magnesium silicates and iron metal).

We see that liquid droplets would be stable in the protosun only at rather high pressures, more than one atmosphere (15 pounds per square inch) for liquid iron and more than 100 atmospheres for silicate liquids. To be sure, the bulk of the protosun would have been at higher pressures than these during terminal stages of contraction. But our knowledge of the properties of polytropic spheres tells us that regions of high pressure would also be regions of enormously high temperature. Gas at a pressure of 1,000 atmospheres would necessarily have a temperature of 100,000 degrees K. or higher. Conversely, gas near 1,700 degrees would be at very low pressure: a thousandth of an atmosphere or less. The juxtaposition of high pressure and moderate temperature—1,000 atmospheres and 1,700 degrees—necessary for the existence of liquid droplets would not have been even remotely approached in the protosun. Any condensation that occurred in the protosun convection cells must have been directly from the vapor state into solid grains, and laboratory experience tells us that the grains produced would have been extremely small.

It seems, then, that chondrules can only have been made in the nebula sur-



OXIDIZED IRON shown in color is concentrated between chondrules in primitive chondrite (*left*), but during recrystallization it moves into chondrules, as represented at right.



At a recent NABAC Convention held in Minneapolis, NCR demonstrated its On-Line Bank System and Software to hundreds of bankers.

Typical bank saving transactions were entered on a Class 42 Window Machine located on the convention floor and transmitted to a 315 CRAM Computer System at NCR's Data Processing Center in Los Angeles, California.

The 315, operating under control of the On-Line Package Program developed by NCR, processed each transaction by selecting the proper account . . . verifying the old balance . . . updating the central record . . . establishing the required controls . . . and returning the updated transaction to the Class 42 for printing in the customer's passbook.

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rounding the protosun. It is true that in most of the nebula temperatures were too low to allow the existence of liquid droplets; in general, metallic elements must have been present in the form of very fine dust grains. Some of these may have been original interstellar grains that never got hot enough to evaporate; others, grains of matter that condensed in the outer layer of the protosun and then found their way out into the nebula.

Yet there must have been periods of high temperature and pressure in the nebula in which liquid droplets were stable; otherwise chondrites would not contain "abundant small bodies" that show the isotopic effect of particle bombardment. The only ready explanation for these transient temperatures and pressures is that massive shock waves propagated through the nebula from time to time. During the passage of a shock wave [*see top illustration on page 72*] the nebula would at first be compressed and compression would raise its temperature; then after a short time it would decompress and cool. In some cases during the heating phase the dust grains in the nebula evaporated, and during the cooling phase the metal and metal-oxide vapor recondensed into liquid droplets.

The rapidity of cooling after passage of a shock wave is an attractive feature of this hypothesis. We have seen that some of the chondrules contain glass, and these must have cooled quite rapidly—in a matter of minutes or less—in order to be quenched into glass and prevented from crystallizing.

There is every reason to believe that shock waves did traverse the nebula. Events must have occurred in the protosun that are similar to the solar flares we observe today, and these would have injected huge impulses of energy into the surrounding nebula. (Flares are thought to be caused by the local annihilation of part of the sun's magnetic field. The energy that had been bound up in that part of the magnetic field is then dissipated in the form of a massive electrical discharge.)

The shock pressure need not have been as high as 1,000 atmospheres. There may have been a tendency for solid dust grains to be concentrated in certain regions of the nebula—near its equatorial plane, for example, or in the stagnant regions between eddies of turbulent gas. If so, after shock heating and grain evaporation such a region would be richer in metal vapors than other parts of the nebula. The diagram at the left at the bottom of page 72 locates the liquid region on the assumption that metal

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vapors were just as abundant in the nebula as they are in the solar atmosphere today. If, however, metal was locally concentrated in the nebula, the pressure requirement for liquid condensation in the metal-rich region would be *decreased* by the same factor as the metal concentration was *increased*. For example, liquid stability in a region where metallic elements were 100 times more abundant than was average would require a pressure of about 10 atmospheres, not 1,000.

The Two Types of Condensate

After the passage of a shock wave, gas would not always cool through the region of pressure and temperature required for the condensation of liquid droplets, so that much of the recondensation during cooling would have yielded very small solid grains. In time both types of condensate—chondrules and fine dust grains—would occur mixed together in the nebula.

Although the gas was a reducing environment at high temperatures and produced chondrules with little oxidized iron, at low temperatures the same gas is capable of oxidizing iron. Below 100 degrees C. water vapor in the gas tends to turn iron metal to magnetite. Because of their small size dust grains made of iron would be quickly oxidized. But most iron metal in the chondrules would be shielded from oxidation because of its coarser grain size, and also because it is often buried inside silicate minerals. Consequently, if the condensate particles were not exposed to cool gas for a very long time but instead soon conglomerated into planets, we would expect the accreted matter to consist of metal-bearing chondrules mingled with fine-grained magnetite-bearing material. This curious juxtaposition of highly reduced and highly oxidized matter is precisely what we find in the primitive chondrites of Renazzo and Tieschitz.

It is quite likely, then, that chondrites—and in particular their chondrules—are witnesses of the time when the solar system was born. This is an exciting idea. Only recently have we begun to study chondrules as entities. They contain a wealth of information—isotopic, chemical, mineralogical—about the processes that have acted on them. We may be able to learn about the nature and evolution of the solar nebula, the formation of the planets, some stages of the evolution of the sun and the time scales for all these processes. The chondrules have begun to tell a fascinating story.

CUTTING TOOL

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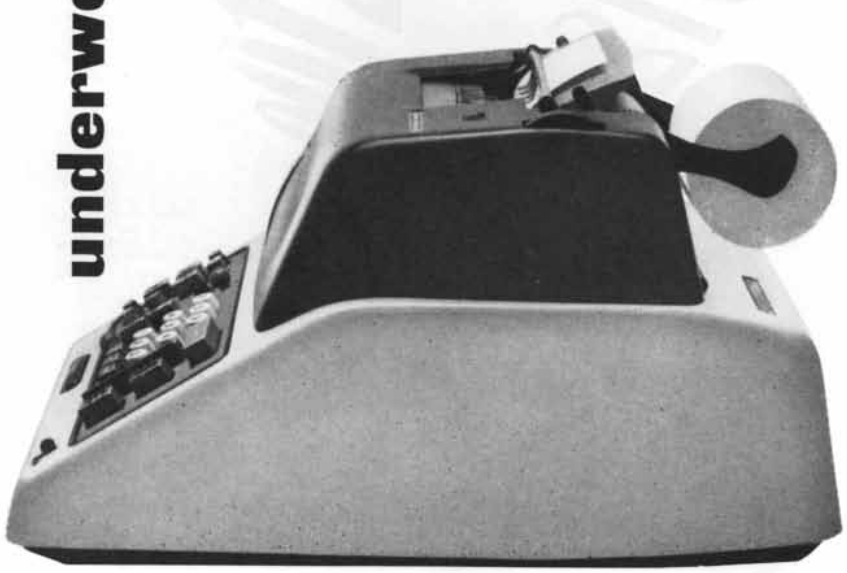
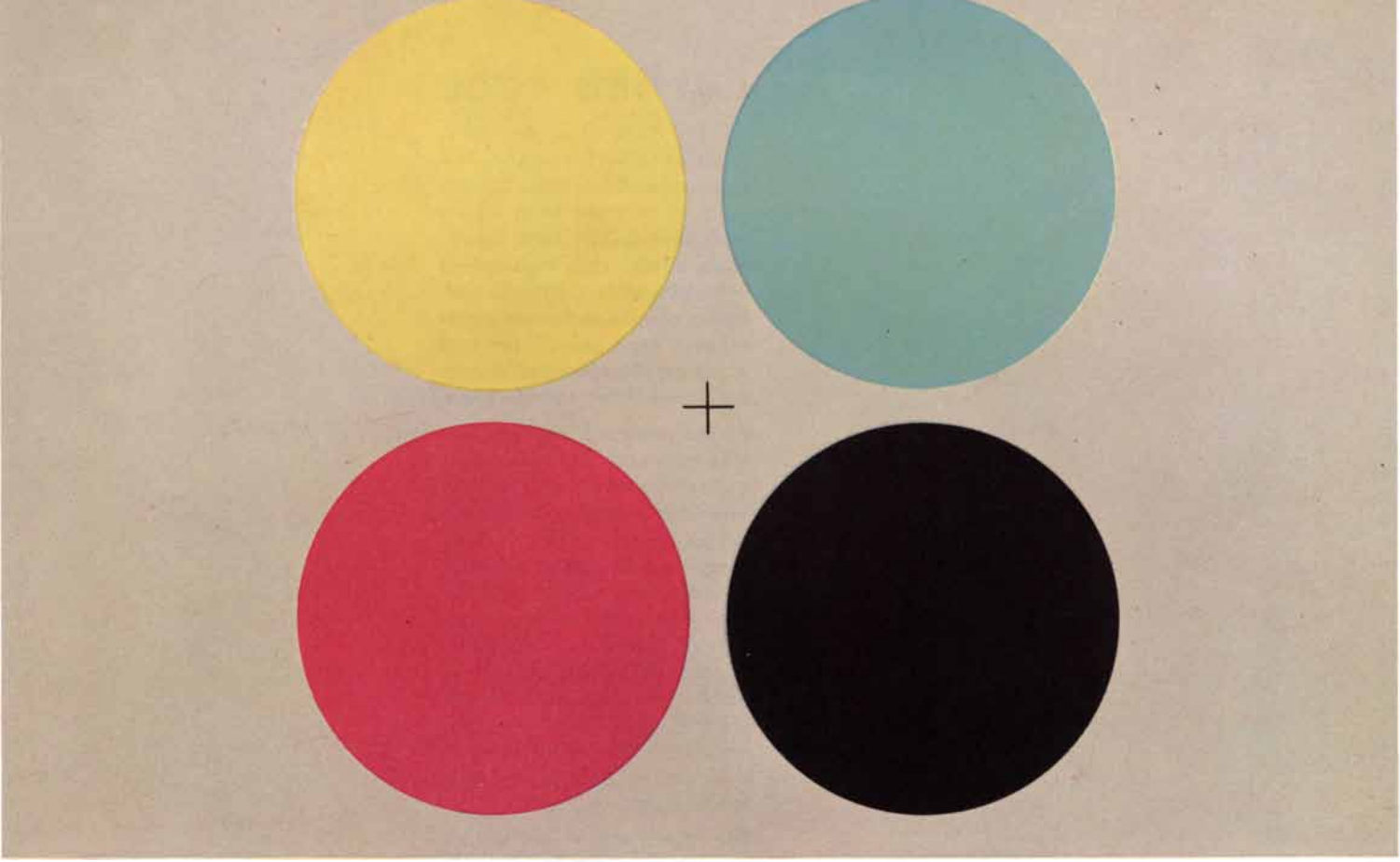
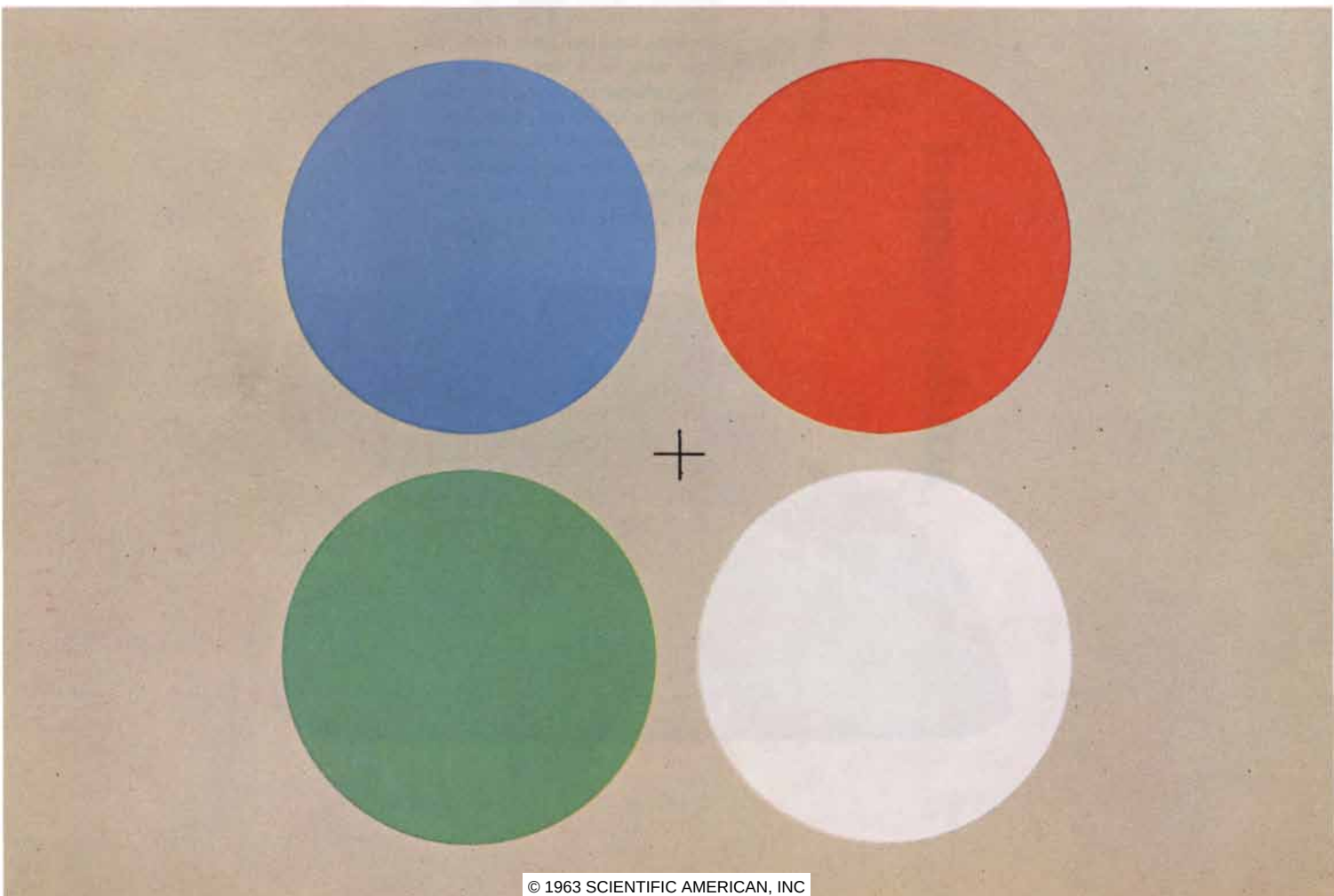




COMPLEMENTARY TEST PATTERNS are used to demonstrate the color changes that take place when a negative afterimage of a brightly colored stimulus is formed on the retina. A negative afterimage of the pattern above resembles the pattern below and vice versa. A positive afterimage of either test pattern retains the colors of the original. Cover one pattern when looking at the other.



AFTERIMAGES

Recent experiments have elucidated the mechanism of these curious visual phenomena and have provided several new insights into the photochemistry of normal human vision

by G. S. Brindley

Look steadily at the small cross in the center of the four colored disks at the top of the opposite page; after about 10 seconds look at a blank sheet of white paper. You should see against the colorless background a set of colored disks similar to those you have just been looking at. The colors of the new pattern will, however, appear to be quite different; in fact, the array will probably look more like a pale, washed-out copy of the test pattern at the bottom of the page. Now if you look steadily at the cross in the center of this illustration for 10 seconds and then look at the white paper, you will see a pale version of the test pattern at the top of the page. In both cases what you have "seen" against the uniformly white surface is a negative afterimage. As in a photographic negative, the dark parts of the original look bright and the bright parts look dark. The colors of the afterimage, however, are complementary to those in the original.

A complementary, or negative, afterimage achieved by this method normally fades into invisibility in about 15 seconds. It can usually be brought back, however, if as soon as it has disappeared the eyes are closed for a few seconds and then reopened. A negative afterimage can be prolonged in this manner for a minute or more. In the laboratory negative afterimages produced under special conditions have survived for as long as 20 minutes.

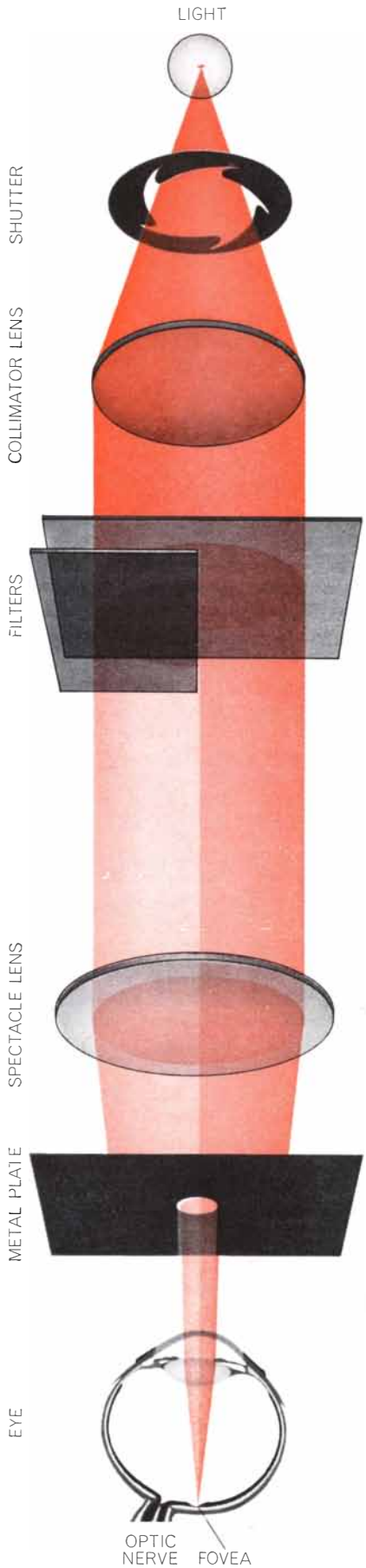
Positive afterimages are much more transient, seldom lasting longer than five or 10 seconds; for this reason they are also more difficult to see than negative afterimages. With luck a positive afterimage can be produced by the following method: In direct sunlight look again at the cross in the center of the top illustration on the opposite page. This time, after only two or three seconds, close your eyes and cover them with your hands without pressing on them. For about the first five seconds you should be able to see a faint pattern similar in shape and color to the test pattern. If this method fails, you may succeed in seeing a positive afterimage in yet another way: Sit indoors in a position from which you can see a window with bright sky behind it. Close and cover your eyes for about half a minute. With your eyes still covered, face the window; then uncover them and look steadily at the intersection of two crosspieces in the window. After about three seconds of steady looking close and cover your eyes once more. For the first five or 10 seconds you will almost certainly see a bright, positive afterimage of the same shape as the window. As in all positive afterimages, bright will appear as bright, dark as dark and colors faded but true.

The classification of afterimages into negative and positive is widely applicable but does not exhaust all the possibilities. Another type of afterimage can be produced by looking steadily for a few seconds at an unshaded light bulb. For a minute or so afterward you will be able to see, either in darkness or against a uniform white surface, an afterimage that passes through several stages of varying bright colors, although the light bulb is perfectly white. In this case no simple relation exists between the color of the afterimage and that of the inducing stimulus. It nonetheless remains true that at any given stage the color of the afterimage seen in darkness is complementary to the color seen at the same stage against a white background.

It is easy to give a rough explanation of afterimages. The negative ones are presumably due to an insensitivity or "fatigue" of some part of the visual system, caused by previous strong stimulation; the positive ones, to the persistence of some of the stimulatory effects of bright light after the light has ceased to shine. To explain why the color of an afterimage seen in darkness is similar to the color of the inducing stimulus, whereas that seen against a white background is complementary, we must suppose the three mechanisms involved in the reception of the three primary colors (red, green and blue) of normal human vision can be fatigued, and can show persistent excitation, independently of one another.

Explanations of this kind were suggested as early as the middle of the 18th century, and one was developed in detail by Hermann von Helmholtz in 1858. The theory proposed by Helmholtz was hampered, however, by the absence at that time of any means of detecting which parts of the visual pathway leading from the retina to the brain were involved in either the fatigue or the persisting excitation. It was not until 1940 that Kenneth Craik of the University of Cambridge provided the first such means. Craik succeeded in making one of his eyes temporarily blind for about a minute by pressing firmly on it to cut off its blood supply; he discovered that a bright light that fell on the eye while it was blind could cause a negative afterimage to appear when he looked at a uniform white surface after recovering from the blindness. This experiment proved that at least part of the fatigue responsible for negative afterimages occurs in the eye and not in the brain, since during the period of blindness the brain could not have received any messages from the eye.

Efforts to locate more precisely the site at which afterimages originate met with little success following Craik's discovery until a few years ago, when my



colleagues and I at the University of Cambridge took up the search. Our experiments have since yielded a twofold profit: in addition to explaining the origin of several types of afterimage, they have made it possible to deduce some of the elusive properties of the receptive cone pigments on which our color vision depends.

One of the principal obstacles we encountered in our search was the difficulty of trying to resolve any afterimage into its photochemical and nervous constituents. Experiments with animals suggested that both these mechanisms were capable of producing afterimages, either in combination or independently. It is a well-known fact, for example, that the receptive pigments of the rods and cones are chemically altered, or "bleached," by light and that after strong illumination it is several minutes before they are restored to their original state. During this period either the lack of pigment where it ordinarily would be or the presence of a temporary product of the photochemical reaction could cause a residual insensitivity to new stimuli or a persistent excitation in the dark. We also knew from experiments with animals that the response of a network of nerve cells—either in the retina or in the brain—may last for many seconds after the stimulus has ceased. Moreover, it had been shown by several experimenters that the nervous response made to one stimulus was capable of influencing or even suppressing the response made to other stimuli coming many seconds later [see "Inhibition in Visual Systems," by Donald Kennedy; SCIENTIFIC AMERICAN, July].

The extremely difficult problem of resolving an afterimage into its photochemical and nervous components could of course be circumvented if it were possible to find an example in which only nervous effects or only photochemical effects are involved. So far attempts to identify an afterimage of purely nervous origin have not been successful, but conditions have been found under which some appear to arise purely from photochemical reactions.

EXPERIMENTAL SETUP was used by the author to test a person's ability to discriminate between two slightly differing flashes of light by means of their immediate sensations and then by means of their late afterimages. Gradations in brightness of the two half-fields were obtained by substituting various combinations of neutral filters (*center*). Subjects were instructed to trigger the shutter (*top*) that delivered the flashes only when they were looking at the dividing line between the two half-fields, thus ensuring that the flashes fell directly on color-sensitive foveal region of the retina (*bottom*).

In our search for an afterimage that depends only on the photochemical effects of the inducing stimulus we made use of a basic law of photochemistry: the Bunsen-Roscoe law, which states that the photochemical effects on any two light stimuli are identical if the products of their strength and the length of time they operate are equal. On this basis it might seem that if two bright flashes of light, one lasting a second and the other lasting a hundredth of a second but being 100 times brighter than the first, were compared by eye, they would be indistinguishable. Obviously this is not the case; the eye easily establishes that the first flash is longer and the second brighter. We are forced to conclude that the two flashes must have different effects on at least some of the nerve cells along the visual pathway. From experiments in which the electrical activity of nerve cells in the retina and brain of various animals have been recorded an even stronger conclusion can be drawn: Two flashes of this sort almost certainly differ in their effects on every nerve cell that responds to them at all.

If we now examine the negative afterimages of these two flashes, we find that during the first 15 seconds the afterimages differ in color and strength. After 15 seconds, however, they are absolutely indistinguishable. This is not simply because we are poor at distinguishing one kind of late afterimage from another (a late afterimage is defined as one that is more than 15 seconds old); if the second flash is made not 100 times brighter but 80 or 120 times brighter, its late afterimage is easily distinguished from that of the first flash. Thus the Bunsen-Roscoe law is valid for this type of late afterimage, since two flashes consisting of the same total amount of light produce identical late afterimages. This suggests that the late negative afterimage of a brief, bright stimulus must depend only on its photochemical effects and not at all on its immediate effects on nerve cells.

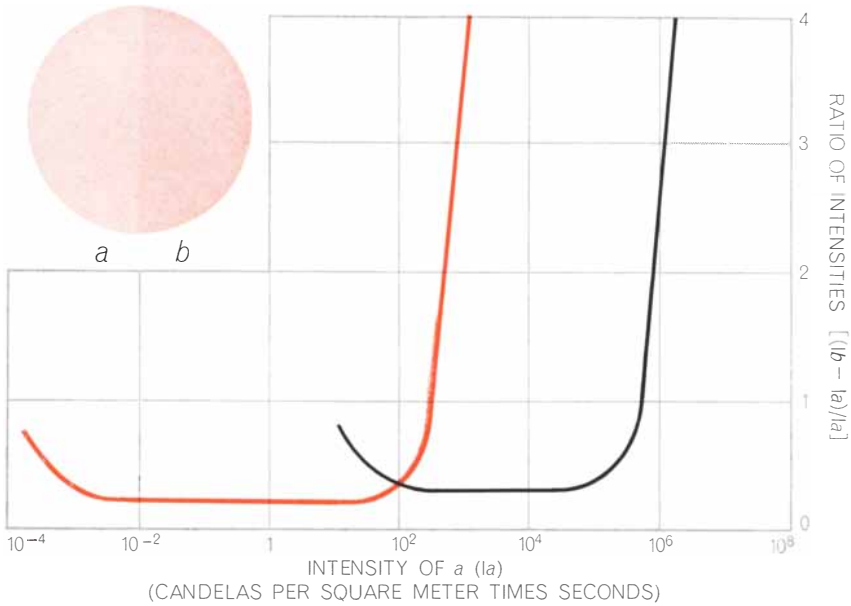
A simple experiment conducted in our laboratory corroborated this hypothesis. The test situation is shown in the illustration at the left. Two flashes of light were presented to a test subject, who was asked to judge which of the two flashes was the brighter, first by means of the immediate sensations they produced, and then by means of their late afterimages. The flashes appeared simultaneously on the left and right halves of

a circular field with an apparent diameter of two degrees, and the subjects were instructed to press the trigger that delivered the flashes only when they were looking at the dividing line between the two half-fields. In this way we made certain that the flashes fell directly on the fovea, the small central depression on the retina that contains thousands of color-sensitive cones but few, if any, rods. Since it was the total amount of light in each flash that we were interested in, we had to take special care to incorporate the time factor into all our calculations. Accordingly we amended the conventional unit of luminance—candelas per square meter—to read candelas per square meter times seconds in order to obtain our unit of the amount of light in a flash.

The graph at the right presents the results of this experiment. When the intensity of the dimmer half-field was between 1/300 and 100 of our units, the ratio of brightness between the two flashes required for discrimination by means of their immediate sensations was small and approximately constant. When the intensity of the dimmer half-field rose above 100 units, however, this ratio became much greater, so that two flashes, one of which was 10 times brighter than the other, gave identical immediate sensations.

When the two flashing lights were compared on the basis of their late afterimages, another mechanism for discrimination was revealed. Although a flash of less than 30 units did not produce an afterimage lasting long enough for any judgment to be made, flashes above 100 units were discriminated much more readily by their afterimages than by their immediate sensations. In fact, it was possible to discriminate between two slightly differing flashes by means of their late afterimages for intensities as high as 100,000 units! Above this threshold the ratio of brightnesses required for discrimination rises sharply, so that an afterimage of a 1.5-million-unit flash cannot be distinguished from the afterimage of a flash 10 times brighter.

This greater capacity for discriminating slight differences in light intensity by means of late negative afterimages fits in nicely with our hypothesis that such afterimages are purely photochemical in origin. Presumably two differing flashes that present the same immediate sensations must have an identical effect on nerve cells throughout all the later stages of the chain of vision. Since the same two flashes do not necessarily produce the same afterimages, however, we can conclude that the total information regarding light intensity capable of being received by the pigments of the retina is greater than the nerve circuitry of the visual pathway can transmit instantaneously; but under suitable conditions it can transmit additional information later, in the form of an afterimage.



DISCRIMINATION between two slightly differing flashes by means of their late afterimages (*black curve*) proved to be more precise at high intensities than discrimination by immediate sensations (*colored curve*). The dimmer half-field (*a*) in the inset at top left corresponds to the double filter in the illustration on the opposite page; the brighter half-field (*b*), to the single filter. Flashes of less than 30 units do not produce late afterimages.

The only two cases in which the late afterimages of widely dissimilar flashes were indistinguishable occurred when both flashes contained the same amount of light (measured in candelas per square meter times seconds) or when both were so bright they were able to bleach nearly all the receptive pigments of the foveal cones. We know from the independent measurements of W. A. H. Rushton of the University of Cambridge that under the conditions of our experiment a flash of 1.5 million units is able to bleach about 98 per cent of the green-sensitive and red-sensitive pigments of the foveal cones [see "Visual Pigments in Man," by W. A. H. Rushton; SCIENTIFIC AMERICAN, November, 1962]. A stronger flash could do no more than increase this amount to 100 per cent, so that it was not surprising that any pair of flashes above 1.5 million units produced indistinguishable afterimages.

These observations led us to examine another peculiar property of human foveal afterimages. In 1955 W. A. Hagins discovered while working at the University of Cambridge that a single very brief flash of light, however bright, could never bleach more than half of a sample of rhodopsin, the receptive pigment of the rods. A second flash delivered within a millisecond had no bleaching effect, but if the flash was delivered several tens of milliseconds later, it would bleach half of the remaining rhodopsin, leaving only a quarter of the original sample. The behavior of the foveal cone pigments appears to be quite similar. A flash of light lasting only two-tenths of a millisecond, however bright, never produces an afterimage as strong as the one produced by a very bright flash lasting many milliseconds. Even if we add to the first flash another similar flash coming about a quarter of a millisecond later, the afterimage produced by the two flashes together does not differ from that produced by the first alone. If, however, the second flash comes four milliseconds later, it makes the afterimage appreciably stronger. From this evidence I argued in 1959 that human cone pigments must share the property discovered by Hagins for rhodopsin. It has since been verified experimentally by Rushton that they do indeed possess this property.

The analogy between the behavior of the rod pigment rhodopsin and that of the various cone pigments involved in the production of colored afterimages extends even further. Molecules of rhodopsin in a rod are not packed at random; they all lie with their chromophore, or color-absorbing, groups perpendicular to

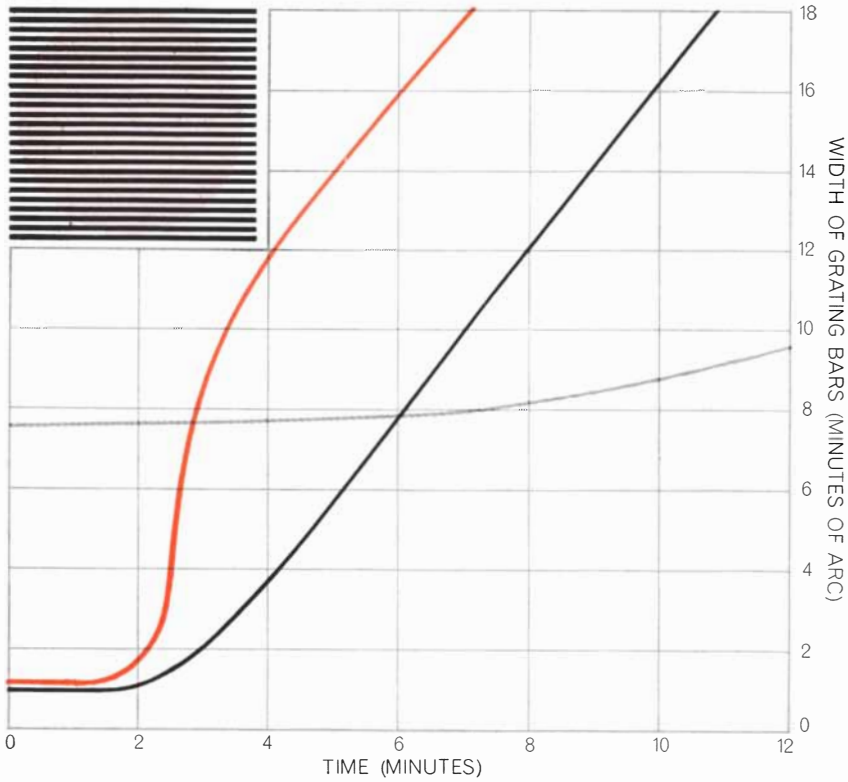
the long axis of the rod [*see bottom illustration on page 90*]. The evidence for this is that rods are dichroic: they absorb light differently according to its direction of incidence or of polarization. Plane-polarized light that strikes a rod from the side is absorbed if its electric vector is perpendicular to the long axis of the rod but not if its electric vector is along the long axis of the rod. The question now arises whether the chromophore groups are free to rotate in the plane perpendicular to the axis of the rod or are absolutely fixed. For rhodopsin this question was answered by Hagins: They are free to rotate, as is shown by the failure of the rods to become dichroic for light striking them from the end after partial bleaching with plane-polarized light also delivered from the end. Our experiments with afterimages have provided us with an answer to the corresponding question for the receptive pigments of the cones. If a flash of unpolarized light is of a strength sufficient to bleach a large fraction of the receptive pigment, and if the chromophore groups are fixed, then a flash of plane-polarized light of the same energy would bleach less because those molecules whose chromophores are parallel to the electric vector of the light would not be affected by it. Following the same line of reasoning, we would expect that if the chromophore groups were fixed, strong plane-polarized and unpolarized flashes of the same energy would give clearly differing afterimages. They do not, however, even if the flashes are as short as 200 microseconds. Therefore the chromophore groups of the cone pigments must be free to rotate, and the time required for rotation must be small compared with 200 microseconds. Flashes bright enough to bleach a large fraction of the receptive pigment in less than 200 microseconds are difficult to produce in the laboratory, but when the technical difficulty is overcome (perhaps by the use of lasers or exploding wires), it may be possible to ascertain how much less than 200 microseconds is the time required for this rotation.

We are now in a position to explain several related phenomena pertaining to the progressive blurring of human foveal afterimages. A flash that is strong enough to bleach nearly all the receptive pigment of the foveal cones produces a negative afterimage that remains visible

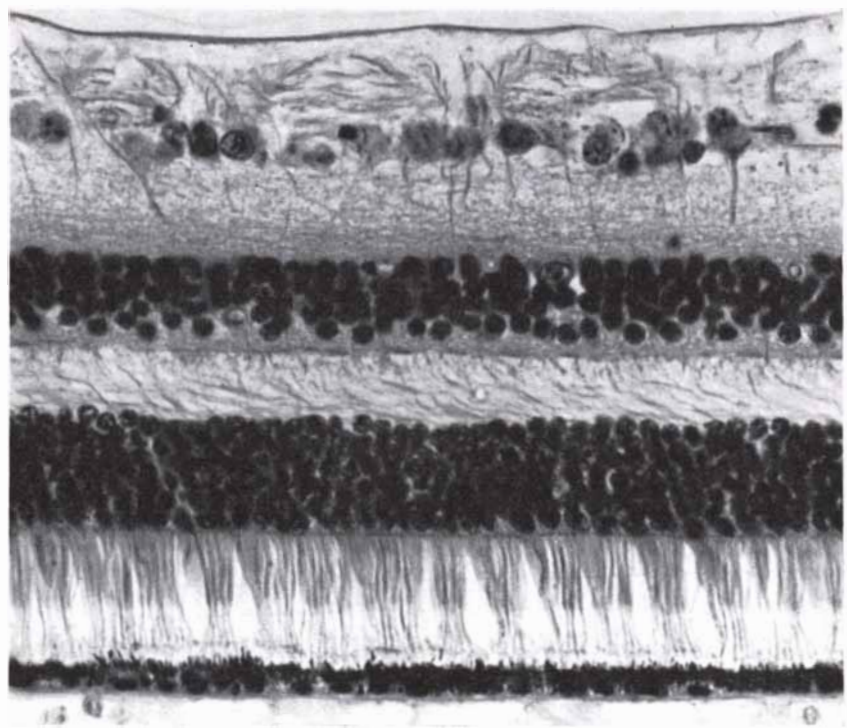
PROGRESSIVE BLURRING of a late negative afterimage is represented here. The stimulus was an extremely bright green flash presented to the fovea as a disk with an apparent diameter of 1.5 degrees crossed by a vertical dark bar 10 minutes of arc in width.

for about 20 minutes. If the source of the flash has sharp outlines and if these are properly focused on the retina, they will appear clearly in the afterimage, at least for the first two minutes. After the end of the second minute, however, such fine details will become progressively blurred, and after 15 minutes only the coarsest aspects of the shape of the stimulus will be resolvable in the afterimage. This progressive blurring is represented in the illustration on the opposite page. In this case the stimulus used was a disk of green light with an apparent diameter of 1.5 degrees crossed by a dark bar 10 minutes of arc wide. The resulting negative afterimage was pink, the complementary color to green. After two minutes this afterimage still showed the sharp edges of the stimulus, although a faint pink cloud had begun to invade the surrounding white. After four minutes the sharp edges had dissolved, the central gap had narrowed and the cloud continued to spread outward. After eight minutes the central gap could be seen only with difficulty, and after 16 minutes it disappeared entirely.

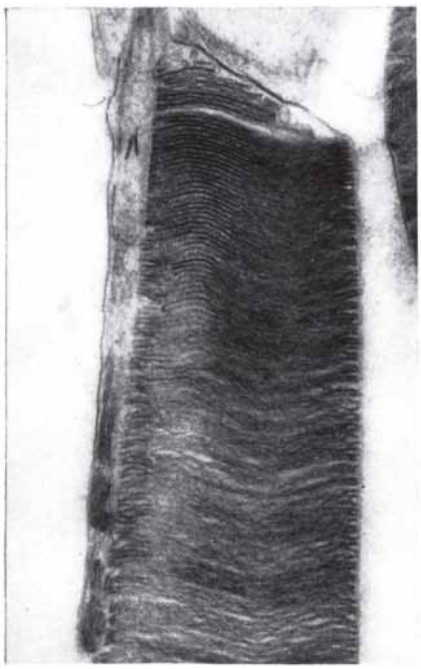
Another demonstration of the progressive blurring of a foveal afterimage was obtained by placing a grating between the stimulus and the eye in order to measure the length of time the individual bars of the grating could be resolved in the afterimage [*see top illustration on this page*]. We tested this technique using three different types of light stimulus: a deep red foveal stimulus, which produces green negative afterimages (probably depending on the cone pigment erythrolabe); a green foveal stimulus, which produces pink negative afterimages (probably depending on the cone pigment chlorolabe), and a green extrafoveal stimulus, which produces gray negative afterimages (probably depending on the rod pigment rhodopsin). In the extrafoveal afterimages the finest gratings could never be resolved, but there was little progressive blurring, so that almost as fine a grating could be resolved at 15 minutes as at one minute. Both kinds of foveal afterimage showed progressive blurring, which took place faster in those produced by the green stimulus. For both kinds the speed of the progressive blurring was unaffected by light conditions between the time of the stimulus and the examination of the afterimage many seconds later; the speed was the same whether the eye was kept in darkness, in steady light or in alternating darkness and light. This constant rate could not have been merely a result of the faintness of the late afterimages; the two-minute afterimage of the weak stim-



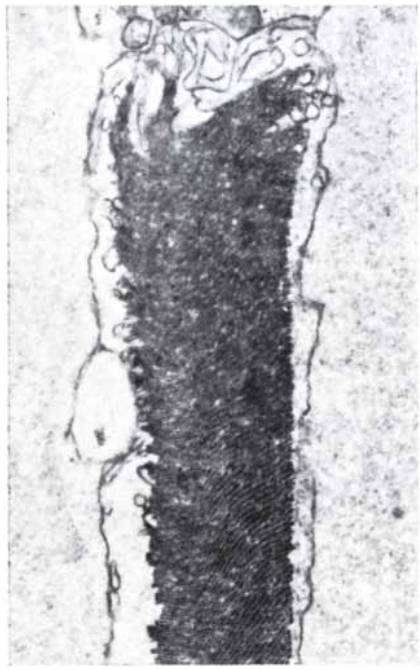
GRATINGS WERE SUBSTITUTED (*inset at top left*) **for the neutral filter nearest the viewer in the experimental setup illustrated on page 86 in order to measure the rate of blurring of several types of late negative afterimage. The colored curve indicates this rate for the afterimage of a deep red foveal stimulus, the black curve for the afterimage of a green foveal stimulus and the gray curve for the afterimage of a green extrafoveal stimulus.**



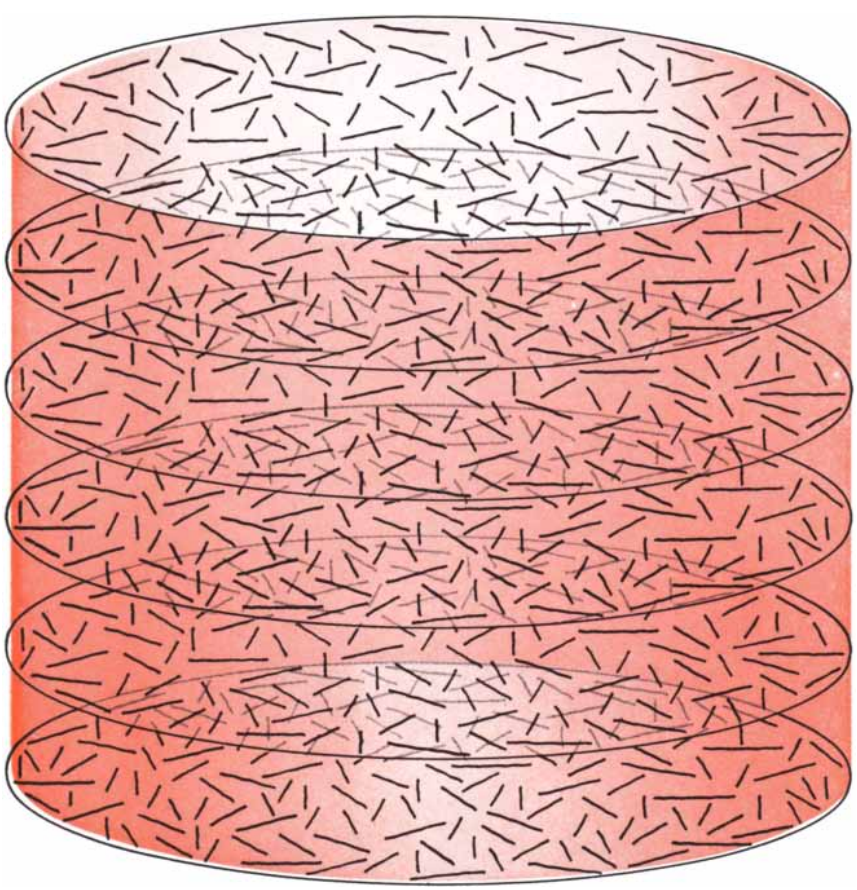
SECTION OF HUMAN RETINA is magnified about 450 diameters in this micrograph made, as are those on the opposite page, by Ben S. Fine of the Armed Forces Institute of Pathology. Light enters the retina from the top and passes through several layers of nerve cells before striking the rods and cones, the spindly vertical structures near the bottom.



ROD in this electron micrograph is magnified about 24,000 diameters. The layered structures are the photoreceptor segments.



CONE in this electron micrograph is located in an extrafoveal region of the retina. Magnification is approximately 13,000 diameters.



VISUAL PIGMENTS are probably arranged in roughly circular layers in both rods and cones. In this highly schematic drawing the chromophore, or color-absorbing, groups of the pigment molecules are the short black lines lying in planes perpendicular to the long axis of the receptor. The protein parts of the molecules are not shown. Experiments with afterimages suggest that the chromophore groups must be free to rotate within their planes.

ulus can be fainter than the 15-minute afterimage of a strong stimulus, but it is always very much sharper.

If, as I have argued, the persisting change responsible for these late negative afterimages is photochemical and originates in the cones, then it may be either a lack of receptive pigment in the bleached cones or the presence of some substance produced by the action of light on the receptive pigment. Lack of receptive pigment can hardly be supposed to afflict other than bleached cones and therefore cannot on any simple hypothesis explain the progressive blurring. A substance produced by the action of light might, however, diffuse from the place where it originated and influence the sensitivity of other structures. If so, these structures must also be cones, because if they were nerve cells engaged in transmitting messages from the cones to the brain, an afterimage would spread in the blurring process much more slowly between two points on opposite sides of the foveal center than between two otherwise similar points on the same side of it. No such discontinuity of spread at the foveal center is observed. To account for the colors of the late afterimages we must assume that the product derived from erythrolabe affects predominantly the sensitivity of red-sensitive cones and the one derived from chlorolabe affects predominantly the sensitivity of green-sensitive cones. To account for the fact that the green negative afterimages of deep red stimuli become blurred faster than the pink negative afterimages of green stimuli we must assume that the product derived from erythrolabe diffuses faster through the retina. For both substances the diffusion rates required to account for the blurring are plausible; that is, they are substantially smaller than those of small organic molecules in water.

This explanation of the progressive blurring of foveal afterimages also provides us with an interpretation of a hitherto unaccountable afterimage phenomenon known as the green halo. When the negative afterimage of an orange-red flash is seen against a uniform white background about eight minutes after the stimulus is administered, the central part of the afterimage is the same pink color as the late afterimages of green or yellow stimuli. Surrounding the pink center, however, is a ring of green whose color is the same as that of a late afterimage of a deep red stimulus [*see illustration on page 93*]. We know from Rushton's experiments that the orange-red stimulus bleaches both erythrolabe and chlorolabe; if we assume that because of the

ANACONDA COMMENTS

new facts about copper—man's oldest metal

NUMBER 11 OF A SERIES

ANACONDA DEVELOPS NEW "SYNTHETIC AGING" STATUARY BRONZE FINISH FOR COPPER METALS

For years, users of architectural copper metals have sought a statuary bronze finish that simulates the effects of natural aging. At Anaconda American Brass Company's Research and Technical Center, a low-cost answer to this need is in the final stage of development.

The new Anaconda method of developing a statuary bronze finish overcomes limitations associated with previous techniques. Examples: It is equally uniform on small or large surface areas. It provides a high degree of control over depth and uniformity of color, and aesthetic color-matching of adjacent architectural panels. And most important of all, it requires a minimum of time-consuming hand labor in final toning.

Nature patterned it

Metallurgists at the new Research Center studied the long natural aging process of bronze and gained a basic knowledge of the chemical mechanisms involved. They applied electron diffraction analysis techniques to identify the coloring film constituents. Finally, they evolved a relatively simple way to simulate nature.

Essentially, the Anaconda method is based on the production of a combined oxide-sulfide film on a copper metal surface. The process depends upon the formation of these compounds in a prespecified manner, resulting in a film closely resembling the composition of the natural film.

No preparatory dezincification or copper plating is required. The copper sulfide distribution in this film is uniform, resulting in an even brown color free from the greenish iridescent undertones present in many artificial coloring films.

Experimentation disclosed that control of process variables provides a more reliable means of reproducing matching color films than reliance on older artisan techniques. Additional experimentation determined optimum temperature and concentration ranges of the coloring solutions.

A variety of copper metals—including extruded architectural bronze, red brass, and Muntz metal—have been processed to simulate the color finish of natural aging, with a uniform, closely controllable statuary bronze flavor and look.

This new statuary finish is one portion of Anaconda's exploratory research into fundamental characteristics of copper metals. Ultimately, such work will extend the capabilities of copper.

ANACONDA RESEARCH CENTER SOLVES STATUE OF LIBERTY CONTROVERSY

A recent dispute among metallurgical scientists was set off by conflicting theories about the green patina that adorns the Statue of Liberty. Papers and letters in a leading trade publication argued as to whether the patina was basic copper sulfate or basic copper carbonate.

As might be expected, a disagreement of this sort is apt to become rather heated. This one did. Eventually, metallurgists from Anaconda's new Research and Technical Center volunteered to collect samples of the Statue of Liberty's patina and put its actual composition on record. (The statue's patina, incidentally, is one of the finest examples of natural patina in the world; the project was undertaken enthusiastically.)

The Anaconda research team obtained the necessary permission from Statue custodians, and went to work. They abraded an area of about two square feet of the northernmost corner of the Statue, approximately 15 to 20 feet above the pedestal balcony. As the patina became dislodged, it fell into plastic bags that had been glued just below the abrasion area.

Analysis ends argument

Resolution of the Statue of Liberty patina controversy followed extensive analysis at the Anaconda Research and Technical Center. Results of X-ray diffraction, semi-micro chemical, and wet chemical processes conclusively supported the faction that favored basic copper sulfate.

In fact, tests proved a predominance of basic copper sulfate in the Statue's patina; basic copper chloride content was found to be less than five percent. It was shown that basic carbonate, if present at all, constitutes less than 0.1% of the patina. And a weak but positive test indicated trace amounts of phosphate salts due to the presence of phosphorus in the underlying metal, either as an impurity or as a deoxidizer.

The real significance of the Anaconda work, however, was finding such a surprisingly low concentration of chloride salts. Many experts believed an abundance of chlorides would be found because of the strong saline atmosphere around the Statue and constant exposure to winds. The predominance of sulfate material is easy to explain, though, considering the high estimated tonnage of sulfur-bearing acids produced in the New York atmosphere every day—and the difference between the free energies of formation of copper chloride and copper sulfate. Moreover, the presence of these acids explains the absence of appreciable amounts of carbonates; carbonates cannot survive in such acidic environments.

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Do you have a question that Anaconda Research may have an answer to, or a controversy we can help you solve? We'd like to hear about it, if you do.

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

ELECTROCHEMICAL ADDITION: 1+1=3

Electroplating is a well-known process . . . on the surface, anyway.

But the plating of just one metal on another may involve a dozen or more physical or chemical events. At the GM Research Laboratories, we are examining some of these to better understand particular idiosyncrasies.

Like the action of organic addition agents. For instance, an organic leveling agent in a plating bath causes more metal to be deposited on low places and less on the high spots—giving a smoother, more level surface. Two together do stranger things. How? Radioactive tracers are telling us.

Example: Take a radioactively tagged leveler. More is adsorbed on the peaks of the surface being plated than in the valleys. Its adsorbed ions tend to block current flow, reducing metal deposition most where the ion concentration is greatest. Then add another leveler. It levels, too, but also causes even more adsorption of the *first* one on the high points. More leveling yet.

This one-plus-one-equals-three synergistic effect has been widely used in decorative plating. Now, supported by unique autoradiographic evidence, we have postulated a theoretical explanation. Details are available on request. Briefly, it involves ion interactions and adsorptions and gets deeper into matters of ion and atom bonding and bond breaking—subjects typical of persistent basic research in General Motors.

General Motors Research Laboratories

Warren, Michigan

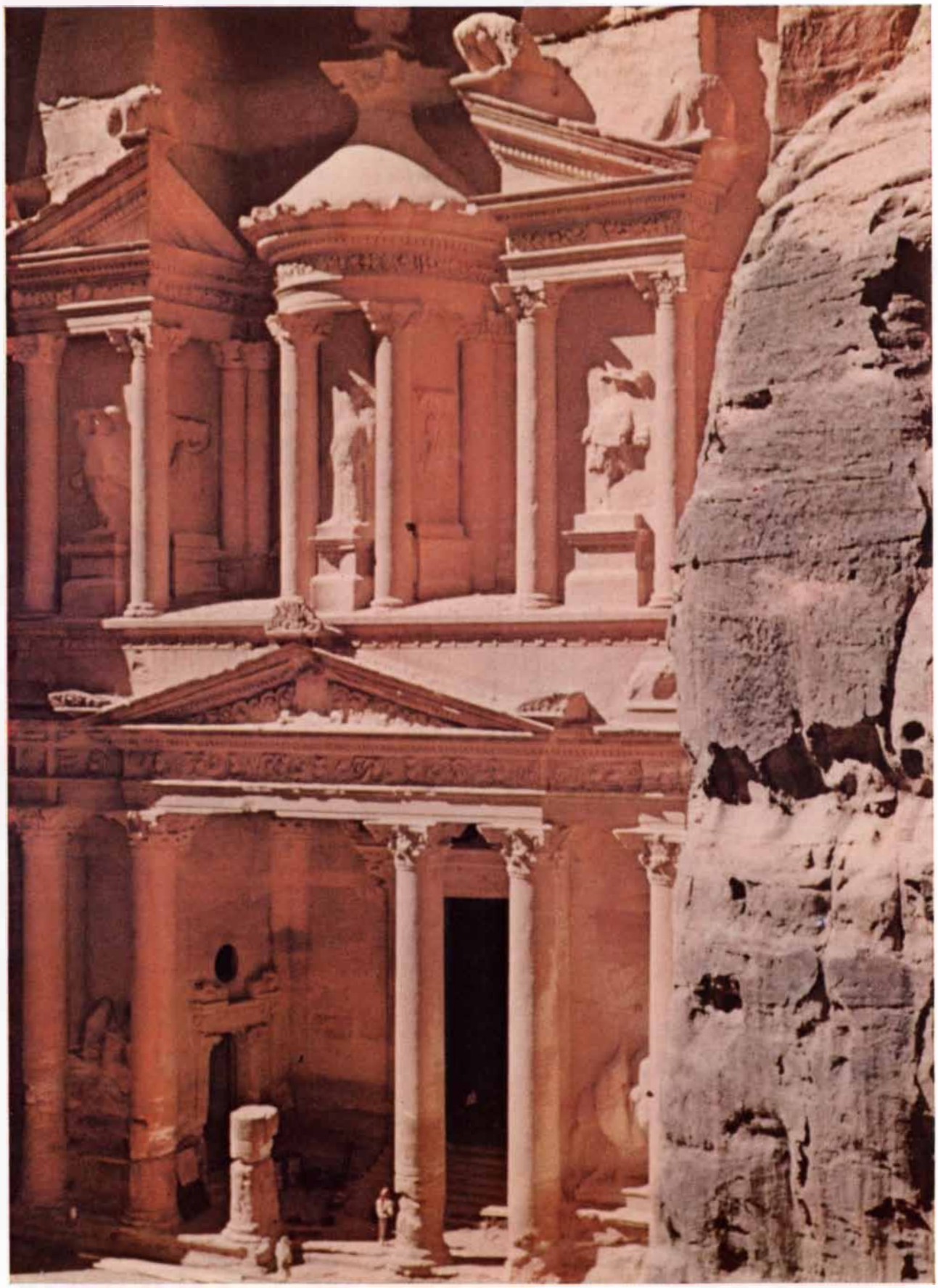
	Before plating	With A alone	With B alone	With A & B
Amount of A adsorbed	0	113	0	189
Amount of B adsorbed	0	0	3	49
Surface roughness	304	279	254	140

Relative adsorptions and roughnesses. Plating with two organic levelers, A and B, added to solution singly and together.

difference in their diffusion rates the chlorolabe product stays mainly in the part of the retina illuminated by the stimulus, and that the erythrolabe product mainly diffuses away into the surrounding region, the green halo is explained.

We still know very little about the chemical nature of these diffusible products or about their possible function in normal vision. We do know that when light acts on the rod pigment rhodopsin, it splits it into a protein called opsin, which remains fixed in the rods, and a substance called retinene 1, which can diffuse out of the rods in which it was formed. The only receptive cone pigment whose chemistry has been investigated is iodopsin, which George Wald of Harvard University extracted from chicken retinas and showed to be made up of retinene 1 combined with a protein different from that contained in rhodopsin. It seems reasonable to guess that each of the human cone pigments chlorolabe and erythrolabe is, like rhodopsin and iodopsin, made up of retinene 1 and a specific protein and is split by light, yielding retinene 1 as its diffusible product; indeed, Paul K. Brown of Harvard has recently obtained direct evidence in favor of this idea. If, however, we accept the evidence from afterimages that different diffusible products are liberated by light acting on chlorolabe and erythrolabe, then we must conclude either that chlorolabe and erythrolabe are not both retinene-1 derivatives or that the diffusible substances responsible for late afterimages are secondary products (not directly derived from the receptive pigments but nonetheless liberated in quantities determined by the quantities of receptive pigments bleached). Regardless of whether these substances are directly derived from chlorolabe and erythrolabe or are secondary, the specific action that each has on the sensitivity of its own kind of cone suggests that they may form a part of the least understood link in the chain of excitation leading from absorbed light quanta to the brain, the link by which a photochemical change occurring in a very small number of molecules of receptive pigment—at most seven and perhaps only one—provokes a cone to send a signal to the nerve cells of the retina.

GREEN HALO appears around the late negative afterimage of a very bright orange-red flash. A stimulus of this type bleaches both erythrolabe and chlorolabe. According to the author's hypothesis the erythrolabe product, which is responsible for the green in the afterimage, diffuses faster than the chlorolabe product, which is responsible for the pink.



TOMBS CARVED IN CLIFFS are the most conspicuous feature of the Nabataean capital of Petra. Photograph shows entrance to a tomb called the Treasury, notable for its elaborate decorations. The rock at right shows the sandstone composition of the cliffs.

The Capital of the Nabataeans

Excavations at ancient Petra in the Middle East indicate something of the process by which a nomadic Arabian tribe became settled and Hellenized over a period of centuries

by Peter J. Parr

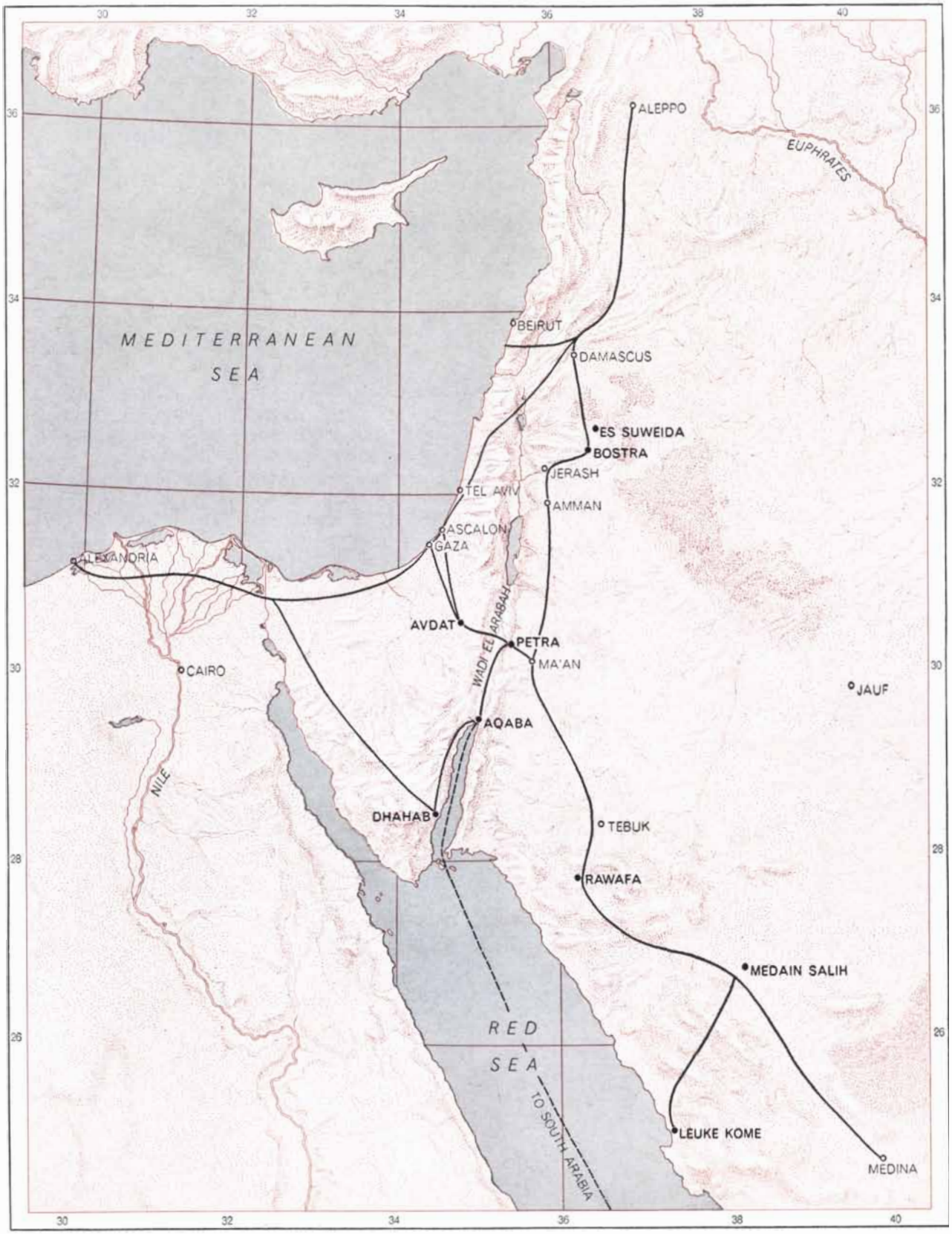
One of the most persistent themes in the history of the Near East has been the gradual movement of the Bedouin out of the desert heart of the Arabian peninsula toward its more fertile and attractive fringes. From prehistoric times onward the lands of the Fertile Crescent—Mesopotamia, Syria and Palestine—have all had their ethnic complexion and their civilization affected by the culture of the infiltrating nomads, and this primitive desert way of life has in its turn been refined and transmuted by contact with the civilizations of the more advanced peoples. The histories of the Amorites, the Aramaeans and the Moslem Arabs, to give but three examples, all illustrate the truth of this statement, but the process by which the desert has invaded the sown is nowhere more clearly apparent than in the stages by which an Arabian tribe called the Nabataeans settled down in southern Palestine and Jordan during the centuries immediately preceding the Christian era.

The world with which the Nabataeans came into contact at this time was in the throes of a great change. Both before the advent of Alexander the Great, and particularly after the establishment of his short-lived empire, the whole of the Near East was rapidly becoming Hellenized. Alexander had broken what barriers remained between East and West, and his successors, the rival Ptolemies of Egypt and the Seleucids of Syria, continued his deliberate policy of implanting Western culture in the ancient lands to which they had fallen heir. Not only in the fields of civil administration and military organization but also in the realms of art and architecture, literature and philosophy the ancient East was becoming westernized. The cultural traffic was, of course, not just one way, and soon the religion, philosophy, literature and art of the West were to become influenced by the Oriental modes. But at least in art and architecture—those aspects of culture with which the archaeologist is mostly concerned—it was the East that was the more profoundly affected, and within a few centuries one language of artistic expression was to stretch from the Tiber to the Tigris and from the Black Sea to the Red.

It is against this cultural background that the expansion of the Nabataeans is set. The Nabataeans came from the heart of an Eastern desert, and they found themselves neighbors of peoples who were no longer truly Oriental. Their history and civilization provide us with a particularly clear picture of the amalgamation of Eastern and Western ways that was everywhere taking place at this time, and it was to throw light on this process of Hellenization that excavations were recently undertaken at the Nabataean capital of Petra by the British School of Archaeology in Jerusalem.

According to some, but not all, schol-

ENTRANCE TO PETRA from the east is through the spectacular Siq, an earthquake fissure gouged out by water to form a mountain pass. During Roman period the floor was paved.



REGION OF NABATAEAN SETTLEMENT is shown on this map. The Nabataeans were typical of many Bedouin tribes that migrated out of the desert heart of the Arabian peninsula to more fertile or otherwise more attractive Mediterranean coast regions such as this. Places identified in heavier type indicate some of the sites where remains of Nabataean civilization have been found. By virtue of their location the Nabataeans controlled much of the caravan trade that moved along the desert routes from the south Arabian coast to the Levant coast, as shown here by black lines. Control of this trade proved highly profitable to the Nabataeans.

ars, the Nabataeans can be equated with the Nebaioth of the Bible and the Nebayat of Assyrian records in the seventh century B.C.; these names apply to one of many Arabian tribes. It was probably during the course of the next two centuries that the Nabataeans began to move northward and westward out of the desert and to settle in the southern part of Jordan, where the formerly strong Edomite state had already collapsed and where, under the lax Persian rule, sedentary occupation had practically ceased. But of these early migrations we know nothing; it is not until 312 B.C., 10 years after Alexander's death, that the Nabataeans appear momentarily in the full light of history.

In that year, according to the first-century-B.C. Greek historian Diodorus Siculus, they were attacked in their stronghold—presumably in Petra itself—by the forces of Antigonus the One-eyed, ruler of Phrygia and one of the most ambitious of Alexander's generals and successors. Although the attack failed, the Phrygian army was able to make off with a large quantity of booty, including 700 camels, and it is this fact that helps to explain why Antigonus was interested in a distant desert tribe. Diodorus Siculus tells us that the Nabataeans had control over a large part of the caravan trade that flowed along the desert routes from the southern coast of Arabia to the eastern coast of the Mediterranean, a trade in spices, perfumes, incense and the like that was of great profit to the middlemen through whose hands it passed. At this stage in their history the Nabataeans were caravaners and middlemen par excellence, and the clear implication of Antigonus' interest is that by the end of the fourth century B.C. they were already rich and powerful.

Little is known of the Nabataeans during the following centuries, although they appear sporadically in the pages of the Apocrypha and in the writings of the first-century-A.D. Jewish historian Josephus, and the first-century Greek geographer Strabo gives us a brief account of their manners and customs toward the end of the pre-Christian era. That they played a part in the political events of the time cannot be doubted, and Josephus bears witness to the number of occasions on which they interfered in the internecine strife that tore Palestine during those centuries.

Taking advantage of the collapse of the Seleucid dynasty, the Nabataeans were able to extend their power early in the first century B.C. as far north as Damascus. It may well have been at this same time that they consolidated their position in northwestern Arabia and also in southern Palestine, where many important Nabataean cities were to rise. The territorial expansion brought with it concomitant perils. Of these the greatest was the antagonism of Rome, which in the person of Pompey was rapidly becoming the most important force in the East. Pompey's settlement of 64 B.C. was not so hard for the Nabataeans as it was for their Jewish neighbors in Palestine, and the Nabataeans were left in control of both their territory and the all-important trade. But at the same time the rulers of Petra—whose names we know from coins and inscriptions from then on—became little more than vassals of Rome, and their territorial expansion was checked. In the long run this undoubtedly had beneficial effects: it encouraged these enterprising Arabs to seek other outlets for their energies. It is from this time on that they began wholeheartedly to adopt the material civilization of their more advanced neighbors and to institute the thoroughgoing agricultural exploitation of their territories that was soon to become the mainstay of their economy and was to shield them from economic ruin when, at a later date, the Arabian trade declined in importance and profit.

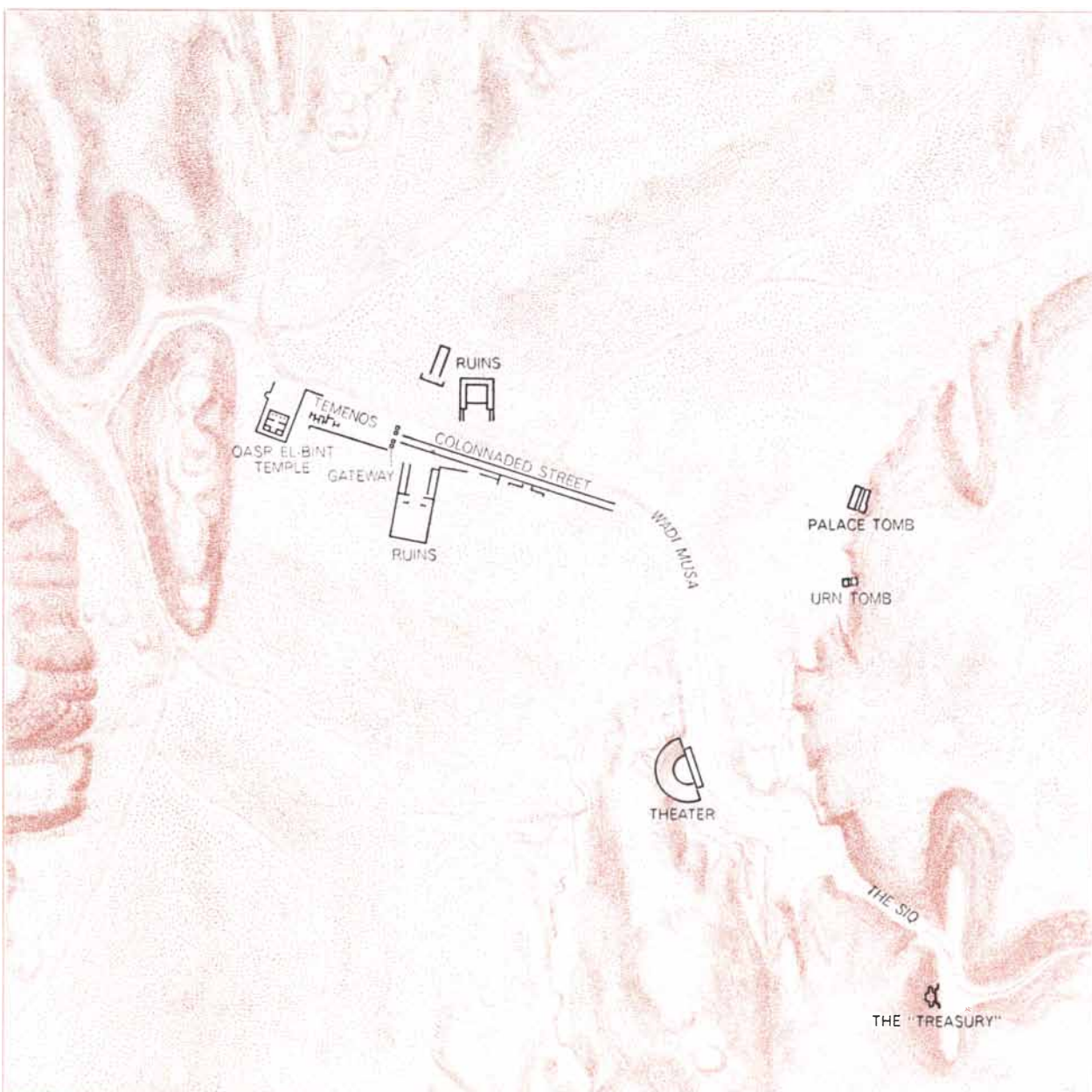
SITE OF PETRA shows, crossing diagonally below center, the stream bed (Wadi Musa) on which the community centered and, along the wadi, remains of a colonnaded Roman road.

The Nabataeans retained their independence until A.D. 106, when they were incorporated by the Roman emperor Trajan into the newly created province of Arabia, with its capital at Bostra in southern Syria. Yet the consequent loss of status does not seem to have affected the former Nabataean capital adversely, and Petra flourished for another century or so. This final period of Nabataean history, however, is as obscure as the earlier phases. A decline in prosperity set in, probably during the third century, concurrently with the general decline in the well-being and stability of the Roman Empire as a whole, and no doubt basically for the same economic reasons. In the middle of the fifth century Petra was a Christian city and the seat of a bishop, in the sixth century it seems to have been a squalid Byzantine town, and early in the seventh it appears to have been virtually deserted; it is no-

where mentioned in the annals of the Moslem invaders who passed along its caravan routes. After nearly 1,000 years the Nabataeans disappeared from history as unheralded as they had come, giving way to yet another wave of Semitic nomads from the vast Arabian reservoir.

It was their concern with the caravan trade of Arabia that must have led the Nabataeans to choose Petra for their capital; the site is a natural fortress and controls important routes. It lies high up in the sandstone mountains bordering the Jordanian plateau and overlooking the Wadi el Arabah, the continuation of the great Syrian Rift Valley south of the Dead Sea. The sandstone is soft and friable and has been weathered into a thousand fantastic shapes by wind and water; the variegated bands of reds, yellows, browns and purples that run through the rock in no apparent geological order only add to the fantasy. Two sweeping arcs of these mountains isolate Petra on the east and west; they form almost impenetrable walls except in one place. Here an earthquake fissure has been enlarged by running water, forming the Siq, or Gorge, the most famous and spectacular entrance to the site.

To the north and south, however, the country is more open, and broad wadies provide the main caravan routes to and from the city. In one direction these routes lead up to the plateau and to the main Arabian trade route that runs along its edge: the King's Highway of the Bible and the modern Pilgrims' Way to Mecca. In the other direction the tracks run south down into the Arabah and across to Palestine and Egypt. Yet even from the north or south the Nabataeans

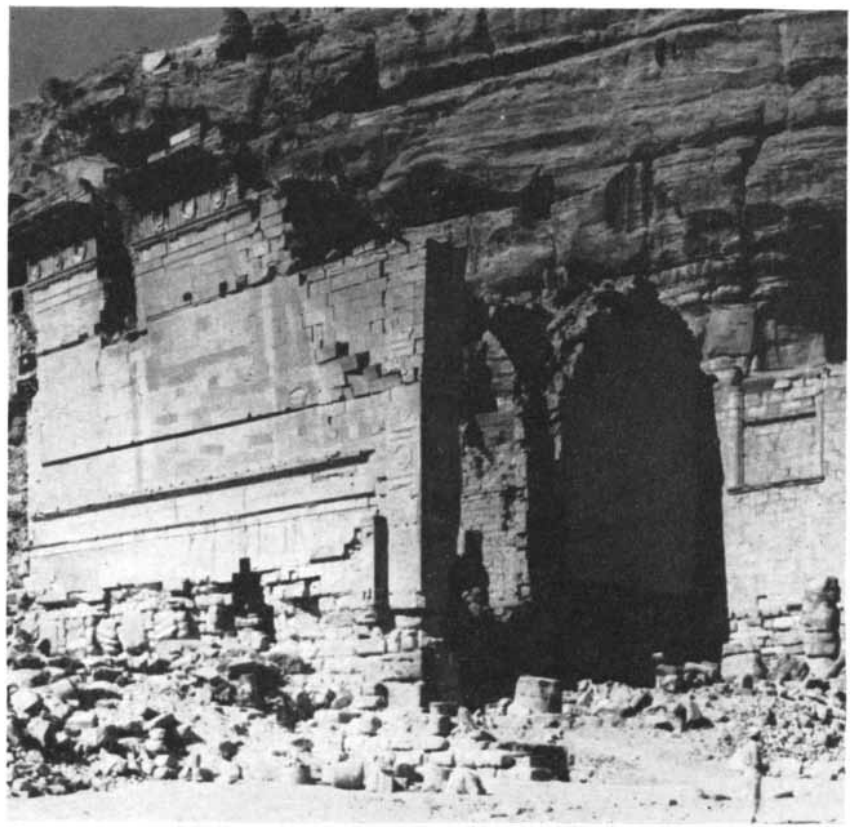


PETRA TODAY is largely a ruin except for the façades of the tombs. Only four major structures other than the tombs remain. From left to right on the map they are the temple of Qasr el-Bint, the monumental triple gateway, the colonnaded street and the theater. The site probably commended itself to the Nabataeans for its topography, inasmuch as mountains to east and west and crags providing lookouts to north and south made it a natural fortress. In addition the site offered control over major routes of trade.

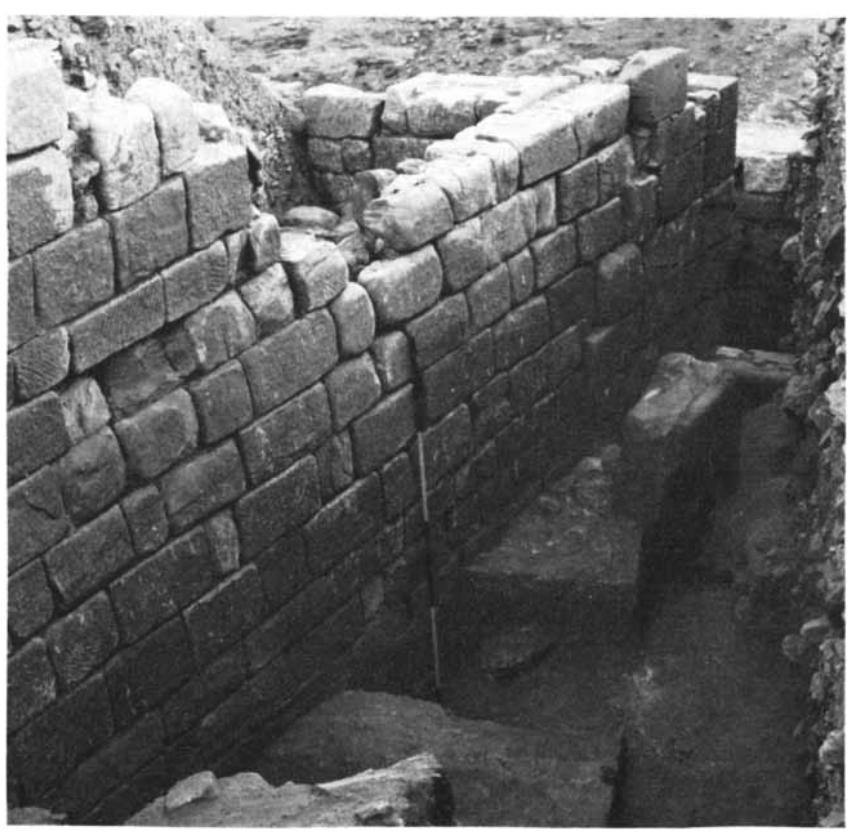
need never have feared surprise attack. Everywhere high mountain crags provide excellent lookout posts, from which a few sentries could have guarded the entire region. At some stage in the history of the site its natural defenses were augmented by man-made ones, and on the more vulnerable north and south flanks strong town walls were built. Two separate lines of these are traceable. The outer is probably the earlier, and it has the typical appearance of a Hellenistic "indented trace." The inner is laid out with greater precision and may well be a Roman military work. But the exact course and dating of these walls are still largely conjectural and need to be verified by excavation.

Within these walls, natural and man-made, lie the ruins of Petra, ruins so utter and complete that for the most part nothing remains but piles of sandy debris hiding a few disconnected lines of foundation. Only four public monuments survive in any degree: a theater, a colonnaded street, a monumental gate and a temple. They are all of Roman date, although they are not any the less interesting for that. What immediately catches the eye are the façades of tombs carved out of the rocky cliffs surrounding the site. So ubiquitous and imposing are these that the visitor might at first suppose Petra is nothing more than a vast cemetery, and the archaeologist might be excused if he pays more attention to these monuments than to the ruins at his feet. In the past more study has indeed been accorded the rock-cut remains than the free-standing ones at Petra, and the scholarly analysis of the various architectural styles of the tombs has certainly contributed much to our understanding of how the East became Hellenized.

The tombs combine in varying degrees elements derived from both classical and Oriental art. They range in style from the purely Oriental, decorated simply with bands of crenelations or of "crow steps" that recall Phoenician or even Assyrian designs, through bizarre, semi-classical façades with applied pilasters and capitals, architraves and pediments in a pseudo-Greek fashion, to great flamboyant baroque-like tombs embellished with every architectural and sculptural device known to the classical architect. It is interesting to observe, however, that even in the case of the last—the most ornate and "classical" of the tombs—the Oriental element has not entirely disappeared. Many of them show traces of having originally had masonry buildings and large open courts in front of them. These would have screened the rock-cut



ONLY WELL-PRESERVED BUILDING at Petra is the temple Qasr el-Bint, built in second or third century A.D. according to a plan deriving from ancient Syrian structures.



OUTER WALL OF HOUSE built for a wealthy Nabataean family in the first century A.D. has good construction, whereas inner walls were poorly built but covered with decorated stucco.

ROMAN COLONNADED ROAD, also shown along Wadi Musa in aerial view on page 97, was a central feature of Petra. This view is to the west, toward the monumental gate and the temple of Qasr el-Bint. They are among few surviving structures from Roman era.

façade to some extent and would have given the original monument the appearance of an Egyptian temple rather than a Greek or Roman one. The excavation of some of the forebuildings undoubtedly presents the most promising line of inquiry into the age of these splendid monuments. Although the stylistic sequence has a certain chronological value, the absolute age of these tombs is still a matter of great uncertainty and even greater scholarly dispute; it is one of the major problems still to be solved at Petra.

The recent excavations conducted by the British School at Jerusalem have not, however, been primarily concerned with this problem, although they have thrown some revealing light on it. With the limited funds available it was thought more profitable to excavate in one or two restricted areas of the city itself. Not only was such work bound to produce well-stratified archaeological material, but also it would help to redress the balance between our relatively detailed knowledge of Nabataean funerary architecture and our complete lack of knowledge of Nabataean civic and domestic buildings. In fact, the most important single result of the excavations has been the recovery of enough stratified and dated Nabataean and Roman pottery to establish once and for all a complete corpus of this material, which will be of inestimable value as an archaeological tool for the further investigation of this and other Nabataean sites.

To this aspect of our work I shall return later. For the moment I shall summarize what we have learned from the excavations about the development of building methods and architecture at Petra, with special reference to our central theme of the progress of Hellenization at the site. Four main phases of building activity have been investigated in various parts of the city, and although it is too soon to speak in detail of these phases, they already seem to make a historically satisfying picture of an orderly and logical progression from a primitive "Oriental" stage of Nabataean culture to a more sophisticated Hellenized stage. We must now turn to the evidence.

The earliest structures uncovered lie some three meters below the level of the Roman colonnaded street, resting directly on undisturbed gravel. They comprise a group of walls, thin but solidly built of wadi boulders packed and faced with stiff yellow clay. Associated with these at one point was a simple clay oven. Unfortunately no complete plan was uncovered in the area cleared, but the appearance of the remains suggests that they belong to domestic buildings. Finds from the thin, worn floors were few and difficult to date accurately, but they include coarse potsherds that recall those found in fifth- and fourth-century-B.C. contexts elsewhere in Palestine. Moreover, from a series of occupation levels overlying these early walls came pottery of the third and second centuries B.C., including fragments of black-glazed Hellenistic lamps, and coins of the same general date. It seems reasonable to suggest, therefore, that the unpretentious structures we have described are the dwellings of the Nabataeans in the first stages of their process of settling down, in the decades following 300 B.C. That they cannot be much earlier than this is clear if we accept the evidence of Diodorus Siculus, who tells us that at the time of Antigonus' attack in 312 the Nabataeans were still completely nomadic and did not build houses. We may also note parenthetically with regard to these early levels that the coins recovered include a much larger proportion of Phoenician issues than of

Egyptian, a fact that could perhaps be interpreted as showing that during the troubled course of the third century, when the Ptolemies and the Seleucids were struggling for control of Palestine, the Nabataeans threw in their lot with the Seleucids, in the hope, no doubt, of seeing the Ptolemies weakened. Egypt was, after all, a dangerous and proximate rival of the Nabataeans in the all-important Arabian and Red Sea trade.

The next stage in the architectural history of Petra, as revealed by the current excavations, is perhaps the most important historically, although it has left few traces. The primitive structures described above continued in use until the first century B.C., but at some point during that century they were abandoned and an artificial fill of earth and gravel was banked up against their ruins. This fill formed a terrace at least 15 meters wide along the side of the central wadi that must have been supported by a massive retaining wall, although no trace of this has been found. The importance of the terrace is that it provides evidence of a deliberate program of town planning, necessitating a greater expanse of level ground in the center of the site than was naturally available, and it implies the birth of a sense of civic pride among the inhabitants of Petra. The dating of this development to the first century B.C. seems assured from the coin and pottery evidence, and again it is historically reasonable, since it is just at this time that the Nabataeans came into close political and cultural contact with Syria and, what was more important, with Rome.

Next we come to the final century of Petra's independence: the first century A.D. At another part of the site a large building of this time has been partially excavated; it is the residence of a wealthy Nabataean family. It consisted of a series of rooms bordering on (but not, apparently, opening on) a long, narrow central courtyard; a similar row of chambers probably exists on the unexcavated opposite side. The building passed through many vicissitudes during the course of its life and not all of these have yet been worked out; at one stage in particular its long western outer wall was destroyed and rebuilt on a slightly different line from that of the original wall. The external appearance of the building is distinguished; the walls (which still stand at a height of more than three meters above the original floor) are of well-laid masonry, dressed with the fine diagonal tooling that seems to be typical of Nabataean work [*see bottom illustration on page 99*].

Inside, however, the story is different. The inner faces of the main walls, and the cross walls in their entirety, are poorly made of second-rate material. These faults were concealed, however, by the Nabataean builders, who covered the interior faces of the walls with richly painted and molded stucco, many fragments of which were found in the debris within the house. Such lavish stucco decoration is a typically Hellenistic feature and can be paralleled at many sites in Asia Minor, Syria, Greece and Italy. This fact serves as an indication of the degree to which Hellenistic influence had permeated Nabataean architecture by the end of the independent kingdom. Yet such foreign influences were still not entirely dominant; both the over-all plan of the building and certain of its constructional details (particularly the method of roofing the smaller chambers with flat slabs of stone resting on transverse arches, as is indicated by the provision of buttresses centrally in the cross walls) are Oriental, if not specifically Nabataean, and indicate a strong native tradition of architecture surviving side by side with the foreign fashions.

We now come to the architecture of Roman Petra. The recent British expedition has confined itself to a study of two of the few surviving monuments of this period, the Qasr el-Bint temple and its triple gateway. The colonnaded street leading through the center of the city to the gate and temple had been cleared some years before by a Jordanian expedition under the direction of Diana Kirkbride. Another imposing monument, a theater, has recently been excavated by a joint American-Jordanian expedition headed by P. C. Hammond of the Princeton Theological Seminary. The work on the street had uncovered a large inscription belonging to a building flanking it and almost certainly contemporaneous with it; the inscription can be dated accurately to A.D. 114, so that it seems that the street was laid out as part of renewed town-planning activity immediately after the annexation of Petra by the Romans.

The architecture of the temple and gateway had already been studied in some detail in the past, although the date of these structures has always been in doubt. The recent work has established some important new facts. In the first place, it has been shown conclusively that the gate is a real gate, not merely

SCULPTURED HEAD OF MERCURY from the monumental gate is about two feet high. Ring curls, staring eyes and fleshy features are among its distinctively Oriental traits.

MAIN TYPES OF OIL LAMPS used by the Nabataeans were about two inches in width. The hundreds of lamps found at Petra evidently came from the same three or four molds.

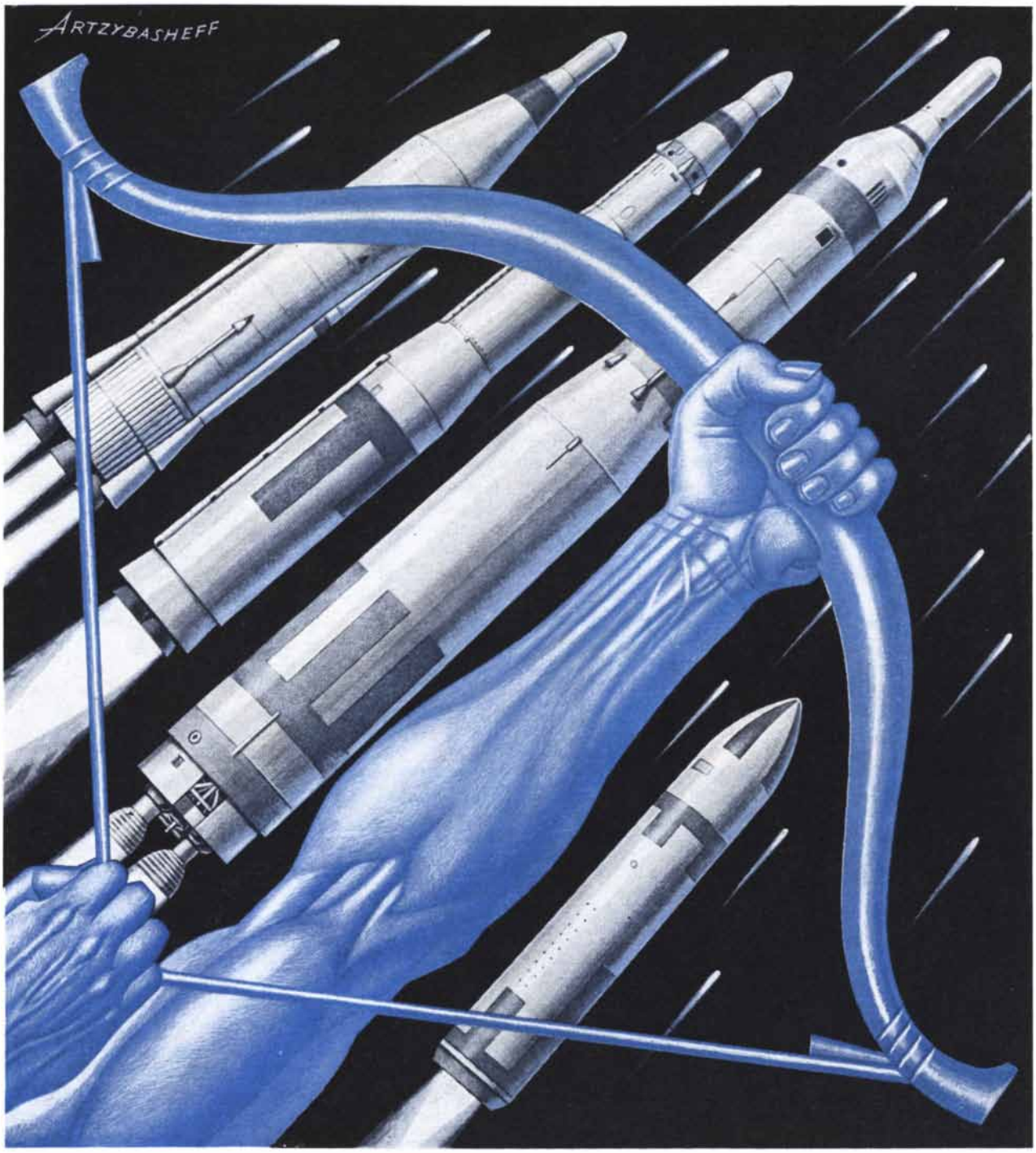
a triumphal arch, and that it provides entry to the temenos, or sacred compound, of the temple beyond. Its plan has been fully revealed for the first time and has been shown to incorporate four free-standing columns on pedestals flanking the triple arches. This fact immediately elucidates the problem of dating. Such a plan is inconceivable before the time of Trajan (A.D. 98–117), and it is much more likely to be of the middle or end of the second century. This is confirmed by the stratigraphy, which shows that the gate is later than the colonnaded street, across whose line it is set.

As for the Qasr el-Bint, this is manifestly contemporary with the gateway and the temenos. The whole sacred precinct bears witness to the magnificence of second-century Petra, a magnificence that itself implies that the compound was built during the reign of the emperor Septimius Severus (193–211). Severus, who was an African and had a Syrian wife, is known to have been particularly interested in the eastern provinces and to have lavished favors and money on their cities.

The investigation of these buildings is important, then, for the historical information it has yielded on the condition of Petra in the Roman period; but of even greater importance is the evidence it has provided of the continuing amalgamation of Eastern and Western elements in Nabataean art and architecture at this late date. The plan of the gate, for example, is distinctively Roman; that of the temple, on the other hand, with its broad, shallow forecourt and cella (closed interior) and its tripartite adytum (inner sanctuary), is ultimately derived from a type of ancient North Syrian temple. The same amalgamation of styles can be seen in the structural and decorative details of the buildings. The base of the temple (a feature only revealed by the current excavations), for example, was originally faced with marble veneer, affixed to the masonry by means of copper and lead hooks in typically Roman fashion; the masonry of the superstructure exemplifies the standard construction described by the great Roman architect Vitruvius, a rubble core between faces of cut stone. Most interesting of all is the embellishment of the gate. Many fragments of sculpture have been recovered from the decorative frieze that originally ran across the top of the arches; in conception these recall the similar decoration on other known monuments of the period of Severus. The sculpture itself, however, belongs to a distinctive Nabataean school that, although it is fundamentally Hellenistic, retains many basic Oriental elements, such as the staring eyes of the faces, the exuberance of the leaved decoration and the use of animal motifs. The study of these buildings is still far from complete, but when it is, it will contribute greatly to our understanding of the art and architecture of the Roman East.

So far we have used some of the structural evidence revealed by the excavations to illustrate the progressive Hellenization of, and the mixture of styles in, Nabataean art and architecture. The pottery at the site can be viewed in much the same way. This pottery closely resembles, and is undoubtedly derived from, that of contemporary Palestine and Syria, but it has distinctively Nabataean traits. In particular, the Nabataeans seem to have had a predilection for thin, delicate vessels, notably cups, bowls and plates. This is another indication of the rapidity with which they forgot their Arabian past; the nomad has no use for pottery, thick or thin. Similarly, several vessels seem to be uniquely Nabataean by virtue of their shape: a small basket-like cup and a closed "inkwell" can be cited as having been found only at Petra. Also of interest are the molded lamps found there; two main types can be called specifically Nabataean, although they are based on Roman originals. These are particularly noteworthy for the information they provide on the Nabataean pottery industry; the many hundreds of lamps uncovered can be seen (from a study of the minor irregularities in their design) to have been produced from the same three or four original molds. This suggests that the manufacture of the lamps was confined to a very few workshops, perhaps even to a single family of lampmakers supplying the whole of Petra's needs.

Most distinctive, original and interesting of all, however, is the painted Nabataean pottery. This ware, in spite of its great fragility, was in such common use by the Nabataeans that Nelson Glueck of Hebrew Union College in Cincinnati has used it to identify from surface surveys alone many hundreds of Nabataean settlements in the southern parts of Jordan and Israel. We have learned much about the origin and development of this beautiful painted pottery from our excavations at Petra. We can now say that it appeared in the first century B.C. and was copied, at least indirectly, from the decorated Hellenistic wares of Syria and Egypt; a single fragment of such a foreign vessel has been found at Petra. The earliest examples have leafed patterns painted in red in a light, free-flowing style, but gradually (probably in the first and second centuries A.D.) the designs became more stylized and the brush technique heavier. The final stage of development (which cannot be firmly dated at present) found the pottery itself and the decoration much coarser and heavier. This degenerate style may have had some influence on the painted pottery of the early Arabic period in Jordan, but the evidence for this is tenuous at present. It seems that the distinctive and highly advanced ceramic art of the Nabataeans disappeared during the dark centuries of the Byzantine age.



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The Control of Growth in Plant Cells

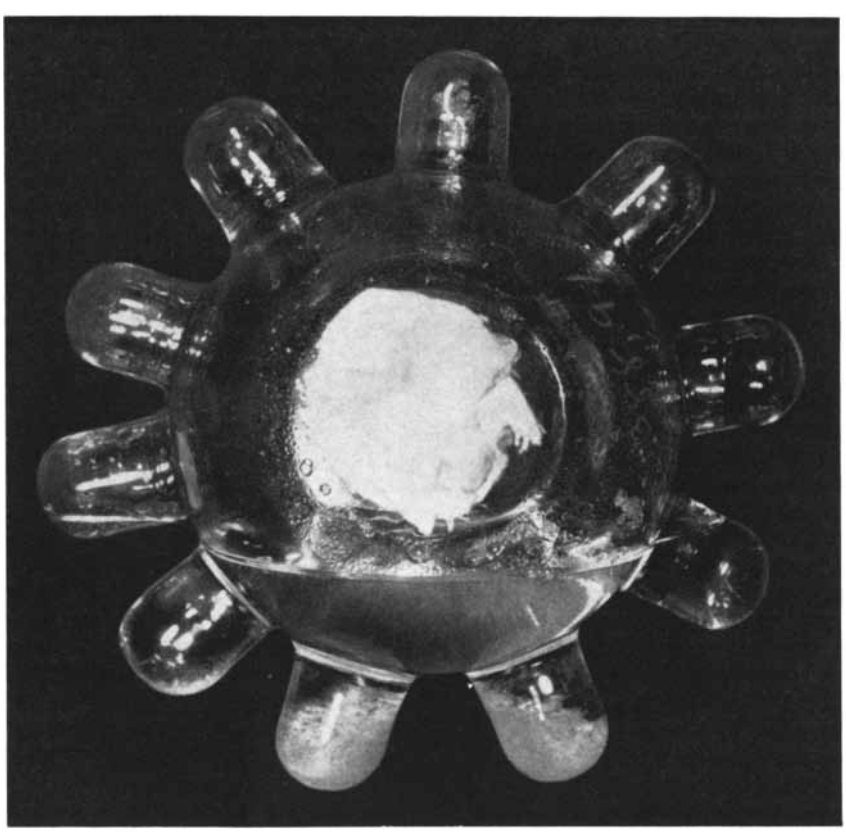
Experiments showing that a new carrot plant can be produced from ordinarily nongrowing cells of the root provide clues about what causes and inhibits growth in living organisms

by F. C. Steward

For all sexually reproducing organisms, plant or animal, the zygote, or fertilized egg, is the bridge between one generation and the next. As such it seems to fulfill a unique role. The division of this single cell starts the building of a new organism. It contains in its nucleus a molecular blueprint (the structure of its DNA) that will determine the constitution of the entire organism, and the blueprint is faithfully reproduced in each of the millions of cells that constitute the new organism. Yet notwithstanding this fixed set of instructions, most of the cells stop dividing and eventually differentiate to form a great variety of tissues and organs.

The mystery of what makes some cells go on growing while in others growth subsides is one of the most challenging present problems in biology. Is there something altogether special about embryonic cells, something inherent that sets them apart from mature cells in their ability to grow? Or is the fate of cells decided largely by external factors—controlling factors in their environment?

Recent work with plant cells, which will be described in this article, has shown the latter to be the case. By supplying certain chemical factors we have been able to stimulate adult cells to grow again—even to grow entire plants from single rejuvenated cells! The investigations lead to the conclusion that the zygote, far from possessing unique properties, is perhaps the least specialized of all the cells in the plant. Its ability to grow is a common property that, under suitable conditions, is displayed by many other kinds of cells.



CULTURE FLASK viewed from top contains carrot tissue in a growth medium. Slow rotation of flask shakes individual cells loose; some can be stimulated to produce new plants.

To understand these experiments we must first look into some of the details of how a flowering plant reproduces. In a flowering plant the process begins in two separate organs of the flower: the anther (at the tip of the stamen), where the male part of the sexual cycle begins, and the ovule (within the ovary), where the female part of the cycle begins. The first step, as in animals, is meiosis: the division of diploid cells (cells with a double set of chromosomes) into haploid cells (cells with a single set).

In plants the haploid cells that result from meiosis are called spores. These cells (or their nuclei) can divide many times before they give rise to gametes: male and female sex cells. The spores that give rise to the male sexual cycle are called microspores; those that give rise to the female sexual cycle, megaspores. Ordinarily spores can grow independently, but a gamete will do so only if it fuses with a gamete of the opposite sex.

In the anthers microspores develop into pollen, and a pollen tube, with two male nuclei in its tip, grows down the style of the flower toward the ovule [*see top illustration on page 106*]. Meanwhile in the ovule megaspores have formed an embryo sac that may contain as many

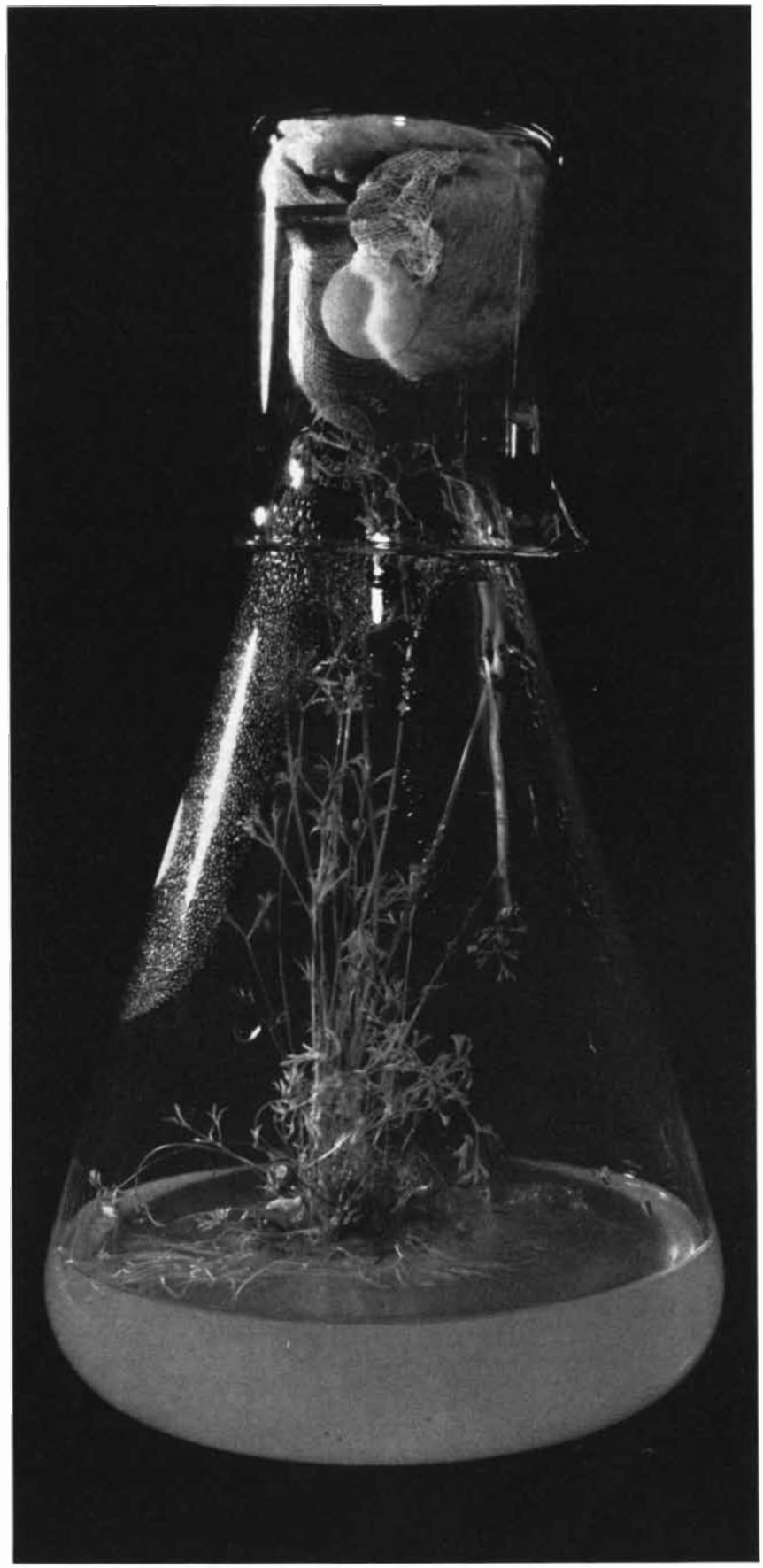
as eight nuclei. When the tip of the pollen tube penetrates this sac, it discharges its two male nuclei. One of these fuses with a female nucleus in the sac, and the result is a zygote.

The act of fertilization itself is a great stimulus to the growth of the egg, but the zygote gets another type of stimulus from its environment in the ovule. The second male nucleus, although it is not a party to the sexual union, turns out to have a crucial role to play. This nucleus combines with a diploid nucleus composed of two nuclei in the embryo sac, and the fused nucleus produces a nutritive tissue called endosperm. The endosperm often develops in advance of the embryo and stores food that nourishes and stimulates the growth of the embryo from the zygote. The first specialized leaves of the young embryo, called cotyledons, absorb food and growth stimulants from the endosperm.

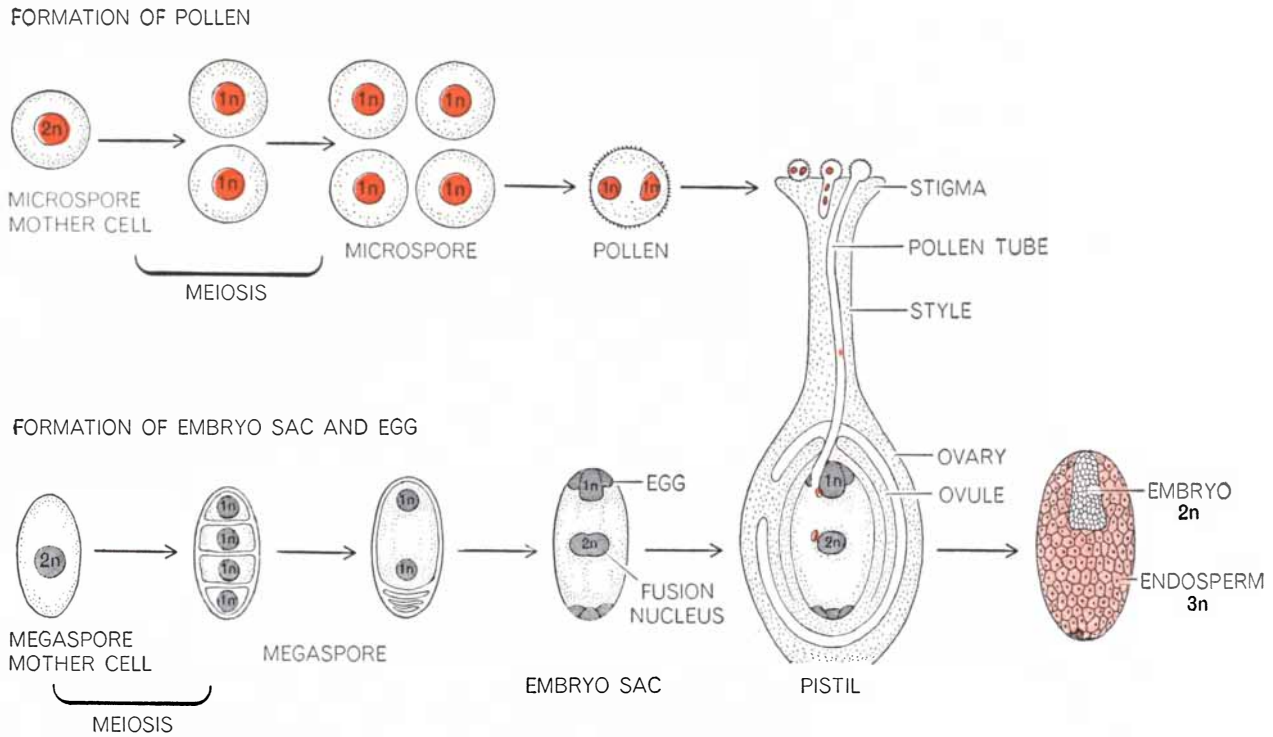
Thus the zygote's built-in capacity for growth gets indispensable help from its environment. As the young plant develops, its growth soon becomes highly localized. Surprisingly few of its cells continue to multiply; the ones that do are primarily those at the extreme tips of the shoots and roots. The main growth of the shoot takes place in a small dome of tissue on its apex less than a millimeter in diameter. Here the dividing cells form bulges that become leaves; in the mint plant, for example, two leaves form on opposite sides of the stem. Other pairs of leaves are present at intervals along the axis. And in the notches between the stem and the leaves small islands of growing cells form buds that later become branches.

Certain tissues of a plant may be able to grow indefinitely. An outstanding example is the cambium of a tree: the tissue that gives rise to the tree's annual rings and causes the trunk and branches to grow in girth. There are sequoia trees in California in which the cambium has been growing, with annual periods of rest or dormancy, for 4,000 years or more, which is as close an approximation of eternal life as occurs on this planet.

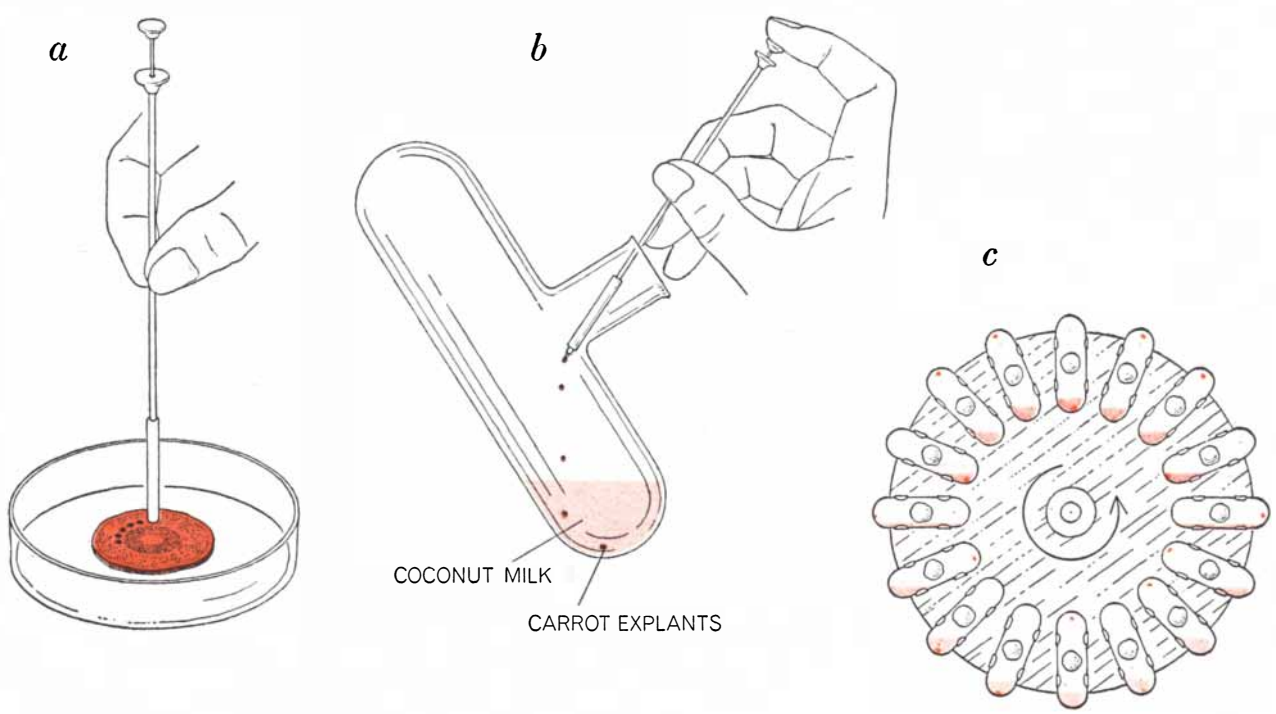
But just as remarkable as the continuation of cell growth is its cessation. What is it that makes the still living cells of the pith and bark of a plant stop dividing and remain quiescent? Why does the growth of an organ such as a potato tuber or a carrot root come to a halt even though it is supplied with an abundance of food and water? If a potato tuber or a carrot root is cut and kept in moist air, its surface cells will start dividing,



SUCCESSFUL EXPERIMENT created a new carrot plant in the laboratory from ordinarily nongrowing cells of a carrot root. The flask contains a carrot plant produced in that way.



NORMAL REPRODUCTION IN FLOWERING PLANTS occurs as depicted here. Sequence at top left shows development of pollen after formation in anther, beginning with a 2n microspore mother cell (meaning that it is diploid, or contains two sets of chromosomes) and progressing through several divisions until one pollen grain lodges on a stigma and gives rise to a pollen tube. Meanwhile, as shown in sequence at bottom left, an embryo sac containing an egg similarly develops from a megaspore mother cell. On the pistil two of the nuclei that have developed in pollen grain start down pollen tube. One nucleus joins the egg to accomplish fertilization; one joins fusion nucleus to create endosperm, a nutritive stimulant to embryo growth. End product is seed containing embryo.



EXPERIMENT BEGINS when, as shown at left, a thin metal tube is used to cut small carrot segments, or explants, which are then placed in a tube containing a growth medium that includes coconut milk. The medium thus imitates the nutritive functions of the endosperm. Several tubes are then rotated on a wheel, as shown at right, to provide a precise mixture of air and the growth medium.

but this growth stops as soon as the wound is healed.

All the cells of a plant receive the same genetic information. We must ask, therefore, what is it that turns a cell's built-in capacity for growth on or off as the case may be? Plainly this controlling signal or stimulus must come from outside the cell itself. In the living, intact plant the signal is evidently supplied by some chemical factor in the neighborhood of the cells in question, as the effect of the endosperm on the embryo suggests. To track down the responsible factor or factors a series of controlled experiments with cultures of plant tissues and individual cells have been performed.

At the turn of the century the Austrian botanist G. Haberlandt envisioned the possibility of growing plants from single cells and discovering their requirements in this way. The work in our laboratory at Cornell University has been toward this goal.

The first question investigated was whether or not a mature, quiescent plant tissue could be forced into active growth by exposing it to a variety of natural and unnatural materials. It turned out that endosperm, which was known to promote the growth of young embryos, was particularly effective. For the tissue to be tested the carrot root was chosen.

From thin cross-sectional slices of the carrot small cylindrical pieces (two to three milligrams in size) were taken from a nongrowing region of the root, a millimeter or two from the cambial ring [*see bottom illustration on opposite page*]. All the operations and manipulations of the tissue had to be done aseptically, with the precautions of a surgical operation. One to three of the tissue pieces were then placed in a nutrient medium in a special glass tube. Air can diffuse into the tube via a cotton plug in a side neck, and the tube was slowly rotated around a horizontal shaft (at one revolution per minute) so that the tissue, clinging to the wall of the tube, was alternately submerged in the liquid and exposed to air. The relative periods of exposure to the nutrient and to air proved to be important, and optimal exposure times were arranged by careful attention to the dimensions of the tube and the relative volume of the liquid medium.

The basic medium was a standard nutrient solution for plant tissue culture. To this was added various plant extracts and other substances that might stimulate the tissue to grow. Although many substances were tried, the greatest success came with coconut milk, or coconut "water," as it is often called.

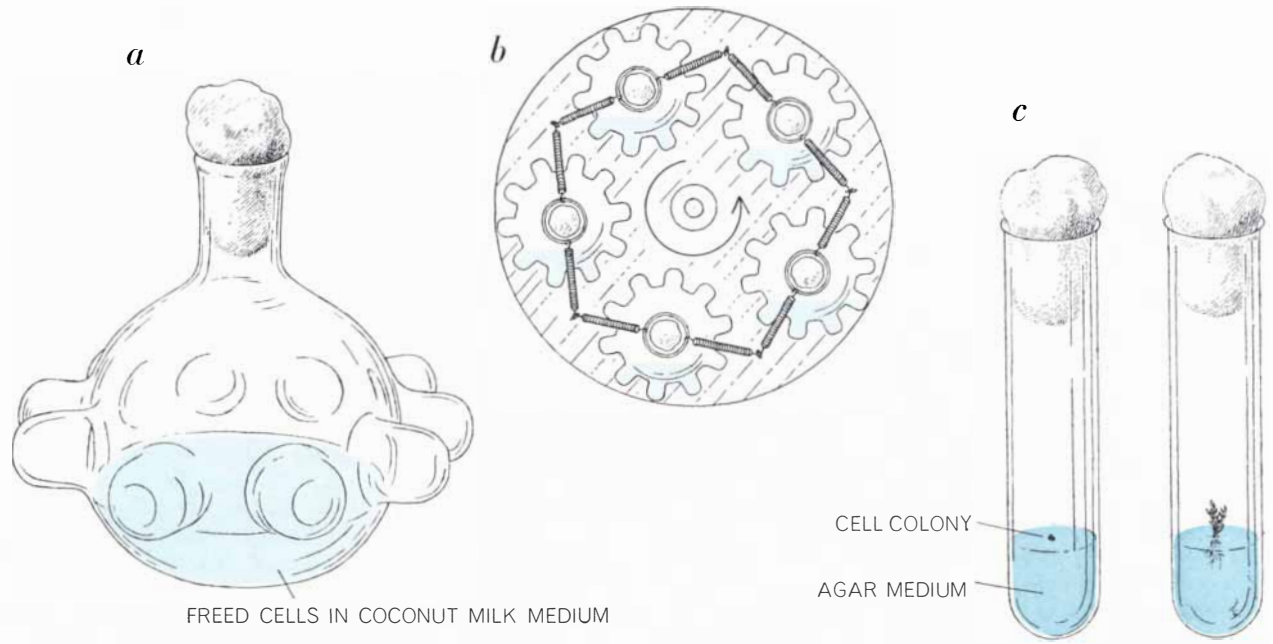
Coconut milk is the liquid endosperm that nourishes the embryo that grows inside the coconut. It was therefore a logical as well as convenient material to try as a possible stimulator of growth in our tissue culture. But we were hardly prepared for its dramatic effect on the quiescent carrot cells [*see upper illustration on page 110*]. The tissue began to grow rapidly, and in 20 days it had multiplied its weight approximately eightyfold!

To measure the effect on the cells themselves the tissues were treated in a mixture of chromic and hydrochloric acids. This procedure separated the cells so that they could be counted in much the same way as blood cells are counted. It then became possible to estimate the average size of the cells (by dividing the weight of a sample of tissue by the number of cells). This analysis, made at various growth stages, showed that at first the cells grew in size without dividing; then, as cell division got under way, their average size became smaller, and finally, as the rate of division subsided, the cell size tended to increase again.

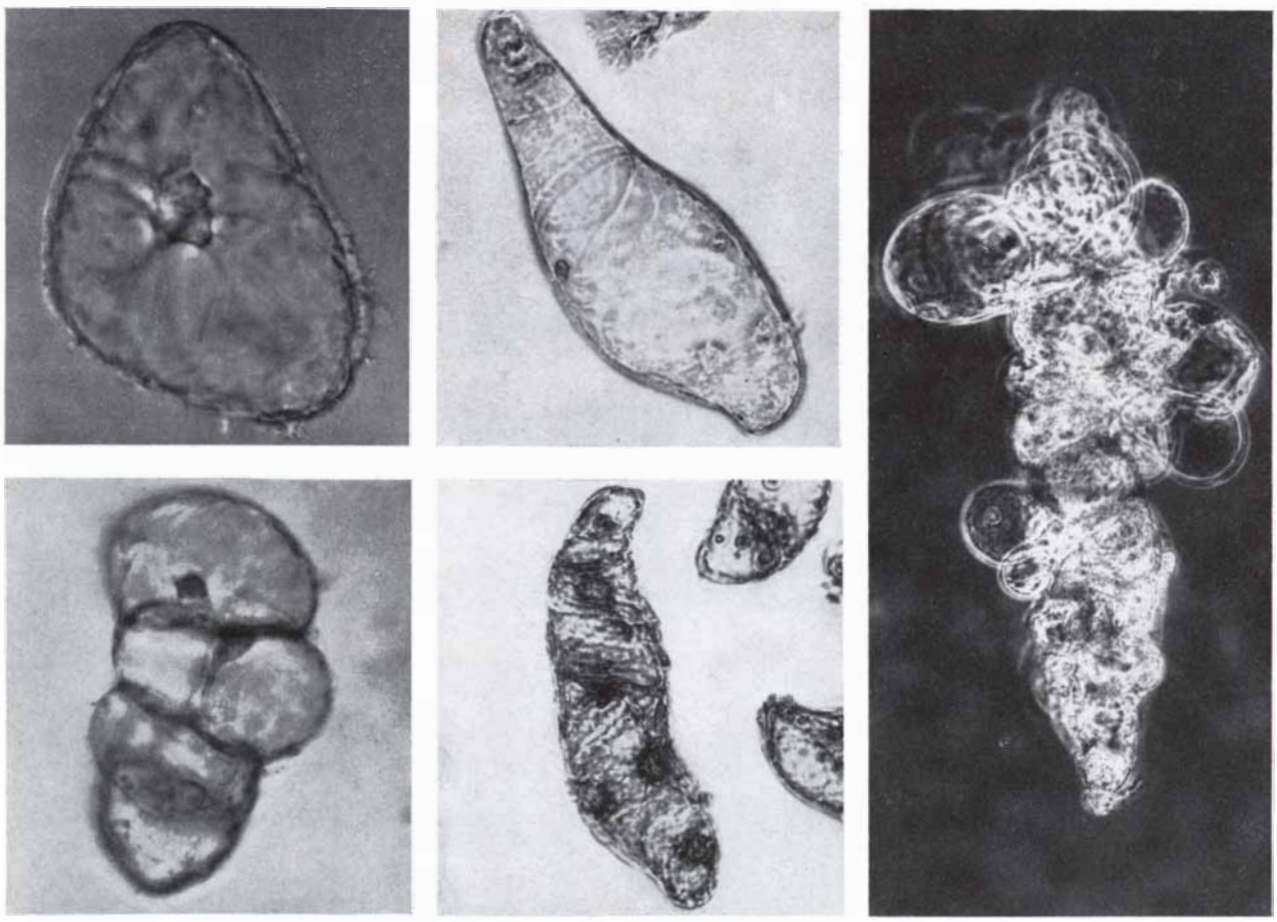
The unleashing of the growth of these otherwise resting cells, which in the carrot root's natural condition would not have grown again, was a startling phenomenon. It was as if the coconut milk had acted like a clutch, putting the cell's idling engine of growth into gear and thereby enabling the cell to use its available fuel to grow again. Something in the coconut milk had turned on the built-in capacity of the carrot root cells for growth.

Certain other cells, however, did not respond to coconut milk in this way. Coconut milk alone failed, for example, to stimulate growth in the potato tuber. Experiments showed that the cells of some organs, for example the onion bulb and the dormant bud of the maple tree, contain substances that counteract the effect of coconut milk. The buds of the maple (and of other deciduous trees) become dormant in late summer. Extracts from these buds prevented the growth of carrot cells when they were added to the medium containing coconut milk. When the dormancy of the buds was broken by winter cold, however, even comparable extracts no longer inhibited the growth-promoting effect of

TUBES AND FLASKS are mounted on revolving apparatus in the laboratory. System was devised to provide a regulated alternation of air and liquid for carrot explants in tubes.



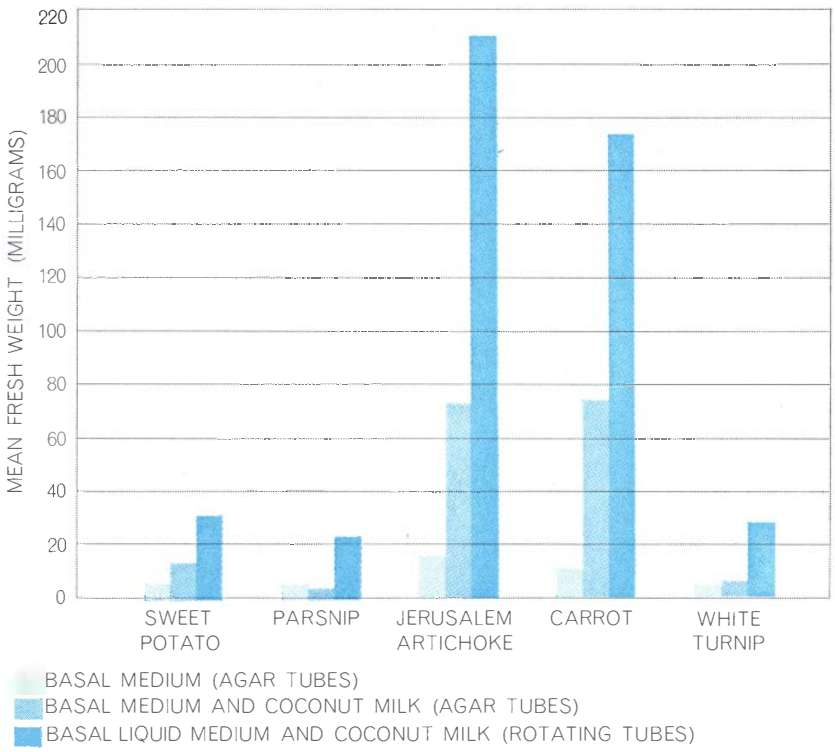
TRANSFORMATION OF FREED CELLS into a carrot plant that is wholly a laboratory creation begins with free cells in a culture flask (*left*), which is then mounted with similar flasks on a revolving wheel (*center*). As cells multiply, clusters are removed and put into an agar medium (*right*). Some cells grow into normal carrot plants similar to those that are raised from seed.



GROWTH OF CELLS in the author's experiments is shown in these photographs. The top photograph at left shows a freed cell, the bottom photograph an older cell after it has begun to grow by dividing. Similarly, the top and bottom photographs in the center panel show other stages in the development of a single freed cell, although with division taking place in a different manner. The photograph at right shows a cluster of cells beginning to assume the polarity characteristic of organized carrot plants.

coconut milk; evidently the chilling had inactivated the inhibitor that causes the buds to be dormant.

There are, however, substances that enhance the growth-stimulating effect of coconut milk. Such substances, which are not effective alone but display an effect when combined with another substance, are called synergists. It was found that coconut milk required the help of an appropriate synergist to initiate growth in certain resting cells. A number of synergists that can augment the effect of coconut milk have since been identified. The first of many was the well-known herbicide 2,4-D (2,4-dichlorophenoxyacetic acid); it speeded up the growth of potato tuber cells when it was added in the proportion of six parts per million to the medium that also contained coconut milk.



CONTRASTING RESULTS occurred when explants from various plants were stimulated with growth medium containing coconut milk. Each group of bars shows, from left to right, effect of basal control medium and various supplements on different explants over 21 days.

Thus the experiments graphically demonstrated that all cells have an inherent ability to grow that is controlled by a delicately poised system of chemical controls. Whether or not a given cell will grow depends not only on the general growing conditions (its food and water supply, temperature and so on) but also on the stimulating or inhibiting complex of substances to which it is exposed.

It follows that mature cells may often start to grow abnormally when their normal chemical balance is disturbed. This is well known in the occurrence of plant tumors; an example is the crown-gall tumor on the stem of the Kalanchoe plant. Extracts from these tumors proved to be capable of stimulating growth in our carrot explants, just as coconut milk did. Only the altered tumor cells contained the stimulating substance; extracts from normal stem tissue of the plant, and from the microorganism that changes the normal cell chemistry and gives rise to the tumor, failed to show the growth-promoting effect.

When pieces of carrot root were stimulated to grow in this way, the new growth had all the characteristics of the explanted tissue: it consisted of unspecialized living cells. But very different events were observed when the tissue was cultured in coconut milk and so treated that cells separated from its surface and were able to grow independently.

This was done in another type of flask consisting of a number of nipples radiating from the central container. The flask was actually designed to grow many carrot explants (up to 100) in a single vessel. As the flask was rotated individual cells were gently loosened from the tissue at its edges. These freed cells were then transplanted into fresh coconut milk growth medium in new flasks just as bacteria are commonly grown by inoculation of a medium.

Freed from the restricting influence of the organized root tissue, the individual carrot cells now began to grow in a variety of different ways. Some grew to giant size, with many nuclei, and showed active protoplasmic streaming. Others put forth tubular outgrowths that became filaments and then divided. Some formed small, uniform buds, almost like the growth of yeast cells. Eventually some of them partitioned themselves into a clump of cells resembling an early carrot embryo.

This striking development was observed when free cells, on dividing, often grew into aggregates that spontaneously formed rootlets. Transferred to an agar medium containing coconut milk, such clusters of cells would then grow shoots opposite the root; that is, they became plantlets very similar to the normal embryo of a carrot plant. Such plantlets, carefully nursed along on the agar medium and then successively transplanted to vermiculite and soil, would eventually grow into mature carrot plants, with normal roots, stalks, flowers and seeds. In short, Haberlandt's old dream was finally realized: complete, normal plants were grown in culture from free single cells.

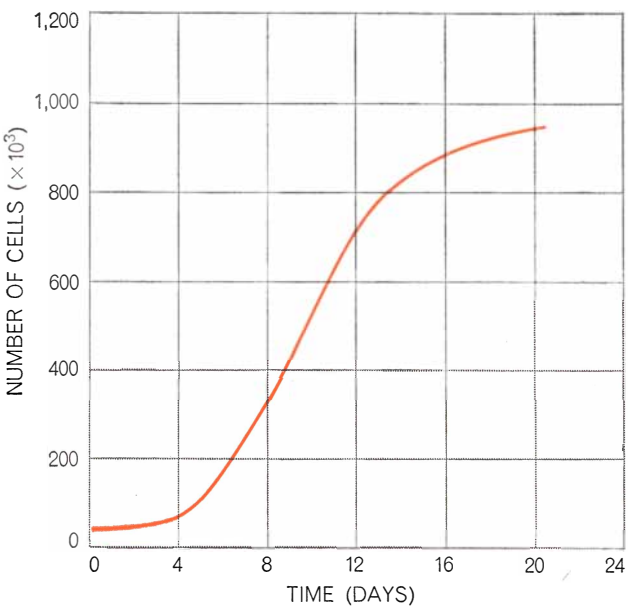
Quite recent work in our laboratory has proceeded further along the same line. If the embryo is dissected from the ovary of the carrot flower, it can of course be cultured as an already organized plantlet. This can easily be done in a medium that contains coconut milk. If, however, a very young embryo is made to proliferate so that cells can be removed from its surface, these freed cells can be grown suspended in liquid in the manner already described. The free cells of embryo origin multiply under these culture conditions, and when a sample of them is spread evenly on an agar medium containing coconut milk in a Petri dish, each cell or small cluster grows. It was estimated that more than 100,000 embryoids, remarkably like true, or zygotic, embryos, occurred on a plate inoculated from a cell suspension derived from one carrot embryo. This obviously means that virtually every cell of the young embryo was itself capable of developing into an embryo and that every cell could, under the right nutritional conditions, behave faithfully like a fertilized egg.

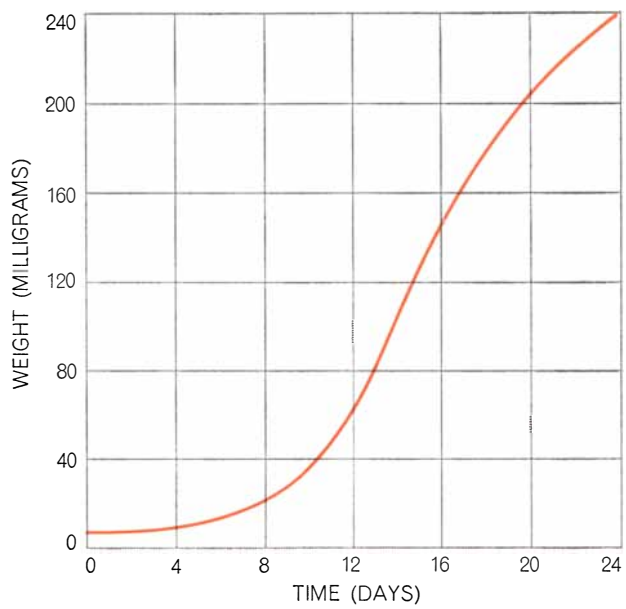
Thus a mature cell taken from the dif-

ferentiated tissue of a carrot has been made to behave like the fertilized egg cell, and the stages of its development into a full plant bear a striking resemblance to the normal growth of a carrot embryo [*see bottom illustration on opposite page*]. Experiments showed that the alteration of the adult cell's behavior can be brought about by two essential conditions: (1) removing the cell from its specialized environment and allowing it to grow as a free cell, and (2) supplying it with the kind of substances from endosperm that normally nourish young embryos. In other words, given the right medium and space in which to grow, the adult cell and the embryonic cell behave in the same way.

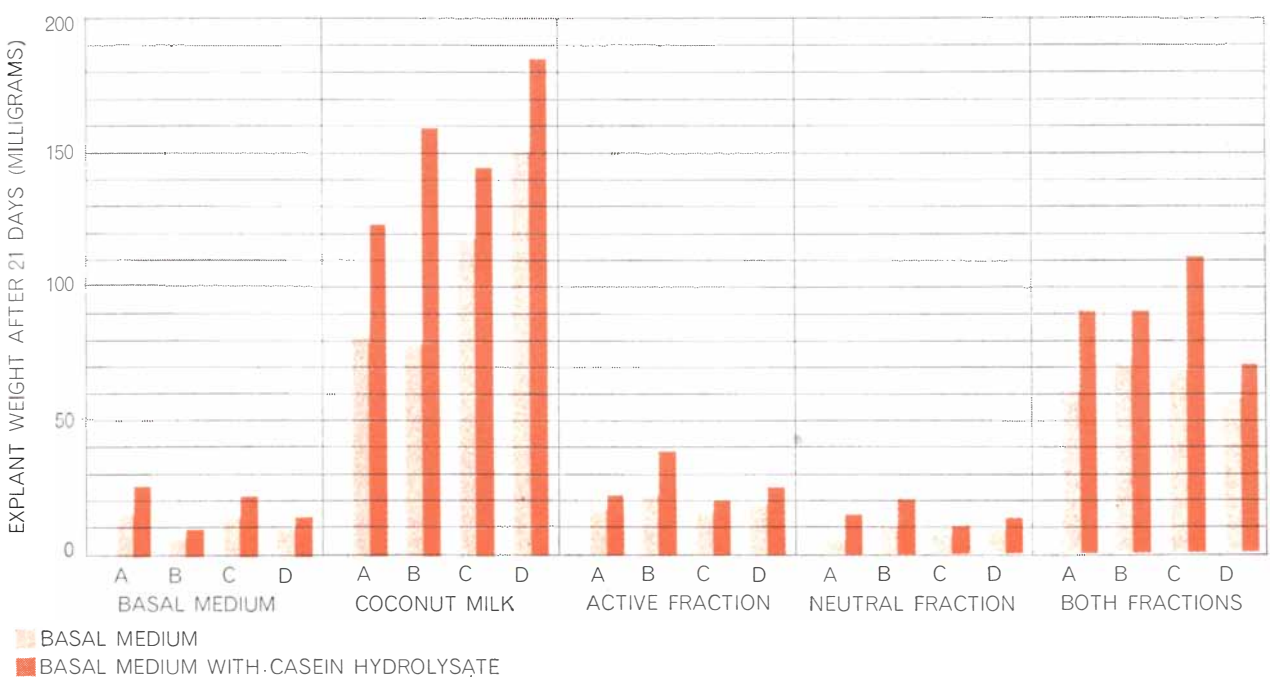
From this point of view a differentiated cell can be regarded as one that has all the capacities of the fertilized egg but is allowed to use only part of the information and directions that are stored in its genetic material. The limitations on its behavior result from its position in the special organ of the plant body in which it is incorporated. These controls now need to be interpreted in chemical terms. What are the specific substances that exercise these controls, turning on and off the action of the genes?

Before we get into this important





DRAMATIC GROWTH of explants from a part of the carrot root where growth under normal circumstances had ceased is reflected in these curves. Each relates to a single explant; curve at left shows example of cell increase; that at right, of weight increase.



GROWTH-STIMULATING SUBSTANCES in coconut milk were separated into "active" and "neutral" fractions. Panel at left shows growth of four sets of carrot cultures in a basal medium with and without nitrogen in the form of casein hydrolysate; succeeding panels, what happened to similar groups of cultures when coconut milk or its fractions were added to those growth media.

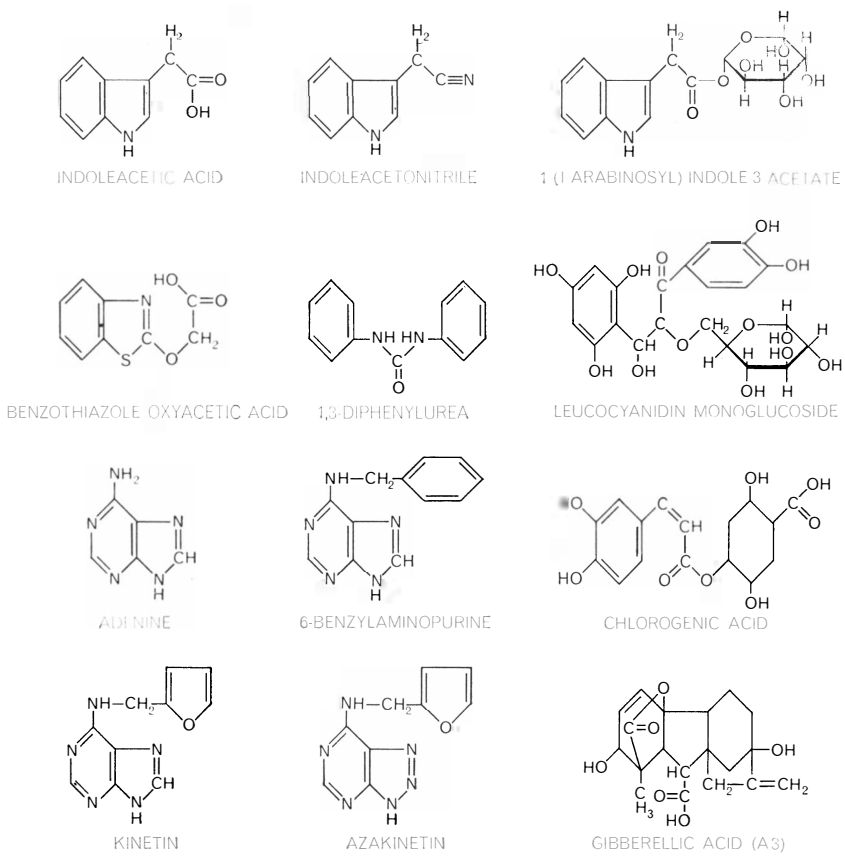
question, we might note some other interesting findings about cell growth.

Armin C. Braun of the Rockefeller Institute has accomplished another important transformation: he has succeeded in converting growing tumor cells into normal tissue. Braun worked with a crown-gall tumor on the tobacco plant. After breaking down the tumor tissue into free cells he cultured these cells separately. A single cell grew into a cluster that Braun then grafted onto the normal shoot of a tobacco plant; after several successive grafts the group of tumor cells grew into a normal shoot. Thus under the powerful influence of the normal plant the tumor cells had been induced to behave again as normal, differentiated shoot cells.

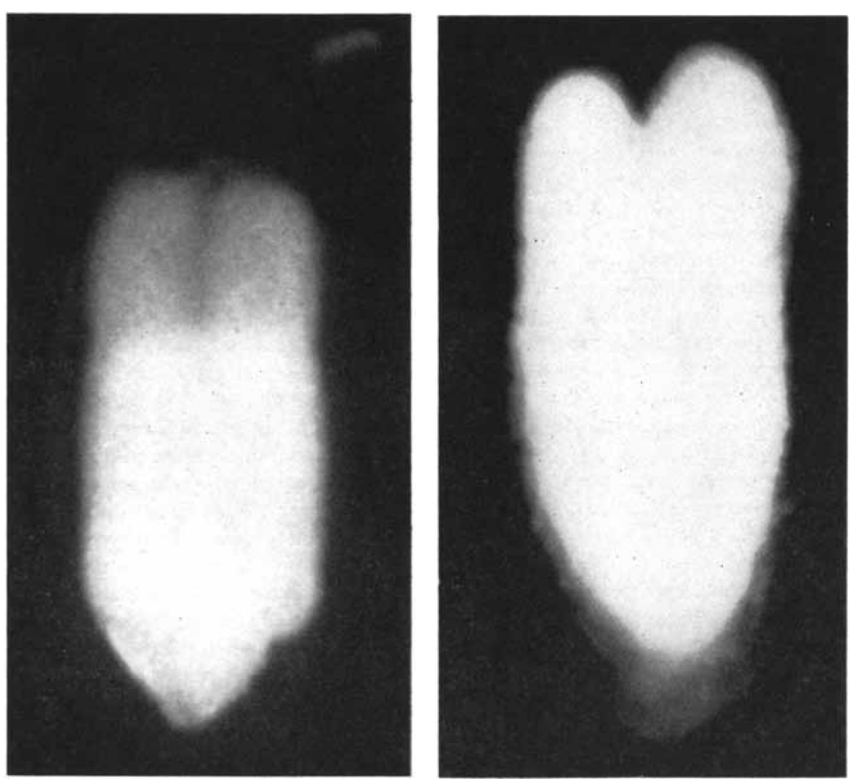
The chromosomal events in cells stimulated to grow by coconut milk have also been investigated in our laboratory. In free-growing cells a number of events occur; some are highly unusual and some, although unexpected in such biological material, are normally associated with phases of reproductive growth. Sometimes the carrot cells grow into giant forms with nuclei containing several times the normal carrot diploid complement of 18 chromosomes. Other cells show distortions of the chromosomes such as are produced by ionizing radiation. Occasionally a cell division produces daughters with only nine chromosomes—the haploid number characteristic of the spores that initiate the sexual part of the life cycle. Indeed, we have seen quartets of cells that look very much like microspores. In cell cultures of the common Western weed *Haplopappus gracilis,* which has only four chromosomes in the diploid cell, we have even seen the exchange of parts of chromosomes that is known as "crossing over," a fairly common occurrence in the normal meiotic division of cells. All this emphasizes that when they can grow free, even adult cells can behave like reproductive cells.

It is now time to look into the all-important question: What are the specific substances that possess this remarkable power of activating the cell's built-in growth mechanism, and how do they act?

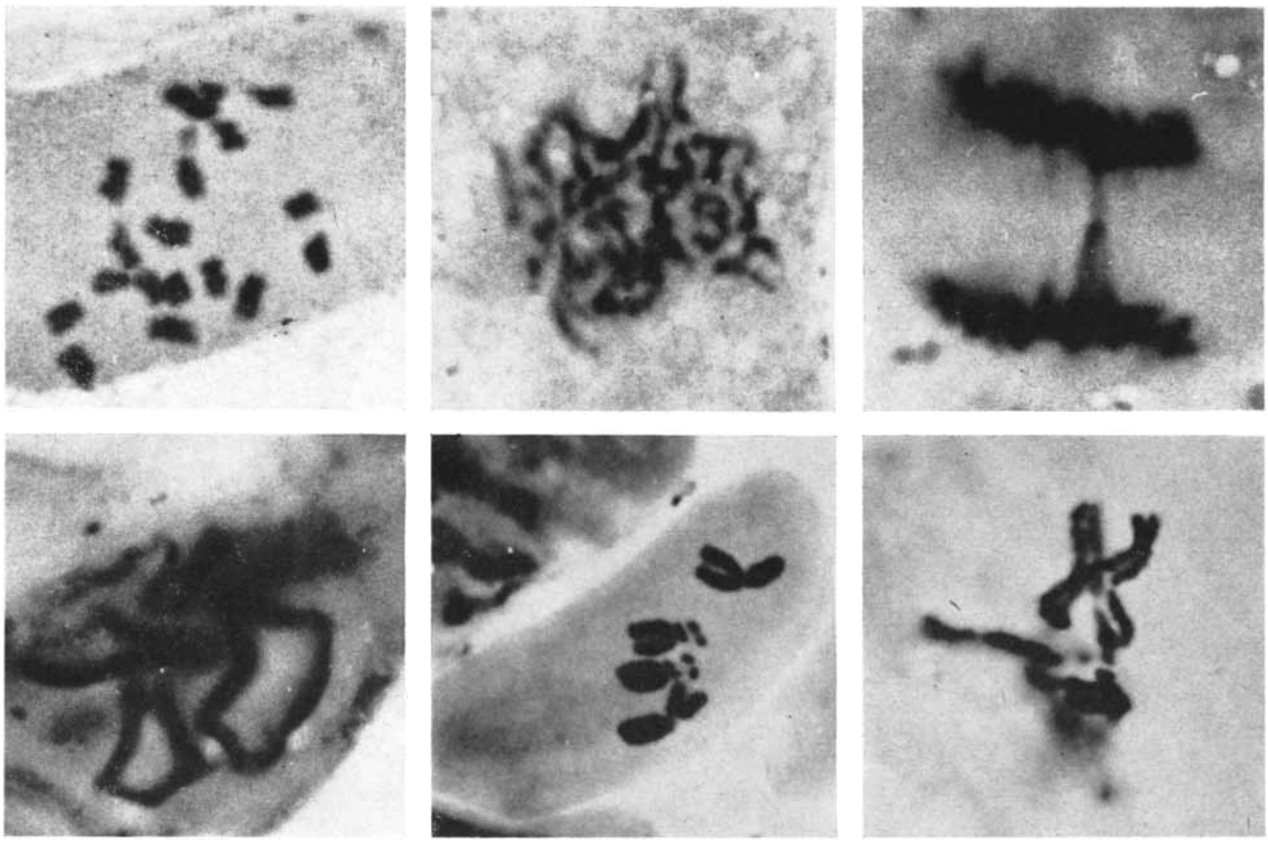
First of all it should be noted that the effects in question are not peculiar to carrots and coconuts. Coconut milk will stimulate growth not only in carrot tissue but also in artichoke tubers and many other plant tissues; with the assistance of a synergist it can even induce the cells of the potato tuber to grow continuously. And there are plant materials other



MOLECULAR STRUCTURE of various growth-promoting substances is shown in these drawings. The only obvious feature common to them is their complex cyclical configuration.



NATURAL AND CULTURED embryos (*greatly magnified*) show marked likeness. At left is young embryo dissected from carrot seed; at right, embryo grown from free cell culture.



CHROMOSOMAL CHANGES occurred in cultured cells. At top, left to right, are normal diploid carrot cell with 18 chromosomes, polyploid nucleus in giant cultured cell and chromosome bridge due to failure to separate cleanly. At bottom are cultured carrot cell with nine chromosomes, normal diploid *Haplopappus* cell with four chromosomes and "crossing over" in cultured *Haplopappus*.

than coconut milk that have the same growth-stimulating effect; among them are extracts from the grains of corn in an immature stage (the "milk stage"), from immature walnuts and from immature horse chestnuts of the species *Aesculus woerlitzensis*.

These various materials have now been fractionated and analyzed to identify specific stimulating substances. The analysis indicates that the growth stimulation requires three types of compound, acting jointly: (1) highly active materials that specifically induce cell division, (2) a neutral fraction that acts as a kind of synergist or catalyst for the active fraction and (3) a source of "reduced" (organic) nitrogen.

The third requirement can be supplied most readily by amino acids or by the decomposition products (hydrolysate) of a protein, conveniently a hydrolysate of casein (the milk protein). The casein fraction has been found to be essential or at least helpful to the action of certain other ingredients in the growth-promoting system.

The second requirement, the neutral fraction, consists of sugar alcohols and the alcohols called inositols. Coconut milk contains the sugar alcohols D-sorbitol (200 grams of it was extracted from 20 liters of the fluid) and mannitol; it also contains the inositols myo-inositol and scyllo-inositol. Although the inositols are present in smaller amounts than the sugar alcohols, the inositols are the more important. Without the neutral fraction, the active fraction of coconut milk shows little or no growth-stimulating activity.

As for the ingredients that promote cell division, several active compounds have been isolated in purified or nearly purified form. Coconut milk and the other growth-promoting materials mentioned contain as somewhat active ingredients certain phenolic substances that are the colorless precursors of reddish pigments in plants. From one large batch of coconut milk, 1,3-diphenylurea was isolated as an active compound. From corn a compound of indoleacetic acid (IAA) and the sugar arabinose that is undoubtedly active in stimulating growth was obtained in a pure state. Indoleacetic acid is an auxin (plant hormone) that is known to promote the growth of cells by enlargement. The synthetic auxin 2,4-D, in combination with the active components of coconut milk, was found to stimulate growth in many tissues that were not susceptible to coconut milk alone. Another synthetic substance, 2-benzthiazolyloxyacetic acid (BTOA), showed a curious ability to stimulate the growth of carrot root and many other tissues in the manner of coconut milk. A synthetic purine known as kinetin (technically 6-furfurylaminopurine), isolated from heated nucleic acid by Folke Skoog and his colleagues at the University of Wisconsin, proved to be effective in combination with IAA in stimulating division of giant tobacco cells and also, to a smaller extent, carrot cells. On the other hand, the well-known growth-promoting substances called the gibberellins have, so far at least, shown only small effects on carrot-cell division.

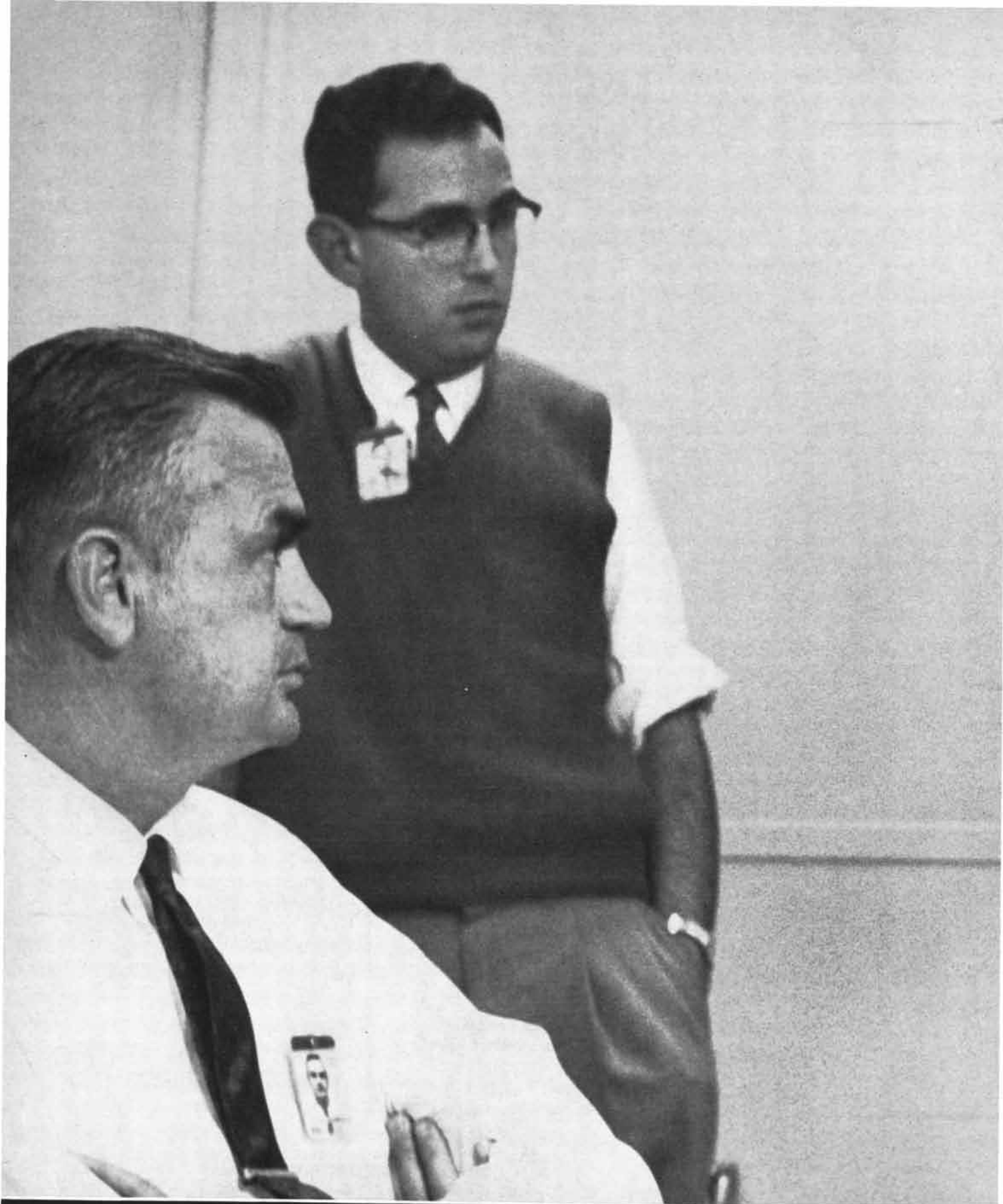
The list of substances that have been investigated is already long, and the end is not yet in sight. They constitute an array of compounds, natural and artificial, with quite different kinds of activity, and in the present state of knowledge it is difficult to see any common feature that might distinguish those that can promote cell division. One thing they seem to have in common is their molecu-

lar architecture: they are composed of five-atom or six-atom rings, in some cases joined by short, three-atom links. Perhaps some subtle feature of their geometry accounts for their ability to stimulate cell division.

We know something about how the substances that cause the cells to divide function chemically in the cell. Most prominently, they promote the synthesis of proteins. In particular they seem to be concerned with producing a type of protein that does not metabolize but simply converts the amino acid proline into hydroxyproline, which is contained in this protein in larger quantities than is usual in plants. This purely structural protein appears to have some special significance in dividing cells. But a growing cell also differs from a quiescent one in many other aspects of its metabolism, so that it is doubtful that this one peculiarity is solely responsible for the cell's distinctive behavior. Significantly, carrot cells and cultured carrot explants, when stimulated to grow by coconut milk, turn green and become capable of photosynthesis. This is another aspect of their capacity for independent development.

To sum up, the fertilized egg, which initiated the development of an organism, is endowed with a hereditary blueprint and a built-in capacity for growth. This is, as it were, the organism's guidance system. Like the guidance system of a missile, the cell's built-in instructions are modulated and controlled by factors in the environment as the organism proceeds on its path through time and space. The initial thrust for its growth comes from powerful stimuli in the endosperm—stimuli so potent that they can even restore adult, differentiated cells to active division and growth. But the embryonic organism could not grow in an orderly, organized way if its cells merely went on multiplying without limitation. Its growth is therefore controlled by a delicately balanced complex of synergists and stimulating and inhibiting substances.

Thus the sequence of development that converts a zygote into an embryo and the embryo into a mature organism is determined by both the hereditary "nature" of the cell and the special "nurture" it receives. The problem of understanding how an organism develops, and the aim of the work discussed in this article, is to discover the details of the chemical mechanisms that control the inherited instructions and equipment of the cell.



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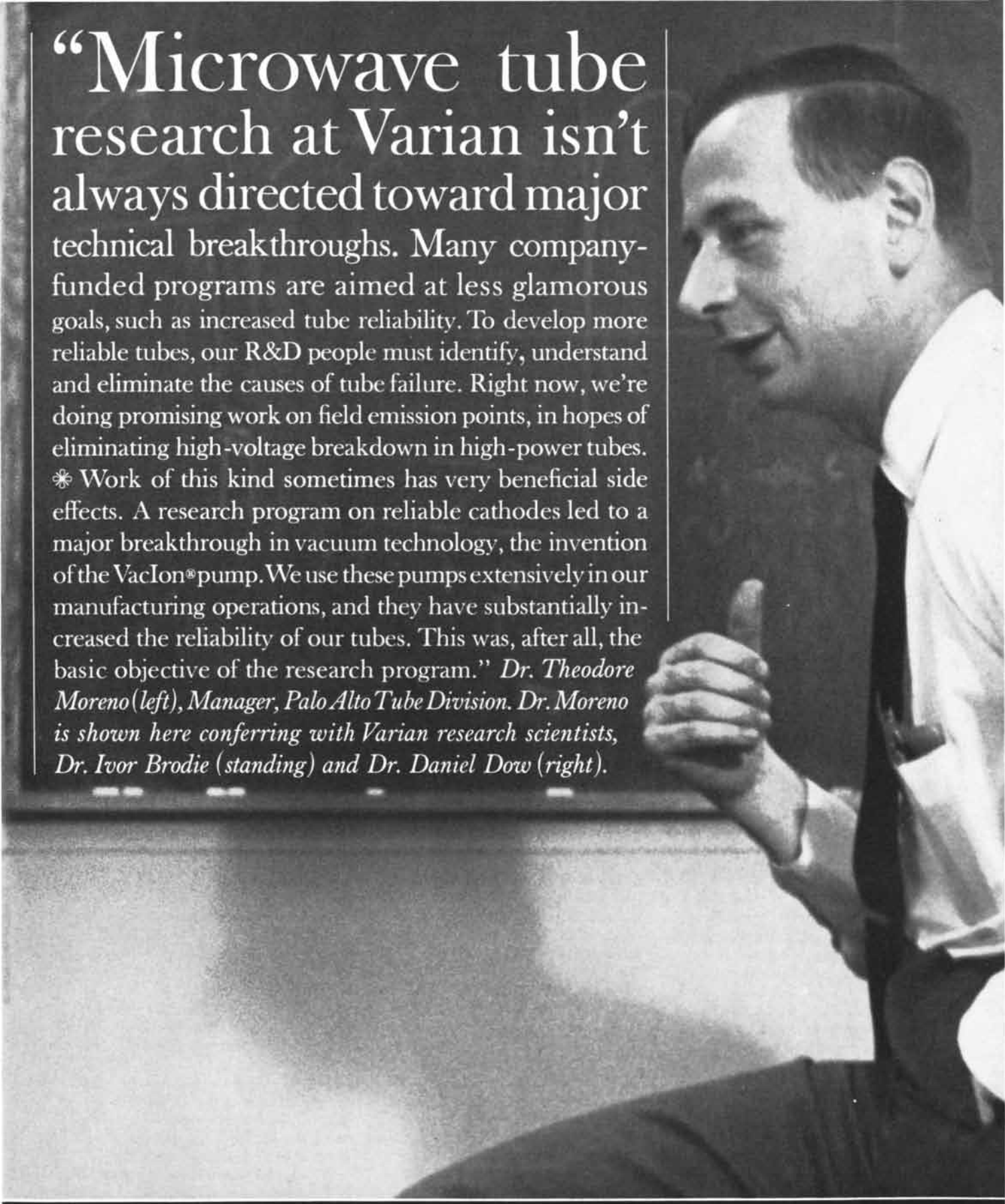

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PLACE-LEARNING

When an animal learns to run a maze, has it learned a sequence of movements or some kind of map? This problem, which bears on the theory of learning, has occupied psychologists for 50 years

by Henry Gleitman

When we see a circus animal performing a trick, we know that this is learned behavior. But exactly what is it that the animal has learned? Has it merely learned a pattern of response to a given situation or has it acquired concepts of broader application? Obviously this is a question of considerable importance for the theory of learning.

Consider a young child adding sums on the blackboard. He has been taught that three plus six equals nine. Confronted with the symbols $3 + 6 =$, he promptly fills in the answer. Suppose now we present the class with a new form of the question: $6 + 3 =$? One child is hopelessly puzzled, another readily answers nine. It is clear that the two pupils have learned different things: the first child has learned a specific answer to a specific question; the second has learned an arithmetical concept.

This example illustrates the truism that successful performance in any particular task does not necessarily indicate what has been learned. The point is a crucial one in theoretical studies of the nature of the learning process, and for half a century psychologists have investigated it with a great variety of experimental tests. They have swung between two rival theories about the learning process, which we might call the "response," or "motor," theory and the "cognitive," or perhaps "concept," theory.

In order to study the essentials of the learning process psychologists naturally have worked mainly with animals, which allow closely controlled experiments in relatively simple situations. The rat is a particularly convenient animal, and one of the favorite instruments for investigating its learning performances is the maze (a natural testing apparatus for an animal that normally lives in tunnels and burrows). Very early in this work it was established that a rat could learn to find its way through a highly complex maze involving 20 or more choices. How did it learn, and of what exactly did its learning consist?

One of the first to suggest an answer (around 1910) was John B. Watson, then a graduate student at the University of Chicago. He argued that what the rat (indeed, any animal) learned was a certain sequence of physical acts that got it through the maze. This sequence was based on sensory stimulations and motor responses: as the rat tried various paths, those muscle responses that took it along the correct path (for example, turning right, then left, then left again and so on) were gradually chained more and more strongly to specific sensory messages. In short, the animal eventually was propelled along the correct pathway automatically by connections forged between certain kinesthetic sensory patterns and specific motor innervations.

Watson and his mentor Harvey Carr performed an experiment that seemed to support this idea. They trained rats to run a certain maze perfectly, then they substituted a maze with exactly the same sequence of turns but with the alleys either shortened or lengthened substantially. In the shortened maze the rats ran headlong into the ends of the alleys; in the lengthened alleys they turned too soon and bumped into the walls. It did indeed look as if the animals had learned very specific muscular patterns, with the result that in the new mazes they tried to run the same distance up each alley as before.

But some further experiments by Watson threw doubt on his motor theory. In one experiment he rotated the original maze 90 degrees; in another he reversed its direction in the room. In both cases the rats performed poorly, making many errors. This indicated that in their original learning the animals had been guided to some degree by cues from outside the maze itself—perhaps by the light from a window or by the sounds from cages of rats at one side of the room.

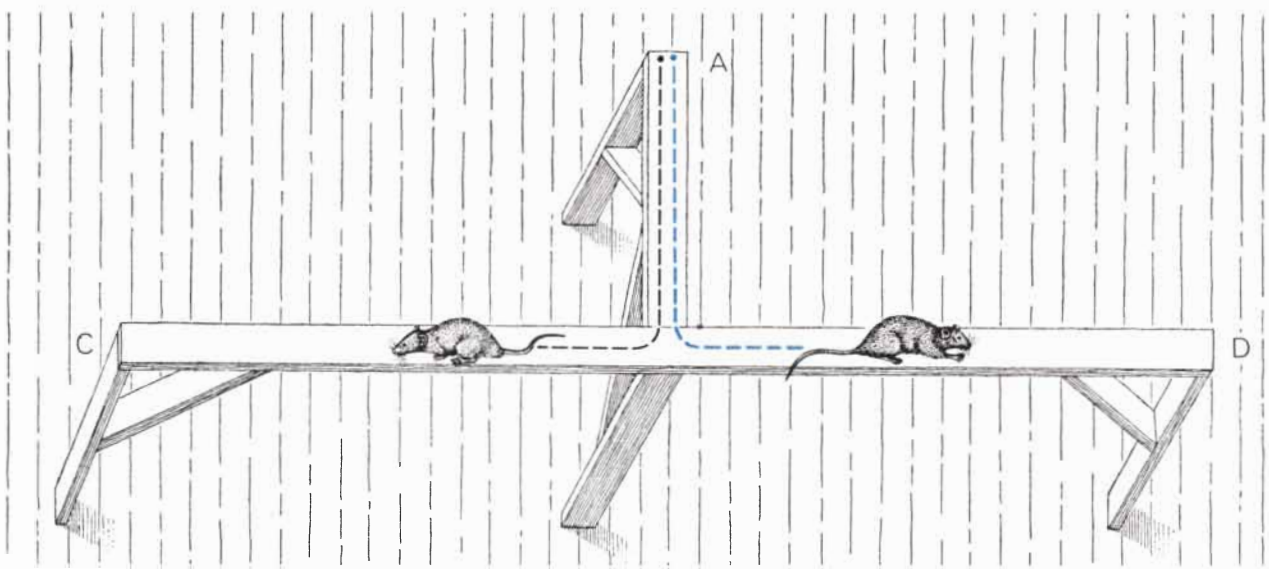
Opposed to Watson's theory was one that had been proposed by the British sociologist and philosopher Leonard T. Hobhouse. Noting that a dog, even in a strange house, would quickly learn to run to its master wherever the master called from, Hobhouse argued that an animal learned not a sequence of movements but the location of the goal, that is, some idea of spatial relations. Through the years many experiments have strongly upheld this view and contradicted Watson's "muscle twitch" theory, as its opponents dubbed it.

In one classic experiment D. A. MacFarlane of the University of California at Berkeley trained rats in a maze and then flooded the alleys with eight inches of water. The animals no longer could employ their running pattern and now had to swim, using an entirely different set of muscle movements. Nevertheless, they went through the maze almost without error. Other experimenters used more drastic methods to make sure that their experimental subjects could not employ the original motor pattern. They operated on the rat's cerebellum, upsetting its postural equilibrium, or they cut the spinal cord, severing the connection between the kinesthetic receptors and the brain, or they amputated a leg. None of these handicaps made any difference in the performance of a rat that had learned the maze thoroughly: swimming, staggering, limping or hobbling, the rat made its way through by the correct path.

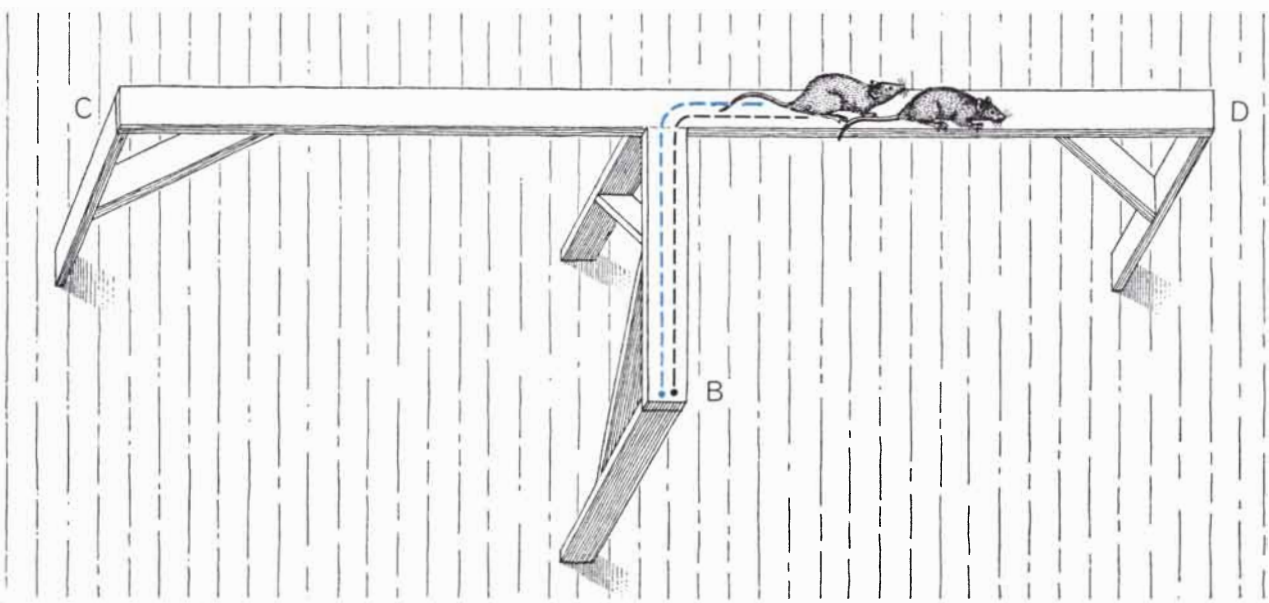
Although these experiments strongly

contested the Watson motor theory, it could still be argued that they were not decisive; the animals might be guided solely by the learned sequence of turns—by a "body twitch" pattern instead of the "muscle twitch" complex. But this point was decisively answered by another type of experiment. It turned out that rats could easily learn to reach a given goal without error even when they had to make different turns from one trial to the next.

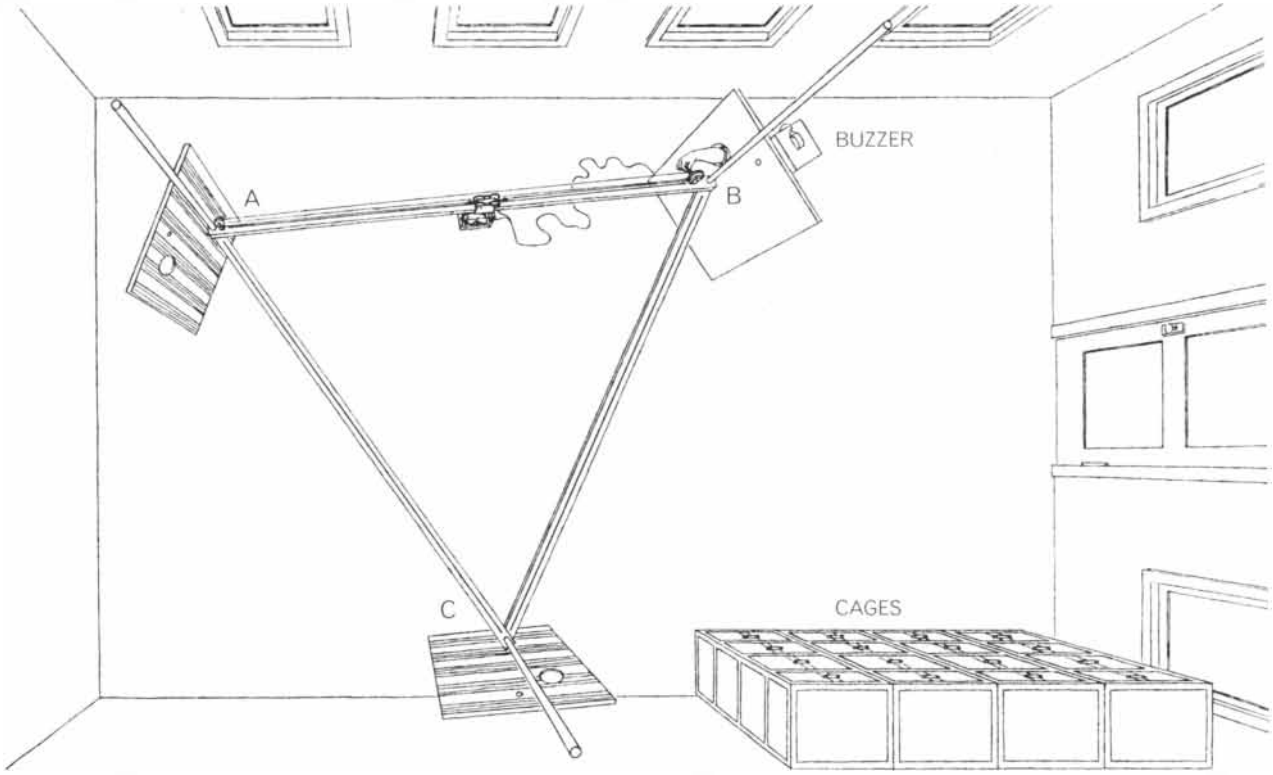
The instrument used for these experiments was the "elevated maze," a maze without walls consisting of a raised runway from which the subject can see and hear cues from outside the maze itself. (In the language of experimental psychology, "maze" does not necessarily mean a tortuous enclosure; it can be a simple T-shaped affair in which the subject merely chooses whether to turn right or left.) Edward C. Tolman, Benbow F. Ritchie and D. Kalish of the University of California at Berkeley tested rats on an elevated T-maze that could be arranged so that the starting point was on one side or the other of the crossbar [*see illustrations below*]. For one group of rats the experimenters always placed the food reward at the same point, namely at the same end of the crossbar. In order to find the food the animals had to turn right if they started from one side of the maze and left if they started from the opposite side. In other words, these rats had to learn the *place* where the food was located, not a particular *turn*. In order to learn



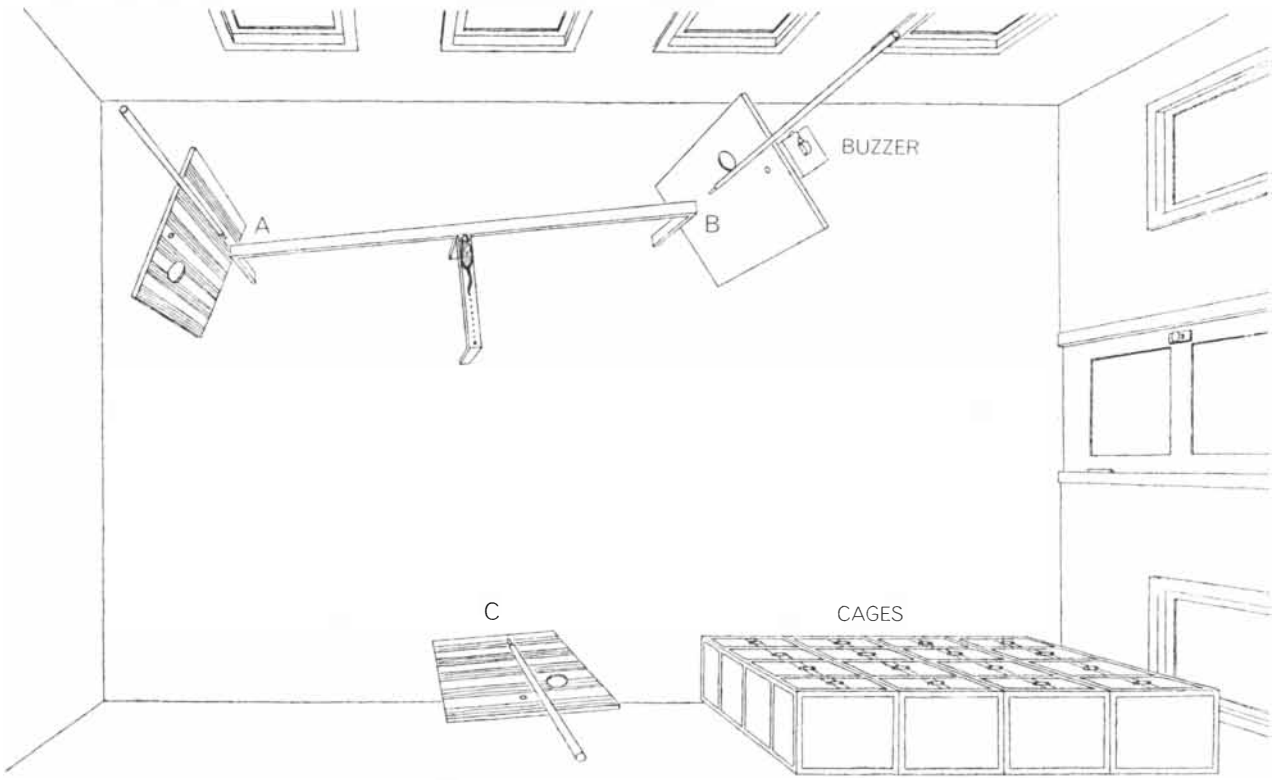
ELEVATED T-MAZE is used to test the effectiveness of different learning processes in rats. In this hypothetical test situation both rats set out from the same starting position (*A*). The "response-learner" (*rat following black broken path*) has been trained to turn right to receive a food reward, whereas the "place-learner" (*rat following colored broken path*) has been trained to use various visual and auditory cues outside the maze itself to find a food reward at point *D*. In actuality only one rat is tested on the maze at a time.



T-MAZE IS REVERSED in order to compare the performances of the response-learner and the place-learner in a new test situation. Both rats now start from point *B*. The response-learner again turns right, which now happens to be toward *D* rather than *C*. The place-learner also heads for *D* but this time must make a right turn rather than a left turn. Given a sufficient number of distinct spatial cues in the room, the place-learners were able to master the problem of the T-maze much more quickly than the response-learners were.



RATS WERE TRANSPORTED over three different 10-foot courses in a transparent Plexiglas trolley car in this experiment conducted by the author. Between the starting and terminal point of each trip the rat was subjected to a continuous electric shock. Windows, striped screens, cages and a loud buzzer provided a variety of spatial cues for the rats to learn the course without actually running it.



RATS WERE TESTED 24 hours later on an elevated T-maze set up at the same height at which the car had traveled. The object was to determine whether or not the rat could locate, by spatial cues alone, the starting point of its trip, where the shock began, and the terminal point of the trip, where the shock ceased. The T-maze was also set up between points *A* and *C* and between points *B* and *C*.

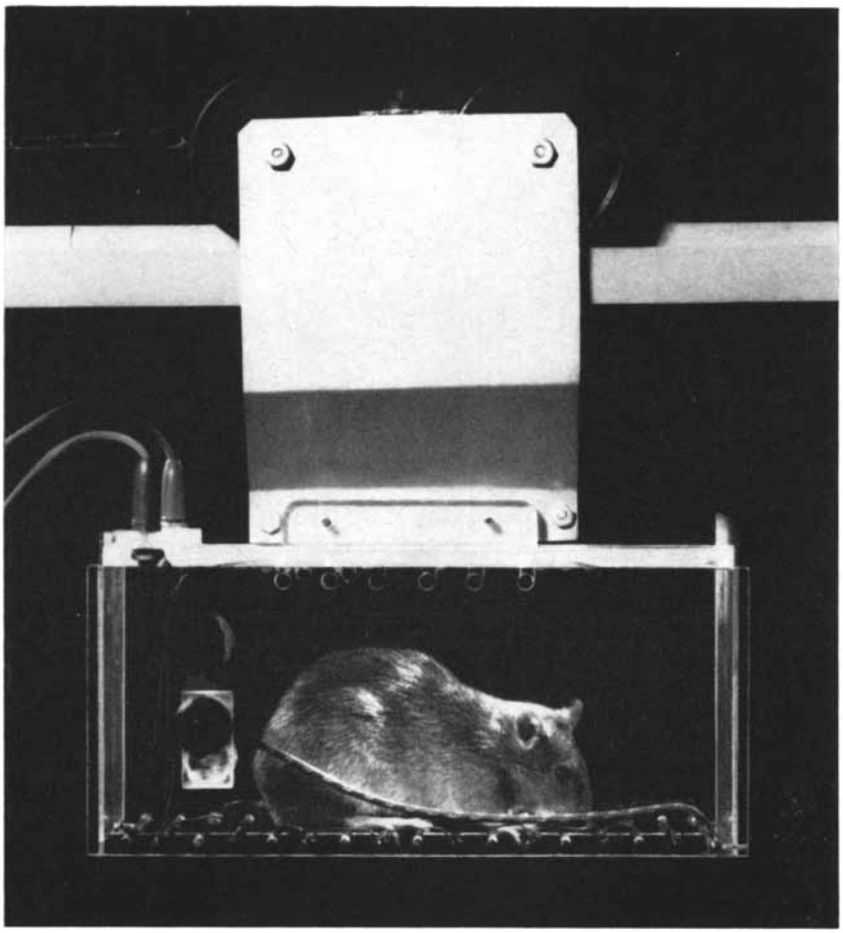
this they had to use cues in the room. For purposes of comparison another group of rats was trained to make the same *turn* each time, the food being placed at the end of the arm that corresponded to the correct turn at each trial. The animals in the first group were called "place-learners"; in the second, "response-learners."

Given distinct cues in the room, the place-learners, as it turned out, mastered their problem much more quickly than the response-learners did theirs. This suggests that animals learn how to reach a goal from spatial cues more easily than from practice in a pattern of turning movements. Tolman concluded that an animal acquires a "cognitive map" that enables it to locate objects of interest to it.

By broadening the definition of "response" one might still contend that these animals were learning only an automatic response to cues, such as the response of "turning toward the light" or of "avoiding the noise." Such a theory was far removed from its muscle-bound predecessor, but it betrayed its parentage by insisting that what is learned *is* the response (a more broadly defined response, to be sure, but a response nonetheless). In contrast, those psychologists who believed that the animal achieves a cognitive map pointed out that the experimental response was only an *index* of learning—a convenient measuring stick, to be sure, but not the thing that was being measured.

The theoretical debate quickly led to an experimental question: Could learning occur without actual performance of the response? The motor-response theory argued, of course, that it could not—that practice in the response was an essential part of the learning process. The general experimental approach has been to render an animal incapable of making its normal response to a stimulus and then test it later to determine whether or not it has learned anything simply from its exposure to the stimulus.

Edward C. Beck and Robert Doty of the University of Utah conducted experiments with cats immobilized by the drug bulbocapnine hydrochloride. While the cat was in this paralytic stupor the experimenters repeatedly applied an electric shock to its foreleg and at the same time sounded a short tone. Normally the cat would have pulled back its leg in response to the shock and then to the tone alone as a conditioned reaction, but the drugged cat of course was unable to



TROLLEY CAR used in the experiment at top of page 118 is made of transparent Plexiglas and is suspended from the track by an aluminum carriage. The floor is wired to shock the rat.

do so. After the drug had worn off, the experimenters tested the animal by sounding the tone without the shock. In most cases the cat promptly bent its foreleg. To make sure that no motor response was possible during administration of the shock, Beck and Doty repeated the experiment with a doubly paralyzing treatment: the drug and an operation on the roots of the motor nerves in the leg. Some 10 weeks later, after the cat had recovered the ability to move its foreleg, they again gave it the tone test, and the cat again responded by bending its leg. The responses of the cats treated in this way were essentially the same as those of control animals that were fully capable and reacted immediately at the time the shock was applied.

At Swarthmore College we carried out experiments of a similar nature, employing somewhat less drastic means of preventing the animals' responses. In these experiments rats were imprisoned and transported over a certain course while they were receiving the electric shock; they were then allowed to run the course themselves to show what they had learned. It was a test of both place-learning and postponed performance.

The chief instrument of the experiment was a small trolley car just large enough to hold a rat. Made of transparent Plexiglas, with a wire-grid floor, the car was suspended from a track 10 feet long. Three tracks were laid out in different directions in the room so that the cues to location would vary; the cues were windows, cages along one wall and a loud buzzer [*see top illustration on page 118*]. The starting and terminal points of the tracks were also differentiated sharply from each other by a different screen at each point, one striped vertically, one horizontally and the third unpainted.

Each rat was placed in the car and drawn over the 10-foot track between two points, the trip lasting about 20 seconds. It was a dolorous journey: the rat was subjected to a severe electric shock throughout the trip. Each rat made 18 trips (over the same route and in the same direction each time), with a 90-second rest period between rides. Twenty-four hours later it was tested on an elevated maze related to the track it had traveled.

What, if anything, had the rat learned about the spatial aspects of the situation during its journeys in the car? The test was designed to determine whether or not the animal could locate the starting point of its trip, where the shock began (presumably a "bad" place), and the end point of the trip, where the shock ceased (presumably a "good" place). In the maze the rats were given a choice between the good and the bad place, or between the good place and a neutral place, or between the bad place and a neutral place. The track and cars were removed from the room and an elevated T-maze was set up at the same height above the floor at which the cars had traveled. The maze consisted of a three-foot stem leading to two five-foot arms. When the choice was between the good and the bad place, the arms were in the same path as the track had been, with one arm leading to the track's starting point and the other to the terminal point; for the choice between the good (or bad) and the neutral place, one arm ended at an end point of the former track and the other at some point in the room not in the path of the track. The animals' selection of good and bad places in the room would depend, of course, on whether or not they had located, and could remember, those places with reference to the room cues: the different screens, the windows, the buzzer, the cages and so on.

Deprived of food for a full day, the hungry rats went looking for food on the maze (having previously been trained to find such a reward on elevated pathways in another room). Would they show a preference for the good arm of the T (leading to the end of their shocking trip) rather than the bad arm (leading to the beginning of shock)? The results were clear: of the animals offered this choice, 26 chose the good arm and only nine the bad. This seems strong evidence that, without any previous exploration of the room by their own locomotion, most of the rats had formed a cognitive map during their trips in the trolley car.

On the other hand, it surprisingly turned out that the animals showed no particular preference between the bad (or good) place and a neutral place. Those that were given such a choice selected the bad arm almost as often

as the neutral one and the good arm slightly less often than the neutral one. Their place-learning, it seems, was not broad enough to discriminate between a known location and an area of the room where they had not been before.

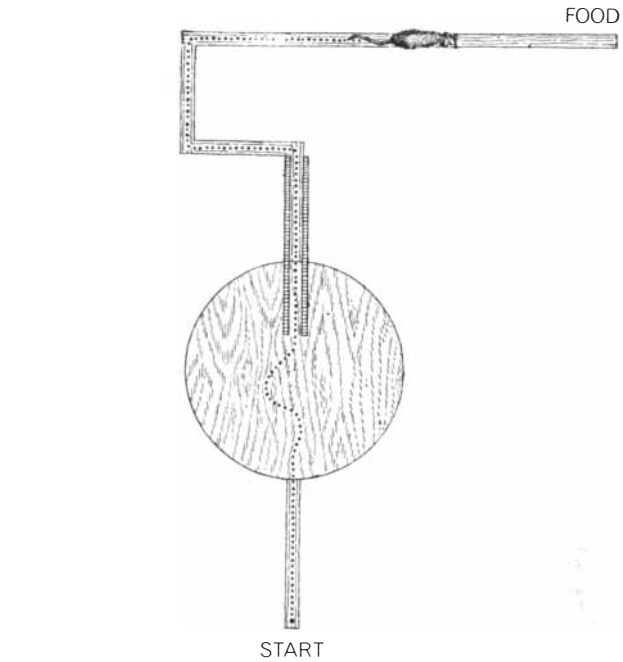
Other experiments, however, have shown that rats can acquire cognitive maps of considerable breadth and complexity. This was demonstrated in a famous experiment by Tolman, Ritchie and Kalish. They trained rats to run an elevated maze on which, to reach the food reward, the animals had to cross a circular table, go through a short alley, turn left, then right, then right again and finally go to the end of a straight path. Near the goal was a light that could serve as a cue to its location in the room [*see top illustration on next page*].

After the rats had run this maze for 12 trials the experimenters changed the design drastically. They cut off the original route at the end of the alley and set up instead a "sunburst" of 18 paths radiating in different directions from the circular table [*see bottom illustration on next page*]. Tested on this new maze, the rats ran as before into the alley only to find it blocked at the end. They then returned to the table and began to explore the other paths radiating from it. But in fairly short order they chose one particular path: the one whose end was closest to where the goal had been before, near the light. Typically the rat would nose a few inches into some of the other paths, then select the correct path and go all the way to the end.

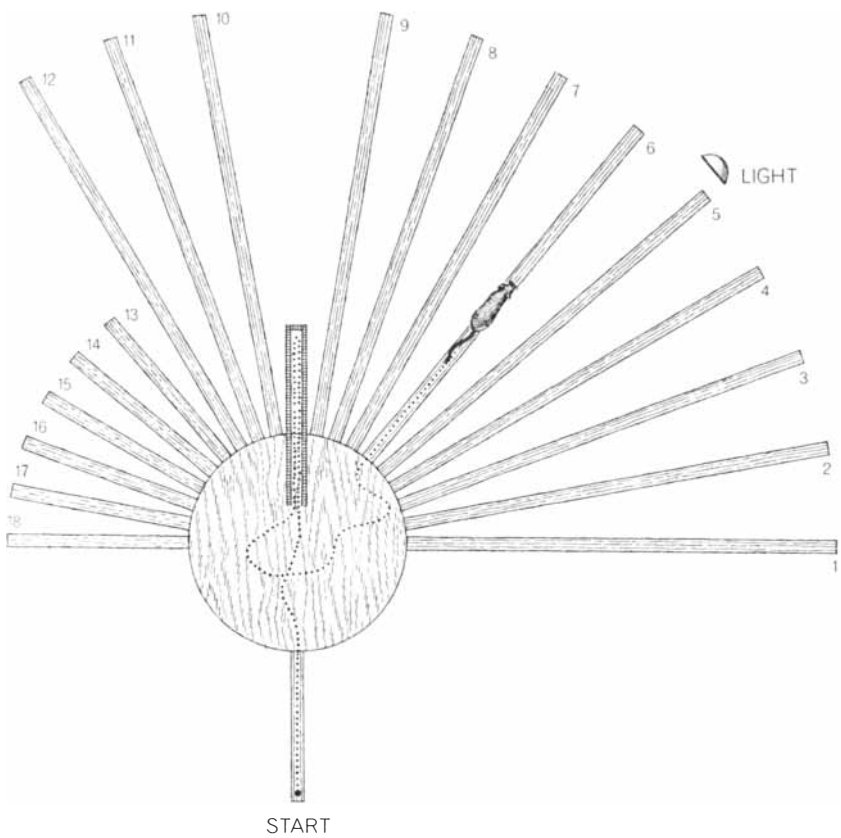
Hobhouse, had he still been alive, would have been highly pleased by this convincing confirmation that animals are capable of place-learning. The pendulum had indeed swung far away from Wat-

	GROUP I	GROUP II	GROUP III
STARTING POINT	9		
TERMINAL POINT	26	16	15
NEUTRAL POINT		19	18

RESULTS of the experiment depicted at bottom of page 118 revealed a preference for a terminal, or "good," place over a starting, or "bad," place. The rats' capacity for place-learning, however, did not enable them to distinguish between a good and a neutral place or between a bad and a neutral place.



TRAINING MAZE used by Edward C. Tolman and his colleagues at the University of California is shown here. The rats set out from the starting point, crossed a circular table and traversed a path with several turns in it before reaching the food reward. The light was presumably used as a visual cue by the rats in forming a "cognitive map" of the test situation.



"SUNBURST" MAZE is a modification of the training maze shown at the top of this page. As before, the rats ran into the alley only to find it blocked at the end. They then returned to the table and, after some exploration, chose the path whose end was closest to where the food had been, near the light. Paths *13* through *18* were abbreviated by the size of the room.

son's view that animals learned only a pattern of movements. But it is not often (at least in psychology) that when a theory is found to be false, its exact opposite is found to be true. Soon the pendulum began to swing back: it developed that rats were not quite as shrewd as the Tolman experiment had suggested.

Other investigators failed to get the same results in spite of earnest efforts to duplicate the conditions of Tolman's experiment. A possible explanation may lie in the fact that their animals were less sophisticated than Tolman's rats. As it happens, his rats had previously been trained to solve a rather complex multiple maze that took about 50 trials to master. The rats used by the other experimenters had had no such training in a complicated problem. It may be, therefore, that in order to form spatial "concepts" a rat must have some prior experience in exploring space by perceptual and motor means. That is to say, an untutored rat may solve a problem by a process of learning that lies somewhere between the theory of Watson and that of Hobhouse.

That complex learning does require a considerable background of sensory experience and other forms of stimulation is indicated by the performances of animals that have been raised under conditions of deprivation. For example, a puppy reared alone in a small cage with little exposure to normal sensory and social stimuli performs very poorly when tested in mazes or in other problems demanding ability in spatial organization. The same is true of primates similarly deprived of experience. For that matter, most of the laboratory rats bred for maze studies are also carefully restricted in experience, so that their performance in experiments will not be contaminated by prior learning. The result is that all these "experimentally naïve" animals perform much less successfully in maze tests than animals that have been raised normally and allowed some modicum of sophistication. The maps of the first are narrow and confined.

We are still far from any complete or detailed description of the learning process. The evidence so far indicates that neither of the two theories we have considered tells a full story. The rat in a maze is neither a mechanical automaton nor a sagacious geometer surveying spatial relations. For naïve animals, at least, it appears that the truth lies somewhere between the two theoretical extremes.

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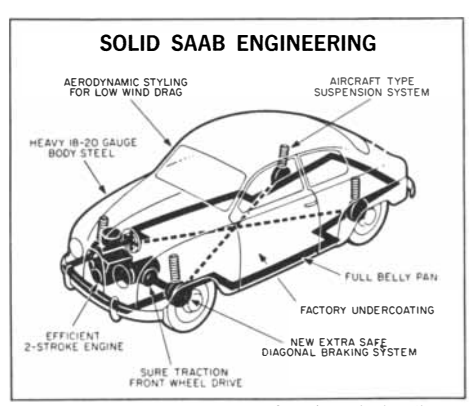

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MATHEMATICAL GAMES

About two new and two old mathematical board games

by Martin Gardner

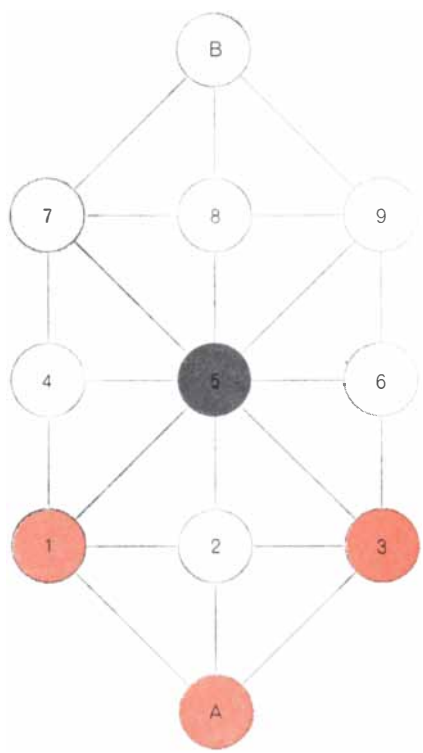
The past six years have seen a remarkable upsurge of interest in mathematical board games. More people than ever before are playing the traditional games such as chess and experimenting with the new games that keep turning up in the stores. More mathematicians are analyzing the strategies of such games and more computers are being programed to play them. This month we examine four excellent but little-known board games, two new and two old. Their playing fields can easily be drawn on paper or cardboard, the rules of play are quite simple and everyone in the family will find the contests great fun.

The Military Game, as it is called in France, is a splendid example of a two-player game that combines extreme simplicity with extraordinary strategic subtlety. According to Édouard Lucas, who describes the game in Volume III (pages 105–116) of his celebrated *Récréations Mathématiques,* the game was popular in French military circles during and after the Franco-Prussian War of 1870–1871. It is a pity that it has since been so completely forgotten; not one of the standard histories of board games even mentions it.

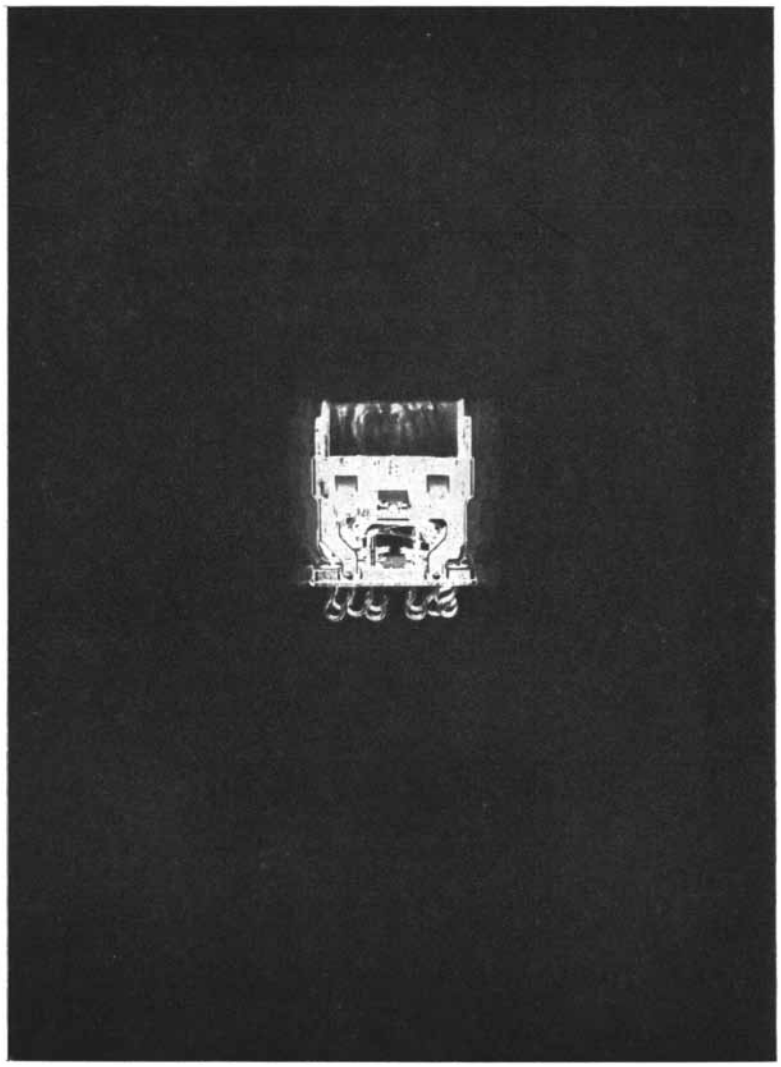
The board for the Military Game is shown in the illustration at the right with the positions labeled to facilitate description. One player—we will call him White—has three men that are initially placed on the colored spots *A, 1* and *3*. Black, his opponent, has only one man, which he places on spot *5* in the center. (Chess pawns can be used for men, or three pennies and a nickel.) White moves first and the game proceeds with alternate turns. Black may move in any direction along a line from one spot to a neighboring spot. White moves similarly, but only left, right or forward (straight ahead or diagonally), never backward. There are no captures. White wins if he can pin Black's piece so that it cannot move. This usually occurs with Black on spot *B,* but it can also occur with Black on spot *4* or *6*. Any other outcome is a win for Black. He wins if he slips behind "enemy lines," making it impossible for White to pin him, or if a situation develops in which the same moves are endlessly repeated.

The game is as simple to learn as ticktacktoe, but it is more exciting to play and more difficult to analyze. Lucas is able to show that White, if he plays rationally, can always win, but there is no simple strategy and the game abounds in traps and surprises. Often the best move is the move that seems to be the worst. An experienced Black has little difficulty escaping from an inexperienced White.

Suppose we increase Black's freedom by permitting him to place his piece, at the start of the game, on *any* spot he chooses? Who now wins if both sides



The French Military Game



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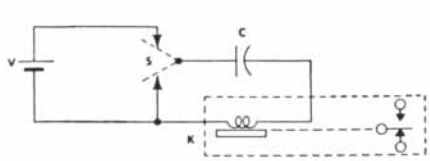
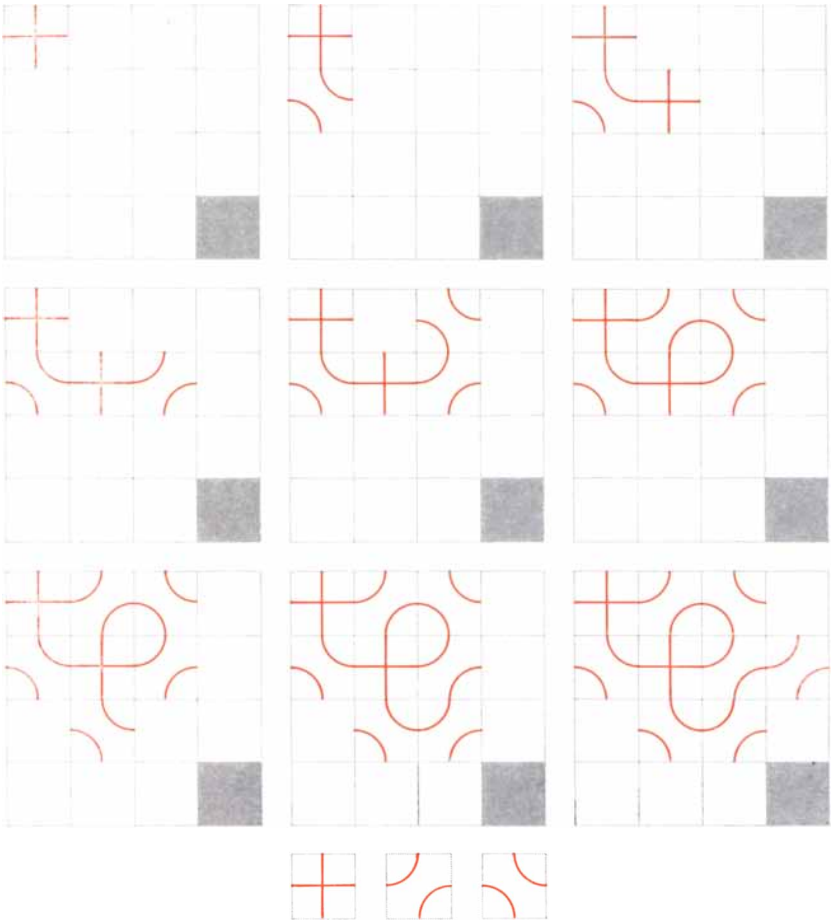




William L. Black's game

play rationally? The answer will be given in this department next month.

Topological board games, on which players construct paths that twist about over the field, are recent developments. Hex, Bridg-it, Zig-Zag, Roadblock, Pathfinder, Squirt: these are trade names of some of the games of this type that have been marketed during the past 20 years. In 1960 William L. Black, then an undergraduate at the Massachusetts Institute of Technology (he is now working at M.I.T. for his doctorate in electrical engineering) made a study of Hex and Bridg-it, two games respectively discussed here in July, 1957, and July, 1961. An outcome of this study was a novel topological game his friends call Black.

Although marked tiles can be used, Black is easily played as a pencil-and-paper game on a checkered field. The size of the field is optional; the standard eight-by-eight field seems ideal, but it is simpler to explain the game on the smaller four-by-four. After the field is drawn the first player starts the game by making a cross in the upper left corner cell as shown in the first drawing in the illustration above. The second player continues the path by making one of three permissible marks in a cell adjacent to the first cell marked. The three marks, shown at the bottom of the illustration, are each composed of two lines. One line represents one of the three ways in which the path can be joined to an open side of the square; the second is added to connect the remaining two sides.

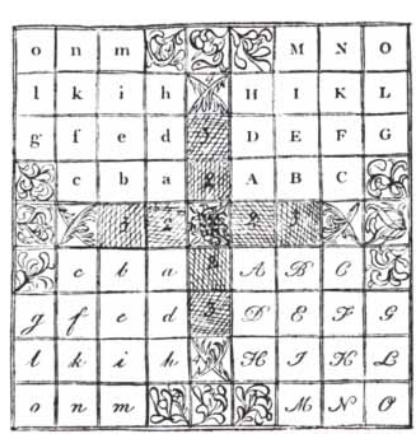
The players alternate moves. Each move must extend the path into a neighboring cell. Each player tries to avoid running the path into a border of the field. If he is forced to carry the path to the border, he loses the game. If he succeeds in extending the path into the lower right corner cell [*shown shaded*], he wins. The illustration shows successive moves of a typical short game. The first player wins by forcing his opponent to play in the upper right corner cell, where any mark will carry the path to the edge of the field. (Note that the cross extends the path only along one of its arms, although the other arm may become part of the path as the result of a later play.)

The game of Black is of special interest because soon after it was conceived a friend of Black's, Elwyn R. Berlekamp (who is also currently pursuing his Ph.D. in electrical engineering at M.I.T.), hit on an elegant strategy that guarantees a win for one of the players. The strategy applies to rectangular fields of any size or shape. Since knowledge of the strategy destroys all interest in actual play, I temporarily refrain from giving it. Readers are urged to play the game and see if they can match Berlekamp's brilliant insight before it is disclosed next month.

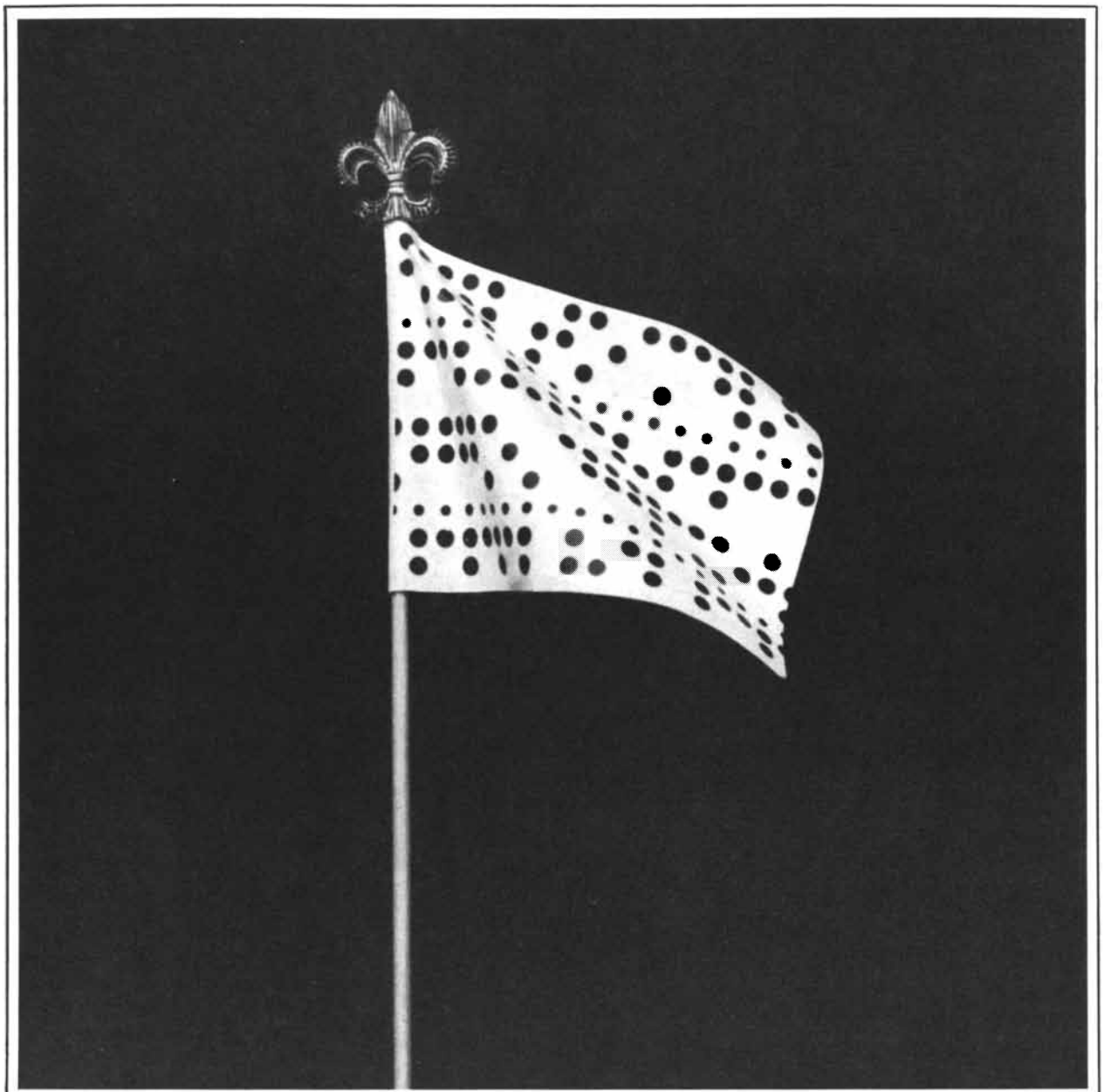
One of the best of many medieval board games is a game that seems to have been first played in Scandinavian countries as early as the fourth and fifth centuries, when it was called *tafl*. In later centuries it was known as *hnefatafl*. The Norsemen introduced the game to Britain, where it was the only board game played by the early Saxons until it began to be replaced by chess in the 11th and 12th centuries. H. J. R. Murray, in his *History of Board-Games Other than Chess*, gives reasons for thinking that this is essentially the same game that was still being played in the 16th century in Wales, under the name of *tawlbwrdd*, and in the 18th century in Lapland, where it was known as *tablut*.

It was Murray who discovered that the great Swedish botanist Carolus Linnaeus included a full description of *tablut* in an extensive diary he kept during his exploration of Lapland in 1732. An English translation of the diary, by Sir James Edward Smith, was published in London in 1811 with the title *Lachesis Lapponica: or a Tour of Lapland*. The illustration below is a reproduction of the *tablut* board as it is shown on page 55 of Volume II of this edition.

White pieces, representing light-haired Swedes, include a single king and eight warriors. Black pieces, 16 in



***The game of* tablut**



Simulation

"New Regime Threatens Stability in Mediterranean Area..."

The "Leviathan" project is part of our continuing simulation of large organizations. Currently in our Systems Simulation Research Laboratory we are staging the environment and data base typical of a highly structured intelligence center, where unexpected political events in a mythical Mediterranean region are presented to a 24-man team. Communicating by means of audio-visual equipment, the human subjects analyze all aspects of a tense situation. Decisions are made. Action is taken. The sense of personal involvement becomes most intense. Scientists observe the dynamic human interplay and decision-making processes. A large computer acts as fact finder, umpire, and score-keeper. To scientists and engineers of SDC, Leviathan offers a continuing opportunity to study man-to-man and man-to-machine interaction, as well as to make objective evaluations of the communicating equipment itself. Leviathan in particular and simulation in general are but one phase of SDC's broad interest in information-systems technology. As newly learned knowledge helps to shape the systems of tomorrow, today's opportunities at SDC become ever more interesting and numerous. Human factors scientists, operations research scientists, systems-oriented engineers and computer programmers who believe their ultimate futures lie with this important and rapidly expanding technology are invited to write Mr. A. J. Granville, Jr., SDC, 2430 Colorado Ave., Santa Monica, California. Positions are open at SDC facilities in Santa Monica, California; Washington, D.C.; Lexington, Massachusetts; Paramus, New Jersey; and Dayton, Ohio. "An Equal Opportunity Employer."

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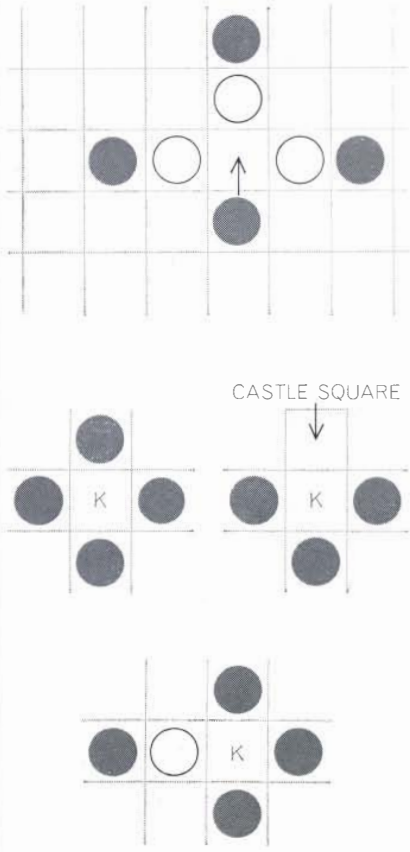


Methods of capture in tablut

number, represent Muscovite warriors. (It is convenient to use a white chess king and eight white pawns for the Swedes. Black chessmen can be used for the Muscovites, but all must be regarded as identical pieces.) Each black and white piece, including the king, moves like a rook in chess, that is, an unlimited distance along vacant cells in a straight line paralleling a side of the board.

The game begins with the Swedish king occupying the center square, which is known as the castle. Only the king is permitted to stand in the castle, although any piece may move through it when it is vacant. Surrounding the king, on the eight shaded squares, are his eight warriors. The Muscovites occupy the 16 decorated squares at the four sides of the board.

Either player may open the game. Enemy pieces are captured by a pincer move that consists of occupying adjacent cells on opposite sides of a piece, the three pieces being in the same row or column. For example, if Black makes the indicated move, he captures the three white pieces simultaneously [*see top drawing in illustration above*]. If a piece moves between two enemy pieces, how-

ever, it is not captured by them. The king may take part in capturing enemy pieces, but he himself is captured only if he is surrounded on all four sides by four enemy pieces or by three enemy pieces and the castle square [*middle drawing*]; he cannot move from his castle into such a formation without being captured.

Linnaeus adds that when the king is in his castle, with three enemy warriors on three sides and one of his own men on the fourth side, the Swedish warrior is taken if a Muscovite moves to the cell next to the Swede on the side opposite the king [*bottom drawing*].

Black's objective is to capture the king. If this occurs, the Muscovites win. White's objective is to allow the king to flee the country by reaching any cell on the perimeter of the board. Whenever there is an unobstructed path along a row or column by which the king can reach the border, White must warn Black by saying "Raichi!" (a remark similar in function to "Check!" in chess). If there are two escape paths, White calls out "Tuichu!" Of course "Tuichu!" announces a win for White because there is no way Black can block two escape routes with a single move.

Sidney Sackson, a New York City engineer who makes a hobby of collecting board games (he owns about 500 actual boards and his files contain details of hundreds of others), knows of only one occasion on which *tablut* has been made and sold in this country. In 1863 it was issued as a Civil War game called Freedom's Contest, or the Battle for the Union. This game is identical with *tablut* except that the king is called the "Rebel chief" and the pieces are Rebel and Union soldiers. The Rebel chief is limited to a maximum move of four spaces. The traditional game seems to favor White, so perhaps this restriction was intended to redress the balance.

Sackson is himself the inventor of many unusual board games, one of the best of which he calls Focus. It is played with 36 counters, half of them one color and half another. Small poker chips of the interlocking variety make excellent pieces. They are placed initially on an eight-by-eight board from which three cells at each corner have been removed. The illustration at the bottom left on the next page shows how the pieces (black and colored in this case) are arranged.

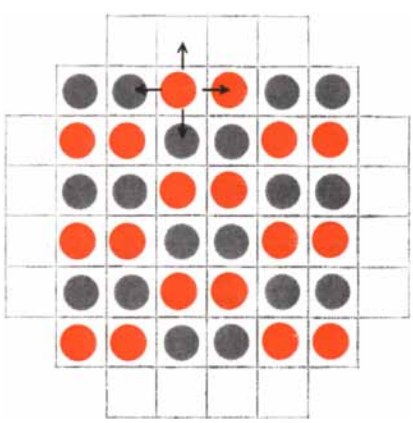
Either side may move first. A move consists of moving a "pile" of pieces (at the outset all piles are one chip high) as many spaces as there are pieces in the pile. Moves are vertical or horizontal, never diagonal. The four pos-

Photographic interpretation by J. Frederick Laval

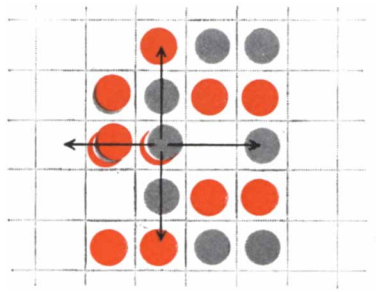
sible moves of one colored piece at the start of a game are shown in the illustration below. If the piece moves up, it lands on a vacant square. A move to the right puts it on top of another colored piece, to the left or down puts it on top of a black piece. The last three moves form two-high piles. Such piles may be moved two spaces in any direction. Piles of three, four and five pieces move three, four and five spaces respectively. A pile is controlled by the player who owns the piece on top. In moving it does not matter whether the intervening cells are empty or occupied by piles controlled by either player. Passed-over pieces are not affected in any way. A move may end on a vacant cell or on another pile. The illustration at the top of the page shows the possible moves of a two-high pile.

Piles may not contain more than five pieces. If a move produces a pile of more than five, all pieces in excess of five are taken from the bottom of the stack. If they are enemy pieces, they are considered captured and are removed from the game. If they belong to the player making the move, they are placed aside as reserves. At any time during the game a player may, if he wishes, take one of his reserve pieces and place it on any cell of the board, empty or otherwise. It has the same effect as a moved piece: if it goes on a pile, the pile belongs to the player who placed it. Using a reserve piece substitutes for a move on the board.

A player may, if he wishes, make a move of fewer spaces than the number of pieces in the pile being moved. He does this by taking from the *top* of the pile as many pieces as the number of spaces he wishes to move. The rest of the pieces stay where they are. For example, a player may take the top three pieces of a five-high pile and move them three



Sidney Sackson's game of Focus



Moves in the game of Focus

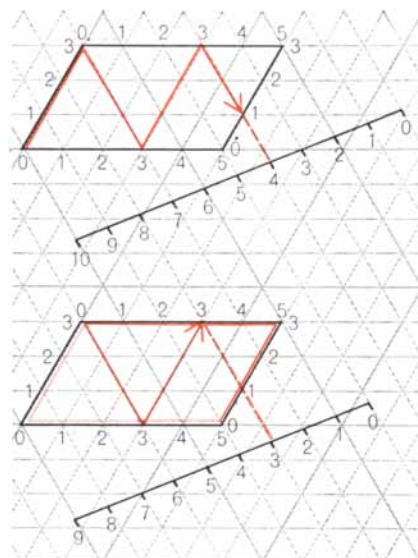
spaces. The pile that *remains* after such a move belongs to the player who owns the piece on top.

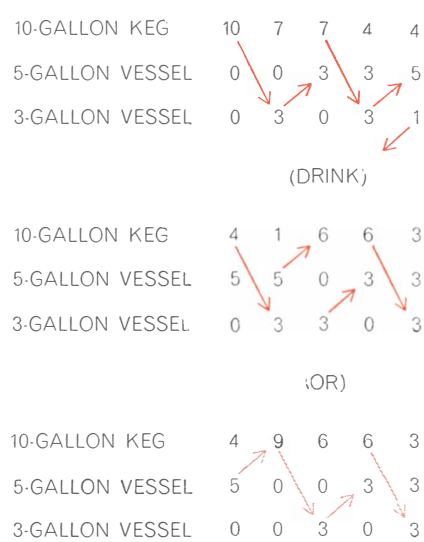
When a player is unable to move (that is, controls no piles and has no reserves), the game is over and his opponent wins. Readers who find this game stimulating may wish to send 25 cents to Sidney Sackson, 1287 Arnow Avenue, Bronx 69, N.Y., for his copyrighted booklet giving the rules in more detail, including a four-handed game and a number of valuable hints for skillful play.

Number play and football are blended cleverly in a game called Number Football, recently developed by the Benedictine Fathers at Benet Lake, Wis. For $1 the Fathers will send postpaid a 24-page booklet explaining the game, together with a pad of gridiron blanks for scoring. And I must not fail to mention that a hard-cover book by Robert Abbott—whom readers of this department know as the inventor of Eleusis, the induction card game—will be published this month by Stein and Day. Although titled *Abbott's New Card Games,* it includes a remarkable mathematical board game of the chess variety. In addition to four card games reprinted from Abbott's earlier paperback, it contains four excellent new card games unlike any the reader has ever played before.

Last month's problem was: Given a 10-gallon keg filled with beer and two vessels of three-gallon and five-gallon capacity, how can one (in the minimum number of operations) drink a quantity of beer and leave equal amounts in each of the three vessels? Since the vessels measure only integral amounts, the beer to be divided into thirds must be a multiple of three: three, six or nine gallons. The first two amounts can be eliminated because in both cases a third of the amount is less than the capacity of each vessel. (After any pouring operation at least one vessel must be either empty or full. Neither situation would obtain if each vessel contained less than its capacity.) We conclude, therefore, that one gallon must be drunk, leaving nine to be divided into thirds.

The ball-bouncing computer explained last month traces a minimum path that measures one gallon [*see upper graph in illustration below*]. After the gallon (in the three-gallon vessel) is drunk, four gallons remain in the 10-gallon keg, five in the five-gallon vessel. The three-gallon vessel is empty. This new situation is diagramed as shown in the lower graph. The ball must now reach a point that marks three gallons in each container. The minimum path is shown in color, with two alternative steps in a lighter shade. Counting the drinking of the gallon as an "operation," the complete solution involves nine operations, which are shown below the two graphs.





Solution to last month's problem

VARIAN INSTRUMENTS AT WORK

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A geomagnetic micropulsation

bears a remarkable analogy to a wind ripple on the ocean's surface. The vast *magnetic sea* also has tides, currents, squalls and storms just as do the earth's waters. The mere detection of these magnetic time variations presents a serious challenge to the geophysicist; their interpretation remains a complex puzzle.

These are the longest electromagnetic waves known. Some stretch out 18,600,000 miles, and the upper limit is still undefined. Despite their great length, the term micropulsation is applied due to their small amplitude. With the development of highly sensitive optically pumped magnetometers they can now be easily measured. Varian supplies these instruments to geomagnetic observers all over the world for use on land, on arctic ice, deep in the ocean, and in outer space.

It is now possible to record total magnetic intensity and detect variations in the magnetic field equal to 1 part in 5,000,000. Using the principles of optical pumping, the versatile new Model V-4938 rubidium magnetometer achieves this extreme sensitivity across a wide band of frequencies. Information can be recorded directly on paper chart or magnetic tape, or it can be transmitted from the observatory site to your data center.

Many scientists will use magnetometers in their studies during the magnetically quiet, but scientifically active, International Year of the Quiet Sun. Would you like additional technical information? Write Sheldon Breiner, Instrument Special Products.

Superconducting magnets which

operate at temperatures near absolute zero (–273°C) have intrigued scientists for several years with their promise of generating very intense magnetic fields with extremely small amounts of power.

Until now, superconducting magnets have not proved practical for research applications requiring useable volumes of highly homogeneous magnetic fields. Now, with the successful development of the X-4120, Varian has taken a giant step forward in this exciting new technology. The X-4120 is a superconducting magnet that can generate a magnetic field of 65 kilogauss which is homogeneous to within 0.1% over a volume ½" in diameter and one inch in length. And the entire field is accessible to a room temperature probe.

The X-4120, combining previously unattained field intensity, volume and homogeneity, opens up new areas of research in materials studies, susceptibility measurements, and magnetic resonance work.

Varian is now offering complete superconducting magnet systems, complementing its line of precision iron magnets. The new systems include the X-4120 magnet, dewar, dewar cap and magnet support mechanisms, plus a special power supply which allows a programmed control of magnet power input.

Further details may be obtained by writing Bob Abler, Magnet Products.

Fingerprints

are unique to each individual. Likewise, each organic compound gives an NMR spectrum entirely its own. You can tell a man by his prints; you can identify a compound by its NMR spectrum. Even a minute change in the structure of a compound creates a slightly different magnetic environment for the hydrogen atoms within a molecule, which the nuclear magnetic resonance spectrometer will detect and record.

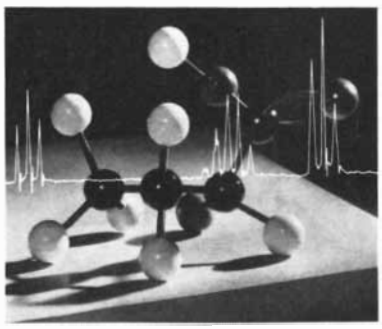
Varian NMR spectrometers can resolve differences equal to 1 part in 2×10^8. Comparing it to today's fine optical instruments, it is roughly equivalent to having a telescope which would let you distinguish one black cat from another near it *on the surface of the moon!*

Such a powerful analytical tool has, of course, been used for many years by leading research laboratories around the world. Since the development of the Varian A-60 Spectrometer, however, the use of nuclear magnetic resonance for routine analysis of organic compounds has grown steadily.

In part, this increase is due to the fact that the A-60 is less expensive than the more powerful research spectrometer. But what's more important is the A-60's ease of operation. Because it provides reproducible spectra on precalibrated charts you can use the A-60 to collect and catalog spectra for fast, routine identifications.

The basic cost of Varian's A-60 Spectrometer system includes installation, warranty, and operator instruction. Furthermore, you continue to receive information on spectra interpretation and discussions of advances in NMR as they occur.

You can get additional technical and applications data by writing Wayne Lockhart, Analytical Instruments.



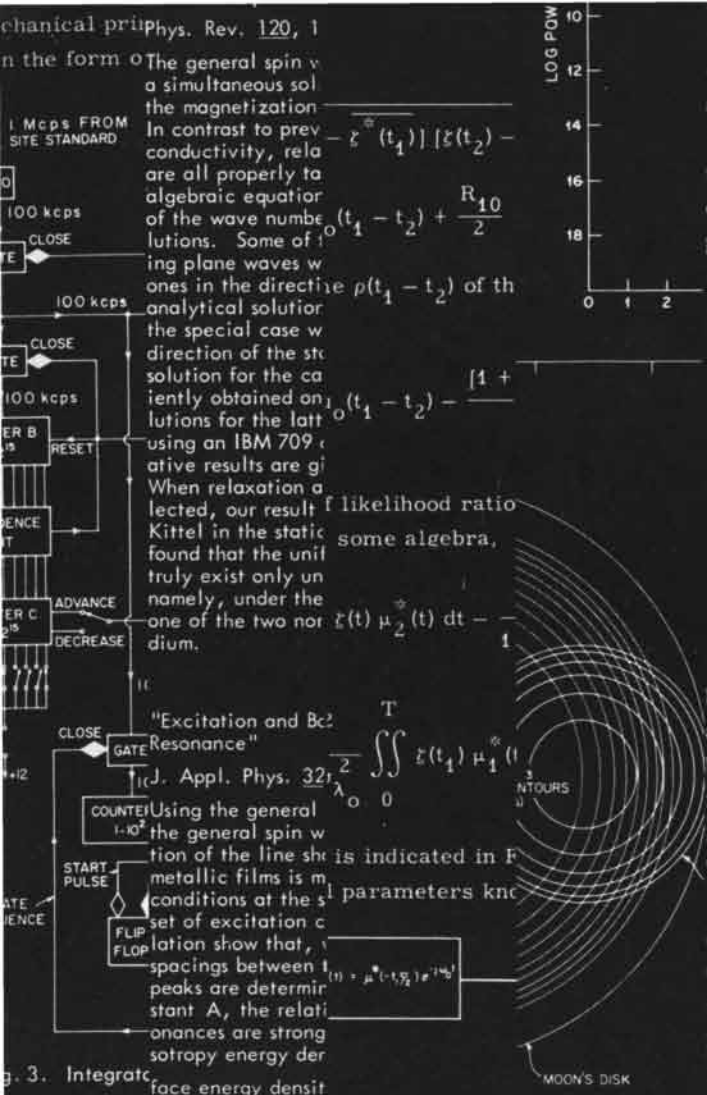


Fig. 3. Integrat

THE AMATEUR SCIENTIST

How to make and investigate vortexes in water and flame

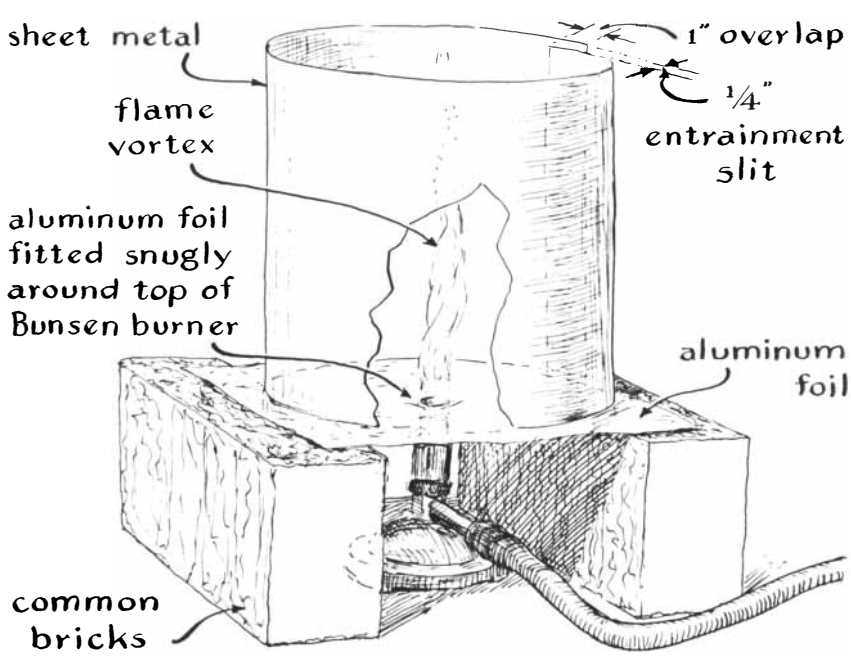
Conducted by C. L. Stong

According to a popular misconception all spiraling vines, whirlpools, dust devils, tornadoes and fire vortexes turn counterclockwise in the Northern Hemisphere and clockwise in the Southern Hemisphere. Some textbooks explain this supposed consistency as a necessary result of the Coriolis force generated by the earth's rotation. Hemispheric preference for right- or left-handedness does appear to govern the large-scale motion of fluids. In the case of the atmosphere, cyclonic winds invariably circulate counterclockwise around centers of low barometric pressure in the Northern Hemisphere and invariably clockwise in the Southern Hemisphere. Similarly, water behind a large dam usually spirals in the expected direction when it flows into a submerged penstock. On the other hand, observers who take the trouble to search the woods of either hemisphere find just about as many vines spiraling to the right as to the left, and a few minutes spent at the kitchen sink demonstrates that water is as likely to spiral one way as the other when the drain is opened. Indeed, the basin occasionally empties without the formation of a whirlpool.

Although the anatomy of the vortex is not a major preoccupation of physics, many questions of vortex behavior continue to interest designers of ships and aircraft, those who construct hydroelectric power stations and foresters concerned with fire prevention. Vortexes in the wake of ships and aircraft represent wasted fuel; their generation requires substantial expenditure of energy. Air entrained by a whirlpool in water entering a penstock limits the power of a water turbine. Vortexes become a serious menace during forest fires because they are capable of picking up large flaming timbers and dropping them elsewhere to start new fires. According to Vincent J. Schaefer of the Atmospheric Sciences Research Center of the State University of New York, fire vortexes are of prime concern to foresters who undertake to burn over an area in order to clean it up before planting it with new trees. Even when care is taken to protect the surrounding area by lanes cleared of all combustible rubble, a vortex can develop during the burn and spread the fire.

What conditions induce the formation of vortexes and what factors determine their intensity and direction of rotation? The answers to these questions developed by theorists during the 19th century are of only casual interest to foresters and engineers because all are based on the analysis of "perfect" (nonviscous) fluids. The behavior of real fluids such as air and water, which exhibit the properties of adhesion and internal friction, does not conform to the theoretical predictions. Apart from observations made in wind tunnels and towing tanks, vortex motion in real fluids still awaits intensive investigation. A series of experiments that illustrates one simple procedure for observing vortex motion in flame and water was made last year by Robert A. Singer of Elmont, N.Y., as a project for a Junior Research Fellowship under Shaefer at a field station of the Atmospheric Sciences Research Center. The techniques Singer describes suggest a number of interesting variations.

"The first requirement of an apparatus designed for experimenting with vortexes," he writes, "is a means of imparting rotary motion to a fluid. Still water in containers up to about five feet in diameter that discharge through a centered port in the bottom always drains in a straight, radial flow. The whirlpool that usually forms in a kitchen sink is initiated by eddies set up in the water when the drain is opened; the direction of the rotation is determined by the sense of the eddy rotation. This can be demonstrated by swirling the water gently one way or the other before opening the drain. The slightest perceptible rotary motion is sufficient to trigger a vor-

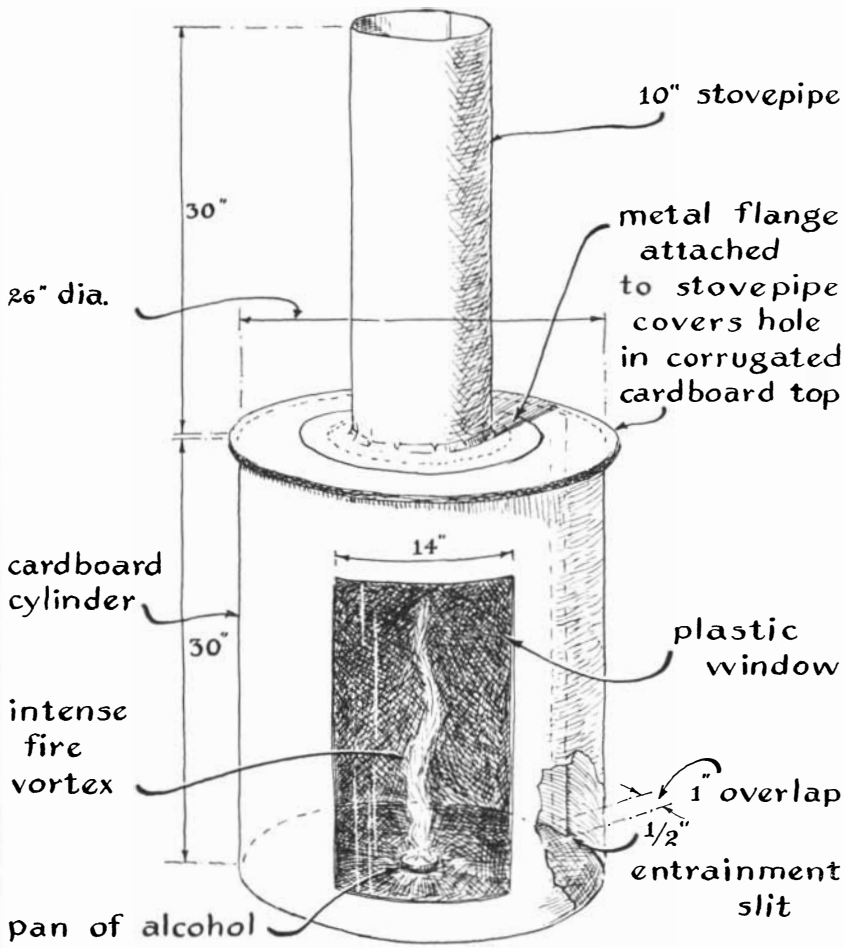


An amateur's apparatus for experimenting with a vortex in a gas flame

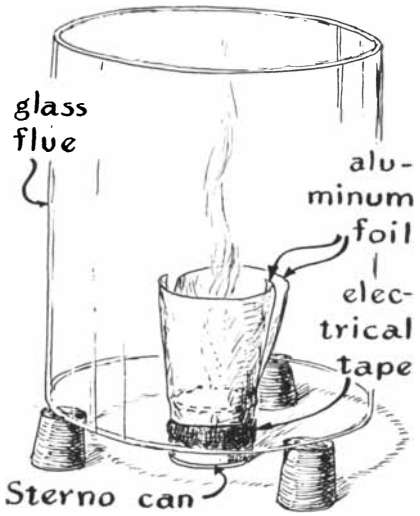
tex in a container the size of a kitchen sink, even as little as one revolution per minute.

"Continuous circulation can be developed in water merely by directing the inflow along the edge of the container. I use essentially the same stratagem for generating vortexes in flame. The fire is enclosed by a container in the form of one or more spirals of sheet metal that admits air at a tangent to the base of the flame. In a typical setup for experimenting with gas flame a spiral of sheet metal about six inches in diameter and 10 inches high is overlapped one inch to make a slit about a quarter of an inch wide. The spiral rests on a base of aluminum foil supported by a pair of bricks set on edge. The top of a Bunsen burner projects through a hole in the middle of the foil [*see illustration on preceding page*]. When the burner is lighted, air drawn through the slit by convection sets up a general circulation inside the spiral. A similar apparatus for burning solid alcohol can be made by fitting the alcohol container with a pair of spirals in the form of interlocking C's cut from aluminum foil and taped to the container. The strength of the resulting vortex can be increased by enclosing the flame with a smooth flue supported on rubber stoppers or small blocks to admit air at the bottom.

"Another version of the apparatus that provides forced draft as well as the required rotary motion has been constructed by George M. Byram and Robert Martin of the U.S. Forest Service. A cylinder of cardboard 26 inches in diameter and 30 inches high is cut and overlapped one inch to form an entrainment slit half an inch wide. The spiral rests on a flat surface and is capped with a cardboard disk fitted with a 30-inch length of 10-inch stovepipe for increasing the draft by convection. A small pan of liquid alcohol serves as fuel; the vortex is examined through a window of clear plastic 14 inches wide and two feet high. Incidentally, when versions of this apparatus are constructed for use indoors, fireproof material is substituted for the cardboard. Lumberyards stock several varieties of thin composition sheets that are fire-resistant; sheet aluminum of the kind stocked by hardware stores can also be used. Several alumi-



Vortex apparatus developed by the U.S. Forest Service



Solid-alcohol flame vortex apparatus

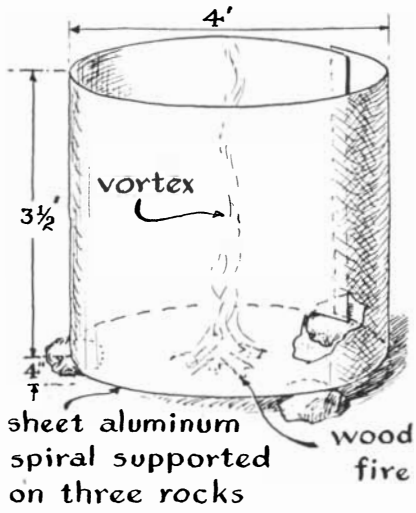
num sheets can be fastened together with metal screws to make large spirals. I made one 36 inches wide and 48 inches high for experimenting outdoors with wood fires. Spirals of this size can be set on a bed of sand or supported by rocks of various sizes, depending on the amount of draft desired.

"Other variations of the spiral include compound baffles for observing the interaction of twin fire vortexes. A pair of sheets bent in the general form of an interlocking E and 3, for example, generates vortexes that rotate in the same direction; three sheets bent to form two C's that interlock with a sheet in the form of a 3 generate a counterrotating pair of vortexes [*see bottom illustration on next page*]. By making a series of compound baffles of increasing height the experimenter can study the interaction of flames that extend above the baffle.

"Accessory apparatus should include instruments for measuring flame temperature and fuel consumption, for observing the flow pattern of the gases and for regulating the input of fuel and air. Temperature can be measured by a pair of Chromel-Alumel thermocouples connected either to a recording potentiometer or, if desired, to a vacuum-tube voltmeter calibrated for a full-scale indication of 50 millivolts. Thermocouples are easily assembled by the method previously described in 'The Amateur Scientist' [SCIENTIFIC AMERICAN, December, 1961]. I measured the rate of fuel inflow, when experimenting with gas flames, by means of a wet-test meter. If an instrument of this type is not available, the rate can be determined by transferring gas to a container of known size, such as a glass jug, displacing the fuel at constant pressure by water and

timing the combustion interval. The effect of forced draft is conveniently investigated by means of a small motor-driven blower. Flow paths constituting the vortex can be easily observed by introducing particles of soot into the base of the flame. The soot can be generated by a small smudge pot that burns turpentine. I made mine by boring a hole through a rubber stopper for a cloth wick and fitting the assembly into a small test tube that contained the turpentine.

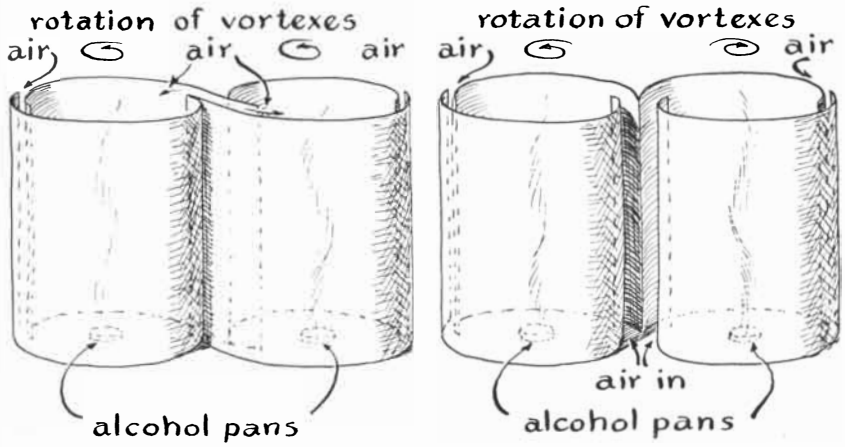
"When I perform an experiment with a new apparatus, I first examine the flow patterns that appear during the interval between the lighting of the fire and the formation of the vortex. In the case of a wood fire the flame begins to rotate slowly around the center of the container in the same direction as the surrounding air and simultaneously to spiral around its own axis. I refer to these motions respectively as external and internal rotation. The flame in the apparatus that burns gas initially exhibits almost pure external rotation that quickly reaches a constant rate of rotation if the fuel input and related factors such as air inflow do not change. In addition the gas flame displays a periodic oscillation I refer to as radial translation. The bright outer gases spiral inward until the flame is concentrated close to its axis. Both the frequency of rotation and the upward velocity then increase appreciably, and internal rotation predominates. In a well-constructed apparatus the internal rotation persists for only a few seconds. The flame then expands to its original radius and initiates the next cycle. In the case of alcohol flames, particularly when they are observed in an apparatus of the Byram and Martin type, the flow pattern begins as a slow external rotation and is followed by radial translation until the flame hugs its axis in the form of a stable



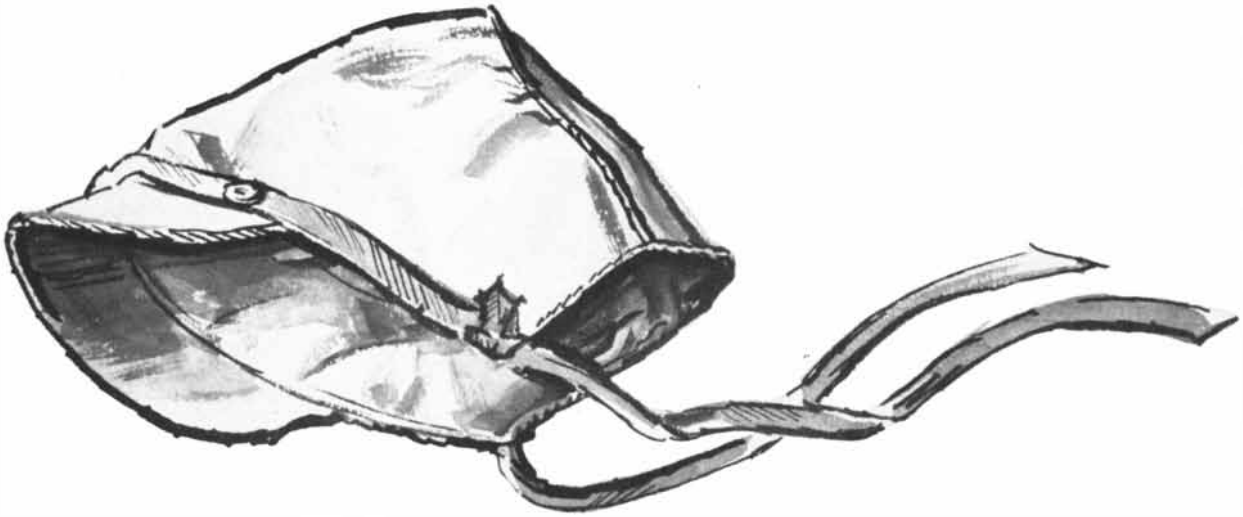
Wood-flame vortex apparatus

vortex of high intensity. When the entrained air is free of eddies, the entrainment slit properly adjusted and the fuel supply adequate, one cycle of radial translation establishes the intense vortex. During most experiments, however, several cycles are observed.

"The type and intensity of any fire vortex appears to be determined by the amount of friction between the surrounding air and the gases that constitute the flame, by the presence or absence of stagnant air and by temperature differences between the several parts of the flame. A vortex of high intensity can form only if the neighboring air rotates in the same direction as the flame and, in the case of small fires, at a higher velocity than is normally induced by convection inflow from the entrainment slit. In the absence of forced draft the required velocity must be gained by the loss of energy from the flame to the environment. As the neighboring air gains



Apparatus for generating parallel vortexes (left) *and antiparallel vortexes* (right)



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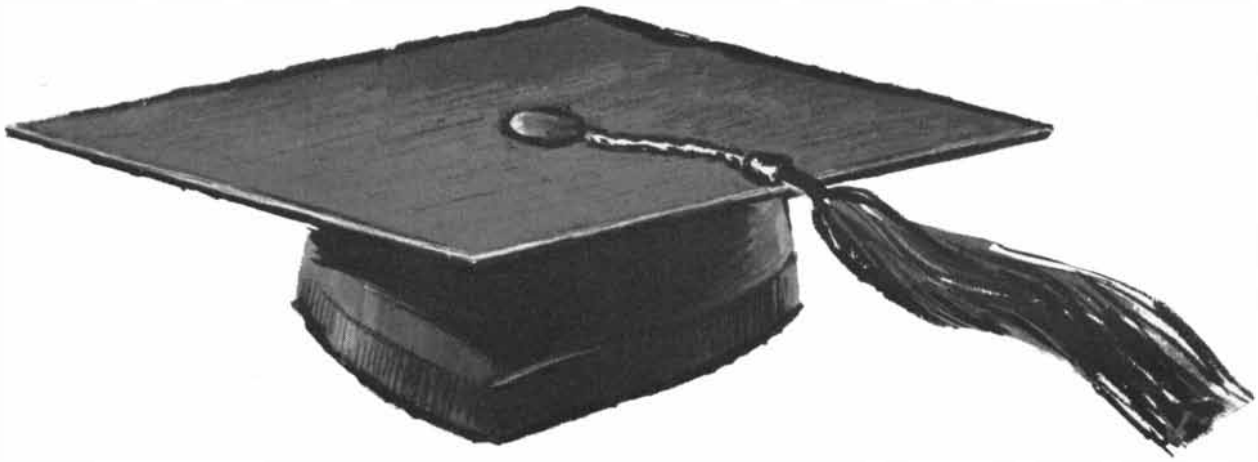

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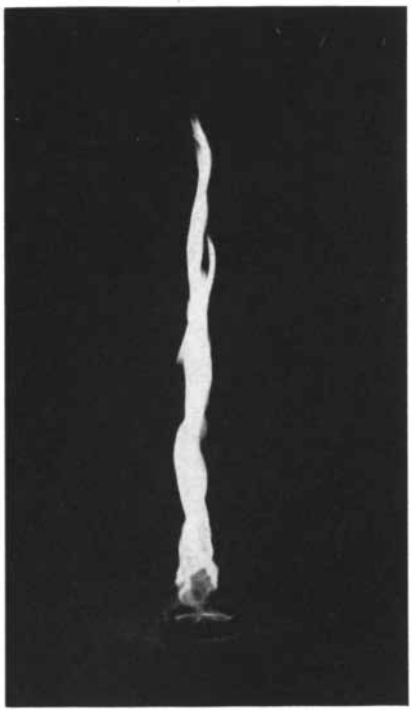


Photograph of high-intensity flame vortex

momentum, friction is reduced and the intensity of the vortex increases.

"The intensity of vortex burning also appears to be related to the efficiency of combustion. A given quantity of alcohol is consumed by a weak vortex flame in approximately half the time required for nonvortex burning. A high-intensity vortex quarters the nonvortex burning time. On the assumption that a vortex that burns its fuel in zero time has an intensity of 100 per cent and a normal burning efficiency of 100 per cent, the flames illustrated in the accompanying drawings have burning efficiencies of 20, 50 and 70 per cent respectively [*see bottom illustration on this page*]. The first of these flames burned in open air without a spiral enclosure. The second was equipped with spiral baffles through which air was forced by a blower. The third was generated by an apparatus of the Byram and Martin type.

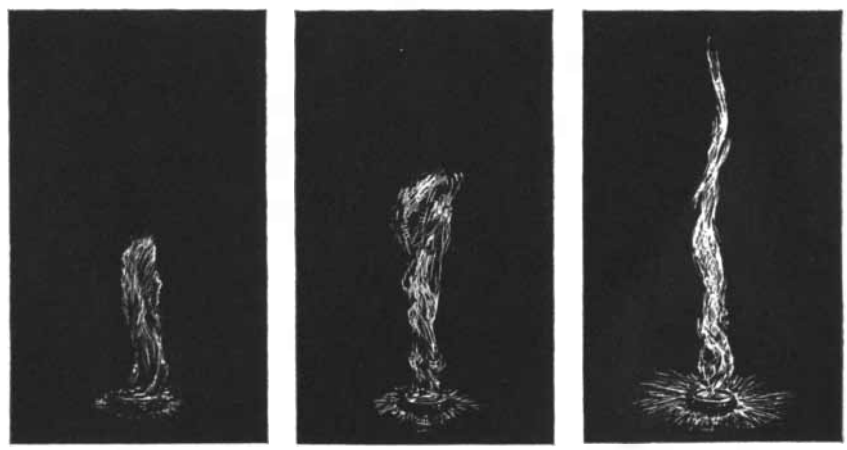
"Examination of a high-intensity flow pattern by means of soot particles discloses that most of the gases are entrained at the base; the general form resembles an inverted water vortex. Three patterns of flow can be distinguished: the core, a cylindrical region of substantial radius that borders the core and, beyond the cylindrical region, a surrounding environmental layer. Gases in the core spiral upward at high velocity. The radius of the core is short with respect to that of the neighboring cylindrical region, in which the rates of rotation and velocity are comparatively low but higher than in the surrounding environmental layer, where the flow is slightly downward.

"Experiment demonstrates that intensity is strongly influenced by the rate at which air enters the entrainment slit and by the angle of the inflow. In the case of an alcohol fire the intensity increases when air from a centrifugal blower is directed upward into one of the slits. The forced draft causes the vortex to incline away from the slit; beyond a critical angle the wind loses its effect. When the blast is directed into the slit horizontally, intensity decreases as a consequence of the disturbed circulation. Maximum intensity is achieved by directing the inflow downward at an optimum velocity that must be determined experimentally and at an angle that does not displace the vortex from the vertical. Suction applied—by a flue, for example—to the top spiral accomplishes much the same result.

"Within limits the velocity of air entrained by convection varies inversely with the diameter of the entrainment slit. A critical diameter exists for each apparatus at which the intensity is maximum. The intensity also varies with the ratio of the areas of the top and bottom of the container. Hence the production of intense vortexes is encouraged by narrow slits and an exhaust port of small area. Intensity decreases as the center of the outflow is displaced from the axis of the vortex; even small displacements can extinguish the vortex. As in the case of water vortexes, standing longitudinal waves appear in the core and increase in amplitude with the increasing displacement of the outflow.

"Temperature profiles were made by inserting thermocouples into the respective regions of the flow pattern and plotting the readings against distance from the core. Fluctuations of temperature that accompany periodic changes of internal and external rotation were plotted against time. In general the temperature is lowest in the center of the core, increases toward the edge and drops sharply at the boundary of the cylindrical region. The temperature profile appears to be related directly to the motion of the gases, because the rate at which the air rises is proportional to temperature differences along the core. The flow of glowing soot particles shows that velocity at the edge of the core is greater than in the center. The radial temperature gradient is also influenced by the spinning motion that tends to reduce the density of the inner core and cool the gases slightly. In a stable vortex, temperature decreases exponentially with height and—what is perhaps more significant—differences of temperature from point to point along the core are proportional to the temperature; the higher the temperature, the greater the differences. Periodic temperature fluctuations of more than 100 degrees centigrade were found just above the tip of the flame in the case of the vortex fueled by gas. The fluctuations occur at a period of about 70 seconds and are obviously caused by the periodic inward and outward spiraling of the flame. The external flame rotates at a rate of approximately one revolution per second.

"The behavior of adjacent vortexes appears to be determined by the relative direction of rotation and the relative intensities of the vortexes. When two neighboring vortexes of equal strength rotate in the same direction, an initial oscillation is observed as each attempts to entrain the other. A single large vortex then forms in the same direction and



Drawings of flame vortexes with burning efficiencies of 20, 50 and 70 per cent

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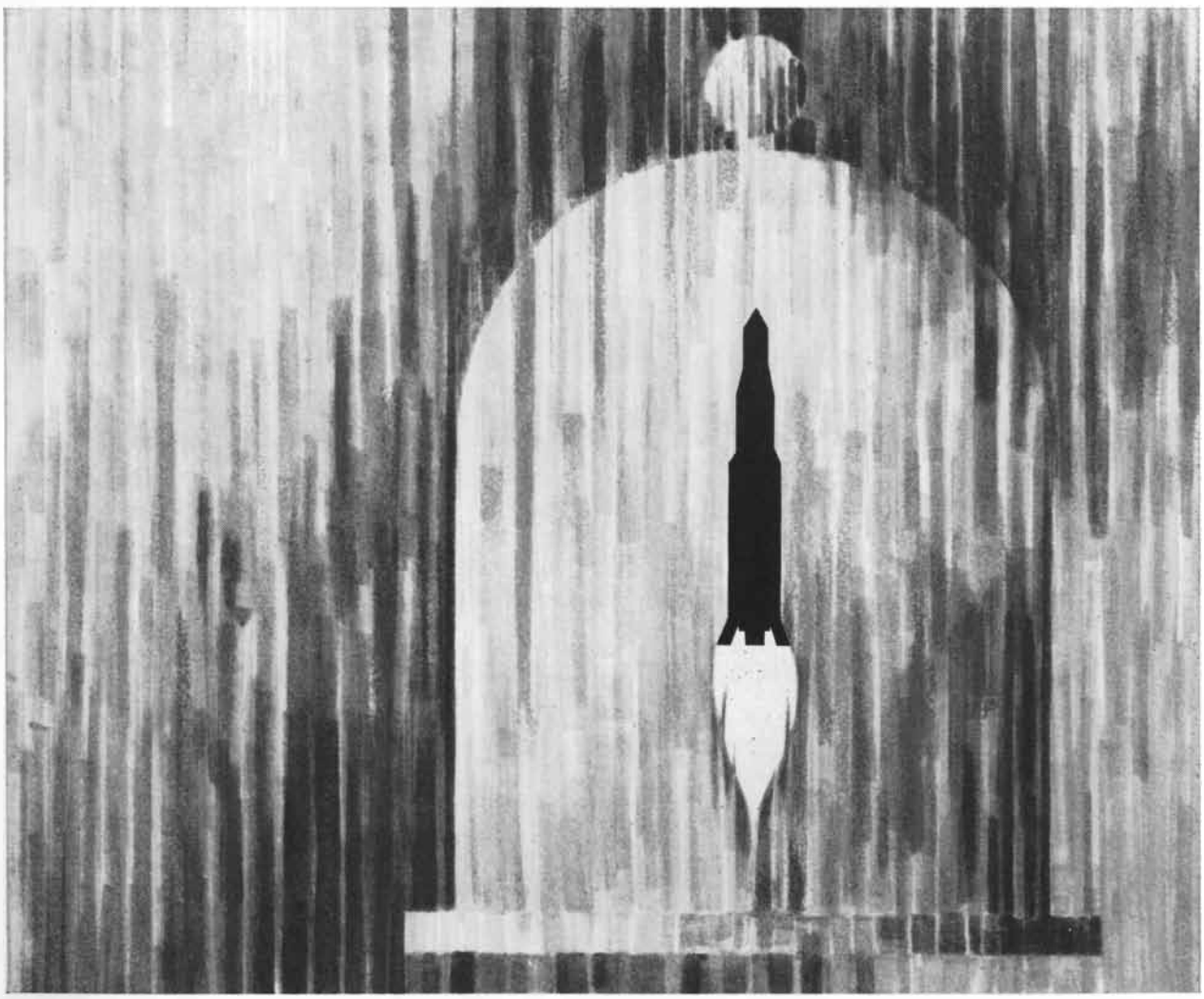

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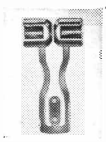

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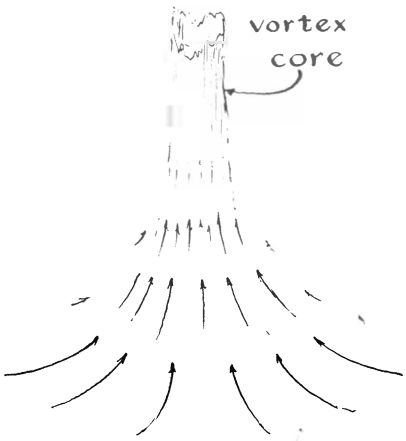


Pattern of vortex entrainment flow

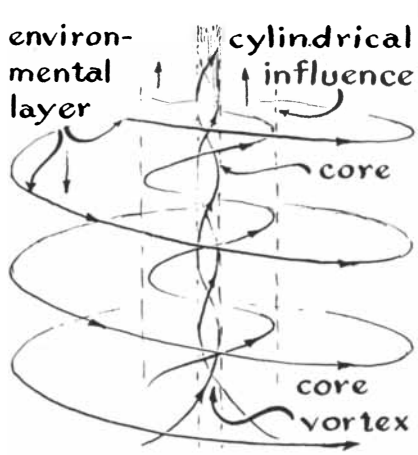
engulfs the original pair. When neighboring vortexes rotate in the same direction but differ substantially in intensity, the more intense member of the pair entrains the one of lesser intensity. Two vortexes of equal intensity rotating in opposite directions continue as individuals but with diminished intensity. The weaker vortex of an antiparallel pair may be entrained by the stronger, but the disparity in intensity must be large.

"Two types of apparatus have been used for experimenting with water vortexes: (1) a rectangular tank enclosing a smooth cylinder that is supported on three large rubber stoppers for equalizing the water level of the cylinder and tank and (2) a circular tank without an inner cylinder. Water is admitted at the top by a hose that directs a jet along the inner edge of the container for inducing rotational motion and initiating the vortex. The rectangular tank measures 15 inches in diameter and width and 24 inches in height. The outlet port is one inch in diameter. The companion cylinder is 10 inches wide and 15 inches high. The vortex forms inside the cylinder and can be displaced or otherwise manipulated by shifting the position of the cylinder. Cylinders in a range of sizes, as well as cones or other shapes, could be used in the tank, but I have not found time to try these variations.

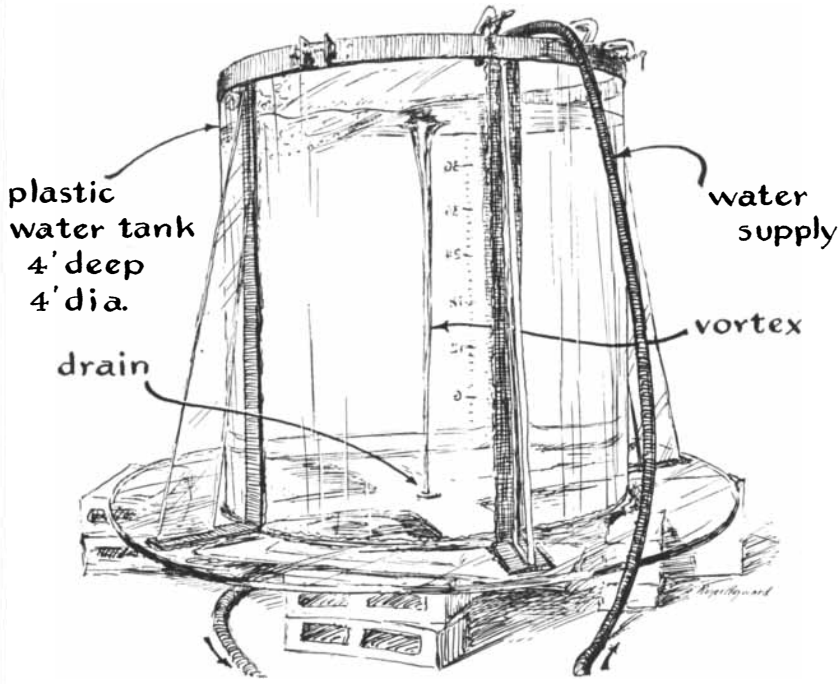
"The circular tank is four feet in height and diameter. Both tanks were made of clear plastic reinforced by metal frames. The outlet port of the large tank is 1½ inches in diameter and makes a snug fit with a size 20 rubber stopper. A set of stoppers was bored with holes that increased in diameter in quarter-inch steps from 1/2 inch to 1¼ inches for observing the effect of variations in outflow on the intensity of the vortex. Both water and time can be conserved by equipping the drain hose with a gate valve, so that the tank will not drain between experiments. In areas where water is in short supply the system can be equipped with a circulating pump. During observations of steady-state flow the water is maintained at a desired level by adjusting the inlet valve. An automatic float valve could be provided but is scarcely justified because the inflow is easily regulated by hand.

"If the outlet port is centered on the axis of the cylindrical container, the vortex forms almost immediately when the outlet valve is opened, and it is characterized by two waves. The first is a standing wave that twists the air core into a corkscrew shape of one or two turns that varies with the displacement of the outlet port from the center of the cylinder. The second is a moving wave on the surface of the core that resembles a loosely coiled helical spring of many turns. The moving wave is most evident when the vortex is unstable and in process of formation. Trains of moving waves are occasionally discharged by the core and generate concentric ripples on the flat surface of the water. The moving waves can be suppressed by adding the oily substance hexadecanol to the water. The resulting increase in surface tension reduces the ripples and produces a core with straight walls. If detergent is added to the water, the surface tension is decreased; the vortex then becomes unstable and, depending on the amount of detergent, may be destroyed.

"The flow pattern can be studied by sprinkling powdered dye or small crystals of potassium permanganate on the water. As in the fire vortex, three regions of flow can be distinguished: the core at the water-air interface, the cylindrical



Pattern of flow in and around flame vortex



Apparatus for experimenting with vortexes in water

layer in the immediate vicinity of the core and the environmental layer beyond. Water in the vortex and in the cylindrical layer spirals downward, that in the environmental layer slightly upward. The formation of a vortex decreases the outflow, so that the difference between maximum outflow in the absence of a vortex and outflow when a vortex is present can be taken as a measure of vortex intensity. The rate of outflow can be determined by observing the time required to fill a container of known volume. Maximum outflow changes when either the diameter of the outlet port or the depth of the water in the apparatus is altered. In order to compare the intensity of vortexes formed in water of various depths and at various rates of outflow I substituted as an index the difference between maximum outflow (O_m) and vortex outflow (O_v) divided by the maximum outflow, expressed as a percentage; the equation is S (the percentage of intensity) $= (O_m - O_v)/O_m \times 100$. A series of experiments was made to determine the effect on intensity of varying the diameter of the outlet port, the displacement of the vortex, the angle of incidence of the inlet jet, the depth of the water and the rate of the core's rotation.

"In general the outflow increases with depth and the diameter of the outlet but the relation is not directly proportional. When a vortex is present, the outflow varies as the square root of the pressure head or depth and as the 3/2 power of the area of the outlet. Doubling the diameter (hence quadrupling the outlet area) results in only a threefold increase in outflow. The angle made by the inlet jet, measured from the horizontal, exerts a pronounced effect on the intensity of the vortex. As the angle is made larger, intensity increases, but the vortex becomes increasingly unstable and beyond a critical angle does not form. As previously mentioned, within limits the vortex is destroyed by shifting the outlet away from the center of the container or by surrounding the vortex with a cylinder that is not centered above the outlet.

"The rate at which the surface water of the core rotates was measured by directing the beam of a stroboscope on a small cork in the vortex. The rate decreases logarithmically with the water level and at any height is independent of the area of the outlet port. The radius of the core increases directly as the diameter of the outlet is increased, because higher angular momentum is required to reduce the pressure of the water to that of the atmosphere, otherwise the core would collapse. Equilibrium must be maintained between the pressure of the water at the surface of the core and the atmosphere, a requirement that determines the maximum surface velocity of the core at any depth as well as the ratio of the radius of the core to depth."

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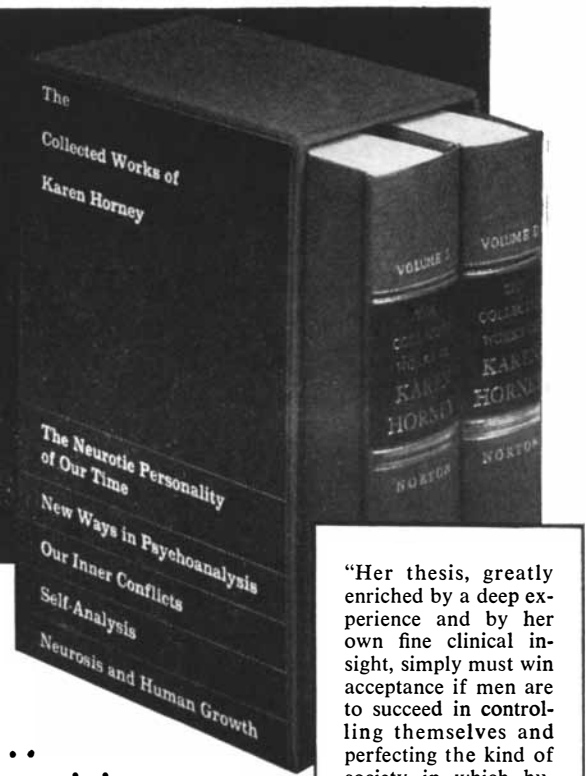

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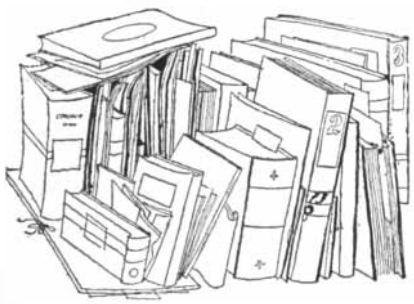

BOOKS

A new attempt to explain the paradoxes of quantum theory

by Ernest Nagel

UNDERSTANDING PHYSICS TODAY, by W. H. Watson. Cambridge University Press ($5.50).

As a rule physicists acquire competence in conducting investigations not by mastering principles of scientific inquiry but rather by developing habits of research that are modeled on examples of sound scientific workmanship. Moreover, discussions that are intended to articulate the structure of scientific procedure usually have no direct bearing on the detailed problems with which physicists are normally occupied. In consequence broad issues in the logic of science are rarely matters of active concern to practicing physicists, and most of them devote little serious thought to such "philosophical" questions as the functions a satisfactory theory must perform, how theory is related to the gross objects of familiar experience, and whether the abstract notions of a theory denote things that have some kind of physical reality.

Nevertheless, questions of this sort may become pressingly relevant to the work of physicists, and may require careful attention from them, when new experimental discoveries or radical innovations in theoretical ideas create puzzles that profoundly challenge entrenched scientific doctrines or habitual modes of analysis. Indeed, the development of physics has not been simply an impressive growth in theoretical and practical mastery of natural phenomena; it has also been a recurrent reassessment of traditional conceptions of human reason and a clarification of the logic of scientific inquiry, a clarification to which physicists have repeatedly made notable contributions. But in any event, in spite of the indubitably great achievements of quantum mechanics in accounting for a vast range of phenomena as well as providing fruitful guidance to fresh experimental study, even professional physicists have been deeply perplexed by some of its novel ways of conceiving fundamental processes in nature. In their efforts to remove such obstacles to understanding the content of quantum theory —for example its apparently paradoxical characterization of light as a propagation of both waves and particles—many physicists have found it necessary to examine issues usually regarded as of interest only to philosophers of science. Undoubtedly the best-known answers to these perplexities are those proposed by the Copenhagen school of physicists in terms of Niels Bohr's principle of complementarity. But agreement on the adequacy of these and other answers has never been unanimous even among members of the profession, and dissatisfaction with them has been on the increase in recent years. The book under review, whose author is professor of physics at the University of Toronto, is a fresh attempt to make intelligible the wave-particle dualism of quantum theory by examining with care, and against the background of certain broad views on the relation of theory to experience, relevant details of elementary quantum mechanics and field theory. Although its meandering argument often conceals the forest with the trees and makes the volume needlessly difficult, it is a valuable presentation of an enlightening approach to the understanding of contemporary physics.

The book is a sequel to one Watson published 25 years ago with a similar title (*On Understanding Physics*), but it can be read independently of its predecessor. The influence on the author of the late philosopher Ludwig Wittgenstein is evident in both books, and the style of thought in the later one as well as the conception of the nature of physical theory controlling its detailed analyses are those to be found in the earlier. The central methodological assumption guiding Watson's discussion is that the meaning of a physical theory cannot be extracted from its abstract structure or formal operations and can be rightly ascertained only by observing the concrete uses to which physicists put the theory in their experimental inquiries. Moreover, Watson believes that a physical theory is misconceived if it is taken to be a description of some reality underlying observable phenomena. On the contrary, he subscribes to a version of what is sometimes called the "instrumentalist" view of theory, in maintaining that rather than being a representation of physical reality a theory is an "accounting system" of rules for *constructing* representations of experimentally identifiable natural processes. Accordingly he declares that the mathematical formalism of quantum theory is not "a picture of the physical system being treated. It is an accounting system . . . [whose use nevertheless] confers on it physical significance. The reality represented with its aid is not to be found as a substratum governed by the mathematical formality: for the essential real supports are to be found in the real world of men and machines and physical instruments and phenomena produced and observed by means of them in the lives of the men who use them. . . . Instead of asserting that the mathematical theory represents reality, we do better to say that we use the theory in managing our experience in the real world with more or less success." In Watson's judgment the persisting dissatisfactions with quantum mechanics derive from the failure to recognize this fundamental fact about the nature of physical theory. The specific task he sets for himself in the present book is to show that the wave-particle locutions of quantum theory are not characterizations of an occult reality behind phenomena but are fully intelligible modes of representing observable physical fact.

Watson therefore devotes most of his attention to the ways quantum theory employs the techniques of mathematical continuity (and the language of wave propagation) to represent the basically discrete and discontinuous phenomena of microphysics (which are symbolized as particles within a space-time continuum). The major conclusion of his analysis is that the words "particle" and "wave" have meanings in quantum me-

chanics that are radically different from those associated with them in classical physics, and his main technical innovation is a reinterpretation of these words in consonance with their use in quantum physics. Thus particles such as electrons are postulated to explain the diffraction of a stream of particles, a phenomenon characteristic of waves; since such particles cannot, by virtue of Werner Heisenberg's uncertainty principle, be assigned indefinitely precise spatiotemporal locations or individually identifiable trajectories, electrons cannot be classical particles. It is nevertheless possible in studying interference in a stream of diffracted electrons to detect experimentally the departure of the particles from a source and their arrival at a target, for example by measuring changes in electric charge at those places. But although classical habits of thought lead us to imagine an intervening process between the events signalizing such departures and arrivals, and although quantum mechanics represents the process as a continuous propagation of waves, the waves are not classical waves; they do not transport energy and momentum in the way that classical wave motion does. In Watson's opinion we must abandon our traditional "metaphysical" preconceptions in interpreting the wave-particle locutions of quantum mechanics, and we must in particular stop thinking of microphysical particles as if they were substantial entities like bullets shot from a gun or of quantum-theoretical waves as if they were physical processes.

Watson's redefinition of the word "particle" is based on his analysis of what constitutes an "atomic existence" in microphysics. In his discussion of interference phenomena, for instance, he maintains that since it is impossible to detect the presence of a particle during its supposed passage from source to target, the process must be viewed as a unitary transaction in which the particle connects the detectable events at source and target in an undifferentiated way. Accordingly "the connection between the events is an atomic existence" and must be thought of as "an indivisible atomic jump." Unlike the classical forms of representation, those of quantum mechanics require us to associate the existence of the particle with the *pair* of events at source and target, with no real existence or motion for the particle between the events, just as the rules of chess require us to say that in the knight's move from one position on the board to another the piece occupies no intervening square on the board. In Watson's view, therefore, a microphysical particle is the temporally ordered pair of detectable but discrete events that mark the beginning and end of some indivisible physical transaction; as he explicitly declares when discussing the transfer of electrons from one molecule to another, "the electron in fact is the name given to the atomic connection between the event at the first molecule and that at the second molecule."

On the other hand, although we are thus precluded from talking about the internal structure of indivisible transformations, the terminating events in classes of such transformations do occur at various times and places with ascertainable relative frequencies. The exclusive function of the continuous wave representation of atomic existences is to enable us to calculate the probabilities of those events. On this basis quantum-theory waves do not represent any process *between* the initial and terminating events of atomic existences but must be construed as referring to the experimentally determinable spatiotemporal organization of families of discrete atomic connections. As a result the continuous motion commonly attributed to such waves is really a statistical property of some family of particles (or atomic existences) rather than of any individual particle. "The wave field," Watson maintains, "is in effect a statistical invention; it applies to connecting the detectable events in which physical effects actually occur. These are the only physical reality to be observed."

In short, Watson seeks to domesticate quantum theory, and to remove baseless dissatisfactions with it, by exhibiting the operative role of its unfamiliar locutions in codifying systematically relations of statistical dependence between types of phenomena that are certainly not foreign to the experience of physicists. As he himself writes in a revealing summation of his frequently tortuous quest for understanding quantum theory: "We are overawed by the success of the theory in practice and, finding that by its help we can establish agreement with experiment through quite long chains of reasoning, we are lured to believe that thereby we have proved that the apparatus of the theory represents nature in some occult way. [But] its purpose is not to put something behind the phenomena but to establish coherent intelligible connections between what we have observed in a great variety of observations and measurements."

Certainly no book in recent years has made out a case for the instrumentalist view of theory in general, or for an instrumentalist interpretation of quantum mechanics in particular, that is as carefully argued as Watson's. Even if some of its readers should doubt that Watson has established his case fully, it is unlikely that anyone will doubt that he has illuminated much that is obscure in quantum theory. Nevertheless, although he has produced persuasive grounds for his conclusions, it is not obvious that what he has to say about the instrumental uses of quantum theory in experimental inquiry is incompatible with the "realist" view Watson explicitly disavows, according to which quantum theory formulates the structure of physical processes "behind the phenomena." Moreover, although Watson outflanks some difficulties that face the realist view, he does not always make clear how various difficulties facing his own instrumentalist interpretation can be overcome. In regard to the first of these comments, consider Watson's claim that the function of quantum-theory wave representations is to enable us to calculate the probabilities with which various events occur. But why should a proponent of the realist view hesitate to accept this obviously sound claim? Its acceptance does not logically compel the realist to abandon his contention that whereas the wave equation does have the function Watson indicates, it *also* articulates characteristics of processes "behind" observable events. In any case, a theory does not necessarily lack descriptive content merely because it has an instrumental use. Indeed, it is easy to demonstrate that it is always possible to formulate a rule for organizing our representations of a subject matter as a descriptive statement *about* that subject matter, and vice versa. Accordingly Watson's instrumentalist account of quantum theory is fully compatible with the realist interpretations of it that he rejects, so that the opposition between them is nowhere nearly as sharp as he appears to believe.

Watson's approach to quantum theory enjoys the great advantage that it can rule out as irrelevant many questions that may embarrass alternative attempts to understand the theory. But his approach generates its own distinctive puzzles, although his book does not adequately discuss how some of them might be resolved. For example, in his view of atomic existence the connection between certain paired events must be regarded as an indivisible jump, with no intervening physical process between the events even though one of them precedes the other. In spite of his instructive ef-

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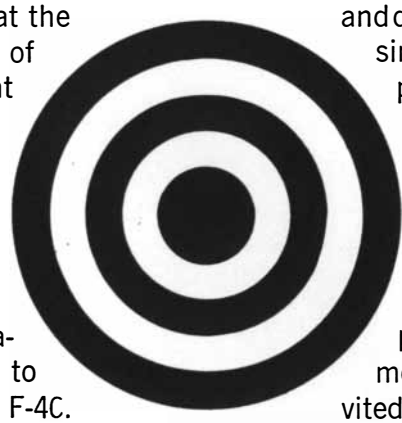

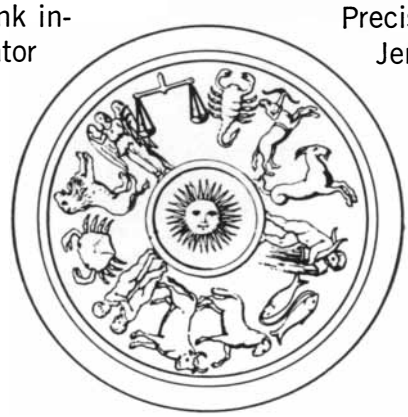

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forts to make this conception intuitively clear, the conception remains no less perplexing than is the currently orthodox interpretation of the dual wave-particle nature of light in terms of the principle of complementarity. It is perhaps a matter of personal taste which of these perplexities is regarded as the more cryptic. Again, in maintaining that the word "electron" does not designate substantial particles and is only the name for certain atomic connections between events, Watson leaves obscure the sense in which electrons so conceived can be said to have a mass and electric charge. Surely mass or charge cannot be predicated of indivisible jumps in any familiar meaning of these expressions, and unless sense can be made of such assertions, Watson's proposed redefinition of "electron" is patently unsatisfactory.

At several points Watson's argument suffers from at least the appearance of inconsistency. For example, he holds that, because of the uncertainty principle, the events defining atomic existences in diffraction experiments cannot be assigned spatiotemporal locations with unlimited precision, and he thus seems to construe the principle as a statement describing a matter of observable fact. The uncertainty principle, however, cannot rightly be regarded simply as an empirical generalization concerning the limitations of our actual techniques for making precise measurements; it is directly based on theoretical assumptions that are part of quantum mechanics. On the other hand, quantum theory according to Watson has no descriptive content dealing with natural events, since it is for him merely an accounting system of rules for representing such events. It is therefore unclear whether, in using the uncertainty principle to support his contention that electrons (and other microphysical particles) are radically different from the particles of classical physics, Watson's argument is inconsistent with his central thesis about quantum mechanics, or whether his argument is merely circular.

A brief comment is in order on Watson's grounds for denying that quantum theory represents physical "realities" other than certain phenomena produced by various instruments and observed by men with their aid. The first point to be noted is that no physical theory *literally describes* anything that is observable either directly or with the help of suitable instruments. But no theory is relevant to the subject matter of experimental physics unless some of its theoretical ideas are associated with experimental concepts that can be applied to observable matters, although usually most terms of a theory are not so associated. Now it is certainly possible to hold that the physical realities represented by a theory are just those things to which the experimental concepts coupled with its theoretical terms can actually be applied, and on this criterion of what a theory represents and what is physically real Watson is obviously correct in denying that quantum theory is about some nonobservable but real physical substratum. It must also be noted, however, that this is only one criterion among many others that are widely employed in physical science. In adopting this criterion Watson has made a choice between equally legitimate alternatives that is not the choice physicists generally make, and, as he in effect acknowledges, his decision to adopt it involves a large element of arbitrary preference. In any event, Watson's denials are much less cogently argued, and far less instructive, than is his positive account of the instrumental functions of quantum theory.

Short Reviews

MEDICAL BIOMETEOROLOGY: WEATHER, CLIMATE AND THE LIVING ORGANISM, by S. W. Tromp. American Elsevier Publishing Co., Inc. ($45). Hippocrates in his book *Airs, Waters, Places* wrote: "Whoever wishes to pursue properly the science of medicine must proceed thus. First he ought to consider what effects each season of the year can produce: for the seasons are not alike but differ widely both in themselves and at their changes." Weather and climate influence the living organism both psychologically and physiologically. For centuries men have experienced the depressing effects of long, dark winters and high humidity, the elation produced by the coming of spring and the higher incidence of certain diseases at certain times of the year or in certain regions. It has been widely conjectured also that racial differences and the development of civilizations can be explained on the basis of climatic changes and differences. In this sense the subject of medical biometeorology is old. But only within the past few decades has a systematic attempt been made by observation, experiment and historical research to determine with some exactitude the effect on living organisms of changes of temperature and humidity, winds and storms, long-term and short-term climatic fluctuations and other meteorological phenomena. It is not surprising that this is a many-faceted and sprawling subject composed more of speculation and conjecture than of firmly established facts. Meteorology itself is inordinately complex and the attempt, however reasonable and inviting, to relate weather and climate to animal behavior is beset with difficulties. This large book reviews the field, indicates the principal facts known so far and describes the problems to be solved. Among the myriad of intriguing unanswered questions are the following: How does weather affect sleep? What is the physiological nature of weather sensitivity (known as meteorotropism)? Are there more suicides in certain months of the year than in others? To what extent is temperature a sex-determining factor? (There is evidence, for example, that among sea urchins warm water produces more males than females and that cold water has the reverse effect.) What diseases are linked to weather and climate? An impressive feature of this book is a bibliography consisting of some 4,400 items.

HELMHOLTZ'S TREATISE ON PHYSIOLOGICAL OPTICS, translated from the third German edition and edited by James P. C. Southall. Dover Publications, Inc. ($15). The average half life of a scientific article is said to be about 15 years. The half life of most books may be somewhat longer, but the half life of Helmholtz' classic, although not yet shown to be equal to that of Galileo's or Newton's, is so exceptional as to constitute a tribute to the great physiologist-psychologist-physicist. This huge handbook, originally published in three volumes in 1856, 1860 and 1866, was rich in exact information, most of which has stood up as fact for a century even though the observations had in most cases been made on only a single pair of eyes—Helmholtz'. Modern experimental psychology is considered to have been "founded" about 1860; this treatise is a reason for Helmholtz' being one of the three men who can be regarded as the creators of the new scientific psychology. The second edition, of 1896, was not so good as the first, and for that reason three editors (A. Gullstrand, J. von Kries and W. Nagel) in 1909–1911 reprinted the first edition, contributing supplements that take up a little more than a third of the new whole. Their updating made the text once again the standard work in the field, but psychophysiological optics was coming on rapidly in the English-speaking countries, and Helmholtz' book was still in German. In 1921, the centenary of Helmholtz' birth, the American Optical Society reprinted in an English translation the entire third

edition together with some new matter, including the color theory of Christine Ladd-Franklin. For some time this version has been out of print, and the need for it has now been met with this excellent, clearly reproduced pair of volumes, one combining the first two original volumes and the second consisting of the old third volume. The Dover reprint, appearing some 100 years after the first edition, will be welcomed eagerly. Not many scholarly books win such objective plaudits as this one has from the hard-pressed students of psychophysiological optics.

THE PHYSICAL GEOGRAPHY OF THE SEA AND ITS METEOROLOGY, by Matthew Fontaine Maury. Harvard University Press ($8.50). Maury was an American astronomer, naval officer and hydrographer who served from 1842 to 1861 as superintendent of the Naval Observation and Hydrographic Office, where he compiled observations, particularly of wind and weather, for use in the navigation of sailing ships. (In 1861 he resigned his commission and became a commander in the Confederate navy; after the war he served as professor of meteorology at the Virginia Military Institute.) The present book, first published in 1855, grew out of his work in the Hydrographic Office and reflects his primary interest in formulating a general system of circulation of the atmosphere as the major determinant of the climates of the earth and of various phenomena of the oceans. Maury was not a particularly competent scientist; most of his theories were more imaginative than sound. In fact, he was not abreast of contemporary knowledge in his subject and in several respects held opinions directly contrary to those of the leading scientists of his time. This, however, did not faze him in the least, and he was quite willing vigorously and brashly to defend his views against all comers. Because he had a "lively, rather florid style" and because there were novel and interesting descriptions and conjectures in his work, it won a wide audience and went through many editions in spite of its lack of scientific rigor. The present reprint carries a useful and informative introduction by John B. Leighly, professor of geography emeritus at the University of California at Berkeley, and is illustrated with the original figures and plates.

MATHEMATICS; SCIENCE: METHOD AND MEANING; ARCHAEOLOGY; ENGINEERING. Edited by Samuel Rapport and Helen Wright. New York University Press ($4.95 each). These books mark the beginning of a new series, the "New York University Library of Science," designed for the general reader and intended to cover the range of the natural and physical sciences. Each contains 20 to 25 selections varying considerably in length, taken from the writings of well-known scientists or popularizers; the selections are prefaced by biographical sketches by the editors. The volumes, which run between 250 and 350 pages, are intended as compact samplers and are no more than that. The illustrations, except for photographs in the volume on archaeology, are scarce and mostly mediocre. (The volume on the method and meaning of science has none, the volume on engineering only a few.) There are neither indexes nor bibliographies, which is most unfortunate. Altogether not a very promising beginning for the series, although good material can be found in each of the volumes and their handy size will commend them to the traveler for casual reading.

THE MARCONI SCANDAL, by Frances Donaldson. Harcourt, Brace & World, Inc. ($5.75). A detailed account of the celebrated Marconi affair. In 1912 Herbert Samuel, Postmaster-General in H. H. Asquith's cabinet, let a contract to the Marconi Company to build a chain of wireless stations to link the British Empire. News of the contract and of negotiations involving the American Marconi Company, which was an entirely independent concern, led to intense speculative activity and a sevenfold increase in the price of British shares. The manager of British Marconi was Godfrey Isaacs, brother of Sir Rufus Isaacs, Attorney-General in Asquith's government. Soon after the government accepted the tender of British Marconi, Godfrey Isaacs came to the U.S., helped to reorganize American Marconi, underwrote a large new stock issue and acquired for his services a substantial block of stock. On his return to England he sold some of this stock to his brother Rufus—who in turn made a portion of the shares available to Lloyd George and other highly placed members of Asquith's cabinet. Rumors of behind-the-scenes hanky-panky were intensified when British and American Marconi shares fell almost as quickly as they had risen. Several unsavory journalists, among them Cecil Chesterton (G. K.'s brother) and the twisted Hilaire Belloc, a virulent anti-Semite, began writing stories accusing Herbert Samuel, Rufus Isaacs, his brother and others of having enriched themselves at public expense and of having taken advantage of inside information to make a killing in the market by obtaining the shares at a low price and dumping them after they had risen. These men, it was charged, were corrupt; worse, they were cunning Jews who had engaged in a conspiracy to drain the blood of innocent Gentiles. The attacks continued for many months but unfortunately none of the accused responded to them as fully and as forthrightly as they should have done. When the government could no longer afford to disregard the rumors and charges, a special Parliamentary committee was appointed to take testimony on the entire affair. The committee reported back to Parliament, and after long and bitter debate the House, along more or less party lines, exonerated the Attorney-General and the others from any wrongdoing. Although none of the central characters suffered in his subsequent career (Sir Rufus, for example, became Lord Chief Justice of England and Viceroy of India), the affair left doubts and an unpleasant aftertaste. Mrs. Donaldson, while fully preserving the dramatic flavor of the events, gives a fair appraisal based on a meticulous examination of official records and contemporary journals.

THE PRICE OF GLORY: VERDUN 1916, by Alistair Horne. St Martin's Press, Inc. ($5.95). A brilliant and at times almost unbearably harrowing account of the longest, bloodiest, most murderously insane battle of World War I. In all the history of armed combat it is doubtful that there was ever a greater display of heroism by the fighting men and of stupidity and moral and tactical bankruptcy by the leading generals. Verdun left an indelible mark on the contemporary world; France in particular never fully recovered from the trauma and the decimation of so many of its villages. Fine photographs.

THE GEOGRAPHICAL DISTRIBUTION OF ANIMALS, by Alfred Russel Wallace. Hafner Publishing Co., Inc. ($24). A reprint, with all the original illustrations and colored maps, of a famous book, published in 1876 but still regarded as the most important work on the subject, by the noted naturalist and explorer who arrived at the theory of natural selection simultaneously with Darwin. While at work on the fauna of the Malay Peninsula, Wallace was struck with the need for "an accurate knowledge of any groups of birds or of insects and of their geographical distribution [which] may enable us to map out the islands and continents of a former epoch—the amount of difference that exists between the ani-

mals of adjacent districts being closely related to preceding geological changes." He thereupon set out, although accurate information was hard to come by, to make a systematic review of the animals to be found in each region and subregion of the earth, the extinct mammals as well as the fauna still flourishing.

PENGUIN SCIENCE SURVEY, 1963 A, edited by Arthur Garratt; PENGUIN SCIENCE SURVEY, 1963 B, edited by S. A. Barnett and Anne McLaren. Penguin Books, Inc. ($1.65 each). These two paperbacks contain a number of popular review articles dealing with advances in the physical sciences, mathematics, space research, agriculture and education. Several of the pieces, including Sir Harrie Massey's summary of what is known about the upper atmosphere and C. M. Yonge's essay on food from the sea, are of uncommon merit. Particularly intriguing is S. Tolansky's paper on optical illusions and scientific measurement. There are good illustrations. Together these compact, well-printed and up-to-date volumes by leading specialists constitute an attractive contribution to contemporary scientific literature.

THE SEA, by Hein Wenzel and others. Rand McNally & Co. ($17.50). A word-and-picture book about the sea, with articles by Hermann Hiltbrunner on man and the sea, Ernst Gagel on exploring the deep sea, Auguste Piccard on the depths of the ocean and Hans Hass on marine life. The articles are mostly pleasant magazine stuff, but many of the photographs of waves and harbors and icebergs are simply stunning. There are 19 color plates, 80 black-and-white photographs and 20 sketch maps; all in all a handsome job by the Swiss publishers Kummerly and Frey.

NUCLEAR REACTOR ENGINEERING, by Samuel Glasstone and Alexander Sesonske. D. Van Nostrand Co., Inc. ($9.20). This book, a revised and much expanded successor to a similar study published in 1955, describes the fundamental scientific and engineering principles of nuclear reactor systems. The progress in reactor technology can be judged from the fact that in the original volume it was possible within the space of 50 pages to describe the characteristics of all the reactors about which information was available, including several in the design stage, whereas a mere listing of today's known nuclear reactors would take many pages. The authors have therefore striven to provide a guide to the basic concepts and to describe representative types of reactors rather than provide a complete and detailed description of "what is now a complicated and mature technology." Bibliographies and 198 illustrations.

HUNGARIAN PROBLEM BOOK I AND II, originally compiled by József Kürschák, revised and edited by G. Hajós and others. Random House, Inc. ($1.95 each). These two books, translated by Elvira Rapaport, consist of mathematical problems based on the famous Eötvös Competitions held in Hungary almost every year since 1894. The problems are in elementary mathematics but they are ingenious and often difficult, demanding a considerable mathematical imagination and ingenuity for their solution. Fortunately the solutions, beautifully worked out, are given for each problem. A fine gift for an aspiring student or teacher. Paperbacks.

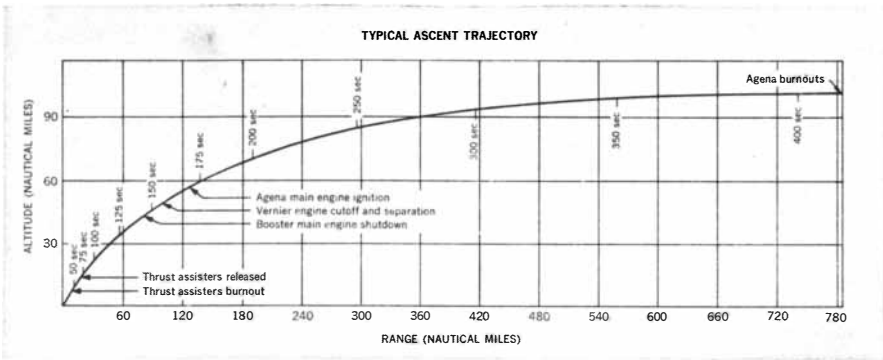
GRAVITATION: AN INTRODUCTION TO CURRENT RESEARCH, edited by Louis Witten. John Wiley & Sons, Inc. ($15). Extensive research is in progress on various aspects of gravitation; Witten's volume reports on this work. It includes papers on experiments in gravitation; exact solutions of the gravitational field equations, equations of motion, conservation laws and general relativity; gravitational radiation, the quantization of geometry, a geometric theory of electromagnetic and gravitational fields and relativistic cosmology.

Notes

PHYSIOLOGY AND BIOCHEMISTRY OF ALGAE, edited by Ralph A. Lewin. Academic Press ($32). This co-operative work consists of some 55 monographs on the major topics in experimental phycology. The main headings are nutrition and metabolism, composition of cells and metabolic products, physiology of whole cells and plants, physiological aspects of ecology. Illustrations and valuable bibliographies.

AN INTRODUCTION TO SCIENTIFIC RESEARCH, by E. Bright Wilson, Jr. McGraw-Hill Book Co., Inc. ($2.95). An inexpensive reissue of a study that attempts to explain as simply as possible certain general principles, techniques and guides for research.

MAGNETOSTATIC PRINCIPLES IN FERROMAGNETISM, by William Fuller Brown, Jr. North-Holland Publishing Company ($7.75). A technical monograph on an important topic in solid-state physics:



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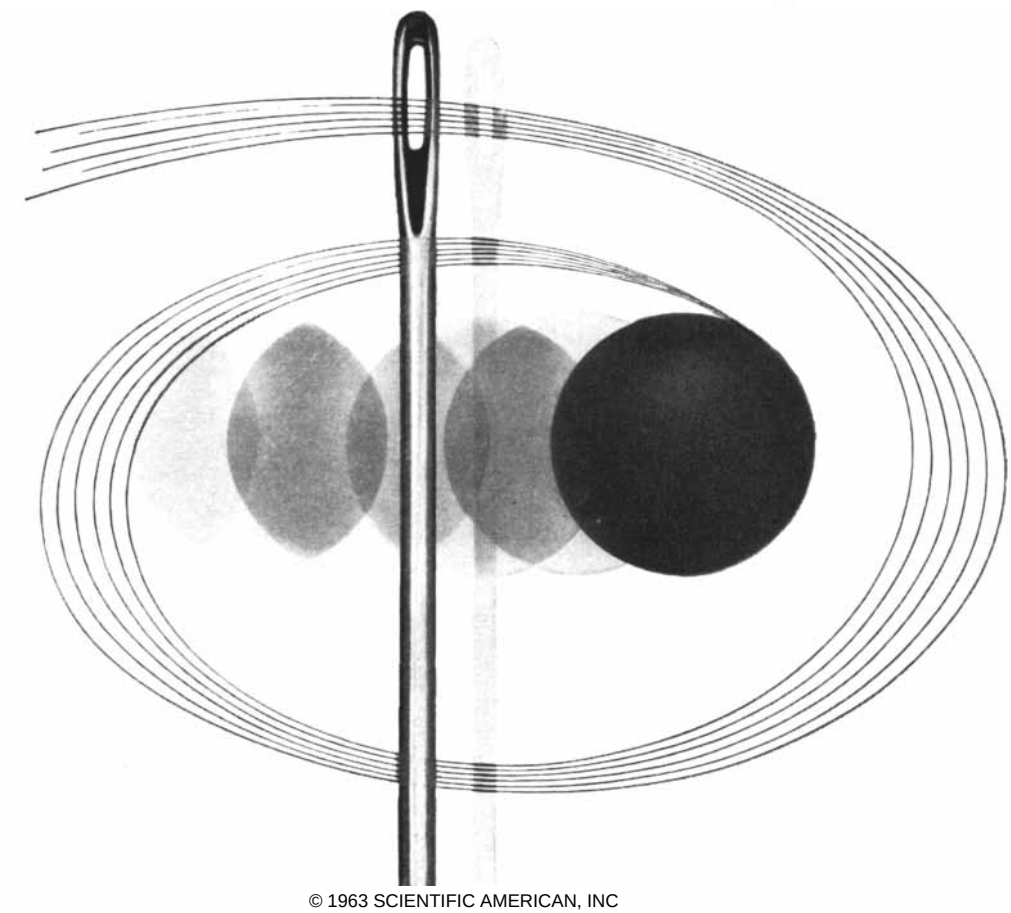

the application of magnetostatic principles in modern ferromagnetic theory.

COMPARATIVE NUTRITION OF MAN AND DOMESTIC ANIMALS, by H. H. Mitchell. Academic Press ($25). The first volume of a two-volume work that sets forth the nutrient requirements of man and his domesticated animals and examines the factors that modify these requirements. Illustrations and extensive bibliographies.

EXPLORATIONS IN PERSONALITY, by Henry A. Murray and others. Science Editions, Inc. ($2.45). A soft-cover reprint of a clinical and experimental study of 51 male subjects of college age, undertaken by the workers at the Harvard Psychological Clinic more than a quarter of a century ago. A major exploration, much of it still good reading.

GALILEO GALILEI: DIALOGUE CONCERNING THE TWO CHIEF WORLD SYSTEMS, translated by Stillman Drake. Foreword by Albert Einstein. University of California Press ($2.95). The first paper-backed edition of Drake's first-class translation of Galileo's immortal account of the way things are. Illustrations.

AUSTRALIA IN THE ANTARCTIC, by R. A. Swan. Melbourne University Press ($9.50). A full account of Australian activity and achievement in the Antarctic from the first sealers and whalers in the early 19th century through the outstanding explorations, ending with the Antarctic Treaty of December, 1959, "which marked the close of the days of purely national activity in Antarctica." An interesting story, with maps and plates.

TREATISE ON LIGHT, by Christiaan Huygens. Dover Publications, Inc. ($1.35). A pleasing soft-cover reissue of Silvanus P. Thompson's translation of Huygens' great book, which enunciates the wave theory and describes the experiments Huygens performed in support of it.

THE MECHANICAL INVESTIGATIONS OF LEONARDO DA VINCI, by Ivor B. Hart. University of California Press ($1.95). A paper-bound edition, revised and enlarged, of an account of Leonardo's investigations in mechanics as he described them in his notebooks. Included is a translation of his manuscript of *The Flight of Birds.*

DIALECTICS OF NATURE, by Frederick Engels. Translated and edited by Clemens Dutt. International Publishers Co., Inc. ($2.25). Engel's famous work on the application of Marxist ideas to science and society here appears in a paper-backed reprint.

NOBEL PRIZE WINNERS IN CHEMISTRY: 1901–1961, by Eduard Farber. Abelard-Schuman Limited ($6.50). A revised, updated edition of a book first published in 1953. It gives biographical sketches of the laureates, explanations in their own words of their work and a commentary by the editor on the importance of their contributions. Diagrams and portraits.

YEARBOOK OF ASTRONOMY: 1963, edited by J. G. Porter. W. W. Norton & Co., Inc. ($3.50). A handbook that gives information on astronomical configurations and events in 1963 and offers topical articles on various subjects of current interest, including the problems of Mars, space research, variable stars, the surface of Venus and stellar clusters. Illustrations. A paperback.

SCIENCE IN PROGRESS, edited by Wallace R. Brode. Yale University Press ($7.50). The 13th volume of this series contains, among others, articles on climatology, nuclear interactions in molecules, sunstorms, natural selection, biophysics, stellar evolution, plasma physics, science and government. Illustrations.

ESSAYS IN PERSUASION, by John Maynard Keynes. W. W. Norton & Co., Inc. ($1.85). A reissue in soft covers of a collection of familiar essays on political economy written over a 12-year period after World War I. Keynes himself referred to the essays as "croakings of a Cassandra who could never influence the course of events in time."

THE PHILOSOPHY OF BERTRAND RUSSELL, edited by Paul Arthur Schilpp. Harper Torchbooks ($3.90). This two-volume soft-cover edition of a work in the "Science Library Series" includes appraisals of various aspects of Russell's philosophy, a charming essay by Russell himself on his mental development and a full bibliography of his writings.

TOTEM AND TABOO, by Sigmund Freud. W. W. Norton & Co., Inc. ($1.25). A soft-cover reissue of James Strachey's translation of Freud's four essays drawing attention to "some points of agreement between the mental lives of savages and neurotics," first published 50 years ago.

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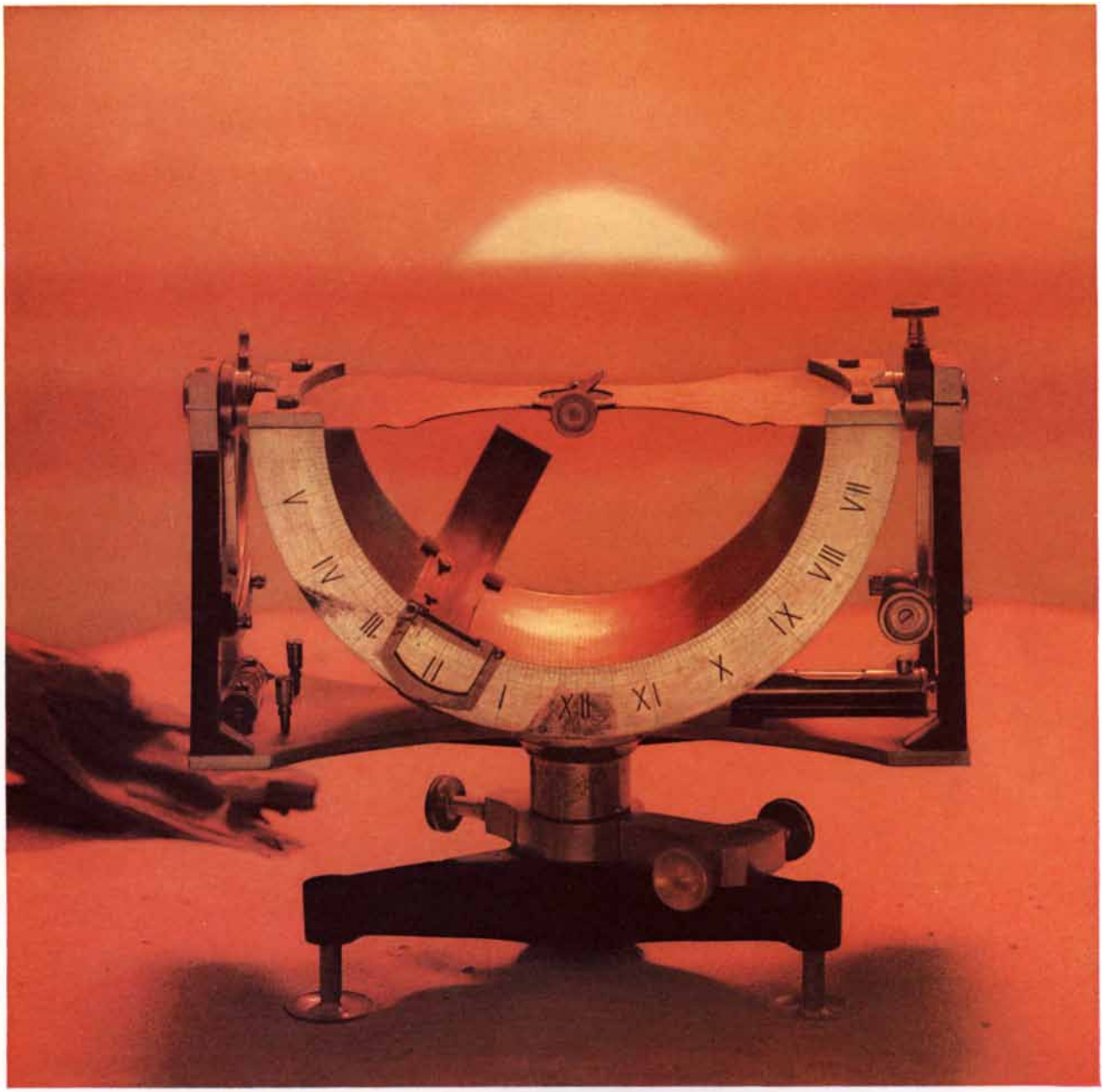

Wheeler's Solar Chronometer (American—19th Century)—Courtesy Cranbrook Institute of Science

from solar chronometer to space booster guidance

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