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SIXTY CENTS

May 1965

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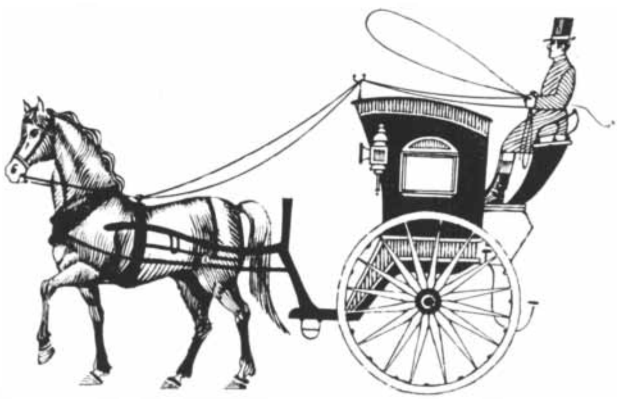

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First 28-volt fuel-cell system to pass 500-hour test at NASA!

Successful completion of this test demonstrated Allis-Chalmers capability to respond to RD & E challenges. The challenge was to fabricate and assemble two 28-volt, 1.8kw fuel-cell systems — subject one system to a 400-hour verification test and deliver the second system to NASA's Manned Spacecraft Center, Houston, Texas, within TWO AND ONE-HALF MONTHS after contract go-ahead!

The challenge was met on schedule. On arrival at MSC, the second system was successfully run by NASA personnel with assistance from Allis-Chalmers for 200 hours.

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- First fuel cells in a land vehicle, 15-kw tractor, applied in 1959.
- First fuel cells to successfully pass zero gravity tests, Wright Patterson AFB, in 1962.
- First fuel cells "qualified for space" with the Air Force, in March, 1964.
- First fuel cells to power an underwater vehicle — Electric Boat Division, General Dynamics Star I submarine, in July, 1964.
- First 28-volt fuel-cell system to pass 500-hour test at NASA.

May we discuss your aerospace and defense fuel-cell application? Write: Market Development, Space and Defense Science Department, ALLIS-CHALMERS, Box 512, Milwaukee, Wisconsin 53201.

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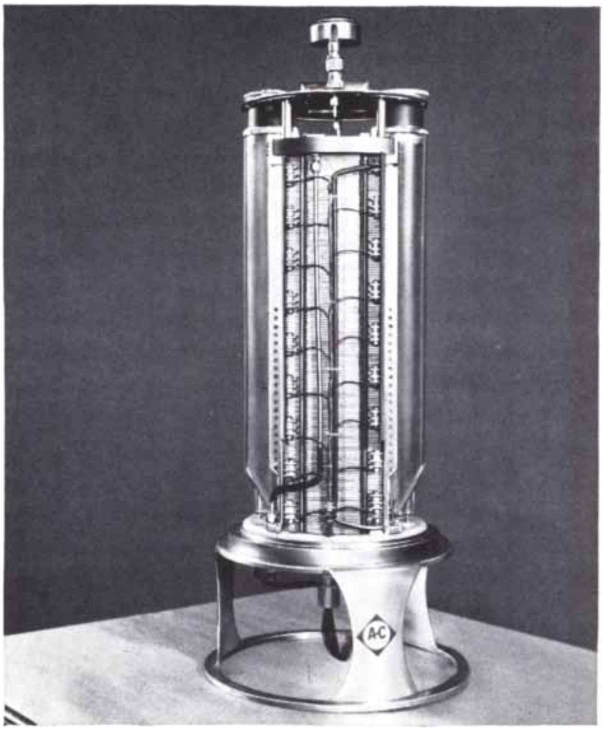
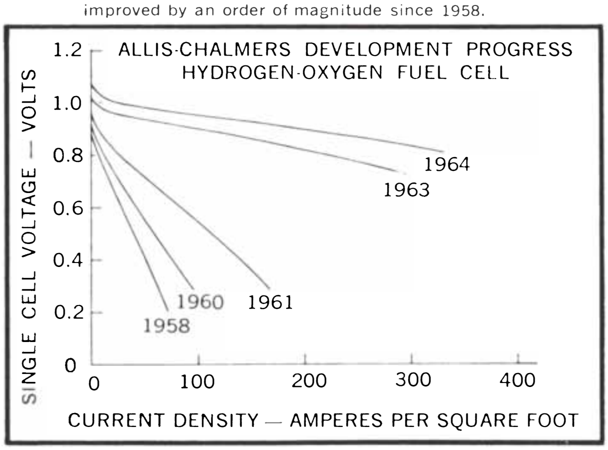

Allis-Chalmers 28-volt, fuel-cell system is the first to successfully pass 500-hour test at NASA.

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



Established 1845 SCIENTIFIC AMERICAN May 1965 Volume 212 Number 5

ARTICLES

DEPARTMENTS

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THE COVER

The photograph on the cover reproduces a detail from a felt cloth of Scythian manufacture that was preserved for more than 2,000 years by the severe cold of the earth pit in which it was buried (see "Frozen Tombs of the Scythians," page 100). The figure is that of a goddess, seated on a throne and holding a conventionalized flowering plant in one hand; the companion figure with which the cloth is decorated, a mounted man, appears in the illustration on page 100. Measuring more than 300 square feet, the cloth probably served as a rug for the tent of a nomadic Scythian chieftain. It now hangs in the Soviet State Hermitage Museum in Leningrad as one of the choicest items in a collection of Scythian artifacts made of wood, leather and cloth unearthed in Siberia between 1947 and 1954.

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Regulated Speed Drive

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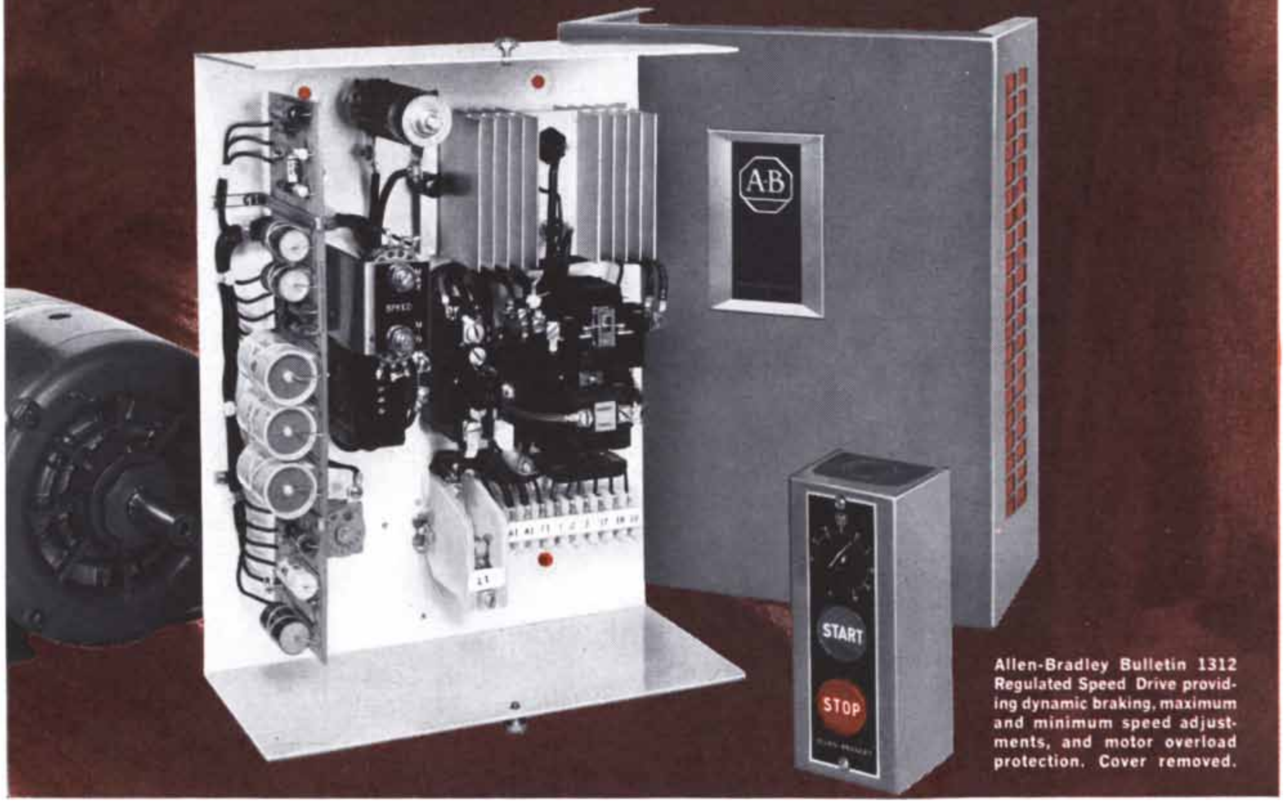

Allen-Bradley Bulletin 1312 Regulated Speed Drive providing dynamic braking, maximum and minimum speed adjustments, and motor overload protection. Cover removed.

■ The Bulletin 1312 describes a new line of Allen-Bradley regulated speed drives for motors up to 1½ hp. Composed largely of an assembly of Allen-Bradley control components, we feel completely safe in claiming long life and trouble free performance for these units. The silicon controlled rectifiers—conservatively applied and fully protected—assure an almost unlimited life. Built to industrial control standards and using a standard NEMA rated contactor gives the customer more value for his money. This is a "quality" design.

The Bulletin 1312 drive provides a standard speed variation of 8:1, and it will hold the setting within ±5% of maximum speed—from 10% of full load to full load. And there's a full range of options available to meet your specific needs, such as a "trip-free" and "tamperproof" thermal overload relay, maximum and minimum speed adjusting potentiometers, extension of speed range to zero, dynamic braking, etc. Jog-Run or Forward-Reverse functions can be obtained.

The Bulletin 1312 construction is compact but not cramped—there's good accessibility to all components. In addition, the line, motor, and control wiring terminate in base-mounted Bulletin 1492 terminal blocks, making installation easy—and thus saves on installation cost.

For more complete information on the Bulletin 1312 regulated speed drives, please write: Allen-Bradley Co., 1204 South Third Street, Milwaukee, Wisconsin 53204. In Canada: Allen-Bradley Canada Ltd., Galt, Ontario. Export Office: 630 Third Avenue, New York, New York, U.S.A. 10017.

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Both get the data they need with SYSTEM/360.

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The engineer who needs high speed acquisition of real time data can solve his problem with SYSTEM/360.

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If you have a large number of people at many locations who want to work with a computer any time they need it, you need a lot of storage to swallow up the many programs, compilers and the operating system. You need high speed transfer of programs or data—getting them in and out of core storage, from a file, quickly. You may want dynamic relocation of programs to optimize use of core storage. You need powerful communications, memory protection and interrupt capabilities.

Once again, IBM SYSTEM/360 fills the bill.

The Fellow Who Needs A Quick Look

When you're running a sophisticated experiment, you often need a quick analysis of how it's going so that you can stop or adjust it if necessary.

You may want a histogram or a curve displayed on a cathode ray tube . . . a typewritten list . . . plotted graph . . . or an audio response.

SYSTEM/360 is the answer.

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Can you get by with a low cost tape drive? We have it.

Do you need a faster card reader (1,000 a minute) to speed throughput in a FORTRAN open shop? We have it.

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The important thing is, you pick and choose only those capabilities you need when you choose SYSTEM/360. And you can change it. Anyway you want. Without penalty.

IBM SYSTEM/360 isn't a single, standard computer. It's your own special-purpose computer—fast, big and versatile.

And any configuration you choose is completely supported with IBM programming systems.

Tape Units

The new IBM 2400 series magnetic tape units come in three models, providing speeds of 30,000, 60,000 or 90,000 8-bit bytes per second . . . or twice that many decimal digits. With any model you can overlap, read, write and compute.

The new IBM 2415 tape unit gives you a data rate of 15,000 bytes or 30,000 digits per second.

Disks

The IBM 2311 Disk Storage Drive provides direct access to 7.25 million bytes on a single interchangeable disk pack. Eight disk storage drives can be attached for a total on-line capacity of 58 million bytes. Unlimited storage capacity is possible due to the use of a removable disk pack.

The data rate of the IBM 2311 is 156 thousand bytes per second. Average time is 85 milliseconds.

For larger storage requirements, choose the IBM 2302 Disk Storage. Capacity can be either 112.14 or 224.28 million bytes.

Access time is 165 milliseconds average. The transfer rate between the 2302 and the processing unit is 156,000 bytes per second.

Whether for data, programs or systems residence, SYSTEM/360 has the direct access file you need.

Drum Storage

The IBM 7320 Drum Storage provides on-line direct-access to 820,000 bytes on a magnetic drum. Maximum data rate is 135 thousand bytes per second.

The IBM 2301 Drum Storage provides direct access to approximately 4 million bytes at a data rate of 1.2 megabytes per second. Access time averages 8.6 milliseconds. Data records can be of variable length.

Data Cell Drive

The IBM 2321 Data Cell Drive economically extends on-line direct-access storage capabilities to a volume of data beyond that of other storage devices. It's especially useful for storing digitized graphic data. Each 2321 provides 400 million bytes of storage. Eight 2321's may be attached for a total on-line capacity of 3.2 billion bytes per control unit.

Graphic Output

The IBM 7404 Graphic Output Unit automatically plots graphs, maps, and diagrams from computer-generated information.

It plots points, prints symbols or draws lines (at a rate of up to 280 inches per minute) on a 29" square surface.

In science and engineering, it can be used to evaluate results of wind-tunnel tests, prepare census and weather maps, draw portraits of underground petroleum fields, simulate and test piping networks.

Graphic I/O: When you need to see what you're doing right away

A new IBM computer-controlled system lets you work with graphic information at electronic speeds. A design engineer, for example, can scan an existing microfilm image or call out an image that has been stored digitally within SYSTEM/360.

He can display this image on a CRT, change it with a light pen, record the image permanently on microfilm and see it projected 19 times original size within seconds.

The system includes an IBM 2250 Display Unit, an IBM 2280 Film Recorder, an IBM 2281 Film Scanner or an IBM 2282 Film Recorder/Scanner. Each unit in the system can also be used independently. They are linked to IBM SYSTEM/360.

DISPLAY—With an electronic light pen on the 2250, you can change displayed images that have been called from storage or microfilm. You can create original drawings right on a cathode ray tube. The light pen enables you to draw lines, modify a curve, change a dimension or label. Up to five display units can be used simultaneously with SYSTEM/360.

2280 FILM RECORDER – Records images on 35-mm. roll film. Maximum image size is 1.2 in. sq. After the first image has been exposed, it can be projected within 48 sec. The 2280 develops the film at 40 in./min. The processed images can be magnified 19 times and viewed on a rear-projection screen.

2281 FILM SCANNER—This unit transmits images, in digital form, from the film to SYSTEM/360. Lines on the film can be as fine as 1/2,000 of image size and spaced 1/500 of image size apart.

The 2282 combines recording and scanning functions in one unit.

Use this graphic data processing system to help design bridges, electrical circuits, machine parts, buildings. Use it for display of mathematical results. Use it to monitor experiments. It lets you see results of your work while you're working.

When you need to collect, reduce and analyze a lot of data in a hurry, you need SYSTEM/360

IBM SYSTEM/360 not only gives you a fast way to manipulate large or complex masses of data. It gives you fast economic ways to collect it through an 1800 Data Acquisition and Control System via an 1827 or 1070 Process Control Terminal.

With the 1800, you can have a real-time, on-line open or closed loop testing system—one that you can expand later, in the field, without penalty . . . one that is completely supported with a monitor programming system that makes it easier to use.

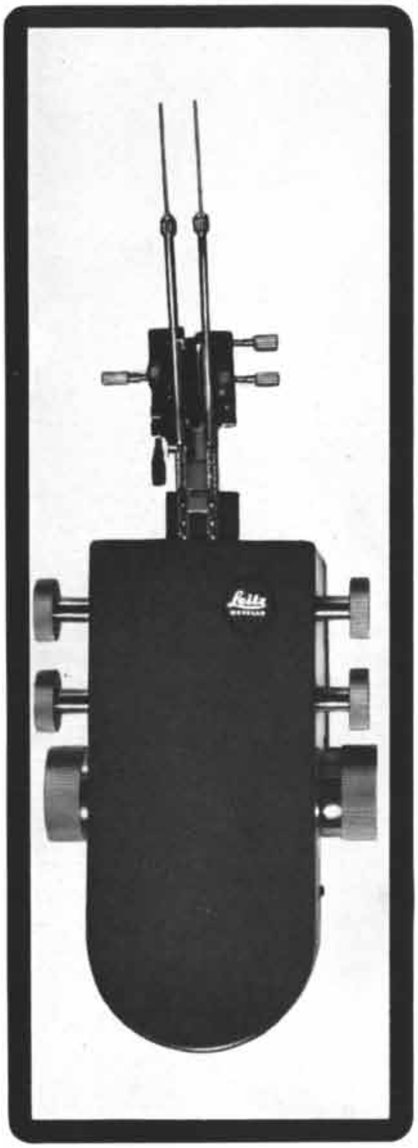
The 1070, located at a remote installation, connects either to an 1800 system or SYSTEM/360 over standard communications lines. It gives either the 1800 or SYSTEM/360 direct communication with instruments and control devices.

With the 1070 or 1800, coupled with SYSTEM/360, you can 1) determine the feasibility of an experiment, 2) determine sensitive variables and their acceptable levels, 3) predict and explain the validity of results, 4) predict the safety margin and control stability of your experiment, 5) simulate your total test facility, 6) conduct a planned test program.

SYSTEM/360 allows you to choose the on-line system you need. You can couple an 1800 with SYSTEM/360 for tremendous versatility and power. You can use the 1800 alone. Or you can connect analog and other input devices directly to SYSTEM/360.

If you're involved in jet engine testing...X-ray therapy control...electrocardiogram analysis . . . bubble-chamber film scanning . . . controlling a fluid process—either off line or on, closed loop or open—IBM SYSTEM/360 can help you.

The spectrum of I/O devices provided with SYSTEM/360 can provide you with the tool to hand tailor your own man-machine system. Together, you and your computer can shorten design or experimental time, reduce your clerical computational load in data collection, reduction and analysis and free you to do what you were trained to do.



LETTERS

Sirs:

In the March issue of *Scientific American* Robert A. Chipman did well in interpreting the complex subject of De Forest and the triode detector. Recognized are both the weak infancy of the device as a radio detector, contributed to by the shortcomings of the inventor himself, and the subsequent flowering of it as an amplifier, largely in the hands of others.

On March 14, 1907, Lee De Forest gave a lecture on the subject of wireless at the Brooklyn Institute of Arts and Sciences. I was one of several youthful amateurs who attended. The speaker was his usual animated self and in the course of his talk rather incidentally passed around the audience his "latest" detector, a curious little bulb with things in it. It created no particular interest, and De Forest was not clear on its mode of operation, but it proved to have been the grid triode—this was its first appearance in public! Several of us afterward managed to buy one. It proved to be quite a gamble; mine burned out before I became well acquainted with it.

On the lecture platform that evening with De Forest was his boyish assistant, John V. L. Hogan. Both of them became lifelong friends of mine. I noticed afterward that the admission card to the lecture mentioned that De Forest was associated with the American De Forest Wireless Telegraph Company. We did not know then that he had been discharged from that company in the fall of 1906 for misleading the management into infringing the electrolytic patent of Reginald A. Fessenden. That spring (1907) De Forest made radio-broadcast experiments (reception of which we reported by mail), but we did not know that he was infringing a patent granted to Valdemar Poulsen for an oscillating arc in an atmosphere of high thermal conductivity such as hydrogen (Patent No. 789,449 of 1905). Nor did we realize the extent to which De Forest's first "audion," the diode described before the American Institute of Electrical Engineers in October, 1906, had been a copy of the Fleming valve.

My long years of friendship with De Forest were pleasant ones; he was good company, romantic, challenging and of an egotism so naïve as to be enjoyable. He seemed to be a lone-wolf kind of Robin Hood: likable, shrewd and knavish, intent on speculative patents and on stock certificates as a means of robbing the rich in the wondrous woods of wireless. That in the course of infringing the Fleming valve patent he should have hit on the magic intervening-grid form of control, although without really understanding its *modus operandi*, was the marvel of the age. But that he did arrive at the grid tube we must recognize and give him due credit. During the last decade of his life I tried repeatedly to learn from him how he had arrived at that invention, with what motivation (Chipman reveals part of it), with what prompting from science and the prior art (there had been other triodes in vacuum tubes) and with what part played by others such as his assistant Clifford D. Babcock—all to no avail.

What is said in the article concerning De Forest's patent for a "system for amplifying feeble electric currents" is in need of correction. That patent was applied for on October 25, 1906, rather than June, 1907, and came before the grid patent. The control element was a second plate, and the scheme was an attempt at amplification, as distinct from detection. But De Forest never succeeded in making the device work, and it would have been a poor amplifier at that. The patent was issued on January 15, 1907, as No. 841,387. It had been drawn up by George K.

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Woodworth, who had been one of the U.S. patent examiners who had passed on the Fleming valve patent; on resigning from Government service he had become De Forest's attorney. Another point calling for comment is the statement that "the discovery that the triode could perform the function of amplifying voice-frequency signals was made independently by De Forest in 1912 and by. . . ." But De Forest was not independent, either as a worker or in his mind, when in 1912 he realized amplification from his grid detector. He had fled to the Pacific Coast following the collapse in New York of his Radio Telephone Company—into the arms of the Federal Telegraph Company. The president of that company, Beach Thompson, asked him to investigate his audion as a possible amplifier, after Thompson had received a "tip" from John Hays Hammond. The latter, in turn, had learned of the functioning of De Forest's audion as an amplifier from his associate Fritz Lowenstein and Benjamin F. Miessner. Fritz had had the audion working as an amplifier in 1911; he had even tried it on a long-distance call. Probably he had been prompted by reports of the success of the von Lieben group in Germany. So it went—nothing very independent!

The von Lieben triode amplifiers, made in several forms from 1906 to 1912, had descended from the Wehnelt diode of 1904. The latter had come down from earlier scientific inquiries into cathode-ray tubes, notably those of Hittorf and of Elster and Geitel, both thermionic tubes of fairly high vacuum. Probably it was knowledge of this line of European work, plus De Forest's self-seeking, that prevented Stockholm from awarding De Forest the Nobel prize.

Interestingly enough, the achievement of a high-vacuum, nonionizing tube came from De Forest's poorly evacuated tube rather than from the Germans, who had retreated to the mercury-vapor tube. Thus started electronics in the U.S., beginning, say, in 1913.

LLOYD ESPENSCHIED

Kew Gardens, N.Y.

Sirs:

My article "De Forest and the Triode Detector" has brought a number of interesting letters containing a good deal of useful information on the early history of wireless telegraphy and of radio tubes.

Lloyd Espenschied's comments are of especial interest because he was personally involved in some of the important events of early wireless history and has written about them on several occasions.

In connection with De Forest's early amplifier patents, let me note that De Forest had two patents with the same title: "System for Amplifying Feeble Electric Currents." One was No. 841,-387, applied for in October, 1906; the other, No. 995,126, was applied for in June, 1907. My reference was to the latter, which used grid-triodes as detectors; a reference to the former would also have been in order.

Dr. Espenschied is quite right that my speaking of a discovery being "made independently by De Forest in 1912" was a very unwise use of the word "independently." Important roles were played in the event by his immediate co-workers Logwood, Van Etten and Elwell, and there may have been influences from more distant sources. The sequence Miessner-Lowenstein-Hammond-Thompson-Elwell is a very difficult one to document and I am not aware of any published primary material that establishes it to a historian's satisfaction. This part of the triode story should profit from further investigation. My article deliberately avoided raising these issues but should have indicated that De Forest had close collaborators at that period.

ROBERT A. CHIPMAN

Department of Electrical Engineering
University of Toledo
Toledo, Ohio

ERRATA

In the article "How Opiates Change Behavior" (SCIENTIFIC AMERICAN, February) two corrections should be made. On page 80 it is stated: "No one knows exactly how many morphine addicts there are in the U.S., but estimates range upward from 40,000." The word "morphine" should be changed to "opiate." On page 88 it is stated: "The experimenter may set up, within the confines of a hospital, a reinforcement situation that effectively extinguishes the opiate-intake response." The word "differential" should be inserted before "reinforcement."

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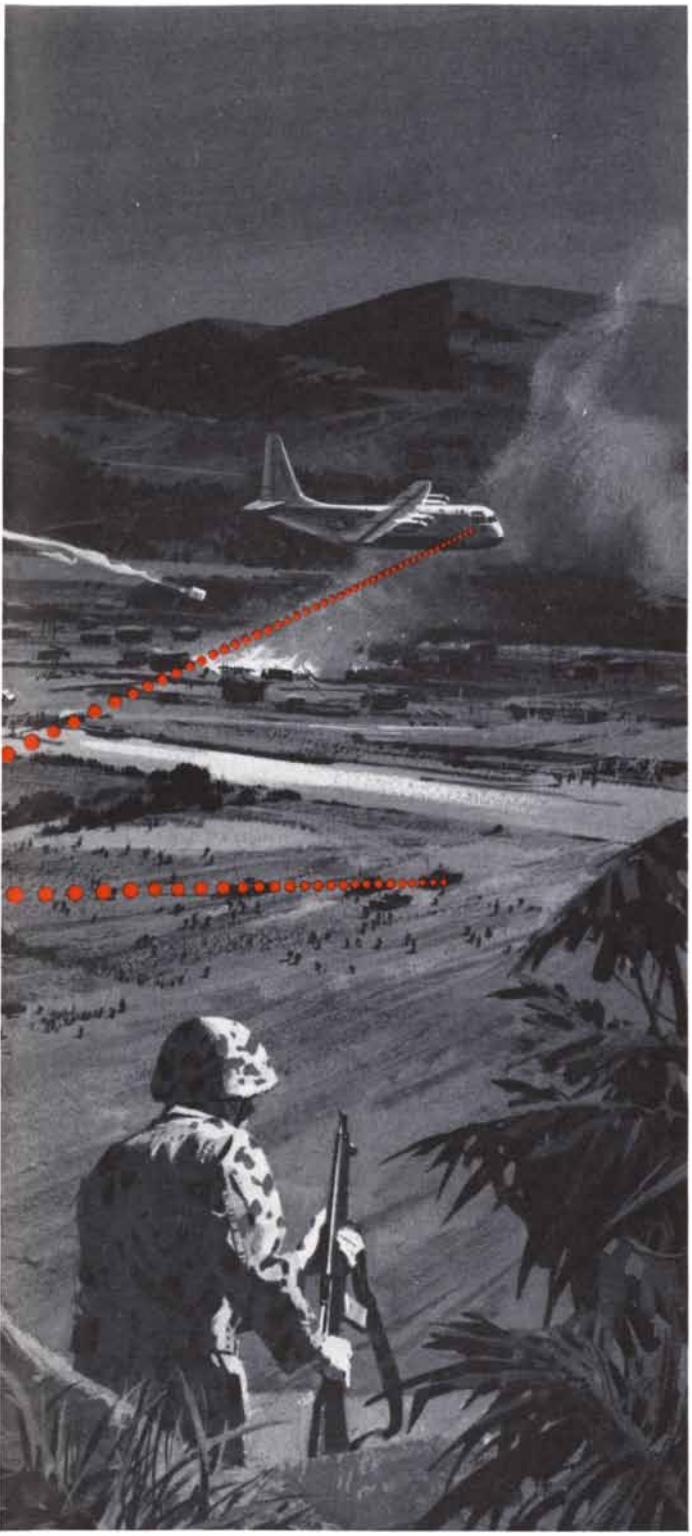

Finding new and better ways to improve vital military communications is a challenge we continually meet at General Telephone & Electronics.

Not long ago, our scientists and engineers developed a modular pack of four command radio sets that permits tactical communications between anti-guerilla fighters in forward areas and friendly forces, base headquarters, field personnel, and aircraft pilots—all at the same time! With this communication package, one man can command and control all ground and air movements toward the objective.

A major advance in weight reduction, this 48-pound command pack can be carried by a single parachutist or dropped into a forward area to do the same job which formerly required approximately 300 pounds of equipment. It provides the full flexibility of 8 communication channels in the high frequency, very high frequency, and ultra-high frequency bands. With it, a forward observer or forward air controller can communicate with ground forces up to 25 miles, aircraft up to 100 miles and base stations up to 500 miles away. And each of the four transceiver units can be removed and operated independently as each has a self-contained rechargeable battery. Yet, in spite of the versatility of this command package, it was designed and produced in just 120 days.

Quick reaction to the military's urgent need for better communications is one of the many ways the scientists and engineers of General Telephone & Electronics serve the nation. The vast communications and electronics capabilities of GT&E, directed through Sylvania Electronic Systems, can research, design, produce, install and service complete electronic systems. These systems include detection and tracking, electronic warfare, intelligence and reconnaissance, communications, data processing and display.

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50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

MAY, 1915: "As our readers very well know, during the heart-rending struggle which has been taking place in Europe these many months SCIENTIFIC AMERICAN has maintained an attitude of neutrality. It has endeavored to follow out strictly the injunction of the President at the beginning of the war. During the past few weeks, however, the nature of the war has changed, and not only the feeling but also the demand for a strict moral neutrality has been disturbed by certain acts of the Teutonic allies which cannot be excused or palliated. We refer of course to the attacks which have been made upon ships of neutral nations. The people of this country have viewed with the gravest anxiety the apparent systematic policy of the German government to carry out its imperial will irrespective of the rights of nations or of individuals. The horror following the sinking without warning of the *Lusitania* only emphasizes the shocking character of the situation. Has this ceased to be a war of army against army and degenerated into a war against civilians and women and children, no matter of what nationality? Our people do not accept as a mandate the claim that 'war is war.' They have the highest respect for and belief in the justice of international law, but such a code has limitations which do not harmonize with the ideals of the American people, who realize that there is a higher law—the law of humanity and civilization—which is being outraged and trampled upon. And it is for that reason, and in spite of the calm and generally neutral attitude of the American press, that underneath there has been a strong current of opinion among the American people which absolutely condemns the methods of war now being conducted by the Teutonic allies."

"Einstein's incessant efforts to improve his theory of gravitation in its first form have resulted in the admirable theory which he has recently published in collaboration with Grossman. In this improved and very complex theory a field of gravitation is characterized not by a single potential but by 10 parameters which depend in general on the geometrical co-ordinates and the time and whose variations determine all the effects of gravitation. The improved theory leads to the conclusion that gravitation is propagated with the velocity with which light moves in the absence of a gravitational field. Einstein has pointed out some results of the theory that may perhaps make it possible to observe almost directly the variation of luminous velocity in a field of gravitation. First: A luminous pencil should be curved by the influence of weight. Einstein calculates that a ray of light coming from a star and grazing the sun's surface would be bent inward by .83 second, increasing by that amount the apparent angular distance of the star from the sun's limb. This effect might possibly be observed in a total solar eclipse. Second: If light coming from two sources of different heights is examined with the same spectroscope, the spectral lines of the higher source should be a little nearer the violet than the corresponding lines of the lower source. For two similar molecules, situated respectively on the sun's surface and at the earth's distance from the sun, the difference is about a hundredth of an angstrom unit. Hence the Fraunhofer lines of the solar spectrum should be nearer the red by this amount than the corresponding lines of a terrestrial source. Displacements of this order of magnitude have actually been observed. They have been attributed to effects of pressure and movement, but they may be due to the cause indicated by Einstein."

"It is a well-recognized fact that the progress of science is seriously impeded by an overabundance of scientific journals. Almost every scientific man finds that a deplorable amount of his time is given to the task of gathering together from scores of periodicals the *disjecta membra* of the literature in which he is especially interested, and, to make matters worse, there is always a certain residuum of such literature that escapes his vigilance on account of its out-of-the-way place of publication. Hence the advent of a new scientific periodical is not hailed with general satisfaction unless there are very special reasons to justify its existence. Such reasons undoubtedly authorize the appearance of the monthly *Proceedings of the National Academy of Sciences,* which began publication in January. In fact, the *Proceedings* at once takes rank among the few journals that are indispensable. The aim of the new organ of the National Academy, as announced, 'will be to furnish a comprehensive survey of the more important results of the scientific research of this country.' It is not designed to replace or displace any previously existing journal, since its contents will be limited to brief advance notices of important scientific achievements, the more detailed reports of which will appear elsewhere."

Scientific American.

MAY, 1865: "Our European exchanges come to us filled with expressions of profound grief at the death of President Lincoln. The London *Star,* in its notices of the various meetings of condolence held in the principal towns of England, says:—'Among the latest demonstrations was one by the workingmen of London, who in addition to resolutions of condolence adopted one rejoicing at the recent Union successes and the destruction of slavery.'"

"One of the signs of returning peace was brought to our notice recently in the case of an inventor in Richmond applying for a patent through the Scientific American Patent Agency. As fast as the territory of the United States is reclaimed and the flag reinstated, we receive intimations that our friends have not forgotten us. It is gratifying to notice that inventors generally have been true to the Union."

"Of the velocity of a spark discharge some notion may be formed from the brief duration of its light, which cannot illuminate any moving object in two successive positions, however rapid its motion. If a wheel be thrown into rapid rotation on its axis, none of its spokes will be visible in daylight, but if the revolving wheel be illuminated in a darkened room by the discharge of a Leyden jar, every part of it will be rendered as distinctly visible as though it were at rest. By a very ingenious application of this principle Wheatstone has shown that the duration of the spark is less than a millionth part of a second. By a modification of the apparatus he was also enabled to measure the velocity with which the discharge of a Leyden jar was transmitted through an insulated copper wire. He estimated the rate of its passage at 288,000 miles in a second."

Report from
BELL LABORATORIES

SUPERCONDUCTING MAGNET FOR MASERS PROVIDES UNIFORM FIELD, ADJUSTABLE BANDWIDTH

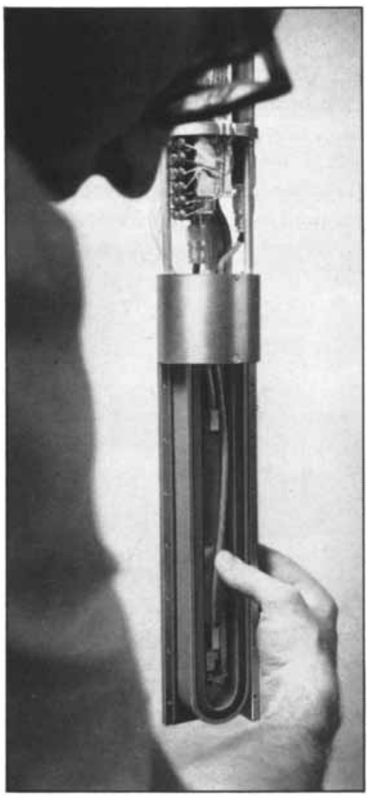
For efficient operation, a low-noise traveling-wave maser needs a very low-temperature environment such as that of liquid helium (4.2°K) and a uniform magnetic field which determines the maser's operating frequency. These requirements suggest using a superconducting magnet for providing the field.

A compact maser amplifier based on this concept has been developed at Bell Laboratories. It incorporates an 8-pound superconducting magnet immersed in liquid helium, replacing an earlier 500-pound Alnico magnet mounted outside the dewar. This maser also provides the desirable feature of an adjustable bandwidth of amplification.

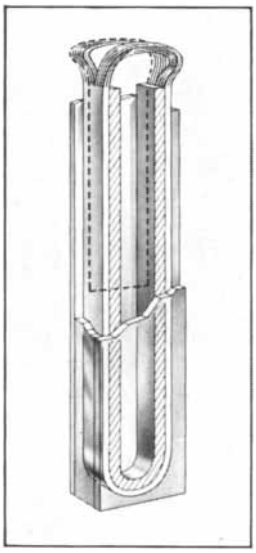
As shown in the illustrations, the uniform field is obtained with a superconducting solenoid enclosed in a close-fitting box of high-permeability iron. Adjustable bandwidth is obtained with an auxiliary superconducting trimmer coil which overlays one half the solenoid cross section. This coil modifies the main field, creating two discrete and individually uniform field regions. Changing the current in the coil adjusts the "step" between the two fields and thereby changes the bandwidth.

The two fields are each uniform to one part per thousand near 3300 gauss, and the maser bandwidth can be adjusted smoothly from 14 to 55mc centered at an operating frequency near 4170mc.

At the broadest band, its gain is 34db with an effective noise temperature of 5°K. The maser has demonstrated stable low-noise performance in a variety of satellite communications experiments.

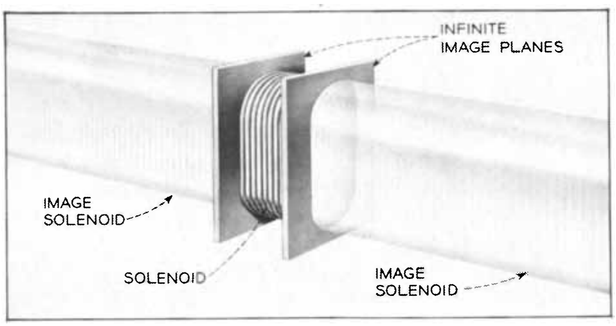


New maser magnet (left) has front and left side of enclosure removed to expose superconducting solenoid. Drawing (center) corresponds to photograph and shows solenoid inside box enclosure. Solenoid is wound on U-shaped nonmagnetic form and is spread apart at top to permit insertion of the maser. Dotted line indicates position of trimmer coil. Drawing at right indicates how front and rear plates of enclosure act as "image planes." These high-permeability plates are made to appear very large by the magnetic return paths provided by the sides of the box. The resulting magnetic field approximates the ideal uniform field of a solenoid of infinite length.



Bell Telephone Laboratories

Research and Development Unit of the Bell System

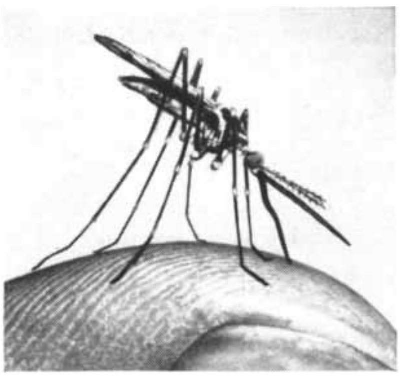


Who will save

A town in terror...An orphaned house...A drowning road?

Downing Death on the Wing

Houston: The more deadly female struck again. Encephalitis-carrying Culex mosquitos laid siege to Houston. Only the female carries the dread disease, better known as sleeping sickness. Quickly it mushroomed into an epidemic. Many died. Major weapon in Houston's bitter war:



Cyanamid's Malathion insecticide. The city sprayed hundreds of tons; residents helped by spraying around their homes. The war is over now. Houston won. Malathion helped.

Free $50,000 House, Anybody?

New York: What a World's Fair souvenir this is—a full size yes-you-can-live-in-it World's Fair House! Formica Corporation, a Cyanamid subsidiary, will give away a 3-bedroom, $50,000 home as part of its 1965 $100,000 World's Fair House Sweepstakes. Win it! See the original at the Fair. Discover the many new uses of Formica® laminated plastic, Creslan® acrylic fiber and Acrylite® cast acrylic sheets. Register at the Fair or with the cooperating builder in your area. He'll be letting you know who he is soon.

Solid Citizen – But a Floater

Boston: Doomed! The mile of Massachusetts Turnpike Extension to be built under the water table. Problem: water seeps in, freezes, buckles and cracks the road. Solution: waterproof it. Cyanamid did—with a special membrane of Wascoseal® plastic flashing, originally designed to protect buildings from water damage. Laid four feet below the surface and surrounding the sides, Wascoseal

even lets the road "float": it can expand and contract independently of all surrounding structures.

IN HOME, HEALTH, FARM AND INDUSTRY CYANAMID AMERICAN CYANAMID COMPANY, WAYNE, N. J. SCIENCE IN ACTION FOR YOU

THE AUTHORS

ALEXANDER H. LEIGHTON ("Poverty and Social Change") is professor of anthropology, sociology and psychiatry at Cornell University and director of the Cornell Program in Social Psychiatry. A graduate of Princeton University, he obtained a master's degree in physiology from the University of Cambridge and an M.D. from Johns Hopkins University. He writes that "my interest in behavior goes back to precollege days, when I studied and even published on birds and mammals." Then, "like Koko in *The Mikado,* I worked my way up through the animal kingdom to man, but with more benevolent interest." Some of his work in psychiatry led him into the social sciences, particularly anthropology, and that in turn led him to investigations designed to illuminate the relations "between individual and sociocultural environment." The Cornell Program in Social Psychiatry is an outgrowth of those studies.

ZDENĚK KOPAL ("The Luminescence of the Moon") is professor of astronomy and chairman of the department of astronomy at the University of Manchester. During the current academic year he is serving as astronomical adviser to the aerospace division of the Boeing Airplane Company in Seattle on a project designed to put a manned 120-inch telescope in orbit. In addition he is organizing, with the support of the U.S. Air Force, a worldwide net of observing stations for monitoring lunar luminescence. He has also worked with the Air Force for several years in large-scale mapping of the moon. Kopal was born in Czechoslovakia and came to the U.S. in 1938 after taking a doctorate in astronomy at Charles University in Prague. He has written 14 books and more than 150 papers on astronomy, aerodynamics and applied mathematics.

ALEXANDER ZEITLIN ("High-Pressure Technology") is vice-president of Barogenics, Inc., in Mount Vernon, N.Y. He was born in Kiev, Russia, and received a degree in mechanical engineering at the Institute of Technology there. Later he took a degree in electrical engineering at the Berlin-Charlottenberg Institute of Technology in Germany. Zeitlin, who arrived in the U.S. in 1938 with $4 in his pocket, says that "I will never make the mistake of asking what this country can do for me: it has done everything a country can do for a penniless immigrant." In addition to his interest in hydraulics and high pressures he has "two hobbies, engineering and fishing." Of these he says: "Once started, I will continue talking until stopped by my listeners." He holds more than 30 U.S. patents and is the author of many papers published in professional journals.

O. R. FRISCH ("Molecular Beams") is Jacksonian Professor of Natural Philosophy at the University of Cambridge and a Fellow of the Royal Society. He was born in Vienna and took a doctorate at the University of Vienna in 1926. Since then he has pursued a research career that has taken him to Germany, Denmark and the U.S. in addition to Britain. He has been at Cambridge since 1947. Frisch is the author of numerous books and papers on atomic and nuclear physics. Among his avocations is music: he plays the piano and the violin.

ARCHIE CARR ("The Navigation of the Green Turtle") is professor of biology at the University of Florida. He was graduated from that university in 1933 and also received master's and doctor's degrees there. His investigations of marine animals, particularly sea turtles, have taken him to many parts of the world. He is currently writing a book on sea turtles. In addition to his work with marine animals, Carr has studied the wildlife of Africa, and two of his six published books deal with that subject. Another of his interests is the Caribbean Conservation Corporation, of which he is technical director. He writes that he is "hoping to have the help of a Navy airplane again this summer to carry out another 'Operation Green Turtle,' spreading 20,000 more baby Tortuguero green turtles among a dozen Caribbean localities."

CARLETON B. CHAPMAN and JERE H. MITCHELL ("The Physiology of Exercise") are respectively professor and assistant professor of medicine at the University of Texas Southwestern Medical School. Chapman, a native of Alabama, was graduated from Davidson College in 1936 and spent three years as a Rhodes scholar at the University of Oxford before obtaining a medical degree from Harvard University. He was on the medical faculty of the University of Minnesota for six years before assuming his present post. His interest in exercise extends to jogging a mile in a Dallas park early every morning. "The most important point in keeping active," he says, "is that when one reaches, say, 65, one will be physically fit. The tragedy is not so much an early demise as it is incapacity around and beyond the retirement age." Among many professional activities Chapman is president of the American Heart Association for 1964–1965. Mitchell is a Texan who was graduated from the Virginia Military Institute in 1950 and obtained his medical degree at the University of Texas in 1954. Before taking his present post in 1962 he spent four years at the National Heart Institute in Bethesda, Md.

M. I. ARTAMONOV ("Frozen Tombs of the Scythians") is director of the State Hermitage Museum in Leningrad and professor of archaeology at the University of Leningrad. He has specialized in the archaeology of the early Middle Ages. As a young man he devoted particular attention to the history of Khazar, a medieval Russian polity. Since 1940 he has concentrated his attention on the archaeology of the Scythians and the Slavs. He has been at the University of Leningrad since 1935 and was made director of the Hermitage Museum in 1950.

EMILE ZUCKERKANDL ("The Evolution of Hemoglobin") is an investigator with the French National Center for Scientific Research, working at the Physico-Chemical Colloidal Laboratory in Montpellier. A native of Vienna, he became a French citizen in 1938. After he was graduated from the Sorbonne, he obtained a master's degree at the University of Illinois and then returned to the Sorbonne for his doctorate. For several years he served at a marine biological station in Brittany, investigating proteins. From 1959 to 1964 he worked with Linus Pauling at the California Institute of Technology, investigating hemoglobin. He is now at work in "the new field of chemical paleogenics," attempting "to elucidate questions related to the evolutionary succession of major and minor components of a polypeptide chain and to the correlation, in hemoglobins, between structure and function."

KENNETH E. BOULDING, who in this issue reviews *On Economic Knowledge: Toward a Science of Political Economics,* by Adolph Lowe, is professor of economics at the University of Michigan.

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Poverty and Social Change

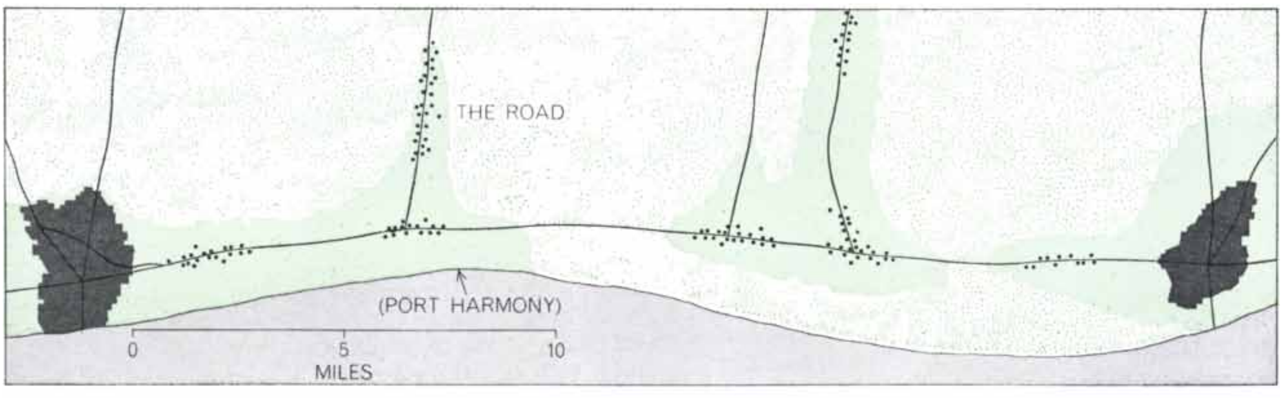
A rural community's experience indicates that an essential element in a "war on poverty" is inducing slum dwellers to develop patterns of social functioning, including group action and local leadership

by Alexander H. Leighton

Much of the poverty that is evident in North America is found in cities, but of course rural areas have their share of deprived and dependent families. Almost anyone who has done much driving outside the city has seen the small, dilapidated dwellings, the untidy yards and the rusty automobiles that characterize such households. In some areas, such as the Appalachian region of the eastern U.S., impoverished families are common; in other areas they are rare. Taken together, however, rural slums constitute a major portion of the objective against which the "war on poverty" is directed.

In 1949 my colleagues and I, beginning an undertaking that later became the Cornell Program in Social Psychiatry, selected one such neighborhood for intensive investigation. Our initial purpose was to find out what correlation there might be between the conditions of life in several communities in the region and the prevalence of psychiatric disorder among their residents. Before we could pursue this objective we had to establish the nature of each community: its precise economic situation, the attitudes of its people and the character of the communities around it. Having done this over a period of several years, using a combination of techniques from anthropology, psychiatry, psychology and sociology, we did find a high correlation between the many deprivations suffered by the people of the selected neighborhood and the extent of psychiatric disorder evident among them.

In this article—in the preparation of which I have had the assistance of my colleagues I. Thomas Stone, A. L. Nangeroni, A. M. Macmillan, D. C. Leighton and R. A. Danley—I shall deal with the psychiatric aspect of our study, but only briefly; my main objective is to describe another phenomenon we have observed and to discuss its implications for the problem of bringing about constructive changes in such communities. The phenomenon is the gradual transformation of the neighborhood from a state of disintegration into one of com-



GEOGRAPHIC SETTING of "the Road" is shown with some modification to disguise the identity of the region. It is a coastal region, with two communities (*left and right*) large enough to have consolidated schools and other services. The Road and the other smaller settlements shown have fewer than 200 inhabitants each. "Port Harmony," a shipbuilding community, was abandoned after the industry collapsed.

parative independence and self-sufficiency. For reasons that are important both to the people of the area and to our study, I shall disguise the identity of the community.

In 1950 the neighborhood, which I shall call "the Road," consisted of 118 people living in 29 houses. Sixty-six of the residents were under the age of 21. The dwellings, small and cramped, were scattered irregularly along a country road and were somewhat separated by fields and woods from the other communities of the region. The Road's economic base was obviously low: when the men worked, they cut logs for pulp, dug clams and hired out as day laborers. Many of the women were occasionally employed shucking clams at a plant in a nearby town. Certain kinds of Government allowance played an important part in the life of the community.

The Road had an unenviable reputation in the surrounding county. If you asked about it, you were almost invariably told that the people who lived there were mentally retarded. The informant would often add that they were the products of inbreeding, that insanity, alcoholism and delinquency were rampant among them, that they were lazy and unreliable as employees and that it was impossible to do anything to help them. Indeed, they were known throughout the county by an uncomplimentary nickname.

We began our study with an attempt to answer the question of whether or not the Road people did exhibit an unusually high prevalence of mental deficiency. After months of effort a member of our staff won sufficient cooperation to be able to give intelligence tests to all the children. For purposes of comparison he also tested children from five other rural sections that were generally regarded as normal in their sociological and psychological attributes. Rural communities were chosen for comparison because by and large rural populations score lower than urban populations on intelligence tests. Most psychologists interpret this difference as meaning that the tests have been developed in a way that puts rural children at a disadvantage and not as meaning a difference in intelligence.

When the intelligence scores of the Road children were projected against those from children in the "normal" communities, no difference could be found. In other words, the Road children as a group showed essentially the same range from stupidity to better-than-average intelligence that was shown by the other children. Since it is not likely that a group of inbreeding, constitutionally inferior adults would produce a child population with normal intelligence, we were led to conclude that whatever might be wrong with the people of the Road, it was not a biologically determined lack of intelligence. It seemed more plausible that there existed a set of cultural patterns with which those who grew up in the neighborhood became inculcated—patterns that had properties considered indicative of mental handicap by those in the surrounding larger society.

With this start we began to study the Road in a broader frame of reference than that of mental deficiency. Historical investigation showed that the neighborhood had existed as a human group for more than 100 years. The original inhabitants had been workers in shipyards on the coast a few miles away or had hauled logs to the coast from the forested interior. At that time the shipyard community of "Port Harmony" was flourishing, and the Road shared in this economic and social well-being. The men of the Road were almost entirely French-Canadians who had moved in from some distance, attracted by the employment opportunities. As far as one can tell now, they came from normal farming families in which they were economically supernumerary children: offspring beyond the number the farms could support. In the beginning the men probably did not intend to stay permanently, therefore they chose land that was both close to their work and cheap. It was cheap because it had a thin, rocky soil, unsuitable for either farming or lumbering. With continuing employment and the passage of time, French-Canadian wives joined the men and families became established.

Cultural erosion and change began gradually. The Road people were employed by and surrounded by English-speaking Protestants and were separated from their own church and ancestral families by distance. Intermarriage took place bit by bit, and proselytizing by Protestants loosened the hold of the Roman Catholic faith even if it did not succeed in making any large number of converts. The measure of cultural confusion entering the lives of the people is indicated by the fact that although they stopped speaking French, the English they acquired was limited and had an accent that was a source of amusement to outsiders.

The real turning point for the Road, however, came at the beginning of the century. The coastal industry of building wooden ships collapsed and was not replaced by any comparable eco-

GRADUAL TRANSFORMATION of the Road from disintegration to a state of comparative self-sufficiency is indicated by differences between the kind of house that used to

nomic activity in the region. This change was part of the more general economic shift in North America from commerce to industry and from widely scattered small manufacturing enterprises in towns and villages to centralized mass production in urban centers. People with education, fluency in English and capital resources were able to move out of the region or otherwise adjust to these changes. Today even the name of Port Harmony is scarcely remembered; one has to look carefully to find a few waterlogged stumps of pilings where the wharves once stood.

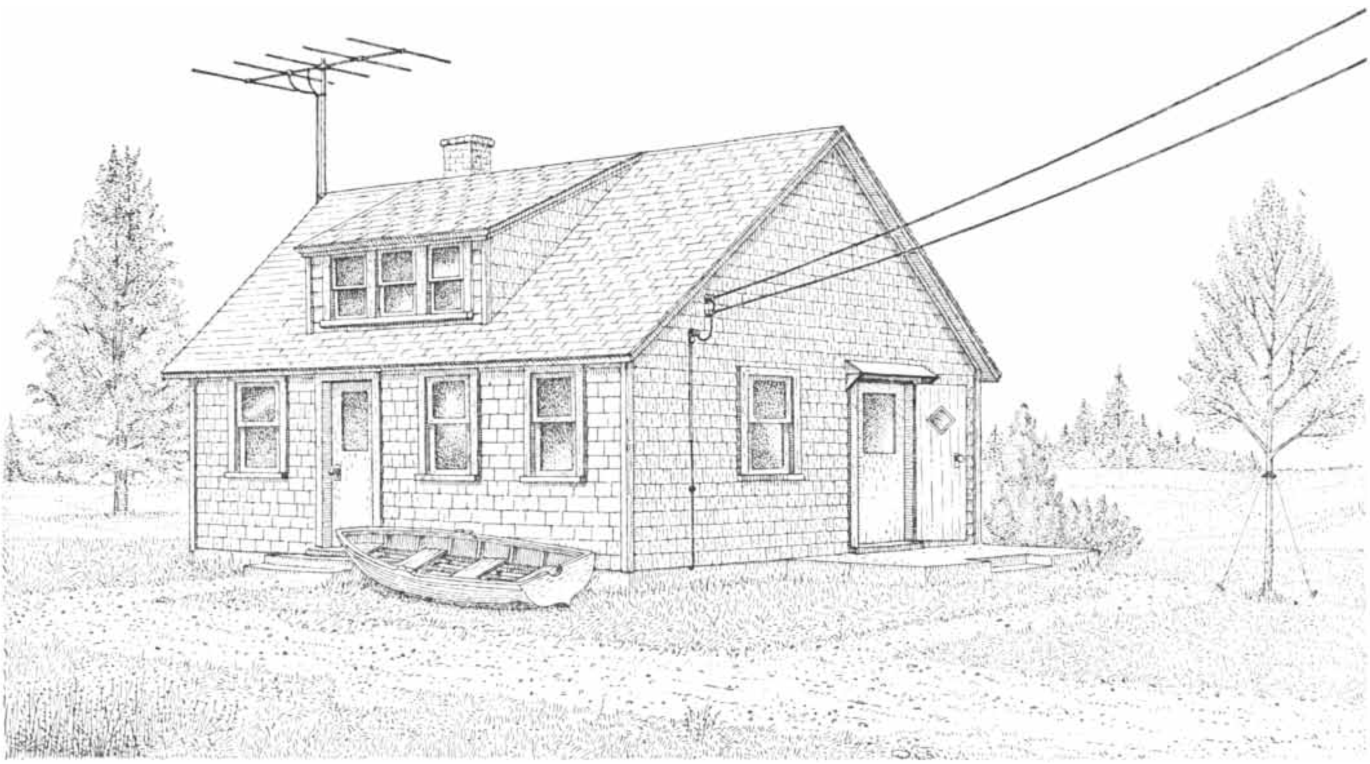
The people of the Road thus suffered a precipitous loss of economic resource. Although some were able to move, enough of them remained to perpetuate the existence of the group and deterioration set in. By 1950 their poverty was manifest in their low and undependable income, lack of capital, lack of property and lack of credit. The educational level was nominally fourth or fifth grade, but among the adults were eight who could read and write little or not at all. The typical house was described as "one and a half stories." It had three small rooms on the ground floor; the "half" was a garret reached by a ladder. There the children usually slept, often on the floor. Cooking was done mostly on wood stoves, occasionally on oil stoves. The houses had no electricity and no inside toilets. Furnishings were few and tawdry, although one house had a real living room with a woven-wicker settee and matching chairs. Only about half the families had vegetable gardens and most yards were unkempt.

The families that lived in this physical setting showed a high prevalence of broken marriages, interparental strife and child neglect. The last was often due to the fact that both parents were simultaneously away at work, leaving younger children to be cared for by siblings not much older. Between families there was a surprising degree of isolation. Individuals were not bound together in groups by any kind of formal social organization except the church, which they rarely attended.

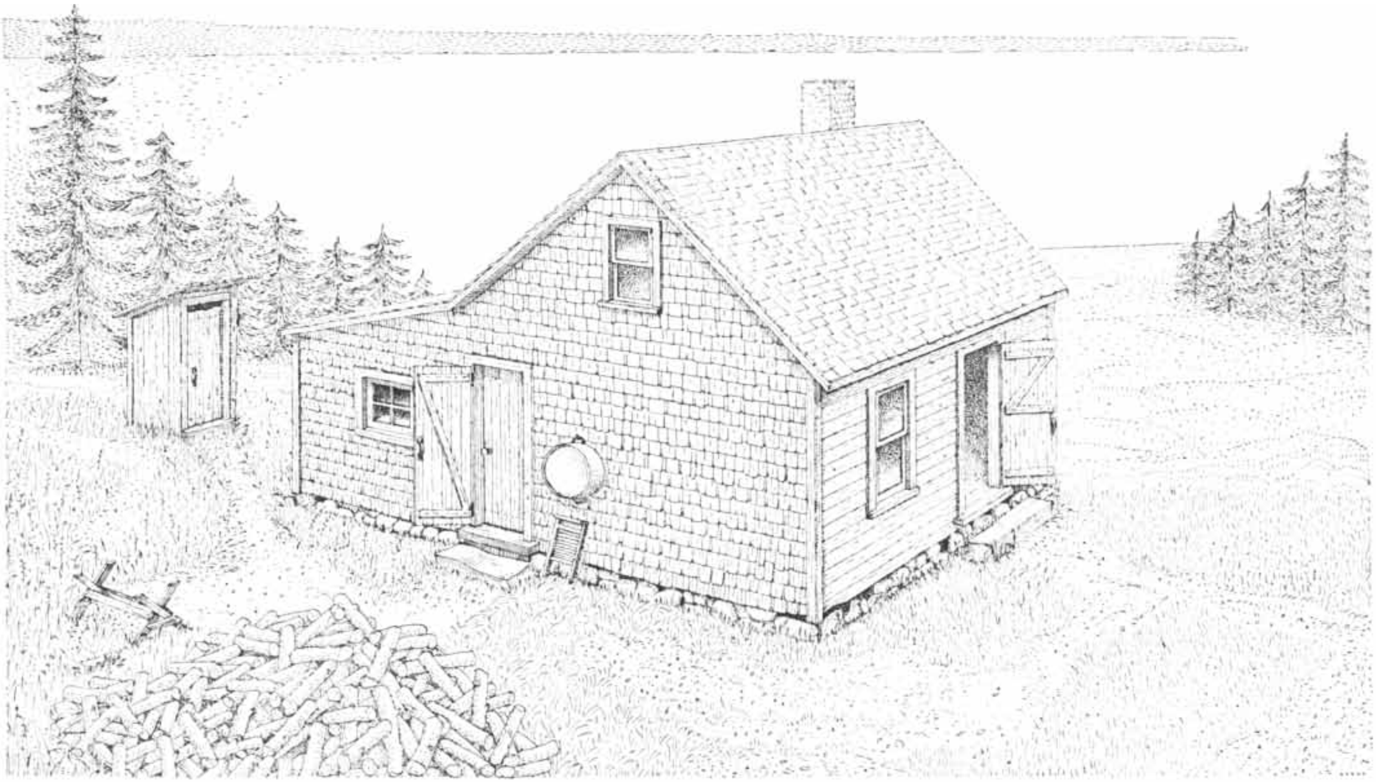
Some informal organization was evident, primarily as house-to-house visiting by the women. The men of the neighborhood did not participate much in such visiting patterns but gathered to idle away spare hours at a filling station near the Road; they also hunted together and at times worked and camped near tidal flats some miles from the Road. The nearest thing to leadership outside the family was the role assumed by one man in assembling woodcutting teams and by one woman who did the same for clam-shucking.

The Road was, in short, not really a community but a neighborhood based on exclusion. One often heard residents of nearby communities refer to Road people with such remarks as "They had better keep their place" and "We don't want them here." Attitudes of this kind put innumerable limitations on the people of the Road, making it difficult for them to obtain work, form friendships and find mates. The mates were mostly from similarly depressed areas and so tended to perpetuate the character of the Road.

The sentiments prevailing among Road people reflected the disintegrated nature of the neighborhood. Although most of the values found in the larger society were also evident on the Road, expressions of them by Road residents were comparatively pale and lacking in commitment. An example was the merely nominal Catholicism of the Road people. In addition the people voiced strong sentiments of self-disparagement, mistrust of each other and mistrust of outsiders, particularly those in positions of authority. Work was regarded as virtueless—a necessary evil to be avoided when possible. The people showed little in the way of foresight. They tended to regard the future as uncontrollable, an attitude reflected by the fact that most of them thought the best thing to do with a dollar was to spend it at once, because only in that way



characterize the community (*left*) and the kind built in recent years (*right*). The older houses lacked electricity and inside toilets and were poorly furnished. Houses built more recently have modern amenities; they also have better furniture and are better kept.



HOME IMPROVEMENT **has been extensive on the Road recently. It reflects the economic and social gains of the community in the past decade. These views of a single house in 1950 (*left*) and now (*right*) indicate the kind of improvement that has been ac-**

could they be assured of getting full use of it.

I should temper my description by noting that it leans toward caricature. There were a few residents of the Road who differed from the others in their attitudes. Among some of the women in particular there was a feeling that conditions could be improved and that education was a means to that end. (This view was not shared by the men and boys, who looked on escape from school as a sign of entry into manhood.) In sum, however, one must say that in spite of individual variations the people of the Road were in the grip of interlocking factors, internal and external, that tended to keep them mired in degraded circumstances. The people had few resources, to be sure, but it should also be noted that they made very poor use of the resources they did have—not only because they lacked knowledge, skills, manners, habits of cooperation and leadership but also because of their deeply rooted tendencies toward hostility, disparagement and suspicion.

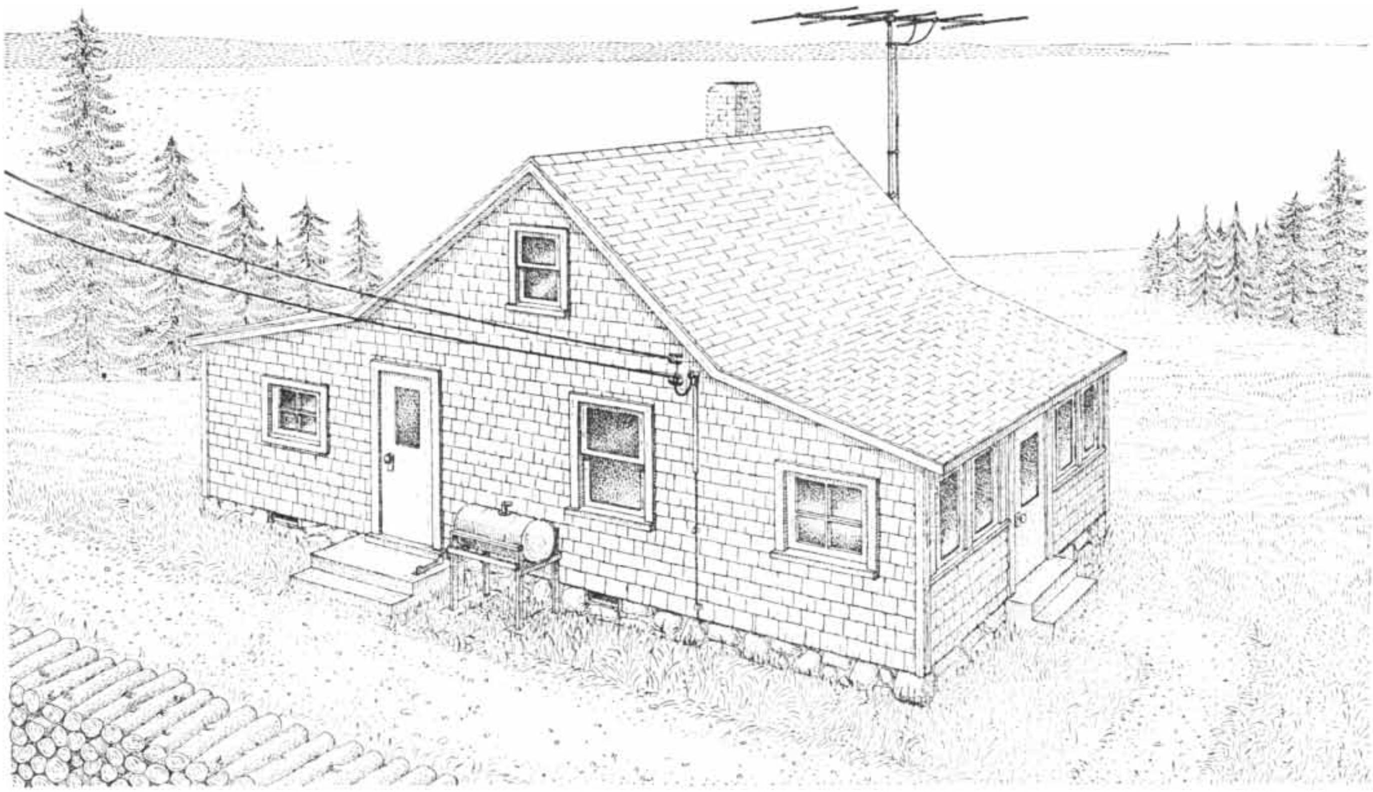
In 1950 our group gave a report to county officials listing several needs that would have to be met if the disintegration of the Road was to be arrested and reversed. At the top of the list were three things: (1) the introduction of social organization and social values through the development of leadership, (2) education and (3) improved economic opportunity. County and regional officials gave attention to these recommendations. Gradually, as the result of a series of events, conditions along the Road began to improve.

The first event was an experiment undertaken by the official responsible for adult education in the area. He defined his objective as improving the manners and skills of the Road people so that they would be better able to get and hold jobs, not only locally but also in urban centers. His intermediate goal was to establish adult-education classes in the local school. As a step toward that end he decided to organize meetings at which motion pictures would be shown.

In order to promote attendance at these meetings he enlisted the support of the local schoolteacher, who happened at that time to be a woman appreciably more competent and aware of the Road's problems than the succession of substandard teachers who had come and gone at the school before. She and the adult-education official began by showing motion pictures to the schoolchildren during school hours. Then they sent the children home with the word that evening showings of motion pictures would be available at the school without charge for anyone.

Since there was no electricity in the school, the first film showings (at which attendance was fairly good) required a portable generator. Eventually the official pointed out that if the programs were to continue, the school ought to be electrified. He told the people that the regional department of education would meet half of the cost if the other half was raised locally. His reasoning in this move was that the people would have to develop internal leadership and gain experience in cooperation before any more ambitious program could succeed. He was aware that he ran the risk of having his undertaking collapse for want of interest in the wiring project. As it turned out, however, the people of the Road, canvassed by schoolchildren with a petition drafted by the teacher, raised their share of the money and enough more to pay for the electricity for the following year.

At this critical juncture the program did collapse, because the adult educator was transferred to a different district. Such a turn of events was so thoroughly in keeping with the Road's chronic attitudes of mistrust and with



complished. A major contributing factor was a marked increase in the use of electricity along the Road in the early 1950's. With the improvement in conditions residents have tended to paint and remodel houses, put in lawns and gardens and do some landscaping.

the predictions of the venture's opponents on the Road that recovery seemed impossible. The schoolteacher, however, stepped into the breach by continuing to promote group activity, such as evening bingo games at the school to finance the purchase of new desks. It is possible that, being a woman, she was even more effective than the adult educator had been with the Road women, who had begun to take some interest in improving educational conditions in the neighborhood.

One of the teacher's most important moves was to bring up, at the suggestion of the school authorities, the question of having the district admitted to the consolidated school of the region. Such admission would mean the daily bus transportation of all children above the sixth grade to the consolidated school in a town some miles away, where the educational opportunities were considerably richer and the way was clear for going on to high school. It would also mean, of course, an increase in taxes for landowners in the school district.

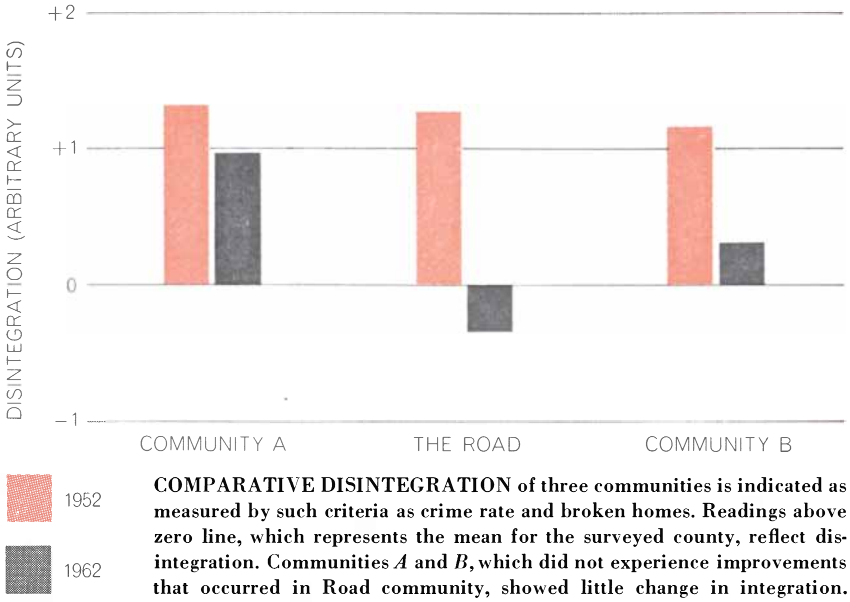
The question of admission to the consolidated school had been raised some years earlier and had been voted down at a district meeting. This is not surprising when one realizes that although most of the children in the school were from the Road, virtually all the taxes were paid by owners of the surrounding farms and woodlots, many of whom had no children in the school and most of whom saw no sense in spending money on the education of those they considered constitutionally incapable of benefiting from education. Furthermore, few adults from the Road had appeared at the meeting during which the vote was taken. This time, however, enough people from the Road attended to swing the vote, and the Road became a part of the consolidated school system.

When the first group of Road children appeared in the consolidated school, the teachers noted that they were easily distinguishable from the other pupils because they stood apart, said little and were awkward. Moreover, their clothing was out of keeping with the local fashion for young people and was often ill-fitting. One day about five months later the principal noticed at an assembly that none of the Road children seemed to be present. He asked one of his assistants if they had stopped coming to school. The assistant replied that they were there but that they had now blended with the rest of the student body. The speed of this adjustment was doubtless facilitated by the fact that each year the new children entering the school included some from rural areas in which clothes, manners and language were different from those of the student majority. Thus the situation was not one of a large gulf between the Road children and everyone else; rather there was a continuum with the Road children at one extreme.

One supposes that the children began to bring new ideas about deportment, clothing, values and motivation back to the Road neighborhood. No doubt this was resisted and treated with ridicule at first, but as the number of children going to and from the consolidated school increased they were able more and more to reinforce each other. There was a gradual but progressive impact that could never have been achieved if only a few people had been involved.

Coincident with these developments came an upswing in the availability of employment in the area. Of particular note in this connection was a nearby public works project that employed 300 to 400 men over a period of three years. One of the labor recruiters for the project came to the Road, and by this means many of the men found fairly steady work.

This employment had one unusual



COMPARATIVE DISINTEGRATION of three communities is indicated as measured by such criteria as crime rate and broken homes. Readings above zero line, which represents the mean for the surveyed county, reflect disintegration. Communities *A* and *B*, which did not experience improvements that occurred in Road community, showed little change in integration.

feature that introduced something quite new to life on the Road. The recruiter also acted as an agent for electrical appliances. He combined his recruiting on the Road with a sales campaign, offering appliances on the installment plan. Electricity had by this time come to the Road as part of the general power development of the county. As a result the purchases were by no means useless; in fact, it is reasonable to suppose they led to the development of some new trends in the economic life of the community. First, having acquired a washing machine, a refrigerator, a vacuum cleaner or a television set, the Road dweller became accustomed to using them. In due course this had its effect on his values and habits. Television in particular appears to have been an influence in bringing the dress, speech and manners of the Road more in line with those regarded with approval by the larger society. Second, since the appliances were removed if the payments were not kept up, the Road men became far more diligent on the job than had been their custom. Finally, and perhaps most important, the Road people discovered the principle of credit. For the first time in their lives a degree of useful credit was extended to them. From this start they went on to a greater use of the principle, thereby binding themselves more tightly to the wage economy and the values and motives that go with it.

Another important development took place when a few Road people found unskilled work in a city 800 miles away. Gradually the Road people adopted the custom of going to the city to work for a few months and then returning home. By 1957 there were 21 people from the Road in the city; by 1962 some individuals had made the circuit several times. This arrangement had the obvious advantage of bringing money to the Road. It also helped to reduce the fear of the unknown that had characterized the Road people.

As a result of all these influences the Road today differs considerably from the Road of 15 years ago. The houses, although still small, are larger than they used to be. Nearly all are neatly painted and have lawns, gardens and occasionally ornamental shrubbery. Almost every family has a comfortably furnished living room, and the furnishings of the other rooms have improved comparably.

Paralleling these physical changes are changes in the situation and attitudes of the people. The level of education has risen markedly: many of the children go beyond sixth grade and some continue through high school. It is the exceptional person today who has manners and clothing that set him off from the average of the county. Many of the adults hold semiskilled jobs, and several of the men have joined in business ventures requiring capital and cooperation. There has been a notable reduction in idleness, drunkenness and brawling. One also finds the emergence of values oriented to the future and concerned with responsibility. People from the Road now participate in formal organizations, such as the church and the parent-teacher association. Various informal organizations have sprung up.

The changes on the Road are recognized in the surrounding areas, often with expressions of amazement. The benefits of this recognition include the lowering of barriers to friendship and employment. Thus the advances taking place on the Road are being reinforced by the surrounding society.

Against this background it is now appropriate to consider what the transformation of the Road may mean in terms of the social and psychological evaluation that can be made of it. Two questions present themselves at once. The first is whether or not it is possible to measure what has happened. The second concerns the generalizations that can be made from the Road's experience with a view to applying them in other communities of similar impoverishment.

In an effort to measure what has occurred along the Road we have undertaken to isolate the social and psychological factors that seemed to be involved. To them and to the close interrelation that is evident among them we have applied the label "sociocultural integration." The term requires some elaboration. It is derived from the fact that we visualize human communities as semiorganic systems that perform various functions on which the survival and well-being of the group depend. Among the functions are the acquisition of food, shelter and other material necessities; the organization and distribution of work; the indoctrination of children into the ways of the system; the use of leisure time, and processes of decision-making on the part of the group when it is confronted with new situations.

The storage of resources against future need is also an important aspect of function. Such resources range from economic entities such as money, land and possessions to accumulated knowledge. Increases in the quantity and diversity of stored resources tend to increase the capacity of the group for taking advantage of opportunity and for coping with adversity.

With this model in view I have selected 10 criteria by which communities can be judged in terms of their sociocultural integration. These criteria, set forth in negative terms and therefore indicative of sociocultural disintegration, are: economic inadequacy, cultural confusion, widespread secularization, high frequency of broken homes, few and weak associations, few and weak leaders, few patterns of recreation, high frequency of interpersonal hostility, high frequency of crime and delinquency, and a weak and fragmented network of communications.

We began by using these criteria as a guide in observing and describing several communities. Our method was chiefly that of the cultural anthropologist: fieldworkers spent time in the communities talking with people and watching what was going on. They also systematically interviewed people who knew the communities well. On the basis of such information we organized the communities in a series ranging from high integration to low. In the process we discovered that independent observers easily agree on whether a particular community belongs at the bottom, in the middle or at the top of the range.

From this start we resolved most of the criteria into several more precise and objective components that could be handled by quantitative methods. Participant observers, spending an average of five months in each community, were able to fill in a household survey that included such items as the number of "broken" families (defined as families with one parent absent or intact families in which parents were constantly in conflict). Further, interviewing and observation throughout the communities made it possible to count leaders, if they existed, and to classify them by type. We used the same methods to estimate the extent and kinds of hostility among the people.

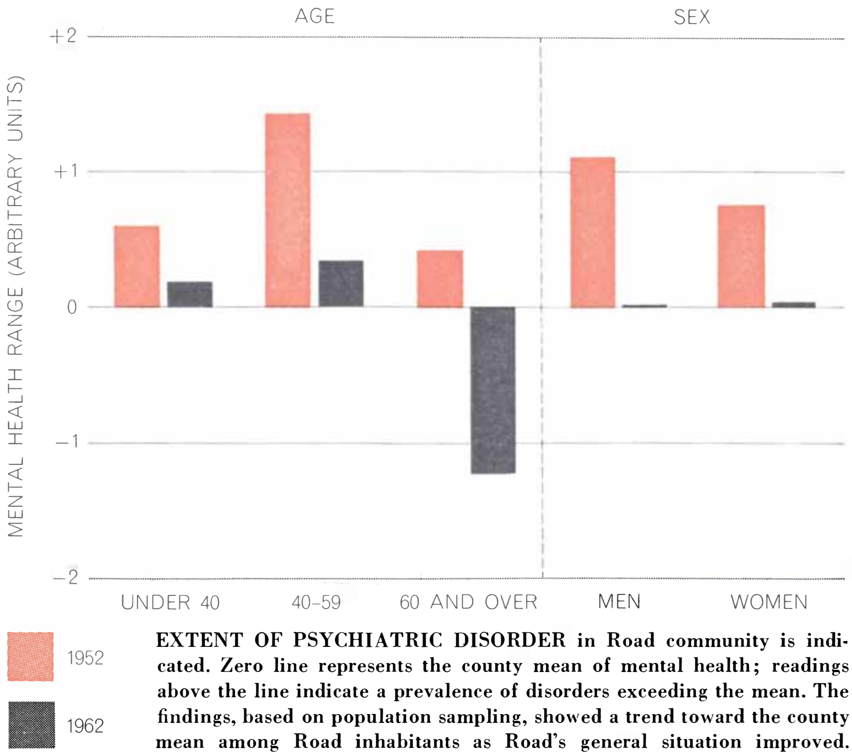
In addition we gave a questionnaire to a systematically selected sample of adults. On the basis of this questionnaire it was possible to calculate such matters as participation in religious activities and sense of identity with an ethnic group. By using the questionnaire in conjunction with direct observation, we gathered data on the economic resources of each respondent in the sample. More recently we have been constructing an atlas of community activities and finding ways to estimate the amount of time a sample of individuals spends in each kind of activity. These techniques are making it possible to state more precisely the differences in integration among communities and ultimately also in the same community at two different points in time. All these methodological steps present new questions and therefore new possibilities for advance in understanding the processes at work and the causal factors involved in the shifts of groups from integration to disintegration and vice versa.

Parallel to our interest in sociocultural process we have maintained a corresponding interest in the psychological states—and shifts of states—among the people of the communities. It has become clearly evident that the people of the Road and of the other disintegrated neighborhoods we have investigated have a frame of mind that is characteristic and that differs from the frame of mind found in well-integrated communities. The psychological climate in the disintegrated neighborhoods can be represented by such words as "apathy," "interpersonal hostility," "anxiety," "depression," "suspicion" and "an unrealistic view of human affairs." This condition often runs to extremes in certain individuals, as shown by our findings of a high prevalence of psychiatric disorder in the Road and other disintegrated communities.

In this connection it is significant that the prevalence of such disorders on the Road was far lower in 1962 than it had been in 1952 [*see illustration below*]. Improvement in mental health closely paralleled the growing integration of the community. Conversely, other communities that were disintegrated in 1952 and remained disintegrated in 1962 have shown no comparable decline in the prevalence of psychiatric disorder.

The people of the disintegrated communities find themselves in the grip of two interlocking and self-defeating forces, one sociocultural, the other psychological. As a result these people do not make adequate use of the admittedly meager resources available to them. Even more significant for the success of any "war on poverty," they are not in a position to make adequate use of the resources that might be offered them in a development program.

With that observation I come to the question of what generalizations can be made on the basis of the Road's experience. There are several. Clearly, increased economic and educational opportunities will not be enough to bring about a turn for the better in a disintegrated community, although such opportunities are essential to the process. What is needed in addition to them is the development of patterns of social functioning: leadership, followership and practice in acting together cooperatively. In other words, it is necessary that the offers of better education and of training in marketable skills go hand in hand with help in learning the elements of human relations. Rooted in this necessity is the requirement that the people be enabled to gain confidence that some things can be done to better their lot; that they be assisted in modifying unrealistic or nihilistic views of the world, and that they be encouraged to develop motivation. Without social and psychological changes of this kind the people will retain their inability to make adequate use of educational and employment opportunities.



EXTENT OF PSYCHIATRIC DISORDER in Road community is indicated. Zero line represents the county mean of mental health; readings above the line indicate a prevalence of disorders exceeding the mean. The findings, based on population sampling, showed a trend toward the county mean among Road inhabitants as Road's general situation improved.

THE LUMINESCENCE OF THE MOON

There is more to moonlight than reflected sunlight. The moon's surface sometimes glows with its own luminescence, apparently stimulated by the impact of charged particles from solar flares

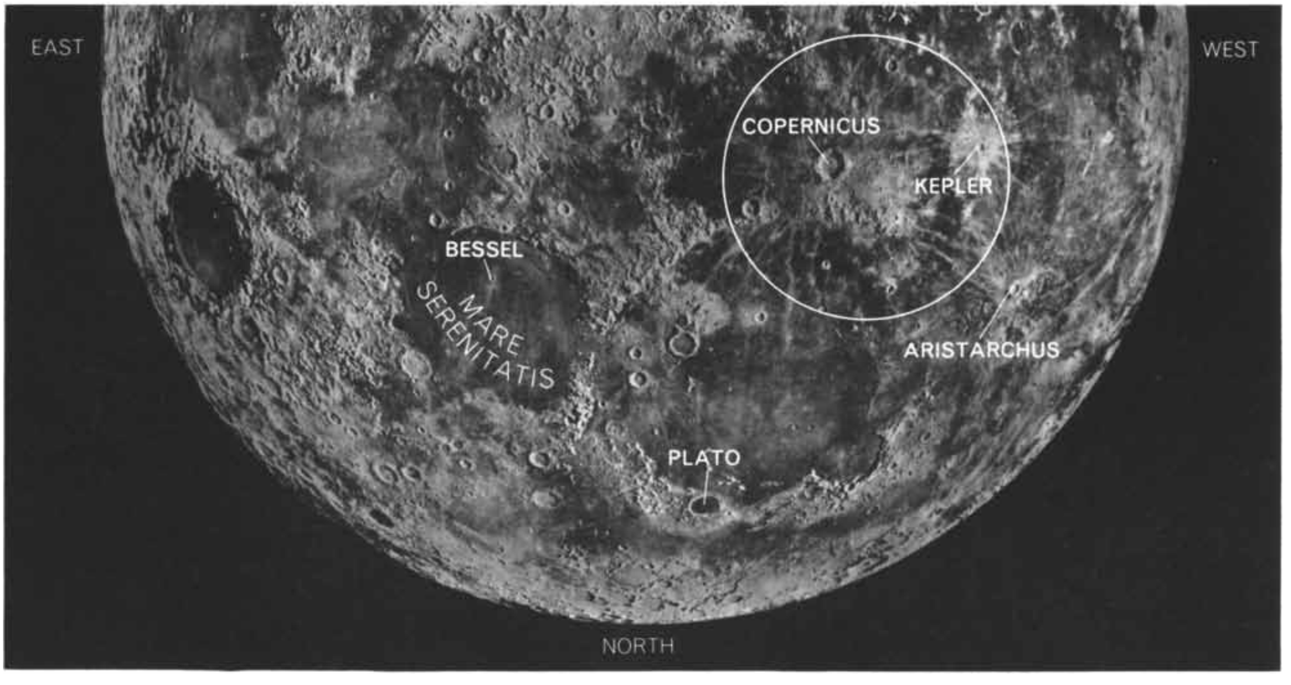
by Zdeněk Kopal

What is moonlight made of? It is mostly reflected sunlight, of course, but is there something more? The answer is yes: the moon gives off some light of its own. The purpose of this article is to review the evidence indicating that there is an indigenous component of moonlight and to propose an explanation for it.

The surface of the moon, unprotected by any atmosphere to speak of, is exposed not only to visible radiation from the sun and to high-energy ultraviolet and X radiation but also to corpuscular radiation: the charged particles of the "solar wind." These protons and electrons give rise to X-ray emission from the lunar surface. They do this by causing electrons to be ejected from the innermost orbits of the atoms of the lunar surface material, thus ionizing the atoms; as the electrons recombine with the atoms, X rays are emitted, mainly at wavelengths between 10 and 100 angstrom units. These very short electromagnetic waves cannot penetrate the earth's atmosphere but they have been detected by instruments in high-altitude rockets. The system is like an X-ray tube of cosmic dimensions, in which the sun is the hot cathode and the moon is the target, or X-ray source.

Now, when an electron is dislodged from an atom, it can return to its inner orbit in a single transition, giving rise to an X-ray photon, or it can return in stages—an orbit at a time. In that case it gives rise to photons of longer wavelength, including photons of light. If this process were to occur among the atoms of the lunar surface, they could of course emit radiation that would penetrate the earth's atmosphere, namely visible light. It now appears that they do, and that their luminescence makes an appreciable contribution to the total light of the moon.

The most elementary evidence for an extra component in moonlight is the fact that the brightness of the moon sometimes varies in a way that cannot be accounted for simply by changes in the moon's distance from the earth or



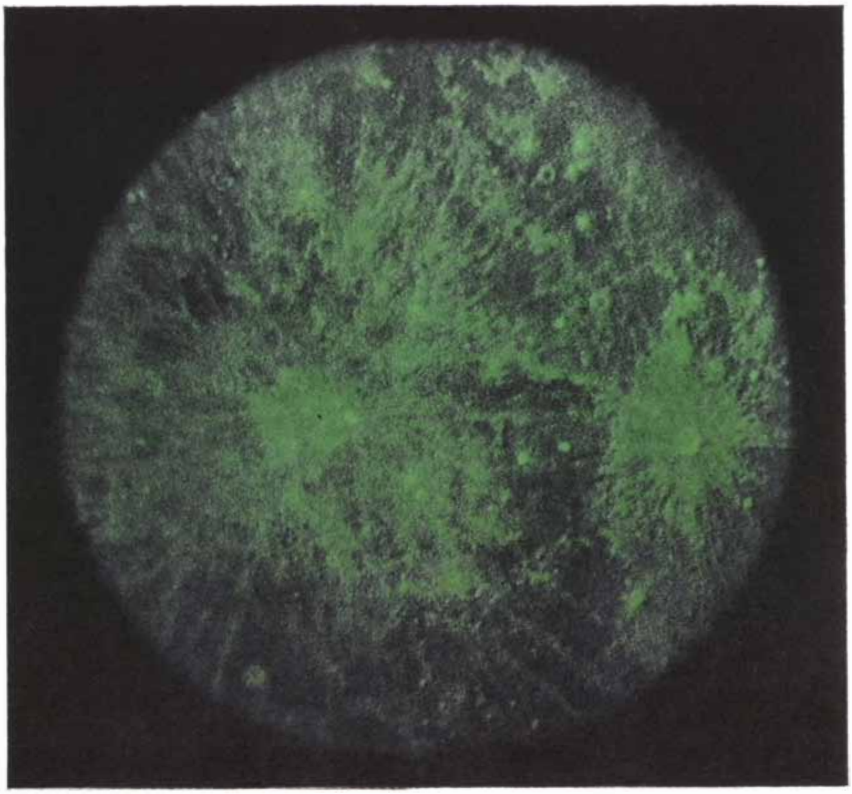
LUMINOUS PHENOMENA have been noted at a number of sites on the moon, some of which are located on this photographic map, a mosaic made by the Aeronautical Chart and Information Center of the U.S. Air Force. The northern hemisphere of the moon is seen here inverted, as in a telescope. The circle outlines the approximate area of the bottom photograph on the opposite page.

by its librations, which cause it to present slightly different areas of its surface to the earth at different times. A number of observers have noted that these variations in brightness seem to be correlated with the 11-year cycle of sunspot activity, and that the amplitude of the variations in the moon's brightness is greater than the fluctuations in total solar radiation. According to the most recent and reliable photoelectric measurements, made by Tom Gehrels, now at the University of Arizona, the lunar surface was between 10 and 20 percent brighter in visible light from 1956 to 1959, near the maximum of the last solar-activity cycle, than it was from November, 1963, through January, 1964, when solar activity was near its minimum. Gehrels found, moreover, that the light of the moon is polarized to a greater extent when its brightness is at a minimum than when it is at a maximum. Since light tends to become polarized when it is reflected, this finding suggests that moonlight at its brightest includes some light that is not reflected sunlight.

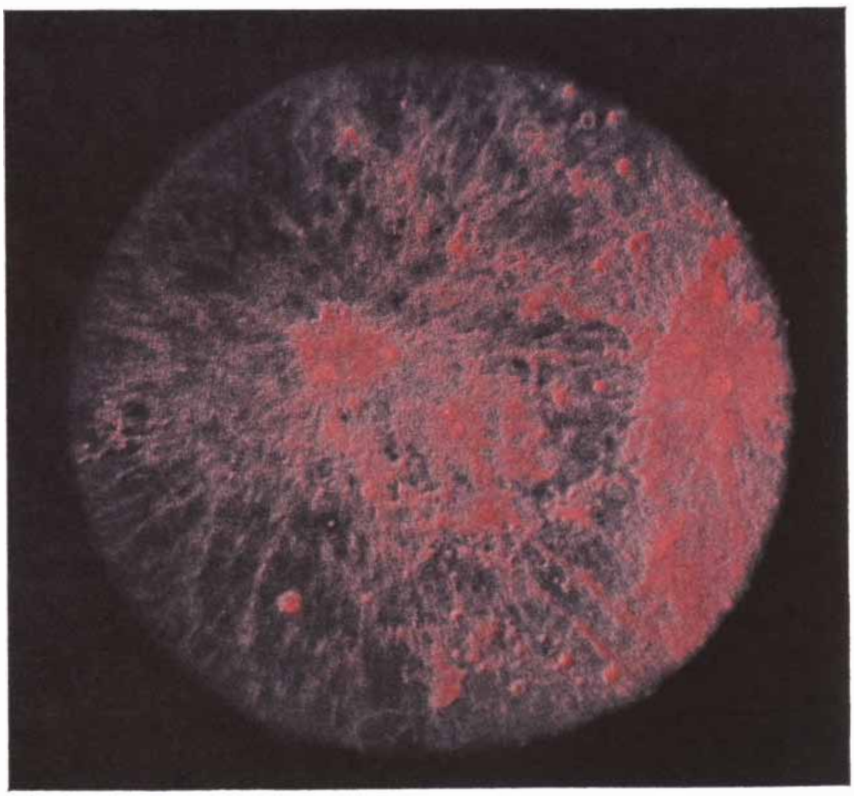
What solar emanation other than visible radiation affects the brightness of the moon? The first clue came from a study of lunar eclipses. In 1920 the French astronomer André-Louis Danjon discovered, by examining data extending back over three and a half centuries, that the residual brightness of the moon when it is totally eclipsed by the earth is closely correlated with solar activity.

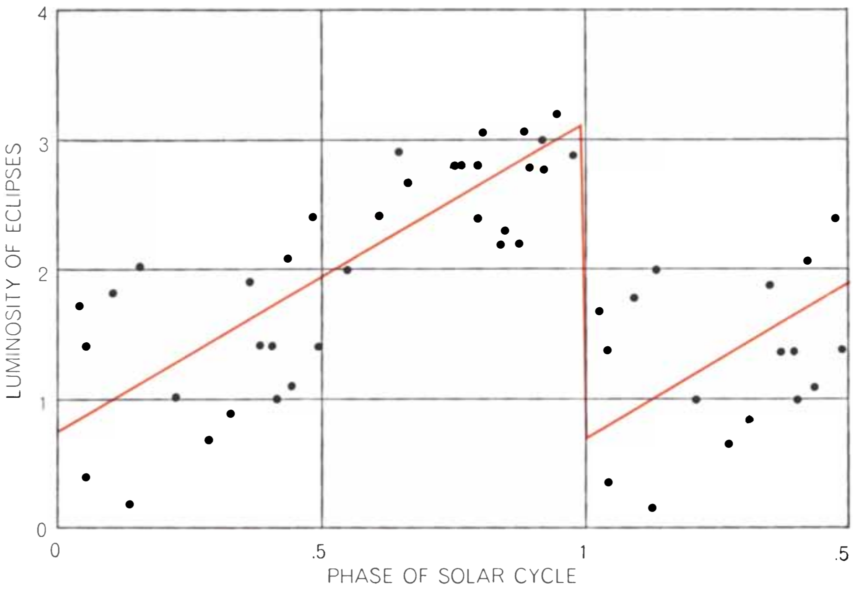
This residual brightness increases as the sunspot cycle advances and drops abruptly at the time of minimum solar activity; the eclipsed moon is about two and a half times brighter just before a minimum than just after a minimum [*see top illustration on next page*]. Two recent eclipses in which the moon was unusually dark took place in 1963 and 1964, just before and after such a minimum point in the solar cycle. Another feature that changes abruptly at this same minimum point is the location on the solar disk of sunspots and other disturbances. They vanish from near the solar equator at the end of a cycle and reappear in the high solar latitudes at the beginning of the next cycle.

Corpuscular streams emanating from disturbed regions of the sun are not restricted to the optical path taken by visible light. They could reach the surface of the eclipsed moon and there excite luminescence that might account for the residual brightness of the moon. This luminescence should be brightest when the sunspots are near the solar equator and the plane of the earth's

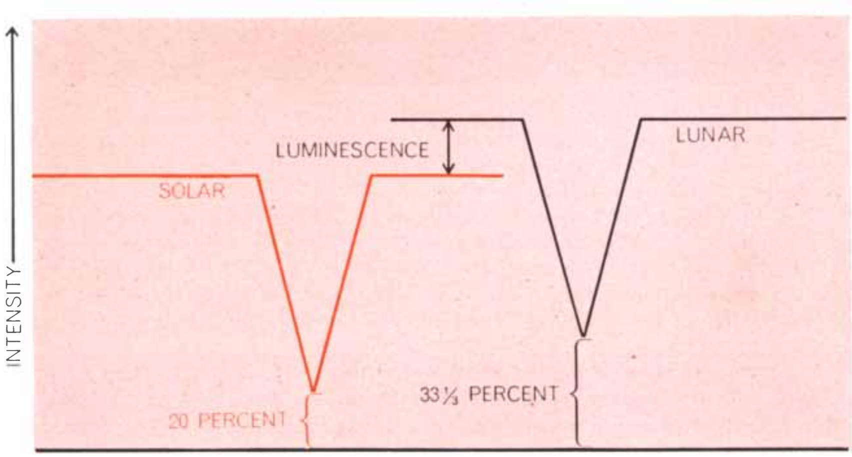


LUNAR LUMINESCENCE around the crater Kepler is revealed by a comparison of these photographs made with the 24-inch refractor of the Pic du Midi Observatory in France by the author and Thomas W. Rackham at 00:35 on November 2, 1963. The plate shown above was exposed through a filter that passed only a band of green light centered at 5,450 angstrom units, the one below through a filter centered at 6,725, in the red. Instead of being printed in black and white the photographs are printed here, for illustrative purposes, in black and a green and red that approximate the filter colors. Each shows a circular area some 640 miles in diameter, with the crater Copernicus left of center and the crater Kepler at the right. The area around Kepler is much brighter in red light: it is luminescent.

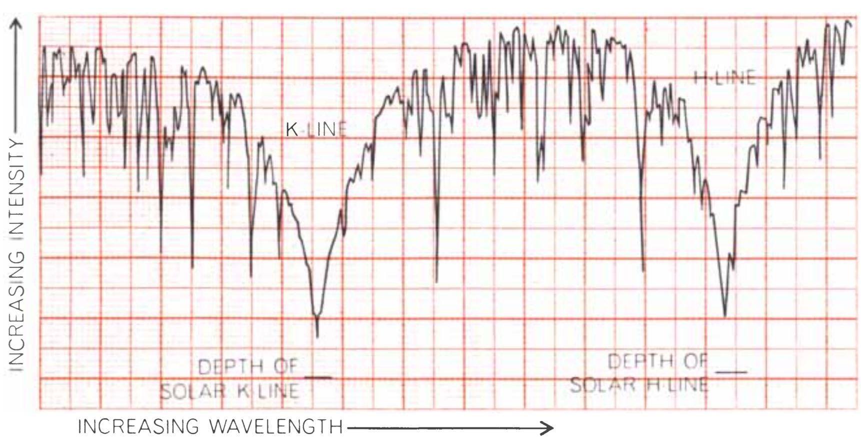




RESIDUAL BRIGHTNESS of the moon when it is eclipsed by the earth varies with the 11-year cycle of solar activity. The luminosity of the eclipse is greatest not in mid-cycle, at the peak of solar activity, but just before the minimum point at the end of the cycle.



LINE-DEPTH METHOD of detecting luminescence calls for comparing profiles of absorption lines in the spectrums of the sun (*left*) and moon (*right*). An increase in the residual intensity (*brackets*) in the case of the moon is a measure of the light (*arrow*) attributable to lunar luminescence, which in this example is 16.67 percent of the total moonlight.



PROFILES of two lines in the ultraviolet part of the moon's spectrum were recorded by Hyron Spinrad of the University of California at Berkeley. Because of luminescence the lunar *H* and *K* lines are not as dark (their traces are not as deep) as the solar *H* and *K* lines.

orbit; when the sunspots move to higher latitudes, the excitation they cause should decrease in intensity. Danjon's finding of just such a pattern provided indirect support for the idea of corpuscular excitation of lunar luminescence.

Further evidence came from photometric studies by the Czech astronomer František Link of partial phases of lunar eclipses. Since the diminution of light during these phases was less than would be expected simply on the basis of the geometry of the disks of the sun and the earth, Link surmised that significant effects were being produced by the uneclipsed parts of the solar corona. The corona radiates little visible light but emits a significant amount of X radiation; Link suggested that coronal X rays give rise to luminescence on the moon.

Although photometric observations demonstrated a relation between solar activity and the light of the moon, they revealed little about the spectrum of the hypothetical luminescence. Link suggested a spectrometric method based on a comparison of the absorption lines in light from the sun and the moon. The spectrum of sunlight is interrupted by dark lines at the wavelengths that are absorbed by elements in the sun's atmosphere; if the intensity of sunlight is recorded at each wavelength across the spectrum, the trace dips sharply at each such line. Since reflection by the lunar surface has little effect on wavelength, the same absorption lines show up in the spectrum of moonlight, and if moonlight consisted only of reflected sunlight, the intensity profiles of each line would be exactly like those of the sun's. If, on the other hand, the portion of the lunar surface covered by the slit of a spectrometer luminesces, then the depth of the lunar-line profiles should be shallower than those of the sun by just the amount of the luminescence.

This "line depth" method was employed by Nikolai A. Kozyrev of the Pulkovo Observatory in the U.S.S.R. and Jean Dubois of the Bordeaux Observatory in France during the 1950's. Both of them found indications of luminescence at various points on the moon's surface and at various wavelengths; the intensity ranged as high as 13 percent of the total brightness at adjacent wavelengths and seemed to vary with time. Kozyrev's and Dubois's results were suggestive rather than conclusive because their photographic technique was not accurate enough. A precise photoelectric measuring device was needed.

Between 1960 and 1962 our department of astronomy at the University of Manchester embarked on a systematic study of lunar luminescence, with support from the U.S. Air Force's Office of Aerospace Research. A photoelectric spectrograph capable of resolving wavelength differences of .1 angstrom, which was built by John F. Grainger and James Ring, was fitted to the 50-inch telescope of the University of Padua's observatory at Asiago in Italy, and observations were started in 1961. For the most part we scanned the profile of the *H* line of ionized calcium (which lies in the violet part of the spectrum at a wavelength of 3,970 angstroms) for the same reasons that had led Kozyrev to choose that line: both its width and its darkness with respect to adjacent wavelengths make any luminescence easier to detect. Our work generally confirmed that of Kozyrev and Dubois, establishing the existence of lunar luminescence beyond reasonable doubt. The strongest glow, amounting to about 10 percent of the total light, was emitted by a bright "ray" of lunar material that crosses the Mare Serenitatis through the crater Bessel; other regions, including some spots near the crater Plato, luminesced almost as strongly. The effect was clearly local in nature; it varied greatly as we shifted the slit of the instrument, which covered a rectangle of about one mile by 10 miles on the moon's surface. It also varied with time, but we had too few data to show any correlation between the lunar glow and events taking place on the sun.

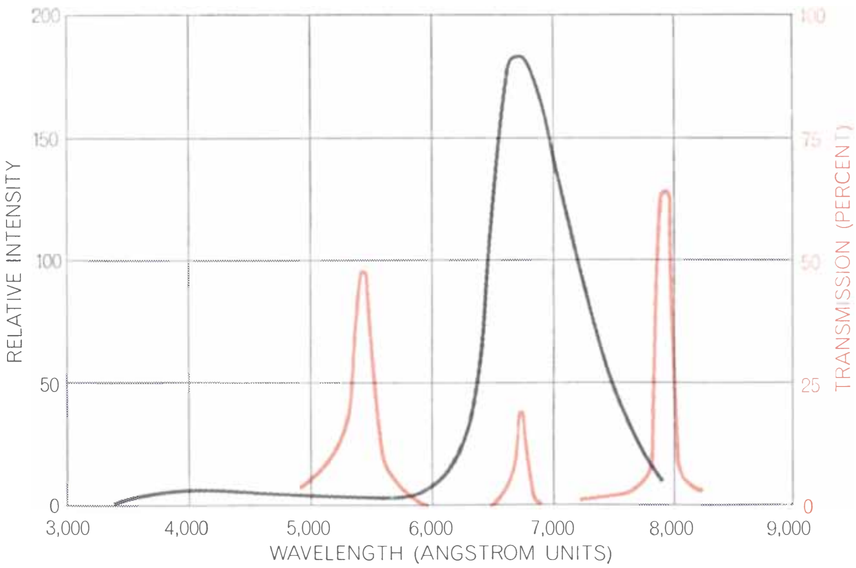
The line-depth method has been extended to other absorption lines by C. D. Scarfe at the University of Cambridge. On October 5, 1963, near 5,450 angstroms in the green region of the spectrum, he observed strong luminescence ranging as high as 30 percent of the total light. The effect was strongest in the crater Aristarchus but was also evident in the regions of Copernicus and Kepler. Scarfe noted that "integrated" sunlight that had been diffused by a plate coated with magnesium oxide exhibited line profiles virtually identical with those of diffused moonlight. He concluded that it is not the constant light of the sun that causes observable luminescence, and that the luminescence must rather be related to solar activity.

Later in 1963, when the expiring solar cycle was in its last throes, two remarkable luminous phenomena were observed on the moon. The first observation was made on October 30. James A. Greenacre and Edward Barr, experienced lunar observers working at the Lowell Observatory in Arizona under the auspices of the U.S. Air Force, were examining the moon visually when, at about 1:30 Universal Time, they saw three distinct areas in the neighborhood of the crater Aristarchus suddenly flare up in orange-red light. The glow was intense enough to be noticed without a filter; it lasted for only about 25 minutes and there was not time to make photographs or to record spectra. The observers' vivid recollections provided some information, however. Greenacre's impression that he was "looking into a large, polished gem ruby but could not see through it" left no doubt that the emission was in the red and that its intensity was at least comparable to that of reflected sunlight. His recollection that "within about two minutes these colors had become quite brilliant and had considerable sparkle" suggested a phenomenon with a rapid onset.

Later that same week there occurred another and far brighter and more extensive "lunar flare." This time Thomas W. Rackham and I, working with the 24-inch telescope of the Pic du Midi Observatory in the French Pyrenees, managed for the first time to record it photographically. Before discussing the pictures we made I should like to explain how we came to make them.

Earlier observations had suggested, as I have pointed out above, that transient lunar phenomena might be connected with corpuscular radiation from the sun. The principal constituent of such radiation is protons. Now, it seems probable that the lunar surface is at least partly covered with meteoritic dust swept up by the moon or deposited where large meteorites have struck the moon. We therefore decided to investigate the luminescence of actual specimens of meteoritic material, which we borrowed from the British Museum. In 1963 C. J. Derham and J. E. Geake found that bombardment with protons caused certain stony meteorites known as achondritic enstatites to luminesce brightly over a broad band of wavelengths near 6,700 angstroms. It seemed quite possible that this red glow might occur on the moon in regions where meteoritic material is exposed on the surface. Rackham and I therefore undertook a systematic program of lunar photography with three interference filters that passed only narrow bands of the spectrum centered at 6,725, 5,450 and 7,900 angstroms. The first filter transmitted red light at the peak of the emission band of the meteorites; the other filters, respectively yellow-green and infrared, excluded red light and provided photographs that served as controls. Our practice has been to make pairs of photographs, exposing one plate through the red filter and the other through one of the control filters, usually within the same minute.

On October 30, when Greenacre and Barr observed the luminous flares near Aristarchus, the sky was cloudy at the Pic du Midi and we were in total ignorance of what our colleagues were seeing from Arizona. Two nights later,

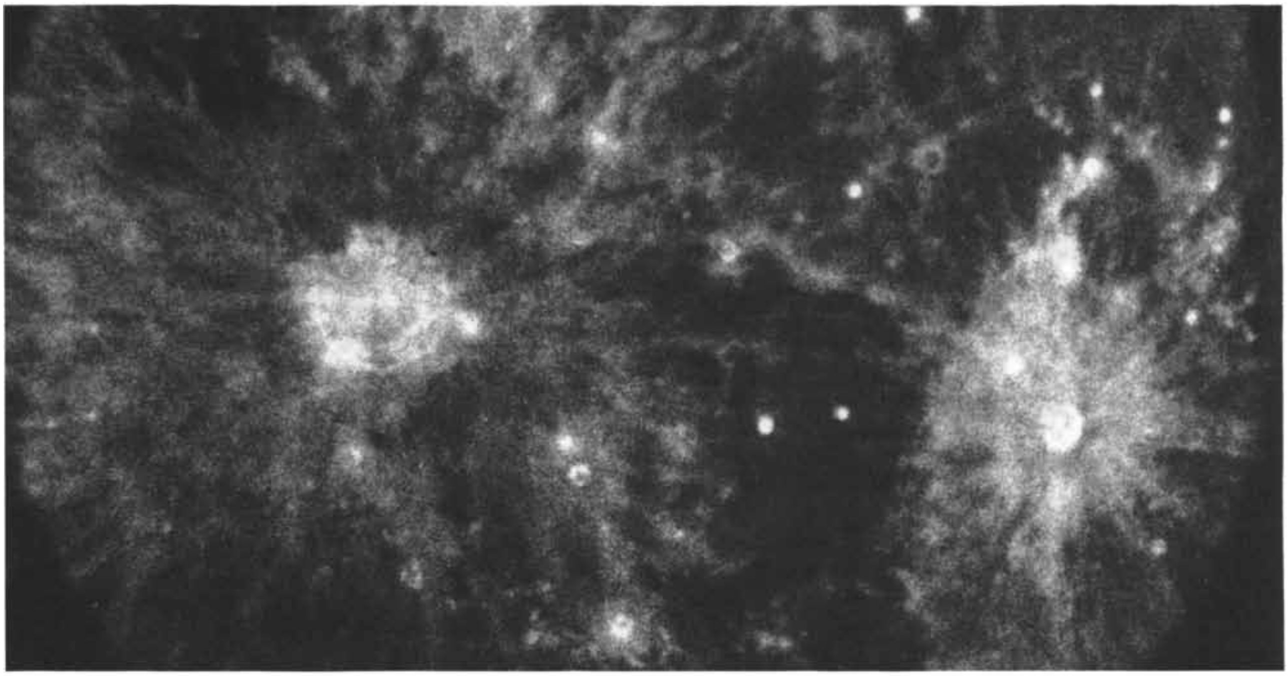


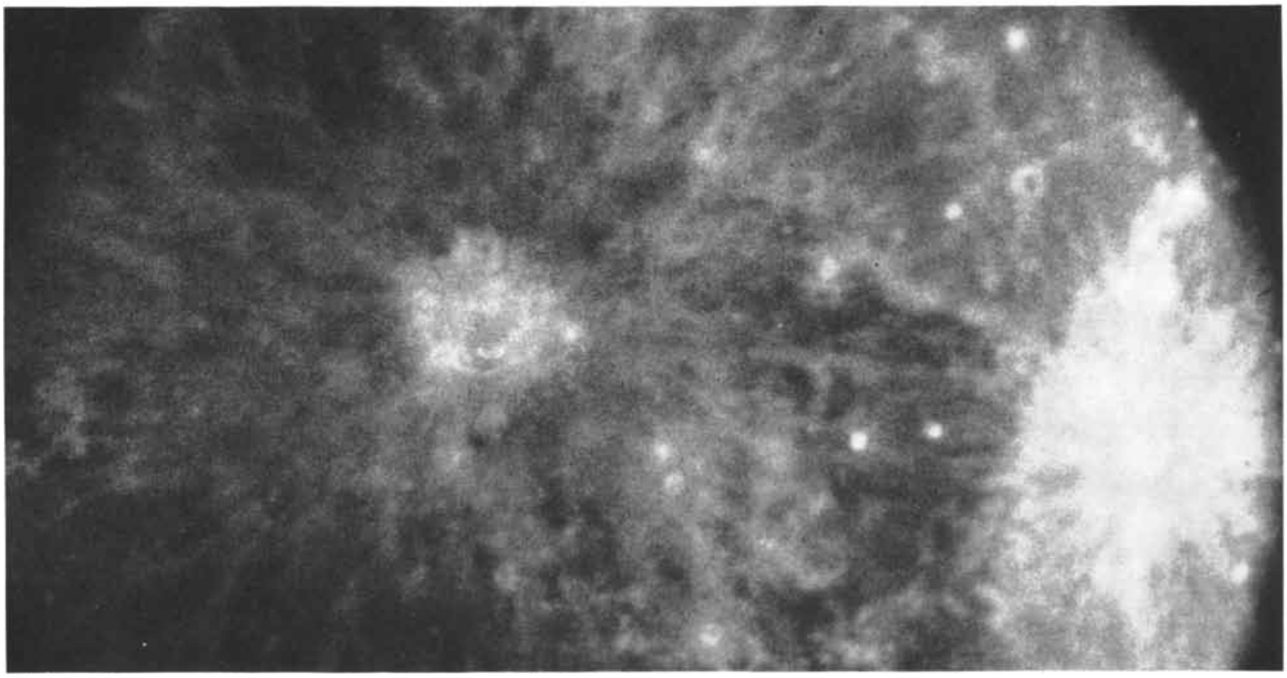
EMISSION BAND, centered in the deep red, of meteoritic material bombarded with protons is shown by the gray curve. The colored curves indicate the bands of light passed by the green, red and infrared filters with which the author detected lunar luminescence.

however, the weather cleared. Our program called for us to make exposures in the area of the Oceanus Procellarum, which contains the craters Copernicus and Kepler as well as Aristarchus. The sky was exceptionally transparent and our plates, which we developed as they were made, revealed a remarkable sequence of events.

The first pairs of plates to show something unusual were exposed between 22:35 and 22:45 U.T. on November 1. In both cases the red plate showed a striking enhancement of the surface brightness of a large area around and to the north of Kepler. The green plates showed no trace of this brightness. On two more pairs of plates, exposed between 23:00 and 23:08, the red enhancement had virtually disappeared. It became distinct again after midnight, appearing on four pairs exposed between 00:20 and 00:35, and there is some evidence that the contrast between the red and the green plates actually increased within that 15-minute period [*see illustrations on these two pages*]. Then, while we were processing the latest plates in the darkroom, cumulus clouds moved overhead and the sky remained obscured for the rest of the night.

When it cleared the next evening, we made more filter photographs, but these showed no sign of the enhancement that had been so conspicuous at two different times the night before. The weather was generally unfavorable at the Pic for the remainder of that



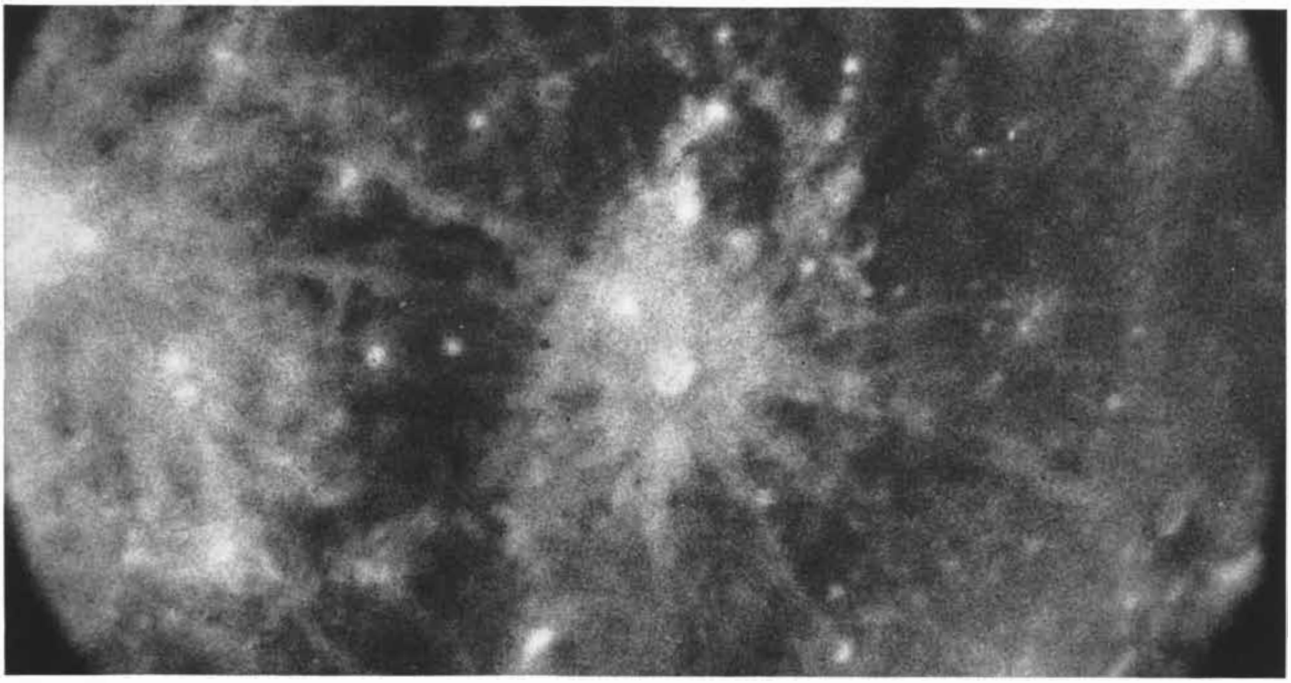


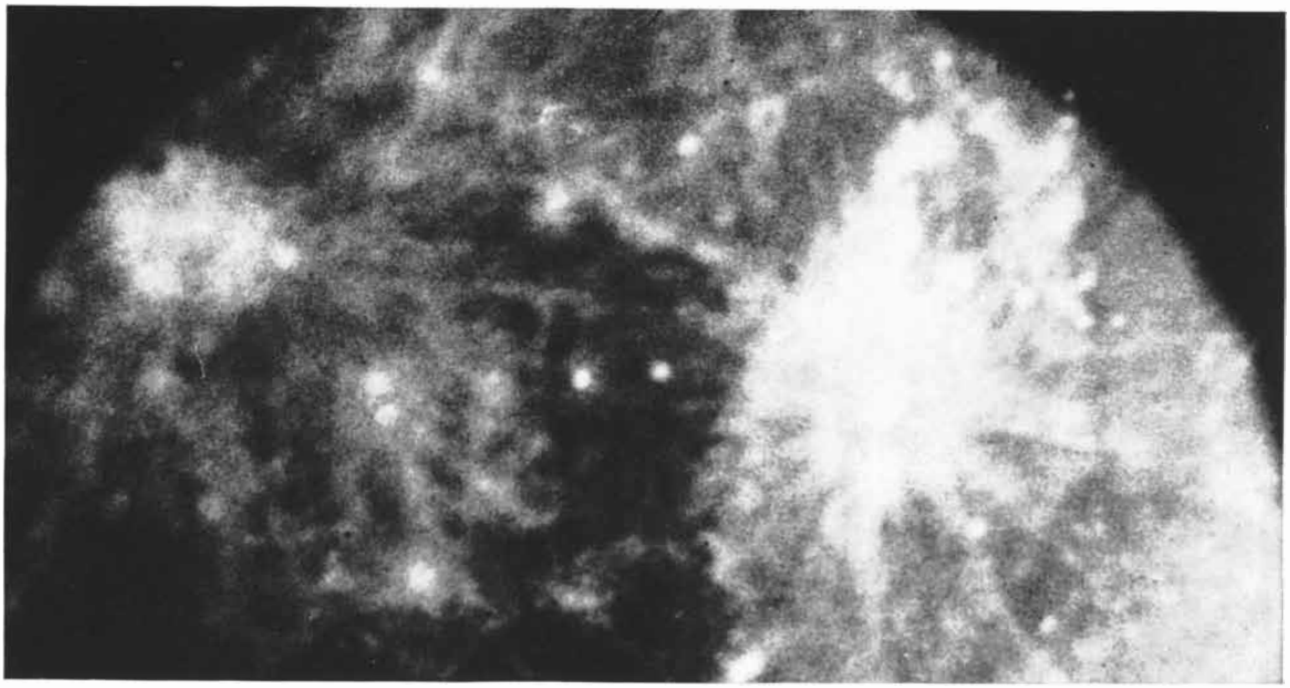
PAIR OF PHOTOGRAPHS was made at 22:45 on November 1, 1963. On the plate exposed through the green filter (*above*) Copernicus (*left*) and Kepler (*right*) are about equally bright. On the plate exposed in the red (*below*), however, Kepler is brighter.

lunar cycle. During the next cycle we searched intensively but could observe no anomalous red-green contrast. Photoelectric measurements indicated, indeed, that under ordinary conditions the Kepler area was not only fainter but also somewhat bluer than the region around Copernicus. Unfortunately it was cloudy again at our observatory on November 27, when Greenacre and Barr reported a recurrence of the reddening at several points near those that had been active a month before. This time the glow persisted for more than an hour and was witnessed by several other astronomers.

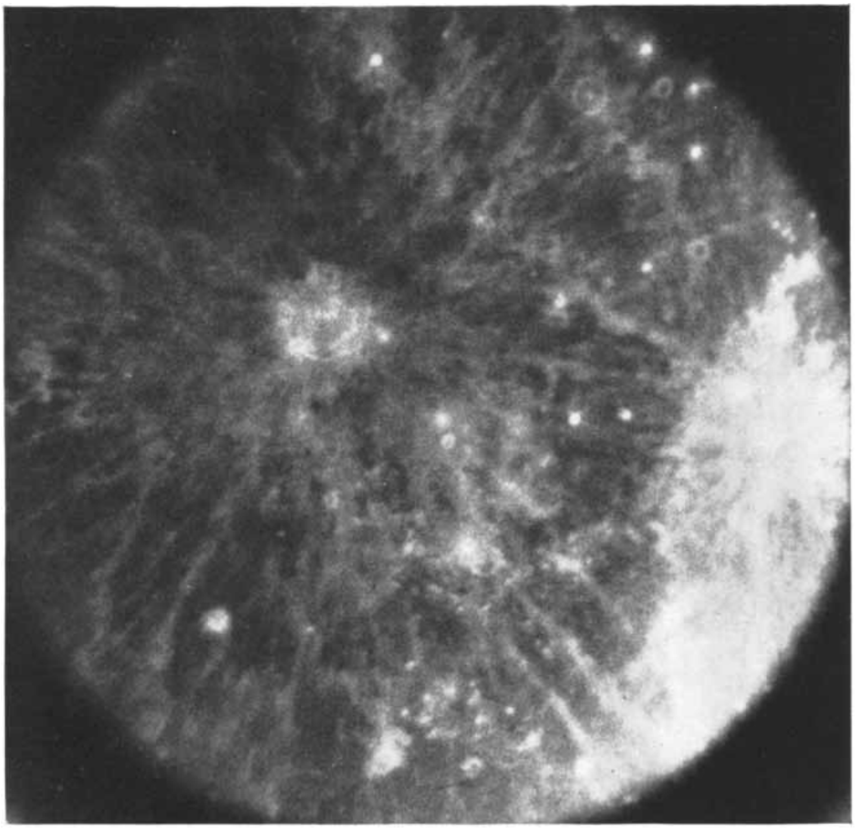
We are not sure that the glowing spots Greenacre and Barr saw were manifestations of exactly the same phenomenon represented by the bright areas on our photographs; the two kinds of observation were quite different. Analysis of our plates with a microdensitometer reveals that the red light in the Kepler region was about 80 percent brighter than normal, several times as great an enhancement as had ever been reported on the basis of line-depth spectroscopy. The spots Greenacre and Barr saw may have been as intense but the area they covered—a few square miles in all—was minute compared with the bright area of our photographs, which extended over some 50,000 square miles of the moon's surface; the glowing spots near Aristarchus could scarcely have been resolved in our filter photographs.

Since that week in November there

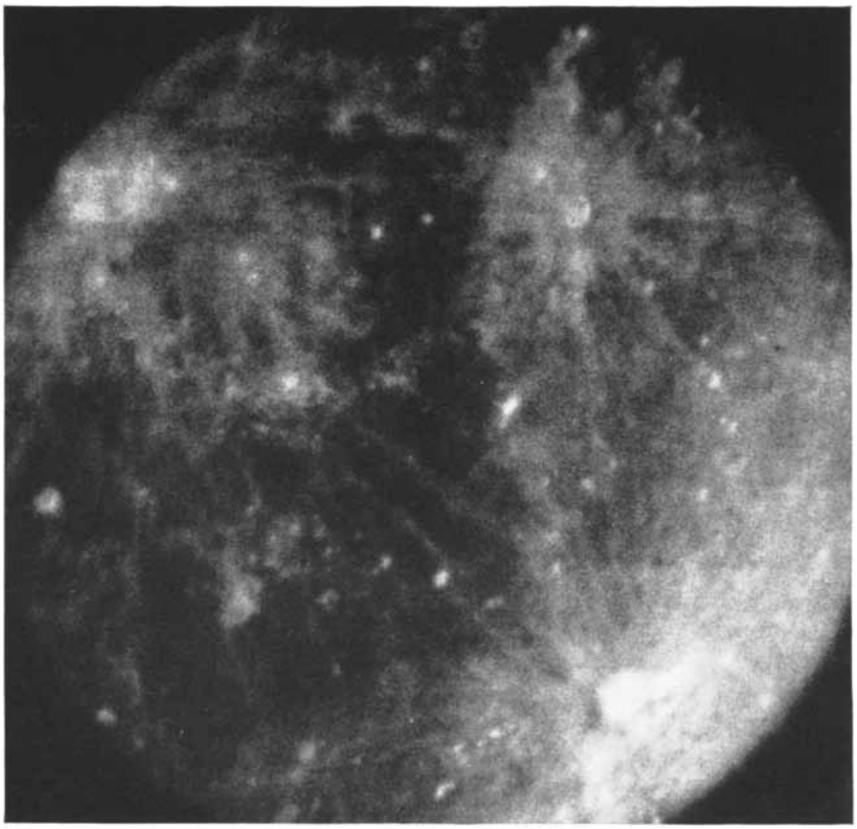




ENHANCEMENT IN RED was missing on plates made half an hour after those on the opposite page. It reappeared, however, on this pair, which was exposed at 00:22 on November 2. Copernicus is at far left, Kepler near center; green plate is above, red below.



COPERNICUS-KEPLER REGION was photographed through the same red filter with the same exposure and the identical emulsion at 00:22 on November 2, during maximum enhancement of the Kepler area (*above*), and at 21:44 on November 30. In the later photograph (*below*) conditions are normal, with no luminescence around Kepler (*upper right*).



have been no further significant observations of luminous phenomena on the moon. There would seem to be a good reason: 1964 was the International Year of the Quiet Sun; the solar-activity cycle was at its minimum. During this quiet period some of us turned to a scrutiny of the old literature. We found that phenomena of this type had been reported before, but the instances were isolated and had no collective impact until the dramatic events of late 1963 focused attention on them.

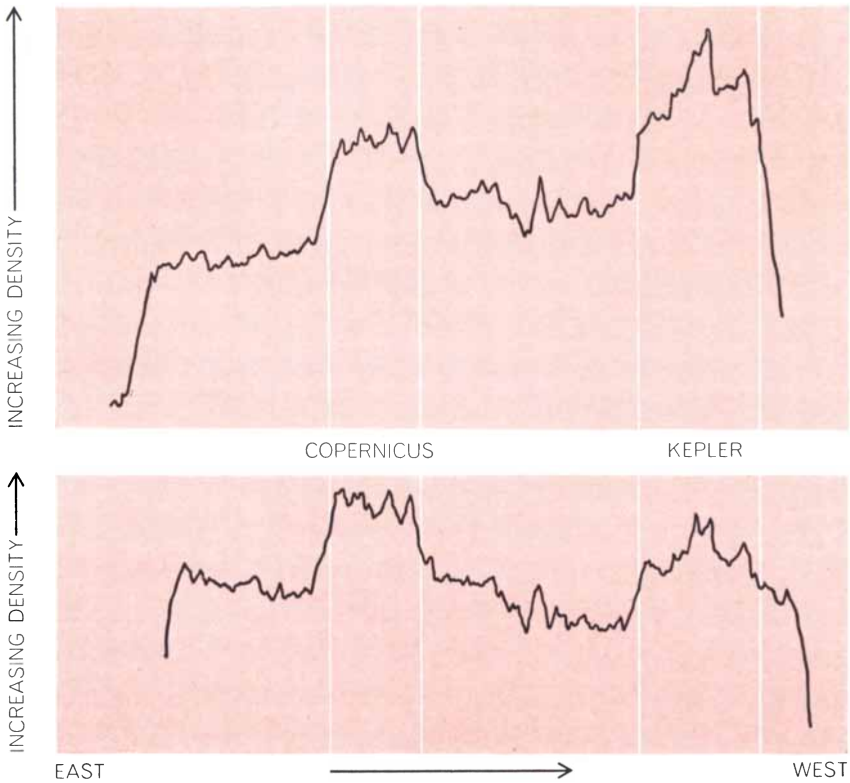
It was William Herschel, the great English astronomical observer, who first noted and recorded a transient luminous phenomenon on the moon. During the night of April 18–19, 1787, he saw spots glowing like "slowly burning charcoal thinly covered with ashes" in the neighborhood of Aristarchus—perhaps the very same spots seen by Greenacre and Barr. Herschel called the spots "volcanoes on the Moon," and he invited his royal patron George III to come and look at them through his telescope. Now, in May of 1787 an unusually active solar cycle was just about at its maximum. This is indicated by the fact that on April 18 and 19 polar auroras were visible as far south as Padua—something that happens no more than once in a decade.

E. J. Flamm and R. E. Lingenfelter of the University of California at Los Angeles have recently searched old records and found that various observers noted transient glowing of this kind near Aristarchus on 16 different occasions during the years from 1787 through 1963; they also found references to similar events in other places on the moon. There seems to be no doubt that these temporary enhancements represent recurrent events that are characteristic of the lunar surface. How is one to account for them?

No ordinary thermal explanation will serve, since no known kind of matter could possibly heat up and cool again to the extent required on a time scale nearly as brief as that of the fluctuations in brightness observed on the moon. Some luminescent process stimulated by heat might be considered, but this is ruled out by the fact that the brightness cannot be correlated either with monthly temperature changes on the moon or with daily local changes in temperature as the sun rises above the lunar horizon and travels across the lunar sky.

Several observers have suggested that although the moon is generally assumed to be "dead," gas may sometimes escape from the interior through fissures in the surface, and that this gas might be dissociated by solar radiation and also made to luminesce by it. Polydore Swings of the University of Liège suggested recently that the spots near Aristarchus might result from the dissociation of ammonia (NH_3) into H and NH_2 and that the NH_2 might then luminesce in the red. Quantitative considerations rule out such a hypothesis. A great mass of gas would be required to account even for the Greenacre-Barr spots, and the discharge of such a mass of gas into the vacuum at the lunar surface would be bound to bring about noticeable changes in the microstructure of the landscape. Such changes have not been observed. The magnitude of the Kepler enhancement recorded in our photographs makes this explanation even more unlikely.

The lunar flares recur in certain places and at certain times unrelated to any lunar calendar. They appear, then, to be associated with certain types of lunar surface material but to be caused by some nonlunar influence. The most likely such influence is the sun. As Danjon made clear, the rhythm of the solar cycle is reflected in the residual brightness of lunar eclipses, and it is only natural to ask if the transient lunar flares are caused by transient solar events.



LUMINESCENT EFFECT was quantified by microdensitometer measurements of photographic plates. The top curve is a trace across the Copernicus-Kepler region of a plate exposed through the red filter; the bottom curve is a similar trace made on the paired green plate. Since plates are negatives, an increase in density means an increase in brightness.

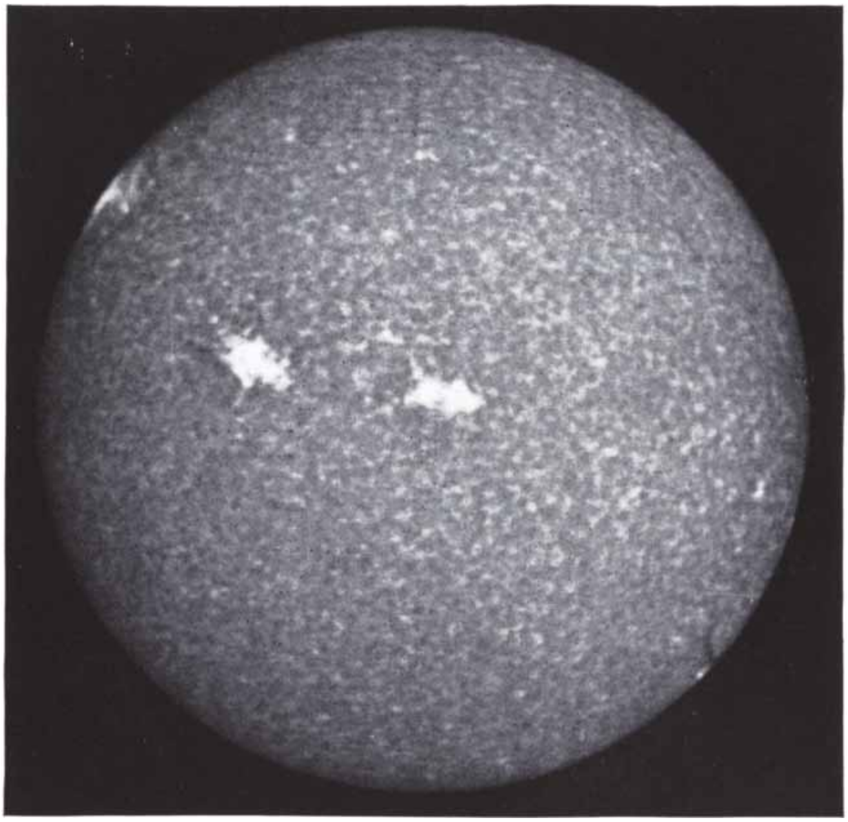
The events that seem most likely on the basis of their energy and time scale are solar flares. They are as shortlived as the lunar flares. While they last they emit enough energy, both electromagnetic and corpuscular, to disturb the inner precincts of the solar system for hours and days afterward.

Astronomers currently keep close track of solar disturbances by photographing the sun and by monitoring its radiations and their secondary effects with instruments on the earth and in artificial satellites. The records reveal that on October 28 at about 2:00 U.T. the largest solar flare of the year flashed from the surface of the sun. That flare introduced a week of turmoil that profoundly affected the density of particles in the region of the earth; there were several minor flares, including a double flare on November 1. The red glow observed by Greenacre and Barr occurred just 48 hours after the great flare of October 30. The enhancement Rackham and I photographed began 118 hours after that flare and eight and a half hours after the flares of November 1. (Some of the older observations, such as Herschel's, can also be correlated with disturbances on the sun; the Greenacre-Barr observation of November 27, on the other hand, came when the sun was exceptionally quiet.)

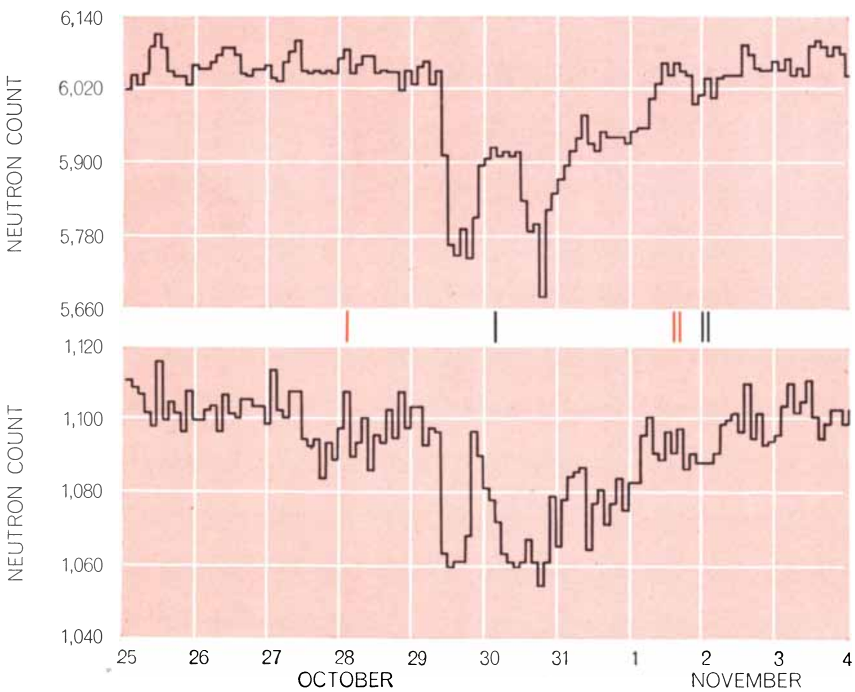
One significant fact that emerges from the available data is that not one of the recorded lunar brightness phenomena occurred simultaneously with a solar flare or any other major solar disturbance. The lunar phenomena therefore cannot be caused by electromagnetic radiation such as X rays, since any such radiation from a flare would have its effect on the moon at about the same time that the flare was observed. The case against direct electromagnetic excitation is closed by the fact that Herschel's "volcanoes," and indeed (according to Flamm and Lingenfelter) the majority of the previously reported lunar events, were observed on the dark side of the moon, where no X rays could have been impinging at the time.

Corpuscular radiation thus seems to be the only possible explanation, and in principle it is feasible. First of all, corpuscular radiation would normally reach the moon after a time lag of from several hours to a few days. Moreover, particles with enough energy, spiraling along lines of magnetic force, could reach any part of the day side or night side of the moon at any time. The only requirement is that the radius of the particles' spirals exceed that of the moon, and measurements of interplanetary magnetic fields indicate that this would be the case for protons of sufficiently high energy.

Unfortunately the quantitative aspects of the situation are not so clear. The large enhancement we photographed in 1963, which temporarily almost doubled the brightness of the Kepler region in red light, indicated that the energy flux of the incident particles must have been some 100,000 ergs per square centimeter. Assuming that the velocity of the protons was some 5,000 kilometers per second (which corresponds to the time lag between the occurrence of the double flare and our photographs), their density would have to have been in the neighborhood of 500 protons per cubic centimeter. The trouble is that the actual density in interplanetary space of protons of the appropriate energy is about one per 10



DISTURBANCES on the sun show as white areas on this calcium-light photograph made at 15:45 on November 1 by Helen W. Dodson at the McMath-Hulbert Observatory. The two small solar flares recorded that day came from the disturbance at the center of the solar disk.



SOLAR ACTIVITY affected the neutron flux at Deep River, Canada (*top*), and at London (*bottom*) late in 1963. Notable solar events were the great flare of October 28 and the small flares of November 1 (*colored bars*). Associated lunar events were the Greenacre-Barr sightings on October 30 and the author's observations of November 1–2 (*black bars*). Data are from T. Thambyahpillai of the Imperial College of Science and Technology in London.

cubic centimeters when the sun is quiet and only some 10 to 100 times greater during strong disturbances.

The lunar-night events are easier to explain. On the dark side of the moon a glow 10,000 times fainter should be visible from the earth; it might be caused by an energy flux as low as from one to 10 ergs per square centimeter. Moreover, only protons with very high energies, and therefore with velocities in excess of 50,000 kilometers per second, can follow trajectories curved enough to enable them to impinge on the dark side of the moon. As a matter of fact, the majority of the fast protons emitted by solar flares are known to move at speeds near 150,000 kilometers per second. At that speed a discernible nighttime luminescence could be accounted for by a density of only one proton per million cubic centimeters—and solar flares do emit very high-energy protons having such densities or even greater densities.

Nighttime lunar luminescence, in other words, can be explained by the energy conversion of high-velocity protons with densities that have actually been measured. The daytime luminescence, however, seems anomalously large. This gives rise to a suspicion that the effects of solar activity may depend on processes that are not yet understood and to which these lunar observations may be offering a clue.

This suspicion is strengthened by several reports concerning related phenomena. In 1958 D. E. Blackwell and M. F. Ingham of the University of Cambridge, working at Chacaltaya in the Bolivian Andes, noticed a temporary reddening and increase in brightness of the zodiacal light following a very large solar flare. The zodiacal light, a diffuse glow that is often visible in the Tropics at dawn and dusk, is a result of the scattering of sunlight by interplanetary dust particles. Blackwell and Ingham surmised that the enhancement they had observed was due to luminescence produced by the corpuscular output of the flare, but they were faced by the same quantitative difficulty that occurs in the case of daytime lunar luminescence: the energy flux required to explain what they had seen called for a proton density that seemed to be out of the question. These same two workers later pointed out that the brightness of the zodiacal light seems to be correlated with variations in the intensity of the earth's magnetic field.

A. G. W. Cameron of the Institute for Space Studies in New York has suggested that intense lunar luminescence may be caused not by the direct impact of solar particles on the moon but indirectly by their effect on the terrestrial magnetosphere, the envelope within which the earth's magnetic field is confined. The pressure of the solar wind apparently compresses the magnetosphere on the sun's side of the earth; on the opposite side of the earth the wind creates an elongated cavity into which the magnetosphere can expand [see "The Magnetosphere," by Laurence J. Cahill, Jr.; SCIENTIFIC AMERICAN, March]. Solar particles might be accelerated by the shock wave that marks the boundary of the magnetosphere or might somehow be trapped and stored in the long tail of the magnetosphere on the side of the earth away from the sun. In this connection Cameron pointed out that in all instances of intense luminescence the moon has been close to full; that is, it has been on the side of the earth away from the sun.

Recently Helen W. Dodson and E. Ruth Hedeman of the University of Michigan have pointed out an apparent correlation between the particle fluxes associated with solar activity on the one hand and the lunar cycle on the other. This may actually represent a correlation between solar-particle activity near the earth and the positions of the moon and the magnetosphere, but not enough data are yet available for one to be sure.

In summary, it is now clear that the luminescence of the moon, which has long been suspected on the basis of several lines of evidence, must be accepted as a fact. All known examples of lunar luminescence seem to be directly or indirectly related to some activity of the sun, but the relation is not simple and need not be based on overall sunspot activity. Although it is still not possible to trace each lunar enhancement to a specific solar event, one can say that the lunar flares are probably caused by protons emitted in solar flares. The energies and densities of these protons are sufficient to account for luminescence visible on the dark side of the moon but not for the daytime phenomena; for these it is necessary to look for an explanation in terms of some secondary accelerating or storage mechanism.

Whatever it is that glows on the moon seems to be localized, in some cases in very small regions, as in the spots near Aristarchus. The study of luminescence, by leading to the identification of the luminous materials, may provide a valuable tool for long-distance geological prospecting in the moon's outer crust. The work described in this article is pointed in a different direction, however: I think of the moon as a tool with which to probe the relations between the sun and the earth.

As we launch artificial satellites to examine the contents of space we should not forget that we have at our astronomical doorstep a natural satellite that exposes a large target to the cosmic particles it encounters in orbit. The moon is, in fact, a valuable space probe: parts of its surface can be regarded as natural wavelength converters that transform high-energy corpuscular radiation into visible light through the medium of luminescence. Someday the lunar flares that result from this process will be monitored systematically, under an international cooperative program, just as solar flares and their associated phenomena are now. There is hope that such a program will be instituted in the near future.

PIC DU MIDI OBSERVATORY, where the first photographs demonstrating lunar luminescence were made, is 9,400 feet above sea level in the Pyrenees. The observatory is one of the world's highest but is also quite accessible. The air is remarkably free of dust, so the observatory is ideal for lunar photography. The 24-inch refracting telescope is housed under the dome in the foreground.

HIGH-PRESSURE TECHNOLOGY

It has advanced rapidly since the synthesis of diamond a decade ago, not only in the building of larger presses but also in the evolution of mechanical concepts for dealing with high pressures in general

by Alexander Zeitlin

At one time the study of what happens to materials subjected to very high pressures was conducted in the spirit of alchemy. Would-be makers of diamonds had learned by the end of the 18th century that the gem is a form of elemental carbon. In the 19th century the work of Willard Gibbs in thermodynamics suggested that a form of carbon such as graphite might be transformed into diamond at certain high pressures and temperatures. But how to define the exact conditions of this transformation, and how to build the equipment to attain such conditions? The alchemists asked physicists.

Percy W. Bridgman, the Harvard University physicist who investigated the behavior of matter at high pressure from 1905 to 1959, reported that he was approached several times a year with offers to participate in diamond-making schemes. Ironically the goal of diamond production was not inappropriate for serious investigators: diamonds are indispensable for industrial grinding and the anticipated demand far exceeds the natural supply. When Bridgman's methods were finally used to make industrial diamonds, he spoke of the development with the enthusiasm another man might have had for the making of gems.

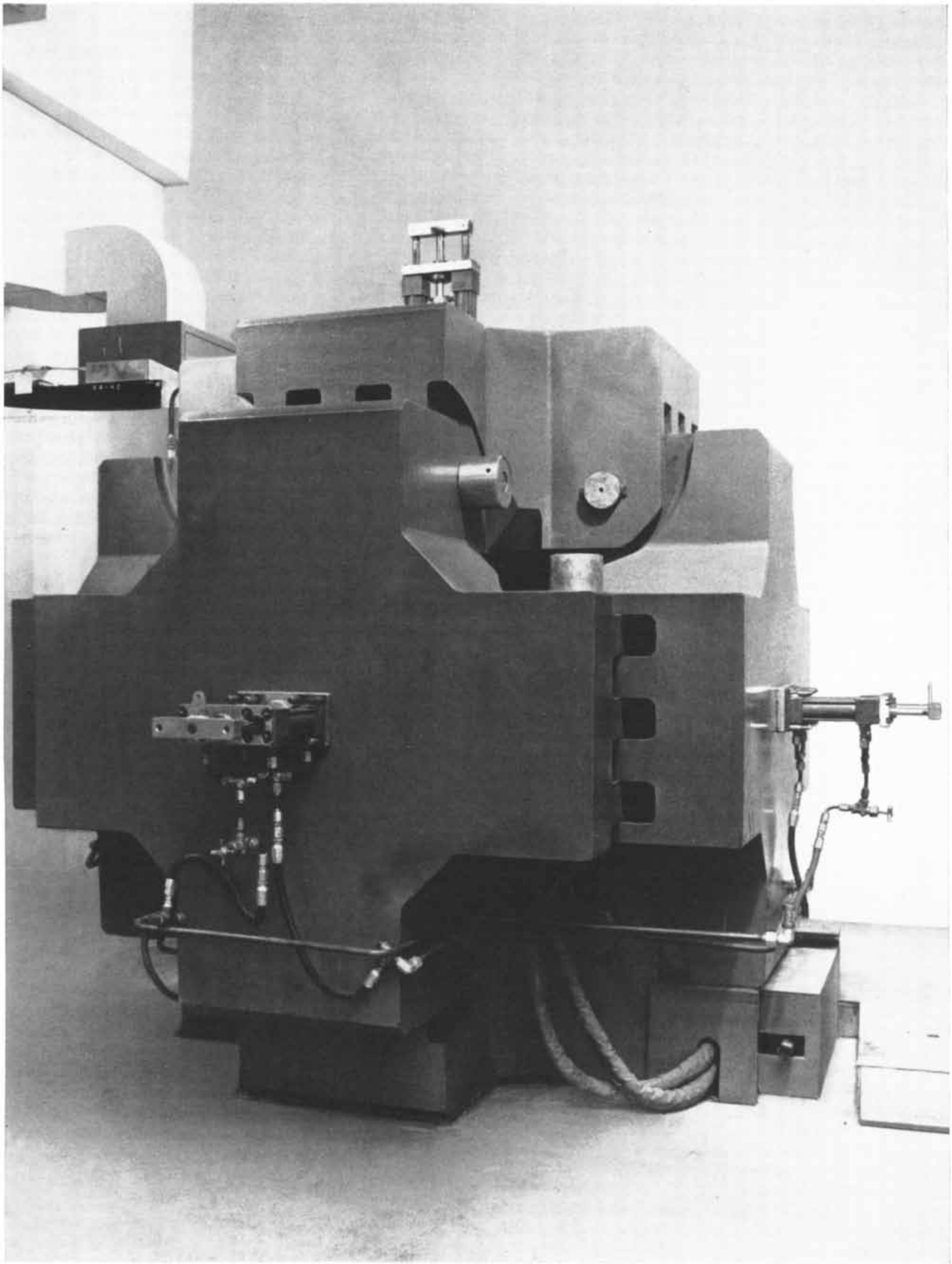
The hydraulic press that produced the first systematically grown synthetic diamonds was capable of exerting a pressure of about 700 tons per square inch. Today there are presses that can attain more than 3,000 tons per square inch. At the same time the temperatures and pressures needed to transform graphite into diamond have been somewhat reduced.

Diamonds have been made since 1955 in high-pressure facilities distributed throughout the world. Today the dollar volume of high-pressure technology can be estimated at about $25 million annually, with about 80 percent of the total made up by the sale of synthetic industrial diamonds produced in the U.S., the Union of South Africa, the U.S.S.R., Sweden, Japan and Ireland. Other direct applications of high-pressure technology are becoming economically important, and perhaps even more significant is the role of high-pressure technology in the design of pressure vessels for chemical processes, of shells for pressurized nuclear reactors, of facilities for simulating conditions deep in the ocean and of presses themselves. High-pressure laboratories have succeeded in compacting powdered beryllium into a solid, in squeezing porous materials such as graphite down to their theoretical density and in synthesizing entirely new metallic compounds. Also in progress are high-pressure studies of such fundamental properties of matter as electric conductivity, magnetic resonance and the irreversible rearrangement of molecular structures.

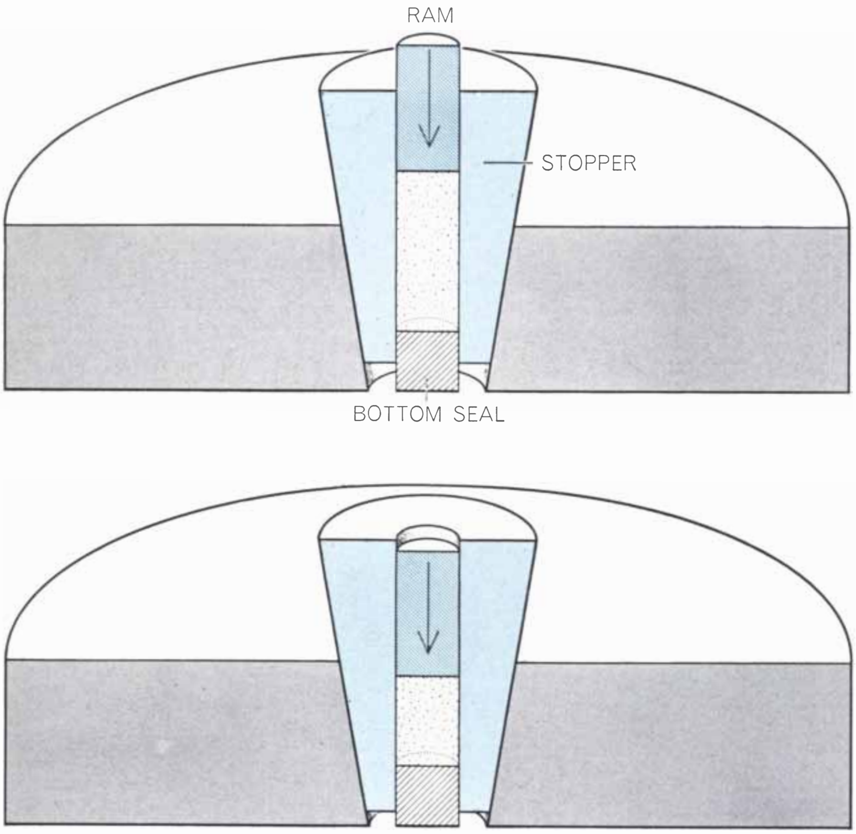
In view of the variety of these achievements one must now distinguish between the goals of the investigator and those of the industrial technologist. It is one thing to demonstrate that high pressure gives rise to an increase in the electrical conductivity of a certain material and quite another to produce the better conductor in quantity. Bridgman's primary concern was of course the investigation of the effects of high pressure; thus he designed equipment only to accommodate samples of matter little bigger than a pinhead. The past decade of high-pressure technology has been characterized by the design and construction of equipment to process larger quantities of material. Even in this post-Bridgman era, however, the legacy of Bridgman is profound; it was the principles and concepts he developed in the laboratory that made possible the new equipment for industry.

The problem of designing a device for concentrating a large force on a small area is made considerably easier by the law of physics that states that when pressure is exerted on a liquid enclosed in a container, the pressure is the same throughout the liquid and against the walls of the container. Thus an initially small force can be enormously amplified by a series of piston-and-cylinder units connected in such a way that the pressure exerted by the piston in a smaller cylinder is conveyed to the piston in a larger cylinder; the amplified force can finally be concentrated by a piston pushing a thin rod. The limit of the conventional piston-and-cylinder arrangement is established only by the strength of the materials of which it is made.

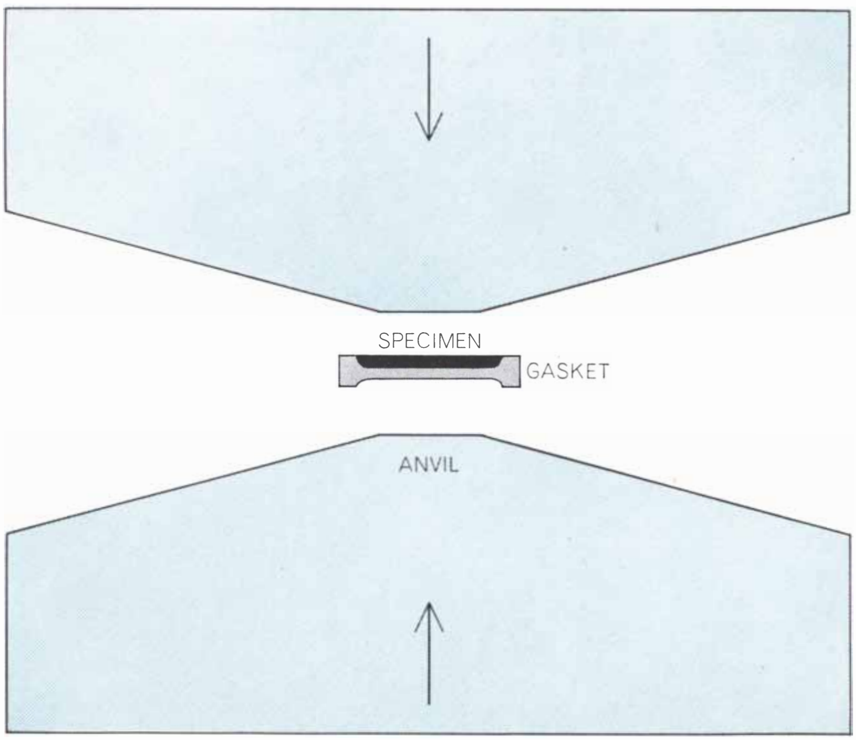
Even with the introduction of exceptionally strong materials (for example cemented tungsten carbide, which has twice the compressive strength of steel), designers of high-pressure equipment were still faced with the fact that they could generate higher pressures than their containing structures could withstand. One modification of the ordinary piston-and-cylinder arrangement that suggested itself was to reinforce the cylinder with a "shrink ring": a cylinder of slightly larger diameter that is heated, slipped over the smaller cylinder and allowed to cool. The shrinkage of the outer cylinder then exerts a compressive inward stress that counters the tensile stresses generated during the pressure stroke. The support offered by the shrink ring is of course limited by the cylinder's ability to bear the compressive shrink stresses when it is not subjected to internal pressure. In practice the shrink ring made it possible to



CUBIC PRESS has six large "heads" of forged steel. Within each head is a cylinder fitted with a ram that thrusts against a steel plate that transfers pressure evenly to the cemented tungsten-carbide working face of an anvil, which in turn presses against a cubic gasket of pyrophyllite, a volcanic rock, containing the batch to be pressed. Each anvil can exert 2,700 tons of pressure. The press, designed by the staff of Barogenics, Inc., is used for research at the U.S. Army Electronics Laboratories in Fort Monmouth, N.J.



"STOPPER" DEVICE designed by Percy W. Bridgman of Harvard University is a steel ring with tapered hole accommodating the cylinder of a press. When piston inside the cylinder pushes it down (*bottom*), the stopper binds it tightly, counteracting the potentially explosive internal stress. The bottom seal is anchored to the stopper and moves with it.



MASSIVE SUPPORT is given to the small working face of an anvil by widening of the cross section just behind it. Bridgman devised this arrangement to replace one in which the thrust of a piston was transmitted to a specimen by means of a thin, easily breakable rod.

double the range of pressures that could be contained in a cylinder.

Bridgman himself modified many parts of the traditional high-pressure equipment. He did away with the method of placing the specimen in a cylindrical container, then plugging one end and applying pressure by advancing a piston from the opposite end. He replaced it with a "stopper" arrangement that called for a heavy steel ring with a tapered hole to accommodate a cylinder tapered on the outside [*see top illustration at left*]. The higher the pressure created in the cylinder by the advancing piston, the greater the force with which the cylinder—the stopper—is driven into the tapered hole and the greater the compressive force counteracting the internal pressure. When it is time to reduce the internal pressure and withdraw the stopper, however, it is almost impossible to maintain the balance of forces inside and outside a large cylinder; the cylinder sometimes ruptures. This difficulty obviously limits the usefulness of the stopper design in industrial technology.

The weakest part of the traditional apparatus—the thin rod that concentrates the thrust of the final piston—was also eliminated by Bridgman. He substituted a "massive support anvil": a cylinder that ended in a truncated cone. By placing two such anvils in opposition to each other, he was also able to eliminate the stopper. The specimen to be subjected to pressure was inserted into a gasket shaped like an indented pill [*see bottom illustration at left*]. The massive support given the small round working faces of the anvils by their increasing cross section enables them to withstand stresses that the stopper cylinder cannot.

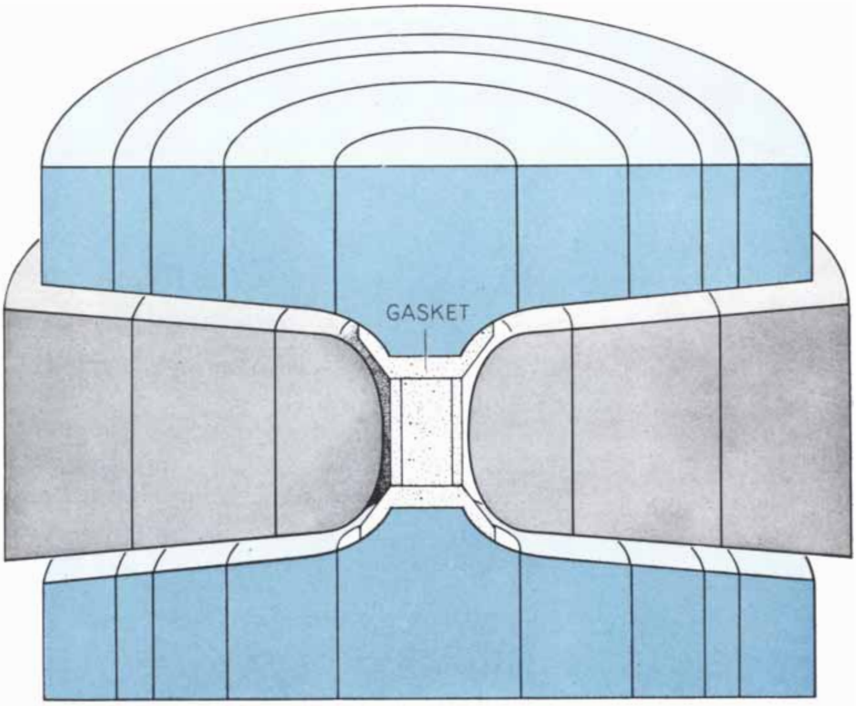
Ingenious adaptations of Bridgman's principle of massive support to piston-and-cylinder machines made possible the three very similar devices for transforming graphite into diamond that were used by H. Tracy Hall at the General Electric Company, J. F. H. Custers at the Adamant Research Laboratories in the Union of South Africa and L. F. Vereshchagin at the Institute of High Pressure Physics in the U.S.S.R. The piston—called a ram—of each device is shaped like a Bridgman anvil except that the end of the ram is curved as well as tapered. In each device the ram fits into a cylinder that is reinforced by several superimposed shrink rings and resembles a massive-support anvil in that it tapers to a blunt cone.

The escape of the specimen (it is called a "charge" in industrial production) through the narrow space between ram and cylinder is prevented by another Bridgman stratagem: a gasket of pyrophyllite, a volcanic rock. These gaskets flow under pressure, but once the pyrophyllite oozes outside the region of pressure it immediately solidifies and prevents any of the charge from escaping.

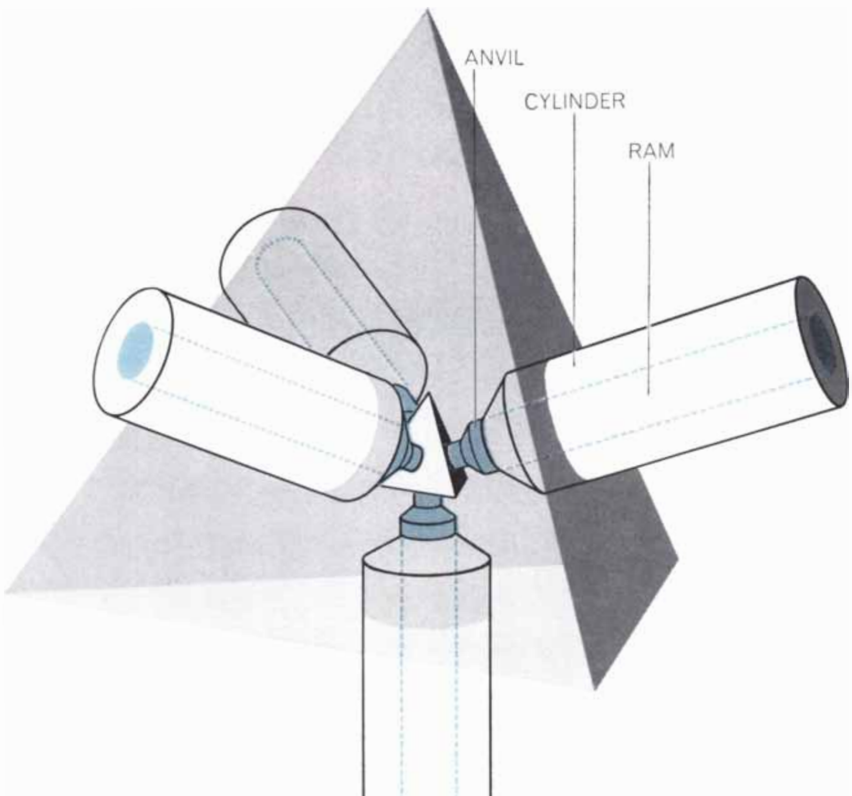
The use of shrink rings led Hall to nickname his machine "the belt." It accommodated a charge of graphite that yielded three to four carats of diamond grit, or less than one gram of final product for each cycle of pressure. Today the largest belt unit is a Soviet model that, according to reliable sources, produces somewhere around 20 carats of diamond per cycle. These batches are not large enough to make economically practicable the industrial processing of any material less precious than diamond grit, which sells for $2.80 per carat.

The special interest I share with my colleagues at the engineering firm of Barogenics, Inc., is the application of high-pressure techniques to the production of substances other than diamond—for example metals. For this purpose our group began in 1957 to explore the feasibility of developing high-pressure machines in sizes far exceeding any then in existence. Realizing that an attempt simply to increase the size of existing piston-and-cylinder devices would be futile, we (and independently Hall) began paying attention to devices that simultaneously apply the pressure of several rams to a specimen. Hall designed a unit in which each of four anvils exerted a pressure of 200 tons on a tetrahedral container; the total pressure (not pressure per square inch) was thus 800 tons. At our firm we concentrated on designing a unit in which pressure would be exerted from six sides on a cubic container. A cubic arrangement seemed desirable because the geometry of a cubic specimen assembly provides a useful volume about seven times greater than the specimen assembly of a tetrahedral machine that exerts the same total pressure. Our cubic hydraulic press also incorporated another innovation of design that set it apart from Hall's tetrahedral press. This was "link pin" construction, which can be described as follows.

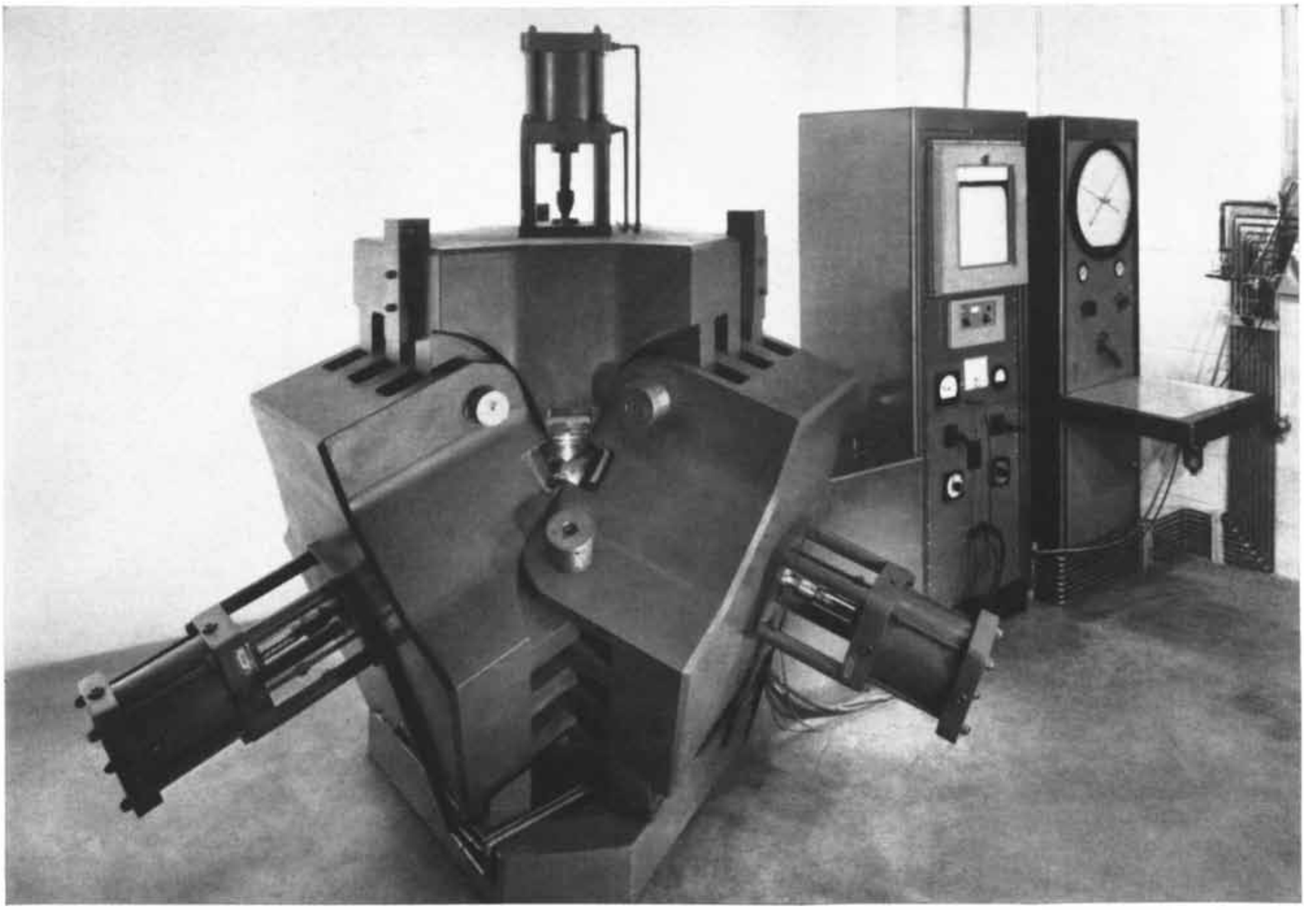
A cubic hydraulic press has, by definition, six "heads." Each head consists of a cylinder, a ram, a tungsten-carbide anvil and a steel plate that transmits the thrust of the ram evenly to the anvil. The heads of a hydraulic press are conventionally connected by massive



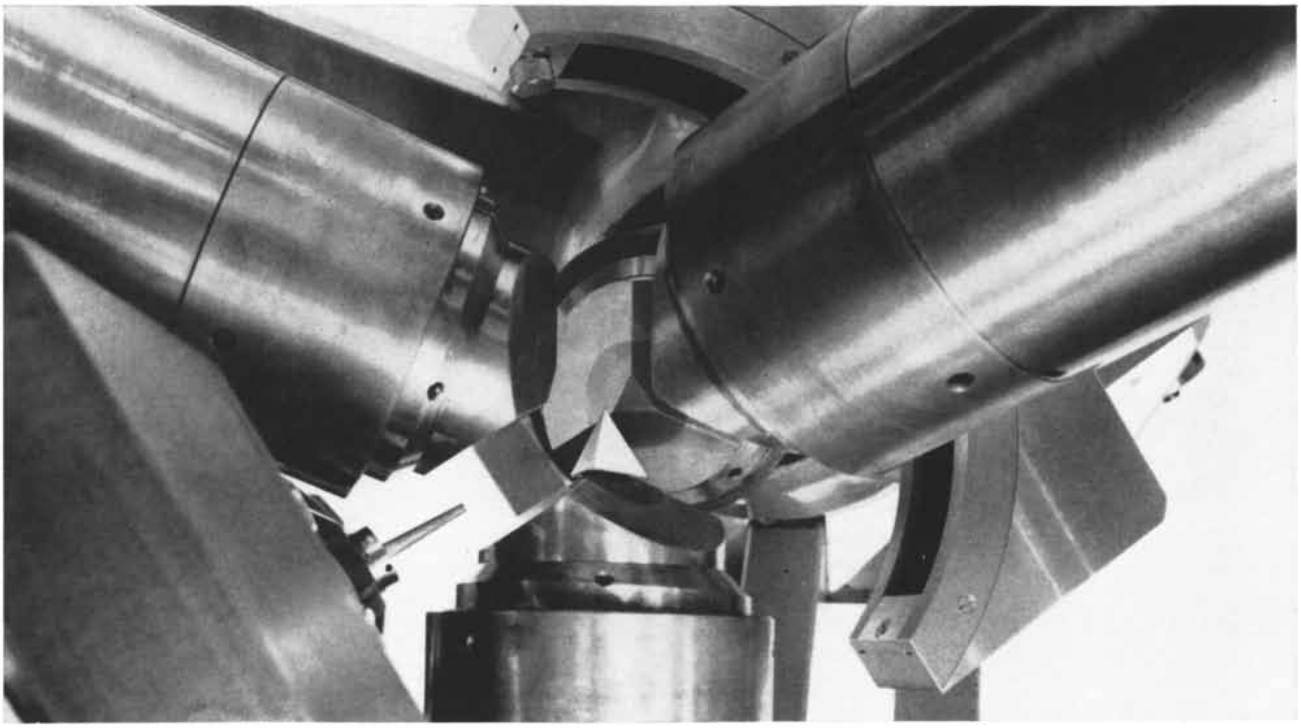
"BELT" DEVICE uses compressive rings, superimposed on one another, to oppose the stress generated by ram (*color*) descending in cylinder. Rings are shown in section from top.



MULTIAXIAL PRESS, exemplified by this tetrahedral device, exerts pressure from many sides at once. The feasibility of this idea was first demonstrated by H. Tracy Hall, now of Brigham Young University. The movable parts of the machine are in color. The dotted line shows that in each cylinder there is a movable ram that thrusts anvil against specimen.



TETRAHEDRAL PRESS consists of four heads hinged together by link pins. Entering into each head is a cylinder containing a ram that thrusts an anvil against a gasket containing the specimen to be processed. Two consoles at right are control panels. Each anvil of this press exerts 2,000 tons of pressure. The press is at the Monroeville, Pa., plant of the United States Steel Corporation.



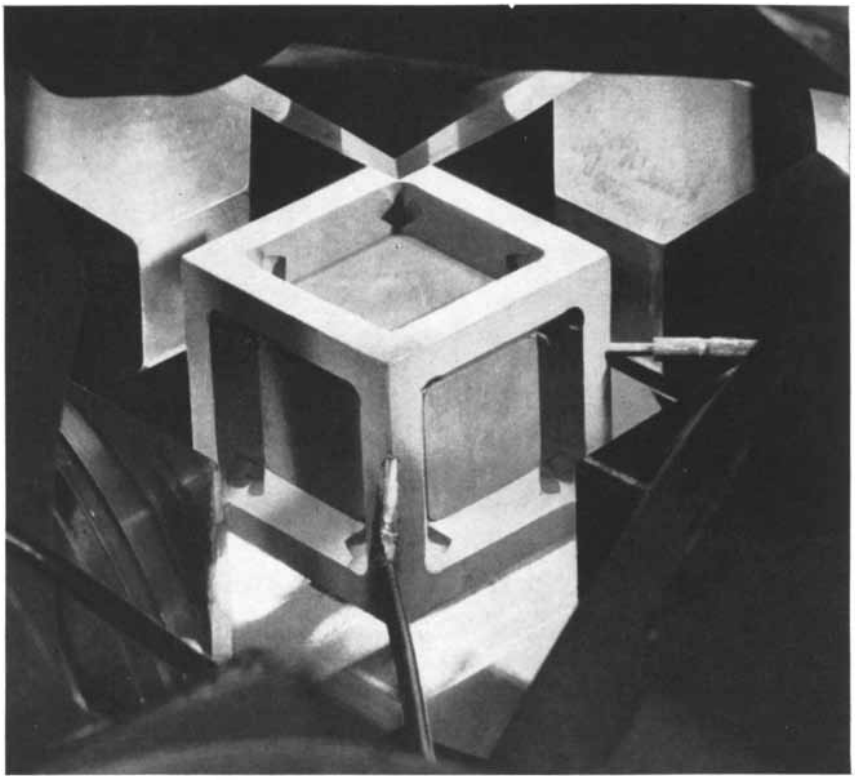
SPECIMEN ASSEMBLY OF TETRAHEDRAL PRESS consists of a tiny tetrahedral gasket on which four anvils are trained. Behind the tungsten-carbide working face of each anvil is a ram. Thin rod at lower left directs an X-ray beam at specimen so that a diffraction pattern appears on film in semicircular camera (*upper right*). This press is at the Hanscomb Air Force Base in Bedford, Mass.

threaded tie rods and are oriented with respect to one another by steel beams; Hall's tetrahedral press is conventional in this sense. We discovered that the tie rods could be replaced by a frame resembling a set of interconnected hinges. Whereas the stress on a tie rod is entirely exerted on a single cross section of the rod, the stress on a hinge device is distributed along its link pin as a series of shear stresses. The use of a link-pin frame in high-pressure machines was found to save space, weight and costs. Perhaps even more important, it greatly facilitated the alignment of the press heads and did away with certain deflecting stresses that the tie rods tended to exert.

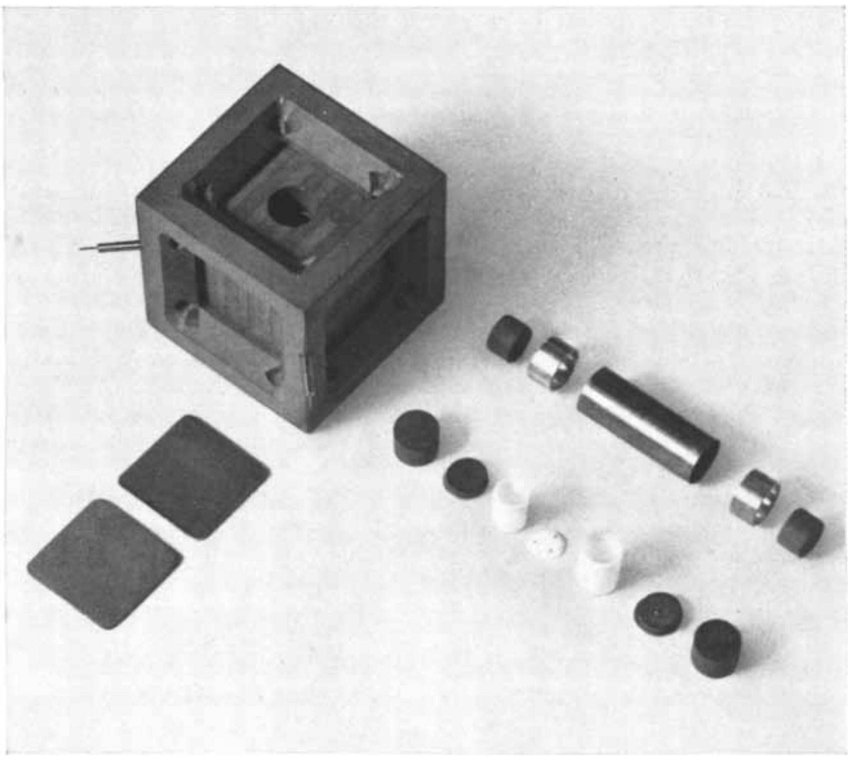
Soon after we filed to patent the link-pin frame in April, 1959, a group of 24 Soviet inventors announced the development of a similar arrangement. Since that time the evolution of high-pressure machines in the U.S. and the U.S.S.R. appears to have proceeded at about the same rate. Current Soviet technical literature mentions machines producing 100-carat batches of diamond grit, approximately the same amount that can be handled in one cycle by the largest cubic presses built in the U.S. The six anvils of these cubic machines can exert a total pressure of 16,200 tons. The way in which the pressure is concentrated can be changed by changing the surface area of the anvils; the greater the area, the less pressure exerted. Operating with anvils whose square faces are two and a half inches on a side, a cubic machine can exert a pressure of 450 tons per square inch; with anvils whose faces are three inches on a side the pressure is 300 tons per square inch.

To the eye a cubic machine consists of six heads enclosed by massive link-pin assemblies; the working space and its tools are concealed within the machine. In the working space six anvils designed in conformity with Bridgman's principle of massive support are trained on a cubic gasket of pyrophyllite. As the anvils press inward the pyrophyllite is extruded against the portion of each anvil that is subjected to the greatest stress, counteracting to some degree the anvil's tendency to fracture. Of course, forces absorbed in the gasket do not serve the primary purpose of the apparatus: compression of the specimen. The beneficial effect of the gasket on the life of the tungsten-carbide anvils, however, compensates for the loss.

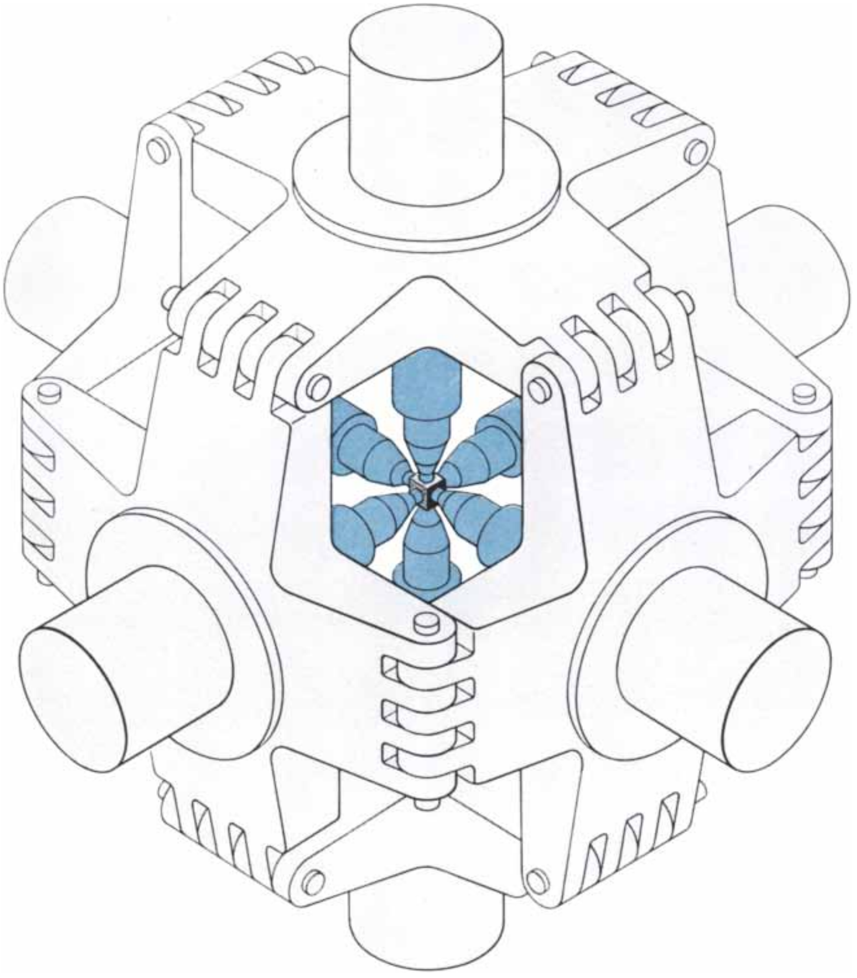
The quality of tungsten-carbide an-



CUBIC GASKET made of pyrophyllite is held in place by a frame fitted to accommodate the working face of the anvils visible in background. The wires leading from the frame of the gasket are for relaying data about the temperature attained within the assembly.



SPECIMEN ASSEMBLY OF CUBIC PRESS is dismantled. The square plate closest to the frame is a tab for conducting heat from the face of an anvil to the specimen. The other plate is a pyrophyllite outer casing for the gasket. In top row at right of gasket, from center out, is the cylinder that holds the specimen, rings to bind plugs into each end of the cylinder, and the plugs themselves. In bottom row, from center out, is a pressure cap with three leads for coaxial cable, a two-part Teflon jacket for the specimen, spacers and pyrophyllite plugs.



LINK PINS hinge together the six metallic heads of a cubic press. The pins form a rigid frame for the heads, help to distribute stresses evenly and make the machine self-aligning.

vils was a particular problem in the development of large high-pressure machines. The manufacturers of tungsten-carbide tools seemed somewhat reluctant to undertake experimental research. Since the practicality of large machines was the issue at hand, scaled-down models would have been meaningless. We were obliged to conduct our own experiments with full-sized tools costing $500 to $1,000 each, and we were naturally chagrined when many of them cracked. In 1961 alone our firm fractured tools worth more than $60,000. Today, fortunately, the problems associated with tungsten-carbide anvils can be considered solved.

Not every aspect of making presses bigger creates problems. The task of controlling pressure and temperature actually becomes easier as one works with larger specimen assemblies. The reason is simple: given a small batch, any draft of cool air into the working space of the machine or any momentary fluctuation in the electric current powering its compressor motors can induce a drastic change in the specimen. With a large batch the effect of such small changes is proportionately less. The specimen assembly of a 120,000-ton press designed recently will have a working space with a volume of 570 cubic inches, or almost two and a half gallons, within which it can be expected that the temperature will remain quite constant.

One of the most dramatic results of the effort to construct larger high-pressure equipment was the finding, made simultaneously by our firm and by the research staff of the Swedish General Electric Company (Allmanna Svenska Elektriska Aktiebolaget, or ASEA), that the cylinder-and-ram arrangement is not the only way to apply pressures to a specimen assembly from several different directions. The same result can be achieved if a set of massive nested anvils surrounding it is enclosed in a resilient, impervious envelope that is in turn surrounded by a pressurized liquid. When hydrostatic pressure is applied to the large outside areas of the anvils, the radial force that is generated is concentrated on the much smaller anvil areas in contact with the specimen assembly.

The differences between the first two of these hydrostatic units are comparatively minor. The unit made by Barogenics used rubber for the resilient envelope and exerted a primary hydrostatic pressure of about 15,000 pounds per square inch; the ASEA unit used a copper sheet and exerted a pressure of between 60,000 and 90,000 pounds.

In our second-generation hydrostatic units the rubber envelope has been replaced by a cage with cylindrical openings in which the rams are guided. "Floating" seals are placed between the rams and the cage in accordance with a Bridgman principle that calls for maintaining a pressure between seal and seal support that is much higher than the overall pressure in the system. The seals prevent the pressurized liquid from penetrating the space between the rams.

The primary pressure actuating the units can be generated elsewhere and delivered to the unit by appropriate pipelines, or it can be generated directly in the unit. The latter method is used by ASEA; it involves placing the hydrostatic unit on the bed of a powerful cylinder-and-ram press and using an extension of the ram as a plunger to actuate the hydrostatic pressure. When ASEA began to use units of this design for the commercial production of industrial diamond grit, it was demonstrated that cylinder-and-ram units and hydrostatic units can be used for the same practical ends. Since that time hydrostatic units have been used for such purposes as forging metals at high temperature, forming precise metal parts and making sintered substances denser. The Union Carbide Nuclear Corporation employs a hydrostatic unit for compacting powdered metals and cermets (ceramic-metal combinations). For the General Dynamics Corporation a hydrostatic machine has been designed to produce dense graphite bricks for moderating and reflecting neutrons in nuclear reactors. This unit will be much larger than any now operating: each of its six anvils will exert a pressure of 8,000 tons for a total pressure of 48,000 tons, and the graphite cubes it produces will be eight inches on an edge.

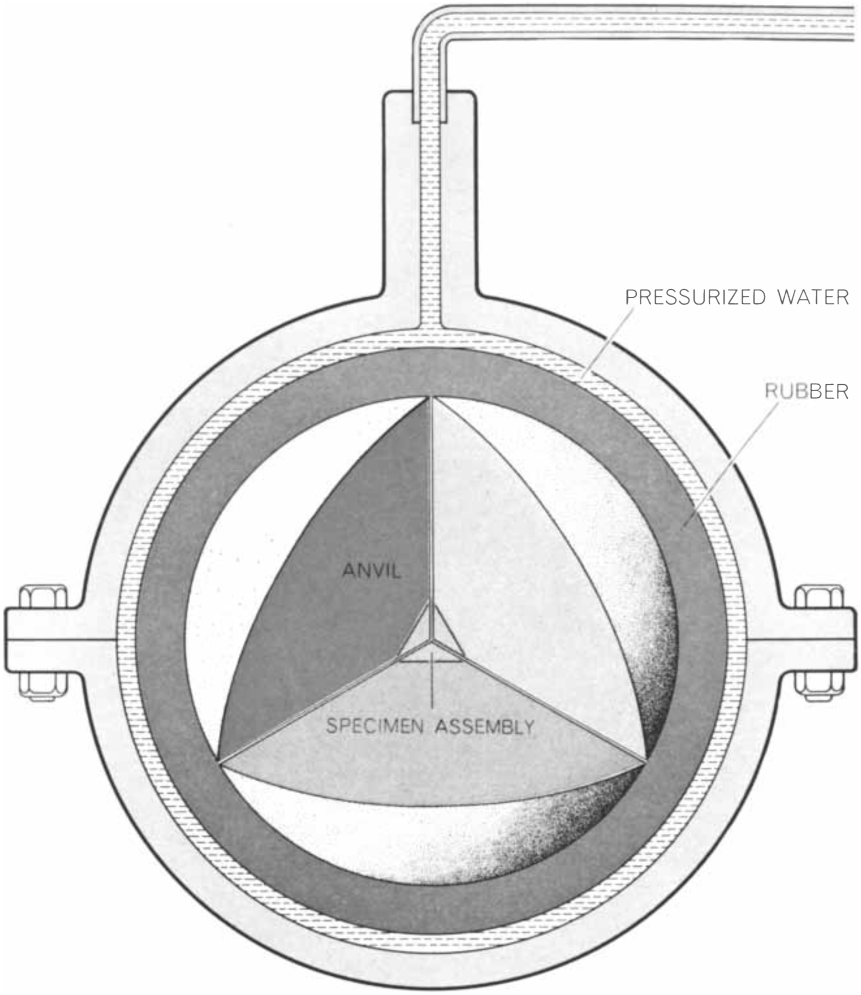
The hydrostatic units built so far by ASEA or Barogenics are not very large, and even those being designed are too small to be widely useful in industrial production. In attempting to scale up the designs, however, we run into basically the same problem that prevents the scaling up of machines in which a ram exerts pressure within a cylinder. In both hydrostatic and ram-and-cylinder machines the enclosing vessel is subjected to radial bursting stresses ("hoop stresses") distributed so unevenly that the metal near the inside of the vessel is fully stressed and the metal outside it is hardly stressed at all. Increasing the thickness of the vessel is not much help; eventually those regions that bear the stresses give way.

It was pointed out as early as 1951 by Thomas C. Poulter of the Stanford Research Institute that the only solution to the problem is to eliminate the hoop stresses by somehow dividing the containing vessel into segments. But how to hold together segments that, under the influence of internal pressure, would tend to move out and away from each other? Here the link-pin arrangement offered a satisfactory solution. It also indicated that single-cylinder presses were not yet a thing of the past.

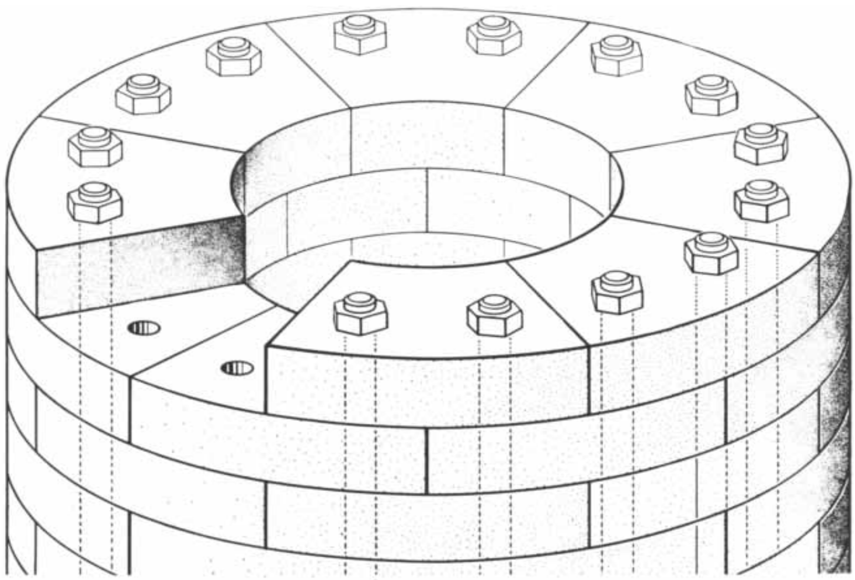
The cylinder could be divided into strips running its full length, with the edges of the strips mating with each other like hinges. The link pins would run the length of the cylinder through the holes in the hinges. Before we could put this idea into practice, however, it was superseded by a better one. Why not divide the cylinder not only along its length but also around its circumference? The cylinder would then be constructed like a brick wall, with the overlapping bricks fastened together by link pins.

The stress relations in such an arrangement can be analyzed as follows. All the link pins located on a given diameter of the cylinder are exposed to a bursting force that is a function of internal diameter and internal pressure. The tensile stress borne by the segments determines the diameter of the pins; the shear stress borne by the pins similarly determines the thickness of the segments. If it had not been for the development of the segmented wall, cylinders of large diameter that can withstand great pressure could not have been made. As a bonus, segmented cylinders can obviously be fabricated and shipped in parts. This is an important advantage; the manufacture of large one-piece high-pressure vessels is beyond the capability of existing facilities for forging and machining.

Another important application of the link-pin concept should be mentioned.

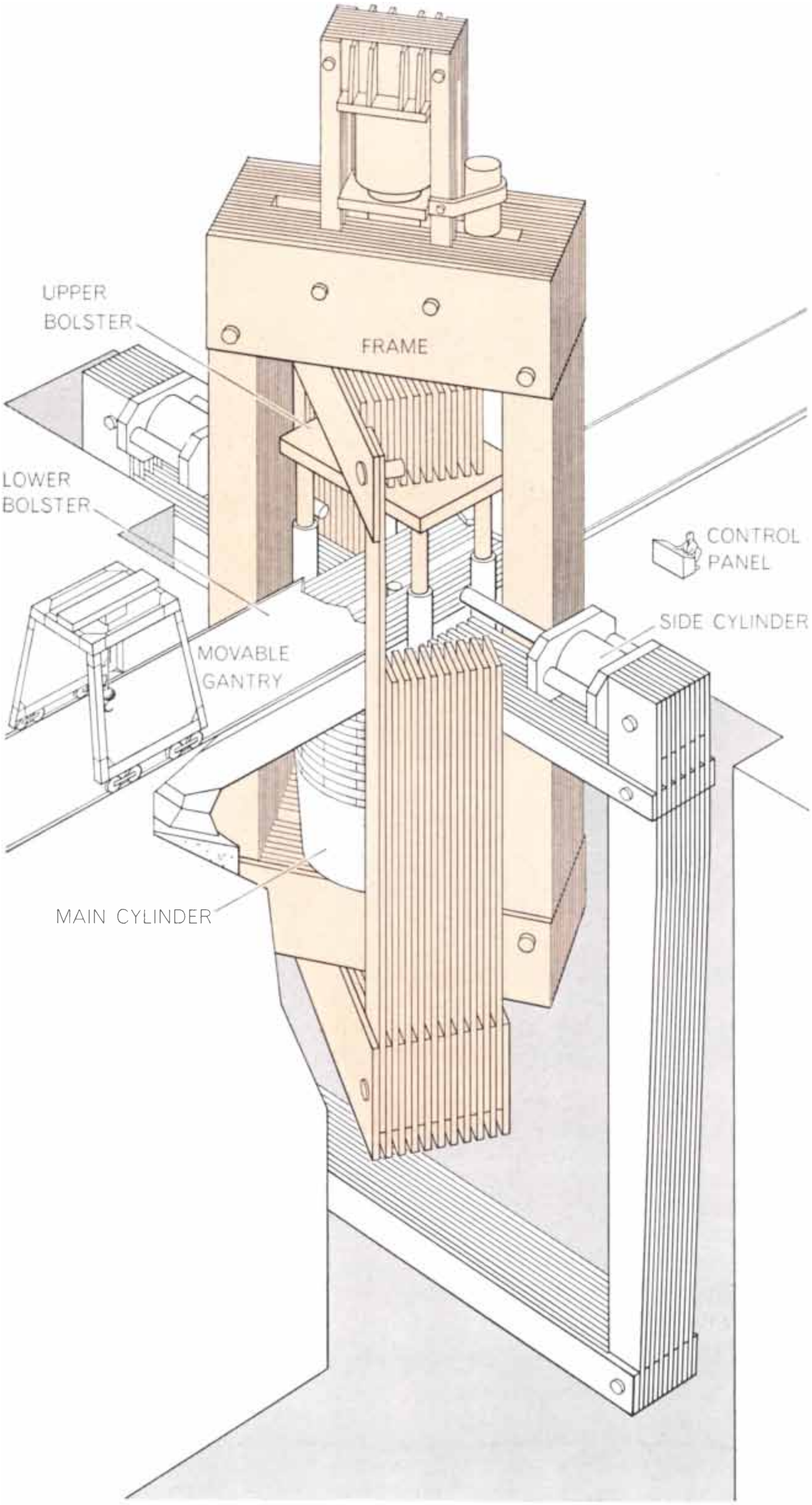


HYDROSTATIC PRESS is illustrated schematically in cross section. The outer shell is steel. Pressurized water is pumped into the area between the shell and an inner sphere of hard rubber. The rubber transmits pressure exerted by the water to the curved bases of the anvils. The anvils thrust against the specimen assembly at the very center of the press.



SEGMENTED WALL of a pressure-containing cylinder is made by assembling bricklike units of forged steel and connecting them with link pins that help to distribute stresses.

The thick one-piece dome that closes the end of the cylinder can be anchored on the link pins of the cylinder or it can be supported by an independent frame connected by link pins. The advantage of an independent frame is that no stresses are transmitted from the dome to the cylinder; thus the cylinder is not subjected to additional forces and its life expectancy under a recurrent load increases.



MOST POWERFUL PRESS yet designed is this 220,000-ton single-cylinder hydraulic press that the Wyman-Gordon Company will use to forge airplane and submarine parts. The press will be 10 stories high and will have a bed large enough to handle material 18 by 28 feet in area. Hydraulic pressure actuates the machine when a ram thrusts down within the cylinder that is located beneath the bed. The colored parts of the apparatus descend and pressure is thus exerted on the bed, which does not move. On pathway at left is a movable crane that brings materials onto the press. Two side cylinders near top apply pressure in the direction perpendicular to that in which the main cylinder operates. The immense pressure generated in the main cylinder could not have been contained by any wall but a segmented one.

The development of the segmented vessel is perhaps the most dramatic event in the post-Bridgman era of high-pressure technology. In making it possible to build larger single-cylinder presses the link-pin concept has brought the field full circle. It now seems practical to develop a single-cylinder press far more powerful than any of the multicylinder presses currently in use or under construction.

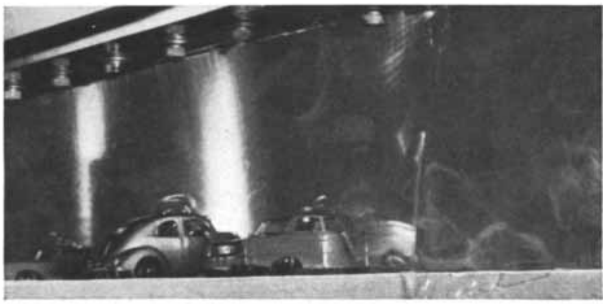
It was realized as early as 1960 both in this country and in the U.S.S.R. that the single-cylinder press was best suited to concentrating a huge force on a comparatively small area. In that year, however, the largest single-cylinder machine could not exceed a total pressure of 75,000 tons. Now plans are under way to produce a 220,000-ton press in the U.S. and a press of similar capacity in the U.S.S.R.; the U.S. design has been developed jointly by the Wyman-Gordon Company and Barogenics. The latter press will be used to forge airplane and submarine parts on a bed 28 feet long and 18 feet wide. Over a small part of the bed it will be able to exert, by means of a massive-support device, a pressure of 750 tons per square inch. Its single-cylinder design would have seemed unworkable a scant five years ago.

In 1961, during one of his last appearances at a scientific conference, Bridgman expressed the wish that the high-pressure field would not be limited to his contribution but would be advanced by those who had learned from him. Today his wish is being carried out by scientists and engineers designing more powerful and efficient high-pressure equipment. The many contributions being made simultaneously by groups working independently throughout the world indicate the activity of the field and augur well for its future development. The study of high pressure, one man's special interest at the start of the century, is now an independent branch of science and technology exerting its influence on many fields.

Kodak advertises:

Murphy and the flowing curtain . . . optimism about fine temperature differences . . . holography

Pour the package over the product



—and it just might prove practical for real ones, too. Call it the EASTOFLOW System. Recognize it as a great leap forward we are sponsoring in that most contemporary art form, packaging. Just pour the package over the item as a bubble-free liquid curtain of a suitable thermoplastic, pull it skin-tight by a short suck, and trim the congealed excess. What a way to move a chemical solid product from you to them protected from the malevolent air! What a way to keep track of a large-value, small-size electronic item, mounted on its own punched card for inventory control! What a saving over the old skin-packaging, where first you pay for nice flat sheet and then you pay for pulling it into the shape of the object!

An enthusiast named John Murphy, who can be reached at Eastman Chemical Products, Inc., Kingsport, Tenn. 37662 (Subsidiary of Eastman Kodak Company), knows better than to let anybody sign a lease for an EASTOFLOW *Machine unless likely to wind up better off for having done so.*

The possible dawn of the cholesterol age

D.C.B., a chemist of ours and an extremely busy man, took a day off. Mrs. B., a clever girl enjoying a fine run of good fortune on a nationally televised contest, had reached the stage of competing for a substantial prize in Florida real estate. He kept her company to New York for the shot at the big one. But to make good use of his hour aloft, he took along *Scientific American* to catch up on science as an aspect of modern culture. There, in the August 1964 issue, he found an article on the cholesteric state of matter. Suddenly a question answered itself. Suddenly he understood why our Eastman Organic Chemicals Department had been getting inquiries lately for the esters of cholesterol.

A fellow giant no less respected than Kodak was permitting one of its scientists to disclose in the magazine certain exciting physical properties of the esters of that greasy stuff which has lately become familiar by name to prosperous, middle-aged males. The new-found properties offer little apparent cause for worry. On the contrary, the author winds up on a broadly optimistic note hinting at forthcoming discoveries that might assign cholesterol a central role in the sensory mechanism of the vertebrates. The optimism is generated by a remarkable sensitivity to fine temperature differences and to traces of various vapors that is seen in the color of the light reflected by layers of the esters. Though cholesteryl esters are old stuff, as are the nematic, smectic, and cholesteric interregna between the liquid and solid states of matter, new visions arise of salves that show the physician epidermal temperature anomalies difficult at best to find with complex instruments,[1] of simple nondestructive test methods that reveal structural unsoundness through singularities in heat flow.

So it came to pass that Mrs. B., calmed and comforted by a husband beside her engrossed in his *Scientific American*, went on and won the big house and lot in Florida. Further did it come to pass that we can now offer *3-Chlorocholest-5-ene* (EASTMAN 9562, "Cholesteryl Chloride"), *Cholesteryl Acetate* (EASTMAN 2391), *Cholesteryl Myristate* (EASTMAN 9693), *Cholesteryl p-Nitrobenzoate* (EASTMAN 9697), *Cholesteryl Nonanoate* (EASTMAN 9669), and *Cholesteryl Propionate* (EASTMAN 4742). Orders may be placed with Distillation Products Industries, Rochester, N. Y. 14603 (Division of Eastman Kodak Company).

Now where do you get directions for the use of these esters? You don't. At least not yet. Finding the directions for use we assume to be what your employer might be paying you to do. Least of all do we offer assurance of success. You and the firm we avoided mentioning are up against a hard fact of life. That the author got clearance to yield to the blandishments of *Scientific American* is no accident. The big company, even as our own, has to publish enough to make itself attractive to the scientific community, whence will come its future strength. Yet the old sense of property, the basis of the firm's very existence, inhibits it from tossing to the four winds those few nuggets of practical information for which much gold has been traded.

Meanwhile we keep thinking of more and more cholesteryl esters and wondering whose move is next.

[1] *The Journal of Investigative Dermatology*, 43, 89.

Photography by Fourier

Five years hence, most people reading this ad will have seen a hologram. Maybe. We are not sure. The prophecy will come true if some smart apple watching the stunt done with a He-Ne laser, a mirror or two, and a photographic plate will turn to his buddy and say, "Hey, Louis, do you suppose this would be any good in our—" and there he goes. It may have happened already. Perkin-Elmer showed holograms at the Physics Show, the Optical Society of America, and the I.E.E.E. Perkin-Elmer has been doing this to drum up trade for their lasers. We for our part are always drumming up trade for photography.

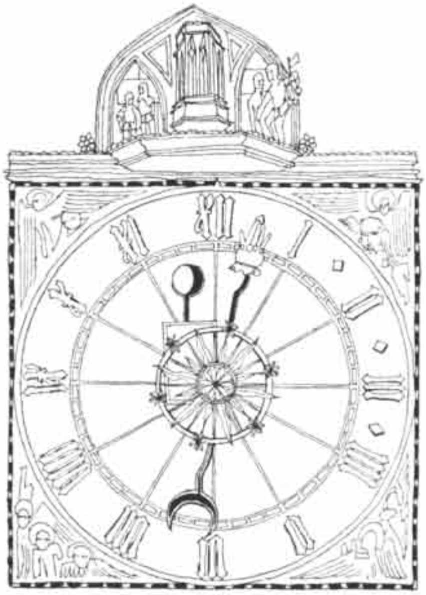
This is peculiar photography, where the photographic record is quite invisible to the naked eye and doesn't really depend on silver density. The photograph, if you want to call it that, is merely a representation of all the phases and amplitudes in a scene or collection of separate scenes. In the reconstruction, which is astonishingly simple and direct, you get a choice between a three-dimensional virtual image or a series of real images in different planes. You can read all about it in *J.O.S.A. 53*, 1377 (1963) and *54*, 1295 (1964) and accept it intellectually, but it wouldn't hurt to convince your own eyes. Looking at one of these plates, you recall wondering at an early stage in your career what kind of a dance is being executed by a molecule of air in your ear while listening to a full orchestra and chorus. Baron Fourier sure was ahead of his time.

Just because we are giving holography a little shove here, don't assume we offer the perfect photographic material to do it on. The early holographers have been using KODAK Spectroscopic Plates, Type 649-F, a red-sensitized product with the same capacity for detail as KODAK High Resolution Plates.[2] When they tell us they don't need all the super-resolution this type of emulsion can provide and would like to trade some of it off for a little more speed, we suggest KODAK Spectroscopic Plates, Type V-F. If this should all turn into more than a *succès d'estime*, it is most unlikely that either of these emulsions would remain the best choice.

If anybody is interested in speeding the advent of such a new and best choice, he had better keep in touch with Eastman Kodak Company, Special Sensitized Products Division, Rochester, N. Y. 14650.

[2] This has little to do with holography and more with detail rendition for micro-electronics production, but KODAK High Resolution Plates now have an emulsion that is about 6μ thick before processing and 4μ after (hitherto 9μ and 6μ, respectively).

SCIENCE AND



Crime and Social Protest

Data indicating that crimes of violence by Negroes declined markedly in three communities at times when the civil rights protest movement was active there have been reported by a group of investigators from Howard University and Johns Hopkins Hospital. Writing in *Archives of General Psychiatry,* the investigators advance the hypothesis that "Negroes release long-dammed-up resentment of segregation" by associating themselves directly or vicariously with civil rights movements and that these associations "may reduce the need for aggressive outbursts of a violent sort, thus reducing the incidence of such crimes." If the data can be broadly substantiated, the writers add, "there is then a very strong argument that the kind of community organization and psychological mobilization inherent in the civil rights struggle may be of prime importance in the development and implementation of various crime-prevention programs and 'antipoverty' programs."

The members of the investigating group are Fredric Solomon and Jacob R. Fishman of the Howard University College of Medicine, Walter L. Walker of the Center for Youth and Community Studies at the university and Garrett J. O'Connor of Johns Hopkins Hospital. They based their findings on police and medical records and on interviews with people involved in the civil rights demonstrations in the three communities. Although the investigators do not identify the cities, beyond saying that two are in the South and one is in a border state, incidents they describe indicate that the communities are Atlanta, Ga., Albany, Ga., and Cambridge, Md. The report emphasizes that the findings are "preliminary" but points out that they tend to be substantiated by the observations of civil rights leaders and by newspaper accounts in several cities where civil rights demonstrations have occurred. The findings suggest, in the opinion of the writers, that "in the long run the effects of the civil rights movement on the self-image and social behavior of the American Negro will be as important as the movement's direct effect on segregation patterns."

Structure of a Genetic Molecule

For the first time the complete sequence of nucleotide subunits in a nucleic acid has been determined. The nucleic acid is the ribonucleic acid alanine transfer RNA, a long-chain molecule that has 77 nucleotide subunits. Each nucleotide consists of a "base" (a small group of atoms including atoms of nitrogen), a ribose sugar and a phosphate group. The role of alanine transfer RNA is to combine with the amino acid alanine and deliver it to the site in the living cell where it can be linked up with other amino acids—each transported by its own specific transfer RNA —to form a protein molecule. The determination of the sequence of nucleotides in alanine transfer RNA was accomplished after six years of work by a team of Cornell University and Department of Agriculture investigators headed by Robert W. Holley of Cornell. Holley's co-workers were Jean Apgar, George A. Everett, James T. Madison, Mark Marquisee, Susan H. Merrill, John Robert Penswick and Ada Zamir.

Determination of the nucleotide sequence in alanine transfer RNA opens the way to the analysis of the other transfer RNA's, and of the still longer molecules of "messenger" RNA, which comprise from a few hundred to a few thousand nucleotides. Messenger RNA transcribes from the cell's repository of genetic information—coded in deoxyribonucleic acid (DNA)—the code-word sequence for each protein manufactured by the cell.

The analysis of alanine transfer RNA also provides another opportunity to check the validity of current hypotheses about the mechanism used by the cell to make proteins. It is believed that each amino acid in a protein is represented in DNA by a sequence of three bases called a codon. Each codon in DNA is transcribed into a corresponding codon in messenger RNA, which carries the genetic message to the protein-assembly units called ribosomes. Acting as a kind of tape reader and jig, the ribosome moves along the messenger RNA and holds it in place as transfer RNA's deliver in sequence the amino acids designated by each of the codons. On this hypothesis each transfer RNA must contain an "anticodon": a sequence of three bases complementary to the codon triplet in messenger RNA. The hypothetical anticodon enables the transfer RNA to recognize the "address" to which its amino acid should be delivered.

Although rapid progress has been made in unraveling the genetic code and assigning codons to various amino acids, the codon to which transfer alanine RNA responds has not yet been identified. Therefore it is not possible to say which triplet sequence of bases in alanine transfer RNA may serve as the anticodon. Holley has tentatively identified two triplet sites that seem to have the necessary qualifications. One is near the middle of the molecular chain and has the base sequence cytosine-guanine-guanine; the other has the sequence inosine-guanine-cytosine. Inosine, which should resemble guanine in coding properties, is one of several unusual bases found in alanine transfer RNA.

The method for determining the nucleotide sequence in alanine transfer RNA resembles the one used for determining the amino acid sequence in proteins. The chainlike molecule is digested by enzymes that are known to attack the linkage between certain of its constituents. The fragments are then analyzed into their constituents. The success of the method depends on finding digestive agents that will produce fragments of various lengths so that there are overlapping sequences. A major problem in analyzing transfer

RNA was to find agents that would yield large enough fragments. This was finally solved by the discovery that one of the digestive enzymes that produces 17 fragments under one set of conditions produces as few as two large fragments when the digestion is carried out at zero degrees centigrade.

Embarrassment of Symmetries

The present period in theoretical physics is reminiscent of the epoch in the late 1920's, when quantum mechanics had just emerged and was being intensively developed. Today the attention of theoretical physicists is focused on the use of mathematical symmetry principles to classify the steadily growing assemblage of subnuclear particles and to predict their properties. The schemes have proliferated almost as rapidly as the particles themselves. The first of the schemes, known as SU(3) symmetry or the "eightfold way," has been succeeded by a variety of more complex symmetries: SU(6), SL(6,*c*), U(12), $\tilde{U}$(12), M(12) and others. The big difference between the present period and the 1920's is that today there are many more theorists, all of whom hope to achieve the ultimate synthesis. The result has been a logjam in papers reaching the desks of journal editors.

The prime target has been the weekly journal *Physical Review Letters,* which offers speedy publication and worldwide readership. The beleaguered editors recently threw up their hands and published a batch of eight papers on symmetry without subjecting all of them to the customary critical review by a referee. The eight papers had a total of 21 authors; one of the papers originated in Israel, three in Italy and four in the U.S. So furious is the exchange of "preprints" that all eight papers refer to work "to be published." In at least three cases the papers so designated appear elsewhere in the same issue.

In an editorial George L. Trigg, assistant editor of *Physical Review Letters,* describes the journal's predicament: "There are as yet only a limited number of physicists who are qualified to serve as referees for these papers. We have therefore been forced to overload some of them, and we take this opportunity to apologize. In addition, we theorists are extremely touchy about the significance of our own work, even when we are aware that it is merely working out explicitly an idea that is current and that others are also considering. As a result almost every suggestion that a paper in this field does not warrant letter speed is greeted by an indignant outburst and a request for reconsideration.

"On this issue, we gave up, in an attempt to sweep our desks clear. There are eight such papers.... We make no claims for soundness, as some of them (we will not state which) have not been reviewed."

The Lie Detector Investigated

A Congressional committee has issued a report casting serious doubt on the validity of polygraph "lie detector" tests and castigating the Federal Government for their indiscriminate application. The report by the Committee on Government Operations was based on a study made by its Foreign Operations and Government Information Subcommittee, of which Representative John E. Moss of California is the chairman. The subcommittee took testimony from private polygraph operators, Government officials and a panel of scientists and questioned 58 Federal agencies about their practices with regard to lie-detector tests.

The committee's primary conclusion was: "There is no 'lie detector,' neither machine nor human. People have been deceived by a myth that a metal box in the hands of an investigator can detect truth or falsehood." The report points out that the polygraph is an instrument that records a person's respiration, blood pressure and pulse and also his "galvanic skin response" (the flow of electric current across the skin, which changes with variations in sweating). These are physiological responses that "may or may not be connected with an emotional reaction—and that reaction may or may not be related to guilt or innocence." It is possible to "beat" the machine and it is quite possible for the machine to implicate a person who is not in fact lying.

The committee reported that many agencies rely on polygraph tests "for everything from top security investigations to minor pilfering cases" and recommended that the Federal Government immediately prohibit the use of the machines in all but "the most serious national security and criminal cases." The committee found that those who administer the tests are generally unqualified and urged that they be better trained. It also suggested a number of steps to protect the rights of people subjected to investigation and called for comprehensive research to determine the validity and reliability of polygraph examinations.

The Problem of Man's Emergence

Dating by means of radioactive isotopes has now shown that the Pleistocene epoch, the geological period during which modern man appeared, began some three million years ago—three times earlier than had been supposed. One would think that the additional two million years would give the builders of hypotheses about human evolution more time to organize their fossil evidence into a coherent scheme, but such is not the case. This was made clear in March at a conference in Chicago of leading paleontologists, anthropologists, prehistorians and geneticists.

The conference, sponsored by the Wenner-Gren Foundation for Anthropological Research, was called by Sol Tax of the University of Chicago to review evidence concerning the origin of man uncovered since a similar conference he had chaired in 1959. The participants in the reconvened meeting agreed as a starting point that the hominoid line of evolution first split into proto-apes and proto-men during Miocene time: from 13 to 25 million years ago (see "The Early Relatives of Man," by Elwyn L. Simons; SCIENTIFIC AMERICAN, July, 1964). After that, however, there is an immense barren period before the first firmly dated hominid remains appear about 1.8 million years ago, or a third of the way through Pleistocene time. These oldest Pleistocene hominids are the various proto-men uncovered by L. S. B. Leakey in the lowest level at Olduvai Gorge in East Africa. The first hominids the majority at the conference considered members of the genus *Homo* are not found until a million years later; these are the earliest examples of the species *Homo erectus,* long known from sites in Java and China and more recently in Africa. Students of early man agree that modern *Homo sapiens* evolved directly from *Homo erectus,* although there is no direct evidence for the transition.

The most controversial subject at the conference was Leakey's new arrangement of fossil hominids from various levels at Olduvai. In addition to the two lowest-level forms, *Zinjanthropus* (first announced in 1959 and now identified as an East African variety of australopithecine proto-man) and *Homo habilis* (first announced in 1964 and of uncertain classification), Leakey presented

a restored skull nicknamed "George" (first announced in part in 1964 and then tentatively assigned to *Homo habilis*). "George," Leakey stated, represents still a third hominid species at Olduvai: an East African variety of *Homo erectus*. In support of his view Leakey drew attention to a comparatively recent hominid skull from Olduvai he had uncovered some years ago and named the "Chellean" skull because of its association with stone hand axes similar to French ones of that name; on reexamination, he declared, the "Chellean" skull had now proved to be another *Homo erectus*.

Leakey concludes that three hominid species coexisted at Olduvai for as long as 1.5 million years; in his view both australopithecines and *Homo erectus* became extinct, leaving *Homo habilis* as the sole immediate ancestor of modern man. African specialists at the meeting, notably J. T. Robinson of the University of Wisconsin, were tentatively prepared to welcome both "George" and the ex-Chellean to the ranks of African *Homo erectus*. They were unprepared, however, to accept *Homo habilis* as anything but another variety of australopithecine.

CO on the Highway

The carbon monoxide fumes inhaled by a commuter on a Los Angeles freeway are concentrated enough to present at least a possible danger to his health and driving ability, according to A. J. Haagen-Smit of the California Institute of Technology. With a new carbon monoxide analyzer designed by Paul Hersch of Beckman Instruments, Inc., Haagen-Smit and Thomas W. Latham measured the concentration of the gas encountered during eight trips along the commuter route between Pasadena and Los Angeles during peak traffic hours, making records of the carbon monoxide level measured near the driver. Their work is reported in the Cal Tech publication *Engineering and Science*.

The carbon monoxide is produced, of course, by the incomplete combustion of gasoline. Because hemoglobin binds it in preference to oxygen, the gas tends to cause oxygen starvation in tissue; exposure to high concentrations can lead to delayed physical reactions, loss of judgment and muscular coordination and eventually asphyxiation. Normally Los Angeles air contains 10 to 12 parts of carbon monoxide per million parts of air. The California State Health Department says that 30 parts per million is an "adverse" level and that 30 parts for

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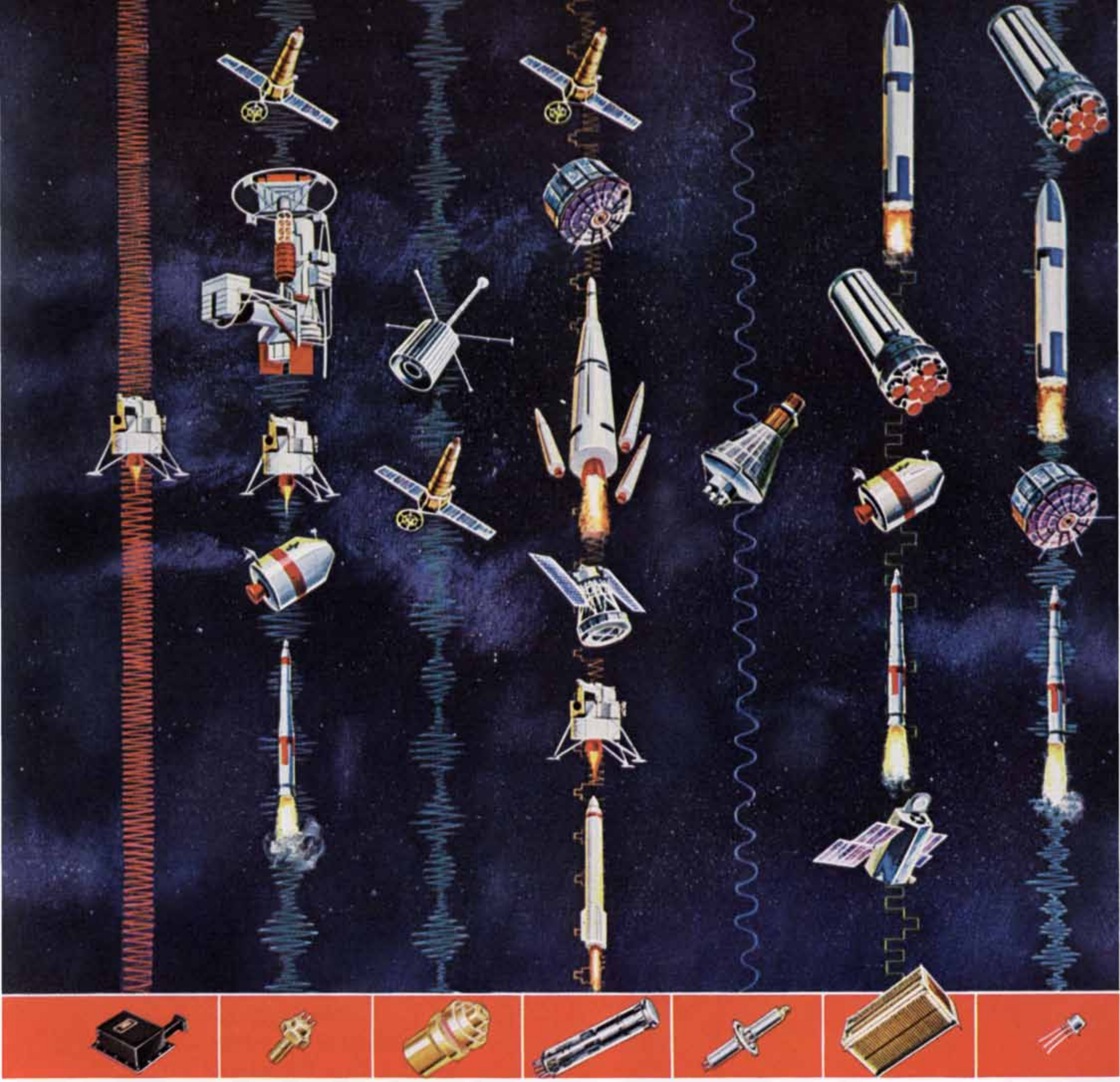

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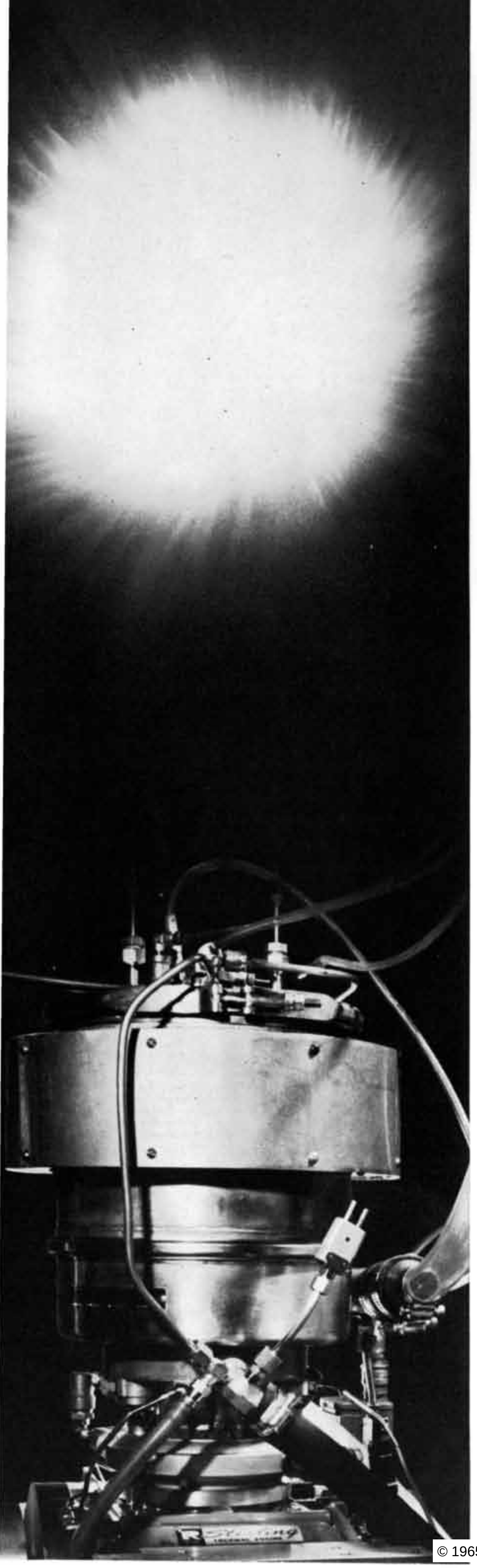

One of a series briefly describing GM's research in depth

Our Stirling Engine: Just Add Heat.

It's a thermal engine—a remarkably quiet device that can run even on heat from the sun.

There are no explosions in the cylinders, just quiet expansion and contraction of the working fluid, pushing the pistons. The fluid—hydrogen or helium—is sealed in the engine. Heat to expand it can come from any outside source . . . burning fuel, a nuclear reactor, a heat storage system, as well as the sun.

The Stirling cycle is reversible, too. Crank in mechanical power and the engine absorbs heat, becomes a refrigerator.

Invented back in 1816, the Stirling Thermal Engine is now becoming practical for modern applications. Current improvements have grown out of a cooperative development program with N. V. Philips' Gloeilampen-fabrieken, of the Netherlands. Performance of the latest models is encouraging (40% thermal efficiency, for instance, compared to about 28% for conventional spark-ignition engines). An experimental three-kilowatt generator set is being tested for Army field use, where quiet is important. Inaudibility at 300 feet has already been attained.

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At GM Research, engineers study all kinds of engines. The research may be all-encompassing, from basic thermodynamics and engine cycle analyses to the design of prototype units. It helps us find a better way.

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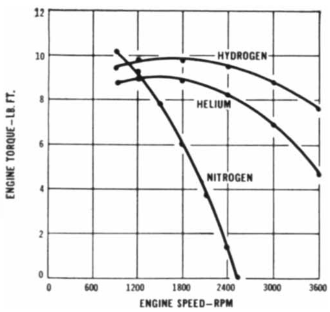


Effect of working fluid on engine output—from a recent GMR paper on Stirling engine research.

eight hours or 120 parts for one hour is a "serious level of pollution." The level measured by Haagen-Smit and Latham during their trips was 37 parts per million; in slow and heavy traffic the average was 54 parts, with peaks as high as 120. The level dropped rapidly on less heavily traveled streets but rose again at stop signals.

Two hours in bad traffic would bring the carbon monoxide concentration in a commuter's hemoglobin to the "serious" level, Haagen-Smit said. He recommends a study of the effects of the gas on a person's alertness and driving skill. Although there is widespread disagreement over the extent to which automobile exhaust gases are responsible for air pollution, Haagen-Smit believes that automobile exhaust-control devices, which will be mandatory in California beginning with 1966 models, should significantly reduce the incidence of smog in general as well as the carbon monoxide level in particular.

Fourth Supernova?

A galaxy the size of ours should produce a supernova on an average of once every 200 years; until recently, however, only three of these gigantic stellar explosions were known to have occurred in the galaxy during the past nine centuries: one in the constellation Taurus in 1054 (producing the Crab Nebula), one in Cassiopeia in 1572 ("Tycho's star") and one in Ophiuchus in 1604 ("Kepler's star"). Now a reexamination of 11th-century astronomical observations made in Europe, the Near East and the Far East suggests that a fourth supernova blazed up in the constellation Lupus from May to mid-August of the year 1006.

Writing in *The Astronomical Journal*, Bernard R. Goldstein of Yale University points out that the celestial display in 1006 has generally been interpreted by later astronomers as a comet. In proposing that it was a supernova he cites three statements from the fullest contemporary account, that of the Cairo astronomer Ali ibn Ridwan. The object "twinkled very much"; it remained motionless among the fixed stars; its light, equal in brightness to the quarter-moon, "illuminated the horizon." Comets may appear to be this bright, but they move across the celestial sphere and do not scintillate. On the basis of Ridwan's coordinates Goldstein calculates that the supernova was in the vicinity of, if not identical with, the planetary nebula NGC 5882.

MOLECULAR BEAMS

Studies involving coherent beams of atoms and molecules have had a profound influence on the development of modern physics. Among their technological dividends are masers, lasers and atomic clocks

by O. R. Frisch

The atomic physicist, like everybody else, needs air for breathing, but otherwise it is in his way. At normal atmospheric pressure each air molecule is involved in nearly a billion collisions a second. Only in gases at a much lower pressure—in what is loosely called a vacuum—do molecules attain a reasonable degree of privacy. We measure such low pressures in units called "torr," after the Italian investigator Evangelista Torricelli, who devised a method for obtaining fairly good vacuums in 1643. (Atmospheric pressure is about 760 torr.) More than 200 years later, in 1855, the German glassblower Heinrich Geissler used Torricelli's method to evacuate glass tubes down to about .01 torr; this achievement led directly to the discovery of cathode rays, which were eventually identified as beams of free electrons by J. J. Thomson in 1897. At such a pressure electrons can travel many inches, but at the same pressure the mean free path of an air molecule between collisions is only about a millimeter. To achieve a coherent beam of any kind of atom or molecule one needs a much better vacuum—at least .00001 (10^{-5}) torr or better.

Techniques for obtaining very low pressures were developed rapidly during the first decade of this century, and in 1911 the French physicist L. Dunoyer succeeded in producing the world's first molecular beam; he demonstrated that in a good vacuum the sodium atoms that comprised his beam moved in straight lines. Dunoyer's elegantly simple apparatus consisted of an evacuated glass tube with two constrictions [*see top illustration on page 60*]. When he heated some sodium in one of the end compartments, a dark deposit of sodium appeared in the compartment at the opposite end. The deposit covered only the area that could be reached by atoms that had passed in straight lines through the constrictions.

In essence Dunoyer's apparatus was the prototype of all modern molecular-beam devices. The three necessary elements of any such device are (1) a source of molecules (usually called an oven, even though it is not always heated) with an aperture through which the molecules can escape into a vacuum, (2) a second, collimating aperture, which forms the beam by stopping or deflecting all the molecules that do not pass directly through it, and (3) a method for detecting the effects of various influences on the beam. In contrast to beams of subatomic particles, which can be accelerated to speeds approaching the speed of light, molecular beams normally travel at "thermal" speeds: a mile a second or so. The generic term "molecular beam" applies both to groups of atoms (for example neutral hydrogen, each molecule of which consists of two hydrogen atoms) and to single atoms (for example sodium vapor).

Molecular beams can be made to pass through magnetic or electric fields; they can be directed at various obstacles, such as crystals or gas molecules; they can be illuminated with intense light, bombarded with electrons or crossed by other molecular beams. From such experiments much has been learned about the basic structure of matter that could not have been learned in other ways. The invention of masers and lasers arose out of a molecular-beam experiment, and a beam of cesium or hydrogen atoms in an "atomic clock" is the most accurate timekeeper ever built.

The Stern-Gerlach Experiment

The idea that gas molecules are in rapid motion goes back to a treatise written in 1738 by the Swiss mathematician Daniel Bernoulli. He pointed out that bombardment by fast molecules would exert a pressure on the walls of a container, and that the pressure would rise in proportion to the number of molecules per unit volume, or the density of the gas (as Robert Boyle had observed some 80 years earlier). Bernoulli also explained the rise of pressure with increasing temperature by assuming that the molecules move faster when the gas is heated. Of course Bernoulli was right in every respect, but his suggestions raised at least as many questions as they answered.

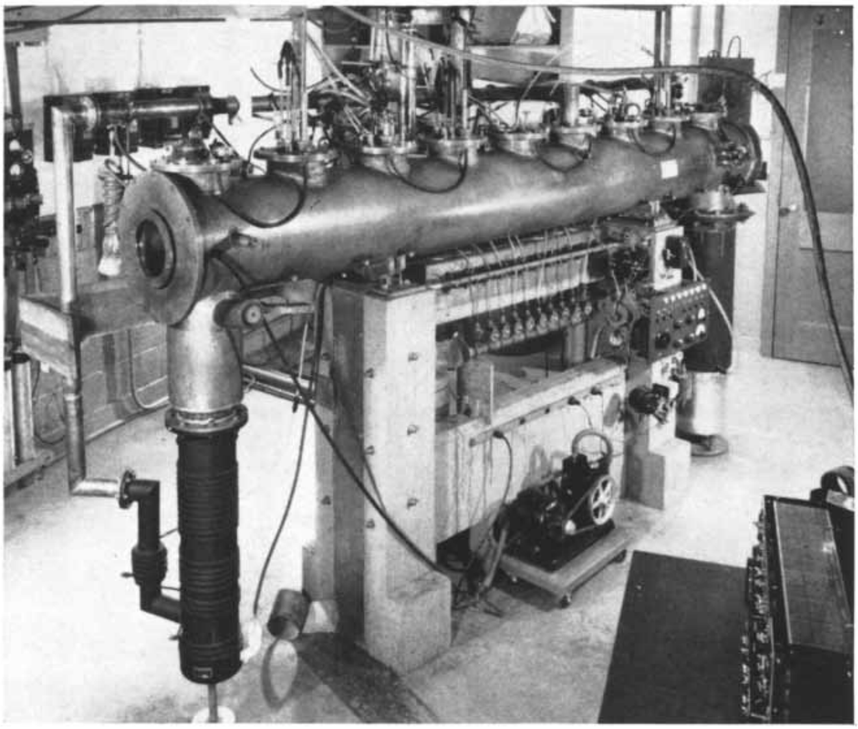
Gas molecules move as fast as rifle bullets; why, then, does it take minutes for a smell to spread from one end of a room to another? We now know the answer is that the molecules keep colliding and therefore make little headway. In fact, from the rate at which a smell does spread—to put it more generally, the rate at which one gas diffuses into another—it is possible to calculate how often the molecules in a gas collide every second. Such calculations were not made until the middle of the 19th century and only then did physicists begin to regard atoms and molecules as real and not merely as fictions convenient for chemists. Several methods were devised for computing the speed of molecules and their mean free path between collisions. In general the results agreed and supported the new kinetic theory of gases, which was firmly established during the latter half of the 19th century by James Clerk Maxwell of Britain, Ludwig Boltzmann of Austria and other theorists. Nonetheless, the evidence for the kinetic theory remained indirect.

The first direct measurement of the speed of gas molecules was made in 1920 by Otto Stern, who was then working at the University of Frankfurt; it was also the first measurement in which a molecular beam was employed. Instead of an oven Stern used a hot platinum wire plated with silver and positioned in the middle of an evacuated bell jar. Silver atoms evaporated from the wire in all directions, but only those that passed through a narrow slit were able to reach a glass detector plate, on which they left a deposit in the form of a narrow line. As long as the apparatus remained stationary the speed of the atoms did not matter; fast or slow, they all followed the same straight path.

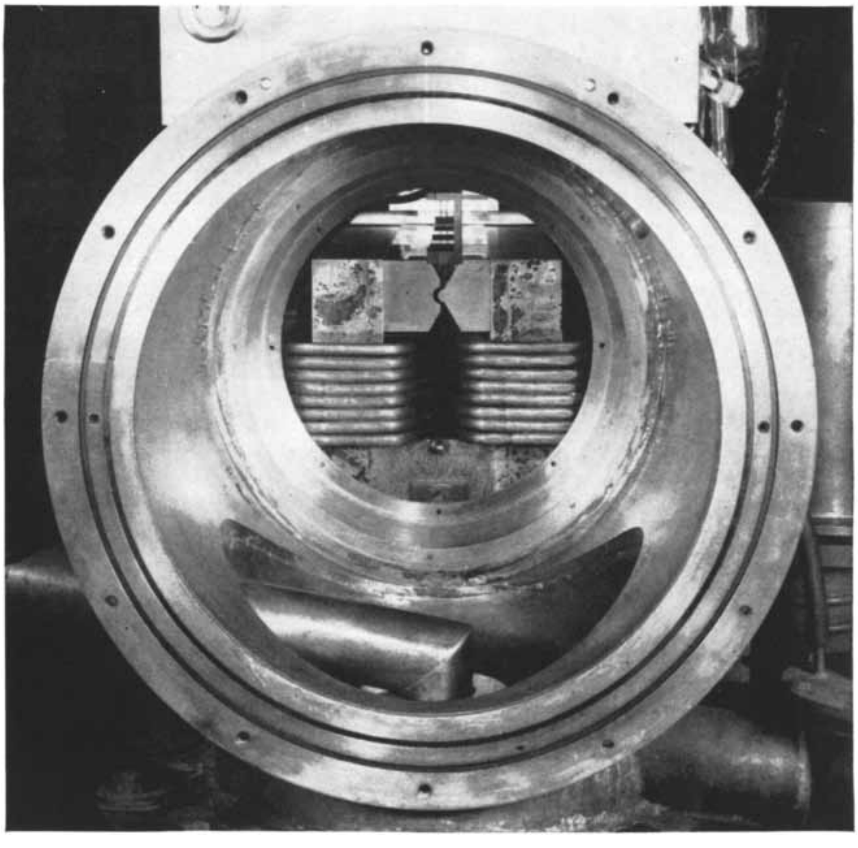
But Stern had mounted the main parts of his apparatus—the silver-plated wire, the slit and the glass plate—on a vertical axis that could be made to rotate at some 1,500 turns per minute inside the bell jar [*see bottom illustration on next page*]. At that time, with vacuum techniques still in their infancy, this was quite a tour de force. When the apparatus was rotating, the deposit was formed in a slightly different place, because now the glass plate was moving as the atoms were heading for it. From the amount of shift Stern was able to estimate the average speed of the atoms at 580 meters per second; this was within a few percent of the figure predicted by the kinetic theory of gases. Moreover, he observed that the deposit formed during rotation was a bit fuzzy; this showed that not all the silver atoms had the same speed, which Maxwell had foreseen.

About a year later Stern published, together with his colleague Walther Gerlach, the result of another molecular-beam experiment. This experiment had a profound influence on the development of quantum mechanics; it supported the rather incredible conclusion, drawn from spectroscopic observations, that the orbit of an electron moving about the nucleus of an atom in a magnetic field must always be at right angles to the lines of force in the field, although the electron can orbit in one direction or the other. Such "spatial quantization" was completely at odds with classical physics, according to which a magnetic field would merely make the electron's orbit precess, or wobble, around a field line rather like a spinning top, without imposing any limit on its orientation.

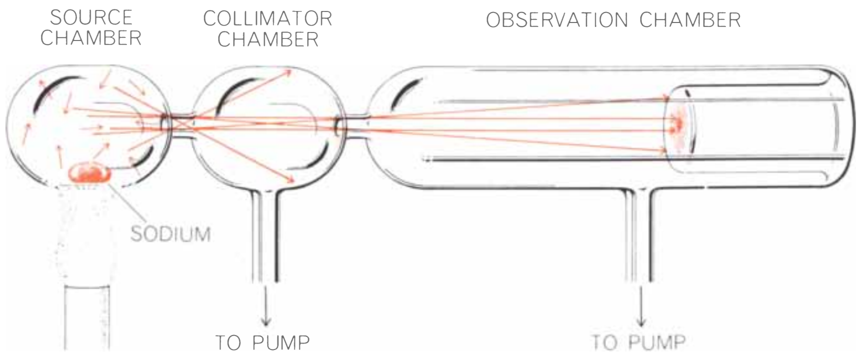
In thinking about the Stern-Gerlach experiment it is helpful to treat the atom as though it were a small bar magnet with a magnetic moment μ. (The magnetic moment of an orbiting charge e, traveling with the speed v on a circle of radius r, is given by the equa-



TYPICAL MOLECULAR-BEAM APPARATUS, photographed in the laboratory of Norman F. Ramsey at Harvard University, is used for studies of nuclear magnetic resonance. A beam of hydrogen molecules enters the apparatus at the far end, passes through several magnetic fields and is detected at the near end (*see schematic diagram at bottom of page 62*).

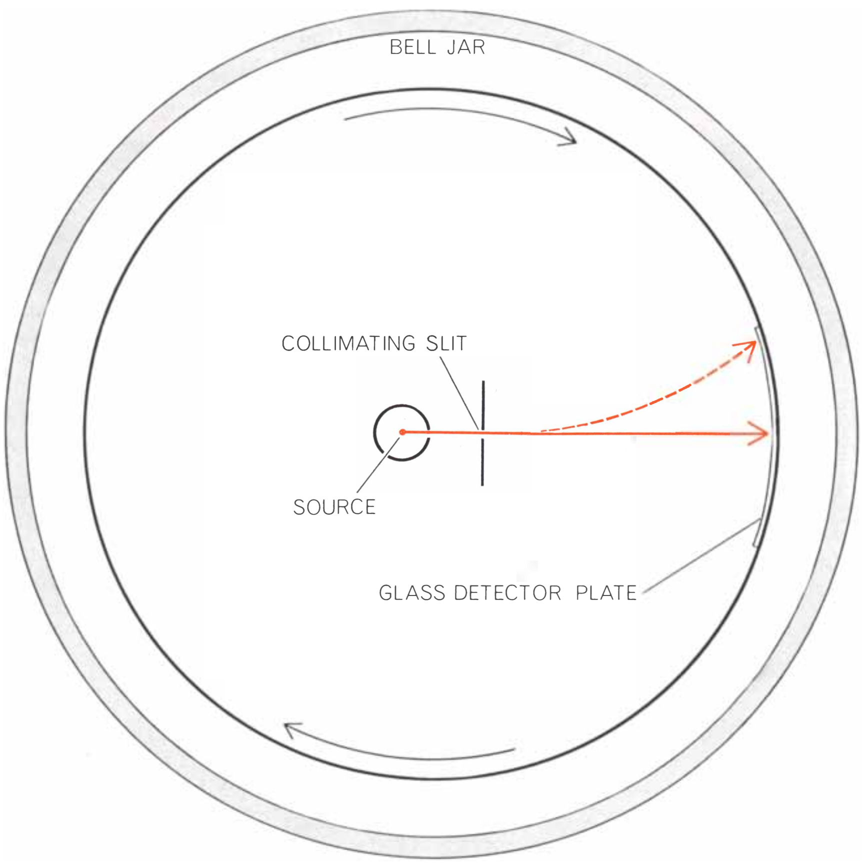


SOURCE-END VIEW of the molecular-beam resonance apparatus shown above reveals the end of the first, or *A*-field, deflecting magnet. The beam of hydrogen molecules passes between the two semicircular-shaped pole pieces at the center. The source equipment and the bulkheads separating the various chambers have been removed for easy viewing.



FIRST MOLECULAR-BEAM APPARATUS was constructed by L. Dunoyer in 1911. When he heated some sodium in one of the end compartments of an evacuated glass tube (*left*), a dark deposit of sodium appeared in the compartment at the opposite end (*right*). The deposit covered only the area that could be reached by sodium atoms that had passed in straight lines through the two constrictions. The tube was about eight inches long.

tion $\mu = evr/2c$, c being the speed of light.) When such a magnet is inserted into a magnetic field H at an angle α with respect to the field lines, its energy content is changed by an amount equal to μH times the cosine of α [*see bottom illustration on opposite page*]. If we consider a large number of such magnets, oriented at random, then the cosine of α is equally likely to have any value between -1 and $+1$; accordingly the magnetic energy could have any value between $-\mu H$ and $+\mu H$. If spatial quantization existed, however, the energy could have only the two extreme values $-\mu H$ and $+\mu H$ and nothing in between.



FIRST DIRECT MEASUREMENT of the speed of gas molecules was made in 1920 by Otto Stern; this was also the first measurement in which a molecular beam was employed. The main parts of the apparatus (*shown from above in this schematic view*) were mounted on a vertical axis that could be made to rotate at some 1,500 turns per minute inside an evacuated bell jar. When the apparatus was rotating, a deposit was formed in a slightly different place on the glass detector plate than when the apparatus was stationary. From the amount of shift Stern estimated the average speed of the atoms. He also observed that the deposit formed during rotation was fuzzy; this showed that not all the atoms had the same speed.

For nearly a decade before the Stern-Gerlach experiment the classical concept of randomly oriented electron orbits had been in conflict with the Zeeman effect, the fact (first noted by the Dutch physicist Pieter Zeeman in 1896) that the lines in a spectrum are often split into two or more lines when the emitting atom is placed in a magnetic field. At first the reason for the remarkable sharpness of these spectral lines was unknown. The first step toward an understanding of this phenomenon came in 1900 with the introduction of Max Planck's quantum postulate, which made the rather startling assumption that light is emitted in quanta, or discrete parcels of energy. In 1913 Niels Bohr made the further assumption that the energy content of atoms must also be quantized, and that the emission of spectral lines is caused by the atom's transition from one energy state to another. According to Bohr's model the energy difference between the two states is carried away by the emitted light quantum and thus determines the wavelength of the emitted light. The sharpness of the energy states guarantees the sharpness of the spectral lines.

If atoms were oriented at random in a magnetic field, their energy content would, as we have seen, be "blurred" by an amount equal to twice μH. The Zeeman effect, however, demonstrated that spectral lines are not in fact blurred but instead are split into two or more sharp lines. An analysis of the Zeeman splitting of the spectral lines of silver showed that in their normal state the silver atoms should be capable of only two orientations, corresponding in terms of magnetic energy to the values $-\mu H$ and $+\mu H$.

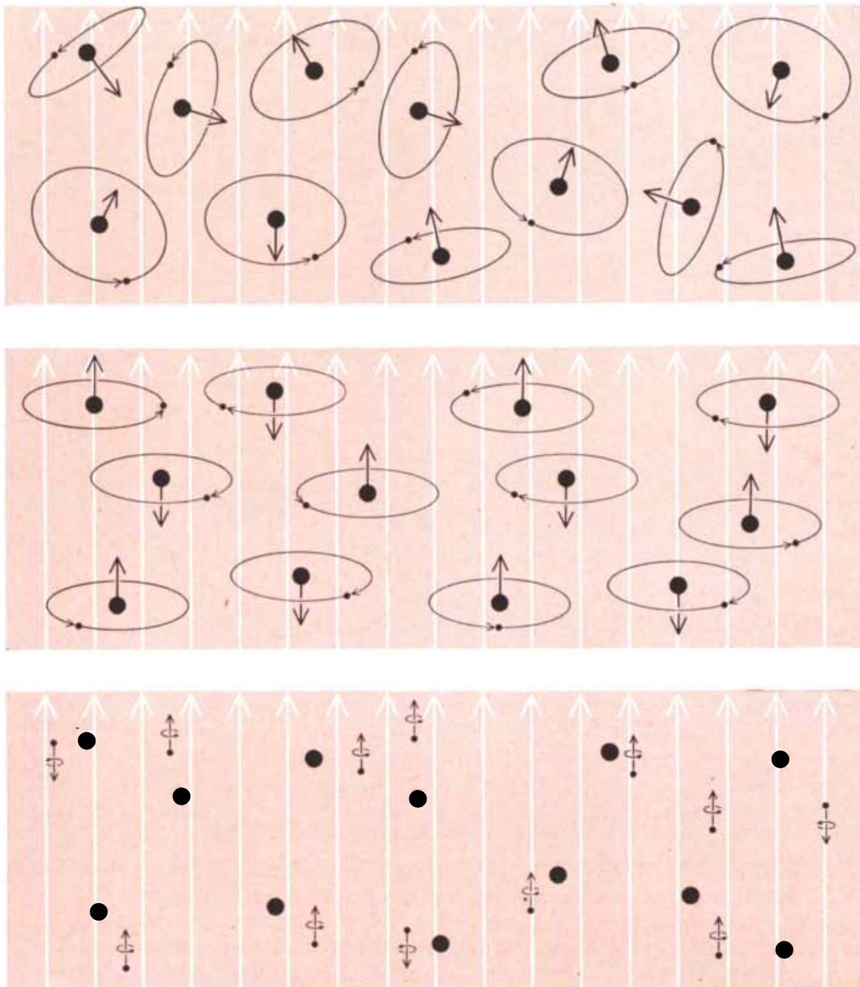
Now, Stern argued as follows: If a magnetic atom were placed in an inhomogeneous magnetic field (a field whose intensity varies from point to point), then the atom's energy content would also vary. In order to move the atom from point to point work would have to be done. In other words, the magnetic field would exert a force on the atom as a whole; the force would of course depend on the orientation of the atom with respect to the magnetic field. If the atoms were oriented randomly, the force would vary continuously from $-\mu G$ to $+\mu G$, G being the field gradient, or the change in field intensity per centimeter. If, on the other hand, spatial quantization obtained, the force would always be either $-\mu G$ or

$+\mu G$. By making the force large enough to cause observable deflections in a beam of silver atoms, Stern reasoned that it might be possible to decide experimentally how atoms orient themselves in a magnetic field.

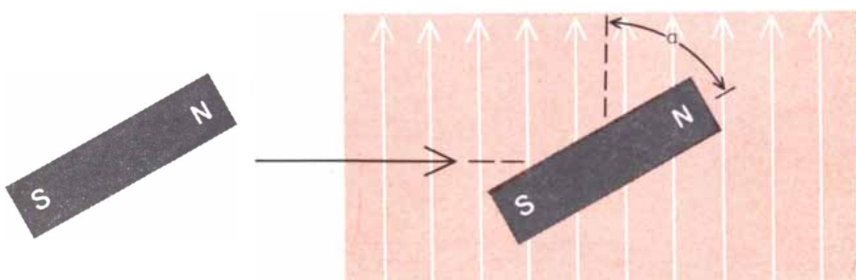
Quite by chance Gerlach had been measuring the gradient of a magnetic field near the sharp edge of a magnet. Stern computed that such a magnet should deflect silver atoms enough for his purpose, so they joined forces. Their experiment was a complete success: the fine line of silver that had been deposited in the absence of the magnetic field was distorted into a fuzzy, asymmetric loop when the magnet was turned on [*see illustration on page 63*]. The fuzziness was caused by the Maxwellian distribution of the speeds of the silver atoms; the asymmetry, by the fact that the field gradient was greater near the knife-edged magnetic pole than away from it. The crucial finding was that the deposit was a loop and not a blur: near the middle there was practically no silver. If the silver atoms had been oriented at random in the magnetic field—as classical physics demanded—there should have been no fewer atoms with small deflections than atoms with large ones. The experimental result was in perfect agreement with the concept of spatial quantization.

Stern could foresee many other potential uses for molecular beams, and in 1923, when he became professor and head of the department of physical chemistry at the University of Hamburg, he set out to develop the method systematically. During the next 10 years he and his students published a series of 30 papers reporting many important findings—a massive demonstration of the power of intelligent planning. I had the good fortune to work with Stern from 1930 to 1933, and it was wonderful training. Our whole campaign had been outlined in the first of those 30 papers; in due course most of the original problems were attacked and solved, as well as some problems that had not been foreseen but that grew out of our work. Nothing was left to chance or conjecture. Every piece of apparatus was designed with care and its behavior was checked out in advance; in this way any shortcoming was quickly revealed and, if possible, remedied before the piece was put into use. With this sort of training Stern's students were well prepared to go out in the world and start their own successful schools of work, and some of them did.

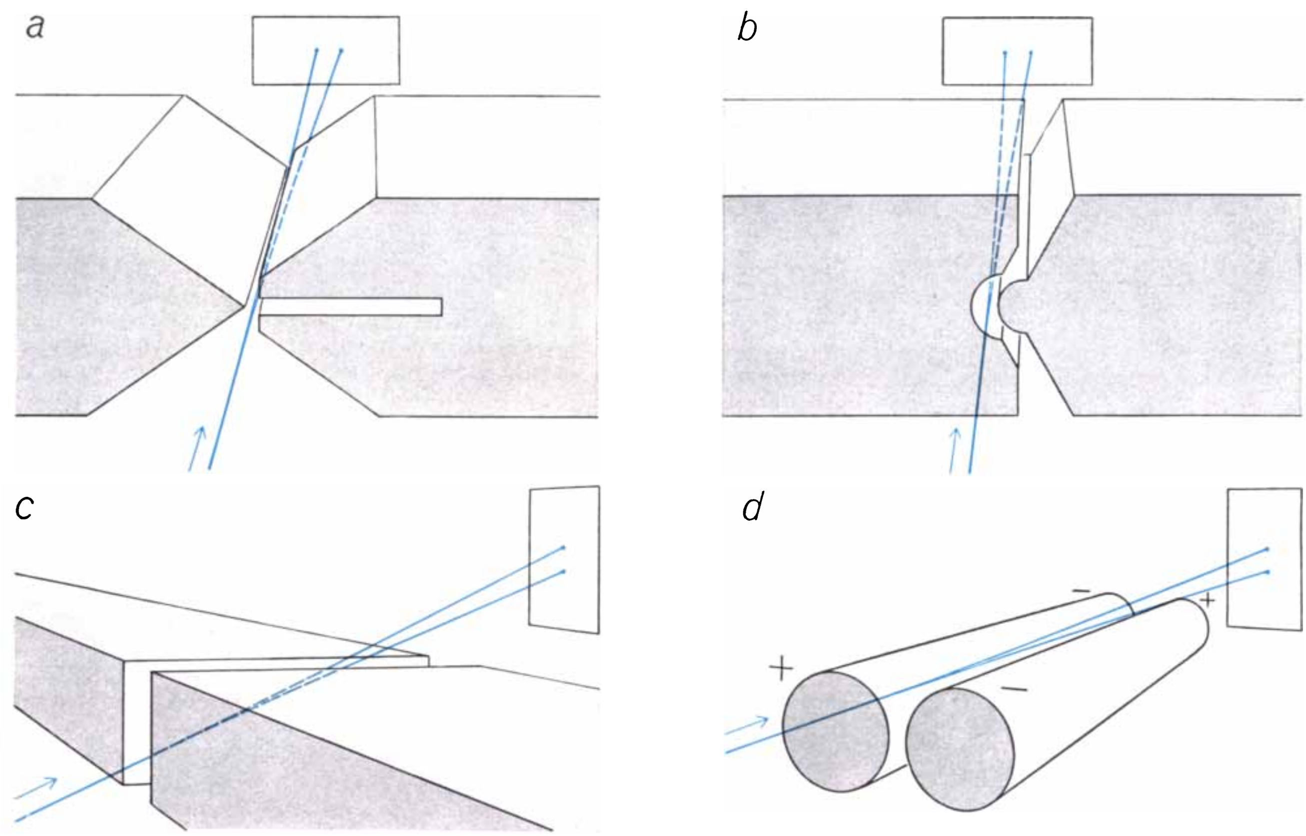
One of the experiments Stern had proposed in that first paper was a test



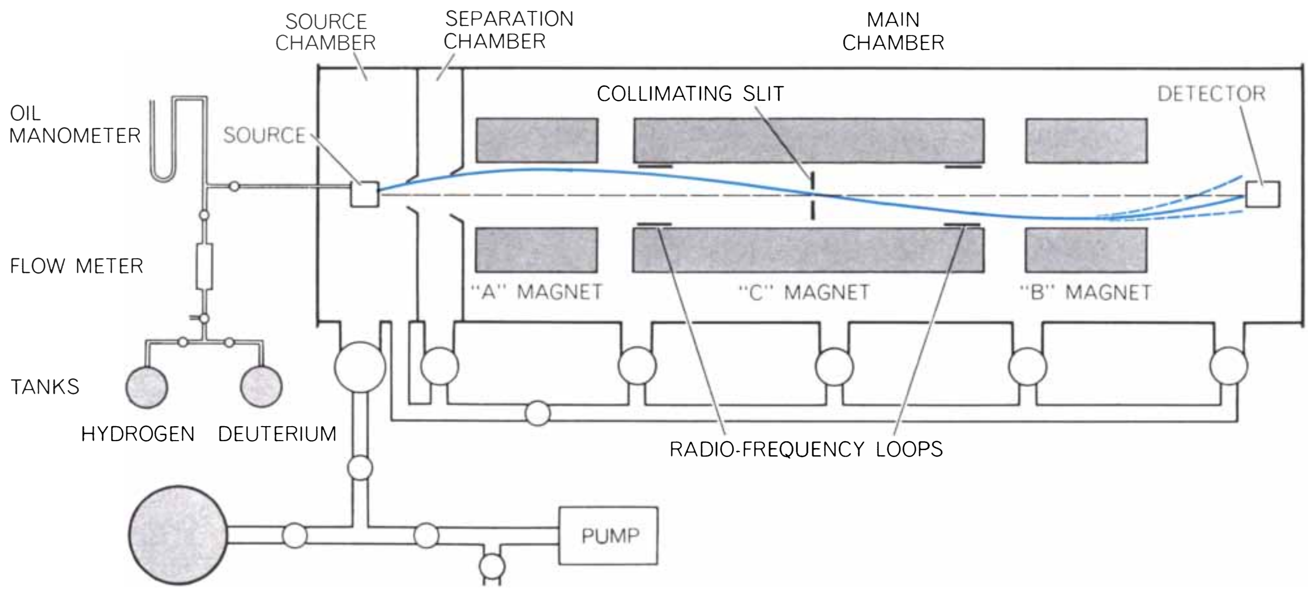
DEVELOPMENT OF ELECTRON THEORY is reflected in these three drawings, which represent three different concepts of the behavior of the electron in a magnetic field. According to classical, or pre-quantum-mechanical, physics (*top*), the magnetic field would merely make the electron's orbit precess, or wobble, around a field line, without imposing any limitation on its orientation. According to the Bohr model of the hydrogen atom (*middle*), the electron's orbit in a magnetic field must always be at right angles to the field lines, with the electron orbiting in one direction or the other. This concept, called "spatial quantization," was supported by the observed Zeeman splitting of spectral lines and also by the Stern-Gerlach molecular-beam experiment. Since 1925 the spin of the electron has been known to contribute to the total angular momentum of the atom that undergoes spatial quantization. In the case of hydrogen or silver atoms in their ground state (*bottom*) there is no orbital momentum; hence electron spin is aligned parallel or antiparallel to magnetic field.



MAGNET ANALOGY is helpful in thinking about the Stern-Gerlach experiment; according to the analogy, the atom is treated as though it were a small bar magnet with a magnetic moment μ. When such a magnet is inserted into a magnetic field H at an angle α with respect to the field lines, its energy content is changed by an amount equal to μH times the cosine of α. If we consider a large number of such magnets, oriented at random, then the cosine of α is equally likely to have any value between -1 and $+1$; accordingly the energy could have any value between $-\mu H$ and $+\mu H$. If spatial quantization existed, however, the energy could have only the two extreme values $-\mu H$ and $+\mu H$ and nothing in between.



INHOMOGENEOUS MAGNETIC FIELDS, used for deflecting beams of magnetic atoms and molecules, can be set up in several ways. The pole-piece arrangement in *a* is similar to that used in the original Stern-Gerlach experiment. The arrangement in *b* is a later version for which the field can be more readily calculated from the dimensions of the pole pieces. In *c* the beam is directed through the edge of a homogeneous field; the deflection depends only on the angle of incidence and the strength of the field between and outside the pole pieces. In *d* an inhomogeneous field similar to that in *b* is set up by two cylindrical conductors through which a strong electric current is passed in opposite directions; the absence of iron in this arrangement facilitates the calculation of the field. In all four examples a pencil-like beam of atoms is shown being split into two component beams having opposite magnetic moments.



MOLECULAR-BEAM RESONANCE APPARATUS, used for measuring the nuclear magnetic moments of hydrogen molecules, is shown in this schematic diagram. The apparatus contains two inhomogeneous magnetic fields: a polarizer (an *A* field) to select molecules of a particular orientation and an analyzer (a *B* field) to test for the reoriented molecules. The transitions from one orientation to the other take place in an intermediate third field (a *C* field), which must be both homogeneous and accurately known. The central region also contains two loops, through which an oscillating current from a small radio-frequency generator is passed. The two inhomogeneous fields are so arranged that the atoms selected and somewhat spread out by the *A* field are brought together again by the *B* field; thus the detector is able to record a good fraction of the original beam. Pressures inside the chambers are kept sufficiently low for most molecules to travel the entire length of the apparatus without being subjected to collisions.

of the suggestion made in 1924 by Louis de Broglie to the effect that a beam of particles should somehow have associated with it a train of waves with a wavelength inversely proportional to the momentum of each particle. This was the germinal idea of modern wave mechanics. Two years later Erwin Schrödinger showed that the energy states of a hydrogen atom could be derived by working out what the De Broglie waves of an electron would do in the electric field of a hydrogen nucleus, and further developments followed in quick time.

Diffraction Experiments

Oddly enough there was no direct experimental evidence of De Broglie's wave hypothesis until 1927, when C. J. Davisson and Lester H. Germer of the Bell Telephone Laboratories found that beams of free electrons produced characteristic diffraction patterns on being reflected from a metallic crystal. Almost simultaneously George P. Thomson of Britain observed the diffraction of electrons that had passed through a thin metallic foil. Even after these discoveries a skeptic might have questioned whether particles other than electrons could be diffracted. He might well have been doubtful, for example, that De Broglie's idea would apply to beams of atoms or molecules.

Stern felt sure that heavy atoms such as those of silver would not do for a diffraction test; their wavelength and hence their angle of diffraction would be inconveniently small. Moreover, heavy atoms would usually condense on the crystal instead of being reflected; even if they did not actually stick, they would gain or lose energy on making contact with the crystal, thus spoiling the diffraction pattern. Therefore he decided to use helium atoms and hydrogen molecules for the beams; both of these gases condense only at very low temperatures. The crystal surface had to be hard and had to contain only light atoms in order to make an exchange of energy with the impinging particles less likely. Lithium fluoride was chosen because it could easily be grown in inch-sized crystals and cleaved into smooth slices.

Of course the whole technique was different from the earlier molecular-beam experiments. The source of atoms or molecules was now a glass bulb, from which the gas passed through a capillary (to control the flow) into the main part of the apparatus. Partitions with holes were again used to define the

RESULT OF STERN-GERLACH EXPERIMENT, which measured the deflection of a beam of silver atoms in an inhomogeneous magnetic field, is shown in this drawing, made from their original 1921 paper. The fine line of silver that had been deposited in the absence of the field (*left*) was distorted into a fuzzy, asymmetric loop when the magnet was turned on (*right*). The fuzziness was caused by the Maxwellian distribution of the speeds of silver atoms; the asymmetry, by the fact that the field gradient was greater near the knife-edged magnetic pole than away from it. The crucial finding was that the deposit was a loop and not a blur: near the middle there was practically no silver. If the atoms had been oriented at random in the field, there should have been no fewer atoms with small deflections than atoms with large ones. Result was in perfect agreement with concept of spatial quantization.

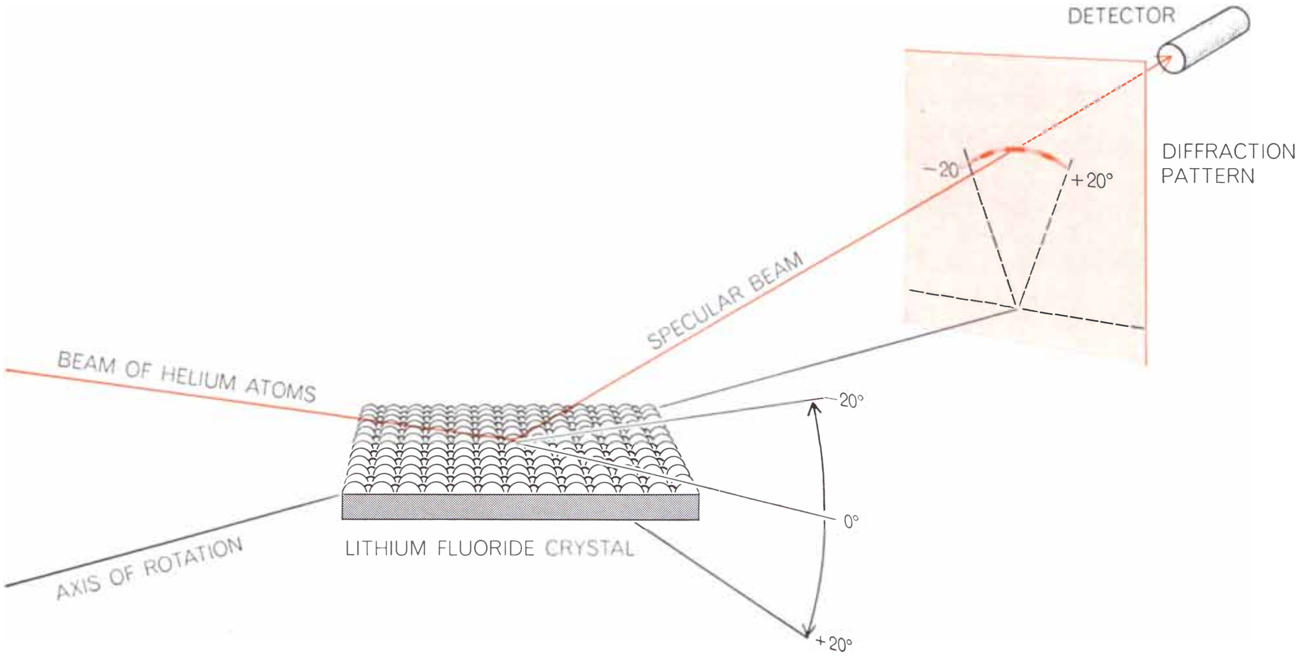
beam, but now the atoms that struck the partitions did not stick and so had to be removed continually with fast pumps. The beam struck a freshly cleaved slice of lithium fluoride, from which some of the atoms were reflected, as light is from a mirror, and some diffracted; the rows of fluorine atoms acted as a diffraction grating. Atoms that had exchanged energy with the crystal would leave it in random directions.

To detect the atoms, Stern had developed, with Friedrich Knauer, an extremely sensitive "hot wire" manometer, based on a principle first put forward in 1906 by the German physicist M. von Pirani. The manometer could detect very small changes in pressures as low as 10^{-8} torr. It was connected to a small tube that was pointed at the crystal in the direction from which the atoms were to be detected. There was some difficulty at first in making this detecting tube movable, so the apparatus was later arranged in such a way that the crystal could be tilted in order to direct the reflected and diffracted atoms into the tube [*see illustration on next page*].

The graph on page 65 shows a typical result obtained when Stern, together with Immanuel Estermann, conducted a diffraction experiment using a beam of helium atoms. The sharp peak at tilting angle zero is caused by the reflected atoms (sometimes called the specular beam). As the tilting angle is increased, the number of detected atoms first drops sharply, but then it rises again when the diffracted atoms begin to enter the detector. The diffracted atoms are spread over a range of angles because of the Maxwellian distribution of their velocity; in accordance with De Broglie's hypothesis, the slower atoms have a longer wavelength than the faster ones.

In a later experiment Stern and I managed to sharpen the test by selecting atoms with a well-defined velocity. This was accomplished by successively passing the beam through two rapidly rotating toothed wheels; atoms that had passed through one of the slots in the first wheel could pass through the second wheel only if they had the right velocity [*see bottom illustration on page 65*]. When this monochromatic beam struck the crystal surface, the atoms were diffracted within a much narrower range of angles. Since we knew both the wavelength and the momentum of the diffracted atoms (momentum equals mass times velocity) it was possible to compute Planck's constant from the experiment (Planck's constant equals momentum times wavelength). The result was within 1 percent of the anticipated value. A discrepancy of 3 percent, which worried us at first, was cleared up when, having looked in vain for other sources of error, we checked the number of teeth on the wheels and found that the lathe on which they had been cut was incorrectly labeled: it had cut 408 rather than 400 teeth! The remaining discrepancy of 1 percent was felt to lie well within the limits of experimental error.

Stern's experiments with helium atoms had proved beyond doubt that beams of complex particles could be diffracted and would exhibit the wave properties De Broglie had foretold. Hydrogen molecules, each consisting of two hydrogen atoms, yielded similar results, although the diffraction maxima were weaker. Tests with heavier atoms, both in Stern's laboratory and elsewhere, showed no diffraction, as expect-



DIFFRACTION OF HELIUM ATOMS by a crystal surface of lithium fluoride was achieved by Stern and his colleagues in 1929. Their apparatus was arranged in such a way that the crystal could be tilted in order to direct the reflected and diffracted atoms into a small tube (*upper right*), which was connected to a very sensitive manometer. The graph at far right shows a typical result. The sharp peak at tilting angle zero is caused by the reflected atoms (sometimes called the specular beam). As the tilting angle is increased, the number of detected atoms first drops sharply but then rises again when the diffracted atoms begin to enter detector. These

ed. Such atoms are always reflected diffusely, as light is from white paper, sometimes with a slight enhancement in the specular direction, as from slightly shiny paper. Not much work has been done in this area, but such studies may be of some use in the future.

Certain anomalies were found in Stern's diffraction experiments that indicated a very weak attraction between the helium atoms and the surface of the crystal. In addition slight irregularities in the shape of the reflected beam, found later by Stern and Estermann, offered a clue to the nature of submicroscopic crystal imperfections. In both cases further research is now dormant, but perhaps it is not defunct.

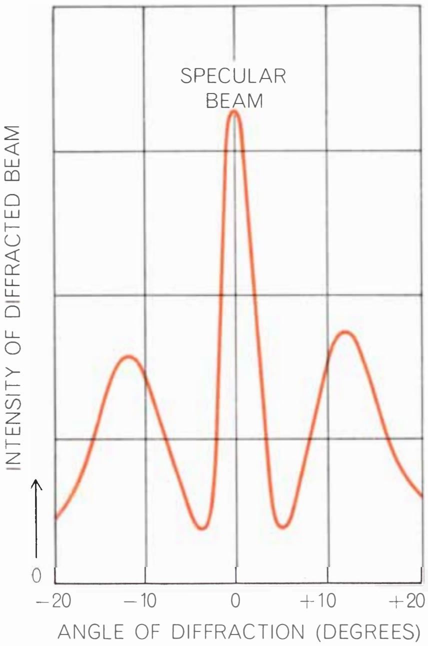
Magnet-Moment Experiments

By far the most fertile line of work in molecular beams has grown out of the original Stern-Gerlach experiment and deals with the deflection of magnetic atoms in inhomogeneous magnetic fields. The interpretation of the Stern-Gerlach experiment changed soon after it was completed; the magnetism of the silver atoms was now believed to be caused not by the orbital motion of its outermost electron, as in Bohr's model of the hydrogen atom, but by the rotation of the electron around its own axis. When the idea of a spinning electron was first published by Samuel A. Goudsmit and George E. Uhlenbeck in 1925, a number of puzzling spectrographic facts fell neatly into place. In some atoms the magnetic moment was apparently due to a combination of electron spin and electron orbital motion, and in 1923 Alfred Landé had already devised an empirical formula for computing the magnetic moment of these atoms to account for the observed Zeeman splitting of the spectral lines of the atoms in a magnetic field. Stern had induced a couple of his students to verify Landé's formula for the elements bismuth and thallium, but on the whole interest in the magnetic moments of atoms seemed to be on the wane.

In 1926, however, Stern pointed out that the molecular-beam method ought to be capable of detecting and perhaps measuring magnetic moments 1,000 times smaller than any previously measured. One might expect such magnetic moments to be created by the rotation of molecules or to be intrinsic to atomic nuclei. Interest in such small moments quickened two years later, when P. A. M. Dirac published his celebrated mathematical theory of the electron. Dirac had tried to improve on Schrödinger's wave equation, which was nonrelativistic (that is, valid only for particles moving fairly slowly compared with the speed of light). Dirac succeeded in designing a wave equation that was remarkably simple, and he was thrilled to find that the electron, if it obeyed his equation, had to spin just as Goudsmit and Uhlenbeck had predicted it would. The magnetic moment of the atom was also given by Dirac's equation.

What about the electron's big brother, the proton? It was 1,836 times heavier than the electron, but Dirac's theory imposed no weight limits. Indeed, there was no reason why Dirac's theory should not apply to the proton as well; if it did, the spin, or angular momentum, of the proton would be the same as that of the electron but its magnetic moment would be 1,836 times smaller than that of the electron.

Here was a fresh challenge for Stern. The diffraction experiments had given him experience with hydrogen beams, and the hydrogen molecule was particularly suited for this new test: its two electrons were known to spin in opposite directions, but its protons usually had their spins pointing in the same direction. Hence the hydrogen molecule would possess a magnetic moment twice that of a single proton. The sensitivity of the Stern-Gerlach experiment would have to be improved about a thousandfold, but Stern was confident this could be done. The inhomogeneous magnetic field was made narrower (to provide a higher magnetic gradient) and longer



experiments proved beyond doubt that beams of complex particles (helium atoms and later hydrogen molecules) could be diffracted and would exhibit the wave properties foretold by Louis de Broglie in 1924.

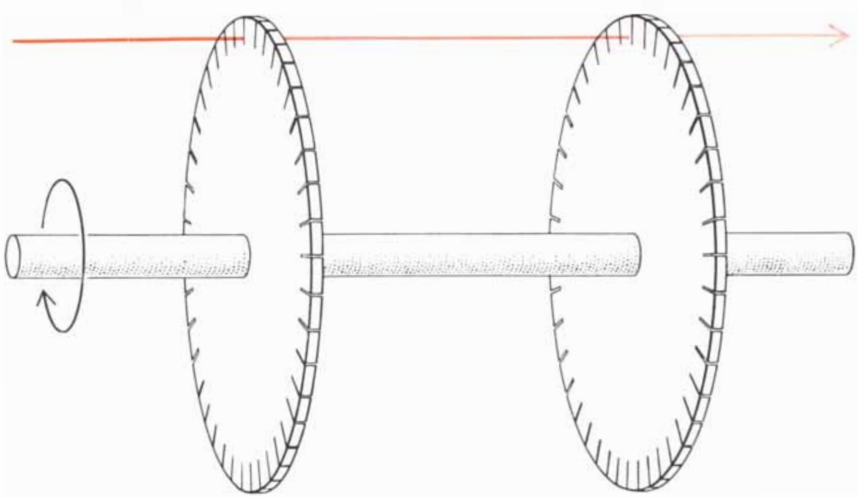
(so that the molecules would be subjected to deflection for a longer time). The deflection still amounted to only a few hundredths of a millimeter. Very fine beams had to be used, as well as very fine detector slits. The latter requirement in turn meant that I had to build new manometers with much smaller volumes, so that pressure equilibrium would be reached within a period of not more than a minute.

The measurements were complicated by the fact that the magnetic moment of a hydrogen molecule is not simply the sum of the two proton moments. The molecule itself also rotates, its two protons swinging around like two dancers doing a waltz, and this rotation gives rise to an additional magnetic moment. By cooling the "oven" from which the hydrogen entered the apparatus it was possible to reduce the molecular rotation but not to stop it completely. The rules of quantum mechanics compel those molecules of hydrogen that have both protons spinning in the same direction (called ortho-hydrogen) to rotate with an angular momentum that is an odd multiple of the quantum of rotation. Thus even at the lowest temperatures these molecules have to rotate, since one quantum of angular momentum would always remain. Hydrogen molecules whose two protons spin in opposite directions (para-hydrogen) are limited to even multiples of the rotation quantum. In these molecules the magnetic moments of the protons would cancel and on being cooled enough the molecules would stop rotating altogether.

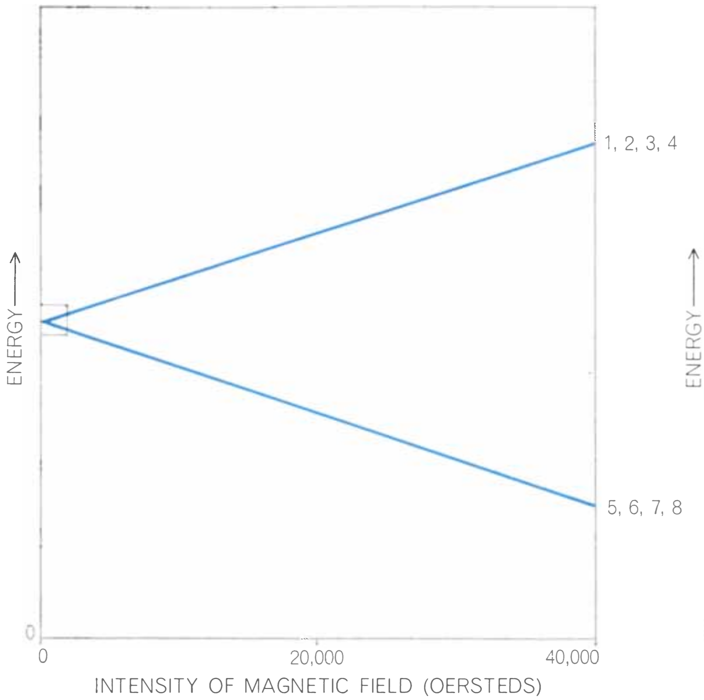
Normally hydrogen is a three-to-one mixture of ortho- and para-hydrogen, but by cooling hydrogen with a suitable catalyst—for example charcoal—one can get practically pure para-hydrogen. A beam of cold para-hydrogen, having neither a net proton spin nor a molecular rotation, would be practically nonmagnetic, as we were able to verify. It could be deflected in an inhomogeneous magnetic field only on being slightly warmed up, and from such measurements we were able to determine how much of the molecule's magnetic moment is actually caused by the rotation of the molecule as a whole. By comparing these deflections with those observed when we used beams of ordinary hydrogen (which is 75 percent ortho-hydrogen) we were finally able to compute the magnetic moment of the proton.

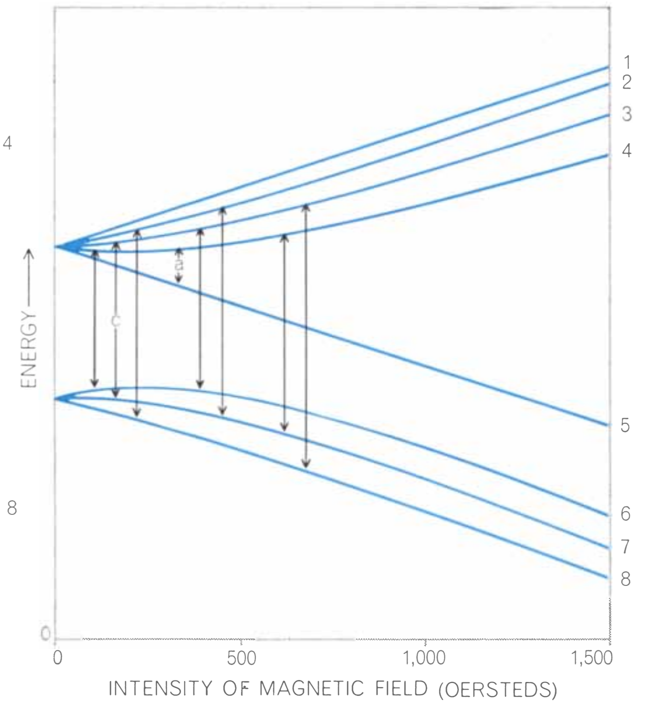
To our great surprise the proton turned out to be two and a half times more magnetic than we had expected! This meant that the proton did not obey Dirac's equation and was in fact not simply the electron's big brother but something far more complex. Today we have plenty of other evidence of the proton's complexity. We now visualize the proton as a beehive of activity, with mesons of various kinds forming and disappearing near it all the time; the motion of these mesons accounts for the extra magnetic moment of the proton. Stern's measurement was the first clear indication that the proton is a much more complex particle than the electron.

The next great advance in the measurement of magnetic moments by means of molecular beams was made by I. I. Rabi, who had worked with Stern in 1931 and had then returned to the U.S. to start his own school at Columbia University. To understand Rabi's contribution requires a bit of backtracking. If one were to plot the energy of a sodium atom, say, as a function of magnetic-field intensity, the result would be two straight lines, corresponding to the parallel and antiparallel orientations of the atom's spinning electrons with respect to the magnetic field [*see illustration at left on next page*]. The foregoing statement is not, however, quite correct; we have neglected the fact that the nucleus of the sodium atom has a spin and hence a magnetic moment of its own. In fact, the spin of the nucleus is greater than that of the electron; as a result the nucleus is capable of more than just two orientations in a magnetic field. The angular momentum of any particle is always equal to the product of the quantum unit of spin times I, where I is one of the numbers in the series 0, 1/2, 1, 3/2, 2 and so on. A system with spin I has $2I + 1$ allowed orientations in a magnetic field. For example, the electron, with I equal to 1/2, has just two orientations. The sodium nucleus, on the other hand, has a spin equal to 3/2 and so has four allowed orientations. Thus the two lines



REFINEMENT OF DIFFRACTION TEST was achieved in a later experiment by Stern and the author by successively passing the helium beam through two rapidly rotating toothed wheels; atoms that had passed through one of the slots in the first wheel could pass through the second wheel only if they had the right velocity. When this monochromatic beam struck the crystal surface, the atoms were diffracted within a much narrower range of angles.





ENERGY OF A SODIUM ATOM, plotted as a function of magnetic-field intensity (*left*), appears to increase along two straight lines, corresponding to the parallel and antiparallel orientations of the atom's spinning electrons with respect to the magnetic field. In actuality the magnetic moment of the nucleus also makes a minute contribution to the total magnetic energy of the atom. Thus the two lines on the graph are actually each a set of four lines, the lines being very close together because the magnetic moment of the nucleus is very small. In a weak magnetic field the interaction of the electron spin and the magnetic moment of the nucleus gives rise to an even more complicated "hyperfine" structure (*right*). The arrows indicate the transitions between the closely spaced energy states that can be studied by the molecular-beam resonance method. Transition *a* is comparatively easy to study because the energy difference and hence the frequency is much lower than for the other transitions. Transition *c* is suitable for use in an "atomic clock."

on our graph are actually each a set of four lines, the lines being very close together because the magnetic moment of the nucleus is very small and makes only a minute contribution to the total magnetic energy of the atom.

In a weak magnetic field the situation is further complicated by the fact that both the electron and the nucleus may be thought to precess in a complex manner. Such pre-quantum-mechanical ways of speaking are of little use, but quantum mechanics enables us to work out the allowed energy values [*see illustration at right above*]. At zero field there are just two energy values, corresponding to the electron spin being aligned parallel or antiparallel to the nuclear spin. These two states have net spins of I equals $+1/2$ and I equals $-1/2$ respectively. For sodium this works out to two and one net spins respectively; thus a weak field splits the energy values into five and three lines, corresponding to five and three allowed nuclear orientations. As the intensity of the field increases, there is a gradual transition to a situation in which the mutual interactions of the electron spin and nuclear spin become insignificant.

All the foregoing phenomena were known for some time before Rabi's experiments, through the study of spectroscopy. As the first crude spectroscopes were improved late in the 19th century it was found that some of the spectral lines were complex. For instance, the yellow sodium line was found to be a pair of lines differing in wavelength by about .1 percent; similar fine structure was found in many other lines. The standard explanation, given by Goudsmit and Uhlenbeck in 1925, was that the electron can spin either in the direction of its orbit or in the opposite direction, the two possible states possessing energies that differ by about .002 electron volt.

As the spectroscopist's tools became more delicate, each of the sodium lines was itself seen as a group of several lines, and many other spectral lines revealed a similar "hyperfine" structure. Sometimes this structure is merely an isotope effect: the element in question consists of several isotopes whose spectral lines do not exactly coincide. Usually, however, the hyperfine structure is caused by the interaction of the electron spin and the magnetic moment of the nucleus, as I have explained above. Complete confirmation of the latter view was difficult because spectral lines are often not sharp enough to allow the clear resolution of hyperfine structure.

Molecular beams were able to help here in two different ways. In the first place they could be used to produce sharper spectral lines. In a flame or an electric discharge the atoms that emit light are flying about with speeds up to a mile a second or so. When an observer at rest receives light from a moving source, he receives more wave crests per second if the source is moving toward him and fewer wave crests if the source is moving away. This phenomenon (known as the Doppler effect after Christian Doppler, who first predicted it in 1842) causes a spread in wavelengths amounting to several parts in a million and obscures some details of hyperfine structure. If the source consists of atoms in a beam, however, and the light that is emitted is observed approximately at right angles to the direction of the beam, the Doppler broadening of spectral lines becomes much smaller. This trick was used successfully in 1928 by the Soviet investigators L. Dobrezov and A. Terenin; in fact, they were the first to observe and measure the hyperfine structure of the yellow sodium lines. Up to that time hyperfine structure had been observed only in heavier elements, where it is more pronounced and where the Doppler broadening is less. A number of other spectroscopists have since used molecular-beam sources, excited either by electron bombardment or by intense light. Very sharp absorption lines can also be observed by studying the light that has passed through a molecular beam.

What Rabi did was something quite different: he used molecular beams to detect transitions between the closely spaced energy states that result from the action of a magnetic field on an atom or a molecule. The idea of studying such transitions had occurred to others; the Dutch physicist C. J. Gorter had tried it, but without success. To cause the transitions was quite easy: a small shortwave radio transmitter produces quanta of the required energy. To detect the transitions was much more difficult, however, and Rabi realized that molecular beams were ideally suited for this.

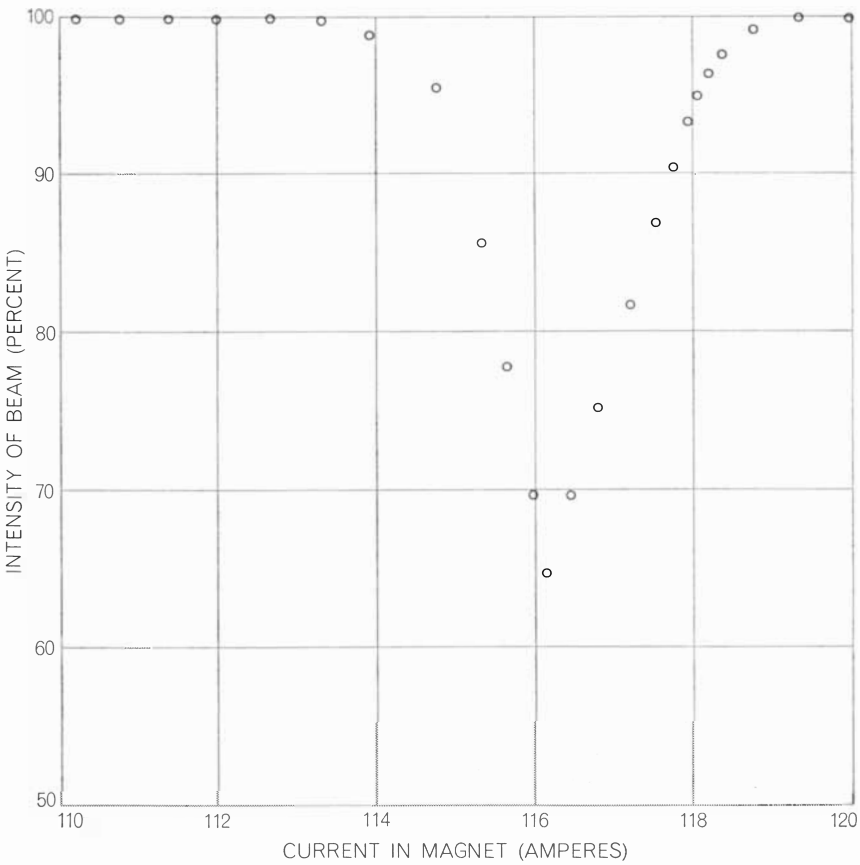
Magnetic-Resonance Experiments

Stern had once posed the question of whether potassium atoms, aligned in a particular direction in a magnetic field (by splitting the beam in a Stern-Gerlach field and then blocking one of the two halves), would occasionally flip over into the opposite orientation if they were passed through a region in which the field direction changed rapidly. By testing potassium atoms in a second Stern-Gerlach field Emilio Segrè and I had found in 1932 that such flip-over processes did indeed occur. Several theorists took an interest in our work and computed the probability of such transitions for various types of field, but they always considered stationary fields in which the atoms experienced variations only as a result of their rapid motion through the field. Rabi was the first to use an oscillating radio-frequency field to obtain "resonance," that is, transitions in a narrow range of frequencies only.

I still remember the thrill of seeing the first nuclear-magnetic-resonance curve, published by Rabi and three of his students (Jerrold R. Zacharias, Sidney Millman and Polykarp Kusch) in *The Physical Review* of February 15, 1938 [*see illustration at right*]. Their very first attempt showed a sharp resonance peak; its width was less than 2 percent of its height. Clearly here was a method for measuring nuclear magnetic moments to an accuracy many times greater than before. The only two quantities that had to be measured were a radio frequency (number of oscillations per unit of time) and a magnetic-field intensity. Time measurements are among the most accurate in physics, and a homogeneous magnetic field could be measured, with care, to a few parts in a million. Rabi's apparatus still contained two inhomogeneous fields, but their precise field gradient no longer mattered. They merely served as a polarizer (an *A* field) to select molecules of a particular orientation and as an analyzer (a *B* field) to test for the reoriented molecules [*see bottom illustration on page 62*]. The transitions from one orientation to another took place in an intermediate third field (a *C* field), which had to be both homogeneous and accurately known. The center region also contained a loop through which an oscillating current from a small radio-frequency generator was passed. The two inhomogeneous fields were so arranged that the atoms selected and somewhat spread out by the *A* field were brought together again by the *B* field; thus the detector was able to record a good fraction of the original beam.

The detector used by Rabi in much of his work deserves a few words. Irving Langmuir—the American pioneer in vacuum physics—had discovered in 1923 that when alkali atoms strike a white-hot tungsten wire, they tend to lose an electron to the tungsten and to depart from the wire as positive ions. John B. Taylor, working with Stern, demonstrated in 1929 that this phenomenon provided a convenient method for detecting alkali atoms quantitatively: one simply had to collect the ions on a positively charged metal plate and measure the current they produced.

A tungsten wire can also detect a beam of alkali halide molecules, and Rabi used such a beam (consisting of potassium chloride molecules) in his first test of the new resonance method. He deliberately chose a molecule containing an even number of electrons, with their spins aligned in such a way that their magnetic moments cancel one an-



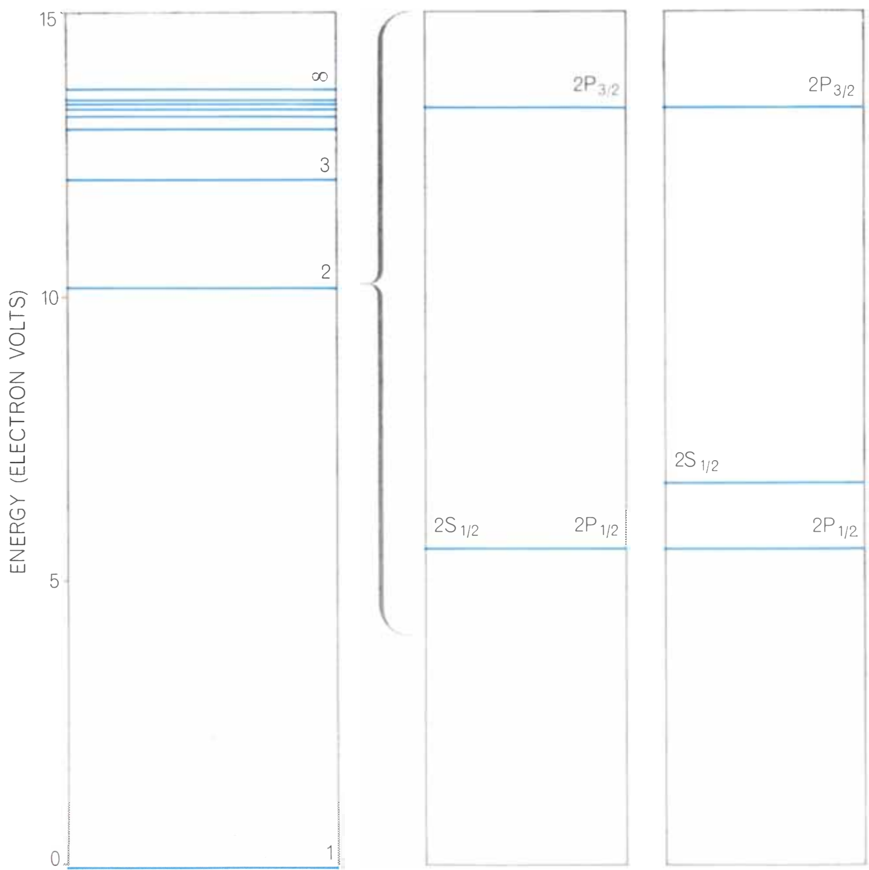
FIRST NUCLEAR-MAGNETIC-RESONANCE CURVE, observed at radio frequency with a beam of potassium chloride molecules, was published by I. I. Rabi, Jerrold R. Zacharias, Sidney Millman and Polykarp Kusch in *The Physical Review* of February 15, 1938. Their first attempt showed a sharp resonance peak, with a width less than 2 percent of its height.

other. The only net magnetic moment of such a molecule is due to its nuclear spin and molecular rotation (as in the case of hydrogen). As a consequence very long and fine beams had to be used in order for the beam to be split appreciably in an inhomogeneous A field. On the other hand, the C field could be made quite strong without getting excessively high resonance frequencies; as we have seen, in a strong magnetic field the mutual interaction of the nuclear-spin moments and the molecular-rotation moments is negligible.

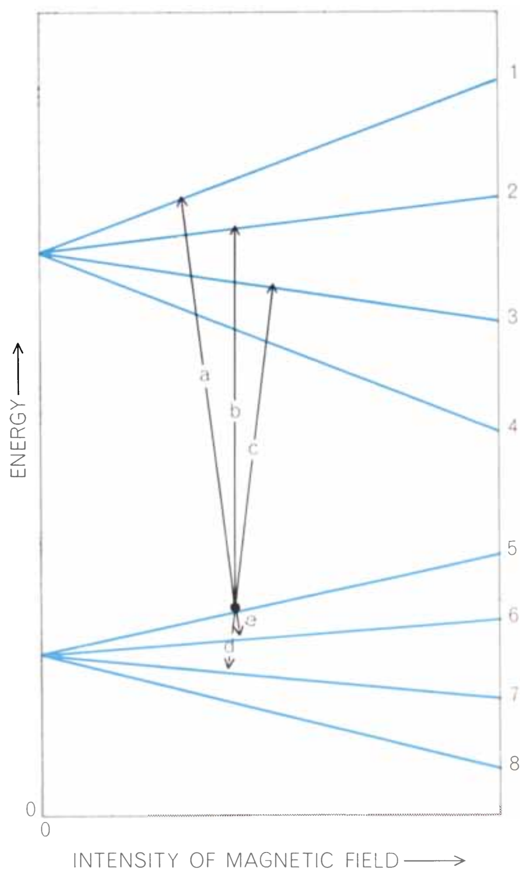
Today, 27 years after Rabi's first resonance experiments, perhaps a dozen laboratories are still using his method to determine nuclear magnetic moments, and there is no sign that its applications have been exhausted. In recent years some competitors have appeared; for example, it is now possible, thanks to methods devised by Felix Bloch at Stanford University and Edward M. Purcell at Harvard University, to measure nuclear magnetic moments in solids. The molecular-beam method remains unbeaten, however, when it comes to measuring the magnetic moments of rare species of nuclei—for instance short-lived radioactive nuclei, of which only minute amounts can be obtained at a time. Moreover, many properties of free atoms and molecules, predicted by quantum theory and roughly tested by the methods of optical spectroscopy, have been investigated in much finer detail by the molecular-beam resonance method. Foremost among these latter applications was the Lamb-Retherford experiment, which was performed at Columbia in 1947.

The Lamb-Retherford Experiment

The spectrum of the hydrogen atom has been the touchstone of atomic physics from the very beginning. The regularity with which the lines in the spectrum are spaced had been noted by the Swiss schoolteacher Johann Jakob Balmer in 1885. Bohr's first model of the hydrogen atom accounted for Balmer's observations and predicted additional spectral lines in both the infrared and the ultraviolet regions of the hydrogen spectrum; the existence of these lines was verified a short time later. Schrödinger's wave equation gave a new meaning to Bohr's model, removing its arbitrariness and some of its inconsistencies. What is more, Schrödinger's equations made it clear how Bohr's hydrogen model could be applied to other atoms. Dirac modified the wave equation to bring it into accord with relativity theory and found that the spin of the electron followed naturally from his modification. He was able to compute the fine structure of the spectral lines of hydrogen without any *ad hoc* assumptions, but it was difficult to decide whether or not the theory really agreed with the facts. The fine structure of hydrogen's spectral lines is particularly fine, and the lines are strongly broadened by the Doppler effect (because hydrogen atoms are so light and hence fast). For nearly 20 years the evidence for Dirac's predictions remained inconclusive. Some spectrosco-



FIRST EXCITED STATE of the hydrogen atom, which corresponds to the second energy level in the diagram at left, was expected (according to the Dirac theory) to be split into three closely adjacent energy states (*center*), of which the so-called $S_{1/2}$ level coincided exactly with the $P_{1/2}$ level. Using the molecular-beam-resonance method, Willis Lamb and R. C. Retherford at Columbia found that these two levels did not in fact coincide but were separated by about 1,000 megacycles (*right*). This separation is now known as the Lamb shift.



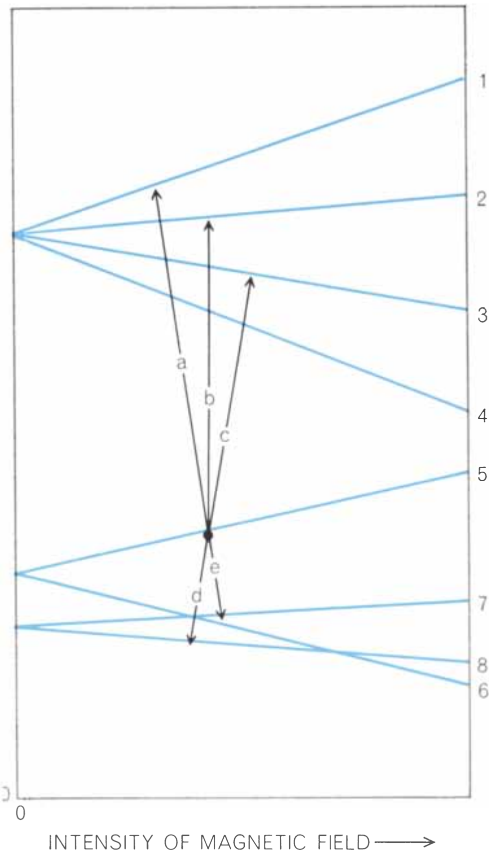
IN A MAGNETIC FIELD the Dirac theory predicted that the three energy levels of the first excited state of hydrogen should be split further, into a total of eight states. According to quantum theory 18 of the 28 conceivable transitions between the eight states pists found small deviations from the theory, whereas others thought all was well.

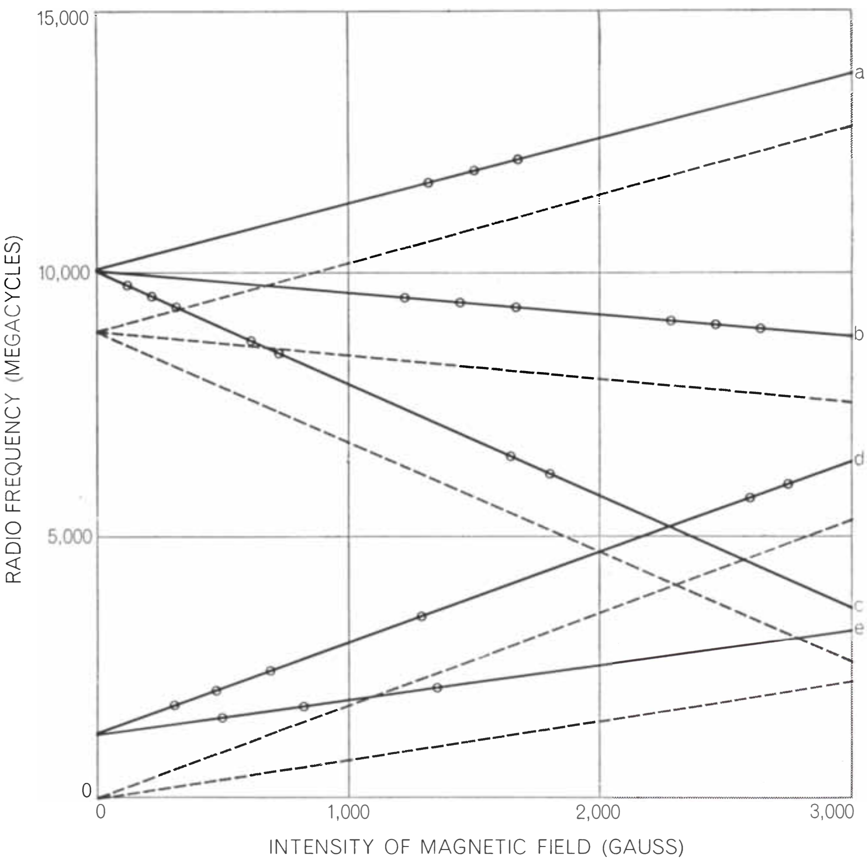
When World War II ended in 1945, many physicists returned to their laboratories keen to take up pure research once more and to use the new tools the war had forced them to design. In particular the development of radar had produced new microwave techniques and increased the scope of the resonance method for studying atomic transitions. At Columbia, Willis Lamb decided to use the resonance method to study transitions between the three closely adjacent energy states into which the Dirac theory had split the first excited state of the hydrogen atom. In the presence of a magnetic field these states should be split further, into a total of eight states. According to the "selection rules" of quantum theory 18 of the 28 conceivable transitions between the eight states should be forbidden, leaving 10 transitions to be observed, of which five were expected to be very feeble.

To obtain hydrogen in the desired state, Lamb and R. C. Retherford first had to break up the hydrogen molecules into atoms. This was done by using a tungsten oven at intense white heat. The escaping atoms were then bombarded by electrons with enough energy to raise them to the first excited state. Atoms that were raised to one of the so-called *P* states would return almost at once to their ground state, emitting a photon, or quantum of light. The *S* state, on the other hand, is metastable; that is, it lasts a much longer time—long enough to let the atom complete its journey through the apparatus. Moreover, a metastable atom is easy to detect: when it strikes a metal plate, it tends to liberate an electron and thus betrays its presence. Only one hydrogen atom in several million was raised to the metastable state, but since a fairly broad beam could be used, there were enough atoms to perform the measurements. To detect the transitions was also easy: an atom that made a transition from the *S* state to one of the *P* states would then immediately radiate a photon and drop to the ground state, losing its ability to release an electron from the metal plate.

The procedure adopted by Lamb and Retherford was similar to that of Rabi's first experiment. The radio frequency was set successively at a number of values, and each time the magnetic field was varied until a dip in the electron current indicated that a transition was taking place. The results were in striking disagreement with Dirac's theory; to explain them one had to assume that the $S_{1/2}$ level did not coincide with the $P_{1/2}$ level as expected but was about 1,000 megacycles higher. This shift—now generally called the Lamb shift—is only about half the typical Doppler broadening of an optical line of hydrogen. No wonder the spectroscopists had been unable to pin it down!

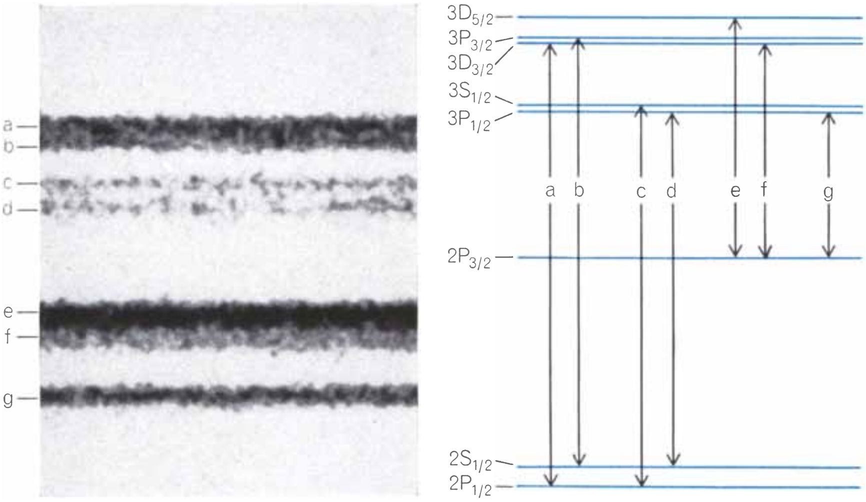
The theoretical physicists rallied quickly from their surprise, and within a few weeks Hans Bethe produced a complete explanation of the Lamb shift. Actually they had not been unprepared





should be forbidden, leaving 10 transitions to be observed, of which five were expected to be very feeble. The remaining five are shown here in the positions predicted by the Dirac theory (*left*) and in the positions found by Lamb and Retherford (*right*).

RESONANCES WERE OBSERVED by Lamb and Retherford at the positions marked by the small open circles on this graph; according to the Dirac theory, resonances should have been observed along the broken lines. To explain the discrepancy theorists were forced to pursue Dirac's calculations beyond a first approximation. The best theoretical figure for the Lamb shift is now 1,057.2 megacycles, whereas experiments indicate 1,057.8. These calculations also successfully predicted a slightly larger magnetic moment for the electron.



EVIDENCE OF LAMB SHIFT in the second energy level of helium is visible in the spectrogram at left, made by G. Herzberg of the National Research Council of Canada. The spectral lines designated by letters are produced by transitions between the hyperfine energy levels indicated in the chart at right. The lines designated *c* and *d* would coincide if the Lamb shift (which is the splitting between the levels marked *2S½* and *2P½*) were zero. Lines *a* and *b* are not as well separated, because their separation is the difference of the splitting in the upper and lower states, whereas the separation between *c* and *d* is the sum of the Lamb shift in the upper and lower states. The other spectral lines are not affected by the Lamb shift.

for discrepancies, since Dirac's calculations had not been pursued beyond a first approximation. The reason was that every attempt to go to higher approximations had produced nonsense; even the energy content of a free electron came out infinite. Lamb's experiment now forced theorists to tackle these infinities in earnest. If the energy of a bound state of the electron came out infinite, one had to deduct from it the energy of a free electron at rest, which was also infinite. That is what Bethe did, and what others did after him with greater refinements. To compute the difference between two infinite quantities seemed a somewhat unsound procedure, but it worked remarkably well. A race for precision between the theorists and the experimenters ended with excellent agreement: the best theoretical figure for the Lamb shift is 1,057.2 megacycles, whereas the experiments indicate 1,057.8 megacycles, a difference of less than .1 percent. Both groups may well be proud of their achievement. The theorists gained a great deal of confidence in their techniques, and much has been done since to put those mathematically doubtful subtraction procedures on a sounder footing. It might be added that these calculations also indicated a slightly larger magnetic moment for the electron, and that too has been very well confirmed by atomic-beam experiments, in particular by Kusch.

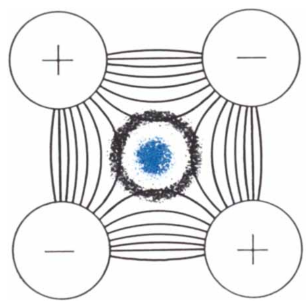
In this kind of work the need for precision is obvious; an important aspect of the theory had to be tested, and a change of a few parts in a million of the magnetic moment of the electron would have indicated that the theory had broken down. Sometimes the value of precision is not so apparent. The knowledge of nuclear spins and magnetic moments has been a great help in constructing nuclear models, that is, in deciding what mathematical approximations are useful in tackling the appalling complexity of atomic nuclei. It is precisely because of this complexity that no one has yet tried to predict a nuclear magnetic moment to anything like the experimenter's five-figure accuracy. All the same, aiming at high precision is usually good policy and is rewarded in the end.

The fundamental limit to the accuracy with which a frequency can be measured is the time during which an oscillating system can be kept under observation. If one were to compare two trains of waves with nearly the same frequency, it would be evident that they can be quite accurately matched for a time but that they eventually get out of phase. The closer the frequencies are, the longer it takes for the phase difference to show up. During the transition between two energy states an atomic system has a wave function that oscillates with a frequency that is proportional to the energy difference between the states. Transitions will be caused by an external oscillating field if the two frequencies are reasonably matched during the time the atom spends in the *C* field. Hence we get a resonance whose peak, under optimum conditions, can be located to perhaps a hundredth of its width.

A typical hydrogen molecule takes about 10^{-4} second to travel an inch; in order to measure its frequency to within 10 cycles per second one needs a *C* field at least 10 inches long; this creates a problem because it is quite difficult to keep the magnetic field sufficiently constant over such a distance. Norman F. Ramsey, who first worked with Rabi and then started his own school at Harvard University, found an ingenious way around this difficulty. He realized that the two ends were the most important places for the comparison of two wave trains, so instead of exposing his molecules to radio frequency all along their path through the *C* field he merely placed one short coil at one end and a second coil at the other. This arrangement sharpened the resonance by as much as if he had lengthened the *C* field by 60 percent. Moreover, small irregularities in the magnetic field no longer mattered.

Atomic Clocks

Ramsey's method was an important step toward the development of atomic clocks. Every clock (except for water clocks and similar primitive devices) depends on a frequency standard, such as a pendulum or a balance wheel, coupled to some kind of gear that dis-



AMMONIA MASER, invented by Charles H. Townes in 1954, was based on a principle enunciated by Einstein in 1909, namely that the presence of a light wave could cause an atom to lose energy rather than gain it; the light wave, on passing through such a plays the number of oscillations that have occurred. Since the frequency standard is under continuous observation, the difficulty I have just mentioned does not arise. But a pendulum, left to itself, will lose much of its energy in a few hundred oscillations; there must be a driving mechanism to replace the energy loss, either continuously or from time to time, and if that mechanism is not carefully designed, it is liable to alter the frequency of the standard. Clearly for high precision it is desirable to use oscillators that conserve a high percentage of their original energy.

With the advent of electronic devices it became possible to use standards that oscillate at much higher frequencies; tuning forks that could oscillate several hundred times a second were soon succeeded by quartz crystals capable of oscillating at frequencies 1,000 times higher. Such crystals hang on to their energy with remarkable tenacity, and for some years quartz clocks held the record for precision, with errors of no more than a few seconds a year. They made it possible to detect small irregularities in the rotation of the earth, which greatly interested geophysicists, who began to ask for still higher precision. That was not easy, however; no two quartz crystals are exactly alike, and even a given crystal changes slightly with time.

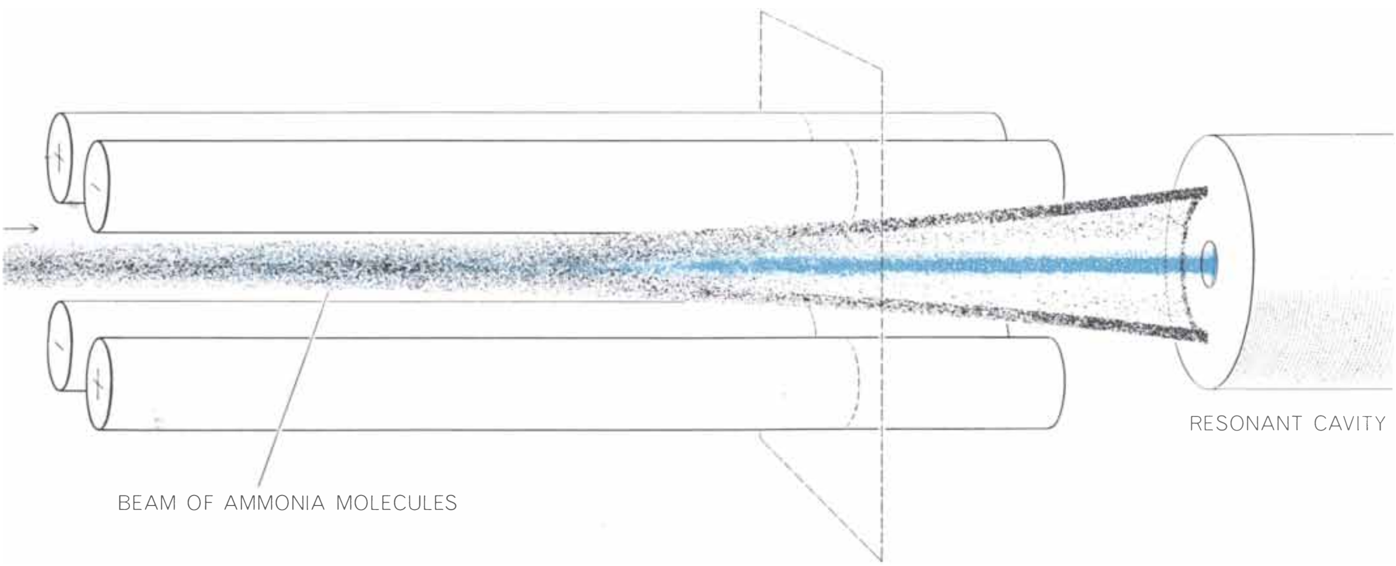
An ideal frequency standard should depend only on the properties of a well-defined atom or molecule and should not be affected by external conditions. Most of the transitions shown in the graph at the right on page 66 occur at frequencies that depend strongly on the magnetic field, but there is one in the region where the effect of a weak magnetic field is very small. All alkali metals have such a transition, but cesium seems to be most suitable. Its atoms are heavy and will evaporate at quite a low temperature; hence they are slow and spend a long time in the *C* field. Their frequency is high, about nine billion oscillations per second, which provides a high fractional precision for a given change in frequency. Cesium can be detected efficiently by its ionization on contact with a hot tungsten wire, and all its atoms are strictly alike because cesium has only one stable isotope.

The oscillations in a cesium clock are made by a small microwave generator whose frequency peak is kept adjusted, by a kind of electronic servomechanism, to within 1 percent or so of the width of the resonance peak. The best value for the cesium frequency is probably the one found by L. Essen in Britain, namely 9,129,631,830 $\pm$ 10 oscillations per second; the $\pm$10 is due mainly to the difficulty in obtaining the astronomical observations by which the length of the second is measured. A cesium clock is a fairly complex assembly of electronic equipment in which the cesium beam merely serves to keep a check on the frequency. Even so, a commercial version has been produced and is at present the most accurate clock in general use.

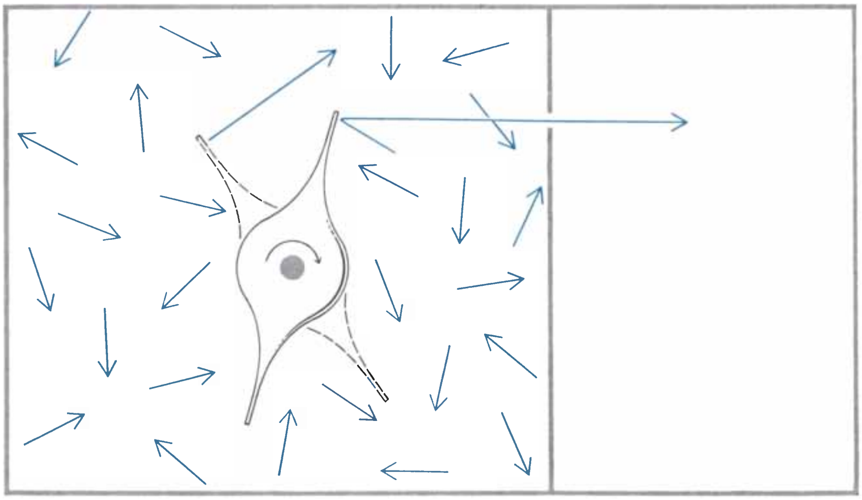
Masers and Lasers

In a resonance experiment of the Rabi type one can select either the higher or the lower energy state for passing through the *C* field. If the higher state is selected, the radio-frequency field will then cause transitions to the lower state. The absorption of radiation, which raises an atom from a lower to a higher state, is a familiar phenomenon, but Einstein had shown, as early as 1909, that the opposite transitions are just as likely. In the latter case the presence of a light wave would cause the atom to lose energy rather than gain it; the light wave, on passing through such a material, would suffer "negative absorption" and get stronger, not weaker. Einstein used the phrase "stimulated emission" for this phenomenon, thus setting it apart from the spontaneous emission by which an atom in a high energy state will eventually lose its energy if left to itself.

Normally a light wave will be absorbed rather than causing stimulated emission, because in normal atomic populations there are many more atoms in the lower state than in the higher one. In an atomic-beam apparatus, however, one can create an inverted population in which the molecules in the



material, would suffer "negative absorption" and get stronger, not weaker. The maser used an inhomogeneous electric field set up by four parallel metal bars to focus the higher-energy ammonia molecules (*color*) toward the end of the field, whereas those in the lower state (*black*) were pulled out of the beam. When the high-energy beam entered a tuned cavity (*right*) in which a microwave oscillation of the correct frequency was present, the beam had the expected effect of strengthening these oscillations. When the pressure of the ammonia was increased, the oscillations could be kept at the same intensity with less input of microwave power; finally the power could be switched off altogether and the beam then acted as a generator of microwave power. A cross section is shown at left.



MOLECULES ARE SLAPPED into rapid motion by a spindle-shaped steel rotor in this device invented by Philip B. Moon. The rotor rotates at more than a mile a second in a vacuum. The molecules escape through a small hole into an adjacent evacuated space, producing a molecular beam with a high and approximately uniform speed, fast enough to make them react chemically with other molecules with which they are allowed to collide.

higher state are more numerous. When this happens, the light wave (in this case a radio wave) will be amplified rather than weakened by the beam. Charles H. Townes, then at Columbia, showed that this actually did happen; he called his apparatus a "maser," from the initial letters of the phrase "microwave amplification by stimulated emission of radiation."

Townes wanted an intense beam, and one that would also interact strongly with electromagnetic radiation. Instead of alkali atoms, whose interaction is rather weak, he used a beam of ammonia. The ammonia molecule (NH_3) is shaped like a pyramid and is capable of oscillating between two configurations, with the nitrogen atom on one side or the other of the plane that contains the three hydrogen atoms. There are about nine billion oscillations per second, and the electric charges moving back and forth have a strong interaction with electromagnetic waves.

The emission or absorption of waves of such high frequency corresponds to a transition between two quantum states that cannot be described in the classical terms we have used so far. Their properties can be worked out from quantum mechanics, however, and it develops that their energy is affected by the presence of an electrostatic field. It is therefore possible to separate molecules in the two states by an inhomogeneous electric field, in analogy to the magnetic separation first achieved by Stern and Gerlach.

Estermann had studied the deflection of molecules in electric fields as early as 1925, and others had followed, but Townes (in collaboration with J. P. Gordon and H. J. Zeiger) used a novel kind of field that caused the ammonia molecules to be focused [*see bottom illustration on preceding two pages*]. The first magnetic focusing field for molecular beams had been developed a few years earlier by W. Paul in Germany. In Townes's device the field was set up by four parallel metal rods, arranged in a square and charged alternately positive and negative. They produced an electric field that was weak in the middle and got stronger toward the outside. The ammonia molecules in the higher energy state were pushed together and roughly focused toward the end of the field, whereas those in the lower state were pulled out of the beam. Thus the beam that left the electric field consisted almost entirely of molecules in the higher state. When the high-energy beam entered a tuned cavity in which a microwave oscillation of the correct frequency was present, the beam had the expected effect of strengthening those oscillations. What is more, when the pressure of the ammonia was gradually increased so that more and more molecules entered the cavity, the oscillations could be kept at the same intensity with less and less input of microwave power; finally the power could be switched off altogether and the beam then acted as a generator of microwave power.

This was an entirely new principle. It was not simply microwave radiation from the molecules, which was much too feeble to be detected. Yet there was no need for a separate microwave generator after the initial stages of the experiment. It was enough to let an inverted-population beam enter a properly tuned cavity; the cavity then began to "ring," or oscillate electromagnetically, extracting energy from the beam by the process of stimulated emission. Einstein's theoretical insight had waited 40 years before Townes found a way to exploit it.

Once a way had been shown it was quickly realized that there were many other means of creating an inverted population, not just in molecular beams but in gases and even in solids. Solid-state masers have now become a routine tool of physicists and radio engineers, both for the generation and the amplification of waves. The range of wavelengths has been extended into the infrared and visible regions, and new applications for such "lasers" ("light amplification by stimulated emission of radiation") are being found all the time. The maser principle has led to one of the greatest breakthroughs in the history of applied physics.

As a clock the original ammonia maser was not a complete success. The ammonia molecule has a very complicated spectrum owing to its rotation and the magnetic interaction of the four nuclei it contains. Moreover, its spectral lines are broadened because the molecules spend only a short time in the cavity, and the actual frequency generated depends noticeably on the way the cavity is tuned. The maser principle can be used with other molecular beams, however, and Ramsey has succeeded in running a maser with the simplest atom of all: the hydrogen atom. In its normal state the spin of the hydrogen nucleus (a proton) can be either parallel or antiparallel to that of the electron, and the energy difference between the two states corresponds to a frequency of about 1.4 billion oscillations per second. This is about six times less than the corresponding frequency of cesium atoms, but one can get very high accuracy all the same because, in view of their weak interaction with electromagnetic radiation, the hydrogen atoms have to spend a long time in the tuned cavity for the stimulated emission to set it ringing.

Ramsey solved the problem by "storing" the beam: trapping the hydrogen atoms in a flask in which they keep

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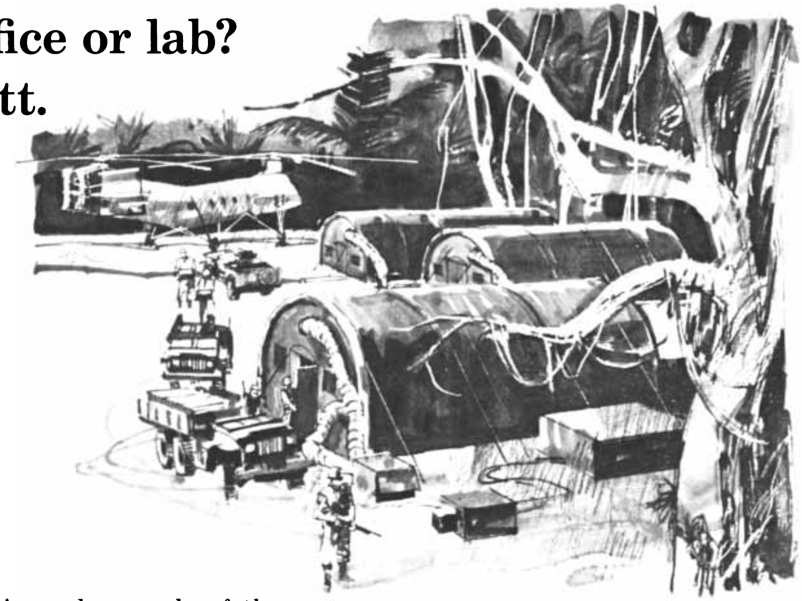

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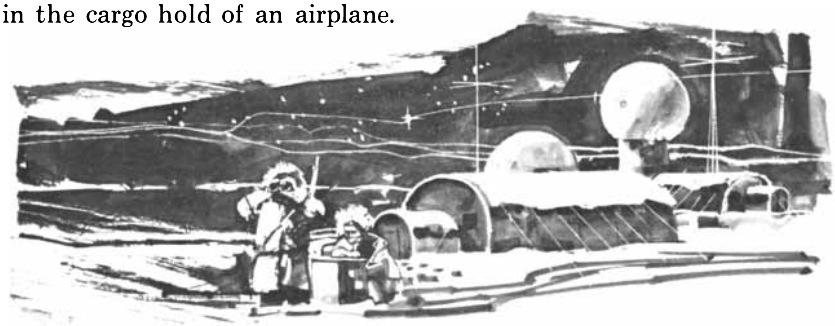

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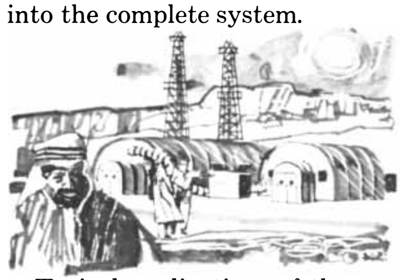

Typical applications of the new field units are: chemical and biological protection; radar installation, communications bases, civil defense shelters; and oil, mining, and construction operations.

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bouncing around for a second or so before they escape again through the small hole by which they entered. The flask itself is in a tuned cavity and its inside is painted with Teflon, an inert material that reflects impinging hydrogen atoms without any significant effect on their transition frequency. At first it may seem strange that a frequency standard can bounce around in a bottle, undergoing 100,000 collisions or so a second, but the proton spin inside a hydrogen atom is well protected from outside disturbances, except for magnetic ones, and Teflon is inert precisely because all its valences are saturated and so its molecules develop practically no magnetic field.

Because the atoms stay so long in the cavity, its tuning has only a minute effect on the frequency that is generated (less than one part in a billion). Moreover, this effect becomes less as the beam is made stronger, and it can be minimized by tuning the cavity until a change in beam intensity is seen to make no difference. Ramsey has shown that two such hydrogen clocks, after being adjusted independently, will keep time to better than one part in a trillion; neither will gain over the other by more than a thousandth of a second in 30 years!

Some Recent Innovations

There are a number of less spectacular uses of molecular beams. For instance, high-energy physicists are currently interested in using beams of polarized protons (that is, protons with their spins pointing predominantly in one direction). Fast protons can be polarized by selecting those that have been deflected through a certain angle by, say, carbon nuclei. This is a most inefficient method, however, since only a minute fraction of the protons in the original beam are deflected in a given direction. A molecular-beam method can do much better, and sources of slow polarized protons, ready for acceleration in whatever machine is available, have been developed in several laboratories.

Collisions between molecules can be studied under controlled conditions by letting a molecular beam pass through a dilute gas or, even better, by crossing it with another beam. It is possible in this way to study the chemical reactions between gases and to observe the single steps that are difficult to separate when the reaction takes place in a mixture of gases. Of course, gases often do not react unless they are hot enough, that is, unless the relative speed of the colliding molecules is high enough. An intriguing technique for giving the molecules extra speed was developed recently by Philip B. Moon of the University of Birmingham. He found he could cause a spindle-shaped steel rotor to rotate at more than a mile a second in a vacuum; if a small amount of gas was admitted, those molecules that got in the way of the rotor tips were slapped into rapid motion, and some could escape through a small hole into an adjacent evacuated space, producing a molecular beam with a high and approximately uniform speed, fast enough to make them react chemically with other molecules with which they were allowed to collide.

A different method, which gives beams of high intensity as well as high speed, is the use of a high-pressure nozzle instead of the usual oven slit. Usually the pressure in the oven is kept so low that the molecules escape without much jostling, each with the velocity it had in the oven. Only the slowest molecules tend to get pushed from behind, and indeed one observes fewer slow molecules than one would expect from Maxwell's formula. If the pressure is raised, more molecules get pushed to a higher speed, and eventually one gets a gas jet that both expands and cools. By the time the molecules emerge from the nozzle they are several times faster than normal beams, but the spread of velocities has become less. When such a "nozzle beam" strikes a solid surface, the surface is subjected to a bombardment somewhat like that to which a spacecraft or the nose cone of a rocket is subjected on reentering the atmosphere. The laboratory study of the effects of such bombardment has attracted the interest of designers of space vehicles.

Molecular-beam research started out as a "family affair" more than 40 years ago. For many years it was all conducted, with a few exceptions, by Otto Stern and his students and their students. Stern has every right to be proud of the enterprise he started; in the immediate "family" alone its success has resulted in five Nobel prizes—to Stern himself in 1943, to Rabi in 1944, to Lamb and Kusch in 1955 and to Townes in 1964. The applications of molecular-beam techniques now extend into all branches of physics and can no longer be said to be strictly a family affair. New projects are being undertaken in laboratories all over the world, and new surprises may well be just around the corner.

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Announces a single-topic issue
concerned with the urbanization of the world population
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To be published in September, 1965

Sometimes the photographer develops right along with the picture.

Photography, we admit, is the awkward stepchild of the visual arts. And understandably so.

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First try, too far away and not very well composed. And so impersonal it could be anybody's family.

that continuous experience. He's practicing a stop-and-go art form. When the average person takes a picture he doesn't know how it turns out 'til days later. Even if he's interested in profiting by his mistakes, it's too late. The location and lighting are different. The mood is gone. The creative continuity is shattered. (Even getting involved in processing your own pictures doesn't do much except shorten the

A minute later, getting better but still not perfect. Now get a little lower and wait for the right moment...

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GREEN TURTLE HATCHLINGS, with colored tags attached to their left hind flippers, scramble across the beach at Ascension Island, headed for the waters of the South Atlantic. In order to trace turtle migrations the author and his colleagues have tagged young and adult green turtles both at Ascension and in Costa Rica at the only nesting beach still frequented in the western Caribbean.

The Navigation of the Green Turtle

These animals are known to migrate regularly to and from nesting beach and feeding ground. Now it appears they can also navigate well enough to make an island landfall after 1,400 miles at sea

by Archie Carr

One of the stubborn puzzles of animal behavior is the ability of some animals to travel regularly to remote oceanic islands. The best-known of the blue-water navigators are birds; recently, however, the green turtle (*Chelonia mydas*) has given evidence of being as keen an island-finder as the sooty tern or the albatross. Because green turtles swim slowly, and do so at the surface of the water or a little below it, they are potentially easier to follow in their journeys than either birds or migratory fishes, seals and whales. The green turtle may therefore prove to be an important experimental subject for students of animal navigation.

The evidence that green turtles can find their way to remote oceanic islands is provided by female green turtles that normally inhabit feeding grounds along the coast of Brazil. It appears that once every two or three years these turtles swim all the way to Ascension Island—a target five miles wide and 1,400 miles away in the South Atlantic—to lay their eggs. By the processes of natural selection this population seems to have evolved the capacity to hold a true course across hundreds of miles of sea, using only animal senses as instruments of navigation. The difficulties facing such a voyage would seem insurmountable if it were not so clear that the turtles are somehow surmounting them.

The green turtle is one of the five kinds of sea turtle found throughout the warmer oceans of the world [*see illustration on next two pages*]. Adult green turtles, which may weigh more than 500 pounds, are herbivorous; they feed on the so-called turtle grass that grows abundantly in sheltered tropical shallows. Although the green turtles of the world are separated into reproductively isolated breeding colonies, they show little tendency to evolve into recognizable local races and species. The green turtles of the Pacific, for example, show only minor differences in form and color from those of the Atlantic. The one area in which what appears to be a well-differentiated species has evolved is the northern coast of Australia, where the form *Chelonia depressa* is found. Green turtles nest only in places where the average temperature of the surface water during the coldest month of the year is above 68 degrees Fahrenheit. In the Atlantic the northern limit of their nesting range seems to have been Bermuda; early voyagers to the New World destroyed the colony there. The most northerly nesting site known in the Pacific is French Frigate Shoal, an outlier of the Hawaiian Islands.

Until a few years ago what was known about the green turtle consisted mainly of cooking recipes and a sea of folklore from which rose only a few islands of fact. Among these were studies by Edward Banks in the Turtle Islands of Sarawak, by James Hornell in the Seychelle Islands off the east coast of Africa, by P. E. P. Deraniyagala in Ceylon and by F. W. Moorhouse along the Great Barrier Reef of Australia. More recently in Sarawak, Tom Harrisson and John R. Hendrickson have independently uncovered a great deal of information on the nesting ecology and reproductive cycles of the huge breeding colony there. Since 1955 my colleagues at the University of Florida and I have been working, with the aid of a series of National Science Foundation grants, at the only green turtle nesting beach that remains in the western Caribbean: Tortuguero in Costa Rica. What is now known about *Chelonia* from all these studies permits the piecing together of a coherent—albeit still somewhat fragmentary—account of its life.

Although green turtles are primarily sea animals, in a few places in the Pacific they sometimes go ashore to bask. They have been seen lying in the sun along with albatrosses and basking monk seals on such small Pacific islands as Pearl and Hermes Reef, Lisianski and Kure Atoll. The females of the Pacific populations sometimes even nest during the day. Neither nesting during the day nor basking appears to be the habit of green turtles in any Atlantic population. Once the Atlantic hatchlings leave the beach the males remain at sea for the rest of their lives. The females come ashore only to nest, and they do so after dark. They always return to the same general nesting area and often to the same narrow sector of beach.

The green turtle is one of the few reptiles that are known to mate at intervals of more than a year. In Sarawak the entire turtle population mates and nests in a three-year cycle. At Tortuguero about a third of the colony returns to nest every two years and the other two-thirds follows a three-year schedule. In our eight years of tagging turtles at this site no turtle has returned after an absence of only one year. When the Tortuguero turtles finish nesting, they travel back to their home pastures of turtle grass and evidently remain there feeding until their reproductive rhythm directs them to return to the nesting beach. Such a feeding ground may be within a few dozen miles of the nesting beach or many hundreds of miles away.

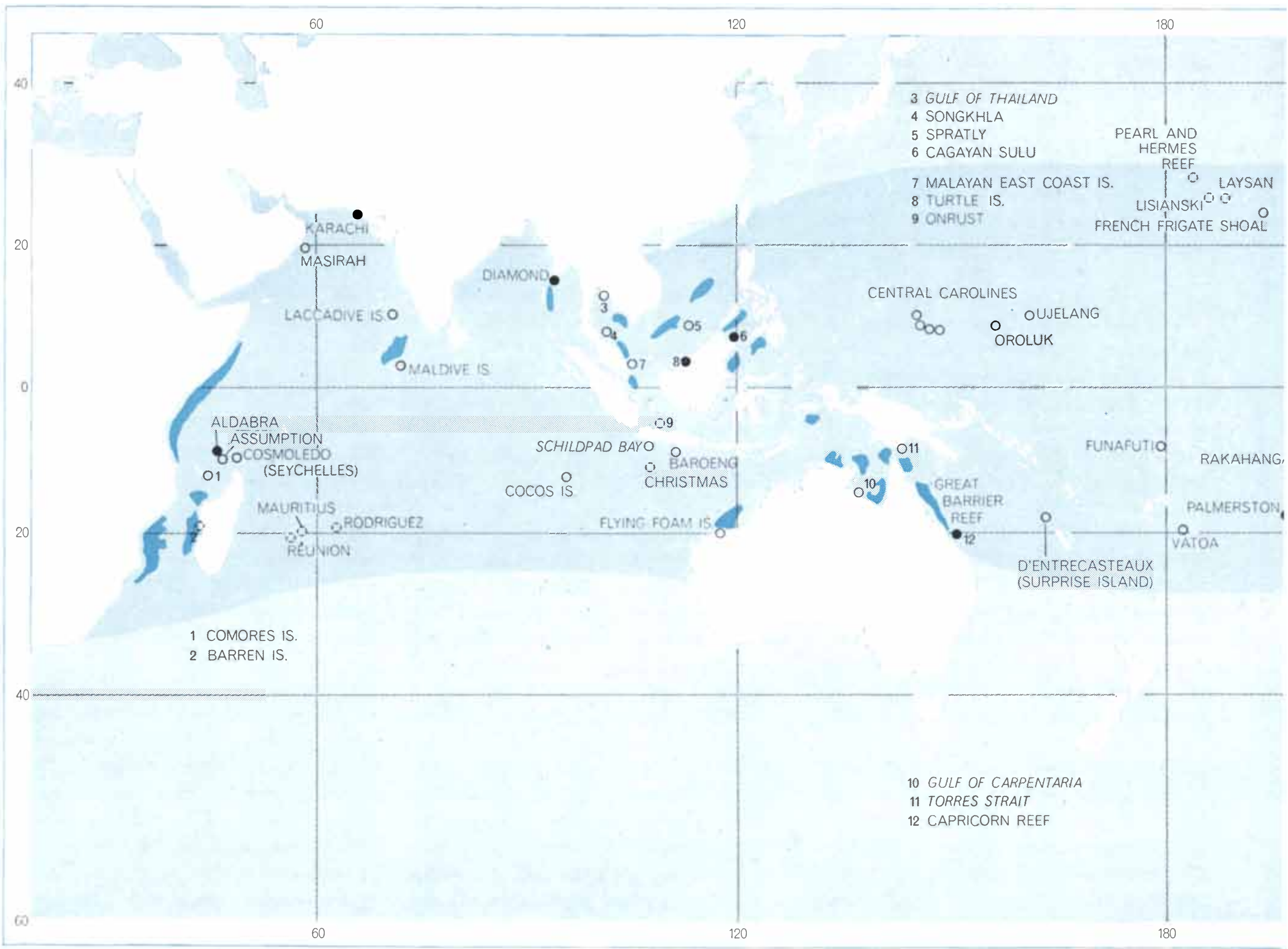
The time of year at which the nesting season begins and the duration of the season vary from one region to another. In some places nesting is restricted to three or four months of the year; in others it may run through the entire year, with a peak during two or three months or even with two separate peaks. Mating takes place at the nesting ground and apparently nowhere else. Either the males accompany the females during their journey from the home pasture or they make an exactly timed rendezvous with them at the nesting beach. In any case, as soon as the first tracks of nesting turtles appear on the shore the animals can be seen at sea just beyond the surf, courting, fighting and mating. Because these activities are mostly out of sight little is known about them. From a low-flying airplane one sometimes gets a glimpse of two males splashing around a single female. Many females come ashore scratched and lacerated, evidently because of the violent attentions of the males.

Some females apparently mate just before their first nesting trip ashore; others do so later. At Tortuguero mating activity appears to end after the third or fourth week of the nesting season. Even when mating precedes the first landing, it must take place after at least some of the female's eggs have formed shells. It therefore seems unlikely that any of the eggs of the current season are fertilized as a result of current mating. The encounter probably serves to fertilize eggs for the next nesting season, two or three years ahead.

Once at the nesting beach the female goes ashore from three to seven times to deposit clutches of eggs in the sand. The interval between nesting trips is about 12 days, and the number of eggs laid on each occasion is 100 or so. Each egg is about two inches in diameter. The shell is flexible, and when the egg is first laid it has a curious dent in it that no amount of pressing will smooth out. The incubation period is about 57 days.

On hatching and emerging from the nest the young green turtles nearly always set off on a direct course for the sea, even when the water itself is completely hidden by dunes or other obstacles. Experiments with a number of different kinds of marine and freshwater turtles indicate that the mechanism of this orientation is an innate response to some quality of the light over open water. It is clear that no compass-like sense is involved: in a series of tests we flew little turtles from Caribbean nests across Costa Rica and allowed them to emerge from artificial nests on a Pacific beach. Even though the sea now lay in the opposite direction the young turtles reached the water as easily as their siblings on the home beach did.

After the hatchlings enter the water, either their sea-finding drive gives way to other orienting mechanisms or they simply keep swimming until whatever

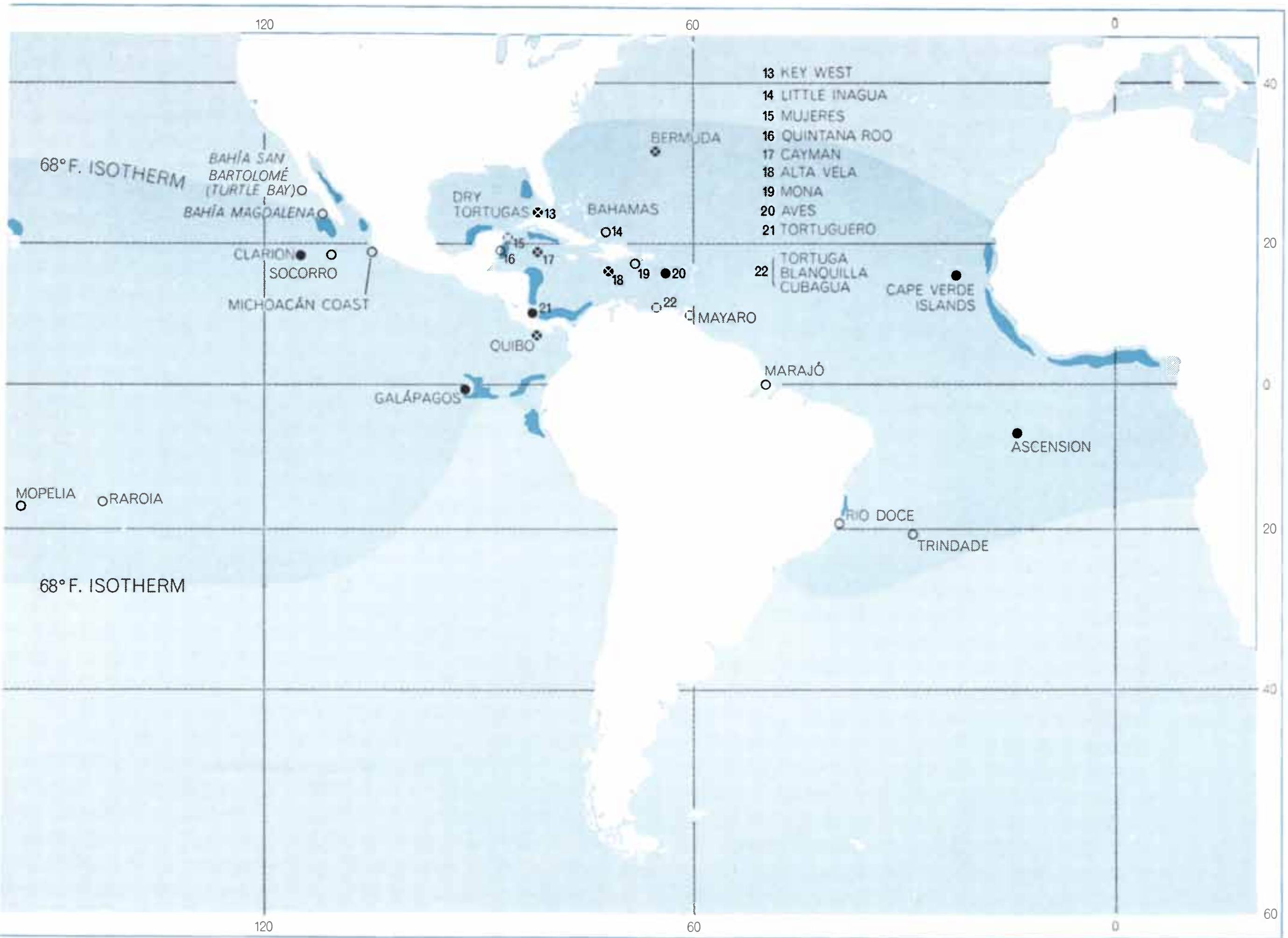


PAST AND PRESENT RANGE of the green turtle was compiled from the accounts of early explorers and later sources by James J. Parsons of the University of California at difference they perceive between sea light and land light becomes too slight to provide a guiding stimulus. By this time they will probably have been picked up by a longshore current. Since the adults navigate over long distances, they must have some kind of compass sense. This sense may be latent in the hatchlings: recent laboratory experiments at Duke University by Klaus Fischer seem to show that this is the case. In nature, however, this sense evidently does not come into operation until the light-beacon sense fails. In any case, tests have shown that the sea-finding drive is not lost even when turtles are kept away from water for as long as a year after hatching. It is also evident that both capacities are present in the mature female. The compass sense must guide her from feeding ground to nesting beach, and the sea-finding drive directs her back to the ocean after she has nested—even though it is out of sight of her nesting place.

A recent experiment demonstrates the kind of ambiguity that can arise in the study of orientation among young green turtles. Several hundred 20-day-old hatchlings from Tortuguero were placed in a circular tank at the Lerner Marine Laboratory on the island of Bimini in the Bahamas. The nearest water was on the bay side of the island, some 40 yards away. The ocean was some 200 yards away in the opposite direction. From turtle's-eye level the rim of the tank blocked any view of either bay or ocean. The skyline was broken by trees and buildings.

The distribution of the young turtles in the tank was recorded over a three-day period, at 9:00 A.M., 4:00 P.M. and 11:00 P.M. each day. During most of that time the wind blew steadily from the bay side of the tank. At night, while the sleeping turtles floated on the surface, the steady breeze piled them up on the ocean side of the tank. Once awake in daylight, however, the turtles showed a marked orientation in the opposite direction. There was active—at times frantic—swimming toward and crowding along the wall nearest the bay [*see illustration on page 83*]. This bias was not simply a tendency to swim upwind; the bay side of the tank was equally favored during a few windless periods. The response could have been an innate direction preference based on a compass sense, but it was more probably the same light-seeking urge that guides hatchlings from the nest to the water. Two months later, however, when the same test was repeated with the same animals, they showed no seaward orientation at all!

Almost nothing is known about the movements and habits of green turtles



Berkeley. His task was complicated by the fact that many animals called green turtles in the literature are one of the four other kinds of sea turtle. The author has amended Parsons' 1962 data on the basis of fieldwork, including his own, done more recently.

during the first year of life. They are mainly carnivorous at this age, but they are able to feed only on small, weak marine invertebrates. Such prey is scarce both at the nesting beaches and at the turtle-grass pastures that feed the grown turtles, and very young turtles are almost never seen in these places. It seems likely that the hatchlings must spend their first months moving from location to location at sea as growth qualifies them to feed on invertebrates of increasing size. All we really know is that the hatchlings disappear.

The only place in the Atlantic and Caribbean regions where we have been able to study green turtles of an age between hatching and maturity is off the west coast of Florida. There a migrating population of young turtles, ranging in weight from 10 to 90 pounds, shows up each April. At this stage most of them have become herbivorous, and they spend the summer months browsing in the turtle-grass flats between Tarpon Springs and the mouth of the Suwannee River. In November they move away to an unknown destination. These Florida visitors may have come from the Costa Rican nesting ground. We have no proof of this, however, because of the difficulty of devising a marking system that will survive the changes in size and proportion of the growing animals.

As recently as 10 years ago it was not definitely known that green turtles migrated long distances from home range to nesting beach. The first clear evidence of periodic long-range migrations came from the tagging program conducted at Tortuguero. During the past eight years 3,205 adult turtles have been tagged; 129 of these have later been recovered. Most of the tags have come to us from professional turtle fishermen operating off the coast of Nicaragua, but other recovery sites are distributed over an area more than 1,500 miles across at its widest point. The eight most distant recoveries are as follows: one from the Marquesas Keys off the tip of Florida, one from the northern coast of Cuba, four from the Gulf of Mexico off the Yucatán Peninsula and two from the Gulf of Maracaibo in Venezuela [*see illustration below*].

These returns furnish grounds for some generalizations that support the reality of migratory travel by *Chelonia*. One such generalization is that no turtle tagged at Tortuguero has ever been recovered there after the end of the nesting season. Another is that no turtle tagged at Tortuguero has ever been found nesting anywhere else. A third is that there is very little correlation between the time elapsed after tagging and the distance the tagged turtle traveled from Tortuguero. This strongly suggests that the turtles are not random wanderers but migrants following a fixed travel schedule between the nesting beach and their restricted home range. Otherwise the animals would tend to cover the same distance in the same time.

TAGGING AT TORTUGUERO, the nesting beach in Costa Rica, has marked 3,205 adult green turtles in the past eight years. So far 129 tags have been recovered. As the relative size of the circles indicates, most of the recoveries have been made along the coast of Nicaragua, but turtles from Tortuguero have also appeared as far away as Venezuela, the Gulf coast of Yucatán and Florida.

OCEAN-FINDING ABILITY is demonstrated by free-swimming green turtle hatchlings in a circular tank. Although the rim blocks any direct view, most of the turtles have gathered along the side nearest the water, guided by some difference in the light from that direction.

Although such findings make a strong case for periodic migration and homing by the green turtles that nest at Tortuguero, they do not prove a capacity for true navigation, that is, oriented travel involving something more than piloting by landmarks and an ability to keep headed in a fixed direction by using the sun or stars for a compass; such piloting is accomplished by many different kinds of animals. The beach at Tortuguero is part of a mainland shore. The green turtles could simply leave their distant pastures on an initially correct compass heading and, on making landfall, follow the coast until things look, smell or taste in ways that mean the ancestral breeding ground has been reached. In their successive nestings during a single season females often return to the same 200-yard stretch of nesting shore they had used earlier.

Indeed, it appears certain that once the turtles have reached the Tortuguero area, they do search the shore for cues to guide them to a nesting site. At the start of the nesting season distinctive "half-moon" turtle tracks appear, usually toward one end of the 22-mile length of nesting beach. These are semicircular or U-shaped trails left by females that have come out of the water, made a short trip toward the upper beach and then turned back to the surf without nesting. Such behavior implies that some sort of discriminatory process is involved in the selection of a nesting site. In the course of coming ashore a female nearly always stops in the backwash of the surf and presses her snout deliberately against the sand, sometimes repeating the process as she moves up the wet lower beach. This behavior appears to be an olfactory assessment of the shore, although it could also be tactile. Little more is known about the senses involved in the selection of nesting sites.

In searching for an instance of turtle migration that clearly involves an ability to make a long, oriented sea voyage in the absence of landmarks, I thought of the green turtle colony that nests on Ascension Island. The capacity for open-sea orientation is the ultimate puzzle in the study of animal navigation. Even human navigators, with their ability to measure the position of the sun and the stars, were unable to calculate positions at sea accurately until the development of precise chronometers in the 18th century. Work with various animals, notably homing pigeons and migratory birds, indicates that there are three inherent aids to navigation: a clock sense, a map sense and a compass sense. On the basis of these senses the navigation feats of animals that migrate overland can be explained, at least in theory. On the featureless open sea, however, the situation is quite different.

One difficulty in the study of open-sea navigation by animals is the dearth of information on routes and schedules of travel. I am not aware of a single instance in which the journey of an oceanic migrant has been traced in detail, with data on headings and speeds. Only when this has been done will it be possible to say that here piloting by visual guideposts is taking place, there celestial navigation can be assumed and elsewhere some cryptic signal must be involved.

Before we could use the green turtle nesting colony on Ascension Island for a study of open-sea navigation it was necessary to establish whether the turtles traveled there from some distance away or were merely a local population. That they were not local residents seemed certain on two grounds: (1) the turtles arrive to nest in substantial numbers each February but disappear by June and (2) there are no beds of turtle grass anywhere in the vicinity of Ascension. It was then necessary to find out where the feeding grounds of the Ascension nesting colony were located. A survey of the coasts of Argentina and Brazil in 1957 yielded no evidence that the abundant green turtle population of the Brazilian coast came from nesting grounds on the South American mainland. Turtles were known to nest on the island of Trindade, some 700 miles off the Brazilian coast, but their numbers were small. It therefore seemed likely that the green turtles that nest on Ascension feed along the coast of Brazil. The next step was to test the reality of this apparent instance of open-sea migration by means of a tagging program.

The green turtles at Ascension, like those at Tortuguero, breed in either two-year or three-year cycles. During February, March and April of 1960 Harold Hirth, then a graduate student at the University of Florida, tagged 206 female turtles at the six nesting beaches on the island. In 1963, when that part of the 1960 population which nests every three years was due to return to Ascension, a tag patrol was set up at the beaches. Three of the turtles Hirth had tagged were found again. In 1964, when the two-year group was due to return for the second time, two more of Hirth's turtles showed up [*see lower illustration on next page*]. Four of these five females had landed on the same short section of beach where Hirth had tagged them; the fifth went ashore on an adjacent beach recently formed by high seas. During the past five years nine more of Hirth's 1960 tags have been recovered from turtles captured by fishermen along the Brazilian coast.

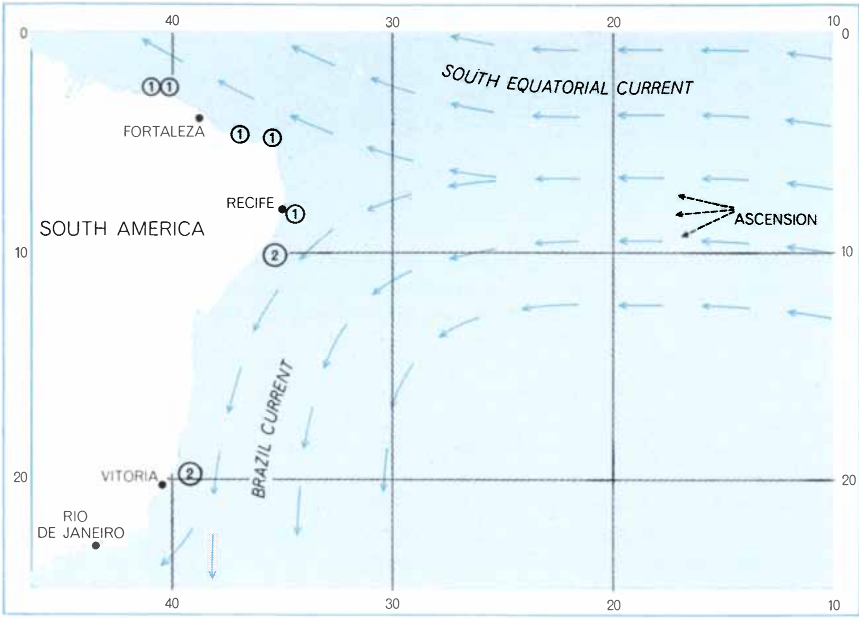
A skeptical statistician might attribute these findings to random wandering. Short of tracking a turtle all the way, clinching proof that green turtles travel from Brazil to Ascension will be obtained only when a turtle tagged on Ascension is recaptured in Brazilian waters, released there and then captured again on Ascension. This is not likely to happen; by the time a tag reaches the University of Florida from Brazil the turtle that carried it has usually been eaten. Thus the evidence remains circumstantial: turtles tagged on Ascension have been captured off Brazil; others have disappeared for three or four years only to return to the same Ascension beaches on which they were first encountered. This does not prove the reality of the migratory pattern beyond all possible doubt, but I think it does so beyond reasonable doubt.

There are three basic questions to be asked about this particular migratory journey: How was it originally established as a behavioral adaptation? What route does it follow? What guides the turtles? With respect to the first question, the establishment of a nesting colony on a tiny mid-ocean island such as Ascension seems an evolutionary venture most unlikely to succeed. The problem is to visualize the selective process and the survival values in the earliest stages of the evolution of such a migratory pattern. If Ascension had once been a much more extensive area of land, the navigational equipment with which the green turtles now find the island could have been slowly refined by natural selection as the area shrank to a small island. I have found no one, however, who believes the area of Ascension can have become appreciably smaller during the past 50 million years or so. Certainly the water around it today is so deep that such a change seems unlikely.

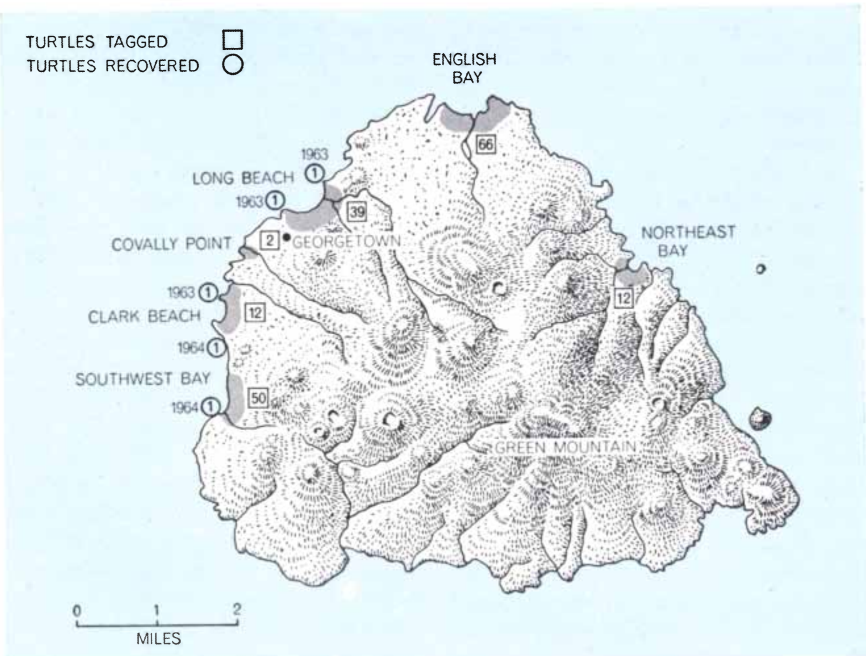
There is one possibility that may decrease the theoretical difficulty to some degree. Perhaps the island was originally colonized by green turtles that had been accidentally carried from West Africa by the South Equatorial Current, which flows from east to west. Another kind of sea turtle—the West African ridley (*Lepidochelys olivacea*)—has colonized the coast of the Guianas, north of Brazil, in just this fashion. If egg-bearing green turtles had landed by chance on Ascension and nested there, the process of selection would have had good material to work on. The hatchlings leaving the island would have been carried to the coast of Brazil by the South Equatorial Current and at the same time could have borne with them "imprinted" information that would help them to retrace their journey at maturity. Such a hypothesis of course does no more than get the nesting colony established on Ascension. It makes no attempt to solve the navigation puzzle.

The next question concerns the route followed from Ascension to Brazil and back. Apart from inference, nothing is known about this. The South Equatorial Current presumably carries the hatchlings to Brazil; the shortest path for mature turtles returning to the island would be directly eastward from Brazil against the thrust of the same current. Such a route would conform to a classic pattern for aquatic migrations: upstream movement for the strong adult animals and downstream travel for the weak and inexperienced young.

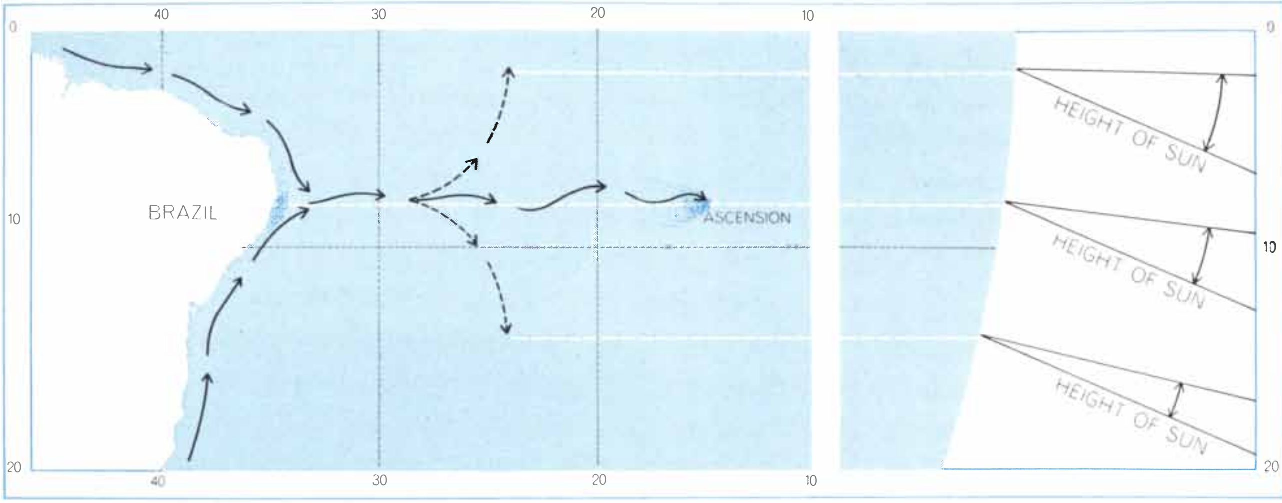
There are two other routes that would allow the entire round trip to be



ASCENSION ISLAND EXPERIMENT was designed to determine if the turtles that nest there are the same animals that feed along the coast of Brazil, 1,400 miles or more away. In 1960, 206 turtles were tagged at Ascension; so far nine have been captured at the coastal points noted, proving that at least some Ascension turtles do travel to Brazil.



REPEATED NESTING AT ASCENSION has also been proved by the tagging experiment. In 1963 three of the turtles tagged in 1960 returned to the island and dug their nests in the same beaches they had used before. In 1964 two more tagged turtles appeared; one of them missed its home beach by a few hundred yards. All had presumably come from Brazil.



MEANS OF NAVIGATION available to the green turtles for their ocean voyage to Ascension remain conjectural. Distinctive chemical cues from the island, carried westward by the currents, may help the turtles to make final landfall; chemical or visual cues unique to the Brazilian coast may also guide them to the latitude of Ascension before they set out to sea. In the open ocean, however, some kind of guidance beyond a simple compass sense must be required if the turtles are to be able to correct for drift and reach the zone of chemical guidance. In this illustration the hypothetical cue is the sun's height above the horizon at noon.

made with the aid of favorable currents. If the Ascension-bound migrants swam northward from Brazil, they would enter the part of the Equatorial Current destined to become the Gulf Stream and could stay in this current until a full circle brought them westward to Ascension from the coast of West Africa. If instead they rode the Brazil Current southward, they could then travel the West Wind Drift to South Africa, catch the northward-flowing Benguela Current and rejoin the South Equatorial Current on its way to Ascension and beyond. The time required for these journeys seems prohibitive. Both would have to be negotiated without food, and the temperature of the West Wind Drift waters can drop to a chilling 40 degrees F. The direct easterly course, or some modification of it, appears to be the most logical route from Brazil to Ascension.

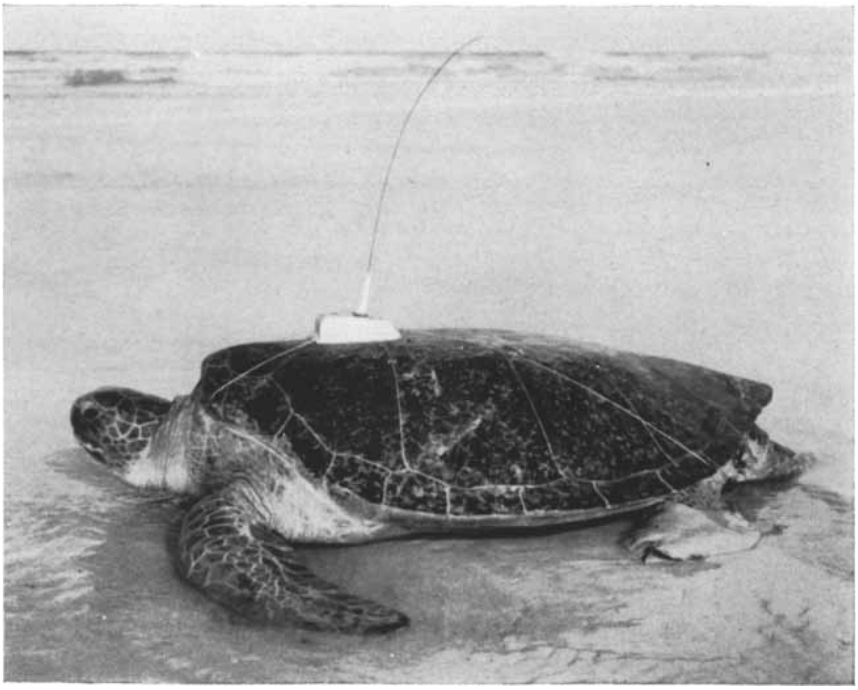
As for the final question, in attempting to judge how the Brazil-to-Ascension migration is guided the first step will be to determine how and where some sort of contact—direct or indirect—is established with the island. Even with a pinpoint target such as Ascension, migrating birds would be able to correct a fairly gross navigational error by visual means. To a turtle, however, an island is out of sight a few miles away. Green Mountain on Ascension stands 5,000 feet high and often has a corona of cloud that rises much higher. The sight of birds converging on the island from miles away at sea might provide an approaching turtle with still another visual guide. Such signals, however, would probably be picked up only in the last 20 miles or so. What cues might there be at longer range?

Very little is known about nonvisual phenomena associated with the presence or direction of an island, nor is anyone sure about what a green turtle can taste, smell or hear. It seems a point in favor of the upstream hypothesis of travel to Ascension, however, that such a route would allow the approaching turtles to detect an olfactory gradient—if indeed such a chemical cue is given off by the island. Perhaps when the hatchlings leave the island they take with them an imprinted memory of the taste or smell of Ascension water. Coming back as mature adults they may be able to detect this Ascension effusion in the westbound current far downstream from the island and to follow it until they make a visual landfall. There are two basic weaknesses in this proposal: no one knows how far downstream a green turtle can taste or smell an island, and there is no information to indicate the direction from which the migrants approach Ascension.

Even if we assume that far-reaching cues guide the final homing of the turtles to Ascension, there remain hundreds of miles of open ocean to be crossed—and crossed with precision—before such signs could conceivably be detected. For the greater part of this distance the animals must be navigating, and the most logical assumption appears to be that the navigating is done with information from celestial guideposts. Colin Pennycuick of the University of Cambridge has recently called my attention to an old island-finding technique used by human navigators before the accurate calculation of longitude was possible. Knowing the latitude of his target, the navigator would sail north or south by compass until the noon position of the sun showed that he had reached the desired latitude; he would then simply sail due east or west (depending on the location of his target) until he made landfall.

This human technique seems particularly worth considering in connection with the migration of green turtles to Ascension. Possibly the turtles go north or south along the Brazilian coast until they reach the vicinity of their first landfall as hatchlings. Visual or olfactory impressions from this first contact with the mainland would identify that coastal point, which should be close to the latitude of Ascension. Thereafter compass sense alone might conceivably guide the turtles on a journey due east to a point where cues from the island could be detected.

This proposal too has weaknesses. Any drifting due to wind or current during the hundreds of miles of open-sea swimming could put the migrant hopelessly off course in spite of a constant compass heading. Unless the turtle were able to make corrections by one means or another the landfall at Ascension would never take place. For human navigators today the ability to make such corrections requires finding not only latitude but longitude as well. Latitude can be judged from the height



RADIO-EQUIPPED TURTLE was used by the author to test the feasibility of tracking movements at sea from shore. To track the green turtles' long journey from Brazil to Ascension Island might require such advanced techniques as satellite-relayed telemetry.

of the sun at noon, but reckoning longitude requires the measurement not only of some celestial body's altitude but also of its azimuth. It is hard to see how this can be done effectively by an animal in the open sea; the azimuth measurement—the horizontal component of the movement of the sun and the stars—could not be made against a featureless horizon. Pennycuick's suggestion nonetheless has hypothetical merit in regard to the Ascension migration. Eastbound turtles that were displaced north or south during the journey could conceivably correct for drift on the basis of latitude reckoning alone. Even this, of course, would be an astounding animal adaptation.

It is clear that an adequate analysis of the travel orientation of the green turtle will require tracking the animals throughout entire migratory journeys. At the University of Florida we have made preliminary tracking tests in which a turtle tows a float from which a helium-filled balloon rises to mark the position of the migrant. This seems promising for short runs. With the support of the Office of Naval Research we are trying to work out procedures for tracking longer trips by mounting a radio transmitter on the back of a turtle [*see illustration above*], on the floats or preferably on the balloons. The length of the journey from Brazil to Ascension, however, has so far made the task of keeping in touch with these migrants a formidable one.

This may soon no longer be the case. The National Aeronautics and Space Administration intends to load apparatus for a number of scientific experiments aboard space vehicles connected with the Apollo program. Tracking the Ascension migrants by satellite could easily prove to be the most efficient method of learning the route they follow. The green turtle could without inconvenience tow a raft, bearing a radio transmitter and power source, for long distances. Each time the satellite passed within range of the towed transmitter a signal would be received; these signals, rebroadcast to a control station, would allow a precise plotting of the position of the turtle.

One key experiment making use of such facilities comes quickly to mind. Several radio-equipped turtles could be released a few hundred miles east of Ascension, where because of the prevailing current no chemical cues from the island could possibly be present. If the turtles nonetheless made their way to the Ascension nesting beaches, this would prove that their feat of navigation is not chemically guided. If satellite-tracking can pin down facts such as that, what may be discovered about animal navigation in general should abundantly repay the effort.

The Physiology of Exercise

Muscular activity causes the body to mobilize an entire array of adaptive mechanisms to meet rising respiratory and circulatory demands. Even the prospect of exercise can initiate the process

by Carleton B. Chapman and Jere H. Mitchell

When Peter Snell of New Zealand ran the mile in three minutes 54.4 seconds and Sixten Jernberg of Sweden covered 50 kilometers on skis in two hours 43 minutes 52.6 seconds, their record performances provided vivid testimony not only to their speed and endurance but also to the prodigious internal adjustments of which the human body is capable. An adult human being at rest gets along on about three-tenths of a liter of oxygen per minute; during maximal exertion the oxygen requirement increases to 10 or more times that amount. Since the body carries no appreciable reserve of oxygen (its entire store would be used up by the muscles in 20 seconds of strenuous exercise), this means that during exertion the body's machinery must step up enormously its intake and distribution of oxygen to the tissues, and it must be able to do so within seconds. On this basic fact hangs a tale that for nearly two centuries has provided physiologists with an absorbing realm of exploration.

The detailed study of muscular exercise began in the 18th century when Antoine Laurent Lavoisier and Pierre Simon de Laplace discovered that the process consumes oxygen and produces carbon dioxide. As investigation progressed it became clear that exercise involves not only the muscles but also many other tissues; that it depends, indeed, on an extraordinary coordination of the respiratory, circulatory and nervous systems, all working together under highly integrated controls. During the 19th century almost every physiologist of the first rank worked on muscular exercise at one time or another. During the 20th century three men—A. V. Hill of Britain, August Krogh of Denmark and Otto Meyerhof of Germany—have received Nobel prizes largely for work relating to muscle or muscular exercise. Among the Americans who made notable contributions in the physiology of exercise were Edward Cathcart, Francis Benedict, Graham Lusk and D. Bruce Dill. In the years before World War II the Fatigue Laboratory at Harvard University became a world center for the experimental study of muscular exercise.

In recent years investigations of exercise have concentrated on processes in the cell and on physiological systems involved in control. This is not all there is to the study of exercise: in order to ensure an adequate supply of oxygen for the working muscle cell the body must coordinate the interaction of the lungs, the blood (specifically the oxygen-carrying pigment hemoglobin), the heart and circulatory system and finally the muscle cell itself. We shall discuss each component of the system in turn.

Oxygen enters the bloodstream—and carbon dioxide leaves it—by way of the alveoli: the tiny sacs that form the ultimate functional structure of the lungs. The total surface area of this multitude of sacs is normally so large that, as far as the body's needs go, the exchange of gases between the air on one side of the walls of the alveoli and the blood bathing the other side is virtually unlimited. A normal man at rest inhales between six and eight liters of air per minute, from which about .3 liter of oxygen is transferred in the alveoli to the blood. Simultaneously carbon dioxide is given off by the blood and exhaled. When the same man is engaged in maximal muscular activity, he may take in 100 liters of air per minute and extract five liters of oxygen.

The rate of oxygen intake provides an excellent measure of the physical work done. The term "maximal oxygen intake," introduced by Hill in 1924, characterizes the upper limit of performance of an individual in a remarkably predictable way and has proved to be an extremely useful physiological tool. In practice an experimental subject performs a series of work tests on a motor-driven treadmill or bicycle ergometer, each test being at a higher load than the one just preceding. The intake of oxygen per minute rises on a virtually linear curve with work load until maximal intake is attained. Thereafter most people can still increase the work load, but the oxygen intake can rise no further. The maximal oxygen intake in normal individuals, however, has to do not with the capacity of the lungs for ventilation or diffusion but with the maximal pumping capacity of the heart. Maximal oxygen intake is therefore a fair index to circulatory capacity but not to pulmonary capacity.

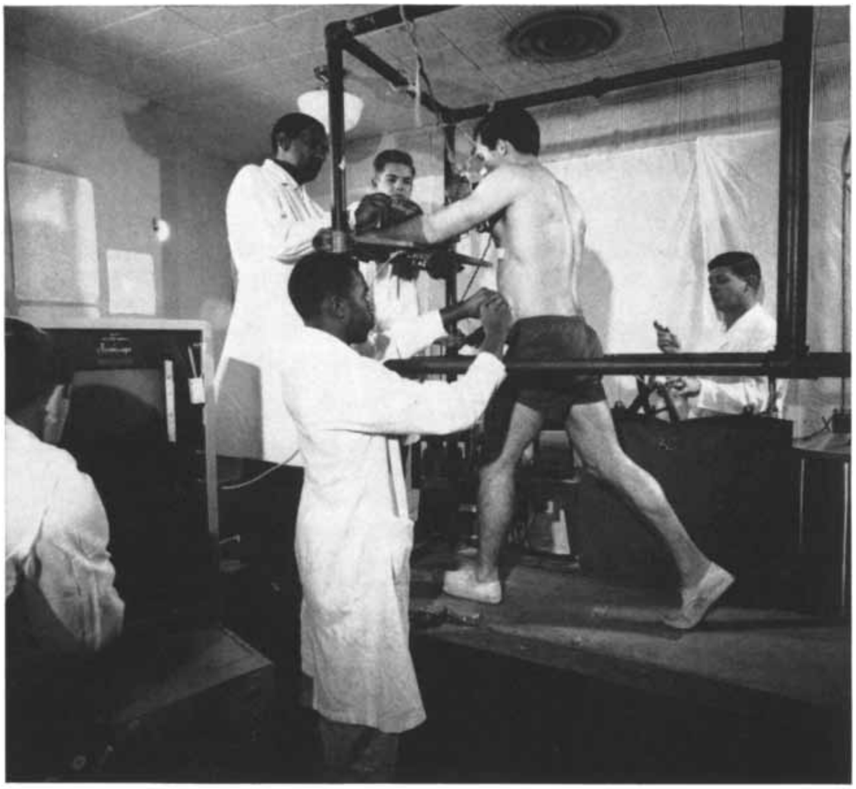
The outstanding question about the ventilation of the lungs is: How does the control system that so neatly balances oxygen supply against oxygen demand work? As long as 150 years ago it was suspected that mammals had a center for the control of breathing in the medulla oblongata; this center was believed to have the function of maintaining rhythmic respiratory movements regardless of the state of consciousness. Although the respiratory center has long been known to be influenced by higher centers in the brain, the identity of the chemical and hormonal factors that affect it has been elusive. The classical paper on the subject, published in 1905 by John Scott Haldane (father of the late J. B. S. Haldane) and John G. Priestley, held that the respiratory center is primarily subject to the influence of carbon dioxide in the arterial blood flowing into it. The amount of carbon dioxide in the arterial blood in turn is determined by the level of carbon dioxide in the alveoli of the lungs.

Haldane's experiments showed that ventilation can be doubled by increasing the amount of carbon dioxide in inspired air from the usual negligible amounts to about 3 percent. He also considered the possibility that lack of oxygen might stimulate respiration. Ultimately he concluded that the carbon dioxide effect is dominant except under circumstances of extreme lack of oxygen. As far as the Haldane school was concerned the primary function of the respiratory center is to govern ventilation in such a way that the level of carbon dioxide in the alveoli is held as constant as possible.

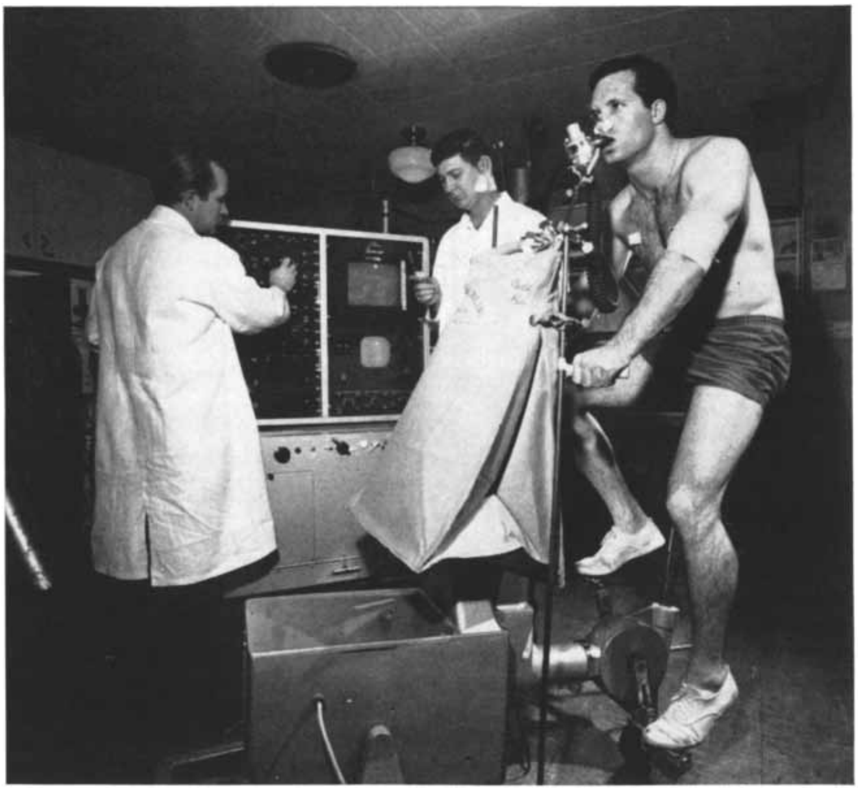
During physical exercise the production of carbon dioxide in the body rises very rapidly and carbon dioxide is brought to the alveoli in increasing quantities by the venous blood. It was Haldane's view that, as a result of increased amounts of carbon dioxide in the alveoli, the arterial blood becomes more acid. He thought that the acidity stimulates the respiratory center and that excess carbon dioxide is blown off in expired air.

More refined studies later showed that Haldane's chemical-control theory was a considerable oversimplification. It turned out that during exercise and recovery from exercise the rate of ventilation does not rise and fall in direct proportion to the acidity, the carbon dioxide pressure or the oxygen pressure of the arterial blood. Because of these findings various other hypotheses have been offered: that some secondary signal—chemical, hormonal or nervous—acts as the stimulus to the respiratory control center, or that small changes in the carbon dioxide and oxygen pressure can cause large changes in the breathing rate by a multiplying effect. The details of the system are still very much in doubt. Whatever its exact *modus operandi,* the respiratory control mechanism ordinarily prevents carbon dioxide from accumulating in any significant degree and virtually assures an adequate supply of oxygen over a range extending from rest to maximal exertion.

Some interesting possibilities were opened up when Hill studied the effect of breathing pure oxygen during exercise. There seems no reason to doubt that an immediate effect of switching



EXERCISE TEST is conducted in the authors' laboratory at the University of Texas Southwestern Medical School. The speed of the treadmill can be varied in order to change the amount of work done by the subject. Recording apparatus at left registers the subject's respiratory and circulatory changes. Technicians are taking blood samples as test progresses.



OXYGEN INTAKE is measured during controlled exercise on a bicycle ergometer. The air exhaled by the subject is collected in the bag to provide a basis for the calculation of how much air he inhaled. Electrocardiograms and other data are recorded on panel at rear.

during steady exercise from ordinary air to air enriched with oxygen is to lower considerably the rate of ventilation. The effect is cited to support the view that a change in arterial oxygen pressure has an influence on the regulation of breathing. Athletes who have breathed oxygen-enriched air during exercise have reported a pronounced relief of subjective distress and have evinced a decrease in ventilation. Moreover, the late C. G. Douglas of the University of Oxford and his colleagues showed that oxygen-breathing extended the work capacity of trained athletes. The topic is an important one, not only with respect to competitive athletics but also with respect to the deficient transport of oxygen in disease and at high altitudes. It is being actively investigated in many laboratories.

Another important mechanism employed by the body when it is under fairly severe stress from exercise is its ability to incur an oxygen debt. In theory the mechanism enables the exercising body to live temporarily beyond its capacity for transporting oxygen to active muscles and to compensate for doing so during rest after the exercise. The phenomenon is well documented by the fact that ventilation and oxygen intake do not immediately return to normal resting levels for some time after vigorous exercise stops.

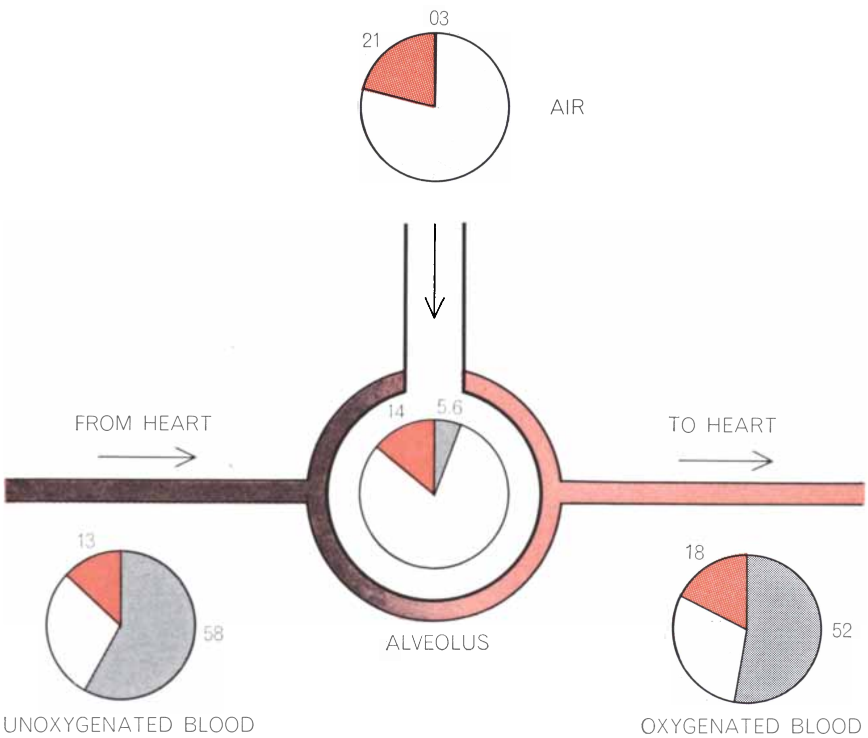
The amount of oxygen debt that can be contracted is limited by the ability of the blood to absorb acid metabolic products without an unduly large change in its acidity. Some degree of oxygen debt is always built up during a short, hard burst of exercise such as a footrace over a distance of 100 yards or a quarter of a mile. Milers or marathon runners, particularly if they are in good physical condition, can cover their distances with a relatively small oxygen debt. The term "steady state" is used by exercise physiologists to define a rate of work that can be performed for considerable periods of time without oxygen debt. Actually most people—probably anyone other than an athlete in training—incur some oxygen debt during exercise at all levels but the very lowest. Waking activity, even if it is quite sedentary, usually involves a continuous process of acquiring and paying off oxygen debt at various rates. During continuous activity, such as walking steadily at three miles per hour for several hours, oxygen debt is built up rapidly at first and then levels off. Thereafter it may remain virtually unchanged for some hours. During violent activity it builds up rapidly and continuously until the activity ceases.

In any event, the contraction of an oxygen debt, like any other form of deficit financing, has its limits. Ideally the entire process of adaptation to physical stress, including the control of ventilation, is adjusted to the work load so elegantly that the oxygen debt incurred is kept at a minimum. The process of contracting a small oxygen debt is part of the normal mechanism of adaptation to exercise; a large oxygen debt is an emergency mechanism that is invoked only in case of dire need and in most sedentary individuals never comes into play at all.

After ventilation of the lungs the next major link in the system of adaptation to exercise is hemoglobin. Without this remarkable substance mammals would be completely incapable of muscular activity. The ability of hemoglobin to transport and deliver oxygen in the body resides in its iron atoms. Everyone knows that when metallic iron and oxygen combine, as they do in iron ore, it takes a blast furnace to separate them. In hemoglobin, however, iron combines with oxygen transiently and releases it readily to the tissue cells at body temperature.

As Christian Bohr of Denmark (father of the physicist Niels Bohr) first noted in 1904, the absorption and release of oxygen by the hemoglobin contained in the red blood cells are described by an S-shaped curve. Where the partial pressure of oxygen is that of ordinary air, as in the lungs, the hemoglobin of the blood becomes almost completely saturated with oxygen; when pure oxygen is breathed, the hemoglobin is 100 percent saturated. It gives up little of its oxygen as it flows through the arterial system, although the partial pressure of oxygen falls slightly there. When, however, the blood arrives at the capillaries and the surrounding tissues, where the oxygen pressure is substantially lower, the hemoglobin freely surrenders its oxygen and the curve of oxygen-binding bends sharply downward [*see illustration on page 93*].

Normally arterial blood contains about 18 percent of oxygen by volume, that is, about 18 milliliters of oxygen per 100 milliliters of blood. (Breathing pure oxygen raises this figure to 18.5 milliliters, and it also increases the amount of oxygen dissolved in the blood plasma from .2 milliliter to 1.9 milliliters.) When a person is at rest, the



LUNG AND BLOOD GASES in human respiration under resting conditions are shown near and in one of the alveoli, the lung sacs where the blood acquires oxygen and yields carbon dioxide. Numbers give the percentage by volume of oxygen (*color*) and carbon dioxide (*gray*). The remaining percentages are accounted for by substances not involved in respiration.

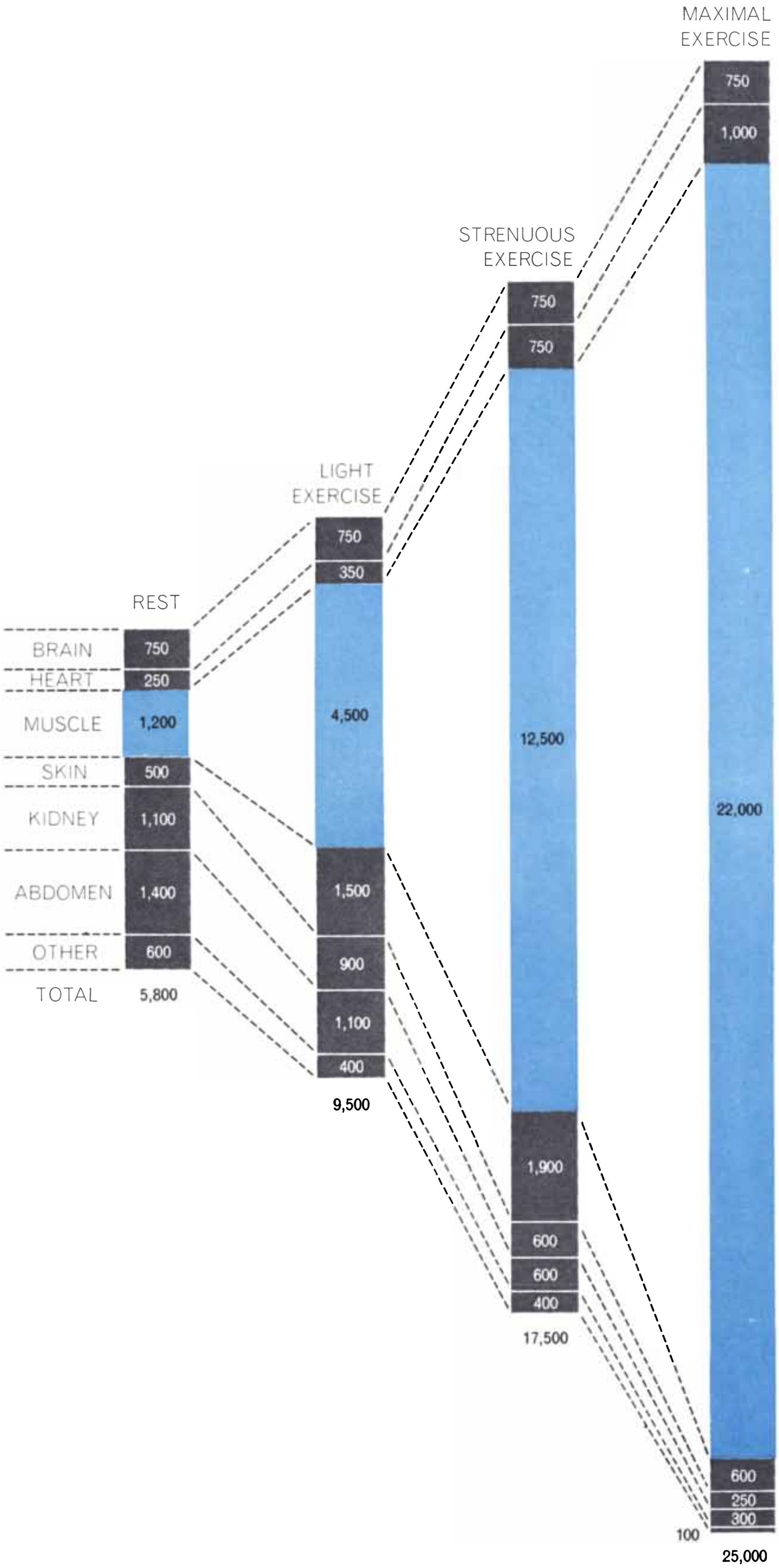
tissues absorb oxygen at a rate that reduces the 18 percent oxygen content of the arterial blood to about 12 percent in the venous blood. The drop is known as the "arteriovenous oxygen difference."

During exercise, on the other hand, the blood may have to give the tissues as much as 15 of its 18 percent of oxygen—about two and a half times more than it surrenders at rest. Several factors facilitate this increased surrender of oxygen by hemoglobin. One, of course, is the depletion of oxygen in the tissues by exercise; this results in a higher gradient between the oxygen pressure in the blood and that in the tissue cells. Another factor is the accumulation of carbon dioxide and acid metabolic products in the exercising muscle fibers, which acts to stimulate the release of oxygen by hemoglobin. Other factors, including the increased temperature of the active muscle cells, may also be involved.

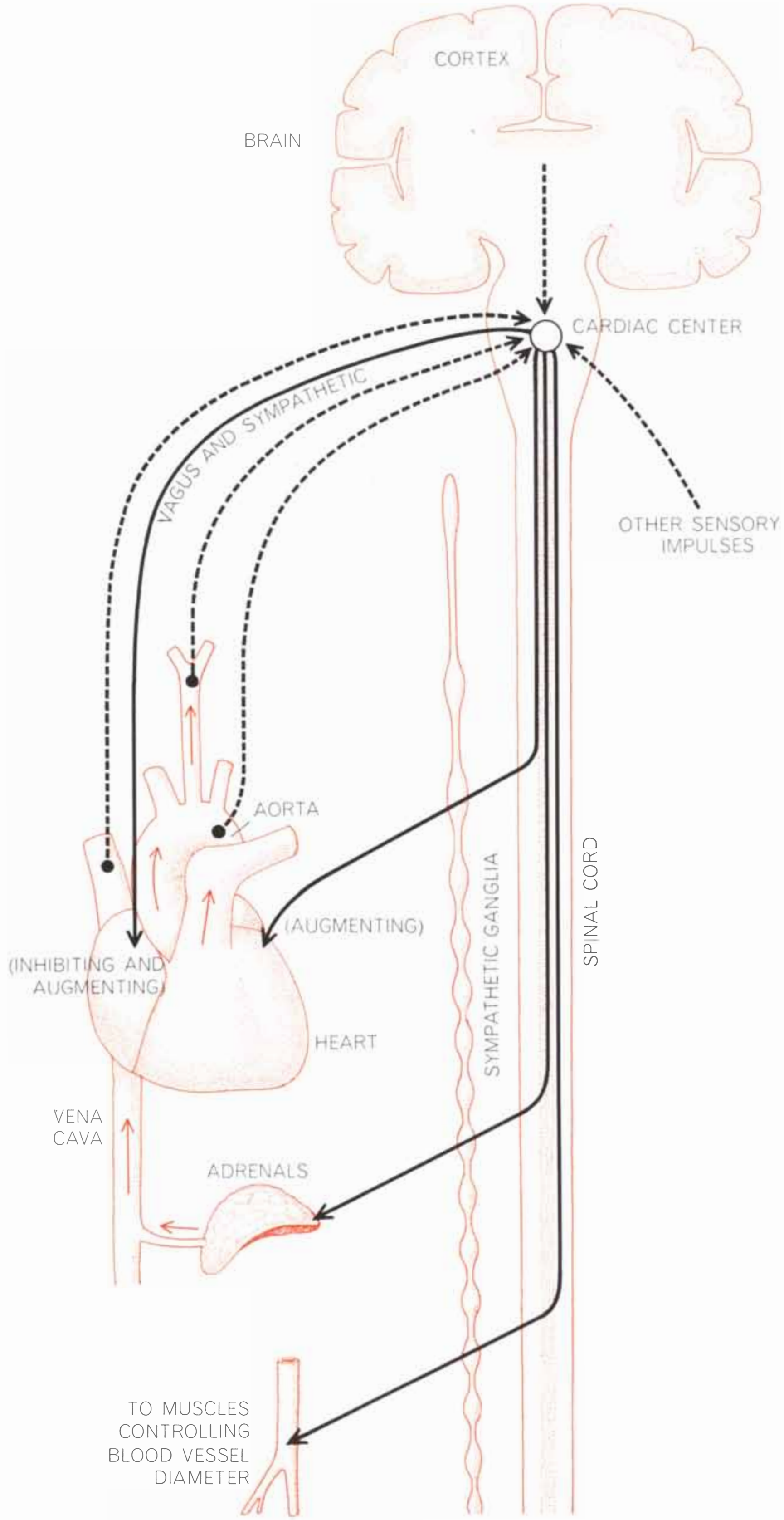
The main point that emerges from this kind of investigation is that the biological properties of hemoglobin play a very important role in enabling the body to adapt to exercise. If the body had to depend solely on dissolving oxygen in a carrier fluid such as blood plasma, even at rest it would have to circulate nearly 300 pounds of fluid per minute—not far from twice the total weight of an average man! Thanks to hemoglobin, a flow of only five liters of blood per minute is enough to supply the body's oxygen needs at rest.

This brings us to the third link in the system of adjustment to exercise: the pumping and circulation of the blood. Comparatively recent developments make it possible to obtain accurate measurements of human cardiac output (the amount of blood pumped per minute) during exercise. It is now established that in a young man the heart can increase its output from about 5.5 liters of blood per minute at rest to nearly five times that figure during maximal exertion. At peak demand for oxygen the heart increases its output both by speeding up its rate of beating and by increasing the volume of blood pumped at each stroke. The pulse rate may double or triple; the stroke volume, which is about 60 to 80 milliliters at each beat when a person is standing at rest, may go as high as 120 milliliters.

The situation at levels of exercise less than maximal is somewhat uncertain. According to the available evidence, it seems likely that under moderate stress



DIVERSION OF BLOOD from certain organs to the muscles is one of the body's major mechanisms for adapting to exercise. Numbers show blood flow in milliliters per minute. The brain is the only organ to which the flow remains almost constant under all conditions.



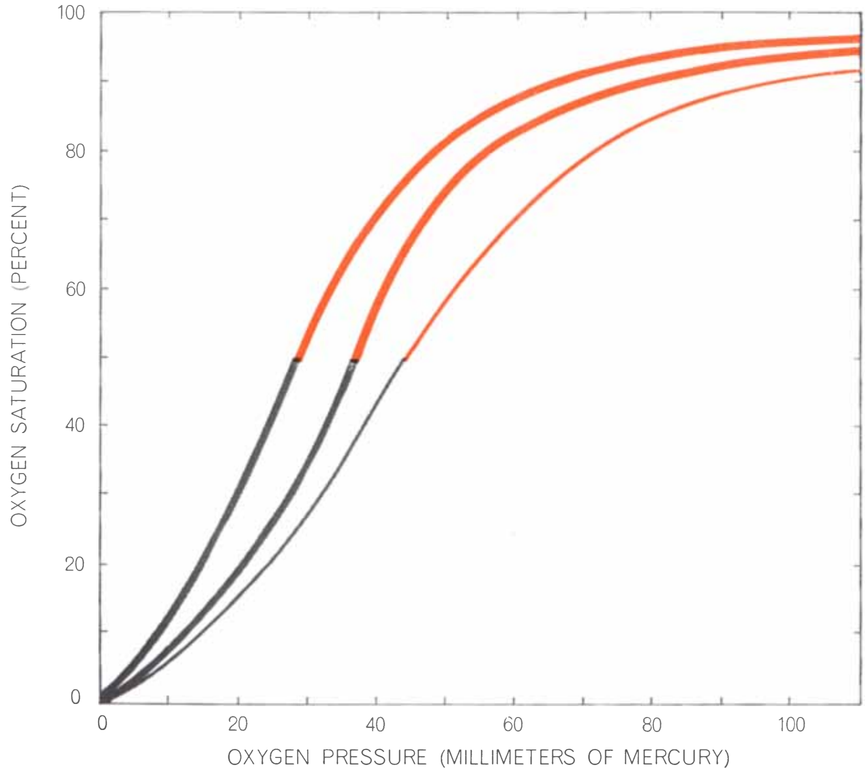
NERVE CONTROLS affecting the action of the heart are depicted schematically. Broken lines represent afferent, or input, nerves; solid lines, efferent, or output, nerves. Some efferent nerves have a sympathetic, or stimulating, effect, in which the sympathetic ganglia participate. Others, such as the vagus, have a parasympathetic, or slowing, effect. Stimuli from cortex, resulting from visual or auditory signals or just from thought, can cause circulatory and muscular systems to begin preparing for exercise before it starts.

the heart may increase either its pulse rate or its stroke volume, depending on the individual's physical training and perhaps on other factors. There is good reason to believe that the heart of a trained athlete increases its stroke volume more readily than that of a sedentary person. Under the stress of emotions such as fear and anger the heart increases its output almost entirely by speeding up its rate of beating. If the nerves controlling the pulse rate are blocked experimentally by drugs, however, the heart will expand its stroke volume. The increase in cardiac output during emotional stress is considerably less than it is under physical stress; even during severe emotional crises it may not rise more than a third over the normal output at rest. The whole subject of the heart's output during stress still leaves much to be learned and is under wide investigation.

The facts we have reviewed so far make clear that the chief limitation on the body's capacity for physical exertion is the cardiac output: the ability of the heart to move blood to the tissues. The heart's capacity for increasing its output fivefold is not enough—even allowing for the ability of hemoglobin to release oxygen more freely—to account for the muscles' consumption of oxygen during violent exercise. An extra margin is provided, however, by a change in the pattern of blood flow. During heavy exercise most of the arterial blood is diverted to the active muscles, where the need for oxygen is most acute.

When the body is at rest, the muscles apparently account for no more than about 20 percent of its total oxygen consumption. Substantial amounts of oxygen go to the brain, the heart, the skin, the kidneys and other organs [*see illustration on preceding page*]. If the muscles' share of the oxygen is about 20 percent, they use at rest only 60 to 70 milliliters of oxygen per minute (the body's total consumption being 300 milliliters per minute). Working at full tilt, as in running or swimming, however, the active muscles need about 3,000 milliliters per minute, or 50 times their resting requirement. The other organs do not require anything like this increase of oxygen; in fact, most of them actually use substantially less oxygen during maximal exertion. (The flow to the skin follows a unique pattern. In light or fairly strenuous exercise there is a substantial increase of blood flow through the skin to dissipate heat generated by the exercise, but when the muscles' need for oxygen becomes acute in maximal exertion, the skin, like the other organs, surrenders most of its claim on the supply of blood.)

The result of this cooperative adaptation by the other organs is that all but a relatively small portion of the cardiac output can go to the active muscles. The absolute amount of oxygen diverted to the muscles by this means is not great: it is no more than about 400 to 500 milliliters per minute. This amount, however, apparently represents a critical margin for the muscles. Experimental drug treatments that block the preferential distribution of blood to the muscles bring about a considerable impairment of the subject's capacity for exertion.



BOHR EFFECT is evident in curves depicting the release of oxygen by hemoglobin. The curve at left represents a condition of rest; the middle curve, exercise. Arterial blood is indicated in color; venous, in gray. Hemoglobin's release of oxygen increases with declining oxygen pressure in the tissues, a condition that is intensified as exercising muscles use oxygen. Such muscles also produce acid wastes, and acidity entering the blood helps to stimulate the release of oxygen by hemoglobin. This is the Bohr effect, reflected in the shift of the curves to the right. A *p*H reading of 7.4, slightly alkaline, is normal for a man at rest; a slightly acid reading of 6.8 (*light curve*) can occur with heavy exercise.

What are the mechanisms that adapt the output of the heart to the muscles' needs during exercise? On this question only fragmentary information is available; obviously it is a difficult question to investigate experimentally. One well-established finding is that the heart muscle itself contains a mechanism for the control of its activity. An experimental preparation of an animal's heart, isolated from any nervous or hormonal influence, still responds to an increase in its rate of filling with blood by increasing the amount it ejects at each beat. This property is known as the Frank-Starling law of the heart, after Otto Frank of Germany and Ernest Henry Starling of Britain, the physiologists who discovered it. Starling called it the "central fortress" of the system whereby the heart adapts itself to varying demands.

Concerning the nervous and hormonal controls of cardiac output certain general facts are known. The heart is powerfully influenced by sympathetic nerves, which stimulate its activity; by parasympathetic nerves (principally the vagus nerves), which depress its activity, and by hormones that reach the heart muscle by way of the bloodstream. These influences, both nervous and hormonal, are in turn triggered by various receptors elsewhere in the circulatory system or by complex factors involving the central nervous system. Typically a receptor at a strategic point in the arterial system (for example in the arch of the aorta) responds to increased pressure by transmitting impulses to integrating centers in the central nervous system. These increase the number of depressor impulses to the heart via the vagus nerves and decrease the number of augmentor impulses via the sympathetic nerves. The net effect is to reduce the rate and force of the heartbeat, thus slowing the flow of blood in the arteries. Conversely, a fall of pressure in the aortic arch gives rise to a signal that stops the sending of impulses to the central nervous system, and so the depression of the heart's activity is diminished.

The eyes and ears may operate in the same way as a blood-pressure receptor. They too, in response to perceptions of the external world, send information in the form of impulses that control the heart's output. The impulses go to the cortex of the brain, which responds by sending appropriate directives to lower centers, whence augmentor or depressor messages are forwarded to the heart. In this way the heart is directed to gear its activity to anticipated needs of the body or to emotional stress.

The ultimate element of the system of adaptation to exercise, and the beneficiary of the marvelously adaptable machinery for supplying oxygen, is of course the muscle cell itself. Compared with many other cell types, the muscle cell is unique in one respect: its tolerance for oxygen deprivation. Certain other types of cell are highly sensitive to even a temporary shortage of oxygen. The cells of the brain, for instance, quickly suffer irreversible damage if the partial pressure of oxygen in the venous blood draining from them falls below 20 millimeters of mercury. Muscle cells, on the other hand, are known to survive even when the venous blood draining from their vicinity shows a partial pressure of oxygen at or near zero!

The extraordinary tolerance of muscle cells for a temporary shortage in the oxygen supply may be accounted for by the presence in these cells of myoglobin. This substance, like hemoglobin, carries oxygen, but it differs from hemoglobin in that it surrenders the oxygen much less readily. The S-shaped curve picturing hemoglobin's uptake and release of oxygen signifies that this behavior varies with the partial pressure of oxygen in hemoglobin's surroundings. As the oxygen pressure rises, the hemoglobin molecules absorb more oxygen; as the pressure falls, hemoglobin gives up its oxygen, and it does so with increasing rapidity as the oxygen pressure in the surroundings drops below 60 millimeters of mercury. (Normally, even during violent exercise, the oxygen pressure in the venous blood coming from active muscles does not fall much below 20 millimeters, at which pressure hemoglobin is about 30 percent saturated with oxygen.) Myoglobin's behavior contrasts sharply with this. Its curve of uptake and retention of oxygen is not S-shaped but hyperbolic, which is to say that after becoming saturated with oxygen the myoglobin molecule does not give up its oxygen until the pressure has fallen to a low level—15 millimeters or less.

Hemoglobin seems designed, therefore, to perform its vital function in surroundings where partial pressures of oxygen range from about 100 down to 20 millimeters (at which level hemoglobin is about 30 percent saturated). Myoglobin, on the other hand, would be of little physiological use (and would relinquish little or no oxygen) if it were confined to the range of partial pressures suitable for hemoglobin. Since myoglobin is found only inside muscle cells, and since there is fair evidence that partial pressures of oxygen in such cells may approach zero during very heavy activity, myoglobin may conceivably serve as a special oxygen store for the cell. According to this view, an intermittently contracting muscle cell might recharge its myoglobin during the resting phase and then, during a succeeding contraction, call on myoglobin oxygen stores when intercellular oxygen pressures fall below 10 millimeters of mercury.

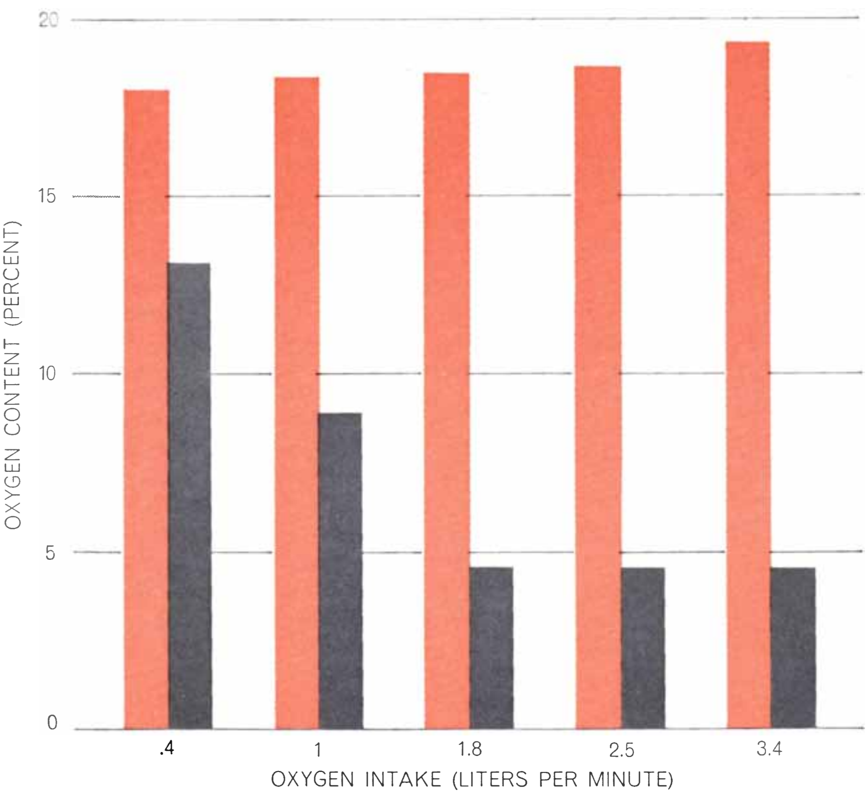
This phenomenon may well account for the fact that mammalian muscles can work more smoothly and effectively when they intermittently contract and relax than when they are kept contracted for an extended period. Actually continuous contraction is probably rare except in laboratory experiments; even in an activity such as weight lifting, which might be thought to keep the muscles under unremitting tension, some of the individual muscle fibrils probably have a chance to relax with each slight shift in grasp and body position.

Myoglobin may also have something to do with the fact that short periods of work alternated with short periods of rest seem to be more efficient—metabolically as well as in work accomplished —than long work periods followed by long rest periods. Another interesting point inviting investigation is the indication that the amount of myoglobin in muscle tissue can be increased by physical training. The physiological significance and functions of myoglobin are a largely unexplored subject and represent one of the most promising frontiers of research on muscular exercise.

Having looked separately at the main components of the system that effects adaptation to physical stress, let us now put them together and see how the system works as a whole. Nature demands that for survival an organism must be able in an emergency to rise to maximal activity on an instant's notice. Usually, however, the anticipatory warning allows enough time for efficient mobilization of the body's machinery. In man and other mammals a great deal of physiological preparation begins as soon as the individual senses that vigorous physical activity is imminent. The autonomic nervous system becomes active and the adrenal glands release the hormones epinephrine and norepinephrine into the bloodstream. The pulse rate quickens, the heart muscle contracts more forcibly and the output of the heart probably begins to increase slightly. The respiration deepens and may speed up. The voluntary muscles become tense. The switching of blood flow from other areas to the muscles begins.

When exercise itself starts, there is an immediate jump in the rate of ventilation of the lungs. The cardiac output, pulse rate and stroke volume rise to their maximal level, probably within no more than a minute or two. Simultaneously the hemoglobin starts to surrender more of its oxygen to the muscle tissues, widening the difference between the oxygen content of arterial and venous blood. By the end of the first minute most of the known adaptive mechanisms are working nearly to capacity. Thereafter, with continuation of the exercise, the muscle cells begin to run up an oxygen debt.

If the exercise is pushed to the point of exhaustion, various mechanisms begin to fail. The rhythm of the heart becomes less regular; cardiac output declines; the oxygen content of the arterial blood may fall, and marked pallor



ARTERIOVENOUS OXYGEN DIFFERENCE is shown as oxygen intake rises with increasing exercise. Arterial blood is represented in color; venous, in gray. The oxygen content of arterial blood remains almost constant. That of venous blood drops rapidly at first, then levels off as the intake of oxygen and the output of the heart become maximal.

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—sometimes even blueness—of the lips and fingernails develops. Finally an inordinate rise in the pulse rate and clumsiness of the muscular movements give warning that collapse is imminent.

Research on the physiology of exercise of course has important practical objectives, particularly with respect to what can be accomplished by physical training. The problem is not simply a matter of enabling astronauts to cope with a landing on the moon. Probably a more useful goal, from the standpoint of the human population at large, is to find training regimes and other measures that will help the body to cope with diseases of the lungs and heart. In many ways the symptoms of chronic heart failure are like those accompanying heavy exercise. The body responds by making the heart beat faster, by attempting to increase the ventilation of the lungs and by surrendering more oxygen from each liter of blood pumped by the heart to the tissues. By acquiring a better understanding of the mechanisms involved it may be possible to improve the body's adaptation to its needs under a wide variety of conditions.

Could special training techniques and other devices, including drugs, raise man's physical performances to greater heights? The training methods of athletes, from the time of the Greeks to the present, have been largely empirical and rule of thumb. With methods based on fuller physiological knowledge it may well be possible to achieve performances now considered superhuman. One must pay due regard, however, to the limits of the human organism. Once the organism has reached its maximal oxygen intake and cardiac output it cannot go further without drawing on its vital reserves, and this must have its limits of safety.

According to Herodotus, Pheidippides, "a trained runner," covered the 150 miles from Athens to Sparta in two days and two nights. Legend (but not Herodotus) says that a few days later he ran the 22 miles from Marathon to Athens to report the Greek victory over the Persians and fell dead at the end of his run. It may become possible to achieve by artificial means the kind of performance that extreme motivation is said to have made possible for Pheidippides, but only at the same cost. In all likelihood, however, there is room for improvement of human physical achievement, well within the bounds of safety, by rationally based methods.

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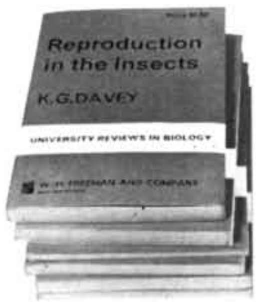

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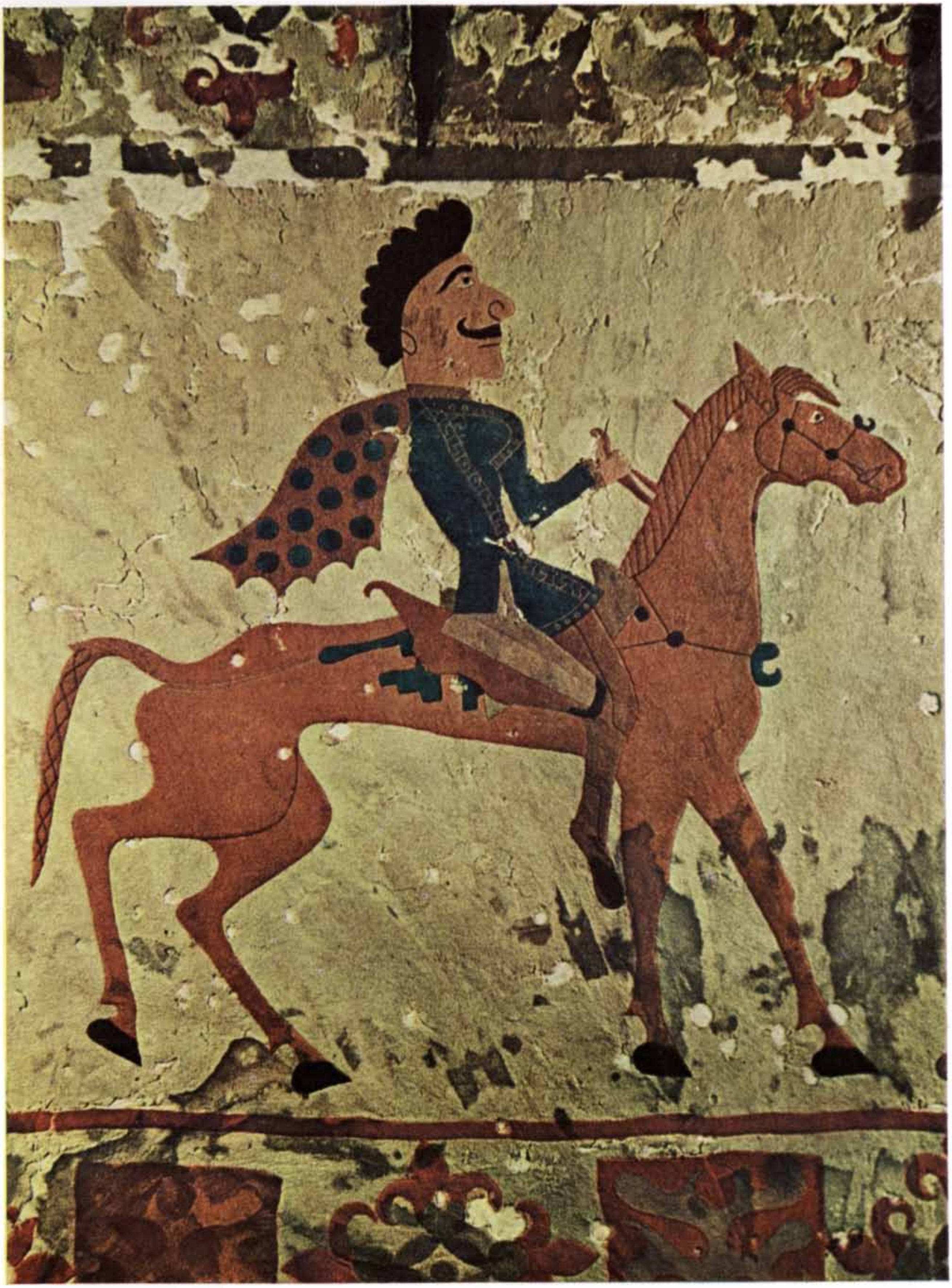


SCYTHIAN HORSEMAN, with flying cloak and bold moustache, is one of two figures used repeatedly to decorate the largest piece of cloth found in the frozen burial chambers in the Pazyryk valley of the Altai Mountains. Made of felt, the cloth was probably used as a rug. The preserved portion measures 15 by 21 feet; horse and rider occupy 16 square feet. The tombs were built about 300 B.C.

Frozen Tombs of the Scythians

Soviet archaeologists, examining several 2,000-year-old graves in Siberia, have found rich stores of normally perishable cloth, leather and wood artifacts almost perfectly preserved by cold

by M. I. Artamonov

Judging by the remains of ancient cultures, one might suppose that the material creations of prehistoric men were limited to objects made of stone, clay, bone and a few metals such as copper, gold and iron. Archaeologists are of course aware that this is a false impression, attributable to the fact that nature is hostile to the preservation of organic materials. Normally anything made of wood, leather, cloth or the like cannot long survive exposure to the disintegrating effects of weather or burial. This circumstance has caused a certain distortion of our view of the everyday life and activities of peoples of the distant past.

Occasionally archaeologists have been fortunate enough to discover ancient settlements at sites where their contents have been preserved by conditions of permanent wetness or permanent dryness—for example in the lake bottoms and peat bogs of Switzerland, in the marshes of the northwestern U.S.S.R. and in the deserts of Egypt. These rare finds give us quite a different picture of ancient life. As if a black-and-white photograph were suddenly rendered in color to reveal a richness of detail not previously visible, they bring to light an astonishing profusion of garments, furnishings and other creations in wood, fur, leather and fiber. In short, they show that the trappings of life in prehistoric civilizations included many of the materials we consider modern.

In central Siberia, a land whose prehistory has been almost completely unknown, Soviet archaeologists have in recent years uncovered the remains of an ancient people kept remarkably intact by still another means of preservation: refrigeration. The find consists of a number of burial mounds high in the Altai Mountains on the border between Siberia and Outer Mongolia. Through an accident of their construction these graves have been frozen virtually since they were made more than 2,000 years ago. In each of the mounds the burial chambers were covered with a layer of massive boulders. This layer was not airtight, and the burial chambers were soon filled with freezing air during the cold Altai winter. Because cold air is heavier than warm, the frigid air below the boulders was not penetrated by warm air during the short Altai summers; only still colder, denser air could settle into the chambers. Thus the graves became natural refrigerators. Here, in these chambers of eternal frost, the bodies of ancient chieftains, with their horses, clothing and varied possessions, have been preserved from decay.

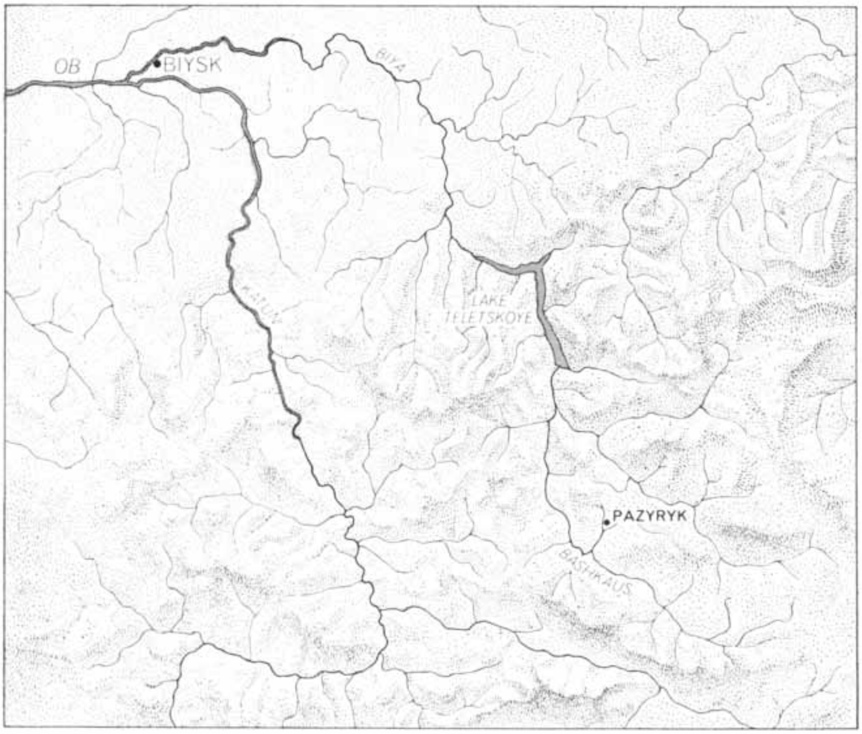
The Altai finds have opened up a significant ancient culture. These buried horsemen belonged to one of the great tribes of "barbarians"—nomads who roamed the steppes of Eurasia in the time of ancient Greece and Persia and were called by ancient writers the Scythians. Little has been known about the Scythians—if we may call them that—of central Asia. Now the graves in the Altai Mountains show that these remote and nearly forgotten people were in surprisingly close contact with the cultures of Greece, Iran and China. What is more, the artifacts from these graves reveal that the people who made them had an unexpected sophistication and creativeness in art.

Let us note first that there has been much speculation about the origins and migrations of the Eurasian tribes. Whatever their origin, throughout the first millennium B.C. these peoples hovered at the entire northern frontier of the established civilizations of Greece and western Asia, ranging the steppes from the Black Sea all the way to China. They traded with the Greeks and Iranians when they had to and raided their cities when they could. But the wandering tribes of the steppes also developed a common way of life of their own, with the same kind of economy (mainly pastoral) and common cultural characteristics. This was the culture described by ancient writers as "Scythian."

Herodotus and other Greek writers give something of a picture of the life of the Scythians, based mainly on the tribes living in contact with Greek colonists on the northern shore of the Black Sea. The Greek accounts, however, are inconsistent and become vaguer as they reach further into the continent of Asia beyond the northern shore of the Black Sea, until finally they fade off into pure legend. They picture central Asia as inhabited by a series of fabulous baldheaded creatures: the Argippaei, the one-eyed Arimaspi and the gold-guarding griffins (beings with the head of an eagle and the body of a lion).

It remained for modern archaeologists to reconstruct a clearer and more accurate account of the Scythians. Excavations of ancient Scythian burial mounds near the Black Sea, beginning in the 19th century, have turned up an extraordinary collection of objects that are considered to be among the greatest treasures of the State Hermitage Museum in Leningrad. Unfortunately most of these graves, like burials elsewhere, had been plundered by treasure hunters before archaeological workers found them. Nevertheless, the archaeologists recovered many remarkable pieces, fashioned in gold, silver, bronze and ceramic materials. Some of these objects had been produced by craftsmen of Greece and Asia Minor, but most were the work of Scythian artists. They were distinguished by their depiction of animal forms—the so-called "animal style" now

ALTAI MOUNTAIN REGION of Siberia (*color*) lies near the boundary between Mongolia and Chinese Turkestan. The Scythian treasures in Siberia first came to light in the 18th century, when some 200 pieces of gold sculpture were sent to Peter the Great.



RICHEST ALTAI SITE is the highland valley of Pazyryk, south of Lake Teletskoye. Six Scythian tombs in the area were excavated by Soviet archaeologists between 1947 and 1949.

famous as a trademark of Scythian art.

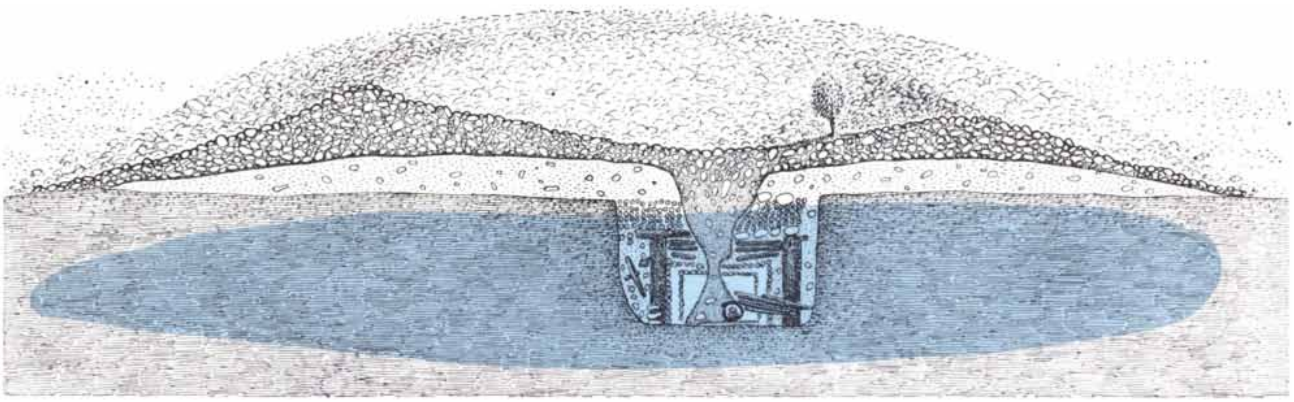
The study of these treasures by scholars at the Hermitage has steadily added to our knowledge of the Scythians and their easterly cousins. For example, for a long time the collection has included a most unusual group of finds from Scythian graves in western Siberia. These objects were extracted from burial mounds by gold hunters around the end of the 17th century and found their way into the possession of Peter I ("Peter the Great"). The more than 200 assorted gold items include plates with extraordinary pictures of fighting beasts and other animals in the distinctive Scythian animal style; they differ from the objects found near the Black Sea only in that they show Iranian rather than Greek influence and picture local animal life of the Siberian region.

It is against this background that we can now place the discoveries in the Altai Mountains, part of the region that the Greek historians supposed to be populated by one-eyed men and griffins. Strangely enough, objects of the Altai type have been known for more than a century and a half, but their significance was not realized until fairly recently. Around the beginning of the 19th century an engineer in the Altai area named P. K. Frolov collected from various sources a number of local art objects of bronze, bone and wood. Some of them were particularly notable wood carvings; all were executed in the typically Scythian animal style. No doubt Frolov realized that the objects were old, but there is no indication that he connected them with the distant past. Then in the 1860's an archaeologist, V. V. Radlov, excavated two big burial mounds in the same region. Among his finds in these mounds were some fur garments in excellent condition and some carved wood like the items in Frolov's collection. Apparently it did not occur to Radlov or anyone else to wonder how it was that these things were so well preserved; at any rate, no effort was made to follow up the discoveries by searching for other graves.

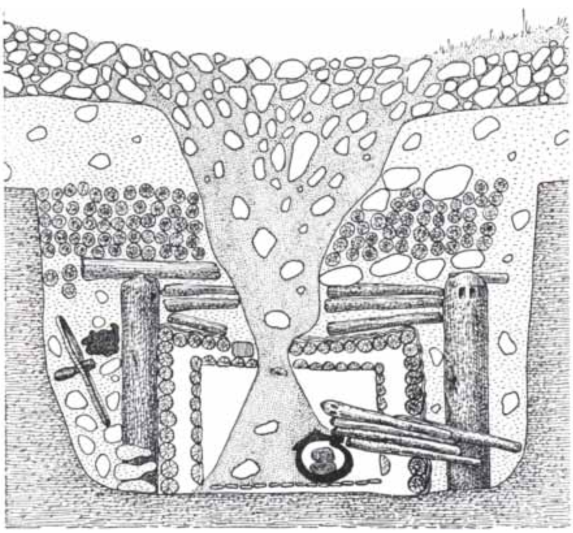
The present scientific interest in digging up the past of the Altai area began in 1927. In that year a Soviet archaeologist, M. P. Gryaznov, went to work on a stone mound in the vicinity of Shiba in the Altai Mountains. In it he found objects of metal, wood and bone like those in the Frolov and Radlov collections. This time the discoveries inspired a systematic and carefully scientific investigation of similar mounds in the region. In 1929 S. I. Rudenko opened a large boulder-roofed mound in the Pazyryk valley, which was to become celebrated for the richness of archaeological finds in it. World War II interrupted Rudenko's work, but he returned to the Pazyryk valley in 1947 and soon excavated six more mounds there. He went on to uncover two others at Bash Adar and two at Tuekte. All these graves were protected by the perpetual frost and their contents were remarkably well preserved. Several other mounds with shallower layers of boulders have also been excavated in the same region; in these the burials had suffered further decay.

The archaeologists found the big, stone-roofed graves partly filled with layers of ice. In the process of excavating them the ice had to be melted bit by bit with boiling water and bailed out. When the diggers finally cleared and examined the burial chambers, they found that every one had been thoroughly looted by plunderers many centuries before. There was clear evidence of the manner and extent of the lootings, and certain clues allow us to guess even the approximate time they took place.

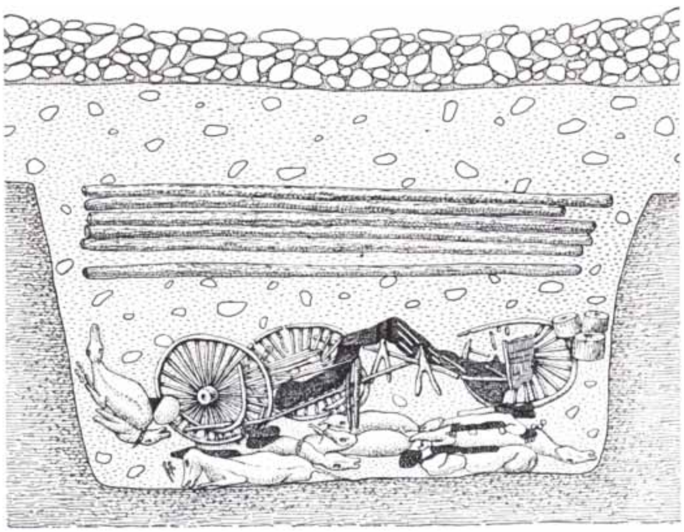
As an example of the construction of the burial mounds, let us take those of the Pazyryk type [*see illustrations below*]. The builders first dug a rectangular pit approximately 15 feet deep and some 25 feet on a side. In this excavation they erected a wood framework, leaving a space between the frame and the earth wall on the north side large enough to receive the dead chieftain's horses, which were slaughtered in the funeral rites; from five to 22 horses were found in this space in the Pazyryk graves. Inside the first framework the grave builders usually constructed a second, filling the space between the two with earth or stone. The inner structure enclosed the burial chamber itself, which was a shallow room no more than five feet high with a board floor and walls and ceiling, all covered with a thick layer of felt. The body of the dead man, sometimes with that of his wife or concubine, was placed in a single large coffin made of the hollow trunk of a larch tree. (Occasionally two smaller coffins were found in a grave.) The coffin was covered with carved figures of animals or with designs cut out of leather or birch bark [*see bottom illustration on next page*]. In the cham-



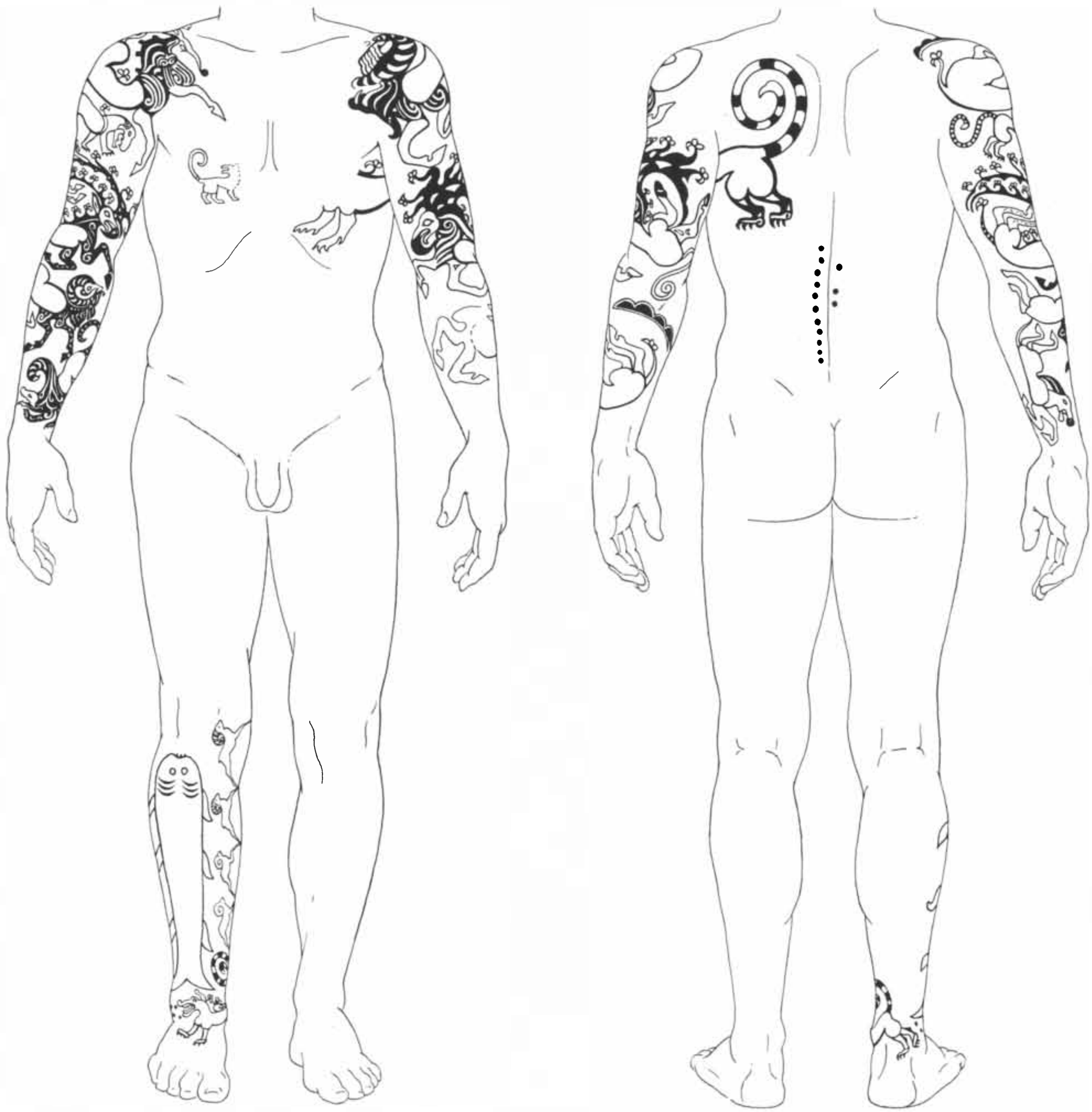
PAZYRYK TOMB, shown in cross section, was built of wood at the bottom of a pit 15 feet deep. A thick layer of logs over the roof of the chamber served to fill the pit up to the original level of the ground, after which the earth from the excavation was used to make a low, wide mound. The Scythians then carted large numbers of boulders to the site and piled them high on the earth mound. The empty spaces between the boulders collected chill winter air that did not reheat during the brief summer. Eventually the earth below the mound became frozen (*color*) and the contents of the tomb were thus preserved. This is mound No. 5 at Pazyryk.



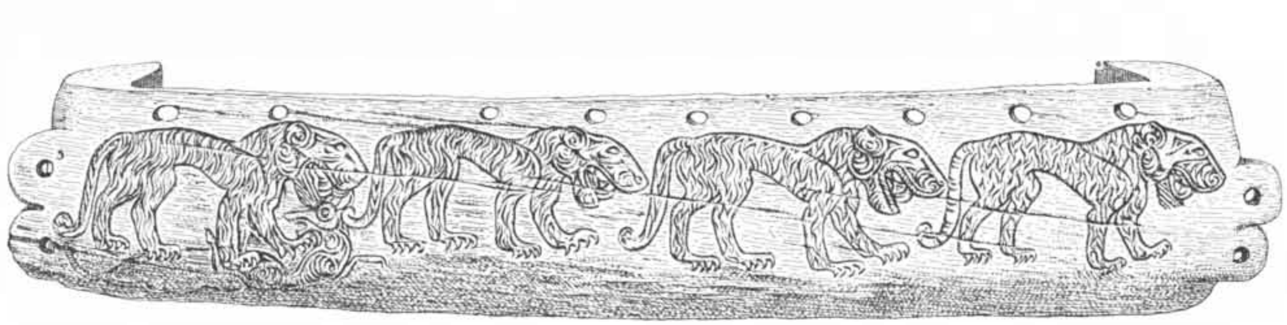
UNDERGROUND STRUCTURE consists of a heavy wood frame within which was built a double-walled burial chamber where the coffin and household goods were placed. Horses were sacrificed and piled along the north side of the pit. Every burial chamber at Pazyryk was looted by robbers, who dug down to the layer of logs and then chopped their way inside (*note the disturbed area*).



HORSE SACRIFICE at mound No. 5 included the wheels and the frame of a four-horse carriage, as well as saddles, harness and other trappings. Mares evidently were seldom ridden or driven; all the slain horses were geldings. Because the ancient looters did not usually dig up the horse sacrifices modern archaeologists have found many of the finest Scythian artifacts among these burials.



TATTOOED CHIEF, most of his skin preserved by the freezing temperature of mound No. 2 at Pazyryk, had both arms and one leg decorated with designs in the celebrated "animal style" of the Scythians. The figures were formed by first pricking the skin and then rubbing in soot. The various carnivores portrayed seem to be mythical felines; the herbivores (*for example the row of mountain sheep on the leg*) are more realistically rendered. The chief's head was scalped and crushed, suggesting death in battle.



ANIMAL STYLE in Scythian art is further exemplified by this quartet of wildcats incised on a coffin made from the trunk of a larch tree. Other tree-trunk coffins in Altai tombs display carvings of deer, mountain sheep, moose, and even roosters arrayed in rows.

ber with the dead were placed various funeral goods—low tables with carved legs, wooden stools, dishes containing food and so on. The chamber was then roofed with several layers of bark and logs. On this was heaped the soil from the excavation, topped by a stone platform some 120 to 150 feet in diameter. The entire mound sometimes rose as high as 13 or 14 feet above ground level.

All the burial mounds discovered in the Altai region had been broken into by plunderers in exactly the same way, evidently by men who knew their construction quite well. The looters first dug a shaft into the mound to the timbered ceiling of the burial chamber, then cut a hole in the ceiling large enough for a man to lower himself through it into the room. They generally took everything of value that was not too heavy to move. They seldom bothered, however, to dig into the space where the horses were buried, because it was too difficult to search through the stones and earth heaped on them and nothing very valuable was interred with them.

It appears that the robbers must have looted these graves some considerable time after they were built—a time probably measured in generations. In the first place, their digging operations were done quite openly, which indicates that there were no living relatives of the dead on hand to stop them. A second clue is presented by the peculiar stratification of the ice in several of the burial chambers. In each case the bottom layer was made up of clean ice in which the archaeologists found funeral objects still embedded. This ice must have formed from moisture wrung by the cold from the thin, dry mountain air. That it took some time for the ice to form can be deduced from the fact that sacrificial meats left at the time of burial had rotted away, leaving only bones, before the burial chamber chilled and the ice accumulated. Above this layer of clean ice the archaeologists found a mass of ice containing dirt and rubbish, which was washed into the chamber by ground water leaking through the hole in the ceiling by which the looters made their entry.

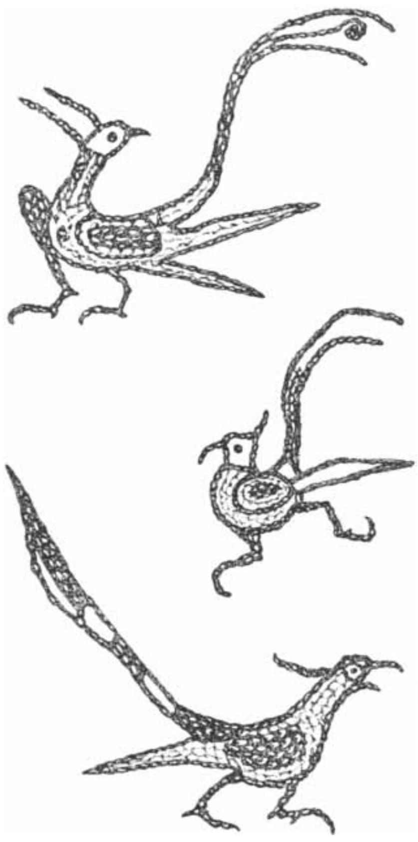
All of this indicates a substantial lapse of time between the burials and the plundering of the graves. On the other hand, the timbers through which the robbers hacked their way into the graves give evidence that they had been cut by primitive metal axes, which means that the robberies must have occurred long ago. In all probability the looters were Turks who invaded the Altai Mountains sometime after the third century B.C.

The ransacked burial chambers were in great disorder, with the bodies of the dead scattered about, their clothing stripped off and their extremities sometimes amputated, evidently so that the thieves could remove necklaces and other ornaments. In one grave, for example, both the man and the woman were beheaded by the looters, and from the woman's body both feet, one leg and the right hand were cut off. The felt coverings were torn from the walls of the chamber, apparently in order to remove the copper nails that had suspended them.

No doubt what the archaeologists have found in the Altai graves is only a small part of their original contents. Nevertheless, even the plundered remains make up a picture incomparably more detailed and more revealing than other graves have yielded, thanks to the permanent frost that preserved these remains.

The bodies of the dead, in the first place, were in remarkable condition, with even the hair and skin still in a good state of preservation. They had been carefully embalmed. The brains, internal organs and sections of muscle had been removed, and to maintain the shape of the body the corpses had been stuffed with grass or hair and the skin was then sewed up with threads made of hair or tendons. One man's skin was covered with tattoos of animals in the

PREDATORS IN ACTION are typical subjects of Scythian art. Both figures are cut from leather; the griffin seizing a moose (*top*) is repeated 20 times along the border of a hide rug from mound No. 2 at Pazyryk. The tiger or leopard striking down a mountain sheep (*bottom*) decorates a saddle; it is also from mound No. 2. The most common predators are felines; the figures are distinctively Scythian but the theme was derived from Persia.



PHEASANTS were embroidered in silk on a saddlecloth found at Pazyryk mound No. 5. Both the use of silk and the style of the figures strongly suggest a Chinese origin.

HEADDRESS for a horse, from mound No. 2, combines a mountain sheep's head and a bird. Such objects were not special funeral wares; they show clear signs of daily use.

typical style of Scythian decoration [*see top illustration on page 104*]. All the corpses had had their heads either partly or entirely shaved, but before their burial hair had been attached artificially to the heads of the women and beards to the faces of the men.

Enough scraps and remnants of clothing were found in the graves to give a fairly good idea of the people's wearing apparel. All the clothing was made of leather, fur or felt, except for some shirts that were woven of hemp or a hemplike fiber. Apparently wool was not used for clothing (although, as we shall see, a woolen rug was one of the items found in the Altai remains). The men wore narrow trousers made of many pieces of chamois-like leather, felt stockings, high boots with soft soles, and a spacious, capelike tunic with long, decorated sleeves. Their headgear was a felt hat with leather-covered earflaps or a peaked felt cap. The women's garments included a similar tunic, with a bib worn over the chest, and felt stockings. They wore dress boots made of leopard fur and elaborately embroidered with beads even on the soles—obviously not practical for walking but clearly suggesting that the women must have been in the habit of sitting cross-legged so that the soles of their boots showed. Their headwear, then as now, was more varied than the men's. One woman had a kind of cap topped with a crown of jagged teeth; another wore a little cap of carved wood attached to a complicated coiffure. Several belts were found, one of them decorated with silver plaques.

Although the looters had stripped practically every piece of jewelry from the graves, a few small items that escaped their notice remain as samples of the rich adornment that must have been buried with the bodies. The Altai Mountains have always been famous as a gold-mining area. In the pillaged remains of the graves the archaeologists recovered only one example of solid gold jewelry—a pair of finely wrought earrings. They also found some gold-covered fragments of a necklace (with representations of griffins!), a few gilded bronze plaques bearing animal figures, which were sewed on clothing, and a small quantity of beads, some of them made of turquoise. There were a few toilet articles, including a comb of horn and three mirrors—one made of bronze, one of silver with a long horn handle and one of a white metal, a kind of Chinese zinc.

Very few weapons were found in the graves. There were fragments, however, which showed that weapons were deposited originally in the burials—pieces of pikestaffs from which the looters had removed the bronze heads, remains of shields made of wooden frames covered with leather (and one made of wood carved to look like leather) and fragments of a short iron sword and a dagger.

Among the more or less intact items of domestic goods were wooden tables, wooden serving dishes with little feet, wooden headboards for beds, wooden and pottery plates, felt mats and a stone lamp. There were bags, flasks, purses and cases made of leather, sacks made of fur and rugs and shawls made of felt and leather. There were also some musical instruments—drums made of horn and an instrument like a harp. One particularly interesting apparatus was a kind of cone-shaped miniature tent, covered with a felt or leather rug, standing over a copper censer. Hemp seeds found on the spot suggest that this contrivance was a special enclosure that could be filled with narcotic smoke from the burning seeds. The use of other drugs was also indicated by the presence of horn containers, in one of which was a small wooden spoon such as is still commonly used with snuff-boxes in central Asia.

It is in the horse burials that the archaeologists have unearthed the most complete and best-preserved picture of the materials and art of the people who built these mounds. As already noted, the plunderers scarcely touched the part of the mound where the horses were buried. Furthermore, this section too was protected by the frost. The horses were found in excellent condition, and so were the accouterments interred with them.

The animals were a mixed collection—some large and of high breeding, others just run-of-the-herd. Almost all were riding horses, and they were all geldings between two and 20 years old. All had their manes clipped and their tails bobbed; some of the tails were plaited and smartly tied in a knot. Before burial with their master each had been killed by an ax blow on the head.

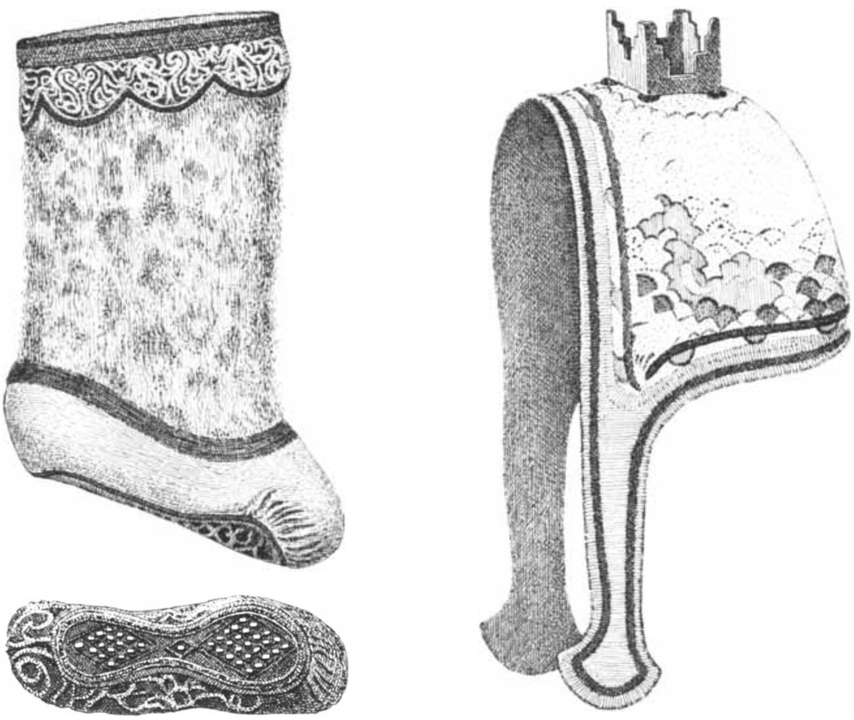
Some of the horses still wore blankets of felt and had leather covers over their tails, but most of the trappings had been removed and merely piled in the grave with the animals. These trappings are in every way remarkable. Each saddle consists of two pillows, stuffed with deer hair or grass and sewed together, combined with a saddlecloth, a girth and a strap passing under the horse's tail. The saddle and saddlecloth are decorated in almost unbelievably elaborate fashion: they are covered with cutouts of colored felt or leather depicting fights between wild animals, with details in colored thread and insets of beaten gold or tin. The saddle and bridle are also festooned with pendants carved out of leather or wood in a great variety of designs. Many of these beautiful and intricate carvings were covered with thin sheets of gold or tin and were found intact. Signs of wear and of repairs show that the gilded equipage was not mere funeral decoration but the regular gear that riders used on their mounts.

This was not all: the horses also wore, even on ordinary occasions, a still more spectacular item of dress in the form of a decorated slipcover, or mask, over the head. One of those found on a horse's head in the Altai graves had two large antlers attached to the top and a picture of a tiger outlined in fur along the muzzle. Another mask depicted a tiger attacking a winged griffin with tooth and claw. A third had a sculptured mountain sheep's head, and on the sheep's neck stood a big bird stretching its wings [*see bottom illustration on opposite page*].

In one of the burial mounds at Pazyryk (the fifth one excavated) two most unusual rugs were found buried with the horses. One is of woven wool, and it has the distinction of being the oldest known article in the world made of wool fiber. Measuring six by six and a half feet, it is woven in many colors and in an incredibly complicated fashion: in an area of 100 square centimeters (about 15½ square inches) 3,600 knots can be counted. The central panel of the rug contains a pattern consisting of four-pointed stars, and its wide border has figures of griffins, spotted deer and horsemen. The other rug is made of felt, with designs applied in color. The main feature is a frieze with a repeated composition representing a horseman with a flying cloak [*see illustration on page 100*] before a goddess who sits on a throne and holds a plant in her hand [*see cover of this issue*]. In its theme and its technique this rug is strongly reminiscent of the Greco-Scythian art in the Black Sea region.

The materials found with the horses tell us something about the technology, as well as the art, of the ancient Altai horsemen. Along with the horses were found parts of primitive wagons. The wheels were of solid wood, cut from the trunks of larch trees. Judging by

USE OF NARCOTICS by the Scythians is evidenced by these objects from mound No. 2. The stoollike device is a censer for burning hemp; the pot contained hemp seeds. The six sticks formed the frame of an 18-inch-high tent in which the hemp smoke was collected.



HAT AND BOOTS found at Pazyryk demonstrate a high level of craftsmanship in furs and skins. The crested hat is a man's, the fur boot a woman's. The sole of a second boot (*bottom left*) is embroidered with glass beads and pyrite crystals; it was obviously not for walking.

the signs of heavy wear in the axle holes, it appears that these wagons were used to drag up the boulders for the barrows and were then thrown into the pit when it was filled in. The fifth Pazyryk mound yielded up pieces of a much more complex wagon—evidently a kind of coach with four large, spoked wheels and a body consisting of latticed sides and a flat roof [*see illustration at bottom right on page 103*]. The shaft's yoke and traces show that the coach was pulled by four horses.

I have given only a quick survey of the finds in the Altai burial mounds; they make up a large collection that has been described in full detail in archaeological journals. We now ask: Who were these people—these artistic "barbarians" who lived in the Altai Mountains well over 2,000 years ago?

It can be said at once that they were clearly of Iranian origin. The woolen rug found in the fifth Pazyryk mound and many of the other objects can definitely be identified as Iranian in style. Beyond this, the obvious Black Sea influence and the general features that run through all the artifacts, particularly the familiar animal style, place the group within the overall Scythian culture that prevailed among the tribes of Eurasia.

At the same time the Altai remains also show a close contact with China. Although most of the individuals buried in the graves are of European stock, some are plainly Mongoloid. Moreover, some of the objects—such as a mirror and a saddlecloth with fine silk embroidery—are Chinese in origin [*see top illustration on page 106*]. There is every indication, indeed, that the Altai area was a meeting place between the Scythian nomads and ancient China. Here, it seems, was one of the ultimate extensions of the great Indo-European migration that stopped at China's doorstep.

Chinese documents of the third and second centuries B.C. tell of an Indo-European people in this region whom they call the Yueh-chih. In all probability these were the same people who built at least some of the Altai burial mounds. The Yueh-chih transmitted the Scythian art style to the Huns of Mongolia and northern China. Eventually they were dislodged from the region and driven westward by the Huns or the Turks.

Estimates of the dates of the Altai graves differ rather widely. From comparisons of the tree-growth rings in the excellently preserved timbers of the burial mounds it has been possible to judge the relative ages of the mounds pretty well. Apparently the difference between the oldest (the first mound at Tuekte) and the most recent (the fifth mound at Pazyryk) is about 200 years. We can be fairly confident about the accuracy of this relative chronology, because the tree-ring results agree with carbon-14 analyses of the wood, but the absolute dates are much more uncertain. The margin of error in the carbon-14 absolute dating is plus or minus 130 years, and the estimates of various authorities on the dates of the individual mounds range all the way from the seventh century B.C. to the first century of our era. The seventh-century date seems to me unlikely. The oldest examples of the Scythian animal style found in Iran and in the Black Sea area go back no further than the end of the seventh century B.C., and it is not to be expected that the style would have appeared earlier in a region near the extreme limit of the nomadic migrations; there is no basis whatever for supposing that the style originated in Siberia rather than at the fountainheads of Scythian culture near ancient Greece and Iran. The most probable dates for the burial mounds in the Altai Mountains are between the fifth (or at the earliest the sixth) and the third centuries B.C. The artistic styles in the Pazyryk mounds, for example, seem closely similar to those found in Iranian burials near the Black Sea (at Semibratny), which date from the fifth and fourth centuries B.C. Like the Semibratny burials, the successive Pazyryk graves show a gradual evolution of the animal style from realistic, three-dimensional forms to stylized, ornamental designs. This no doubt was a delayed but parallel reflection of the Black Sea development.

In any case, we are deeply indebted to the intervention of nature that preserved for us, in the frozen graves of the Altai Mountains, examples of ancient Scythian art in a great variety of materials that elsewhere have been effaced by the destructive processes of time. The Altai remains demonstrate clearly that art has been important to man in all times and among all peoples. Even in the so-called barbaric state man has enriched his life, from the cradle to the grave, with artistic creations. In every culture and age art has served not only to fulfill his aesthetic needs but also to shape his ideological concepts within the framework of his environment, his economy and his social relations.

The Evolution of Hemoglobin

One can reconstruct this evolution by comparing the sequence of amino acid units in the several molecular chains of human hemoglobin and in hemoglobin chains from other animals

by Emile Zuckerkandl

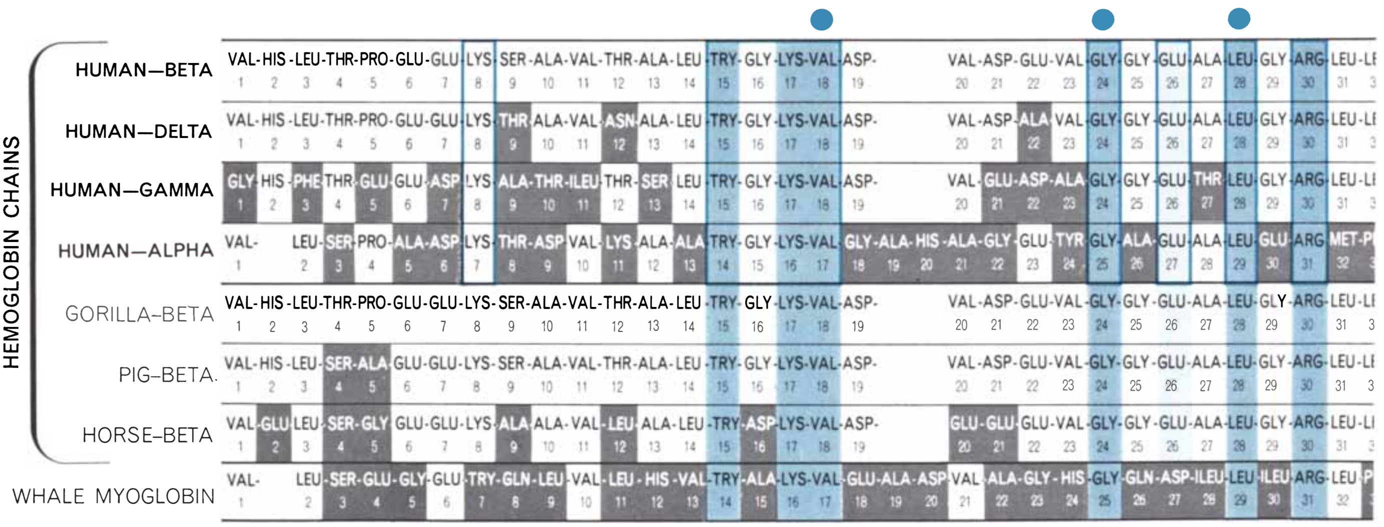
Every living thing carries within itself a richly detailed record of its antecedents from the beginning of life on earth. This record is preserved in coded form in the giant molecules of deoxyribonucleic acid (DNA) that constitute the organism's genome, or total stock of genetic information. The genetic record is also expressed more tangibly in the protein molecules that endow the organism with its form and function.

These two kinds of molecule—DNA and protein—are living documents of evolutionary history. Although chemically very different, they have in common a fundamental characteristic: they are both made up of a one-dimensional succession of slightly differing subunits, like differently colored beads on a string. Each colored bead occupies a place specifically assigned to it unless the heritable changes called mutations either change the color of a bead or displace, eliminate or add a bead (or several beads) at a time. In addition the protein molecules are folded in a specific way that enables them to carry out their specific functions.

To examine these molecular documents of evolutionary history a new discipline has emerged: chemical paleogenetics. It sets itself the ambitious goal of reconstructing, insofar as possible, how evolution proceeds at the molecular level. The new discipline is still in its infancy because almost nothing is yet known about the linear sequence of subunits that embody the code for a single gene in a molecule of DNA. Viruses, the smallest structures containing the blueprints for their own replication, possess from a few to several hundred genes. Each gene, in turn, consists of a string of several hundred code "letters." It has not been possible to isolate a single gene from any organism for chemical analysis.

It has been possible, however, to study and determine the chemical structure of a number of individual polypeptide chains that embody the coded information contained in individual genes. The term "polypeptide" refers to the principal chain of a protein molecule; it describes a sequence of amino acid molecules that are held together by peptide bonds. Such bonds are formed when two amino acid molecules link up with the release of a molecule of water; when they are linked in this way, the amino acids are called residues.

Because three code letters in DNA



FAMILY RESEMBLANCES are exhibited by the polypeptide chains found in several kinds of hemoglobin and by the polypeptide chain of sperm whale myoglobin. Hemoglobin is the oxygen-carrying molecule of the blood; myoglobin stores oxygen in muscle. Polypeptides are molecular chains whose links are amino acid units, usually called residues. The hemoglobin chains comprise either 141 or 146 residues; the myoglobin chain, 153. (The illustration is continued on pages 112 and 113.) Each molecule of are required to make a "word" specifying one amino acid molecule, there is a certain compression of information between the gene and the polypeptide chain it encodes. A "structural" gene containing 600 code letters is required to specify a polypeptide containing 200 amino acid residues. The reason for the three-to-one ratio is that there are 20 kinds of amino acid and only four kinds of DNA code letters, embodied in subunits called bases, to identify them; a minimum of three code letters, or bases, is needed to specify each amino acid. (In fact, three code units can specify 64 different items, and there is evidence that more than one DNA triplet exists for some of the amino acids.)

Enough is now known about the amino acid sequence of certain polypeptides to enable the chemical paleontologist to test the validity of three basic postulates. The first asserts that polypeptide chains in present-day organisms have arisen by evolutionary divergence from similar polypeptide chains that existed in the past. The present and past chains would be similar in that many of their amino acid residues match; such chains are said to be homologous. The second postulate is that a gene existing at some past epoch can occasionally be duplicated so that it appears at two or more sites in the genome of descendent organisms. Thus a contemporary organism can have two or more homologous genes represented by two or more homologous polypeptide chains, which have mutated independently and are therefore no longer identical in structure. The third postulate holds that the mutational events most commonly retained by natural selection are those that lead to the replacement of a single amino acid residue in a polypeptide chain.

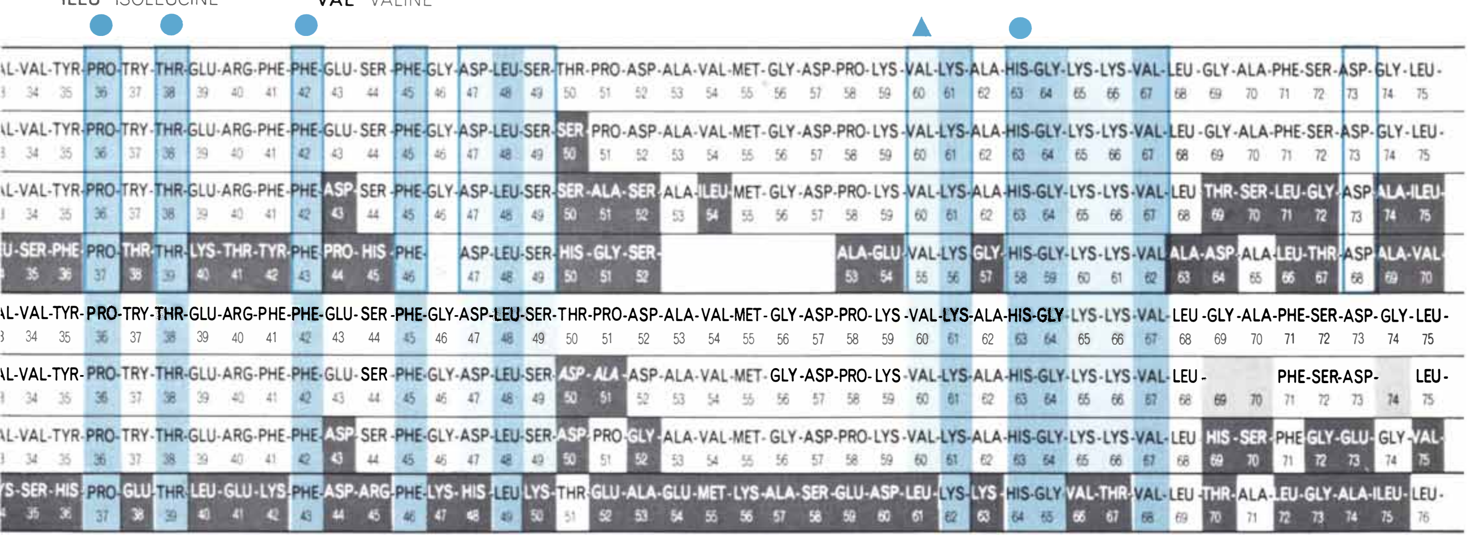
In addition to these three postulates I would like to suggest a fourth that is much more controversial: Contemporary organisms that look much like ancient ancestral organisms probably contain a majority of polypeptide chains that resemble quite closely those of the ancient organisms. In other words, certain animals said to be "living fossils," such as the cockroach, the horseshoe crab, the shark and, among mammals, the lemur, probably manufacture a great many polypeptide molecules that differ only slightly from those manufactured by their ancestors millions of years ago. This postulate is controversial because it is often said that evolution has been just as long for organisms that appear to have changed little as for those that have changed much; consequently it is held that the biochemistry of living fossils is probably very different from that of their remote ancestors. My own view is that it is unlikely that selective forces would favor the stability of morphological characteristics without at the same time favoring the stability of biochemical characteristics, which are more fundamental.

As an example of the application of chemical paleogenetics I shall describe how evolutionary changes are reflected in the molecular structure of hemoglobin, the oxygen-carrying protein of the blood. Hemoglobin is the most complex protein whose detailed molecular composition and structure are known in man, in his near relatives among the primates and in his more distant relatives such as horses and cattle. The composition and structure of hemoglobin molecules in more primitive organisms such as fishes are rapidly being worked out.

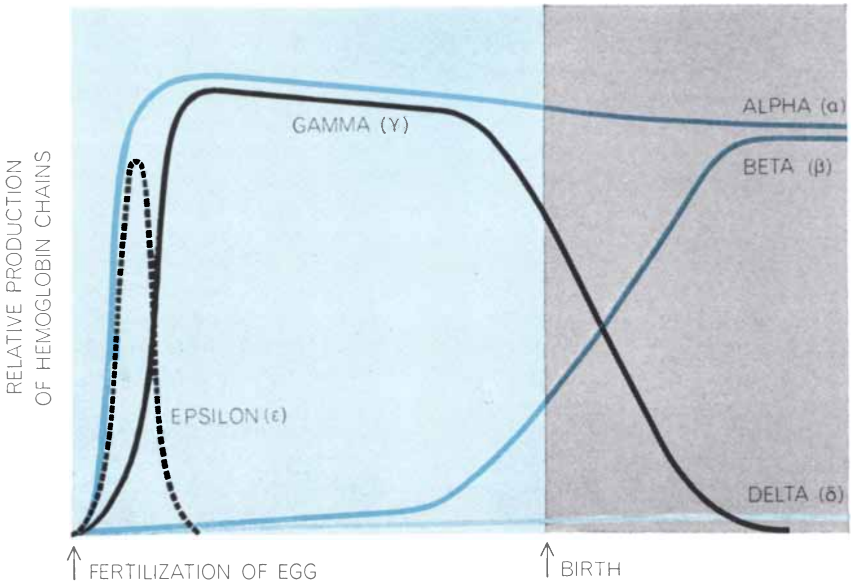
Hemoglobin is a particularly good

ALA	ALANINE
ARG	ARGININE
ASN	ASPARAGINE
ASP	ASPARTIC ACID
CYS	CYSTEINE
GLN	GLUTAMINE
GLU	GLUTAMIC ACID
GLY	GLYCINE
HIS	HISTIDINE
ILEU	ISOLEUCINE
LEU	LEUCINE
LYS	LYSINE
MET	METHIONINE
PHE	PHENYLALANINE
PRO	PROLINE
SER	SERINE
THR	THREONINE
TRY	TRYPTOPHAN
TYR	TYROSINE
VAL	VALINE

RESIDUE THE SAME IN ALL CHAINS SHOWN
RESIDUE THE SAME IN ALL KNOWN HEMOGLOBIN AND MYOGLOBIN CHAINS
RESIDUE THE SAME IN ALL HEMOGLOBIN CHAINS SHOWN
RESIDUE THE SAME IN ALL KNOWN HEMOGLOBIN CHAINS
RESIDUE THE SAME IN FOUR MAIN HUMAN HEMOGLOBIN CHAINS
RESIDUE THE SAME AS THAT IN HUMAN BETA CHAIN
RESIDUE DIFFERENT FROM THAT IN HUMAN BETA CHAIN
RESIDUE NOT DETERMINED
ITALIC RESIDUE ASSIGNMENT TENTATIVE



hemoglobin contains two subunits of a polypeptide chain called alpha (α) and two of a chain called beta (β). In human adults about 2 percent of the hemoglobin molecules contain delta (δ) chains in place of beta chains. Two other chains, gamma (γ) and epsilon (ε, *not shown*), are manufactured during fetal life and can also serve in place of the β-chain. The illustration enables one to compare the four principal chains (α, β, γ, δ) found in human hemoglobin with the β-chains found **(*caption continued on next page*)**



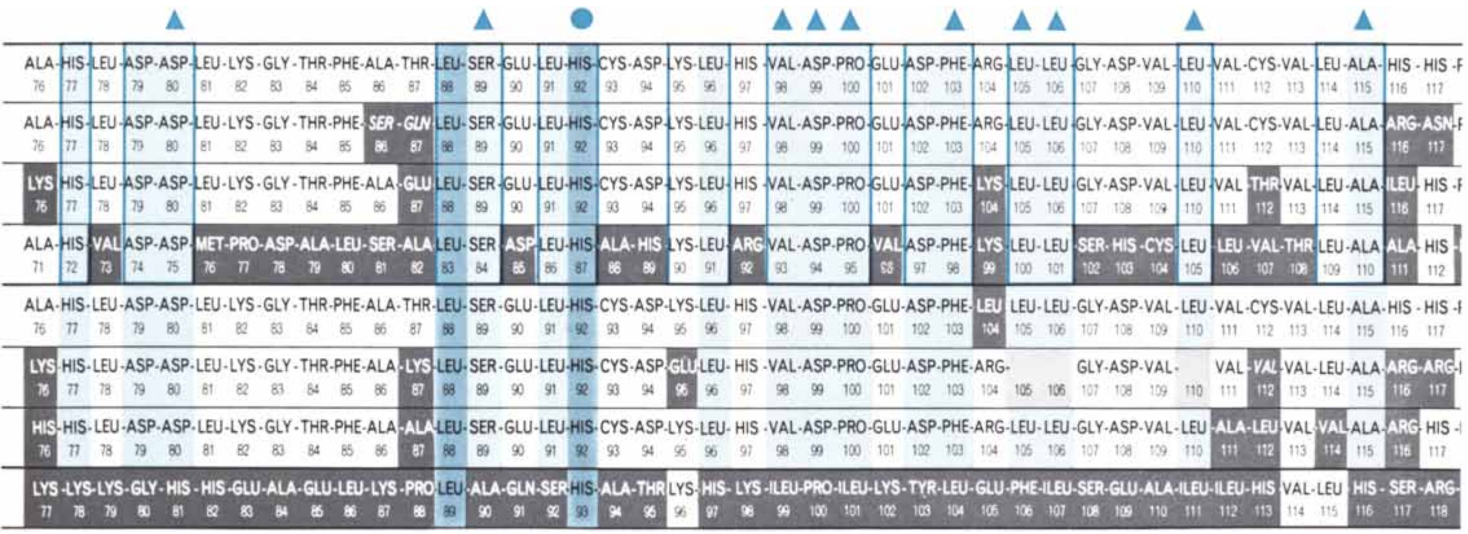
OUTPUT OF HUMAN HEMOGLOBIN CHAINS shifts abruptly during fetal development. Throughout life two of the four subunits in normal hemoglobin are α-chains. These chains pair first with epsilon (ε) chains, then with γ-chains. Just before birth β-chains begin to replace γ-chains. Simultaneously δ-chains appear and also pair with some α-chains.

subject for chemical paleogenetics because it is produced in several slightly variant forms even within an individual organism, and the study of these variants suggests how their components may have descended from a common ancestral form. A molecule of hemoglobin is composed of four large subunits, each a polypeptide chain. Each chain enfolds an iron-containing "heme" group that can pick up an atom of oxygen as hemoglobin passes through the lungs and release it in tissues where oxygen is needed.

The principal kind of hemoglobin found in the human adult is composed of two alpha chains and two beta chains, and it is believed that they too have a common ancestry. The alpha chain comprises 141 amino acid residues; the beta chain, 146. Although the two chains are quite similar in their three-dimensional conformation, they differ considerably in composition. When the two chains are placed side by side, there are 76 sites where the residues in the two chains are different and only 65 sites where the residues are the same. Both the similarities and the differences are of interest to the chemical paleontologist.

The reader may wonder at this point how one can assume that the alpha and beta chains of human hemoglobin have a common ancestry if they are now more different than they are alike. The answer is that it seems most improbable that two different and unrelated polypeptide chains could evolve in such a way as to have the same function, the same conformation and a substantial number of identical amino acid residues at corresponding molecular sites. Consequently the chemical paleontologist interprets their marked difference in amino acid sequence as evidence that a long time has elapsed since they diverged from a common ancestor.

The argument for a common ancestry is strengthened by the fact that in the hemoglobins of man the beta chain is sometimes replaced by chains with still other amino acid sequences known as gamma, delta and epsilon chains. The epsilon chain is manufactured only for a brief period early in fetal life. The gamma chain replaces the beta chain during most of embryonic development and disappears almost entirely shortly after birth. Throughout adult life a small fraction of the hemoglobin in circulation contains delta chains rather than beta chains [*see top illustration on this page*]. The beta, gamma and delta chains are all 146 units long and closely resemble one another in amino acid sequence. There are only 37 differences in amino acid residues between the beta



in the hemoglobin molecules of gorillas, pigs and horses. The δ-, γ- and α-chains are ranked below the human β-chain in order of increasing number of differences. The gorilla β-chain differs from the human β-chain at only one site. The pig β-chain differs at 10 sites, with a number of residues still to be determined, and the horse β-chain at 26 sites. The number of differences indicates roughly how far these animals are separated from man on the phylogenetic tree. Relatively few sites have been completely re-

and the gamma chains and only 10 between the beta and the delta chains. The sequence of the human epsilon chain has not yet been established.

One other oxygen-carrying protein molecule figures in this discussion of hemoglobin evolution: the protein known as myoglobin, which does not circulate in the blood but acts as an oxygen repository in muscle. Myoglobin is a single polypeptide chain of 153 amino acid residues that has nearly the same three-dimensional configuration as the various hemoglobin chains. In fact, the unraveling of the three-dimensional structure of sperm whale myoglobin in 1957 by John C. Kendrew and his colleagues at the University of Cambridge marked the first complete determination of the structure of any protein molecule. Two years later Kendrew's colleague M. F. Perutz announced the three-dimensional conformation of the alpha and beta chains of horse hemoglobin; their topological similarity to myoglobin was immediately apparent [see "The Three-dimensional Structure of a Protein Molecule," by John C. Kendrew, SCIENTIFIC AMERICAN, December, 1961, and "The Hemoglobin Molecule," by M. F. Perutz, SCIENTIFIC AMERICAN, November, 1964].

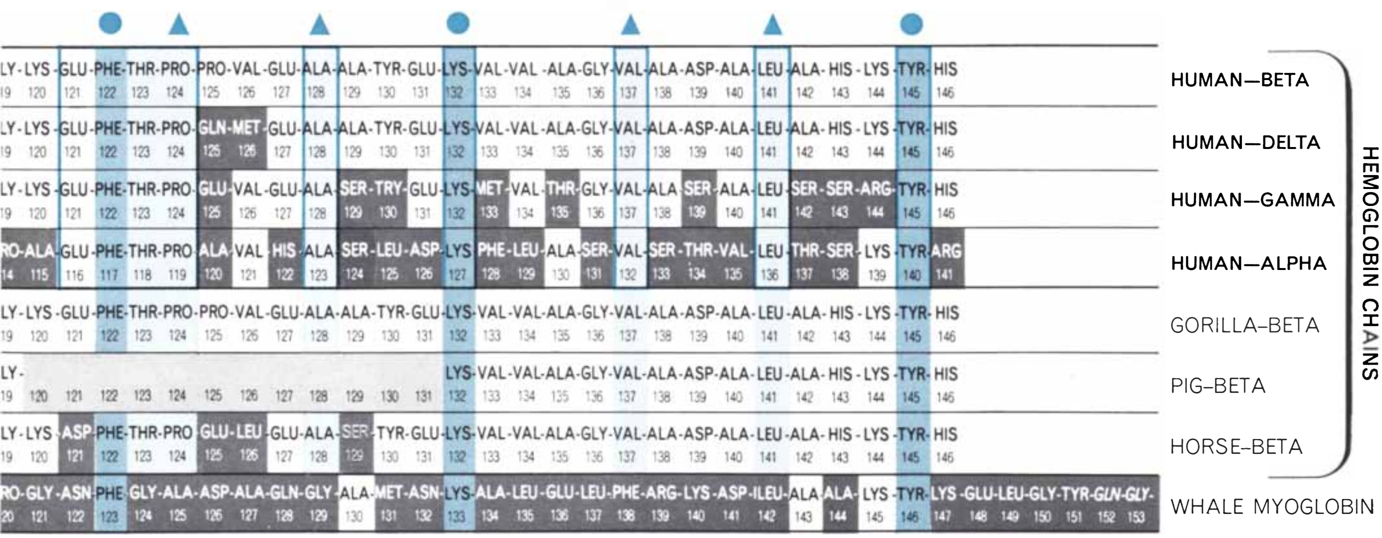
In amino acid sequence whale myoglobin and the alpha and beta chains of human hemoglobin are far apart. The sequence for human myoglobin is only now being determined, and it is apparent that it will be much closer to the sequence of whale myoglobin than to that of any of the human hemoglobin chains. Whale myoglobin and the alpha chain of human hemoglobin have the same residues at 37 sites; whale myoglobin and the human beta chain are also alike at 37 sites. Again the chemical paleontologist regards it as probable that myoglobin and the various hemoglobin chains have descended from a remote common ancestor and are therefore homologous.

Although I have been speaking loosely of the evolution and descent of polypeptide chains, the reader should keep in mind that the molecular mutations underlying the evolutionary process take place not in polypeptide molecules but in the structural genes of DNA that carry the blueprint for each polypeptide chain. The effect of a single mutation of the most common kind is to change a single base in a structural gene, with the result that one triplet code word is changed into a different code word. Unless the new code word happens to specify the same amino acid as the old code word (which is sometimes the case) the altered gene will specify a polypeptide chain in which one of the amino acid residues is replaced by a different one. The effect of such a substitution is usually harmful to the organism, but from time to time a one-unit alteration in a polypeptide chain will increase the organism's chances of survival in a particular environment and the organism will transmit its altered gene to its progeny. This is the basic mechanism of natural selection.

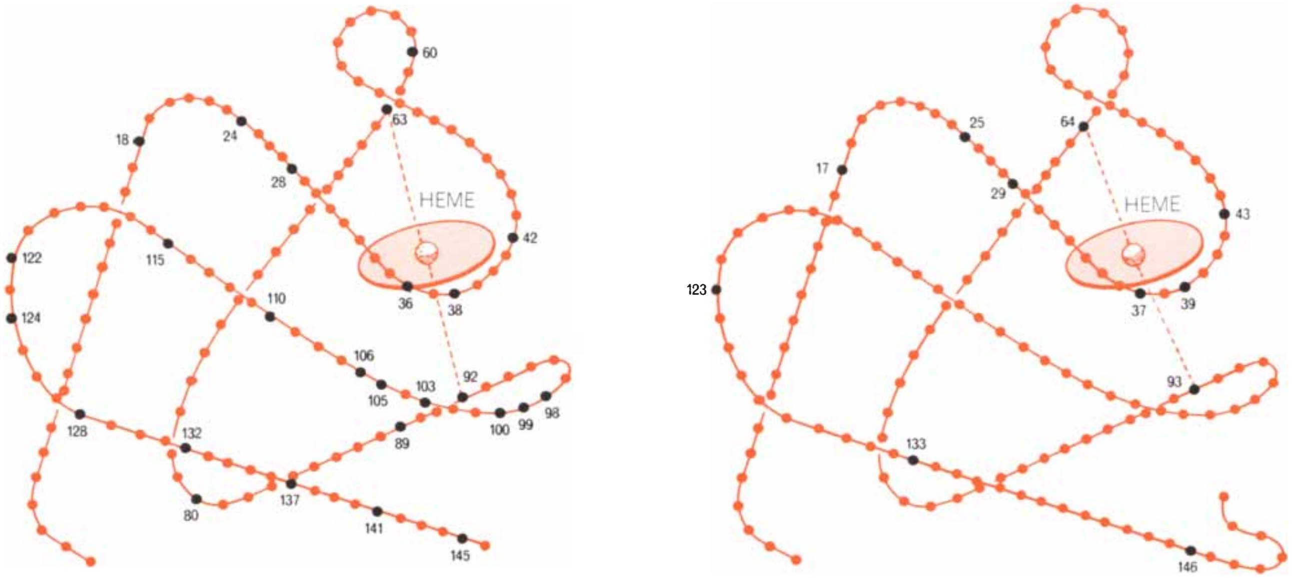
As I have mentioned, there are also types of mutation that produce deletions or additions in a polypeptide chain. And there are the still more complex genetic events in which it is believed a structural gene is duplicated. One of the duplicates may later be shifted to a different location so that copies appear at two or more places in the genome. Such gene duplication, followed by independent mutation, would seem to account for the various homologues of hemoglobin found in all vertebrates.

Duplicate genes may have several values for an organism. For example, they may provide the organism with twice as much of a given polypeptide chain as it had before the duplication. They may also have subtler and more important values. It may be that the gamma chain found in fetal hemoglobin is particularly adapted to the needs of prenatal existence whereas the beta chain that replaces the gamma chain soon after birth is more suitable for life outside the womb. The precise value to the organism of having these two kinds of hemoglobin chain available at different stages of development remains to be discovered. It is somewhat puzzling that adult humans who have a certain genetically controlled abnormality go through life with gamma chains rather than beta chains in a significant fraction of their hemoglobin and show no ill effects.

Even without detailed knowledge of the role of duplicate genes it is clear that they are valuable both for the evolution of species and for the development of the individual organism. For purposes of evolution they provide two (or more) copies of genetic material that



sistant to evolutionary change. Only 11 of the sites (*colored circles*) have the same residues in all known hemoglobin and myoglobin chains, and only 15 more sites (*colored triangles*) have the same residues in all known chains of hemoglobin. Among the four principal chains of normal human hemoglobin the same residues are found at 52 sites. The β-, δ- and γ-chains, which are closely related, have 105 sites in common. The three-dimensional conformation of all these chains is illustrated at the top of the next page.



INVARIANT SITES are identified on knotlike shapes representing the three-dimensional structure of the polypeptide chains of hemoglobin and myoglobin. The 26 numbered sites at left are occupied by the same residues in all known hemoglobin chains. Eleven of these same sites (*assigned slightly different numbers at right*) are occupied by the same residues in all known chains of hemoglobin and myoglobin. Presumably the invariant sites are important in establishing the structure and function of these polypeptides.

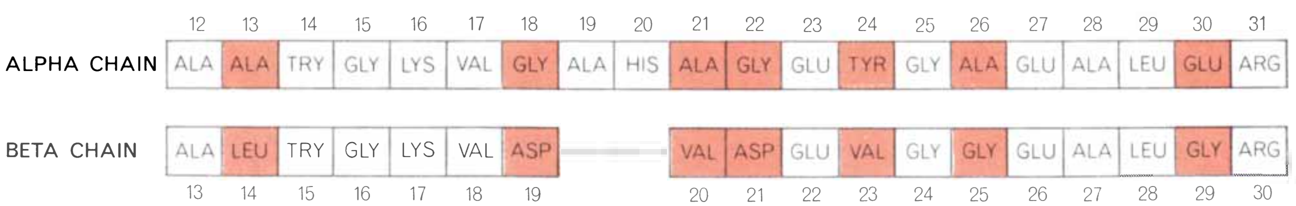
are free to evolve separately. Thus a duplicate gene may be transformed so completely that it gives rise to a new type of polypeptide chain with a function entirely different from that of its ancestor. In the life history of an individual organism the existence of duplicate genes at different sites in the genome enables the organism to obtain a supply of an essential polypeptide without activation of the whole genome. In this way gene duplication makes possible a more complex pattern of gene activation and inactivation during an organism's development.

It is not always easy to decide when two polypeptide chains are homologous and when they are not. As long as one is dealing with rather similar chains that serve the same function—as in the case of the various hemoglobin chains—there is a strong *prima facie* case for homology. As the amino acid sequences of more and more polypeptides are deciphered, however, one can expect ambiguities to arise.

One potential source of ambiguity arises in the identification of "corresponding" molecular sites. Such sites are often made to correspond by shifting parts of one chain with respect to the homologous chain [*see illustration below*]. The shifts are justified on the grounds that deletions or additions of one to several residues in a row have occurred during the evolution of certain polypeptide chains. A shift is considered successful when it maximizes the number of identities between the segments of two chains. The argument, therefore, is somewhat circular in that the shifts are justified by the presumed deletions (or additions) and the deletions (or additions) by the shifts. The argument that breaks the circle is that by invoking a small number of shifts, homologous polypeptide chains can be brought to display remarkable coincidences, whereas nonhomologous chains cannot be. There remains, however, the problem of placing the concept of homology on an objective basis. An effort is being made to do this with the help of a computer analysis of real and hypothetical polypeptide chains.

Now that the reader has this background I can provide a more detailed statement of the aims and methods of chemical paleogenetics. Fundamentally it attempts to discover the probable amino acid sequence of ancestral polypeptide chains and also the probable base sequence in the genes that controlled them. It is concerned with the fate of the descendent line of each gene. It inquires whether gene duplication has occurred and, if so, when it occurred; it asks what became of the duplicate genes, how they may have been shifted to various parts of the genome and how they have mutated. Finally it is concerned with the factors that regulate the rate and timing of the synthesis of the various polypeptide chains.

Present evidence suggests (although exceptions are known) that the number of differences between homologous polypeptide chains of a certain type found in different animals is roughly



CORRESPONDING REGIONS of the α- and β-chains of human hemoglobin show how a short deletion must be inferred in the β-chain to produce a good match at corresponding sites. An earlier one-unit deletion in the α-chain explains why α-site 12 corresponds to β-site 13. By postulating the two-unit deletion shown here the two chains can be made to have the same residues at 11 sites.

proportional to the relatedness of these animals as established by standard methods of phylogenetic classification. Indeed, the readily observable differences among living things must be to a significant extent the expression of differences in their enzymes—the proteins that catalyze the chemical reactions of life—and therefore of differences in the amino acid sequences of the polypeptide chains that form the enzymes. It is probable that observable differences also reflect differences in the regulation of rate and timing of the synthesis of polypeptide chains rather than differences in the amino acid sequence of these chains.

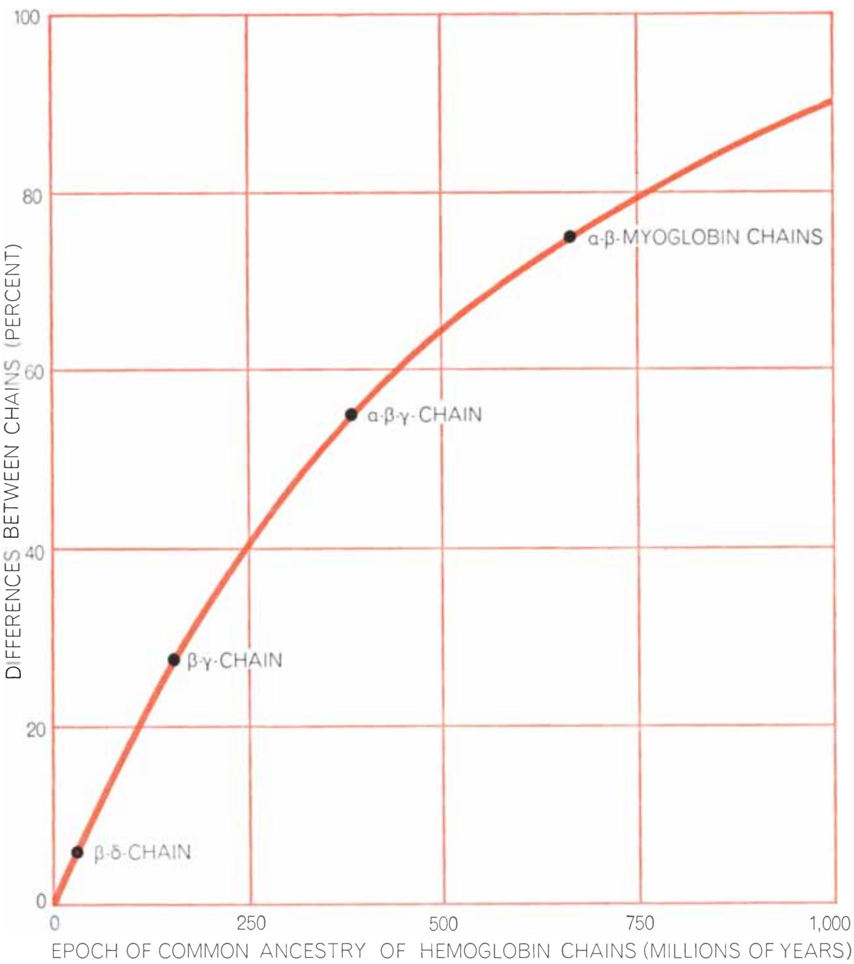
On the other hand, a difference in sequence may express itself primarily as a difference in rate and timing. It is quite probable that regulatory enzymes play an important role, and less obvious regulatory mechanisms may also exist. It has been suggested, for example, that differences in rate and timing may be attributable to certain sequences of bases in DNA that never find expression in a polypeptide chain. It seems in the last analysis, however, that the differences between organisms, if the environment is kept constant, boil down to differences in molecular sequences. These differences may reside in base sequences in genes, which are then expressed in amino acid sequences in polypeptide chains; they may reside in other base sequences that are not so expressed; finally they may reside in the sequential order in which genes are distributed within the genome.

Although chemical paleogenetics will ultimately have taxonomic value in providing a fundamental way of measuring the distance between living things on the evolutionary scale, this is not its prime objective. A major value of analyzing evolutionary changes at the molecular level will be to provide a deeper understanding of natural selection in relation to different types of mutation.

Let me proceed, then, to apply the methods of chemical paleogenetics to the myoglobin-hemoglobin family of polypeptide chains. The top illustration at the right shows the number of differences in amino acid sequence between four animal-hemoglobin alpha and beta chains and the corresponding human chains. For purposes of rough computation let us assume that the alpha and beta chains evolve at the same rate and pool the number of differences they exhibit. The reason for doing this is to

ANIMAL	NUMBER OF DIFFERENCES		MEAN NUMBER OF DIFFERENCES, ALL CHAINS	ESTIMATED TIME SINCE COMMON ANCESTOR
	ALPHA CHAIN	BETA CHAIN		
HORSE	17	26	~ 22	80 MILLION YEARS
PIG	~ 18	~ 14		
CATTLE	27			
RABBIT	27			

COMPARISON OF HEMOGLOBIN CHAINS offers a way to estimate the number of years required to produce an evolutionarily effective change at one site. The values given here for the number of differences represent a comparison with the α- and β-chains of human hemoglobin. The mean of 22 differences between any pair of human and animal chains implies an average of 11 mutations per chain, or about one change per seven million years.



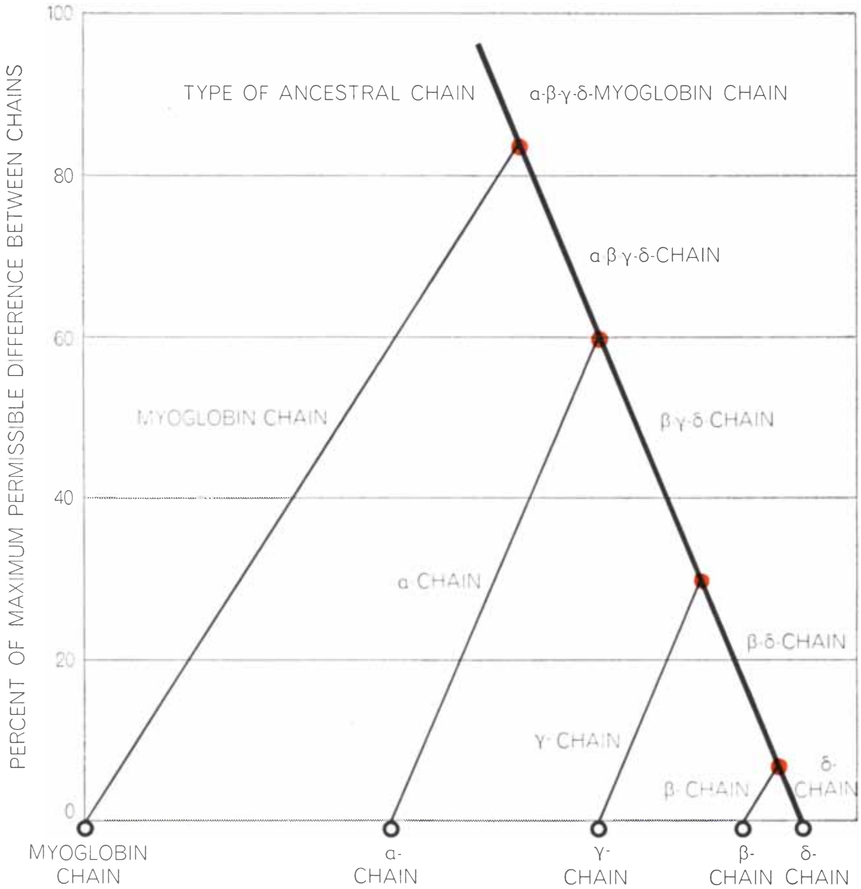
AGE OF ANCESTRAL HEMOGLOBIN-MYOGLOBIN CHAINS is plotted on a curve computed by Linus Pauling. Except for myoglobin the chains represented are those of humans. Where only a few differences are observed it is assumed that about seven million years are needed to establish an effective mutation. But where chains show large differences today it can be assumed that more than one mutation occurred at a given site in the course of evolution. For example, the α-chain and β-chain each differ from the myoglobin chain at about 110 sites. Thus the ancestral α-β-myoglobin chain appears on the curve where the vertical axis reads 75 percent (110/146 is about 3/4). This point corresponds to a period about 650 million years ago rather than the 385 million years that would be obtained if 55 mutations per gene line (110 ÷ 2) were simply multiplied by seven million.

establish a mean value for the number of apparent amino acid substitutions that have occurred in the alpha and beta chains of the four animal species (horse, pig, cattle and rabbit) since the time when the four species and man had a common ancestor. The mean difference is 22 apparent changes in the two chains, or an average of 11 changes per chain. If the common ancestor of man and the four other animals lived about 80 million years ago, as is thought to be the case, the average time required to establish a successful amino acid substitution in any species is about seven million years. Until more chains have been analyzed, however, 10 million years per substitution is a good order-of-magnitude figure.

This figure can now be used for a different purpose: to estimate very roughly the time elapsed since the four principal types of chain in human hemoglobin had a common ancestor. In making such a calculation one must employ statistical principles to allow for the following fact. The greater the number of differences in sequence between two homologous chains, the greater the chances that at some molecular sites more than one amino acid substitution will have been retained temporarily by evolution since the time of the common ancestor. An appropriate calculation was recently performed by Linus Pauling, with the result shown in the bottom illustration on the preceding page. The curve in the illustration allows one to read off the probable time of existence of the common molecular ancestor of various polypeptide chains as a function of the percentage of differences in amino acid sequence between the chains.

The two chains that are most nearly alike—the beta and delta chains—differ at only 10 sites and presumably were the most recent to arise by duplication of a common genetic ancestor. To exhibit 10 differences each gene line would have to undergo only five changes, which implies an elapsed time of roughly 35 million years on Pauling's chart. The beta and gamma chains are different at 37 sites and thus seem to have arisen by gene duplication about 150 million years ago. The beta and alpha chains are different at 76 sites and therefore their common ancestor goes back some 380 million years. If the calculation is valid as a rough approximation, the common genetic ancestor of the hemoglobin chains now circulating in the human bloodstream dates back to the Devonian period and to the appearance of the first amphibians.

The curve also indicates very roughly how long it has been since the chains of hemoglobin and myoglobin may have arisen as the result of duplication of a common ancestral gene. The differences in amino acid sequence between hemoglobin chains and myoglobin are so numerous that their common molecular ancestor may date back about 650 million years to the end of the Precambrian era, long before the appearance of the vertebrates. This suggests, in turn, that it may be possible to find in living invertebrates a distant relative of the vertebrate hemoglobins and myoglobins.



HEMOGLOBIN-MYOGLOBIN RELATIONSHIP is traced back through evolution, based on the number of differences in the various chains. The four colored dots indicate where ancestral genes were presumably duplicated, giving rise each time to a new gene line.

Let me turn now from discussing the overall differences between homologous polypeptide chains to the question of how one might construct a molecular "phylogenetic tree." Such a tree would show an evolutionary line of descent for an entire family of polypeptide molecules. One can also construct individual trees for individual molecular sites. Later this site-by-site information can be synthesized to obtain probable residue sequences for complete ancestral chains.

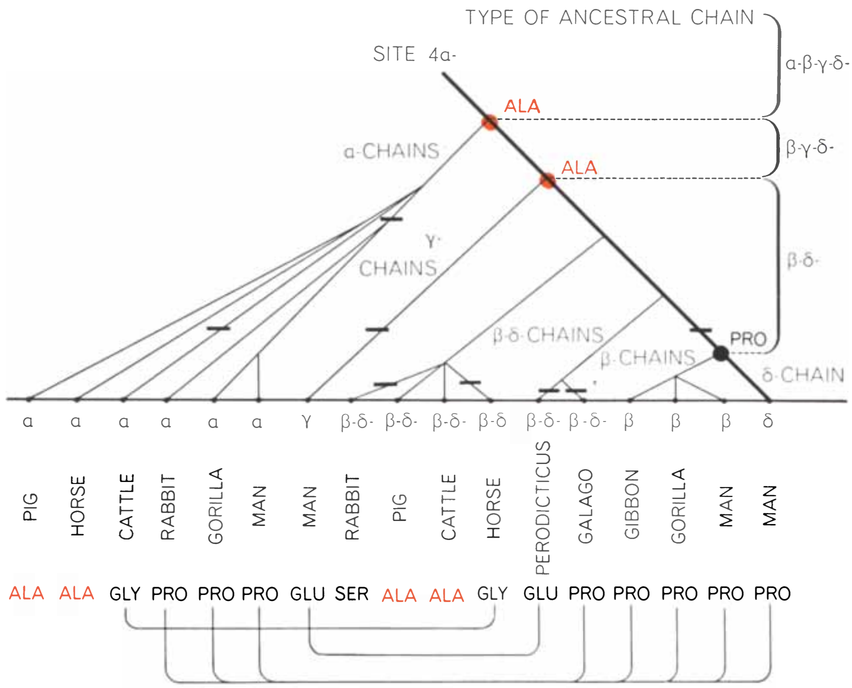
If the amino acid residue is the same in two homologous chains at a given molecular site, there is a certain probability that the same residue was also present in the common ancestor of the two chains. There is also a chance, of course, that the ancestral residue was different and that the identity observed in the two homologous existing chains was produced by molecular convergence or simply by coincidence. Traditional paleontology reveals many examples of convergences at the level of large-scale morphology. In chemical paleogenetics molecular convergence or coincidence is particularly troublesome because the path from difference to similarity runs directly counter to that needed to trace a molecular phylogenetic tree. About all one can say at this stage in the development of the new discipline is that convergence or coincidence do not seem to occur often enough to vitiate the effort of constructing such trees.

The illustration at the left shows

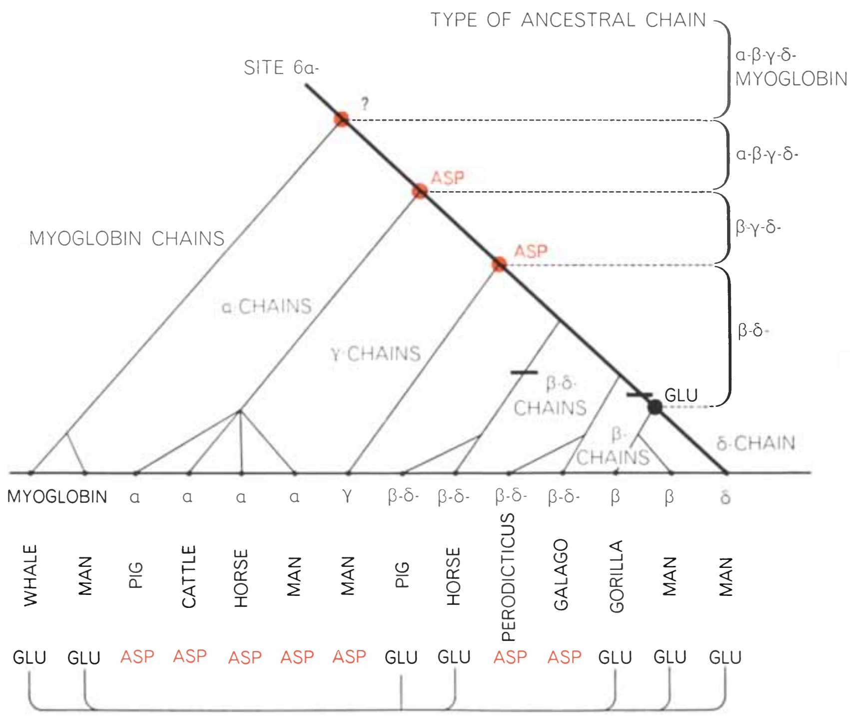
schematically, in the form of an inverted tree, the probable evolutionary relationships for the known chains of human hemoglobin and myoglobin. The tree also represents the relationships of any given molecular site in these chains. The epsilon chain has been omitted because too little is known about it. The vertical axis is not an absolute time scale but shows how chain differences rate on a scale in which the maximum permissible difference is 100 percent. Every branching point in the tree is assumed to coincide with a gene duplication. Following such duplication the resulting independent genes (and their polypeptide chains) evolve separately. The most ancient duplication presumably separated the myoglobin gene from the gene that ultimately gave rise, by repeated duplications, to the alpha, beta, gamma and delta genes of hemoglobin. Additional gene duplications will surely have to be postulated along various lines.

The next molecular phylogenetic tree [*see top illustration at right*] attempts to reconstruct the evolutionary changes at one particular site (site No. 4 in the human alpha chain) that led to the amino acid residues now observed at that site in various animal species, including man. As the genetic code is being worked out, it is becoming possible to distinguish amino acid substitutions that may have occurred in one step from those requiring two or more steps. It is a principle of chemical paleogenetics that in postulating a possible ancestral amino acid residue one should prefer the residue that can be reached by invoking the fewest number of mutations in the genetic message. In the tree just referred to the residue of the amino acid alanine has been selected as the residue at site No. 4 in the ancestral polypeptide chain from which the 17 present-day hemoglobin chains are descended. This selection may seem odd; among the 17 chains eight have proline in the No. 4 position and only four have alanine. (The remaining five chains have glycine, glutamic acid or serine in the No. 4 position.) The explanation is that if proline is assumed to be in the No. 4 position in the most remote ancestral chain, one has to postulate nine or 10 evolutionarily effective amino acid substitutions in the various descendent chains to reach the residues actually observed in the 17 present-day chains, but if alanine is selected as the ancestral residue, only eight effective substitutions are needed.

The choice of alanine becomes more impressive when it is shown that no



ANCESTRAL RESIDUE can be traced by trying to establish the simplest lines of descent for residues now found at a particular site in polypeptide chains of hemoglobin. The residues shown across the bottom occupy site No. 4 in the human α-chain. (*Perodicticus* and *Galago* are small monkeys commonly known as the potto and the bush baby.) Alanine (*ala*) is selected as the probable residue in the earliest ancestral chain because it provides a line of descent requiring fewer mutations than any other that might be selected: eight. They are represented by short horizontal bars. The lines at the bottom identify convergences or coincidences: identical residues that presumably resulted from independent mutations.



AMBIGUOUS ANCESTRAL RELATIONSHIP is encountered when the present-day residues at a particular site are those of two amino acids that frequently replace each other, such as glutamic acid (*glu*) and aspartic acid (*asp*). The sites compared are No. 6 in the α-chain of human hemoglobin. Note that myoglobin has been included in this evolutionary tree.

		1	2	3	4	5	6	7	8	9	10
BETA-GAMMA-DELTA ANCESTRAL CHAIN		(VAL)	HIS	LEU	(THR) (SER)	ALA	GLU	ASP	LYS	?	THR
PRESENT HUMAN CHAINS	BETA	VAL	HIS	LEU	THR	PRO	GLU	GLU	LYS	SER	ALA
	DELTA	VAL	HIS	LEU	THR	PRO	GLU	GLU	LYS	THR	ALA
	GAMMA	GLY	HIS	PHE	THR	GLU	GLU	ASP	LYS	ALA	THR

RECONSTRUCTION OF ANCESTRAL CHAIN represents a synthesis of evolutionary trees for individual sites as illustrated on the preceding page. This chart shows the first 10 sites in the ancestral β-γ-δ-chain and the corresponding region in its three present-day descendants. Residues in the δ-, γ- and ancestral chains that differ from those in the contemporary β-chain are shown in color. Sites No. 1, No. 4 and No. 9 in the ancestral chain are uncertain or unknown. Better knowledge of the genetic code may reduce the uncertainty.

more than one amino acid substitution is needed in any single line of descent to explain the residues currently observed. If proline is made the ancestral choice, double substitutions—the ones least likely to occur—must be postulated in three of the lines of descent. The choice of any other amino acid for the ancestral position would necessitate many more substitutions. Alanine is therefore adopted as the most probable ancestral residue—a conclusion that is not likely to need revision unless the genetic code is revised with regard to proline. In this particular example molecular coincidence is represented in some of the chains that now contain proline, glutamic acid and glycine.

The problem of identifying a probable ancestral residue is often difficult. At a site where there are frequent interchanges between residues that seem to be more or less functionally equivalent, any conclusion about ancestry becomes doubtful. This is demonstrated at site No. 6, as numbered in the human alpha chain, where there is a frequent interchange between aspartic acid and glutamic acid [*see bottom illustration on preceding page*].

The information from a series of molecular phylogenetic trees can finally be synthesized to produce a complete sequence of residues representing the composition of an ancestral polypeptide chain. The illustration above shows such a postulated sequence for the first 10 sites of the polypeptide chain that is presumed to be the ancestor of the beta, gamma and delta chains now present in human hemoglobin.

In order to establish by chemical paleogenetics the evolutionary relationship between two different organisms it should not be necessary to know the sequential composition of thousands or even hundreds of homologous polypeptide chains. To require such knowledge would be discouraging indeed. It can reasonably be predicted, however, that a comparison of relatively few chains—perhaps a few dozen—should yield a large fraction of the maximum amount of information that polypeptide chains can provide. The reason is that even relatively few chains should yield a good statistical sample of the evolutionary behavior of many chains.

Chemical paleogenetics offers many new possibilities. For example, after one has reconstructed a number of ancestral polypeptides for some ancient organism one should be able to make various deductions about some of its physiological functions. One might be able to decide, for instance, whether it could live successfully in an atmosphere composed as we know it today or whether it was designed for a different atmosphere.

From similar polypeptide reconstructions it may be possible to make informed guesses about organisms, such as soft-bodied animals, that have left no fossil record. In this way the state of living matter in past evolutionary times can be pieced together, at least in part, without the help of fossil remains. But one of the main attractions of chemical paleogenetics is the possibility of deriving strictly from molecular sequences a phylogenetic tree that is entirely independent of phylogenetic evidence gathered by traditional methods. If this can be accomplished, one can compare the two kinds of phylogenetic tree—the molecular and the traditional—and see if they tell the same story of evolution. If they do, chemical paleogenetics will have provided a powerful and independent confirmation of the already well-documented theory of evolution.

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MATHEMATICAL GAMES

The lattice of integers considered as an orchard or a billiard table

by Martin Gardner

The simplest of all lattices in a plane—taking the word "lattice" in its crystallographic sense—is an array of points in square formation. This is often called the "lattice of integers," because if we think of the plane as a Cartesian coordinate system, the lattice is merely the set of all points on the plane whose x and y coordinates are integers. The illustration on the opposite page shows a finite portion of this set: the 400 points whose coordinates range from 0 to 20.

Think of the 0,0 point as the southwest corner of a square orchard, fenced on its south and west sides but infinite in its extension to the north and east. At each lattice point is a tree. If you stand at 0,0 and peer into the orchard, some trees will be visible and others will be hidden behind closer trees. Here, of course, our analogy breaks down, because the trees must be taken as points and we consider any tree "visible" to one eye at 0,0 if a straight line from that point to the tree does not pass through another point. The colored dots mark all lattice points visible from 0,0; the unmarked grid intersections represent points that are not visible.

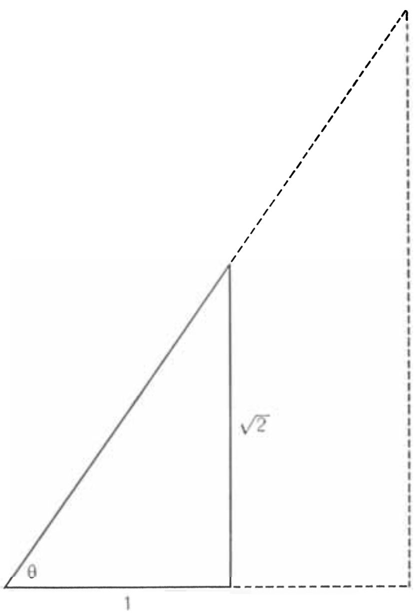
If we identify each point with a fraction formed by placing the point's y coordinate over its x coordinate, many interesting properties of the lattice (properties first called to my attention by Robert B. Ely of Philadelphia) begin to emerge. For example, each visible point is a fraction whose numerator and denominator are coprime; that is, they have no common factor other than 1 and therefore cannot be reduced to a simpler form. Each invisible point is a fraction that *can* be simplified—and each simplification corresponds to a point on the line connecting the fraction with 0,0. Consider the point 6/9 ($y = 6$, $x = 9$). It is not visible from 0,0 because it can be simplified to 2/3. Place a straightedge so that it joins 0,0 and 6/9 and you will see that the visibility of 6/9 is blocked by the point at 2/3. All points along the diagonals that extend up and to the right from 0/1 and 1/0 are visible because no fraction whose numerator and denominator differ by 1 can be simplified.

Note that many of the diagonals running the other way—from upper left to lower right—consist entirely of visible points except for their ends. All these diagonals, Ely points out, cut the coordinate axes at prime numbers. Every visible point along such a diagonal is a fraction formed by two numbers that sum to the prime indicated by the diagonal's ends. Two numbers that sum to a prime obviously must be coprime (if they had a common factor, then that factor would also evenly divide the sum), so such fractions cannot be simplified. Vertical and horizontal lines that cut an axis at a prime get progressively denser with visible lattice spots as the primes get larger, because such lines have invisible lattice points only where the other coordinate is a multiple of the prime.

Is it possible to stand at 0,0 and look into this infinite orchard along a line that will never, even when extended to infinity, intersect a "tree"? Yes; not only is there an infinity of such lines but also there are infinitely more of them than there are lines that hit trees! Consequently if the direction for a line of sight is determined randomly, the probability of finding a tree along that line is virtually zero. How can we define such a line? We have only to slope it so that every point along it has coordinates that are incommensurable with each other; in other words, so that the y/x fraction of any point—which is the same as the tangent of the angle that the sloping line makes with the x axis—is irrational. For example, we move to the right along the x axis to, say, 10, then up to a point with a y coordinate of 10 times pi. If we join this point to 0,0, we produce a line that cannot, no matter how far it is extended, hit a point because 10pi/10 equals pi, an irrational number. (It would take some fine drawing and a superpowered microscope to detect how far the line misses the point at 355/113. This fraction gives pi to six decimal places!)

The black line shown in the illustration has a slope of $\sqrt{2}$. It is easy to prove that a bullet traveling this line could not, from here to eternity, strike a tree. The right triangle shown on this page has a base of 1 and an altitude of $\sqrt{2}$, so the tangent of angle θ is $\sqrt{2}$. If we extend the hypotenuse as shown by the broken line to form any larger right triangle on the extended base line, the altitude and base of the larger triangle will have the same irrational ratio. The bases and altitudes of all such triangles correspond to the two coordinates of the sloping line with a tangent of $\sqrt{2}$. Therefore, no matter how far the sloping line is extended into the lattice of integers, the coordinates of any point along that line will form the same irrational fraction. But every lattice point represents a *rational* fraction; therefore no lattice point can be on the line.

Observe, however, that by searching for near misses we can find fractions that are excellent approximations of the irrational slope. Think of the $\sqrt{2}$ line as a taut rope anchored at infinity. If we hold the end at 0,0 and move the rope east, it will press against trees that represent fractions smaller than $\sqrt{2}$, or 1.4142136. . ., but that get closer to $\sqrt{2}$ as one moves away from 0,0. The first tree it touches is 1/1, or 1, a poor approximation. The next is 4/3, a bit better, and the next is 7/5, or 1.4, which is not bad. Similarly, if we move the end of the rope northward,



Tangent of angle θ equals $\sqrt{2}$

it presses against fractions larger than 1.4142136..., but the excess approaches 0 as we move toward infinity. The first fraction, 2/1, or 2, is not very good; 3/2 is better, 10/7 still better and 17/12, or 1.41666..., misses $\sqrt{2}$ by only .0024+.

One of the simplest ways to express $\sqrt{2}$ is by the endless continued fraction

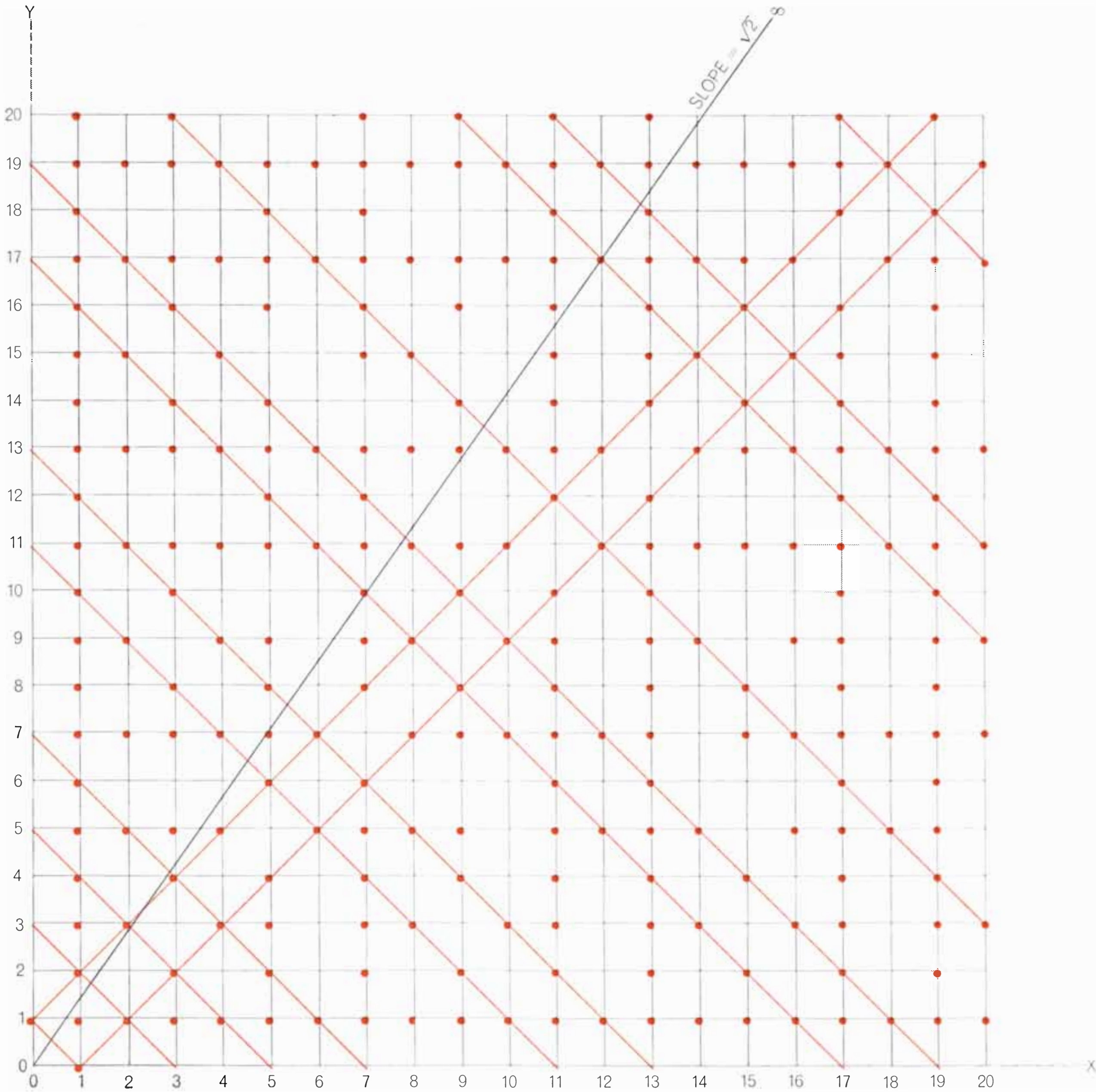
$$1+\cfrac{1}{2+\cfrac{1}{2+\cfrac{1}{2+1\ \ddots}}}$$

If we start at the top and form partial sums (that is, 1, 1 + 1/2, 1 + 1/3 and so on), we get just those fractions mentioned above: 1, 3/2, 4/3, 7/5, 10/7, 17/12. They come closer and closer to $\sqrt{2}$ as their lattice points come closer and closer to the sloping line.

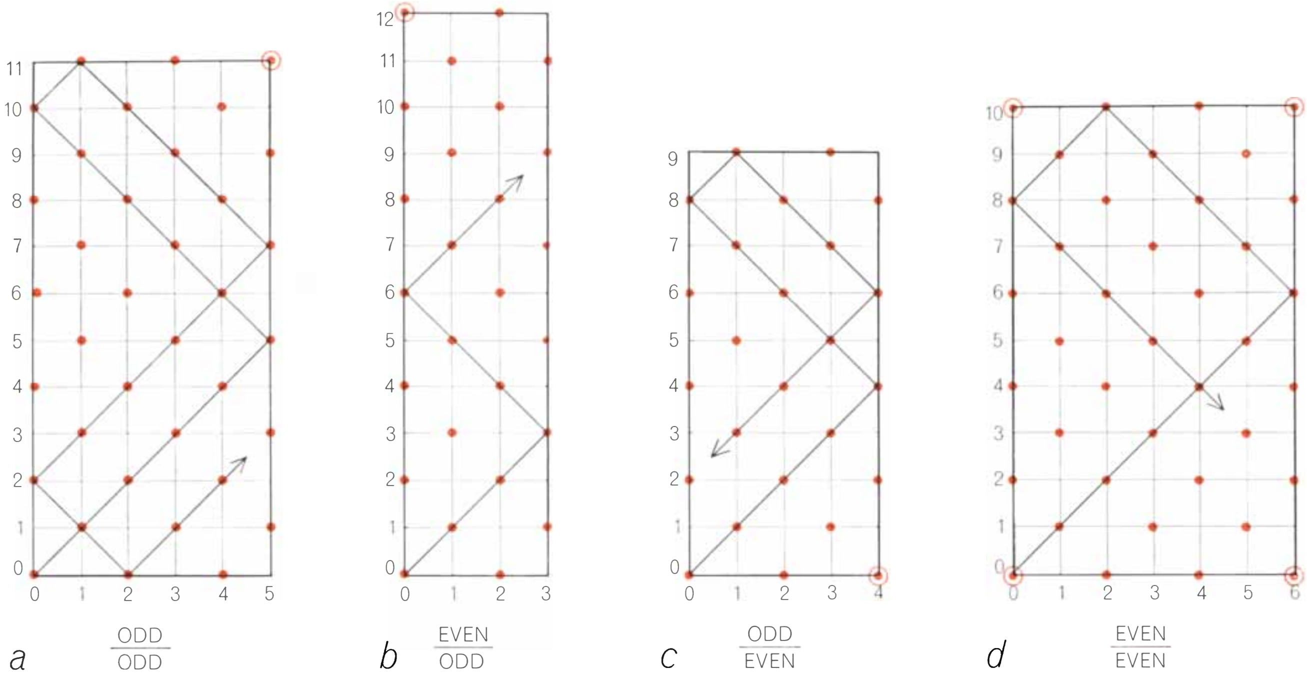
The discussion of irrational numbers suggests the following problem: Let the coordinates of a point be $y = \sqrt{27}$, $x = \sqrt{3}$. Does the infinite line passing from the origin through this point cut any points other than 0,0?

If a billiard ball is placed at 0,0 and stroked so that it travels up the main diagonal at an angle of 45 degrees, it will of course continue forever, passing only through lattice points whose fractions reduce to 1 (the tangent of 45 degrees). Now suppose we confine the lattice to rectangles of arbitrary size, provided that heights and widths are integral, and assume that the ball rebounds from all sides and rolls without friction over the surface of the latticed billiard table. It is not hard to show, by a reflection technique depicted in Hugo Steinhaus' *Mathematical Snapshots* (revised 1960 edition, page 63), that whatever the dimensions of the rectangle, the ball will strike one of the table's other three corners after a finite number of bounces.

This statement can be made stronger.



The infinite orchard and the points visible from 0,0 on the lattice of integers

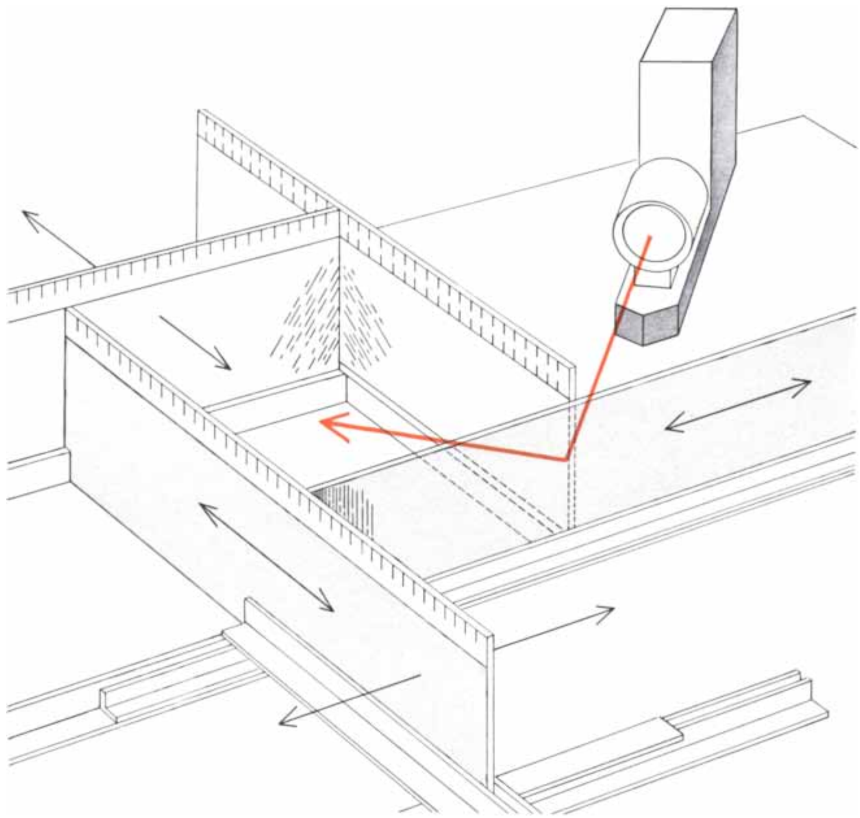


Parity coloring checks for billiard-ball paths

Regardless of the angle of the first shot, if the ball strikes the first cushion at a point that is a rational distance from a corner, it will eventually strike one of the table's corners. But if it hits the first cushion at an irrational spot, every rebound will be at an angle with an irrational tangent and the path will never touch a lattice point. Since the corners are lattice points, the ball will never strike a corner. There are infinitely more irrational points on a line than there are rational points. Therefore the probability is infinitely close to zero that an ideal ball (we must think of the ball as a point) shot from the corner at a random angle will strike the first cushion at a rational point. Imagine the table covered with a fine screen of lattice points—billions of them, all with rational coordinates. The randomly shot ball will move forever around the table, never going over a path twice, never once touching a single lattice point!

Here we are concerned only with the simpler case of a ball traveling along diagonals that form 45-degree angles with the table's sides. An intriguing question (first sent to me by Joseph Becker of Milwaukee) immediately arises. Given the table's dimensions, how can one predict which of the three corners the ball will hit? We can always draw a graph and find out, but if the table has, say, a width of 10,175 units and a length of 11,303 units, graphing a solution would be tedious.

As Becker points out, if at least one side of the table is odd, a clever parity check leads to simple rules for determining which corner the ball will hit. Suppose both sides are odd. We color the 0,0 point and every second lattice point [*see "a" in illustration above*]. Clearly the ball will pass through the colored points only. Of the three possible terminating corners, only the northeast corner is colored, so this must be the corner the ball will strike. (The reader can verify this by continuing the ball's path through the colored points.) If one side of the table is even and the other odd, the same parity coloring



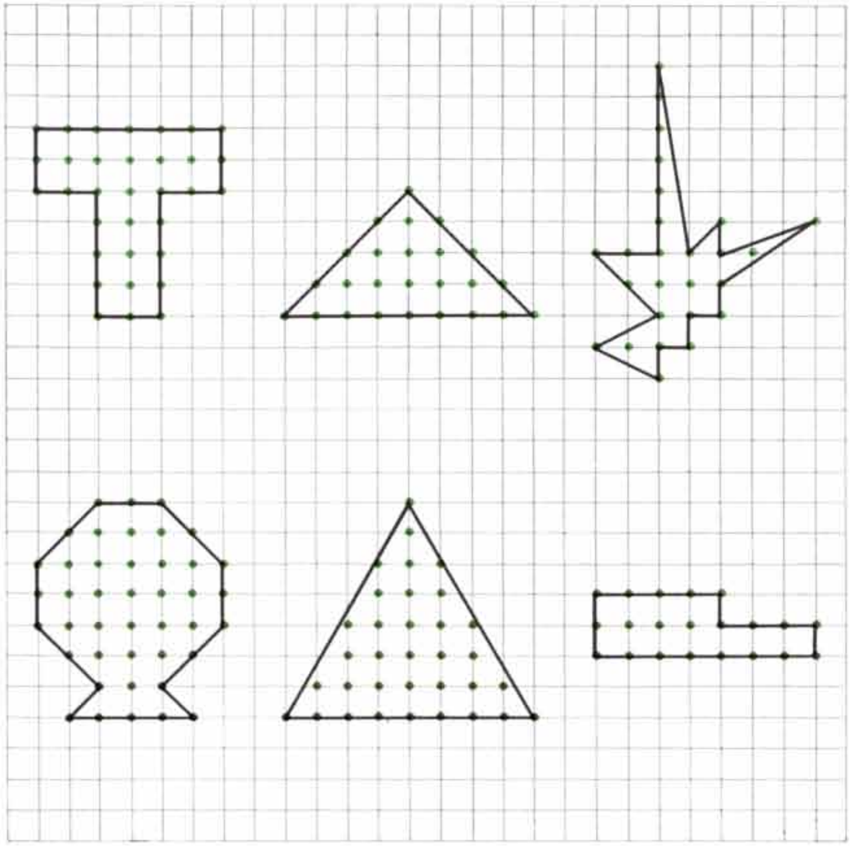
Zavrotsky's device for finding greatest common divisors ["*b*" *and* "*c*"] shows that the ball must strike the corner adjacent to the origin and on the table's even side.

When both sides of the table are even, we run into an unforeseen difficulty. There are colored spots on *all four* corners [*d*]. Which of the three possible terminal corners will the ball hit? A little experimenting on graph paper will show that all three can be reached on various even-even tables. Can the reader devise an arithmetical rule for quickly determining, on any table with even sides, which corner the ball will hit?

A hint for the solution to this problem lies in the curious fact that the point on the table's longest side that is nearest the origin, and on the ball's path as well, is always exactly twice the greatest common divisor (g.c.d.) of the two sides. If the two sides are coprime, then of course the g.c.d. is 1. This is the case in *a* and *c* at the top of the opposite page. Sure enough, on the longest side we see that the point on the ball's path nearest to 0,0 is 2, or twice the g.c.d.

This property of 45-degree paths of a bouncing ball inside a rectangular lattice of integers suggested to Andrés Zavrotsky of the University of the Andes in Venezuela an optical device for finding the greatest common divisors of pairs of integers. A sketch of his invention (U.S. patent 2,978,816, April 11, 1961) is shown at the bottom of the opposite page. Four mirrors with integral scales on their edges can be adjusted to form a rectangle with sides equal to the pair of numbers under investigation. A pencil of light is introduced through a crack at one corner, as shown. It rebounds at an angle of 45 degrees from the corner—the zero point on the two scales meeting at that corner—and continues its path from mirror to mirror until it terminates at one of the other three corners. The illuminated mark closest to the corner of origin of what Zavrotsky calls the "optical billiard" on the rectangle's long side is twice the g.c.d. Zavrotsky intended his invention to serve as a teaching device. Readers should have little difficulty proving that the device cannot fail to work, and solving this problem: Given the rectangle's sides, find a formula for the total length of the light's path, from 0,0 to the corner; also find a formula for the number of times the "optical billiard" rebounds from a side.

By connecting pairs of lattice points with straight lines one can draw an infinite variety of simple polygons [*see top illustration on next page*]. ("Simple"

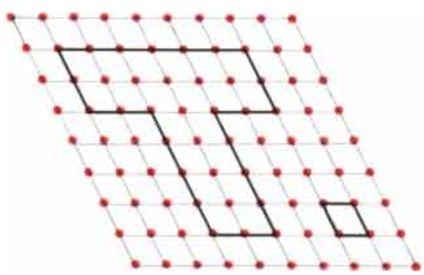


Find the area of these "lattice polygons"

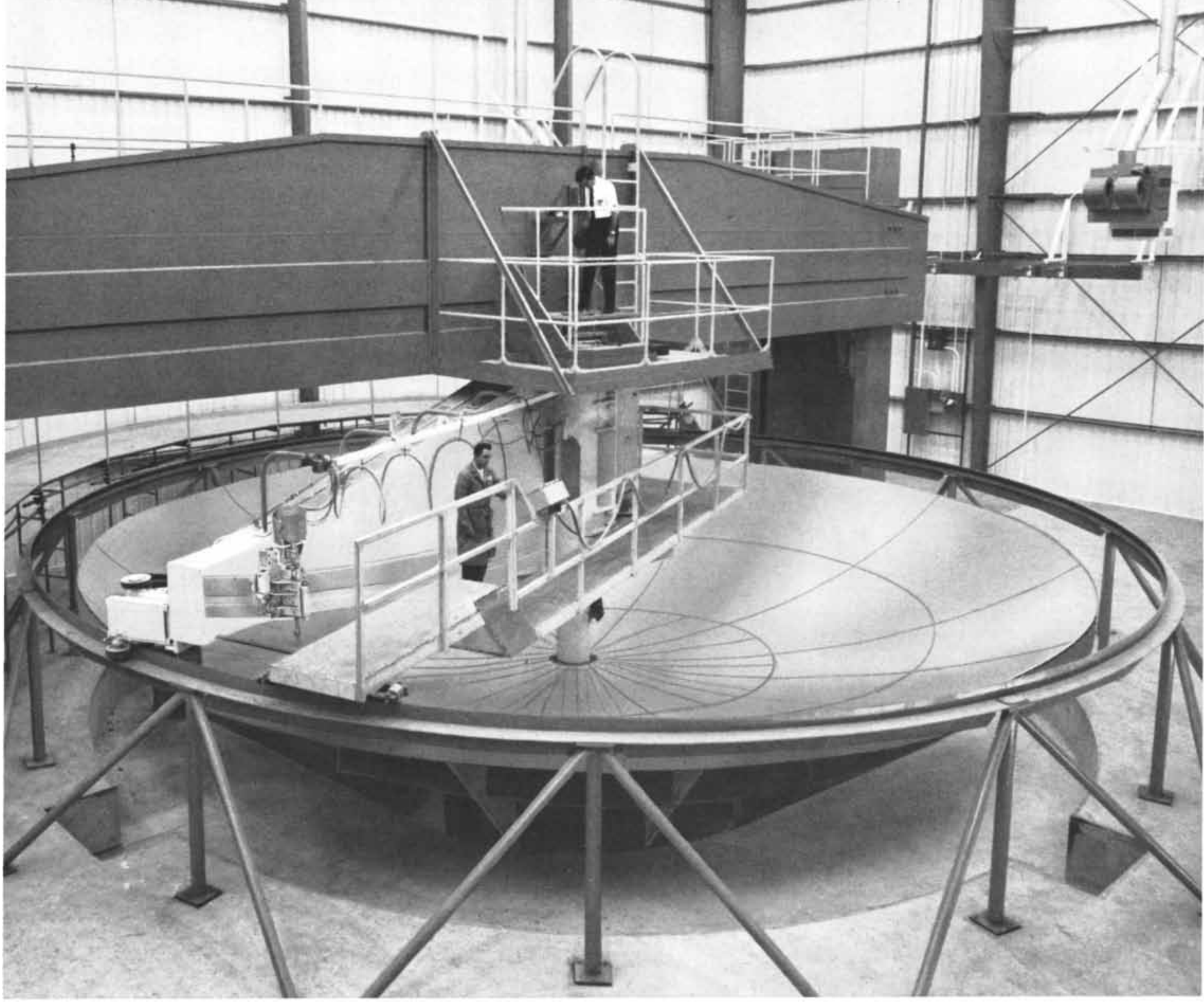
here means that no side crosses another.) The area of such a "lattice polygon" can be calculated by the tiresome method of cutting it up into simpler figures, but again there is an easier and more amusing way to do it. We apply the following remarkable theorem: The area of any lattice polygon is one-half the number of lattice points on its border, plus the number of points inside its border, minus one. The unit of area is the area of the "unit cell" of the lattice.

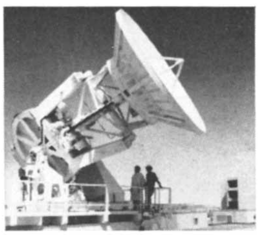
This beautiful theorem, which Steinhaus says was first published by one G. Pick in a Czechoslovakian journal in 1899, belongs to "affine" geometry, a geometry that plays an important role in the mathematics of relativity. This means that the theorem holds even when the lattice is distorted by stretching and shearing. For example, the formula applies to the connect-the-dot polygon on the lattice at the right. As before, the unit area is the unit cell, in this case the little parallelogram shown to the right. This *T*-polygon, like its counterpart above, has 24 points on its border and nine inside; according to Pick's formula, its area is $12 + 9 - 1 = 20$ unit cells, as is easily verified. Readers may enjoy seeing if they can devise a complete proof of the theorem. An outline of one such proof is given in H. S. M. Coxeter's *Introduction to Geometry*, page 209.

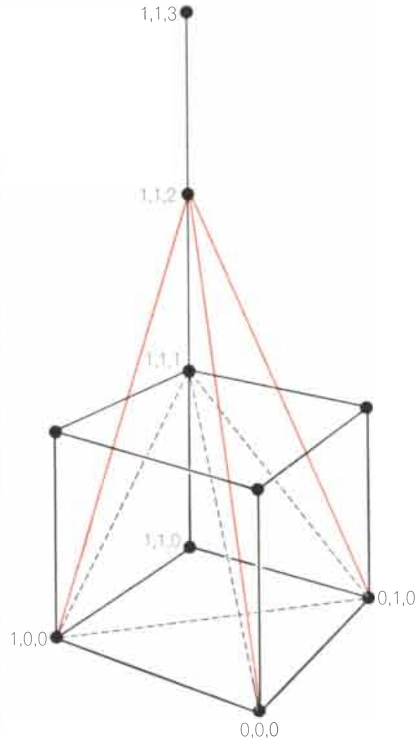
One is tempted to suppose that it would be easy to extend Pick's formula to polyhedrons drawn on integral lattices in three dimensions. The top illustration on page 126 quickly dispels this illusion. It shows the unit cell at the 0,0,0 corner of a three-space cubical coordinate system. The four points at 0,0,0, 1,0,0, 0,1,0 and 1,1,1 mark the corners of a lattice tetrahedron. If we raise the apex of this pyramid to 1,1,2, we increase the tetrahedron's volume but no new lattice points appear on its edges or faces or in the interior. Indeed, by raising the apex higher along the same coordinate the volume can be



"Affine" transformation of lattice polygon







Lattice tetrahedrons

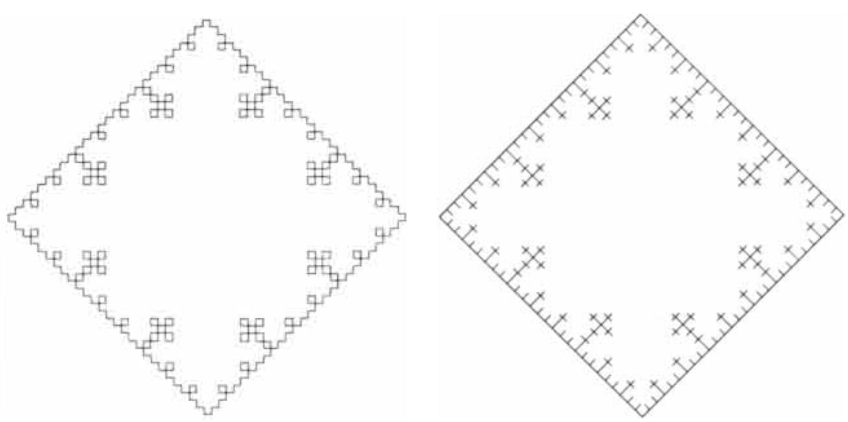
made as large as we please without increasing the number of lattice points involved! It is possible, however, to find a formula by introducing a secondary lattice. The interested reader will find this explained in J. E. Reeve's "On the Volume of Lattice Polyhedra" (*Proceedings of the London Mathematical Society*, Vol. 7, No. 7; July, 1957, pages 378–395). As far as I know no one has yet extended the formula to still higher spaces, although Reeve makes some conjectures in that direction.

A final problem: On the square lattice of integers, connect exactly 12 lattice points to form a lattice polygon of the same shape as the *T*-polygon at the top of page 120 but with an area of 10 square units. (According to Pick's formula, it must surround exactly five lattice points.)

All four problems will be answered next month.

The cross-stitch curve that was the subject of last month's problem has, like its analogue the snowflake, an infinite length. It bounds an area twice that of the original square. The drawing at the left in the illustration below shows its appearance after the third construction. After many more steps it resembles (when viewed at a distance) the drawing at the right. Although the stitches seem to run diagonally, actually every line segment in the figure is vertical or horizontal! Similar constructions of pathological curves can be based on any regular polyhedron, but beyond the square the figure is muddied by overlapping, so that certain conventions must be adopted in defining what is meant by the enclosed area.

In the discussion in January of problems involving the minimum number of marks on a ruler required to measure various integral lengths it was said that nine marks are necessary for a yardstick of 36 inches. This was long thought to be the case, but 10 years ago John Leech of the Computer Laboratory at the University of Glasgow found an eight-mark solution and proved that it was minimal. (Marks are placed at 1, 3, 6, 13, 20, 27, 31 and 35 along the edge.) Several readers wrote to mention Leech's article, "On the Representation of 1, 2, . . ., *n* by Differences" (*Journal of the London Mathematical Society*, Vol. 31, No. 122; April, 1956, pages 160–169). It discusses almost all that is known about this difficult problem.



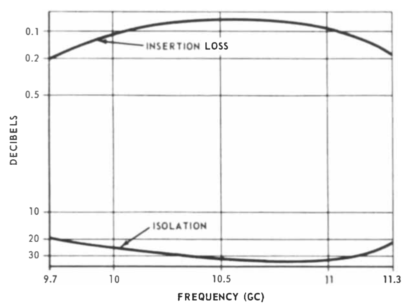
Solution to cross-stitch curve problem

X-band switchable circulator for phase shifter applications
uses square loop hysteresis in toroidal ferrites.

Digital microwave phase shifters handle kilowatts of power in phased arrays.

The remanent magnetic field in toroidal ferrites has long been used for memory purposes in digital computers. In a similar manner, the remanent fields in toroidal microwave ferrites are now being used to position the beams of large phased array antennas. The antenna beam is formed by generating a plane phasefront across its aperture. A tilt of this phasefront steers the beam to a new direction. If digital increments of phase are used in forming the phasefront, the beam may be steered in a discrete manner. The recent development of small, efficient, and inexpensive digital microwave phase shifters now makes feasible their application in large phased arrays. Bendix had developed advanced microwave ferrite components for such application.

Recent advances in microwave technology have included differential phase shifters used in digital phasing of each element in an array. Such "phasors" are becoming available in most of the common microwave bands, but they usually restrict antenna bandwidth because differential phase is limited to less than 360 degrees. To circumvent this restriction, Bendix has developed "time delay" (TD) phase shifters which insert lengths of non-dispersive transmission line to provide phase shift in any desired amount. At the heart of the digital TD phasor are several switchable threeport ferrite circulators, corresponding to binary digits in a digital specification of the phase angle.



Isolation and insertion loss of a switchable waveguide circulator having a bandwidth of 15 percent at "X" band.

Each circulator is used as a low loss "latching" switch. A pulse of current, when suddenly applied to the toroidal ferrite, switches the microwave power flow to a new path. Once changed, the remanent magnetic field persists, maintaining the new path until a pulse of opposite polarity causes the switch to revert to its original configuration. Typical switch isolation is greater than 20 db over bandwidths of 15%, and microwave attenuation is less than ¼ db. Such switches are capable of handling peak power of many kilowatts and average power of hundreds of watts. The drive energy required to switch "states" is about 100 microjoules, and the switching time is one microsecond. This efficiency and speed permit the beam of a large antenna to be moved rapidly with a minimum of switching power.

The new digital switched circulators also find application in microwave switching arrays to provide multiple path signal routing. Many radar and communications systems require this rapid switching of microwave power. The latching switched circulator is often the solution.

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THE AMATEUR SCIENTIST

Zany mechanical devices that draw the figures known as harmonograms

Conducted by C. L. Stong

The ornamental figures among the illustrations accompanying this article can be variously interpreted as frozen music, the flow of electrons in a radio receiver or merely pleasing patterns. All such phenomena arise from the interplay of two or more harmonic motions, such as those that are found in the swing of a pendulum. For this reason the figures are known as harmonograms. They first attracted general interest in 1857 when the French physicist Jules Antoine Lissajous demonstrated his harmonograph, an apparatus for creating harmonograms.

Lissajous's apparatus used light to trace the patterns. To a pair of tuning forks he attached small mirrors that vibrated at different frequencies in separate planes. A beam of light reflected by the mirrors fell on a nearby screen, where the vibrations generated a slowly changing pattern of interlacing curves. The demonstration so fascinated audiences that the design and operation of harmonographs mushroomed into a widespread pastime.

The pastime still has devotees. Last year, for instance, Katherine O. Reed of Concord, Mass., joined with her father, Thomas B. Reed, a chemist at the Lincoln Laboratory of the Massachusetts Institute of Technology, to construct a harmonograph as a project for her high school science fair. By the time the fair had ended the senior member of the team found himself deeply immersed in the century-old avocation. As a result the Reeds have since turned out a succession of harmonographs for creating ever prettier doodles, and they are still at it. Their latest machine is a complicated affair that weighs more than 50 pounds.

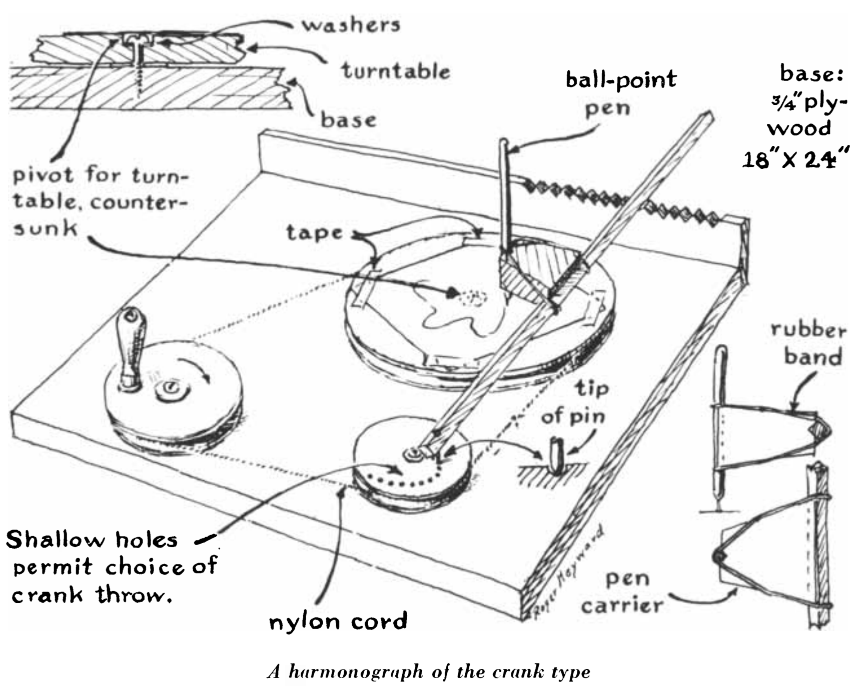
The Reeds write as follows: "Harmonograms can be generated by a number of devices, all of which have certain elements in common. A 'writing' apparatus of some kind is essential; it can be pen and paper, a beam of light that writes on photographic paper, a feather that traces marks on soot-coated glass, an electric spark that darkens conductive paper or a beam of electrons that writes on the phosphor of an oscilloscope. The 'pen,' whatever form it takes, must be moved across the paper by an oscillating mechanism.

"In general, mechanical harmonographs use either pendulums or cranks for oscillators. The movement of a horizontal crank when viewed from the side is the same as that of a pendulum when viewed from the bottom. Both are examples of harmonic motion. Pendulum machines are easier to construct and have the added charm of generating figures that diminish in size as the amplitude of the swing dies away.

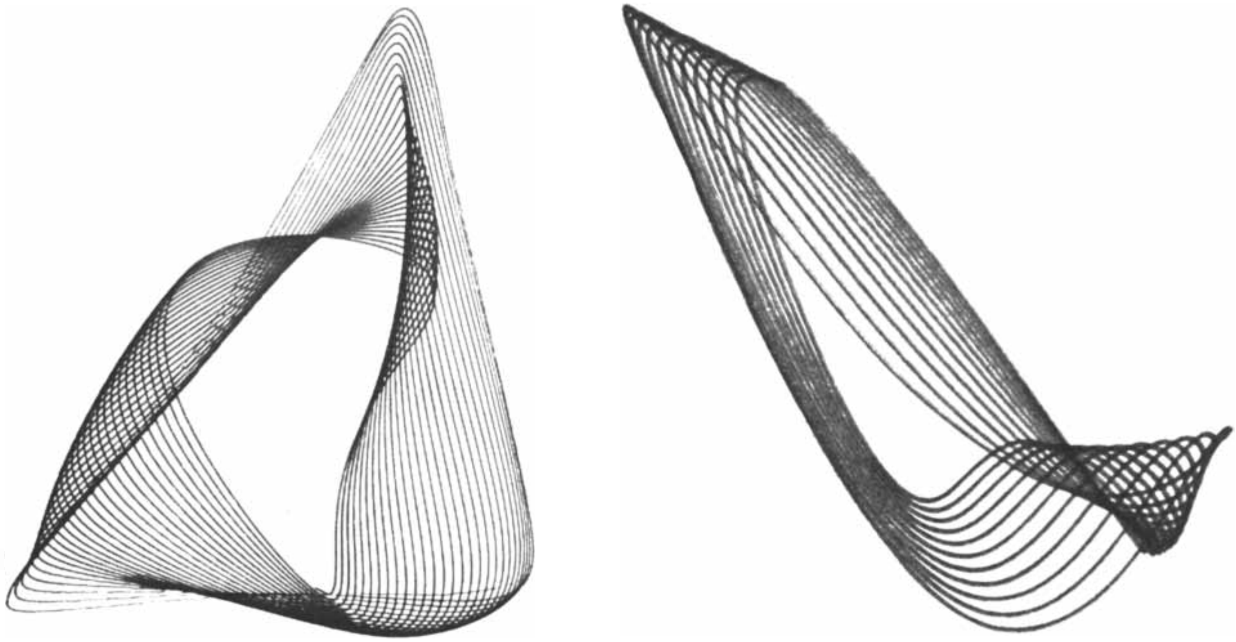
"One simple version of the pendulum machine consists of a flashlight suspended upside down by a slender wire. The bulb is masked so that light emerges through an aperture the size of a pinhole. When the flashlight is made to swing in an ellipse and is photographed from the bottom by time exposure in a darkened room, the light pattern takes the form of a spiraling ellipse. The axis of the ellipse rotates because of unavoidable irregularities in the suspension of the flashlight.

"A more sophisticated pendulum machine that generates figures like those made by Lissajous is credited to the British physicist Hugh Blackburn. This pendulum is made by hanging a weight from two slender wires of equal length attached a short distance apart to the bar or beam used for suspension. At a selected point the wires are bound together by a snugly fitting ring; they then form a single strand that can be lengthened or shortened by sliding the ring up or down. Pendulums of this type, often exhibited at science museums, are equipped with a bob in the form of a conical cup that has a small hole in the bottom for releasing a trail of sand that records the motion.

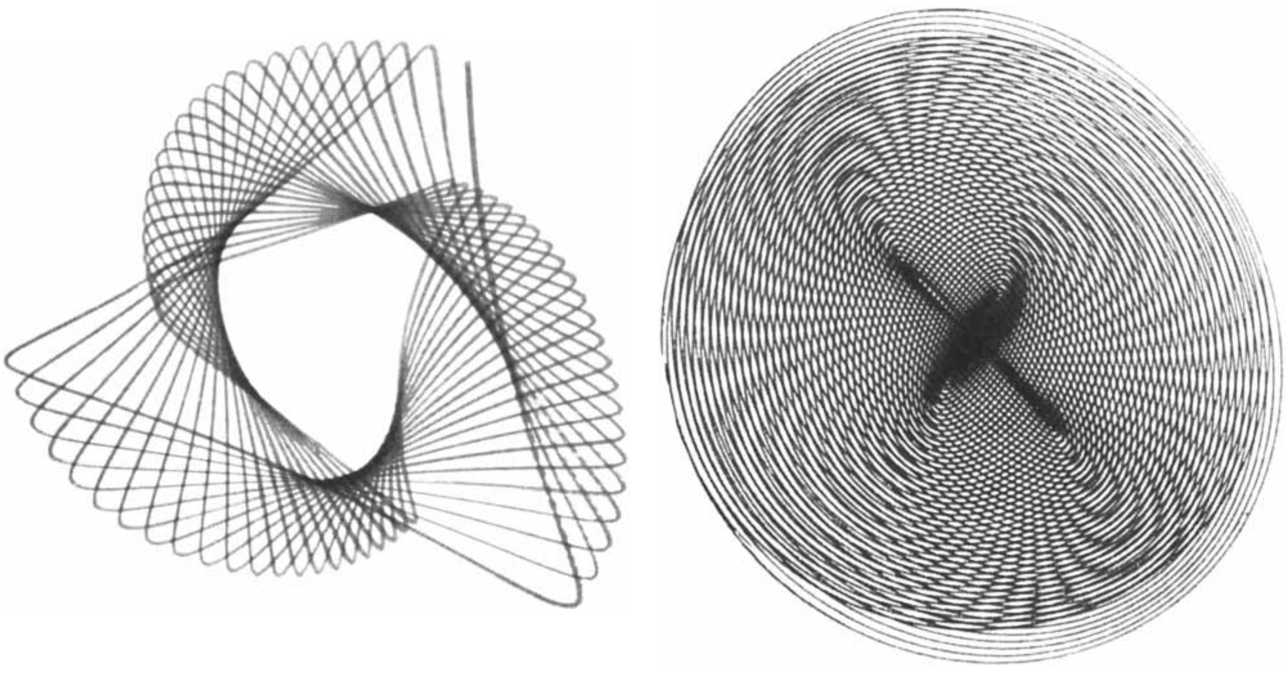
"A simple version of a machine of the crank type is easily constructed of



A harmonograph of the crank type



Figures made by a double-elliptic pendulum harmonograph

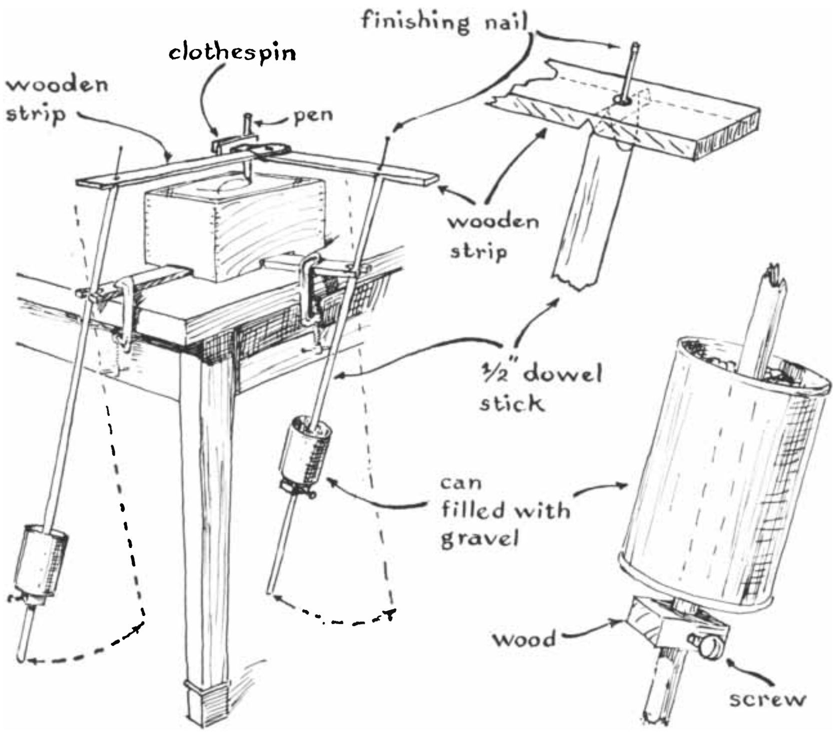


A similar figure (left) *and a moiré pattern* (right) *generated by a single pendulum*

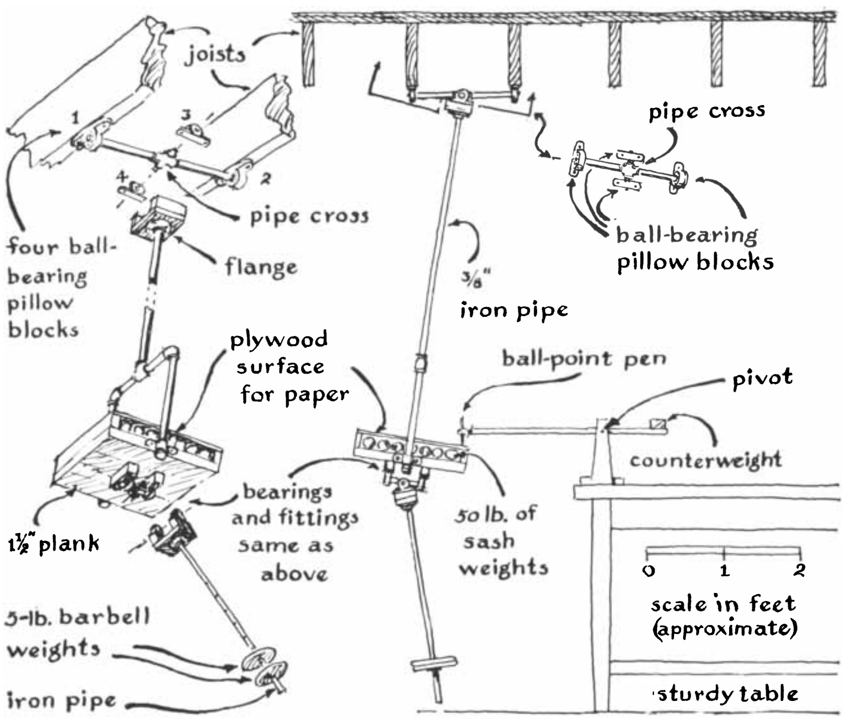
wood. One made recently by Tom Barnard of Tucson, Ariz., rests on a board about 3/4 inch thick and 18 by 24 inches in its other dimensions. The board supports three pulleys linked together by a common belt [*see illustration on opposite page*]. The upper side of the largest pulley, which is about 10 inches in diameter, serves as a turntable for rotating a sheet of paper taped in place. An adjustable crank arm that carries the pen is driven by a smaller pulley. The machine makes its most interesting designs when the diameter of this pulley is not a multiple of the diameter of the largest pulley. The crank arm engages any one of a series of radially spaced holes in the driving pulley. This scheme enables the operator to increase or decrease the throw of the crank as he wishes. The distant end of the arm rides on a notched board at the rear of the machine; the particular notch in which the arm is placed determines the radius of the harmonogram. A conventional ball-point pen is attached to the arm by a sheet metal bracket and a rubber band. A third pulley, turned by hand, powers the device.

"A rather more sophisticated but less portable machine is the twin-pendulum harmonograph [*see upper illustration on next page*]. Two pendulums, linked independently to the pen, swing at right angles to each other. A small table supports the paper in contact with the pen. The rate of vibration of each pendulum can be separately adjusted by raising or lowering the appropriate bob. We made our pendulums of 1/2-inch wooden dowel rods a yard long. The rods pivot on knife-edges about 10 inches from the top end. The bobs are tin cans containing approximately six pounds of gravel.

"We found that the pen writes most reliably when it is weighted with two ounces of iron washers. This arrangement results in figures with rather widely spaced lines because the drag of the pen slows the machine quickly. Patterns of closely spaced lines were made by substituting a Leroy lettering pen for the ball-point pen. The Leroy pen exerts only a few grams of pressure. We enlarged its ink capacity by pushing the upper part of the pen into a 1/2-inch length of tubing with an inside diameter of 3/16 inch. We used the No. 0 and No. 1 pen sizes.



A double-pendulum harmonograph



A double-elliptic pendulum apparatus

"Our most recent machine is a version of the elegantly simple double-elliptic pendulum first described in 1907 by British experimenters. It consists of a small wooden platform weighted with 50 pounds of iron [*see lower illustration at left*]. The platform is suspended through a yoke and a length of iron pipe by ball-bearing gimbals fixed to the ceiling. The figure is drawn on paper that is taped to the platform; the drawing instrument is a pen attached to one end of a counterweighted lever arm. This simple arrangement generates only circles, ellipses and straight lines. The interest of these figures can be enhanced by making identical drawings and superposing one on the other with a slight displacement; moiré patterns then appear.

"The most astonishing increase in the versatility of the machine can be made, however, by suspending a second, less massive pendulum from the bottom of the platform, again using a gimbal arrangement. When it vibrates at its own natural period, the shorter pendulum perturbs the motion of the swinging platform in an infinite number of ways. The handsomest patterns are generated when the frequency of the upper pendulum bears a whole-number ratio to that of the lower pendulum—a ratio such as 3:2 or 2:1. The adjustable factors that describe any given figure are then the two amplitudes of the upper pendulum, the phase angle between them, the phase between the upper and lower pendulum, the phase and amplitudes of the lower pendulum and the ratios of the frequencies of the upper and lower pendulums. We have scarcely begun to investigate the variety of patterns that can be generated with the double-elliptic pendulum machine.

"Equally interesting are crank machines, particularly those that generate hypotrochoids and epitrochoids. A hypotrochoid results when one circle is made to roll inside another; an epitrochoid, when one circle rolls outside another. Machines of this type can be adjusted for generating the family of curves that includes the cardioid, limaçon, deltoid, astroid, trifolium, quadrifolium, ellipse, circle and even the straight line.

"A simple crank machine has been

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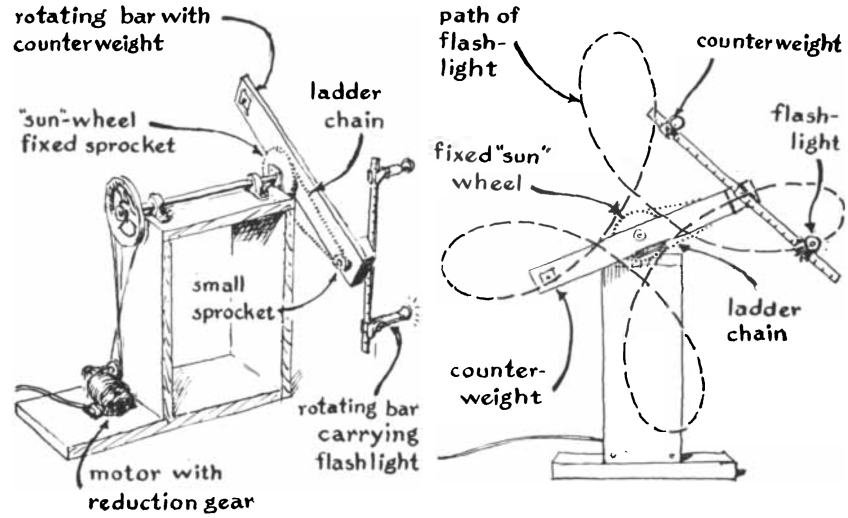
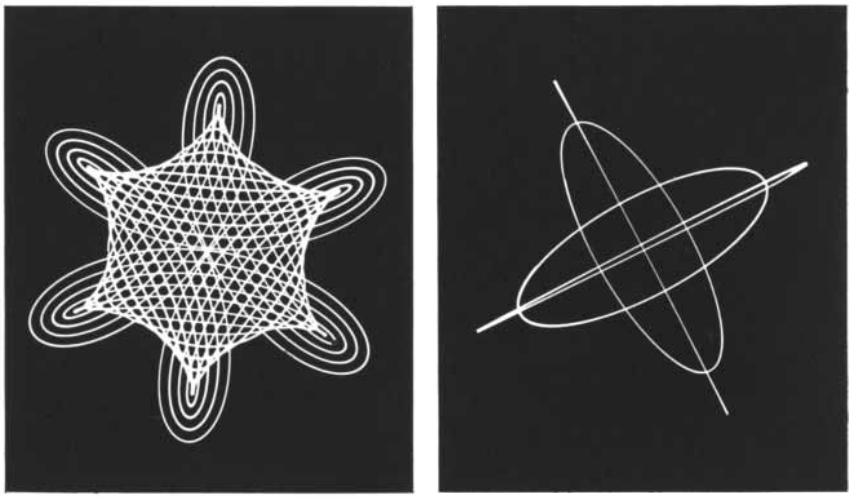


A hypotrochoid harmonograph



Figures drawn by a hypotrochoid harmonograph

constructed by Everett Clement of Peterborough, N.H. He undertook the project as a means of investigating the patterns that appear on the face of a cathode-ray oscilloscope when two electrical signals of appropriate wave form and phase relation are applied to the input terminals. His device consists of a motor-driven arm that carries at its outer end a second arm rotated by means of a planetary sprocket and a ladder chain that engages a 'sun,' or fixed, sprocket [*see upper illustration above*]. A flashlight carried by the second arm is photographed by time exposure in a darkened room. The motion of the first arm describes a circle, whereas the flashlight, which marks a point on the second circle, generates hypotrochoids. The radius of the figure can be adjusted by altering the position of the flashlight on its supporting arm.

"A more complex and versatile machine of this type has been made by H. A. Cata of Geneva, Switzerland. He calls his machine a cyclograph [*see illustration on page 134*]. It generates both hypotrochoids and epitrochoids. In addition to all the figures that can be made with Clement's machine the cyclograph also demonstrates that the cardioid, limaçon and nephroid are merely special cases of the epitrochoid. Spirals, cubics, quartics and other curves of higher order are beyond its present capabilities, however.

"All machines except the simple pendulum types can be made to generate stereoscopic harmonograms, which are patterns that appear in three dimensions when viewed through a stereoscope or with the aid of a prism. With practice some people find it possible to see the patterns in three dimensions by

Statue of Benjamin Franklin by James Earle Fraser in The Franklin Institute, Philadelphia

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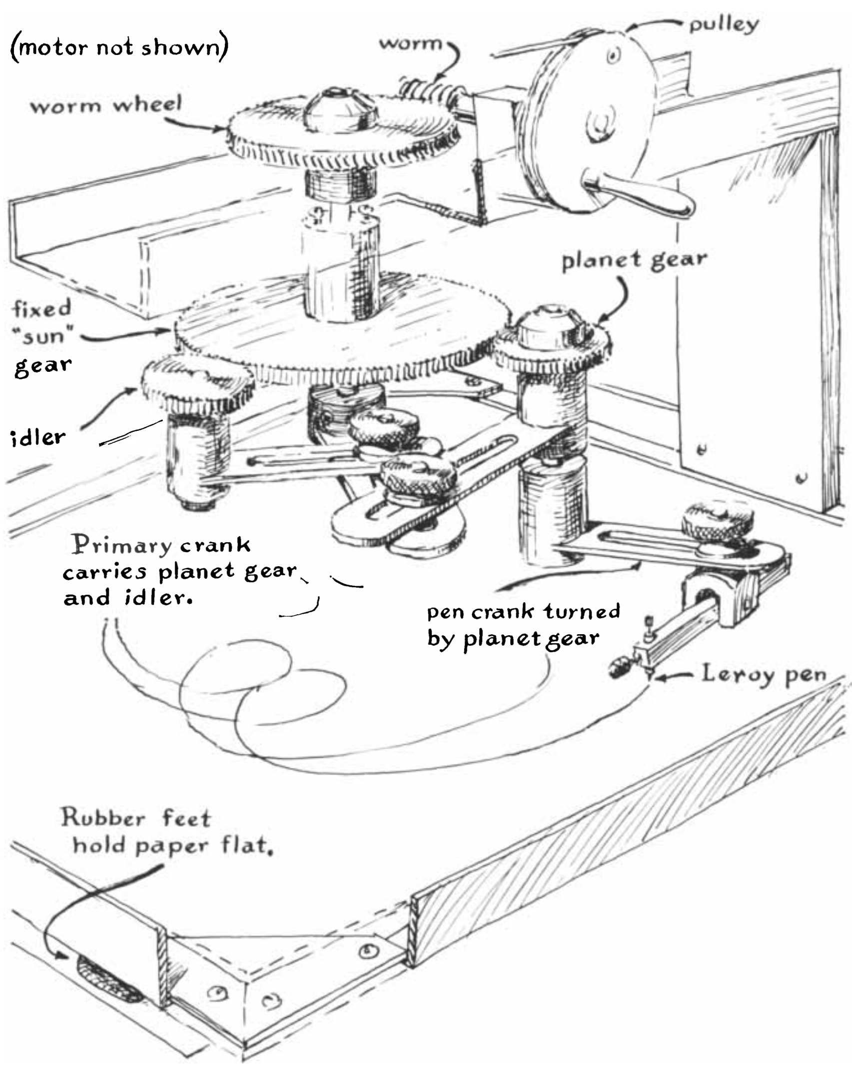
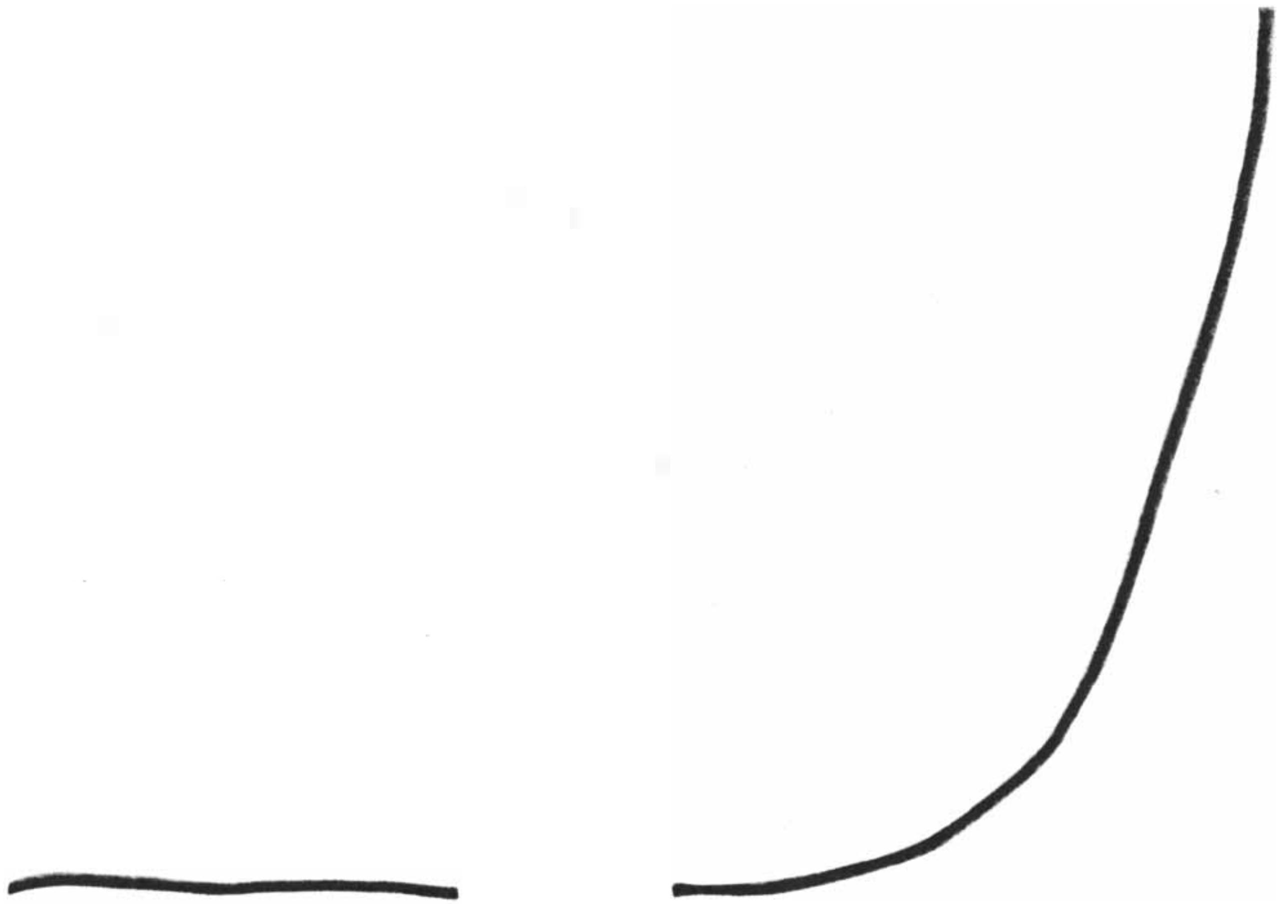
crossing their eyes in such a way that the left eye views only the right figure and the right eye only the left one. To make stereoscopic pairs with a double-pendulum machine, such as the one shown in the upper illustration on page 130, the pendulums are first released simultaneously. When the resulting figure is finished, its stereoscopic mate is made by releasing one pendulum slightly before the other; thus it has a head start of about five degrees of swing. The resulting figures are then photographically reduced in size so that they do not overlap when they are mounted side by side at a center-to-center distance of 2½ inches. When mounted, the figures must be oriented so that they would be in register if they were displaced and superposed. Stereoscopic harmonograms can be made by machines of the gear type merely by increasing the radius of the pen arm about 5 percent when generating the second figure.

"Although several versions of easily constructed harmonographs have been presented along with examples of the figures they generate, the subject would not be complete without at least passing mention of the basic physical and mathematical principles that underlie the production of the designs. Simple harmonic motion has rather a special meaning in the field of physics: the projection on any diameter of a point moving in a circle at uniform velocity. As rigorously described, the position of the projected point at any instant is equal to the product of the angular velocity of the point, the time in seconds that it has moved and the trigonometric sine of the angle through which it has moved. This type of motion—rapid near the center and slowing down gradually to a stop at one end, then accelerating toward the center only to slow down and stop again at the opposite end—was doubtless as familiar to the caveman dangling from a vine as it is to the mod-



A cyclograph



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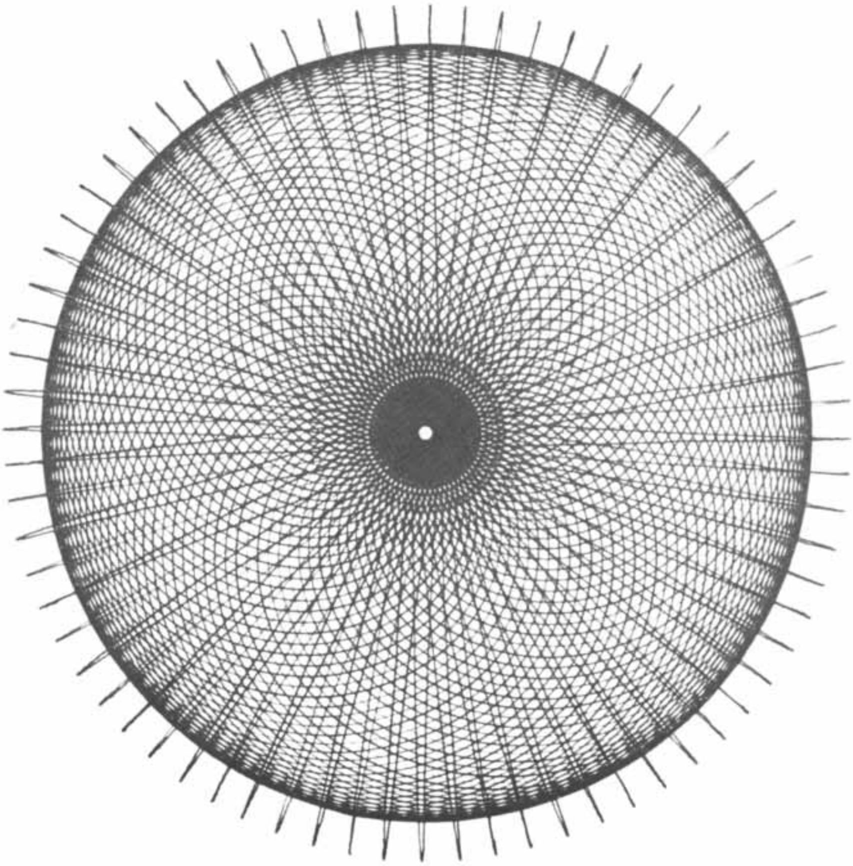
ern child on a swing. Other examples include the motion of a weight bobbing at the end of a rubber band and various kinds of vibration—of a violin string, of air compressions in wind instruments of the pipe family and of subatomic particles responsible for the emission of electromagnetic waves. In short, the simple motion so charmingly portrayed by harmonograms is found at the root of all natural phenomena."

The subatomic particles that made the trails in the unanalyzed nuclear interaction that appeared in this department last month were: trail a, p; b, Λ^0; c, $K_1{}^0$; d, π^+; e, p; f, π^-; g, π^-; h, π^+.



Hypotrochoids superposed on epitrochoids

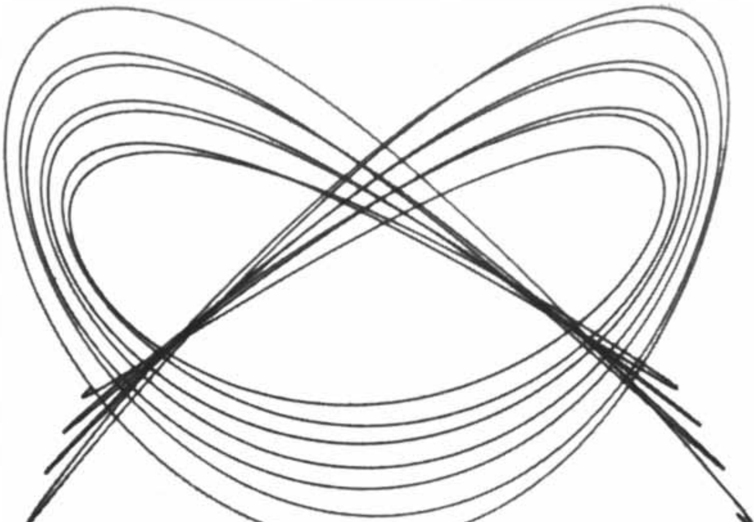


Figure from a Blackburn pendulum

Eminent Engineers and Scientists

Arthur E. Flock, Jr.

Arthur E. Flock, Jr., Chief Engineer of Lockheed-Georgia Company, started making important decisions early. When he was a 12-year-old in his native state of Indiana, he decided he wanted to be an airplane designer. It is typical of Art Flock that even as a lad, he sought all the facts he needed before determining which school to attend. He asked for and received information about curricula from some 10 accredited institutions awarding B.S. degrees in Aeronautical Engineering. He revealed another facet of his character when he chose Parks Air College (now affiliated with St. Louis University) because Parks was, at that time, the only advanced aeronautical school in the country requiring an Airplane and Engine Mechanics license and flight training to qualify for a B.S. degree. "It seemed to me," says Flock today, "that this background and experience would well serve an airplane designer."

One of the 16 from a starting class of 65 members who was graduated in 1936, Flock was called in by Oliver Parks, the aviation pioneer who founded the College. Parks commented that he had had his eye on young Flock, and suggested that he apply for an engineering job with an up-and-coming young aircraft company — Lockheed. After joining the company, Flock first went to work on the original Lockheed Electra. As he continued with work on such aircraft as the XP-38, the XP-49, the Constitution (model 89), the airplane which became the C-130, and several others, Flock steadily climbed the ladder, working in preliminary design, then as a group engineer, assistant project engineer, and in mid-1958, he was promoted to chief advanced design engineer. In February, 1959, he came to Lockheed-Georgia as chief engineer. Flock's organization created the C-141 StarLifter, and the design for Lockheed-Georgia's proposal for the Air Force's C-5A heavy logistics transport.

Engineers and Scientists who are interested in becoming associated with the group at Lockheed-Georgia Company are invited to address inquiries to: Mr. Arthur E. Flock, Chief Engineer, Lockheed-Georgia Company, 834 West Peachtree Street, Atlanta, Georgia 30308, Dept. R-80.

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BOOKS

Is economics obsolescent?

by Kenneth E. Boulding

On Economic Knowledge: Toward a Science of Political Economics, by Adolph Lowe. Harper & Row, Publishers ($6.95).

This is a reflective work that comes out of a long life of thought and study. Adolf Lowe, professor emeritus of economics at the New School for Social Research, is one of the few people in the world today who deserve the title of economic philosopher. He consistently struggles with important questions—questions that are hard to answer or perhaps even cannot be answered. He is not much interested in questions to which answers can easily be given. One therefore finds in his work a good deal of wisdom, even if it is not overly spiced with wit.

The problem with which Lowe is struggling in this volume is an important one, not only for economists but also for anyone interested, whether theoretically or practically, in understanding social systems. Social systems differ from physical systems in that knowledge about them is an essential part of them; the more we know, the more we change what we are trying to know. Under these circumstances the test of knowledge becomes not prediction but control. Lowe quotes John Stuart Mill as saying that what is "insufficient for prediction" is "most valuable for guidance." We cannot escape the fact that the testing of knowledge in social systems consists in the application of values, and hence cannot be considered apart from a value system, that is, a system of ultimate or at least proximate goals. I take this to be the central message of Lowe's work, and it is a message every social scientist should ponder.

The implications of Lowe's message are that economics is obliged to be "political economics," that the idea of economic theory as a kind of "mechanics of utility and self-interest," as W. S. Jevons called it, is illusory, and that economics must face the fact that the goals of the economy are set in the political process and are not autonomously generated by the system of exchange. This applies particularly to the goals of rapid and stable economic growth, and, one might add (Lowe does not stress it), to the goal of distribution of wealth and income in conformity with whatever sense of equity is able to express itself through the political system. With these propositions I am, and I imagine many economists would be, in general agreement.

I now find myself, however, in the peculiar position of being in strong sympathy with the central message of Lowe's book and in almost complete disagreement on every detail of it. I am somewhat addicted to the unsatisfactory dialogue—perhaps I should say monologue—of marginal notes, and I find that I have scrawled protests on almost every page. To some extent this unseemly behavior is the result of an internal quarrel among economists that should not intrude on the attention of the readers of this magazine. It is, however, an important quarrel and one in which a good many outsiders have joined, so perhaps I shall be excused for putting it before those interested in all the sciences. It is a quarrel about the validity and role of economic theory, about the nature of the history of economic thought and about the political implications of economics. The quarrel is so intricate that one can find oneself on different sides of it at different times, and having considerable difficulty in telling the "good guys" from the bad.

The quarrel begins, as good quarrels should, with a dispute over what economics is all about in the first place. In Lowe's view economics is essentially concerned with "provision," particularly of material things. Thus he says (the italics are his): "Then *our definition of Economics* as the provision of material means *restricts economic behavior to those activities which always claim, in addition to the use of immaterial resources, the use of some material resources.*" His economic man irresistibly reminds one of A. A. Milne's Pooh, laying up provisions, mostly edible, as he goes off on an "Expotition." Even in Lowe's last chapter, in which he discusses the vindication of goals, he says: "We shall be satisfied with a provisional yardstick capable of guiding one of our major decisions in the narrow realm of provisioning without foreclosing any answers to the larger question of 'what life befits Man.' "

My economic man, in contrast, is a generalized chooser and decision-maker who sacrifices a little ham for a little more eggs in a breakfast, or a little red for a little more green in a painting, or a little justice for a little more progress in a policy. My economic man, in other words, is more like Christopher Robin. He is more interested in decisions than in provisions. His economics arises out of scarcity, simply because it is scarcity that forces him to make decisions. If there were no scarcity, he would not have to make any choices. On this basis economics emerges as a generalized theory of choice. Lowe rejects such views quite explicitly. He says: "*Unqualified scarcity of resources cannot be made the criterion for economic activity.*" Economics, then, only deals with means, and material means at that—never with ends. Once, thanks to technological progress, the provision of means has become easy and provisions cease to be scarce, economics virtually ceases to exist, even if noneconomic scarcities continue. This is a point of view that tends to be characteristic of the left, from Marxists through to the authors of the "triple revolution." It is a view, however, that the main stream of economics rejects. To make an unsound generalization, Pooh is the almost perfect symbol of what might be called the decent left: furry, attractive and rather simpleminded about honey. I cannot help displaying my prejudice; it is the economist, alias Christopher

Robin, who is more in command of the situation and has a more realistic appraisal of what the world is like. To my mind the basic attitude of "Pooh economics" leads to a whole succession of misunderstandings about the essential nature of the economic process, the nature of economic theory and the nature of the history of economic thought. A few illustrations will have to suffice.

One of the fundamental principles of economics, for instance, is what Paul A. Samuelson calls the theory of maximizing behavior (which I have called more simply the principle of the best alternative), namely that we always choose what we think is best at the time. This is a principle so formal that it seems almost devoid of content, yet even in the hands of Adam Smith it led to an extraordinarily powerful theoretical formulation that I have called the principle of equal advantage. The latter principle still provides the best explanation of why, for example, there are differences in money wages, why the price structure is what it is, why land is dearer in Manhattan than in the Adirondacks, and so on. Lowe calls this principle the "extremum" principle—a slightly unfortunate name because it confines the principle to the maximization of material provision. In his hands it ceases to have any explanatory power whatever. He does not seem to see that the extremum principle is just as applicable to the demand for leisure or for services as it is to the demand for commodities.

A similar misapprehension clouds his statements of the law of demand and supply. He seems to think that price theory stands or falls with the maximization of money receipts or the minimization of money expenditures. He is well aware of what 19th-century economists called "peculiar cases of value," but he seems to have no idea of the extraordinary generality of the concept of a normal price set, that is, a set of exchange opportunities and terms of trade, divergence from which generates dynamic movements in the society. Consequently he often writes as if he simply wanted to throw away traditional price theory. On the other hand, when he comes to construct something like a theory of his own (in Part 4 of his book), in a sense he reinstates the extremum principle, and indeed pretty much the whole of price theory, in a reasonably acceptable form, recognizing that the control of the overall economy always requires a manipulation of the environment of each decision-maker to the point that what he thinks is best for himself is also adjudged best for the society. What Lowe does not stress is that this environment is largely an exchange environment. It is the terms of trade—what we get per unit of what we give—that have to be manipulated if individual behavior is to be directed into socially desirable channels.

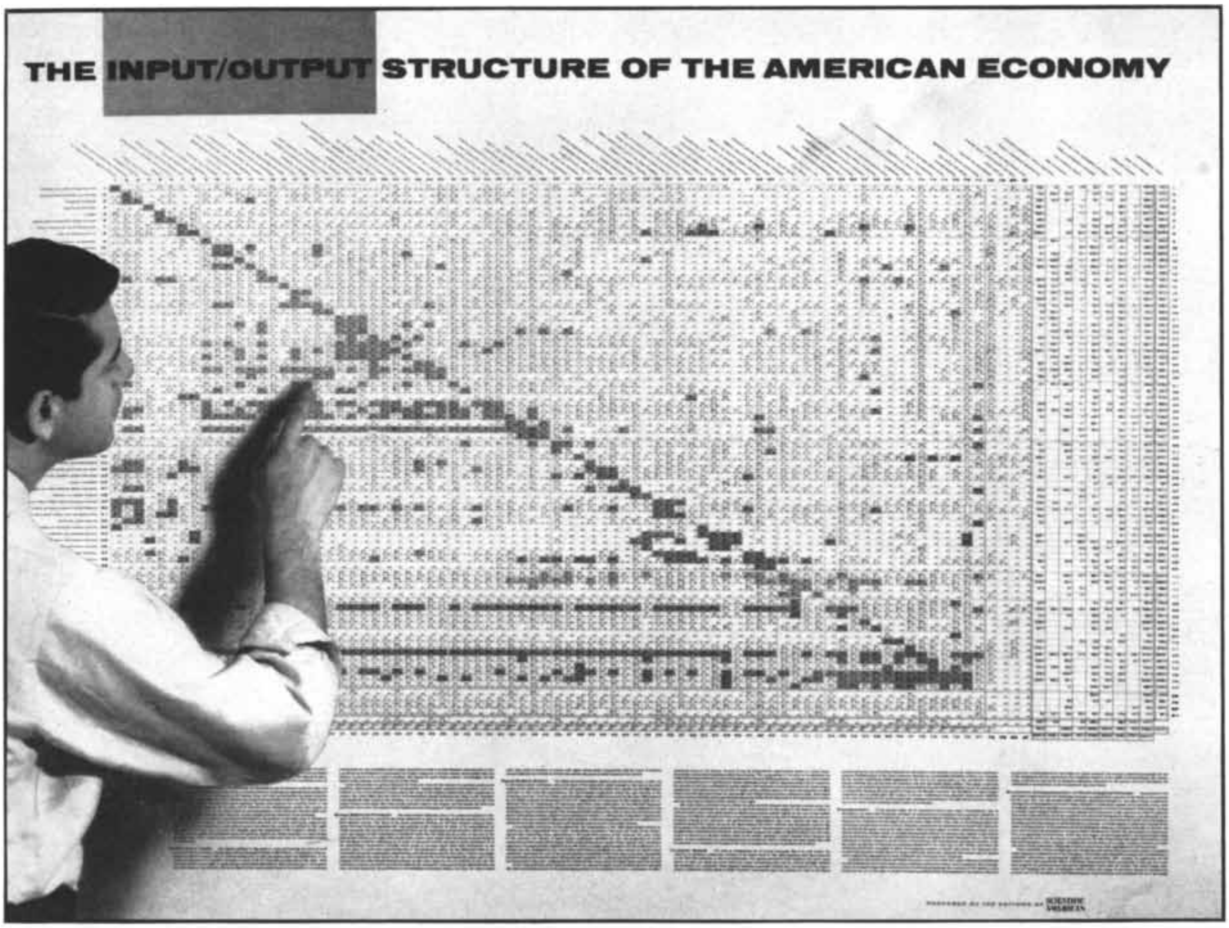
Lowe's brief account of the history of economic thought in his Part 3 is extremely revealing of his general cast of mind. Our disagreement here can be summed up by saying that what he sees as erosion I see as development. He sees the classical system of Adam Smith and David Ricardo as being fundamentally undermined by John Stuart Mill. In the system of Alfred Marshall he sees the decline of economic theory from a grand-scale body of truth to a mere tool for inquiry; in the system of Karl Marx he sees an alternative to the original system that is equally subject to erosion; in the system of J. M. Keynes he detects what he calls the rudiments of political economics.

Lowe thinks that classical economics is the product of a peculiar period in history, in which economic man really existed and operated, and that it therefore simply became irrelevant with the rise of large-scale organization and controlled economies in the 20th century. My own view, both of economic history and of the history of economic thought, is very different. I see a continuous development from the time of Adam Smith, with a great refinement of analytical tools—which do not much change the substance of the theory. One does, of course, see certain shifts in the foci of interest, for instance a shift away from a concern with economic development and irreversible dynamic processes in the neoclassical period of Marshall and his successors and a return to this concern in the modern era. The Marxian stream I regard as something of a diversion, drying up eventually in the desert of a fruitless orthodoxy. The main stream from Adam Smith right through to Keynes I would visualize not as a process of erosion but as a continually swelling river of thought. Lowe gives no systematic treatment of economic history in this book, but I detect in many places that his image of the past 200 years is quite different from mine. Where he sees the decay of the ideal mobile free-market economy of the 18th and early 19th centuries I again see a development, in which the business cycle and even the great depression is a learning process that is slowly teaching us to build the institutions of a managed free society. Indeed, from some observations in his last chapter I catch hints that Lowe himself has finally come around to something like this position.

Much of my technical quarrel with Lowe's book arises over the question of what is the basic nature of economic abstraction. Economics, of course, is an abstraction; this is both its power and the source of its limitation. Lowe seems to regard the essentially technological problem of provision as the basic abstraction of economics. Once we have our pot of honey the problem is solved and we can get on with the real business of life. In my view the basic abstraction of economics is the phenomenon of exchange, wherever this occurs, and the central problem of economics consists in the understanding of how exchange organizes society. The most important single parameter in any exchange is the ratio of exchange, that is, the terms of trade, or what we get per unit of what we give. The study of ratios of exchange is price theory; price theory is therefore central to economics. It cannot be thrown away. It is central even to political economics, simply because it is really the only thing we can manipulate in order to guide individual behavior into socially acceptable directions without coercion.

To my mind the exchange system is the only way to reconcile individual liberty with overall social goals. Furthermore, the set of exchange opportunities is not arbitrary, and even though it can be manipulated to a considerable degree it can be distorted beyond a certain point only at the cost of grave social consequences, as both socialist planners and the designers of U.S. agricultural policy have discovered most painfully. This is why price theory is just as central to political economics as it is to pure economics. Pure economics, indeed, is merely a heuristic step toward the understanding and successful conduct of economic policy. To judge from the last three chapters of Lowe's book (which, incidentally, are by far the best), I do not think he would disagree with this proposition. In the earlier chapters, however, there is constant evidence of something that I have to invent a German word to describe: *Preisschmerz,* a sort of woe about the price system that seems to be an inescapable accompaniment of progressive thought, and that turns into a serious handicap when progressive thinkers have to put their ideas into practice.

We might use here an analogy from agriculture. Even though it is true that the appearance of corn in an Iowa field



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cannot be explained by the principles of pure ecology but can be explained by what might be called political ecology (imposing a human value system on the distribution of nonhuman species), at the same time there are fundamental principles of genetics, plant physiology and so on that can be used but cannot be violated. These principles are not just relics of the 18th and 19th centuries, when agriculture had not begun and prairie grass competed uninhibitedly with the encroaching oaks, but are a basic underlying property of any agricultural system whatever. I would thus defend price theory against the charge that it is a relic of a bygone free-market economy. I would deny also that price theory is merely a matter of technology, even though it is true that production coefficients are perhaps the most important single set of facts in determining the equilibrium price system. The economic planner who thinks that economics is just technology is in for some rude shocks.

I am not suggesting that the price system, or an economy of absolutely free private property and exchange, is the answer to all our problems. There are a great many areas of social life that we cannot, and should not, leave to the market. Furthermore, the market itself is subject to certain pathological disorders such as general deflation or inflation, monopoly rigidities and meaningless competitive fluctuations. The exchange economy continually needs to be supplemented, not only with an adaptable legal framework but also with a grants economy, representing direct social allocations. The grants economy, however, is subject to at least as many diseases as the exchange economy, and it is much less subject to feedback and control. If the Ford Motor Company produces an Edsel, it soon finds out that it is a failure; if the Ford Foundation produces an Edsel, nobody will ever know that it is a failure, least of all the Ford Foundation.

The sad truth is that although the idea of a political economics is attractive, when we try to spell out the content of such a science, the results are extremely disappointing. The process of economic growth, for example, which all agree is one of the major goals of economic policy, is imperfectly understood. It is certainly not mere technology: physical inputs and outputs, dams and roads, even though these things must be part of the process. Neither is it mere economics: stabilization and trade, investment and consumption, money and budgets. It involves subtle things such as motivation and morale, conflict management and political legitimacy, family structure and religious belief, and so on almost indefinitely. With none of these things does Lowe even attempt to deal. One must conclude that whereas someday we may have something like a general social dynamics, which is what political economics is striving for, the idea of a political economics separate from, and perhaps simpler than, an instrumental social dynamics is an illusion, and perhaps even a dangerous one. The illusion diverts attention from what is the real contribution of economics, which is the study of the role of exchange and its concomitant production and consumption in organizing the fabric of social life. Even when we are considering the contribution of economics to the understanding of economic development, it is the very price theory that Lowe seems to reject that makes the most telling contributions: warning the would-be developing country that terms of trade, both external and internal, are important, that quotas and quantitative restrictions are immensely destructive, that administered prices constantly look backward to a frozen past, and that it is the free market that, in spite of its many defects and difficulties, looks forward to the unknown future.

Preisschmerz is a disease that afflicts thinkers in developed as well as in underdeveloped societies. The people who talk as if cybernetics and automation were going to destroy the market economy altogether are simply talking nonsense. Cybernetics and automation are in fact a rather small part of a large and continuing process of technological change, and there is not even much evidence that they have speeded up the rate of such change. This is something Lowe does not talk much about, and I should probably not saddle him with it.

I hate to sound cross with him, because he is wise and gentle and his central theme is important and true. This kind of writing, however—and there is a great deal of it—gives aid and comfort to men who are neither wise nor gentle and who think economics can be thrown in the ash can as a relic of an earlier day. Whether or not we call economics a science is a matter of semantics, and a rather unimportant matter at that. The testing of economics can only be done through the policies it inspires, and this is a long, painful and difficult process. To reject economics without testing it can legitimately be described as unscientific. With these propositions I think Lowe would also agree. I only wish he had stated them in a firmer and less equivocal manner.

Short Reviews

My View of the World, by Erwin Schrödinger. Cambridge University Press ($3.50). Erwin Schrödinger was a leader of modern physics, a highly sensitive and gifted writer and a thoroughly good human being. Apart from his brilliant contributions to quantum mechanics and other provinces of physics, he wrote several books of a philosophical cast that, although quite short (none runs to more than 100-odd pages), have distinction in inverse proportion to their size. This volume, his last, consists of two essays separated by an interval of 35 years and now both published for the first time. Anyone who has read two or three of the other Schrödinger books has recognized in them a leitmotiv that is also present in these essays. As early as the 1920's, and perhaps even earlier, Schrödinger had found congenial and moving the Indian writings of the Veda, and he was particularly drawn to the notion that our world consists of a single consciousness of which each individual's consciousness is but a single aspect. (The classic image is that of a many-faceted gem, each face of which mirrors the surrounding scene from different angles.) Schrödinger freely admitted that this view of the world is mystical and metaphysical and altogether beyond the reach of logical deduction, but these attributes did not discomfit him, not only because he had an intense and intuitive commitment to the theme but also because, as he argued most persuasively, the widely held belief in an external world that is "real," that is able to affect our minds and that our minds are in turn able to affect is even more paradoxical, mystical and metaphysical. In support of this latter opinion he is able to muster arguments that are at once ingenious and formidable. This is in some ways a less fully worked out and less compelling book than others he wrote, but it is more than merely moving as an eloquent last testament: it is in parts finely reasoned and beautifully written.

The Language of Nature: An Essay in the Philosophy of Science, by David Hawkins. W. H. Freeman and Company ($7.50). There are a goodly number of contemporary books on the philosophy of science, among the more noteworthy of which are those by R. B.

Braithwaite, Philipp Frank, Ernest Nagel, Arthur Pap, Hans Reichenbach and Hermann Weyl. Hawkins' essay has strong points of its own. It is marked by breadth of coverage—he discusses topics not commonly found in books of this kind, such as the relation of thermodynamics to problems in biology, psychology, information theory, economics and ethics—and a fresh imagination that informs models and hypotheses, enlists vivid analogies and eschews hackneyed appraisals of classical questions of science. Hawkins writes firmly and succinctly, at times perhaps too succinctly, with the result that only the specialist will be able to follow the analyses of certain advanced theories of physics and mathematics. But in the round this is a praiseworthy essay, one that will enlighten readers by its critique of prevailing views and its unification of often seemingly unrelated ideas.

We Are Not Alone: The Search for Intelligent Life on Other Worlds, by Walter Sullivan. McGraw-Hill Book Company ($6.95). An intelligent, ably written journalistic roundup of what is known today about the possibility of life on other planets, by the science editor of *The New York Times*. The book gives the historical background of modern cosmology, recounts essentials of astronomy bearing on modern cosmological speculations and then explains topics that include the chemistry of life, the behavior and nature of meteors and meteorites, the life-on-Mars question, radio astronomy and the problem of communication with intelligent beings of other worlds. In the supporting cast are a very good bibliography and illustrations.

Asimov's Biographical Encyclopedia of Science and Technology, by Isaac Asimov. Doubleday & Company, Inc. ($8.95). Isaac Asimov, who professes biochemistry at Boston University, is a man without brakes. Over the past 15 years he has written more than 25 popularizations of the sciences from mathematics to geography, not to speak of other works. A reviewer therefore picks up this book, subtitled "The Living Stories of More than 1,000 Great Scientists from the Age of Greece to the Space Age," with a feeling approaching ennui. But one of the most rewarding things about being a reviewer is that the task is punctuated by agreeable surprises, and this tome, which one has every reason to expect will be no more than routine, turns out to be the best biographical compilation of its kind. Its arrangement is bizarre, it neglects to mention men who made serious and respectable contributions to science while including others (for example Charles A. Lindbergh and Admiral Hyman G. Rickover) who do not belong in this sphere, it garbles ideas and slurs over concepts; nevertheless, it presents a better overall survey of the movers, shakers and geniuses of science than any comparable reference book. Asimov is remarkable, although one sometimes wants to scold as well as praise him for his prodigality.

Of Men and Galaxies, by Fred Hoyle. University of Washington Press ($2.95). In this volume—based on the John Danz Lectures delivered at the University of Washington in 1963—Fred Hoyle, in his characteristically free-wheeling and versatile way, touches on a variety of subjects, from overpopulation and human ethics to life on other planets and the "dinosauric" bigness of modern science. His social views, although enlightened, are not out of the usual run, but his conjectures about the physical universe are often provocative and exciting. In discussing computers Hoyle is of the unequivocal opinion that as these machines become less and less simple there will be no "hard and fast dividing line" between them and the brains of animals, including ourselves. He argues that men are computers produced by the universe through a long process of biological evolution, and that mechanical computers, although they are artifacts made by us to do our donkey work, are no less children of the universe. This is as persuasive as contending that a talking doll is a close relative of its manufacturer or that a woman's hat is a woman because it was made by a woman. Still, even when Hoyle's speculations are specious, they are never dull.

The Mad Motorists, by Allen Andrews. J. B. Lippincott and Company ($5.95). A diverting account of the almost unbelievable 1907 race (it was called a "raid") in which four motorcars (five started originally)—an Italian Itala, a Dutch Spyker and two French de Dions—traveled 10,000 miles from Peking to Paris to win a prize and also to demonstrate that an automobile could go *anywhere* except up into the sky and under the ocean. In three months the vehicles (and their drivers) climbed mountains, ripped through boulder-strewn ravines, slogged across marshes, forded streams and rivers, crossed (and on at least one occasion fell through) crumbling bridges that even the local inhabitants would not dare to traverse on foot, staggered over the fearsome Gobi Desert, covered thousands of miles of the Siberian steppes guided only by telegraph poles and verst markers (none of the cars had speedometers, or even windshields), jarred over the ties of the Trans-Siberian Railway and endured violent storms, land pirates and bands of marauding horsemen. Food, water, fuel, extra tires and spare parts had to be toted along or made available at depots along the way (not infrequently when the cars arrived supplies had not been delivered). The essential passengers were mechanics, who were so conscientious that every few days they would strip the vehicles down to the last bolt, repair, refurbish and put them together again. That today's automobiles are more comfortable and more powerful than those of 1907 is certain, but that any modern four-wheeled marvel could make the journey these gallant little buggies achieved is beyond imagination.

OPTICAL ILLUSIONS, by S. Tolansky. The Macmillan Company ($5). Geometric optical illusions attracted much attention from both physicists and psychologists during the latter half of the 19th century. Although pictures of such patterns continue to appear in psychology texts, the illusions, in one form or another, are now more widely known. Tolansky, a British physicist, addresses his little book, which reviews many of the illusions, "to the layman, to the artist and to the scientist." Primarily the volume is a *jeu d'esprit* intended to entertain, but Tolansky also has a serious purpose, namely to show how in different kinds of experimental research the investigator is likely to be grossly deceived if he relies simply on judgment by eye. Mistakes arise in visually assessing curves, in evaluating distances and sizes, in interpreting microscopic images, in using eyepiece cross hairs, in appraising the size of the moon, in reading X-ray plates, in scrutinizing X-ray diffraction patterns. Tolansky rides his hobby hard—most investigators today do not, after all, need to be urged to make measurements when they are engaged in serious work—but his book is a pleasant diversion.

BONES, BODIES, AND DISEASE, by Calvin Wells. Frederick A. Praeger ($7.50). In Sir Thomas Browne's famous essay on urn-burial there appears the line "But to subsist in bones, and be but Pyramidally extant, is a fallacy in duration." Yet the bones, although not everlasting, endure long enough to enable man to reconstruct segments of the past and even to deduce evidence of disease and abnormality in our ancestors thousands of years ago. This study, a minor cousin of archaeology, goes under the name of paleopathology, and as its findings are here described gives us knowledge of a variety of human disorders: a caveman's osteomyelitis, the cerebral hemorrhage suffered by a Persian woman of the fifth century B.C., the clubfoot of an Egyptian aristocrat, the leprosy of Robert the Bruce, the pyorrhea of a Peruvian peasant and the mortal wounds inflicted on all kinds of people in all parts of the world where men for millenniums have murdered each other with all kinds of weapons. Many illustrations.

THE WORLD OF ATGET, by Berenice Abbott. Horizon Press Publishers ($20). A collection of 176 photographs by Eugene Atget, one of the masters of this art, whose pictures of Paris—historical monuments, churches, grand boulevards, wretched alleys, prostitutes, windows of cheap shops, street workers, noble courtyards, cartwheels, rag pickers' huts, canal barges, river scenes, cabarets, amusement places—have never been equaled. Atget was for years a sailor and an actor. He began his new profession at the age of 40 and for many years thereafter—using enormous, clumsy equipment—trudged through Paris and its environs taking thousands of photographs, which he was usually unable to sell. A few of the leading painters recognized him for the giant he was, for his innocent, unclouded eye that saw as a man might see on the first day of creation. Berenice Abbott, herself a distinguished photographer, may be said to have discovered him and to have brought his masterpieces to the attention of a much wider audience. Her book, which includes a somewhat gushy introduction and a group of first-rate portraits of Atget that she made but he did not live to see, is the best tribute yet paid to this artist. The reproductions are excellent.

BIRDS OF PREY OF THE WORLD, by Mary Louise Grossman and John Hamlet, with photographs by Shelly Grossman. Clarkson N. Potter, Inc. ($25). A comprehensive account of the two orders of raptors (the hawklike birds and the owls), giving information on their evolution, their relation to man, their ecology, their special adaptations for survival and their conservation. The second part is an atlas and field guide for each genus. Illustrated by 70 color photographs (some of which are stunning), 283 photographs in black and white, 425 maps and some 600 flight silhouettes. A most desirable bird book.

ANCIENT SOCIETY, by Lewis H. Morgan. Harvard University Press ($7.95). A reprint, edited by Leslie A. White, of a pioneering book on the theory of the evolution of human society, first published in 1877. Morgan's essay, informed by exceptional insights regarding social and familial relations, had a powerful influence on anthropological thought when it appeared, then was thrown onto the scrap heap of outmoded systems and only in recent years has been recognized again for its originality and for the validity of many of its notions.

THE POISON BELT, by Sir Arthur Conan Doyle. The Macmillan Company ($4.95). A highly diverting science-fiction story written by Conan Doyle in 1913 and, in spite of its age, much more implausibly plausible than most contemporary tales of this genre. Illustrated by William Pène du Bois, with an introduction by John Dickson Carr and an epilogue by Harlow Shapley (who gives a *nihil obstat* to most of Conan Doyle's scientific assumptions).

Notes

STUDIES OF MACROMOLECULAR BIOSYNTHESIS, edited by Richard B. Roberts. Carnegie Institution of Washington ($7). A selection of the publications of the Biophysics Section of the Carnegie Institution of Washington during the period 1955–1963, including reprints from journals and excerpts from the Carnegie yearbooks, together with comments on the various articles.

A FIELD GUIDE TO THE STARS AND PLANETS, by Donald H. Menzel. Houghton Mifflin Company ($4.95). This new volume in the "Peterson Field Guide Series," hitherto devoted entirely to natural history, is a compact manual packed with information about all celestial objects and equipped with a large number of sky maps, charts, drawings and photographs.

INTERSEXUALITY IN VERTEBRATES, INCLUDING MAN, edited by C. N. Armstrong and A. J. Marshall. Academic Press ($14). A cooperative work that assembles current knowledge on the absorbing subject of sex reversal, which was already noted in antiquity by Aristotle.

EQUIVALENTS OF THE AXIOM OF CHOICE, by Herman Rubin and Jean E. Rubin. North-Holland Publishing Company ($5.50). This volume in the series "Studies in Logic" gives a selection of different forms of the celebrated axiom of choice, which for more than half a century has provoked considerable philosophical discussion and controversy in the study of logic and the foundations of mathematics.

PENGUIN SCIENCE SURVEY 1964 A, edited by Arthur Garratt; PENGUIN SCIENCE SURVEY 1964 B, edited by S. A. Barnett and Ann McLaren. Penguin Books ($1.65 each). Contributors to these volumes of articles on recent advances in science and technology include O. R. Frisch ("Experimentation with Elementary Particles"), J. C. Evans ("The Units and Standards of Measurement in the Physical Sciences"), Alexander Mikhailov ("Soviet Space Research"), J. D. Bernal ("Life beyond Tellus"), W. E. Le Gros Clark ("The Origin of Man"), Ritchie Calder ("Communication or Jargon?") and W. H. Pearsall ("Biological Invasions").

100 YEARS OF METALLURGY, by W. H. Dennis. Aldine Publishing Company ($8.95). A history of progress in the major branches of the metallurgical industry over the past century, beginning with the most important invention—made independently in 1850–1855 by Sir Henry Bessemer and William Kelly (a Kentucky ironmaster)—and continuing through such topics as ore-dressing, nonferrous metals, precious metals, the shaping of metals and metallography.

THE REAL VOICE, by Richard Harris. The Macmillan Company ($4.95). An account of the late Estes Kefauver's Senate investigation of the drug industry, which exposed the greed and dishonesty of certain large U.S. manufacturers of pharmaceuticals.

AGEING: THE BIOLOGY OF SENESCENCE, by Alex Comfort. Holt, Rinehart and Winston, Inc. ($7.50). The second edition of this compilation of facts about aging in man and other animals has been substantially revised: about a third of the text is wholly new, including the sections on radiation and somatic mutation and much of the bibliography.

EARTHQUAKES AND EARTH STRUCTURE, by John H. Hodgson. Prentice-

Hall, Inc. ($3.95). A nontechnical primer on earthquakes, their causes and detection, with some discussion of building to resist earthquakes. Good photographs. A paperback.

SPACE PHYSICS, by Harrie Massey. Cambridge University Press ($6.50). A survey of the objectives, techniques, methods and results of modern space research addressed to the physical-science specialist. Photographs and diagrams.

THE BIRDS OF ARIZONA, by Allan Phillips, Joe Marshall and Gale Monson. University of Arizona Press ($15). A survey of the more than 400 species of birds to be found in the diverse life zones of Arizona. The volume includes 64 full-color reproductions and 126 maps.

HELLAS, by C. E. Robinson. Pantheon Books ($4.95). A reissue of an ably written short history of ancient Greece, which on its first publication in 1948 drew acclaim from leading scholars.

ATLAS OF THE MOON, by Vincent de Callatay. St. Martin's Press ($15). This volume, which is illustrated by 146 photographs and 66 diagrams, gives a clear, authoritative description of what is currently known about the moon.

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