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Canola 164P

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SCIENTIFIC AMERICAN

Established 1845   December 1970   Volume 223   Number 6

THE COVER

The photograph on the cover shows the familiar iridescent "eye" of a peacock's tail feather. The colors reflected from such a surface change as the angle of the incident light is shifted, a property that is characteristic of the phenomenon of optical interference in a thin layer. The structure of the feather, in which there is a periodic variation of refractive index, is similar in design to some of the most advanced optical coatings produced by modern technology (see "Optical Interference Coatings," page 58).

THE ILLUSTRATIONS

Cover photograph by Lee Boltin

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SCIENCE/SCOPE

The first Intelsat IV communications satellite was delivered to Comsat in November by Hughes, prime contractor to the International Telecommunications Satellite Consortium (Intelsat) and is scheduled for launch this winter. The 17½-foot-high satellite will be capable of relaying 3,000 to 9,000 two-way telephone calls, depending on the mode used, or 12 color television programs, or any combination of communications including data and facsimile, from its synchronous orbit 22,300 miles above Earth. Intelsat recently contracted with Hughes for four additional satellites, making a total of eight.

Los Angeles' overburdened communications system is under the scrutiny of aerospace technology. A team of Hughes scientists is at work on a special study aimed at giving the city's emergency services -- police, fire, and ambulance -- a modern command-and-control system. They are evaluating the efficacy of equipping all police vehicles and control centers with electronic devices that would make it possible to determine every vehicle's location almost instantaneously in order to speed the nearest patrol car or cars to respond to a specific situation.

A temperature/humidity infrared radiometer (THIR) for the next two versions of NASA's Nimbus weather satellite is being built by Santa Barbara Research Center, a Hughes subsidiary. The THIR is a two-channel, high-resolution scanning radiometer which measures the earth's terrestrial, cloud, and atmospheric radiation to provide day-night cloud maps and moisture distribution on a global basis. The timely information it will provide on storm buildups and movements is expected to aid in weather forecasting.

A new insulation to shield wiring from high heat has been developed by Hughes research chemists for the U.S. Air Force Materials Laboratory. Electrical wiring coated with the polymeric material can withstand temperatures of $600^{\circ}F$. indefinitely -- or $700^{\circ}F$. for short periods -- without degradation or danger of fire. The new material, in development for nearly two years, also seals wire against the effects of moisture and air and maintains its flexibility down to $-100^{\circ}F$.

Needed at Hughes: analog and digital circuit designers experienced in the design of digital-to-synchro and synchro-to-digital converters, feedback amplifiers and active filters, and high-speed digital equipment using LSI/MSI techniques for radar signal processing. Also: logic designers for display applications; microelectronic applications engineers with thick- and thin-film hybrid circuit design experience. EE degree and U.S. citizenship required. Please write: Mr. R. S. Roth, Hughes Aircraft Company, P. O. Box 3310, Fullerton, Calif. 92634. Hughes is an equal opportunity employer.

A supersensitive level sensor invented by a Hughes scientist is so accurate that it could level an imaginary beam 100 miles long to within 1/32-inch of true level. It is now being used by various government and private agencies in tilt measuring instruments, leveling systems, and level reference bases. At Hughes, for example, the sensor holds a 3600-pound granite block level for 15 hours during the final testing of accelerometers for the inertial guidance system of the U.S. Navy's Poseidon missile -- despite vibrations, temperature variations, tides and earth tremors.

Creating a new world with electronics

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LETTERS

Sirs:

For a number of years I have had to face the problem of telling my students of the absurdity of having the rods and cones of the retina point away from the source of light. This apparently senseless scheme forces the image to filter through at least three layers of cells before it is neurally encoded. I have searched in vain for an answer to this enigma. In spite of the fact that he does not mention the problem, Richard W. Young in his article "Visual Cells" [Scientific American, October] provided a likely solution for it.

If the rods and cones were oriented toward the source of light, the disks of the rods would slough off into the vitreous humor or the fluid medium through which the image must travel. It is eminently probable that the humor would become very murky in a relatively short period of time. By having the rods point into the epithelial cells the discarded disks can be disposed of rather quickly and not interfere with the image in the process.

It seems that, given the necessity of continually regenerating rods, Nature's Architect has once again displayed infinite wisdom and provided us with the best of all possible designs.

Thaddeus M. Cowan

Department of Psychology
Kansas State University
Manhattan, Kan.

Sirs:

I should like to add some remarks to Dr. N. W. Pirie's question ["Letters," Scientific American, October] relating to the C-shaped cranks in the article "Medieval Uses of Air," by Lynn White, Jr. [Scientific American, August].

In medieval days and well beyond, machinery both large and small was built in freehand fashion following the pictures in a *Theatrum Machinarum,* or perhaps just recollections of something seen. There were neither dimensioned drawings nor other modern aids such as bending dies, jigs and fixtures.

The critical dimension of a crank is its radius, or throw. If we think of the medieval blacksmith making a crank from a round (wrought) iron bar by giving it two right-angle bends in the same plane, he will find it difficult to meet a specified crank radius, since the necessary "bend allowance" will depend on the temperature and diameter of the iron, the corner of the anvil around which the bend is being made and the speed with which he works. When the smith has finished, he has a crank whose throw, correct or not, is fixed; it cannot be changed without reheating one bend, straightening it and trying again.

On the other hand, if the crank is curved—C-shaped, as Dr. Pirie puts it—the crank throw is easily adjusted by closing or opening the ends of the C: closing the C shortens the throw, opening the C increases it. In other words, the C-shaped wrought-iron crank is readily adjusted to the proper radius.

The length (throw or radius) of the crank enters into what the kinematicians call the "Grashof criterion," a relation dealing with the lengths of all links of the mechanism (1883). If the proportions are correct, then the shortest link, the crank, will rotate as hoped for. We may speculate that the old-time machine designer and builder appreciated the C-shaped crank for its easy adjustability and took the aesthetics as they came.

The curved and particularly S-shaped spokes of later cast-iron wheels reflect the fact that solidifying cast iron shrinks about an eighth of an inch per foot. With three different masses of iron—compact hub, relatively light spokes and heavy rim of large circumference—cooling and becoming rigid at quite unequal rates because of not only their different volumes but also their surface areas, curved spokes will flex instead of tearing or crushing. It may be that the old "experts" who thought that the curves were without function were themselves without shop experience or observation.

Richard S. Hartenberg

Professor of Mechanical Engineering
Northwestern University
Evanston, Ill.

Sirs:

Martin Gardner's interesting review on the wheel in "Mathematical Games" [Scientific American, September] is not correct in stating "it seems surprising that evolution never hit on the wheel as a means for making animals go."

Many unicellular animals as well as circulating cells in larger organisms often use rotation (along one or several of their axes) to move about.

Intracellular organelles, particularly the nuclei of mammalian cells, have been shown by time-lapse cinematography to be able to rotate freely and frequently quite rapidly as part of their metabolic activity.

Could it be, then, that man has once again unwillingly copied from nature?

Abel L. Robertson, Jr., M.D.

Case Western Reserve
School of Medicine
Cleveland, Ohio

Sirs:

When I said that evolution had failed to exploit the wheel for making animals "go," I had in mind wheels that transport animals across ground, but if wheel is taken in a wider sense, then of course Professor Robertson is right. Among imaginary animals the most notable use of wheels in the narrow sense is in L. Frank Baum's *Ozma of Oz,* in which Dorothy and her robot friend Tiktok are attacked by the Wheelers, a race of humanoids who travel on all fours by means of wheeled feet and hands.

Martin Gardner

Hastings-on-Hudson, N.Y.

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ROAD LOVE

RENAULT

50 AND 100 YEARS AGO

DECEMBER, 1920: "Our national budget for the recent fiscal year, which ended July 1, aggregated $5,686,005,-706. Of this vast appropriation only about 1 per cent, or $57,093,661, was devoted to research, educational and developmental activities. To the layman who carefully studies these figures it appears that Congress practices parsimony and economy backside forward when it minimizes the scientific and developmental funds. It is largely through these agencies that the wealth and financial resources of the country at large are increased. To impede their maximum development and operation is to curtail the potential productivity of many industries and allied activities."

"The winner of the Pulitzer Trophy race, held last Thanksgiving Day at Mitchel Field on Long Island, was Lieut. C. C. Mosley of the United States Army Air Service, who piloted the Verville-Packard American-built airplane to victory. The engine of this machine is the Packard 600-horse-power engine, designed by Col. Jesse G. Vincent. The Verville-Packard machine attained a speed of 178 miles per hour, thus marking a new record for American planes and engines. Certain changes are being made in its gasoline feed, in the belief that when these are completed it will be possible to reach a speed well beyond 200 miles per hour and thus break all records."

"The remarkably interesting and important announcement was made in *Flugwelt* that certain German scientists have succeeded in producing synthetic benzine. It has been found that when the coal tar of lignite is heated under high pressure, hydrogen combines with the hydrocarbides contained in coal tar. The general statement is made that it has been found possible to produce hydrocarbides analogous to those found in petroleum by means of high pressure."

"We note in a dispatch to the press from Washington that there was brought to the attention of Secretary of the Navy Daniels the suggestion of Senator Borah for an agreement between the U.S., Great Britain and Japan to curtail naval construction for a period of five years. Commenting upon this, the Secretary is reported to have made the extraordinary statement that an alliance of this kind would be interpreted as an attempt by these three nations to dominate the world. The General Board of the Navy recommends that in these times of peace, when practically the whole of the world has quit warship building, we not only complete 18 capital ships and other ships that we are building but also that Congress authorize four more capital ships, 30 10,000-ton cruisers, eight gunboats, 18 destroyer leaders, 12 long-radius mine-laying submarines, six cruising submarines, four aircraft carriers, three destroyers and three submarine tenders, or some 90 ships in all. And so the merry game goes on, while the Secretary of the Treasury plays his accompaniment, by suggesting that the income tax for the majority of us good people be raised from 4 to 6 per cent."

DECEMBER, 1870: "In bringing out *Lay Sermons, Addresses, and Reviews* by Thomas Henry Huxley the publishers, D. Appleton & Co., have reprinted on very poor paper and in inferior style the famous lectures delivered before popular audiences in England by Professor Huxley. Few books of greater importance have appeared within a long period. The topics discussed relate to the origin of life, scientific education and the most advanced theories of the new school of thinkers in England. However slow many readers may be to accept the reasoning of the writer, every one must be swift to acknowledge that the subject is handled in faultless language and the most captivating style."

"The most recent accounts we have of the proceedings of the Japanese place them in strong contrast to the 'Western barbarians.' In Japan bridges are being built; in France they are being blown up. In Japanese waters numerous fixed and floating lights and buoys are being provided for the guidance of navigation; in the Baltic they are being removed and taken up. In the one quarter of the world the desire is that the safety of the ships may be secured; in the other, that they may be destroyed. The municipal council of Osaka is carrying out an efficient system of paving and drainage, is macadamizing their suburban roads and adorning the city by planting 600 trees. Paris, the fairest city of the West, is being made a great pest and charnel house by war. The princes of Japan are fitting up improved machinery at their coal mines and building cotton mills; the princes of Prussia are 'assisting' in the destruction of grand and venerable cathedrals, splendid libraries and the most beautiful works of nature and art, and are making 'requisitions' for bread and wine to a ruined and starving French population."

"M. Laurent has invented a new type of incendiary rocket based on the firing of a chamber filled with petroleum oil, which falls like a sheet and continues burning. He has christened it the fusée Satan. Some interesting experiments were conducted recently with this weapon at St. Cloud. In less than 10 minutes a considerable space of ground was covered with a sea of fire. A committee composed of superior officers of artillery presided over the experiments, and the general at their head declared himself appalled at the terrible nature of this engine of destruction. The committee has stated that in its opinion no civilized nation could make use of these rockets except for reprisal. However this may be, the Committee of National Defense has given the inventor a large building and 200 workmen and has ordered the immediate manufacture, on a large scale, of Satan rockets."

"Dr. H. C. Wood, Jr., has written an essay, which he read before the American Philosophical Society, in which he records some experiments with an article of hemp grown in Kentucky. He took an alcoholic extract made from the dried leaves, swallowing at a dose nearly all of the product of an ounce and a half of the leaves, with the effect of profound hemp intoxication. Other trials he has made with it convince him that it has more power than the hemp brought from India. The native plant will always be more reliable than the imported, from the certainty of freshness, while the cost of it is hardly anything."

"We publish elsewhere in this issue the prospectus of the New York *Times,* a journal we are happy to recommend to our readers. The *Times* is very ably edited, and contains all the intelligence of the day—literary, political, social and financial. As a family journal it is particularly good. No parent need fear to allow his children to read the *Times*."
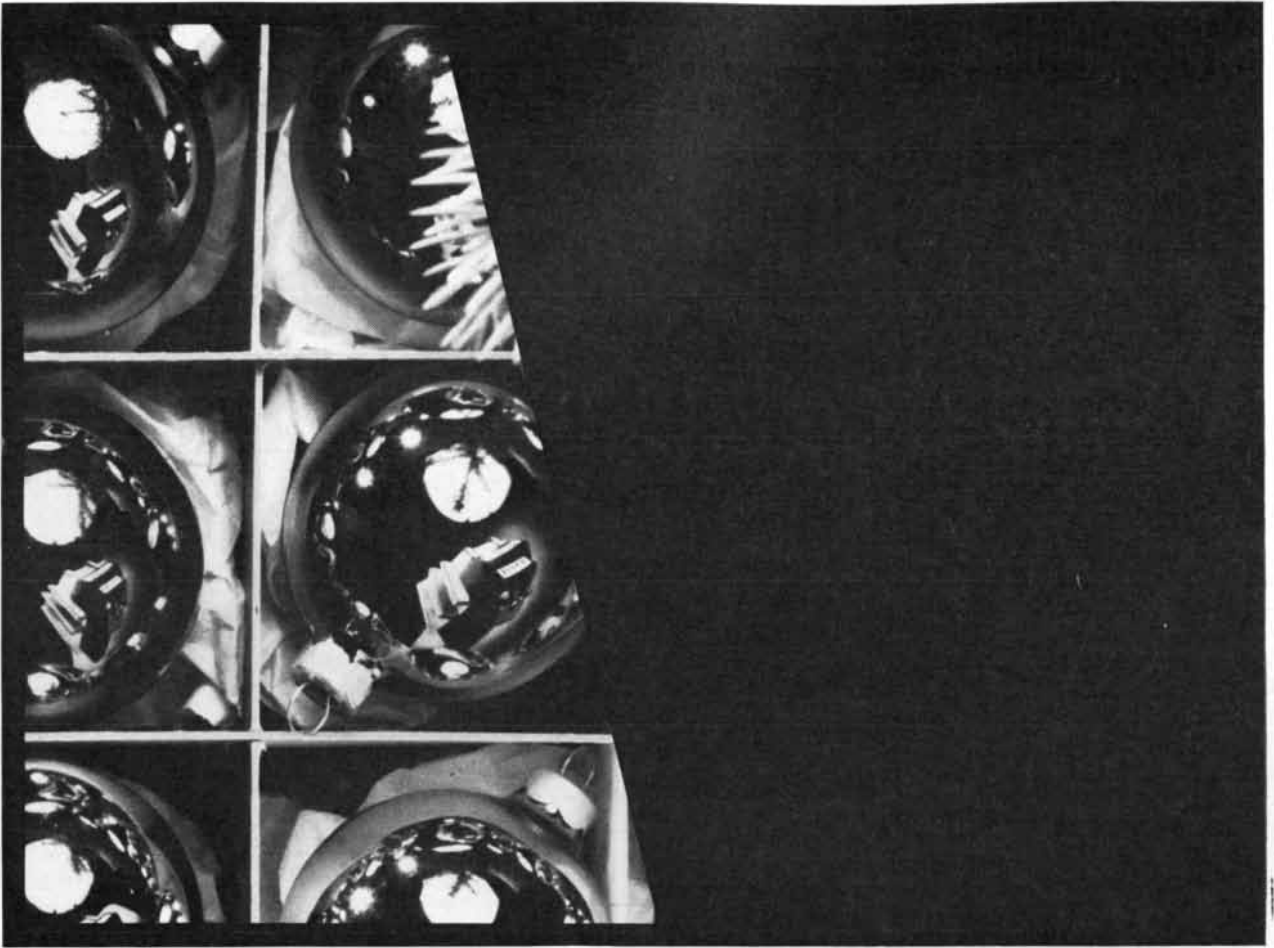
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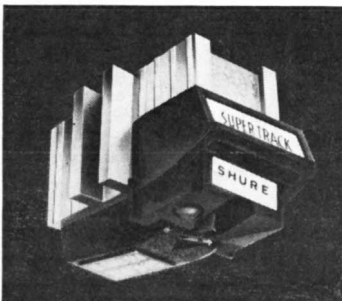
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THE AUTHORS

GIFFORD B. PINCHOT ("Marine Farming") is professor of biology at Johns Hopkins University. "I've worked in medicine, physiology, bacteriology, biochemistry and now in marine agriculture," he writes. "My hobbies are even more widespread. The one that's pertinent to this article is sailing, which I started at the age of 13 by going with my father on a trip to the South Pacific in a 150-foot schooner. Fortunately my wife also likes to sail, and we've had cruising boats since we were married in 1936. We've done a good deal of racing, having been in eight Bermuda races, and I did one transatlantic race. Together we also cruised from the U.S. to Norway and England and, more recently, to Tahiti and back. We also like to ski and fly, and I make some furniture in between. It always makes me feel a little guilty to list so many hobbies, but I do feel that we come this way only once and it's silly not to get as much as we can out of the experience." Pinchot was graduated from Yale University in 1938 and obtained his M.D. at Columbia University in 1942. He went to Johns Hopkins in 1958 after several years of teaching and research at Yale.

E. MARGARET BURBIDGE and C. ROGER LYNDS ("The Absorption Lines of Quasi-stellar Objects") are respectively professor of astronomy at the University of California at San Diego and associate astronomer at the Kitt Peak National Observatory. Mrs. Burbidge, whose husband is the astronomer Geoffrey R. Burbidge, was graduated from University College London and took her Ph.D. in astrophysics at the University of London, where she worked until coming to the U.S. in 1951. In 1964 she was elected a Fellow of the Royal Society. Lynds, who was graduated from the University of California at Berkeley in 1952, obtained his Ph.D. there while associated with the university's Lick Observatory. He was at Lick and then at the National Radio Astronomy Observatory until he took his present position in 1961.

RICHARD M. WARREN and ROSLYN P. WARREN ("Auditory Illusions and Confusions") are respectively professor of psychology and professor of zoology at the University of Wisconsin at Milwaukee. They write: "R. M. received his undergraduate degree at the City College of New York and R. P. at

New York University. We were married in 1950 and took a weekend break from our graduate studies. R. M. received his Ph.D. in organic chemistry from N.Y.U. in 1951, R. P. her Ph.D. in physiology from N.Y.U. in 1954. R. M. worked as a research chemist with the General Foods Corporation. A year's trip around the world made up for no honeymoon and marked the transmutation of R. M. from chemist to psychologist." They worked at the University of Cambridge for two years. On their return to the U.S., Richard Warren worked at the National Institutes of Health while Roslyn Warren taught at Howard University. From 1961 to 1964, when they went to Milwaukee, they taught at an experimental college in Illinois.

R. G. EDWARDS and RUTH E. FOWLER ("Human Embryos in the Laboratory") are husband and wife as well as scientific colleagues. Edwards is reader in physiology at the University of Cambridge. After graduation from the University College of North Wales he obtained his Ph.D. at the University of Edinburgh. He left Edinburgh in 1957 to spend a year at the California Institute of Technology. For the next five years he was at the National Institute for Medical Research in London; he went to Cambridge in 1963. He received a D.Sc. from the University of Wales in 1962. Miss Fowler took her undergraduate and doctoral degrees in genetics at the University of Edinburgh in 1952 and 1956 respectively. She and Edwards were married in 1956; they have five children.

PHILIP BAUMEISTER and GERALD PINCUS ("Optical Interference Coatings") are respectively associate professor in the Institute of Optics at the University of Rochester and manager of optical-coating facilities at Boxton-Beel, Inc., a New York–based firm that is part of the Swedish company AGA. Baumeister was graduated from Stanford University in 1950 and obtained his Ph.D. at the University of California at Berkeley in 1959. He recently spent a year's leave of absence at the Institute for Optical Research in Stockholm, where he studied the optical properties of dielectric-metal mixtures. Pincus received his bachelor's and master's degrees in metallurgy at Columbia University. For several years thereafter he worked in the electrooptics group of the Sperry Gyroscope Company.

W. F. LOOMIS ("Rickets") is professor of biochemistry at Brandeis Univer-

sity. After acquiring his B.S. and M.D. degrees at Harvard University he joined the Office of Strategic Services to organize medical work behind Japanese lines in China in World War II. On his return he held research fellowships at Columbia University and the Massachusetts General Hospital, taught biology at the Massachusetts Institute of Technology and then became assistant director of the Division of Natural Sciences of the Rockefeller Foundation. From 1952 to 1964 he operated a private laboratory, which he built himself; it was the fourth such laboratory in his family since his great-grandfather's time. Loomis is an ardent skier and a mountain climber; he was a member of the team that in 1936 climbed the 25,645-foot peak of Nanda Devi in the Himalayas, accomplishing the highest ascent that had been made up to that time.

JOSEPH J. BECKER ("Permanent Magnets") is with the Metallurgy and Ceramics Laboratory of the Research and Development Center of the General Electric Company. "In 1943," he writes, "I received the bachelor's degree from what was then the Harvard Engineering School. After a couple of years in the Navy fixing radar equipment I returned to Harvard in applied physics, receiving the master's degree in 1947 and the Ph.D. in 1950. Thereupon I came to the General Electric Research Laboratory, now part of the Research and Development Center, and have remained ever since, having found it a consistently stimulating place with a wide variety of basic, applied and exploratory topics ever present. My chief avocation is performing and listening to music. I also enjoy color photography."

THEODORE H. SAVORY ("The Mule") has for 12 years been vice-principal of Stafford House, a tutorial college in Kensington, England. Earlier he spent 40 years as a public schoolmaster, introducing the teaching of biology to Malvern College and later becoming senior biologist at Haberdashers' Aske's School. He has written a number of articles for SCIENTIFIC AMERICAN, mostly in the area of his chief interest, the arachnids, which is the group of organisms that includes spiders, scorpions and daddy longlegs. He notes that he was "impressed by the character of mules" at the time of World War I. Savory, who was graduated from the University of Cambridge in 1918, is also interested in linguistics: he is the author of *The Language of Science* and *The Art of Translation*.

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Marine Farming

Man gets food from the sea essentially by hunting and gathering. Yet the farming of fish and shellfish has been pursued for some 2,000 years, and its potentialities are far from being exhausted

by Gifford B. Pinchot

A major concern of modern man is the possibility that the earth will not be able to produce enough food to nourish its expanding population. A particularly controversial issue is the question of how much food can ultimately be obtained from the sea. It is argued on the one hand that, on the basis of area, the oceans receive more than twice as much solar energy—the prime source of all biological productivity—as the land. This suggests that the oceans' potential productivity should greatly exceed the land's. On the other hand, most of the sea is biologically a desert. Its fertile areas are found where runoff from the land or the upwelling of nutrient-rich deep water fertilizes the surface water and stimulates the growth of marine plants, the photosynthetic organisms on which all other marine life depends. Even at today's high level of exploitation the fisheries of the world provide only a small fraction of human food needs, and there is some danger that they may supply even less in the future because of overfishing.

Does this mean that there is no hope of increasing our yield of food from the sea? I do not think so. It does mean, however, that instead of concentrating exclusively on more efficient means of fishing we must also learn to develop the potential of the oceans by farming them, just as early man learned that farming rather than hunting was the more effective method of feeding a human population. The purpose of this article is to examine briefly the contribution marine farming now makes to our food supply, and to consider some possibilities for its future role.

Marine farming has a long history. The earliest type of farming was the raising of oysters. Laws concerning oyster-raising in Japan go back to well before the time of Christ. Aristotle discusses the cultivation of oysters in Greece, and Pliny gives details of Roman oyster-farming in the early decades of the Christian Era. By the 18th century the natural oyster beds in France were beginning to be overexploited and were saved only by extensive developments in rearing practices.

Carp (*Cyprinus carpio*) were commonly raised in European freshwater ponds in both Roman and medieval times. Records concerning the regulation of salt or brackish ponds for raising milkfish (*Chanos chanos*) in Java date back to the 15th century. Carp and milkfish are both herbivores that thrive on a diet of aquatic plants. Oysters, as filter-feeders, can also be loosely classified as herbivores.

Oysters are particularly appropriate for marine farming because their spawn can be collected and used for "seeding" new areas of cultivation. An oyster produces more than 100 million eggs at a single spawning. The egg soon develops into a free-swimming larval form, known as a veliger, which settles to the bottom after two or three weeks. Veligers attach themselves to any clean surface and develop into miniature adult oysters, called "spat" because oystermen once believed the adult oysters spat them out. At this point the oyster farmer enters the picture. He distributes a supply of "cultch": clean material with a smooth, hard surface, such as old oystershell or ceramic tile. The cultch receives a "set" of spat and is then used to seed new oyster beds.

The bottom is prepared for seeding by removing as many natural enemies of the oyster as possible. In the eastern U.S. this is usually done by dragging a rope mat along the bottom to sweep the area clear of starfish, one of the major predators. In France, where more intensive labor is employed, the spat are usually planted on the exposed bottom of an estuary at low tide. The predators are removed by hand and the oyster bed is fenced to prevent their return. The oysters are moved after a few years to *claires,* special fattening areas where the water is rich in diatoms. This produces

NUTRIENT-RICH WATER from the depths of the Pacific appears dark blue in the photograph on the opposite page. Land (*left*) is the coast of Taiwan as seen from *Gemini X.* Natural upwellings such as this are caused by winds or currents. Areas of continuous upwelling are extremely productive fishing grounds because the organisms eaten by fish flourish in them.

15

oysters of improved taste and color. When the oysters have reached marketable size, they are moved again to shallower water, where they must stay closed for longer periods at low tide. The French oystermen believe this treatment prepares the oysters for their trip to the market.

A significant advance in oyster-farming is the use of suspension cultures. This method, pioneered in Japan, is now spreading to the rest of the world. The spat are collected on shells that are strung in long bundles and immersed in tidal water. The strings, which do not touch the bottom, are sometimes attached to stakes but more generally are attached to rafts. The suspension method has a number of advantages over growth on the bottom. The oysters are protected from predators and from silting, and they feed on the suspended food in the entire column of water rather than being limited to what reaches the bottom. The result is faster growth, rounder shape and superior flavor.

In small areas of Japan's Inland Sea suspension cultures of oysters annually yield 46,000 pounds of shucked meats per acre of cultivated area. This does not mean that one can multiply the total acreage of the Inland Sea by this figure to estimate the potential productivity of the area. Tidal flow allows the anchored oysters to filter much larger volumes of water than surround them at any given time. In addition, inshore waters are generally more productive than those farther from land. The figure does illustrate, however, the production of meat that is possible with our present farming practices in inshore waters.

Luther Blount of Warren, R.I., has tested oyster suspension cultures in Rhode Island waters over the past several years, using spat set on scallop shells. Blount spaces seven scallop shells well apart on each suspension string. At the end of seven months' growth he harvested one group of suspended oysters from 3,200 square feet of float area. The oysters weighed nearly 40,000 pounds and yielded 2,500 pounds of oyster meat.

His experience suggests that the coastal waters of the eastern U.S. might yield more than 16,000 tons of meat per square mile of float per year.

Although the farming of oysters in suspension cultures is a comparatively recent development, the same technique has long been used in Europe to raise mussels. The Bay of Vigo is one of the many Spanish ports where acres of mussel floats are a common sight. French and Italian mussel growers are less inclined to use rafts. Their mussel strings are usually suspended from stakes set in the estuary bottom.

John H. Ryther and G. C. Matthiessen of the Woods Hole Oceanographic Institution have studied the yields obtained by the mussel farmers of Vigo. The annual harvest produces an average of 240,000 pounds of mussel meat per acre. This is equivalent to 70,000 tons of meat per square mile of float, or better than four times the yield of oysters in suspension cultures in the U.S. and Japan.

The farming of fish is more difficult than the farming of bivalves for at least
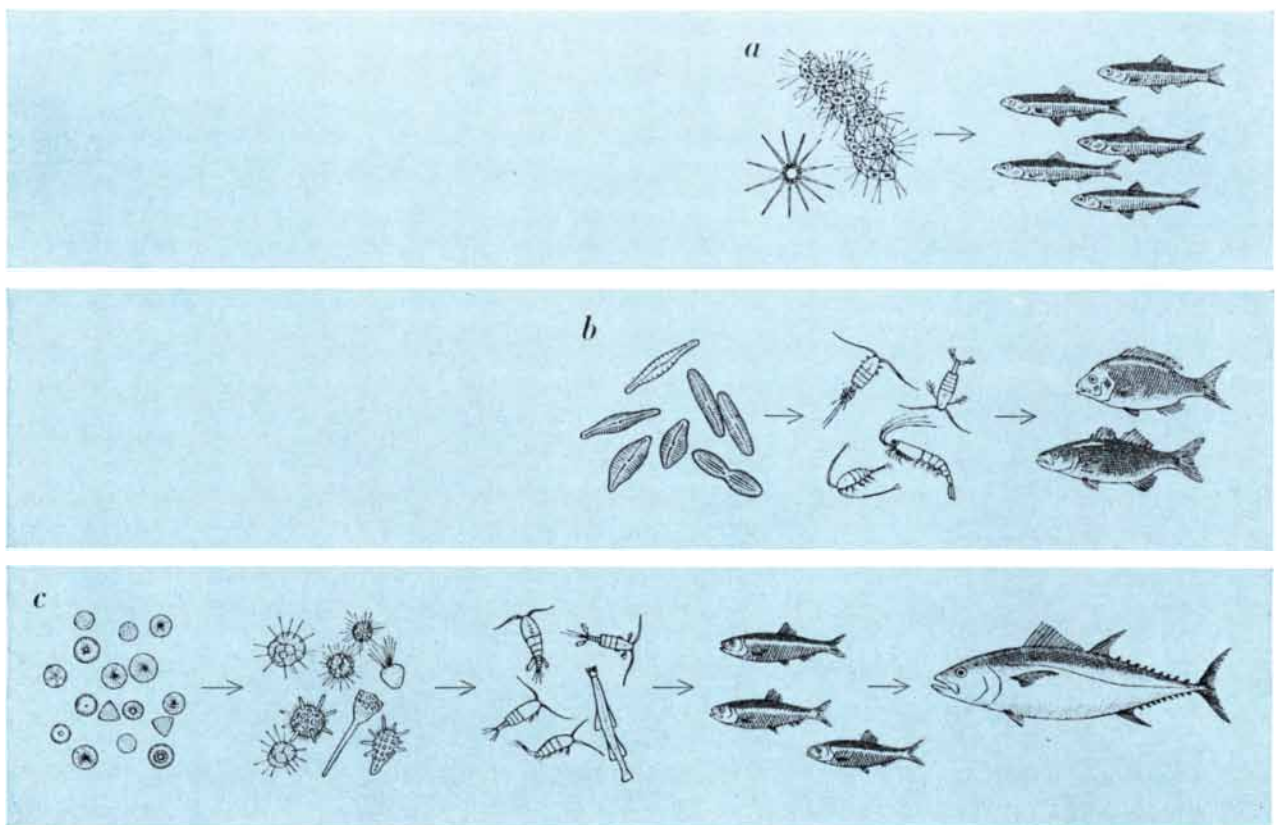
HIGH PRODUCTIVITY of upwelling areas and coastal waters, in contrast to the low productivity of the open sea, is not due only to greater mineral enrichment. In upwelling areas (a) the phytoplankton at the bottom of the food chain are usually aggregates of colonial diatoms that are large enough to feed fish of exploitable size. As a result the food chain is very short, with an average of 1.5 steps. The food chain in coastal water (b) is longer, averaging 3.5 steps. In the open sea (c), where phytoplankton at the bottom of the chain are widely scattered, single-celled diatoms, five steps are needed to produce exploitable fish and the energy transfer at each step is low in efficiency. The length of the chains was calculated by John H. Ryther of the Woods Hole Oceanographic Institution.

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two reasons. First, the fish, being motile, must be held in ponds. Second, the salt-water species that are most commonly farmed—milkfish and mullet (*Mugil*)—breed only at sea. This means that the fry have to be caught where and when they occur naturally, and in some years the supply is not adequate. Furthermore, unwanted species and predators have to be sorted out by hand, with the inevitable result that some of both are introduced into the ponds along with the desired species.

In spite of such handicaps pond farming is remarkably productive. In the Philippine Republic, for example, the annual milkfish harvest is estimated at some 21,000 tons and the productivity of the ponds averages 78 tons per square mile. A comparable estimate for the annual productivity of free-swimming fish in coastal waters, as calculated by Ryther and Matthiessen, falls between six and 17 tons per square mile. In the Philippines, moreover, it is not customary to enrich the pond waters artificially, a process that accelerates the growth of the fishes' plant food. In Taiwan, where milkfish ponds are fertilized, the average annual yield is 520 tons per square mile, and in Indonesia, where sewage is diverted into the ponds in place of commercial fertilizer, the annual yield reaches 1,300 tons per square mile.

Fish farming in Asia is still a long way from reaching its maximum potential. The United Nations Food and Agriculture Organization has calculated that more than 140,000 square miles of land in southern and eastern Asia could be added to the area already devoted to milkfish husbandry. Even if this additional area were no more productive than the ponds of Taiwan, its yield would be more than today's total catch from all the world's oceans. Assuming an adequate supply of milkfish fry, such an increase could be achieved without any technological advance over present methods of pond farming. Even the fry problem may be close to solution. Mullet, a largely herbivorous fish, is now extensively farmed not only in Hawaii and China but also in India and even in Israel. Recently it has proved possible to breed mullet in the laboratory, which brings closer the prospect of mullet hatcheries and a steady supply of mullet fry.

In looking for ways to increase the potential yield of fishponds throughout the world, we are faced with two problems. The first is whether or not we can overcome the sanitary and aesthetic ob-

OYSTER FARM at Port Stephens in New South Wales in Australia is seen at low tide. The rack-and-stick cultivation system was adopted after depletion of oyster beds in the 1870's.
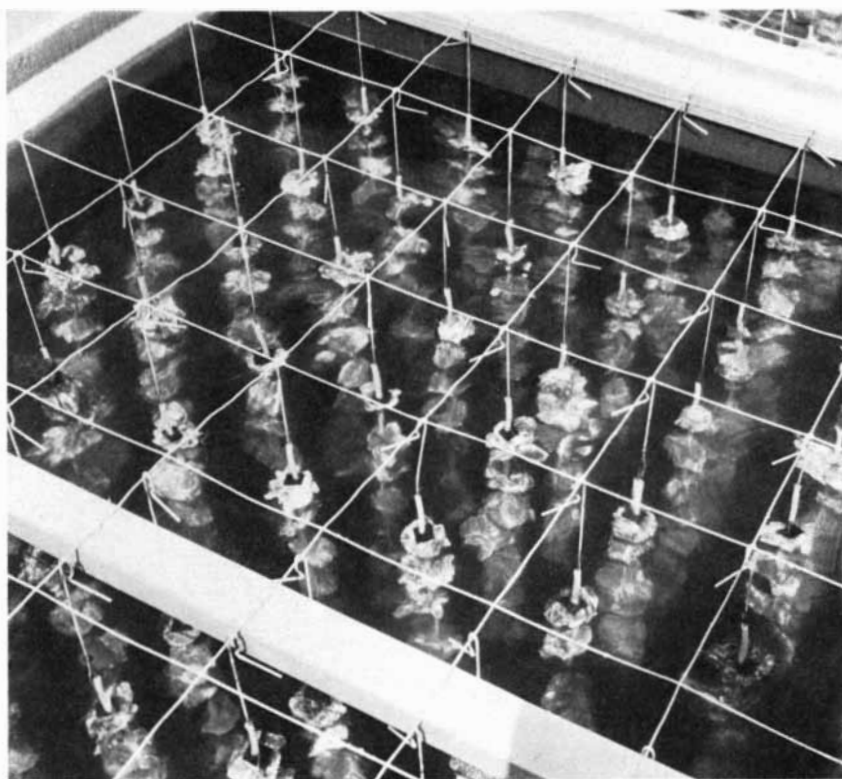
SUSPENSION CULTURE of young oysters dangles from a float in a Rhode Island oyster pond. Each string supports a series of scallop shells set with oyster spat, a product used commercially for seeding conventional oyster beds. Luther Blount, who is farming the oyster suspension cultures experimentally, has recorded four-year weight gains of 1,000 percent.

jections to using sewage as a growth stimulant. This is a complex question, but it is worth noting that some practical progress is being made by transferring shellfish from polluted areas to unpolluted ones for a period of "cleaning" before shipment to market.

An equally important question is to what degree commercial fertilizer could increase productivity. Oysters or mussels suspended from rafts in small ponds should provide a simple test organism for such experiments, and they are particularly appropriate because of their high natural yields.

The effect of adding commercial fertilizer to Long Island Sound water has been studied by Victor L. Loosanoff of the U.S. Fish and Wildlife Service. He wanted to produce large amounts of marine plants as food for experiments in rearing oysters and clams. He found marked stimulation of plant growth, but the zooplankton—the marine animals in the water—also grew and ate the plants, thus competing with the shellfish for food. After trying various methods of inhibiting the zooplankton's growth, Loosanoff finally came to the use of pure cultures of the plants, but this would be a very expensive practice on a commercial scale.

The growing of both marine plants and marine animals in a pond could be rewarding, and the zooplankton could be converted from a pest to an asset by adding an organism that feeds on them. Rainbow trout might fill this requirement: they are carnivorous, adapt readily to salt water and are said to grow faster and have a better flavor than when they live in fresh water. In addition they are readily available from hatcheries and have a good market value. To dispose of the inevitable organic debris sinking to the bottom of the pond one might add clams and a few lobsters, since both are in demand and their young are being reared in hatcheries and could be obtained.

It seems to me of the utmost importance that we follow the principles of ecology in our efforts to develop marine farming, by working with nature to establish balanced, stable communities rather than by supporting large single crops artificially, as we do on land, with what are now becoming recognized as disastrous side effects. Perhaps the single most exciting challenge we have in marine farming is this opportunity to make a new start in the production of food, utilizing the ecological knowledge now available.

If the results of the pond experiments are satisfactory, it is technically feasible to consider applying fertilizer to estuaries or even to the open ocean. The mechanical problem here is that the applied fertilizer sinks to the bottom in estuaries and tends to become absorbed by mud, and in the open ocean it simply sinks below the zone where the marine plant life grows. A solution for this problem would be to combine the fertilizer with some floating material that would disintegrate and liberate it slowly. The political and legal problems of controlling the harvest of the crop seem more difficult than the technical one of developing floating fertilizer.

Beyond the continental shelf in the open ocean the surface water is normally poor in nutrients and as barren as any desert on land. As irrigation projects have frequently shown, the addition of water makes the desert bloom. Adding nutrients to the ocean has much the same effect. There is, however, a significant
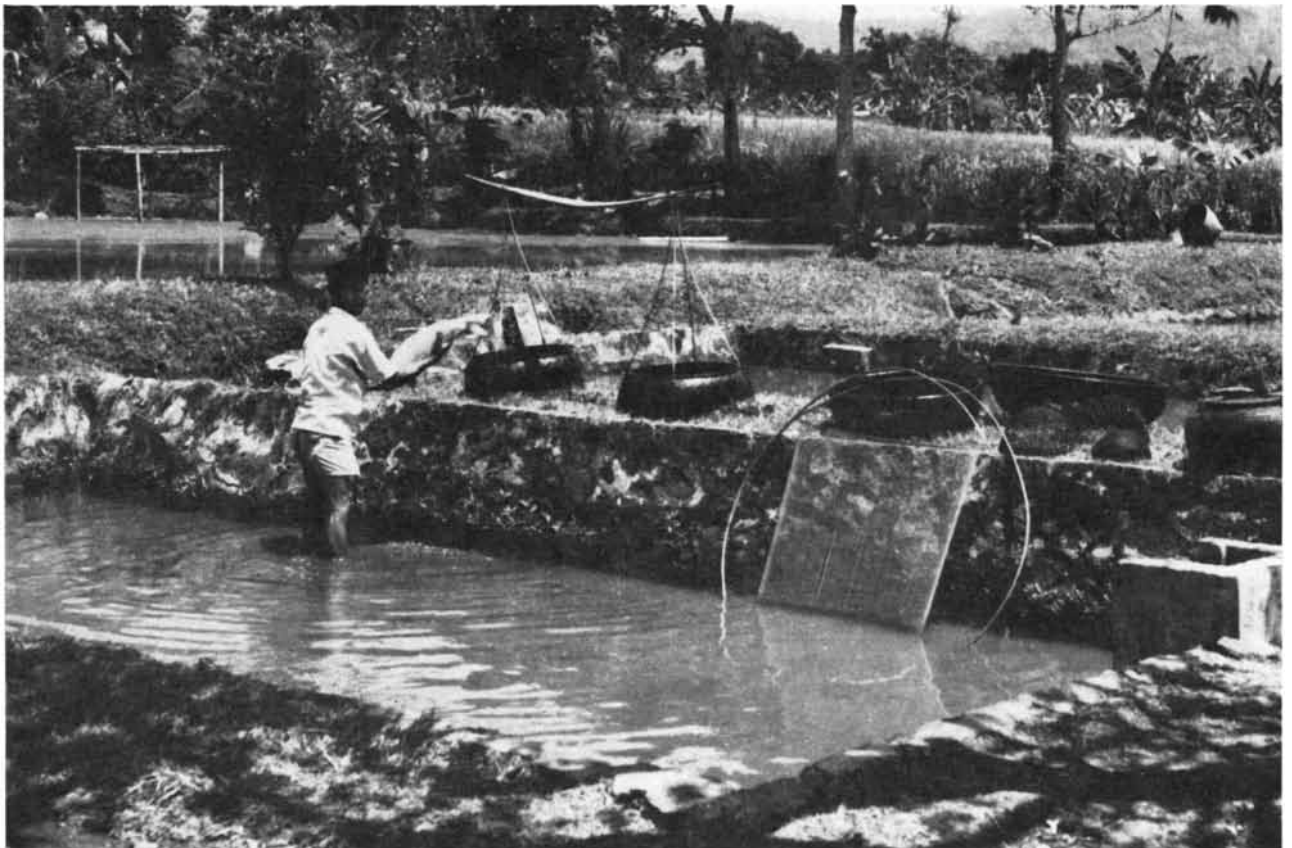
ARTIFICIAL PONDS are widely used in Asia to raise fish fry, netted at sea, until they reach edible size. The ponds seen here are in Indonesia, where the use of sewage as fertilizer for pond algae brings a harvest that is equal to 1,300 tons of fish per square mile.

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difference between the two measures. The availability of fresh water may ultimately limit our agricultural output on land, but the deep ocean holds an immense supply of nutrients that is constantly being renewed.

The concentration of nitrogen and phosphorus compounds in the ocean reaches its maximum value at depths of from 2,000 to 3,000 feet below the surface. That is well below the region penetrated by sunlight, making the nutrients unavailable for plant growth. What then is the practical possibility of bringing these nutrients to the surface? If we were able to do it, would the number of fish increase? The answer to the second question can be found in nature. The upwelling of nutrient-rich deep water occurs naturally in some parts of the ocean, and the world's most productive fisheries are found in these areas. One of the best-known of these is the Peru Current on the west coast of South America. Along the shores of Chile and Peru the southeast trade winds blow the surface water away from the land, with the result that it is replaced by deeper water containing the nutrients needed for plant growth. In 1968, 10.5 million tons of fish—mostly anchovies—were harvested in an area 800 miles long and 30 miles wide along this coast. That is a yield of 440 tons per square mile of ocean surface. If, as seems likely, an equal quantity of fish was taken by predators, it means that this area of natural upwelling approaches the productivity of the heavily fertilized Asiatic fishponds. Incidentally, it far surpasses the production of protein by the raising of cattle on pastureland, which Ryther and Matthiessen give as between 1.5 and 80 tons per square mile.

The Peru Current demonstrates that bringing nutrient-rich water to the surface leads to an enormous increase in fish growth. In fact, the areas of natural upwelling, which comprise only .1 percent of the oceans' surface, supply almost half of the total fish catch, whereas the open oceans, where upwelling does not occur, account for 90 percent of the surface and yield only about 1 percent of the catch. In other words, natural upwelling increases the productivity of the open ocean almost 50,000-fold in terms of fish actually landed.

It would obviously be worthwhile to stimulate upwelling artificially, not only because of the probability of high fish yields but also because the stable ecological communities that inhabit the natural areas of ocean upwelling are models of efficient food production for man, with none of the drawbacks—such as herbicides, pesticides, pollution and excessive human intervention—that such highly productive systems usually entail ashore.

To achieve artificial upwelling we need first some kind of container. Deep water is cold and therefore dense, and without a container it would sink again, taking its nutrients with it. We also need to surround the fish we hope to grow, not only to protect them from predators and to simplify harvesting, but even more important to keep them from being caught by fishermen who have not paid for the upwelling. We also need a land area where the pumping and processing activities can be located and of course a supply of deep water nearby.

There are hundreds of coral atolls in the Pacific and the Indian Ocean that meet these specifications. Rings of coral reef surrounding shallow lagoons, atolls vary in area from less than a square mile to more than 800 square miles. Low is-


FRESHWATER FISH, the herbivorous carp, has been reared in ponds around the world for more than two millenniums. The carp in the photograph are from a pond in Burma. The 1968 crop of carp and carplike fishes in neighboring China totaled 1.5 million tons.
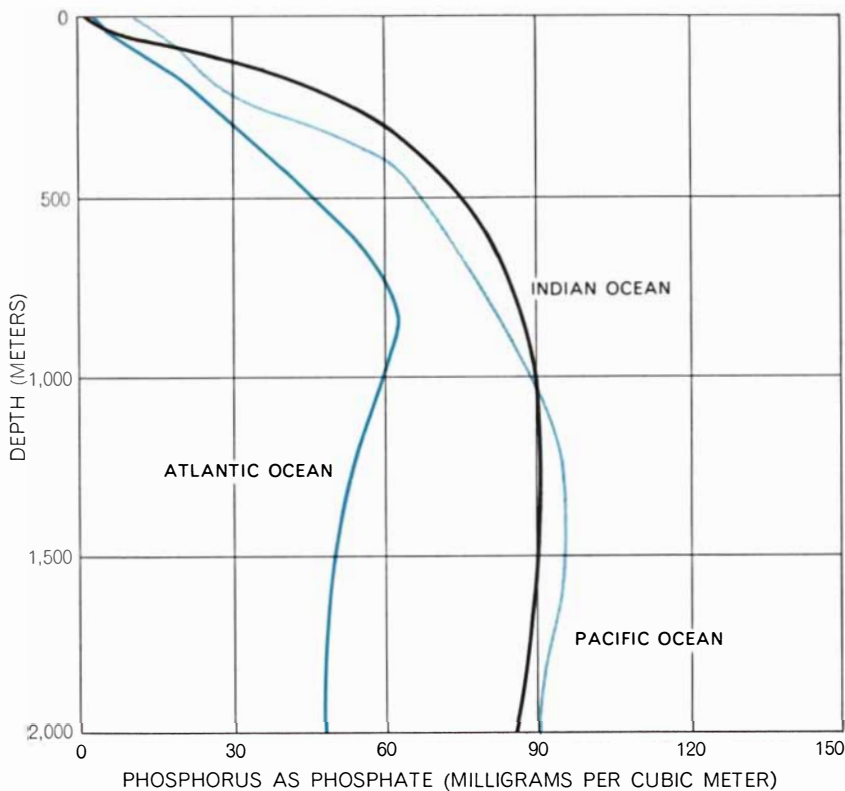
PHOSPHATE IN SEAWATER, present only in small amounts at the surface, increases in the deeper zones and reaches a near-maximum concentration of 90 milligrams per cubic meter in the Pacific and Indian Ocean and about 60 milligrams in the Atlantic at a depth of 1,000 meters. Data are from a study by Lela M. Jeffrey of the University of Nottingham.
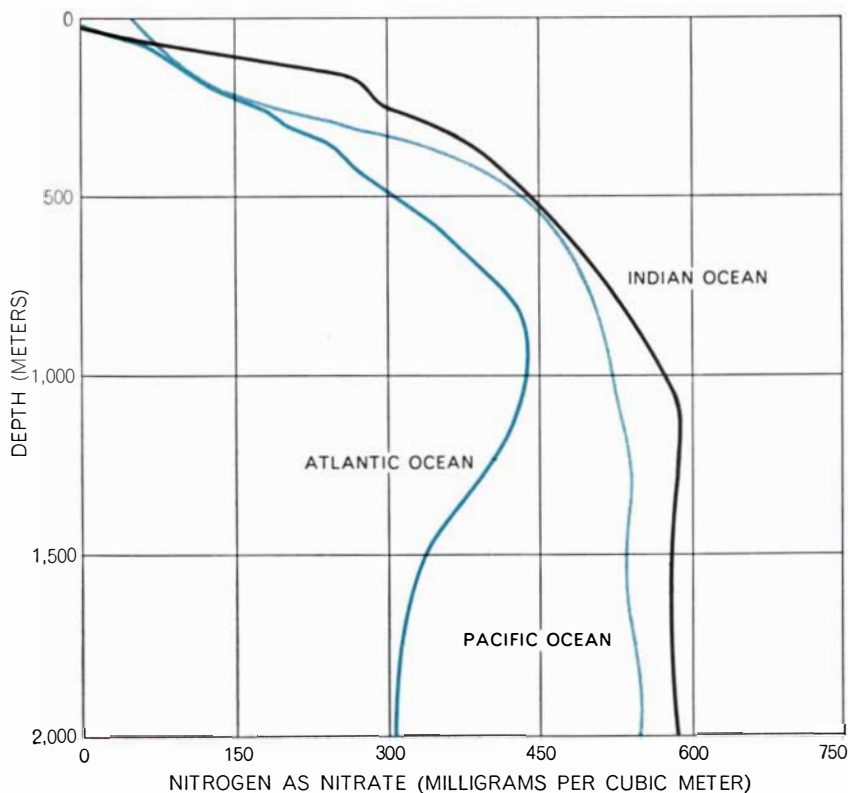
NITRATE IN SEAWATER is also scarce at the surface but approaches its maximum concentration at 1,000 meters. Again the Atlantic has the least; data are from Miss Jeffrey.
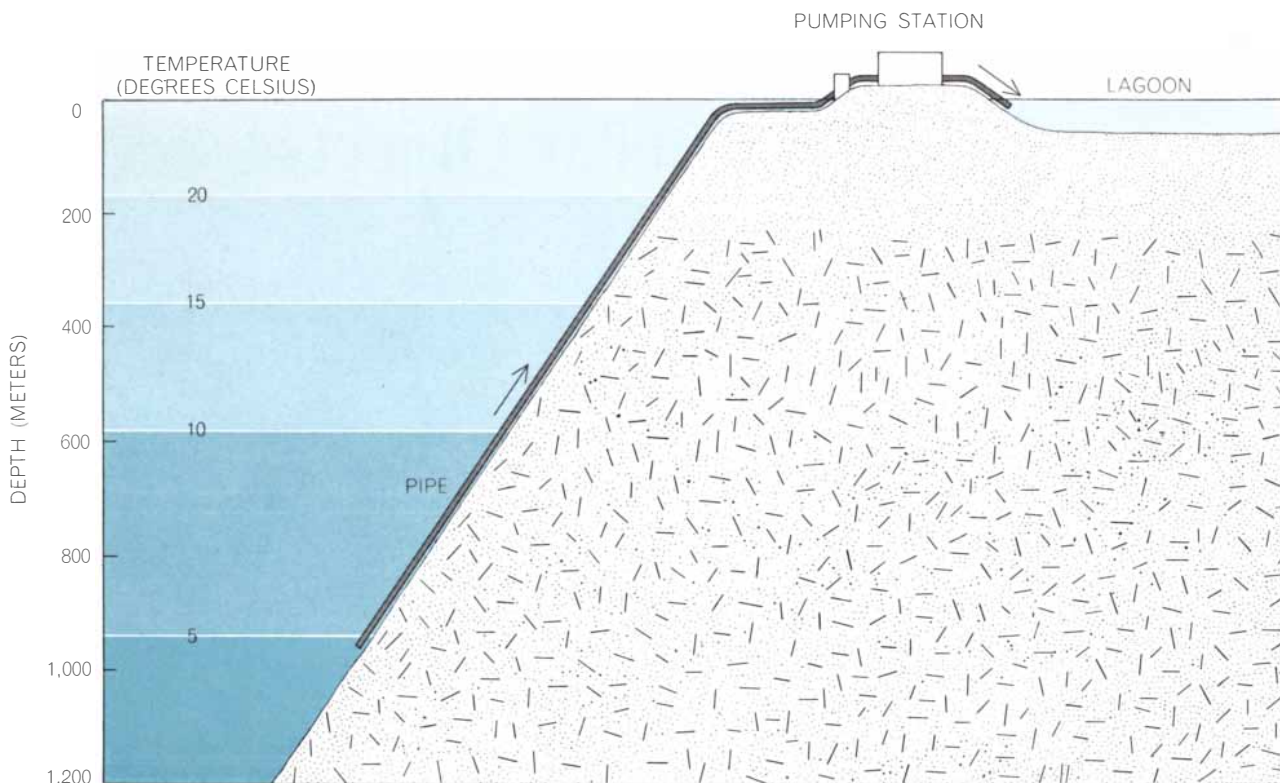
lands are often found on the encircling reef, and since atolls are the remains of sunken volcanic peaks topped with coral they are steepsided, with deep water generally less than a mile from the reef itself. The trade winds blow over many of these islands and carry energy enough to bring deep water to the surface; that, after all, is the mechanism in many natural upwelling areas. There is even a built-in stirring system: the trade winds produce a downwind current on the lagoon surface that is matched by a return current near the bottom of the lagoon.

Given an atoll lagoon filled with nutrient-rich water from the deeps, what kinds of marine plants and animals should be grown in it? Perhaps the simplest procedure would be to leave the passages between lagoon and ocean open and allow nature to take its course in introducing new species. A balanced and stable community such as the one found in the Peru Current might establish itself. If it did not, colonies of plants and fishes from the Peru Current could be introduced in the hope that they could establish themselves in the new location.

Perhaps a crop of suitably large zooplankton such as krill—the shrimplike animals that are the principal food of the baleen whales in the Antarctic—could be raised in a fertilized lagoon. In that case another particularly interesting experiment might be possible. This would be to determine whether or not baleen whales, particularly the now almost vanished blue whales, could adapt to such a restricted environment. A school of blue whales raised in captivity could be regularly culled for a significant yield in meat and edible oil, and at the same time its existence would protect the species from what now seems to be certain extinction.

We know that blue whales migrate into the tropical Pacific to bear their young. The migrants could be followed by attaching radio transmitters to them in Antarctica. Techniques for capturing, transporting and keeping smaller whales have already been worked out. Humpback whales, which are about half the length of blue whales, have been captured at sea by investigators at the Sea Life Park in Hawaii by dropping a net over the whale's head. There is a real possibility that whale farms could be started by capturing pregnant female blue whales and confining them in fertilized atolls.

Artificial upwelling, on a small scale at least, has already been achieved by Oswald A. Roels, Robert D. Gerard and J. Lamar Worzel of the Lamont-Doherty Geological Observatory of Columbia

TEMPERATURE
(DEGREES CELSIUS)

PUMPING STATION

LAGOON

0

200

20

400

15

DEPTH (METERS)

600

10

PIPE

800

5

1,000

1,200

ARTIFICIAL UPWELLING of deep water might be contrived in an atoll setting, as this diagram suggests. The atoll's steep drop to seaward means that the wanted water would be pumped the least possible distance. The central lagoon would provide a catchment basin for the pumped water, retaining its nutrients at or near the surface. The difference in temperature between the surface and the deep water might be used to generate more power than is required for the pumps. A pilot version of this experiment is being conducted by workers in the Virgin Islands, who are pumping deep-sea water ashore and accelerating the growth of phytoplankton in ponds.

University. They have installed on St. Croix in the Virgin Islands a 3½-inch plastic pipe that extends nearly a mile into the Caribbean, enabling them to pump deep water with a temperature of 40 degrees Fahrenheit into small ponds on shore. They find that selected plant life from the seawater off St. Croix grows 27 times faster in water from the pipe than in water from the surface. They are now exploring the possibilities of feeding a variety of marine herbivores on these artificial blooms.

The Lamont-Doherty group has also pointed out in a recent report that the energy represented by the nearly 40-degree difference in temperature between deep water and surface water can be used for air conditioning, the generation of power and the condensation of fresh water from the atmosphere. (The last idea emerged after observation of the condensation of atmospheric moisture on a Martini glass in a St. Croix bar.) In addition the low temperature of deep water offers the possibility of using the water to cool power plants, including nuclear reactors, without causing thermal pollution.

These fringe benefits, particularly the possibility of producing more than

enough power to pump the deep water to the surface, may at first seem to suggest the dream of getting something for nothing. No physical laws would be violated, however; the water-temperature gradient is simply another product of solar-energy input, just as the energy fixed by photosynthetic plants is. From the standpoint of practical economics artificial upwelling may be too expensive to be feasible exclusively for fish farming at the present time. The system seems entirely practical, however, if its cost can be shared with some additional service such as air conditioning or the cooling of power plants.

A less elegant but much cheaper means of enriching the lagoons of atolls would be the addition of commercial fertilizer. To bring an atoll one square mile in area and 30 feet deep to a level of phosphate concentration equal to the level of nutrient-rich deep water would require only about 10 tons of fertilizer and might cost less than $500. In principle, if the lagoon were entirely enclosed, fertilizer would be removed only as the end product of the farming operation. In actual practice, of course, there would be other losses. Even assuming that one recovered only 10 percent of the fertilizer

in marketable fish, however, the cost would be only half a cent per pound of fish produced. From the economic point of view this would seem to be a highly practical experiment.

Advances in technology frequently generate further threats to the quality of our already overburdened environment. It is encouraging to realize that the use of deep water from the sea both to stimulate food production and to obtain power or fresh water is a pollution-free process. The deep water returns to the sea at the same temperature and with about the same nutrient concentration as the waters that receive it, without having an adverse effect on either the atmosphere or the ocean. The same is true of the use of commercial fertilizer in atoll lagoons, since the fertilizer is almost wholly consumed in the process. Yet at the same time animal-protein production could be stimulated to a level not yet approached by conventional agriculture. Large areas of our planet could be developed into highly productive marine farms. The time seems ripe for applying the fundamental knowledge we already possess to the practical problems of developing them.

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The Absorption Lines
of Quasi-stellar Objects

*Emission lines in the spectra of these objects, sometimes called
quasars, are enormously shifted toward the red. Absorption lines
in some of the spectra, however, are shifted by different amounts*

by E. Margaret Burbidge and C. Roger Lynds

Less than 10 years ago optical astronomers succeeded in identifying on photographic plates the first of a remarkable class of strong radio sources, after its position had been precisely fixed by radio astronomers. The radio source was found to coincide with an object that could be mistaken for an ordinary but extremely faint star. Other such objects were soon identified and became known as quasi-stellar radio sources, or quasars. When their light was examined spectroscopically, it was found to be shifted toward the red end of the spectrum by such large amounts that if the red shift is due to the general expansion of the universe, the objects must be receding at a large fraction of the velocity of light. This implies, in turn, that they must be very distant and therefore enormously luminous, as if an entire galaxy were crammed into a starlike object. Subsequently other starlike objects were discovered with similarly large red shifts but with little or no emission at radio wavelengths. The radio emitters and nonemitters are now known collectively as quasi-stellar objects.

For the past several years optical observers and theorists have been trying to make sense of a new discovery pertaining to the quasi-stellar objects. Ordinarily the red shift of an object is determined by identifying the spectral emission lines of specific atoms and measuring how much the lines are displaced from their wavelengths as they are measured in the laboratory. For each object the emission lines always indicate a specific and unique value for the red shift. It has now been discovered that some of the quasi-stellar objects with the largest red shifts

exhibit in addition to the usual emission lines a number of absorption lines whose displacements correspond to several *different* red shifts!

The identification of two or more different red shifts in the same quasi-stellar object was both startling and mystifying. It raises anew the question of whether the red shifts are to be regarded as a direct measure of recession velocity (the "cosmological" interpretation) or whether the red shifts may be due, at least in part, to some other cause intrinsic to the objects themselves. If the latter were shown to be the case, the quasi-stellar objects might no longer qualify as the most distant objects in the observable universe. They could be assigned a lower luminosity and the source of their energy might no longer be so difficult to explain. On the other hand, when one tries to invent models in which the red shifts are made intrinsic to the quasi-stellar objects, one finds that a large release of energy is still required. The discovery of quasi-stellar objects, of radio galaxies and of other peculiar galactic phenomena has upset the old view that galaxies are evolving on such a long time scale that to observers on the earth they are all but unchanging. Astronomers now speak of a "violent universe" as they seek to understand the extreme physical conditions that must be present in the quasi-stellar objects and in the nuclei of radio galaxies to explain the vast fluxes of energy they emit.

The first quasi-stellar objects for which astronomers established red shifts were 3C 273 and 3C 48, objects No. 273 and No. 48 in the Third Cambridge

Catalogue of radio sources. The red shift of 3C 273 was reported in 1963 by Maarten Schmidt of the California Institute of Technology; the red shift of 3C 48 was reported at the same time by Jesse L. Greenstein and Thomas Matthews of the same institution. Both objects, along with some 200 others subsequently examined, produce spectra with broad emission lines, characteristic of a hot, low-density gas consisting mostly of the common light elements (hydrogen, helium, carbon, nitrogen, oxygen, neon and magnesium) from which one or more electrons have been stripped by collisions.

The red shift, usually denoted by z, is obtained by dividing the shift in wavelength by the "rest" (or laboratory) wavelength of the line. The red shift of many quasi-stellar objects exceeds 2; the largest red shift found so far is 2.877, measured by Derek Wills and one of the authors (Lynds) for the source 4C 05.34. This is more than 10 times larger than the maximum red shift observed for ordinary galaxies. If the red shift z is exactly 2, a line with a rest wavelength of, say, 1,216 angstroms (the Lyman-alpha line of neutral hydrogen) will be shifted to 3,648 angstroms (1,216, plus 2 times 1,216). This means that a photon that begins life in the far ultraviolet part of the spectrum is finally detectable at the edge of the visible spectrum by an earthbound observer.
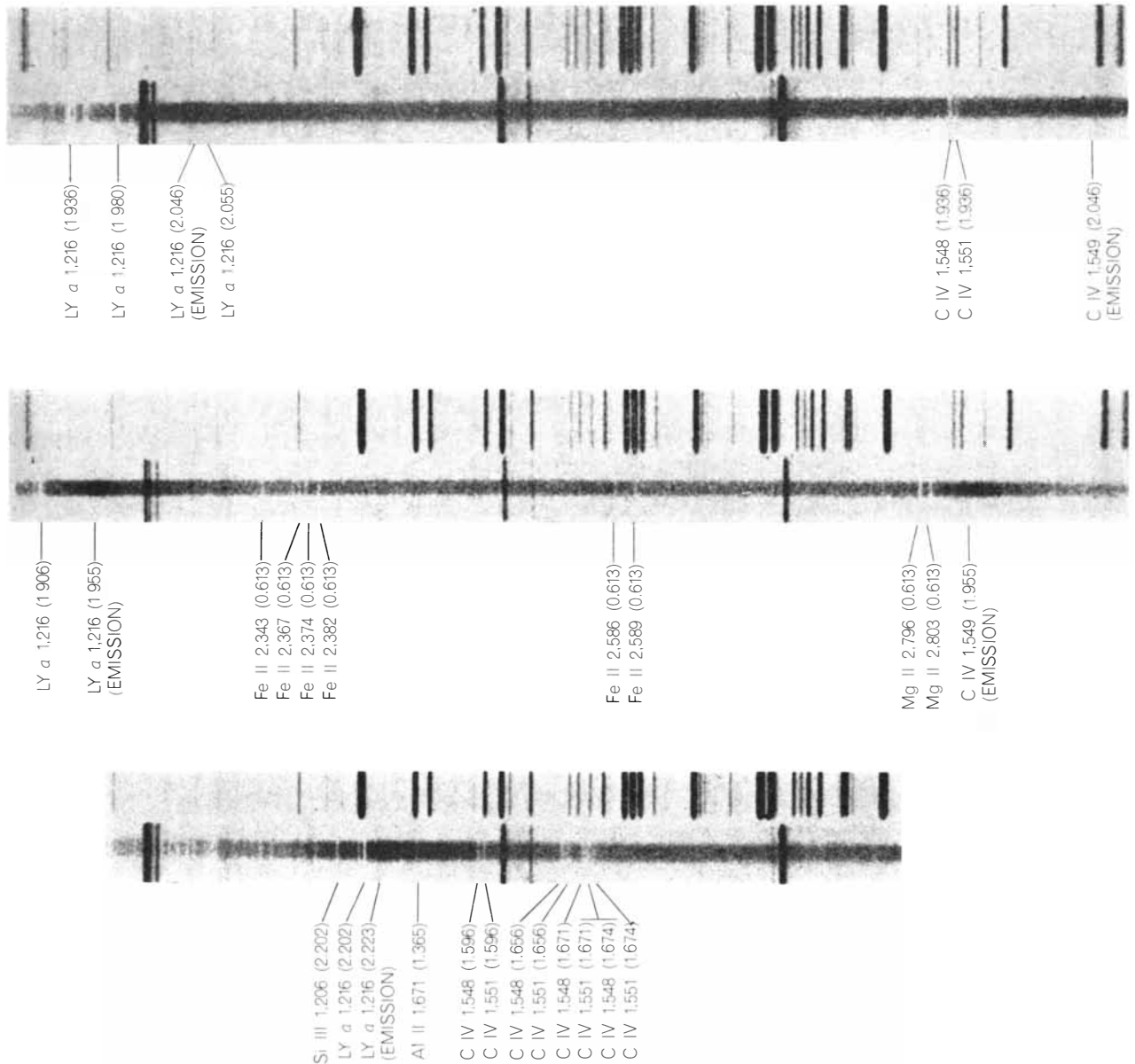
The relation between red shift and velocity of recession is substantially linear for small values of z. Thus an object with a red shift of .1 is receding at a tenth the velocity of light. For large red shifts the relation is made more compli-

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cated by relativistic effects. Even if the red shift were infinite, the velocity of recession cannot exceed the finite velocity of light. When z is 2, the recession velocity is 80 percent of the velocity of light.

After measuring the red shift of many galaxies with the 100-inch telescope on Mount Wilson in the 1920's, Edwin P. Hubble and Milton L. Humason discovered that all but a few nearby galaxies are receding from our own galaxy at velocities proportional to their distance. Their findings led to the cosmological hypothesis that the universe is expanding. The largest galaxy red shifts observed by Humason were about .2, however, so that if the observed red shifts of the quasi-stellar objects are due entirely to this general expansion, it follows that the great majority are more remote than

LY a 1,216 (1,936)
LY a 1,216 (1,980)
LY a 1,216 (2,046) (EMISSION)
LY a 1,216 (2,055)
C IV 1,548 (1,936)
C IV 1,551 (1,936)
C IV 1,549 (2,046) (EMISSION)

LY a 1,216 (1,906)
LY a 1,216 (1,955) (EMISSION)
Fe II 2,343 (0,613)
Fe II 2,367 (0,613)
Fe II 2,374 (0,613)
Fe II 2,382 (0,613)
Fe II 2,586 (0,613)
Fe II 2,589 (0,613)
Mg II 2,796 (0,613)
Mg II 2,803 (0,613)
C IV 1,549 (1,955) (EMISSION)

Si III 1,206 (2,202)
LY a 1,216 (2,202)
LY a 1,216 (2,223) (EMISSION)
Al II 1,671 (1,365)
C IV 1,548 (1,596)
C IV 1,551 (1,596)
C IV 1,548 (1,656)
C IV 1,551 (1,656)
C IV 1,548 (1,671)
C IV 1,551 (1,671)
C IV 1,548 (1,674)
C IV 1,551 (1,674)

PUZZLING ABSORPTION LINES in the spectra of three quasi-stellar objects, Tonantzintla 1530 (*top*), Palomar-Haro-Luyten 938 (*middle*) and Parkes 0237-23 (*bottom*), were studied by the authors, using these spectrograms made with the 120-inch telescope at the Lick Observatory. All three spectrograms are shown to the same scale; above each is a reference spectrogram containing a number of strong emission lines produced by a helium-argon lamp attached to the telescope. The dark gray streak extending across the width of the lower spectrogram in each case is produced by the continuum radiation emitted by the quasi-stellar object. A few faint emission lines are detectable as somewhat darker zones within the streak. The stronger absorption lines appear as sharp white gaps in the emission continuum. (The prominent dark emission lines superposed on the quasi-stellar spectrogram are extraneous features produced by light emitted by the earth's upper atmosphere and by city lamps.) All the spectral lines associated with the quasi-stellar objects are displaced by considerable amounts toward the red end of the spectrum, a characteristic of quasi-stellar objects that can be interpreted in a number of ways. What is surprising about these particular spectrograms is the finding that the red shifts of the absorption lines differ widely not only from the red shifts of the emission lines but also from one another. Each line is identified by an abbreviation of the elemental species responsible for producing it, by its "rest," or undisplaced, wavelength in angstroms and by its red shift (in parentheses), a number computed by dividing the displacement of the line by its undisplaced wavelength.

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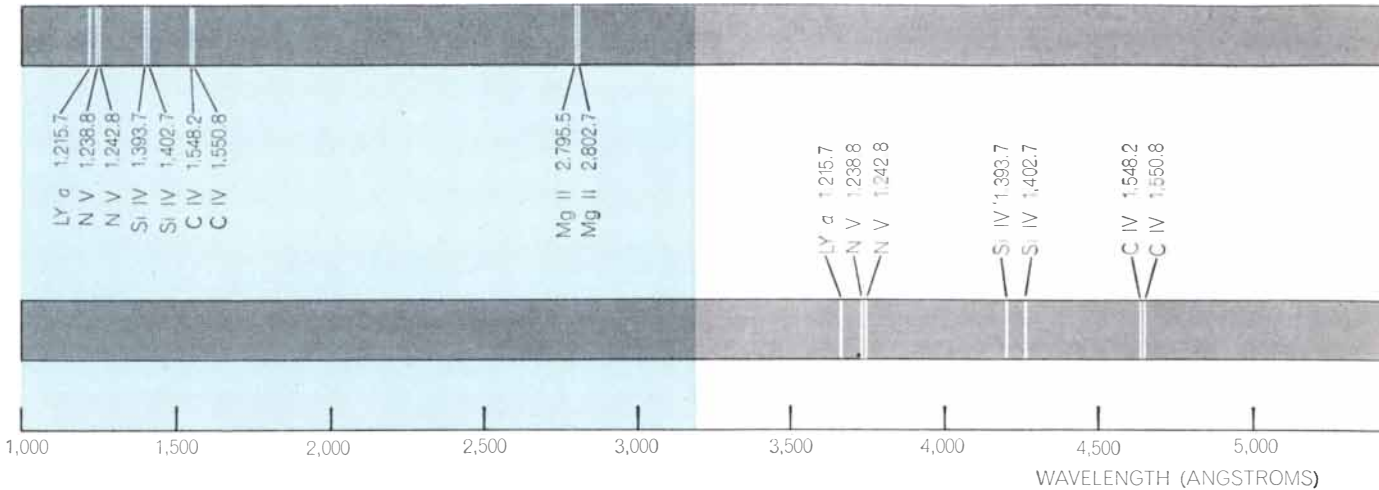
STRONGEST SPECTRAL LINES produced by a hot gas composed mainly of light elements are normally in the far-ultraviolet region of the spectrum at wavelengths below 3,000 angstroms (top). Radiation at the wavelengths of these "resonance" lines is not able to penetrate the earth's atmosphere and consequently is usually not observed by optical astronomers. In the spectra of the quasi-stellar objects, however, these ultraviolet lines (both emission and absorption) are red-shifted into the visible region of the spectrum (bottom), and as a result they can be recorded by ground-based telescopes. (For the purpose of this illustration a red shift of 2 is

any of the galaxies or clusters of galaxies studied by Hubble and Humason.

One should hasten to add that astronomers have found no way to measure distances directly, except in the case of the nearest galaxies. They infer the distance of more remote galaxies by assuming that the brightest of them have about the same intrinsic luminosity; hence the fainter the galaxy, the farther away it is. On this assumption one can plot the red shift z against apparent visual magnitude for ordinary galaxies and for quasi-stellar objects. Allan R. Sandage of the Hale Observatories has shown that in such a diagram the brightest galaxies in rich clusters all fall close to a straight line, indicating a direct relation between red shift and declining brightness. The majority of quasi-stellar objects, however, lie above a projection of this line and show a great deal of scatter [see illustration on page 26]. This indicates that if red shifts are proportional to distance, the quasi-stellar objects are not only more distant than galaxies but also intrinsically much brighter. In addition, for the same red-shift value they show a considerable range in brightness, which the brightest cluster galaxies do not.

The scatter in the red-shift-apparent-magnitude relation for quasi-stellar objects cannot by itself be taken as evidence against the cosmological interpretation of the red shifts. The plot shows a rather steep decline in the number of quasi-stellar objects for red shifts much above 2; moreover, there seem to be an unusual number of objects with red shifts at 1.95, as was first pointed out by Geoffrey R. Burbidge of the University of California at San Diego.

Two possible interpretations have been proposed to show that this distribution is compatible with cosmological red shifts. The Russian astronomers N. Kardashev and Iosif S. Shklovsky have suggested that the clustering at a red shift of 1.95 and the cutoff above 2 are a natural consequence of a particular cosmological model proposed some 40 years ago by Abbe Georges Lemaître. In this model the universe is in a long stagnant
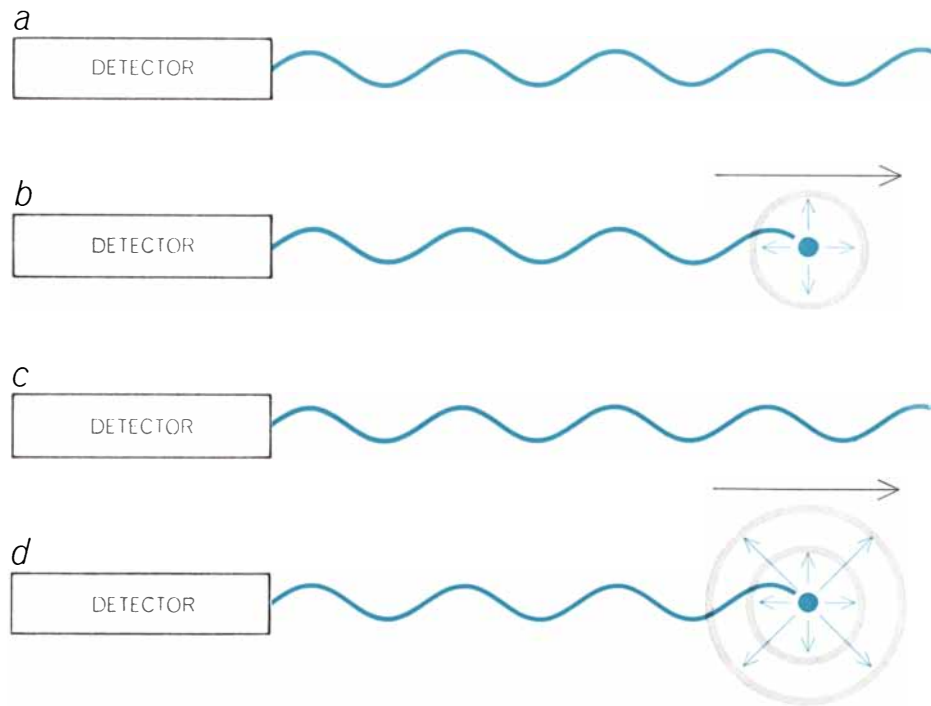
FOUR POSSIBLE INTERPRETATIONS of the nature of the quasi-stellar objects are presented in these schematic drawings. Assuming that the red shifts characteristic of these objects are recessional in origin and are associated with the general expansion of the universe, then they are enormously luminous bodies located at extremely great distances (a). In this case the absorption lines in their spectra (produced, say, by an expanding envelope, or shell, of cooler gas) would be only slightly less red-shifted than their emission lines. Assuming that they are less luminous, comparatively nearby single-shelled bodies that are receding
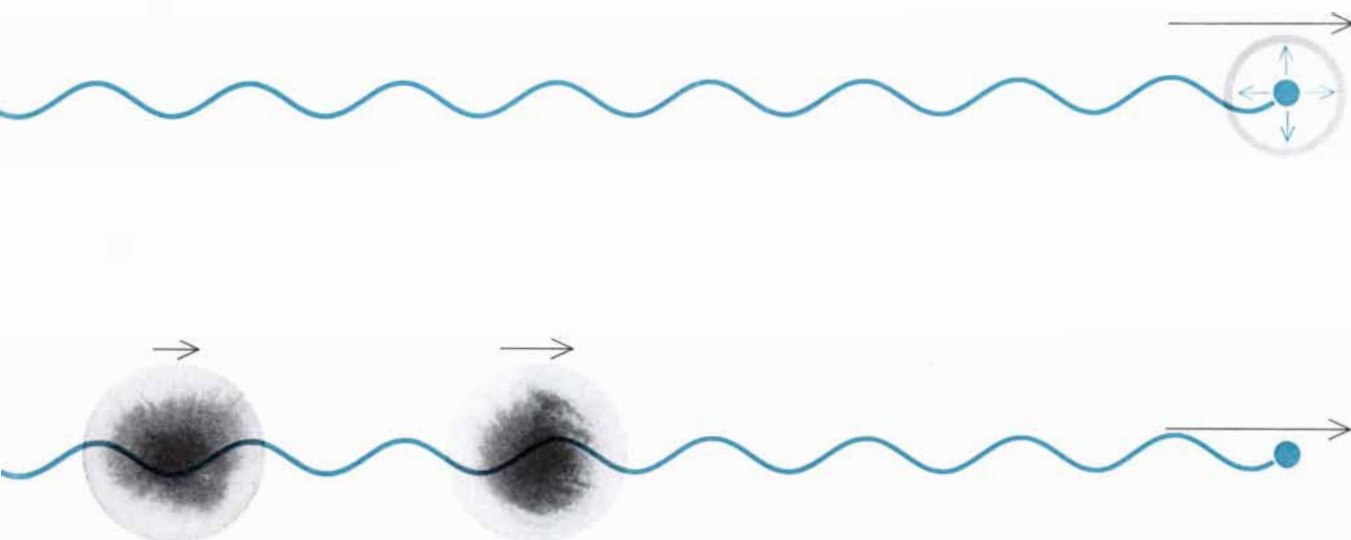
500   6,000   6,500   7,000   7,500   8,000   8,500
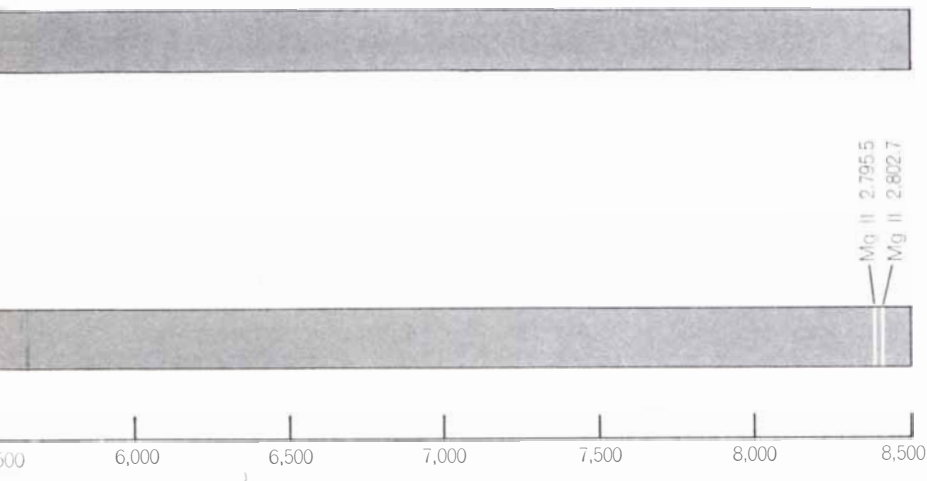
assumed.) The single Lyman-alpha (*Ly α*) line at a wavelength of 1,215.7 angstroms is produced by neutral hydrogen atoms. The remaining lines, all of which are double, are associated with quadruply ionized nitrogen (*N V*), triply ionized silicon (*Si IV*), triply ionized carbon (*C IV*) and singly ionized magnesium (*Mg II*). Ionization state of an element (roman numeral) is one greater than the number of electrons missing from the atom.

phase between an initial expansion and its subsequent resumption; during this quiescent period it may be easier for galaxies (and quasi-stellar objects) to form than during the periods of expansion. Alternatively, Martin J. Rees of the University of Cambridge has suggested that the sharp decline above a red shift of 2 may be due to a large amount of neutral hydrogen present in intergalactic space at distances greater than the distance corresponding to a red shift of 2. This material would absorb the radiation from more distant quasi-stellar objects and make them more difficult to detect. On the other hand, if the red shifts are not cosmological in origin but are intrinsic to the objects themselves, the pileup around 1.95 and the sharp decline beyond 2 probably have deep physical significance for our understanding of these objects.

In addition to the red-shift-apparent-magnitude relation, there are other properties of quasi-stellar objects that seem perplexing. If they are at cosmological distances, it is hard to explain how their light output and radio emission, and probably their infrared emission as well, can fluctuate as rapidly as observations indicate (on time scales of the order of days). The overall brightness of a radiating object can hardly change in less time than is required for a light signal to propagate across it. The rapid changes in flux imply that if quasi-stellar objects are as remote as their red shifts indicate, they must have diameters reckoned in light-months, or even less. This means that such objects are on a scale only slightly larger than that of our solar system, which is about one light-day in diameter. How such comparatively small objects could produce the observed energy flux has thus far defied physical explanation. Of course, if the cosmologi-

at high speeds for some reason unrelated to the general expansion of the universe (*b*), their absorption lines would again be red-shifted only slightly less than their emission lines. Assuming that they are at "cosmological" distances but that their absorption lines are caused by interstellar gas clouds along the line of sight between the emission source and the observer (*c*), the absorption lines would be red-shifted by varying amounts, in some cases far less than the emission lines. Assuming that the objects are nearby but that they are surrounded by multiple gas shells expanding at different rates (*d*), multiple red shifts would again be observed for the absorption lines. The object in example *a* could also possess multiple shells as in *d*. In addition there is the possibility that the large red shifts associated with these objects are not recessional in origin at all but rather arise from some unknown mechanism.

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cal interpretation is wrong, the objects could be much closer and hence intrinsically less luminous and less energetic.

Clearly what is needed are ways of measuring the distance of quasi-stellar objects independently of their red shifts. There are two obvious approaches. One would be to show that a quasi-stellar object is a member of a cluster of ordinary galaxies. One object originally classified as a quasi-stellar object with a small red shift (z less than .1) has been found to lie in such a cluster by John N. Bahcall,

James E. Gunn and Schmidt at the Hale Observatories, but the object is intrinsically faint for a quasi-stellar object and may not be at all representative of the class. Careful searches elsewhere have failed to indicate that any of the brightest and best-known quasi-stellar objects belong to clusters.

A second approach would be to show that the light from a quasi-stellar object with a large red shift has passed through intervening galaxies, clusters of galaxies or clouds of intergalactic mat-

ter. If this could be demonstrated, one might expect to discover an object having a spectrum with absorption lines whose red shift was less than that of the object's own emission lines. Thus the discovery of several quasi-stellar spectra with absorption lines is a matter of great interest. Do the absorption lines reveal the presence of intergalactic matter or not?

Absorption lines are common in the spectra of the sun and other normal stars. They are produced when radiation from a hot source passes through a cooler gas; the gas absorbs just those wavelengths it would itself emit if it were raised to the excitation temperature. The chief requirement in stars is that the ions, atoms and molecules doing the absorbing be approximately in thermal equilibrium with the radiation pouring through them. If they are not in local equilibrium but have, for example, their own source of thermal excitation, they can produce emission lines of their own. This happens in a small number of stars. They are usually hot stars with unstable outer atmospheres that often seem to be ejecting matter from their surface. This matter may exist in an uneasy equilibrium as a shell around the star or it may be pouring outward at high velocity and in large quantities. The explosion of a supernova can involve the ejection of matter at a significant fraction of the speed of light.

On a less violent scale, the gas pouring out of some highly luminous hot stars, such as those in the Great Nebula in Orion, is traveling at some 2,000 kilometers per second. This discovery was made by Donald C. Morton and his coworkers at Princeton University, who used rocket-borne instruments to record the ultraviolet emission of hot gas composed mainly of hydrogen, helium and other light elements. The strongest lines are in the far-ultraviolet part of the spectrum at wavelengths below 3,000 angstroms, which cannot penetrate the earth's atmosphere. Thanks to the red shift, these ultraviolet lines in the spectra of most quasi-stellar objects are displaced into the region of the spectrum that can be recorded by ground-based telescopes.

Stars can also exhibit in their spectra weak absorption lines produced by the thin, cold gas in interstellar space. These lines can be easily recognized because they do not partake of the star's individual velocity; for example, they remain stationary in the spectra of double stars that are revolving around each other. If
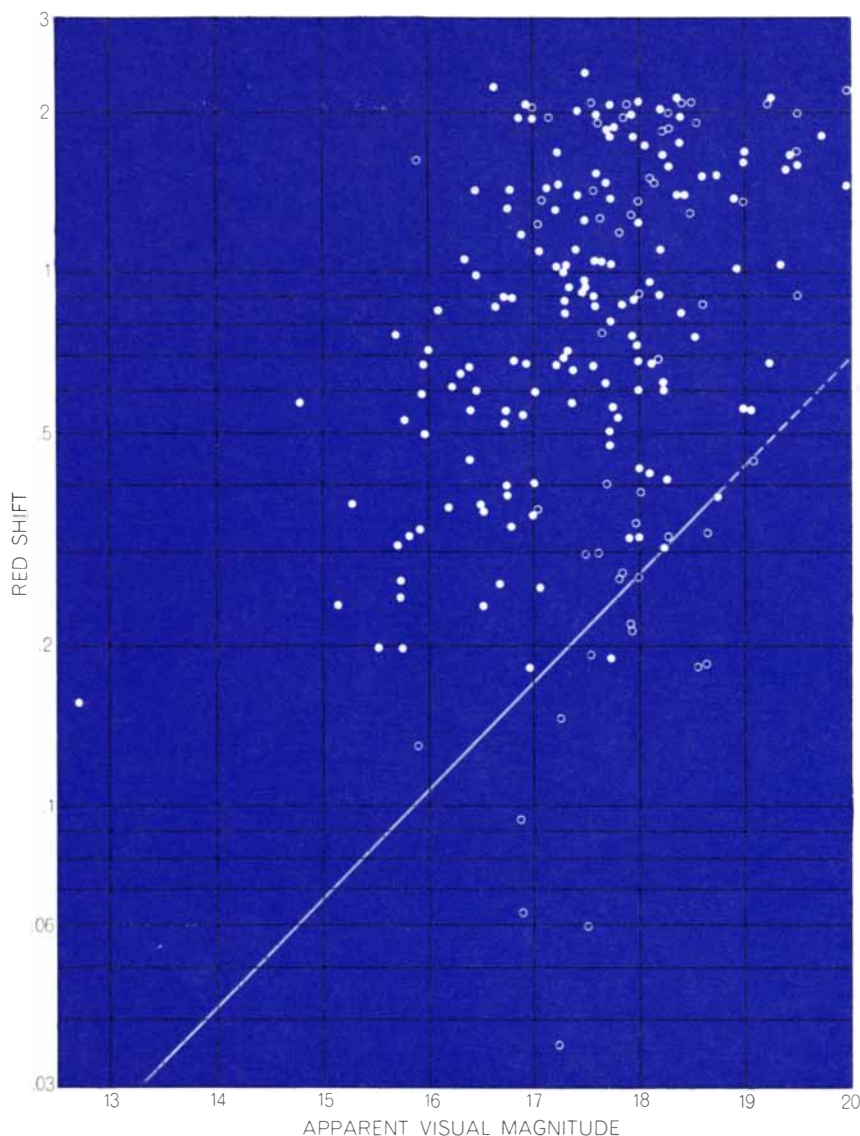
QUASI-STELLAR OBJECTS ARE PLOTTED on this logarithmic graph in terms of the relation between their red shift and their apparent visual magnitude. When the brightest galaxies in rich clusters are plotted on such a graph, they all fall close to the solid line, indicating a direct relation between red shift and apparent visual magnitude. When all the known quasi-stellar objects are plotted on the same graph, however, the majority lie above the projection of the standard-galaxy line; moreover, they show a great deal of scatter. (Solid dots are radio-emitting objects; open circles are radio-quiet objects.) This finding suggests that if the red shifts are proportional to distance, the quasi-stellar objects are not only more distant than galaxies but also intrinsically much brighter. The plot also shows a rather abrupt decline in the number of quasi-stellar objects at red shifts slightly above 2.
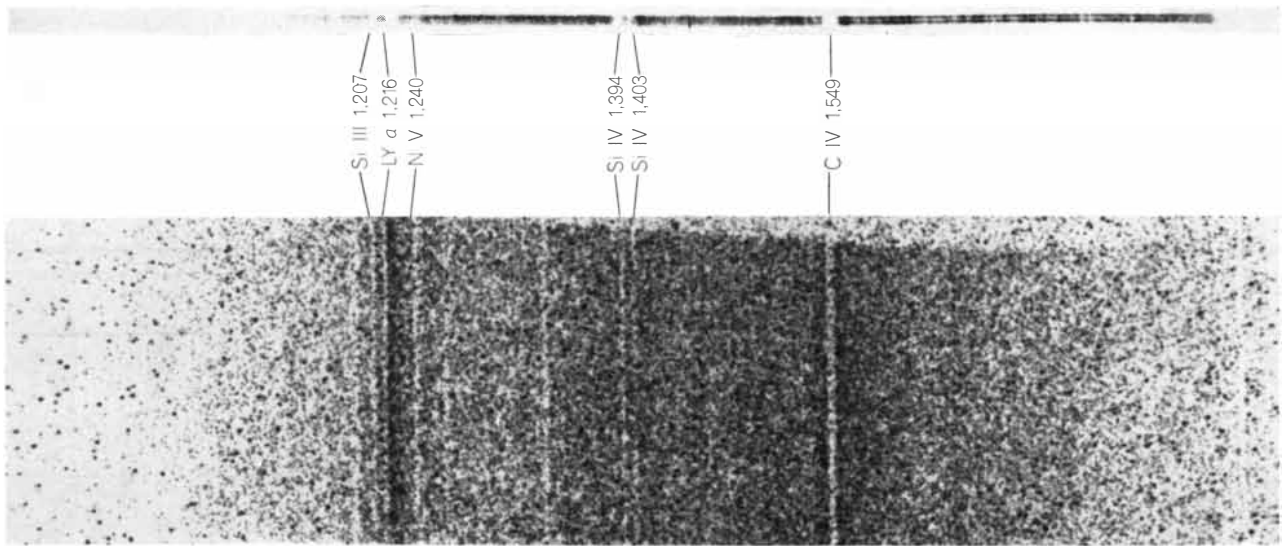
SAME SPECTRAL FEATURES appear in both of these spectrograms, only one of which represents the spectrum of a quasi-stellar object. The spectrogram at top was recorded for a highly luminous hot star in the Great Nebula in Orion by Donald C. Morton of Princeton University, who used a rocket-borne instrument to detect the strong ultraviolet features that are blocked by the earth's atmosphere. The fact that the absorption lines (*sharp white lines*) are red-shifted only slightly less than the corresponding emission lines (*faint dark lines*) indicates that a shell of gas is flowing outward from the star at a speed of approximately 2,000 kilometers per second. The spectrogram at bottom, recorded for the quasi-stellar object 3C 191, was one of the first of its kind in which strong absorption lines were found. In this case the original strong ultraviolet lines are red-shifted all the way into the visible region of the spectrum; they were detected by one of the authors (Lynds) and Alan N. Stockton at the Kitt Peak National Observatory. Again the sharp absorption lines are red-shifted only slightly less than the faint emission lines, suggesting a similar shell structure for 3C 191.

the universe were filled with a smooth substratum of low-density hydrogen, one should be able to detect it by looking for an absorption trough on the short-wavelength side of the strong Lyman-alpha (neutral hydrogen) line, which is normally present in the spectra of quasi-stellar objects with a red shift of 2 or more. Although the trough has been searched for, it has not been found. This means either that the density of neutral hydrogen in space is very low (less than 10^{-11} atom per cubic centimeter) or that the gas is present in higher density but does not absorb because it is hot and ionized. The third possibility, of course, is that quasi-stellar objects are so close that this absorption would not be seen in the observable region of the spectrum. It has been pointed out, however, that if the hydrogen atoms are not spread smoothly throughout space but are concentrated in clumps or clouds, they will show up not as a wide absorption trough but as a number of sharp absorption lines whose red shifts correspond to the distance between us and the cloud. Soon after this possibility was put forward the authors found the first quasi-stellar object with many strong absorption lines.

What absorption lines might one expect to see in the spectra of quasi-stellar objects? Since these objects are at a temperature of some 20,000 degrees Celsius, most of the atoms present are ionized: they have been stripped of one or more electrons. Spectrum lines are produced when an ion changes from one of its many energy states to another. If the gas is at low density and is some distance from the source of radiation, the atoms will spend most of their time in the ground state—the lowest state possible. The most probable transitions an atom or ion can make into or out of its ground state are called resonance transitions; the spectral lines associated with these transitions are the most characteristic and sensitive indicators of the atom's or ion's presence [*see top illustration on pages 24 and 25*]. If either the ground state or the upper energy level associated with it is double (or multiple), the resonance line associated with the transition will be double (or multiple). Many of the transitions of interest in quasi-stellar objects are double or multiple, and the separations are accurately known from laboratory measurements.

The quasi-stellar object 3C 191, which Alan N. Stockton and we discovered in 1966, was the first observed to exhibit many strong absorption lines. It had 16 absorption lines—in addition to the usual emission lines, which showed it to have an emission red shift of 1.956. We were soon able to identify many of the absorption lines, mostly resonance transitions, and we computed the absorption

red shift as 1.947. Because the two red shifts are so close we concluded that the absorbing material must be directly associated with the source of the emission lines and not situated in intergalactic clouds. The absorption could readily be produced by a shell of gas traveling outward from the object at about 600 kilometers per second.

Since this discovery was made absorption lines have been found in the spectra of several dozen quasi-stellar objects. In most cases the red shift of absorption is close to the red shift of emission, just as we found with 3C 191. In a few cases the absorption red shift is slightly greater than the emission red shift, indicating that the absorbing matter is falling back toward the object. In none of these examples were there compelling reasons for attributing the lines to intergalactic gas.

Recently, however, several quasi-stellar objects have been discovered with absorption lines indicating not only multiple red shifts but also shifts quite different from the emission red shifts. We shall discuss three of these unusual objects: Tonantzintla 1530 (emission red shift 2.05), Palomar-Haro-Luyten 938 (emission red shift 1.95) and Parkes 0237–23 (emission red shift 2.22). The first, Ton 1530, was discovered by W. A. Hiltner, Anne P. Cowley and Rudolph Schild at the McDonald Observatory.

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The second, PHL 938, was discovered by T. D. Kinman at the Lick Observatory. The third, PKS 0237–23, was discovered by Halton C. Arp, John G. Bolton and Kinman with the 200-inch Hale telescope. All three objects have spectra with strong absorption lines [*see illustration on page 23*], which the original observers had some difficulty identifying.

In the first attempts to identify the absorption lines it seemed natural to search for red shifts close to the emission red shifts, but none of the line identifications seemed altogether satisfactory. One of us (Burbidge), working with a Lick spectrogram of PKS 0237–23, suggested a set of absorption red shifts at 1.95, but this left many of the stronger absorption lines unidentified.

Greenstein and Schmidt, working with a higher-resolution spectrogram obtained with the Hale telescope, subsequently proposed that two absorption red shifts were present: one at 1.95, the other at 2.2. This was the first time anyone had suggested that a quasi-stellar object might exhibit absorption lines at two distinct red shifts, both different from the emission red shift.

At this point we decided to simultaneously examine all three of the puzzling spectra in the hope that one might somehow explain another. Working with Stockton, we obtained a new set of high-resolution plates, using the 84-inch telescope at the Kitt Peak National Observatory and the 120-inch telescope at Lick. For help we included in our studies another quasi-stellar object with absorption lines: PHL 5200, which one of us (Lynds) had discovered the previous year. PHL 5200 has very broad absorption bands, with red shifts extending from 1.90 to 1.98, adjoining broad emission lines centered on 1.98. This is just the effect one sees in the spectrum of a

supernova, when a thick shell of gas explodes outward at speeds of thousands of kilometers per second. In PHL 5200 the absorption bands correspond to gas flying outward at speeds of up to 10,000 kilometers per second. The bands have a peculiar structure suggesting shock waves or denser regions moving at sharply defined velocities within the expanding shell. One can easily imagine such a shell's traveling outward from the central object, portions of it perhaps accelerated greatly by the enormous pressure of the outgoing radiation and breaking up into a number of separate shells moving at different velocities.

We kept such a model in mind while examining the spectra of the three puzzling objects: Ton 1530, PHL 938 and PKS 0237–23. We also paid particular attention to the multiple resonance lines associated with singly ionized iron (Fe II) and magnesium (Mg II) and triply ionized carbon (C IV) and silicon (Si IV). In our search for identifications we used ratios of wavelengths for multiple lines because then the red-shift factor drops out. For example, if the double line of C IV is present, its two components will be separated by a factor proportional to their rest wavelengths, 1,548.2 and 1,550.8, regardless of how much or how little they are red-shifted. In this way, when one of the strongest absorption lines in Ton 1530 was found to be doubled, it was immediately apparent that the wavelength ratio for the components was the same as the ratio for the C IV doublet. On the other hand, in PHL 938 a double absorption line very near a pair of C IV emission lines turned out not to have the right wavelength ratio for the C IV doublet but the ratio was just right for the Mg II doublet with rest wavelengths of 2,795.5 and 2,802.7 angstroms. This last identification was sur-

prising, because it indicated an absorption red shift of only .613, less than a third the red shift of the emission lines (1.95). This is the largest difference yet found between the red shift of the emission spectrum and the absorption spectrum in the same object. The difference is so large that the identification of the Mg II doublet might have remained open to doubt except for the fortunate circumstance that the spectrum of PHL 938 contains seven other strong absorption lines identifiable as the strongest lines expected from singly ionized iron (Fe II), also at a red shift of .613. One strong absorption line at a red shift of 1.906 has been tentatively identified with Lyman alpha.

The spectra of the other two objects, Ton 1530 and PKS 0237–23, have proved to be more complex. Our study of Ton 1530 disclosed three absorption red shifts: 1.936, 1.980 and 2.055, all fairly close to the emission red shift of 2.05. Subsequently Bahcall, Patrick S. Osmer and Schmidt were able to find two more absorption red shifts: 1.921 and 1.887.

When we finished examining PKS 0237–23, the object with an emission red shift of 2.22, we found that seven red shifts were needed to account for the majority of the stronger absorption lines: 2.202, 1.956, 1.674, 1.671, 1.656, 1.596 and 1.365. We feared that this multiplicity of values might be greeted with skepticism, but it turned out that Bahcall, Greenstein and Wallace L. W. Sargent were simultaneously reaching much the same conclusion. They constructed a "standard" table of the absorption lines to be produced by a quasi-stellar object of normal composition and programmed a computer to calculate wavelengths for a large network of red shifts and to search for coincidences with


O II 3,726.29 (EMISSION)   Ne III 3,869 (EMISSION)   He I 3,889   Ca II 3,933   Ne III 3,968·70 (EMISSION)   S II 4,069·76 (EMISSION)
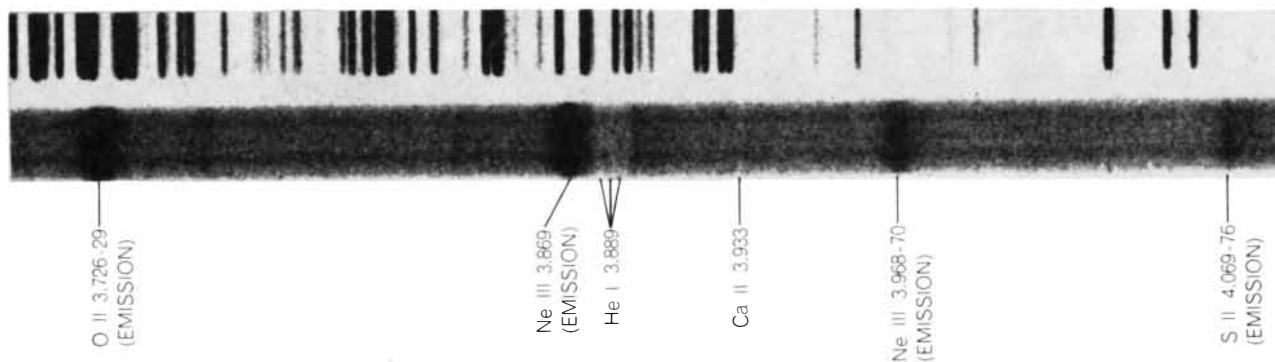
SHELL HYPOTHESIS IS SUPPORTED by this spectrogram of the bright nucleus of the comparatively nearby galaxy NGC 4151, made by Kurt Anderson and Robert P. Kraft at Lick. The multiple absorption red shifts shown by the helium I line are not easily attributable to intergalactic material for an object so close at hand. Outflowing thin shells of gas seem to be the obvious explanation.

wavelengths actually observed. They found five absorption red shifts: 2.202, 1.671, 1.656, 1.513 and 1.364. Four of these values coincide with four of our seven values; only one, 1.513, is different. We take considerable satisfaction from the fact that two groups using quite different methods have come up with such similar results.

What are the possible interpretations of the multiple absorption red shifts found in these spectra? The first, and in some ways the simplest, explanation is that the absorption lines are produced by thin shells of gas moving outward at different velocities. Thus PKS 0237–23 would be surrounded by as many as seven shells. The narrowness of the lines would seem to require some mechanism for sharply limiting the spread of velocities in any one shell. Although each shell need not consist of many atoms in the line of sight, the velocities—and the range of velocities—are considerable. The fastest-moving shell of PKS 0237–23 would have to be traveling away from the object with a velocity of 90,000 kilometers per second, or nearly a third the speed of light, to produce an absorption red shift of 1.365. The shell producing the absorption red shift of .613 in PHL 938 would have to be moving outward at more than half the speed of light. Even if such a shell contained very little gas, the energy needed to expel it at that velocity would be enormous, provided that the material observed represents part of a more or less complete shell. In a few cases the red shifts of absorption lines indicate that a shell would have to be falling back toward the quasi-stellar object, but the inward velocities are fairly small and seem to present no theoretical problem.

The shell hypothesis has recently gained some support from a spectrogram obtained by Kurt Anderson and Robert P. Kraft at Lick of the galaxy NGC 4151, one of a small class of galaxies characterized by intensely bright nuclei discovered 25 years ago by Carl K. Seyfert. Evidence is accumulating that Seyfert galaxies, radio galaxies and quasi-stellar objects may be related in some way. All appear to have been the scene of violent explosive events in the recent past. The nucleus of NGC 4151 shows three sharp absorption lines for helium, corresponding to material ejected at velocities of 280, 550 and 840 kilometers per second. Although these velocities are modest compared with those implied by the shell hypothesis for quasi-stellar objects, they provide an example of multiple ab-
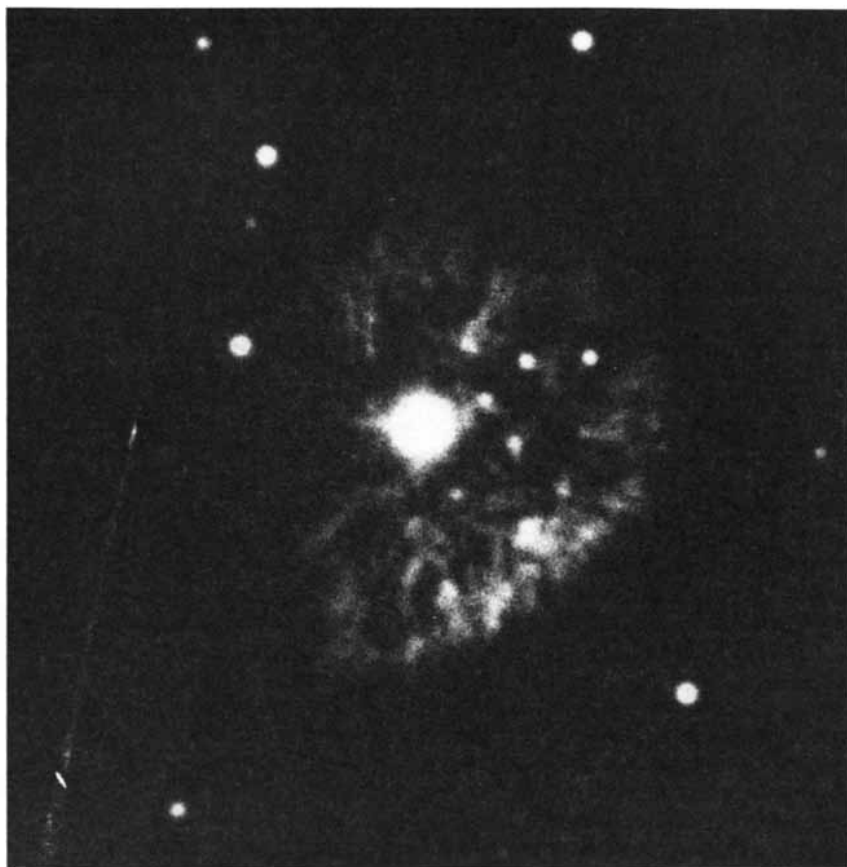
EXAMPLE OF A SHELL-LIKE STRUCTURE that may resemble the structure of at least some quasi-stellar objects is provided by this photograph of Nova Persei 1901. The central star and its surrounding nebula of expanding gas are the remnants of a former nova explosion. The photograph was made with the 200-inch telescope at the Hale Observatories.

sorption red shifts that can scarcely be attributed to intergalactic material.

What, then, are the arguments for and against the hypothesis that quasi-stellar absorption lines may be produced by intergalactic matter of some kind? Of the three quasi-stellar objects we have discussed at length, PHL 938 best lends itself to the intergalactic absorption hypothesis. Robert V. Wagoner of Cornell University has calculated what absorption lines one would expect to see if the radiation from a quasi-stellar object passed through a typical interstellar cloud of the kind known to be present in our galaxy. He finds that such a cloud would absorb just those lines (Fe II and Mg II) seen in the spectrum of PHL 938, except that the lines in PHL 938 are stronger than the lines predicted. If PHL 938 actually lies behind a galaxy like ours, one might expect to see some evidence of its light's being reddened by the dust between the stars in the galaxy. Such evidence has not been found.

A number of theoretical attempts have been made to explain the possible exis-

tence of multiple absorbers in intergalactic space. It has been suggested, for example, that the universe may contain many "dead" galaxies—large collections of stars that have become too faint to be visible—and that several of these could lie in the line of sight between us and a cosmologically distant quasi-stellar object. An alternative explanation is that ordinary galaxies may be surrounded by large halos of gas that could act as absorbers.

All such hypotheses must contend with the fact that absorption lines appear in only a small fraction of quasi-stellar objects, that still fewer show multiple lines and that most of the lines exhibit red shifts that are very close to the emission values. This last in particular gives one the feeling that absorption is associated with the objects themselves. Perhaps the absorption lines are an intergalactic phenomenon, but we personally are doubtful. If the absorption lines are intrinsic to the objects, the most likely hypothesis is that they are produced by clouds of gas moving outward at enormous velocities.

Auditory Illusions and Confusions

These failures of perception are studied because they isolate and clarify some fundamental processes that normally lead to accuracy of perception and appropriate interpretation of ambiguous sounds

by Richard M. Warren and Roslyn P. Warren

For more than a century visual illusions have been of particular interest to students of perception. Although they are in effect misjudgments of the real world, they apparently reflect the operation of fundamental perceptual mechanisms, and they serve to isolate and clarify visual processes that are normally inaccessible to investigation. Auditory illusions, on the other hand, have received little scientific attention. Until recently the fleeting nature of auditory stimuli made it difficult to create, control and reproduce sound patterns as readily as visual ones. The tape recorder made it easy to manipulate sounds, and yet for a time there was little examination of auditory illusions, perhaps because there was no historical tradition to build on—no puzzles inherited from the experimental psychologists of the past century, as there were in the case of optical illusions. Some new investigations, however, have led to the discovery of illusions in hearing that help to explain the human ability to extract information from fleeting patterns of sound. These investigations have also led to the identification of confusions in hearing that help to explain some limitations of that ability.

Consider for a moment that you are at a convention banquet. While you are still finishing your dinner the after-dinner speeches begin. The clatter of dishes masks some of the speech sounds, as do occasional coughs from your neighbors and your own munching. Nonetheless, you may be able to understand what the speaker is saying by utilizing the information that reaches you during intervals that are relatively free of these interfering noises. In order to understand how speech perception functions in the presence of transient noises, we and Charles J. Obusek did some experiments

last year in our laboratory at the University of Wisconsin at Milwaukee. First we recorded the sentence "The state governors met with their respective legislatures convening in the capital city." Then we carefully cut out of the tape recording of the sentence one phoneme, or speech sound: the first "s" in "legislatures." We also cut out enough of the preceding and following phonemes to remove any transitional cues to the identity of the missing speech sound. Finally, we spliced the recorded sound of a cough of the same duration into the tape to replace the deleted segment.

When this doctored sentence was played to listeners, we found that we had created an extremely compelling illusion: the missing speech sound was heard as clearly as were any of the phonemes that were physically present. We called this phenomenon "phonemic restoration." Even on hearing the sentence again, after having been told that a sound was missing, our subjects could not distinguish the illusory sound from the real one. One might expect that the missing phoneme could be identified by locating the position of the cough, but this strategy was of no help. The cough had no clear location in the sentence; it seemed to coexist with other speech sounds without interfering with their intelligibility. Phonemic restoration also occurred with other sounds, such as a buzz or tone, when these sounds were as loud as or louder than the loudest sound in the sentence. Moreover, phonemic restorations were not limited to single speech sounds. The entire syllable "gis" in "legislatures" was heard clearly when it was replaced by an extraneous sound of the same duration.

We did find a condition in which the missing sound was not restored. When a silent gap replaced the "s" in "legislatures," the gap could be located within

the sentence and the missing sound identified. In visual terms, it was as if an erasure of a letter in a printed text could be detected, whereas an opaque blot over the same symbol would result in illusory perception of the obliterated letter, with the blot appearing as a transparent smear over another portion of the text [*see top illustration on pages 32 and 33*]. Of course, in vision a blot can be localized readily, and even the more elusive "proofreader's illusions" can be eliminated when the reader is told in advance just where the error in the text occurs. With phonemic restorations, however, knowledge of the nature of the extraneous sound and of the identity of the missing phoneme does not prevent clear perception of the missing sound—even when the stimulus is played to the listener as many times as he wishes.

The inability to localize an extraneous sound in a sentence was first reported in 1960 by the British workers Peter Ladefoged and Donald E. Broadbent. Since they employed brief intrusive sounds (clicks and short hisses) and took care that no phoneme was obliterated, phonemic restorations did not arise. Similar short, nonmasking extraneous sounds were later used by a group at the Massachusetts Institute of Technology that included Jerry A. Fodor, Merrill F. Garrett and Thomas Bever. They have reported that systematic errors in locating the clicks are caused by various features of sentence structure, and they have used the errors to explore those features.

Perceptual synthesis of the phoneme is accomplished on the basis of verbal context. In the case of the missing "s" in "legislatures" the context prior to the absent sound suffices for identification. What about a sentence so constructed that the context necessary to identify an obliterated sound does not come until

AUDITORY ILLUSIONS are investigated in the authors' laborato-
ry. The subject, listening through headphones to a stimulus signal
generated by the equipment in the background and reproduced
by the tape recorder, reports to the experimenter on what he hears.

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a

| The | state | governors | met | with | their | respective | legislatures | convening | in | the | capital | city. |

b

| The | state | governors | met | with | their | respective | legi█latures | convening | in | the | capital | city. |

PHONEMIC RESTORATION is an illusion that shows the importance of context in determining what sound is heard. A sentence was recorded on tape (*a*). Then the first "s" in "legislatures" was excised and a cough of the same duration (*black rectangle*) was spliced in its place (*b*). When the altered sentence was played to subjects, the missing "s" was heard clearly (*c*) and localization of

later? With the symbol ° representing a loud cough that replaces a speech sound, consider a spoken sentence beginning, "It was found that the °eel was on the ___." The context provided by the last word in the sentence should resolve the ambiguity and determine the appropriate phonemic restoration. Among the words that could complete the sentence are "axle," "shoe," "orange" and "table." Each implies a different speech sound for the preceding word fragment, respectively "wheel," "heel," "peel" and "meal." Preliminary studies by Gary Sherman in our laboratory have indicated that the listener does experience the appropriate phonemic restoration, apparently by storing the incomplete information until the necessary context is supplied so that the required phoneme can be synthesized. We are still investigating the influence of such factors as the duration of extraneous sounds in relation to the duration of the missing phoneme and the maximum temporal separation between the ambiguous word fragment and the resolving context that will still permit phonemic restoration.

The use of subsequent context for correcting errors had been suggested on logical grounds by George A. Miller of Rockefeller University. He reasoned that unless some such strategy were available, a mistake once made while listening to spoken discourse would cause errors in interpreting the following portions of the message to pile up, until the entire system eventually stalled. The long delays in muscular activity that have been observed in the skilled transcription of an incoming message also suggest that storage of incoming lan-
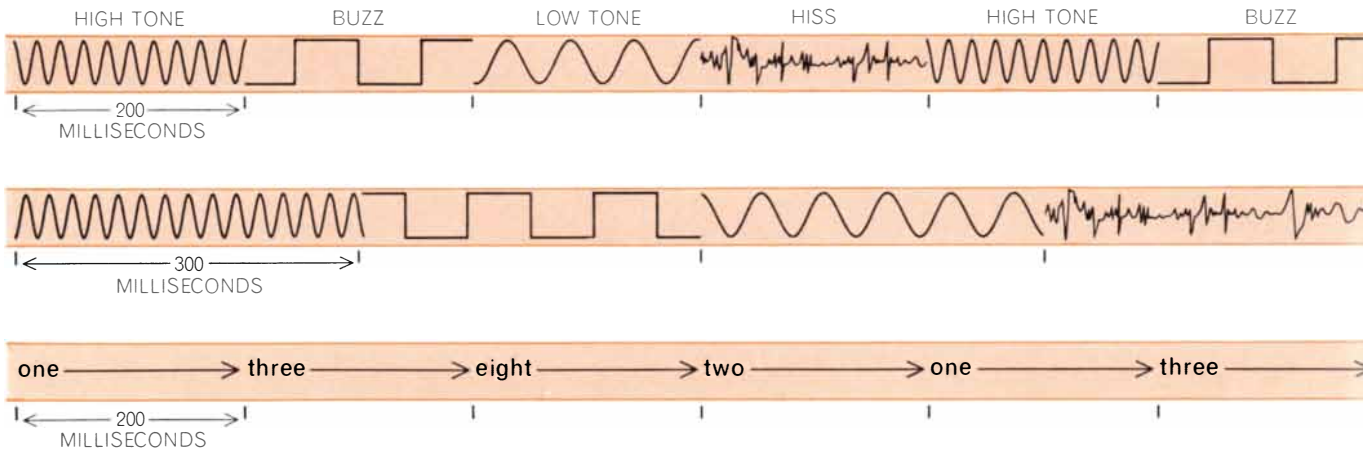
TEMPORAL CONFUSION was observed when a high tone, a buzz, a low tone and a hiss (represented here schematically), each lasting 200 milliseconds, were presented repeatedly (*top*). Subjects could not report the sequence of the sounds properly whether they tried
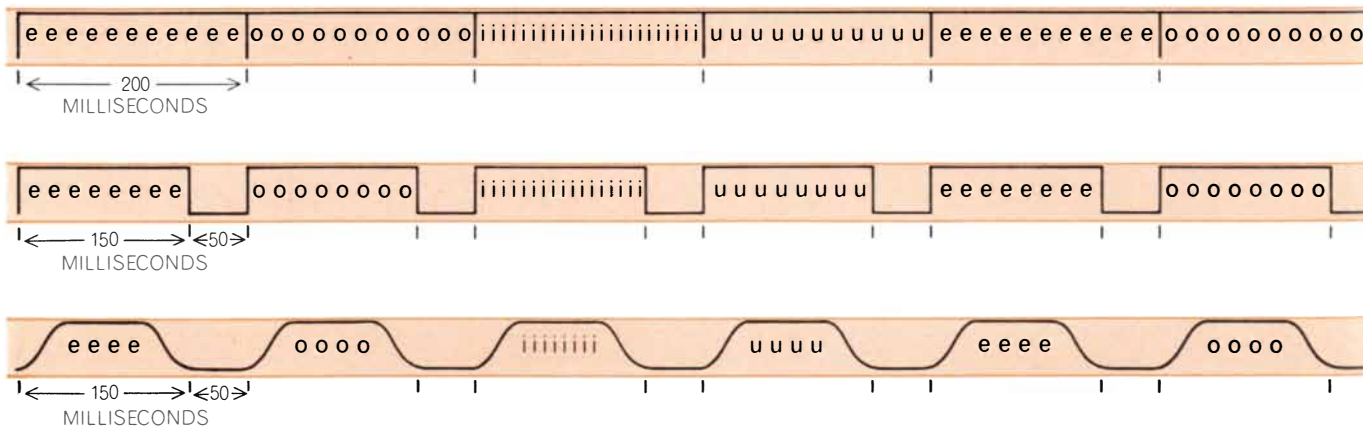
FOUR VOWEL SOUNDS were used in another experiment on temporal confusion. When the vowel sounds of "beet," "boot," "bit" and "but" were presented at a sustained level for 200 milliseconds, their sequence could not be determined (*top*). Deleting 50 milli-

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c

| The | state | governors | met | with | their | respective | legislatures | convening | in | the | capital | city. |

d

| The | state | governors | met | with | their | respective | legi latures | convening | in | the | capital | city. |

the cough was indefinite; when required to guess the location, subjects generally missed the correct position by several phonemes, as indicated (*gray area*). When a silent gap, rather than a cough, re- placed the "s," the gap could be located and the missing sound could be identified (*d*). This illustration, like those that follow, is necessarily an approximate representation of an auditory effect.

guage information is associated with error correction. In the 1890's William Bryan and Noble Harter noted that highly skilled telegraphers listening to Morse code did not transcribe the auditory signals that constituted a word until some six to 12 words after the signals were heard. If subsequent portions of the message could not provide helpful context, as in the case of stock quotations or transmissions in cipher, the telegraphers changed their strategy and followed the message much more closely in time. Telegraph companies charged higher rates for sending such messages precisely because they lacked redundant context, were therefore much more difficult to receive and had to be transmitted more slowly.

This telegrapher's technique illustrates a surprising relation that one encounters again and again in perception: The development of an extremely complex procedure for data processing is necessary to achieve the deceptive impression of an "easy" perceptual task. From time to time other workers have noted the delay between language input and motor response. In 1925 William Book observed the similarity between typewriting and code transcription, reporting that in the case of an expert typist "attention was pushed ahead of the hands as far as possible (usually four or five words)."

Inability to locate the position of extraneous sounds in sentences represents a failure in the detection of temporal order. It might be thought that this temporal confusion results from a conflict between verbal and nonverbal

LOW TONE   HISS   HIGH TONE   BUZZ   LOW TONE   HISS

eight → two → one → three → eight → two →
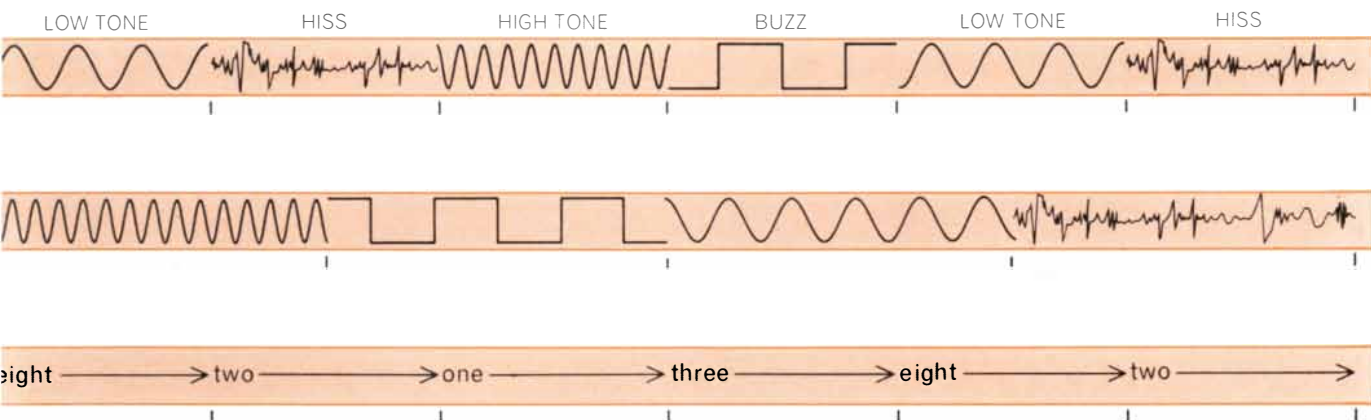
to do so verbally or by ordering four cards, each representing a sound. When sounds lasted 300 milliseconds, subjects could order them with cards (*middle*). When spoken digits were substituted for sounds, it was easy for subjects to report their order (*bottom*).

iiiiiiiiiiiiiiiiiiiiii uuuuuuuuuu eeeeeeeeee oooooooooo iiiiiiiiiiiiiiiiiiiiii uuuuuuuuuu

iiiiiiiiiiiii uuuuuuuu eeeeeee oooooooo iiiiiiiiiiiiiii uuuuuuuu

iiiiiiiii uuuu eeee oooo iiiiiiii uuuu
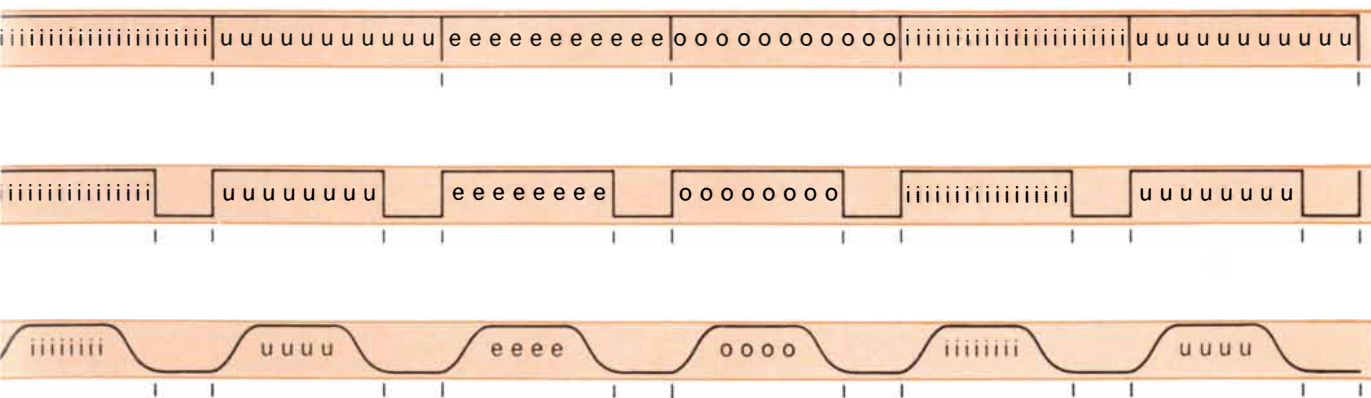
seconds of each sound and replacing it with silence (*middle*) allowed half of the subjects to determine the sequence. The sequence was readily determined when vowels were given normal qualities of gradual onset and decay, suggested by curves (*bottom*).

33

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VERBAL TRANSFORMATION EFFECT is noted when subjects listen to a distinct recording of a single word repeated on a loop of tape (*a*). One might expect a kind of reversal effect, with the stimulus "tress" perceived sometimes as "rest." Instead lack of context

modes of perception. Recent observations in our laboratory have indicated, however, that inability to detect sequence is not restricted to verbal-nonverbal interactions. In 1968, during an experiment on loudness, we noted to our surprise that listeners could not tell the order of three successive sounds repeated over and over without pauses. The sounds—a hiss, a tone and a buzz—each lasted a fifth of a second (200 milliseconds) and were recorded on a tape that was then spliced to form a loop. The duration of each sound was quite long compared with the 70- to 80-millisecond average for a phoneme in speech and was well within the temporal range used in music for the successive notes of melodies; the hiss, tone and buzz could each be heard clearly. Yet it was impossible to tell the order of the sounds. The pattern swirled by, the temporal structure tantalizingly just beyond one's grasp.

It might be thought that a little advance planning would make the task easy. It should be possible, for example, to concentrate on one of the sounds (say the hiss) and then decide whether the sound that follows it is a tone or a buzz; this single decision would fix the third sound in the remaining slot and solve the problem. In practice, however, the single decision cannot be made with accuracy. Out of 50 listeners we found that only 22 named the order correctly—slightly fewer than the 50 percent correct answers that would be expected by chance alone.

This seemed at first to contradict the findings of earlier studies. Results reported by Ira Hirsh of the St. Louis Central Institute for the Deaf and by others had indicated that temporal resolution of such sounds as tones, hisses and buzzes should be possible down to a separation of about 20 milliseconds—even less time than is required for accurate temporal ordering of the sounds forming speech or music. These values, however, had been based on pairs of sounds. The subjects listened to a single pair (such as a tone

and a hiss) and reported their order. It was possible, we reasoned, that subjects could say which sound came first and which last not by actually perceiving the temporal order as such but by detecting which of the sounds occurred at either the onset or the termination of the stimulus pair. In 1959 Broadbent and Ladefoged had suggested that the ability of their subjects to order pairs of sounds might be based on the "quality" of the pair as a whole. Could that "quality" be determined by which sound was present at the onset and/or the termination of the brief pair?

With threshold judgments of this kind, when subjects are working at the limit of their ability, introspection as to how they make their decisions is particularly difficult; they simply cannot say. To determine what criteria are actually being used one must rely on experiments. We returned to our recycled 200-millisecond stimuli (hiss, tone, buzz) that could not be ordered, but this time we inserted a three-second interval of silence between successive presentations of the three-sound sequence. Most listeners could now identify the first and last items in the series correctly, somewhat more accurately in the case of the last sound. This supported our suspicion that "sequence perception" with pairs of sounds represents a special case and is really perception of onset and termination.

In order to examine further the perception of temporal order in the absence of onset and termination cues, we employed a variety of repeated four-item sequences. The chance of guessing the order correctly, starting with whichever sound one chooses, is one in six. With a sequence consisting of a high tone (a frequency of 1,000 hertz, or 1,000 cycles per second), a buzz (40-hertz square wave), a low tone (796 hertz) and a hiss (2,000-hertz octave band of noise), each lasting 200 milliseconds, correct responses were only at the level of chance. It was necessary to increase the duration

of each item to between about 300 and 700 milliseconds (the exact value depending on practice and the response procedure) to obtain a correct identification of sequence from half of the subjects tested. For durations of 300 milliseconds or more, calling out the order of the sounds resulted in more errors than arranging four cards, each bearing the name of one sound, in the appropriate sequence.

We noticed a curious feature of the four-item sequences: listeners frequently could not tell at first how many different sounds were present in the series. The apparent disappearance of one or sometimes even two items could be minimized by telling the listener the number of sounds there were and by first introducing each sound alone. This illusory absence of stimuli could not account completely for the inability to perceive sequence, however: even people who heard the four sounds clearly could not report their sequence. We also found that repetition was not in itself a barrier to sequence perception. When four spoken digits, each lasting 200 milliseconds, were recorded separately (to avoid transitional cues), spliced into a loop and repeated over and over, the subjects perceived the order at once and with certainty.

This great difference between the temporal perception of verbal and of nonverbal stimuli suggested that we could use perception of sequence in an effort to establish which attributes of sounds are responsible for speechlike characteristics. We cut four 200-millisecond segments out of extended statements of separate vowels held at a fixed level for several seconds. When these tape segments were spliced into a loop and played back, the listener heard a repeated sequence of four steady vowels following one another without pauses. Since no speaker can possibly change from one vowel to another in this way, without a transition or a pause, the sequence sounded curiously artificial, like

has a more profound effect: most subjects experience illusory changes involving substantial distortion of the stimulus. A man listening to "tress" repeated 360 times in three minutes heard 16 changes involving eight different words, some illustrated here (*b*).

crude attempts to synthesize speech sounds electronically.

Our subjects did no better than chance the first time they attempted to judge the order of the sounds. By deleting a 50-millisecond portion of each sustained vowel and replacing it with a silent gap, we made the sequence sound more like normal speech, and then identification of order was possible for half of a new group of subjects. The subjects approached a perfect score only when we presented vowels of the same duration (150 milliseconds separated by 50 milliseconds of silence) but recorded with the normal qualities of vocal onset and decay that are characteristic of separate short utterances of vowel sounds. It appears, in short, that accurate perception of temporal order may be possible only for sequences that resemble those encountered in speech and in music—special sequences in which the component sounds are linked together, following specific rules, into coherent passages.

During the 1950's Colin Cherry of the Imperial College of Science and Technology in London wrote about the "cocktail-party problem," the task of attending to one chosen conversation among several equally audible conversations. Apparently such cues as voice quality and spatial localization help the listener to keep fixed on a single voice among many. When a person attends to one of these verbal sequences, he excludes the others, so that presumably it would not be possible for him to relate the temporal position of a phoneme in one conversation (or other extraneous sounds such as coughs) to the temporal position of phonemes in the attended conversation. Such observations lead us to speculate that the inability to perceive the correct order of stimuli that do not form integrated sequences of speech or music may not represent a flaw or defect of our perceptual skills. Rather, this restriction of temporal pattern perception may be an essential step in the continual process of extracting intelligible signals from the ubiquitous background of noise.

Musical and verbal passages have an organization based on the temporal order of their sounds; this organization furnishes a context for the individual sounds. Verbal context, as we pointed out above, can determine completely the synthesis of illusory speech sounds; phonemic restorations are heard when the context is clear but part of the stimulus is absent. Another illusion arises when the stimulus is clear but the context is absent. If one listens to a clear recording of a word or phrase repeated over and over, having only itself as context, illusory changes occur in what the voice seems to be saying. Any word or phrase is subject to these illusory changes, usually with considerable phonetic distortion and frequently with semantic linkages. These illusory words are heard quite clearly, and listeners find it difficult to believe they are hearing a single auditory pattern repeated on a loop of tape. As an example of the kind of changes heard, a subject listening to "tress" repeated without pause heard distinctly, within the course of a few minutes, such illusory forms as "dress," "stress," "Joyce," "floris," "florist" and "purse." This illusion, which we call the verbal transformation effect, has provided unexpected glimpses of hitherto unexplored perceptual mechanisms for organizing speech sounds into words and sentences.

The implications of the verbal transformation illusion were not appreciated fully in 1958, when one of us (Richard Warren) and Richard L. Gregory first reported the discovery of "an auditory analogue of the visual reversible figure." We had been looking for an auditory illusion resembling the one observed in such ambiguous figures as the Necker cube, whose faces seem to pop into different perspective orientations as one looks at it. We reasoned that ambiguous auditory patterns would undergo similar illusory shifts; for example, the word "rest" repeated clearly over and over without pause should shift to "tress," then back to "rest" and so on. We did find such closed-loop shifts but we also found some other illusory changes—to "dress" and "Esther," for instance. At the time, although we noted that perceptual distortion of the stimulus had occurred, we considered it only a curious side effect.

Further study by the present authors has drawn attention to basic differences between the visual and auditory illusions, however. The auditory effect is not limited to ambiguous patterns; any word or phrase will do. Changes are impossible to predict, vary greatly from individual to individual and often involve considerable distortion of the stimulus pattern. A subject listening to the word "see" repeated over and over may hear a phrase as far removed from the stimulus as "lunchtime," particularly if the time is about noon! Changes occur frequently: when a single word is repeated twice a second for three minutes, the average young adult hears about 30 changes involving about six different forms.

There are some remarkable effects of age on the frequency of verbal transformations and the types of illusory changes. These age differences seem to reflect basic changes in the way in which a person processes verbal input over a life-span. Children at the age of five experience either very few or no verbal transformations. At six half the children tested heard illusory changes, and those who did experienced them at the rapid rate characteristic of older children. By the age of eight all the children tested heard verbal transformations. The rate of illusory changes apparently remains approximately constant into the twenties and then declines slowly during the middle years; for listeners over 65 the rate was found to be only a fifth the rate for young adults and was approximately equal to the rate for five-year-olds. This

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decrease after middle age is not due directly to any decrease in auditory acuity with aging. Actually the aged are generally more accurate in this task than the young, reporting common English stimulus words correctly and continuing to respond to the stimulus as it actually is—the same word repeated over and over without change. Moreover, if young adults hear a word played indistinctly against a background of noise (which should simulate a decrease in acuity), they still hear many more illusory changes than the aged.

Besides counting the number of changes, we have examined the groupings of speech sounds to determine the units of perceptual organization at different ages. Children respond in terms of the sounds of English but may group them in ways not found in the language. For example, with the word "tress" repeated over and over, a child might report "sreb" even though the initial "sr" sequence is not found in English words. Young adults group speech sounds only in ways that are permitted in English, but they do report nonsense syllables: given the stimulus "tress," they might report "tresh" as one of the sounds they hear. Older people, on the other hand, report only meaningful words. Presented with "tress," they tend to hear "tress" continuously, and when infrequent changes do occur, they usually are to such closely related forms as "dress." If an older person is presented with a repeated nonsense syllable, there is an

interesting result. If "flime" is the stimulus, for example, the older listener generally distorts the word into a phonetically close English word such as "slime" and tends to stay with the sense-making (but illusory) word throughout.

Our observations with verbal transformations have suggested that as people grow older they employ different perceptual mechanisms appropriate to their familiarity with language and their functional capacities, both of which change with age. We believe specific mechanisms associated with the skilled use of verbal context underlie the age differences in the frequency and nature of verbal transformations. Repeated words do not flow past us as normal components in the stream of language do; like a vortex, they move without progressing. In the absence of the semantic and grammatical confirmation ordinarily provided by verbal context, perception of repeated words becomes unstable for all but the very young and the old. And since each successive perceptual organization is subject to the same lack of stabilizing context, it suffers the fate of its predecessor.

The absence of illusory changes at age five suggests that young children have not yet reached the stage in language development where storage with skilled reorganization comes into play. The loss of susceptibility in alert and healthy elderly listeners suggests that they no longer have the functional capacity for this mechanism. It is rather well established that short-term memory is less ef-

fective in the aged when intervening activity is required between input and retrieval. Concurrent processes of coding, storing, comparing and reorganizing may therefore not be possible, so that the optimum strategy is to employ only the past context of the message as an aid to organization of the current input. The fact that in the presence of repeated stimuli the aged report only meaningful words is consistent with this view. If this interpretation is correct, one would expect that phonemic restoration for elderly people would be limited to replacement of speech sounds identified by prior context; the use of subsequent context, in the manner of young adults, would not be possible. We plan to do experiments testing this prediction.

In summary, it appears that phonemic restorations and verbal transformations provide new techniques for studying the perceptual organization of heard speech, particularly the grouping of speech sounds, the correction of the listener's errors and the resolution of acoustic ambiguities. The observations we have described for the perception of auditory sequence indicate that special perceptual treatment of the sounds of speech (and music) allow us to extract order and meaning from what would otherwise be a world of auditory chaos. It is curious that in studying illusions and confusions we encounter mechanisms that ensure accurate perception and the appropriate interpretation of ambiguities.
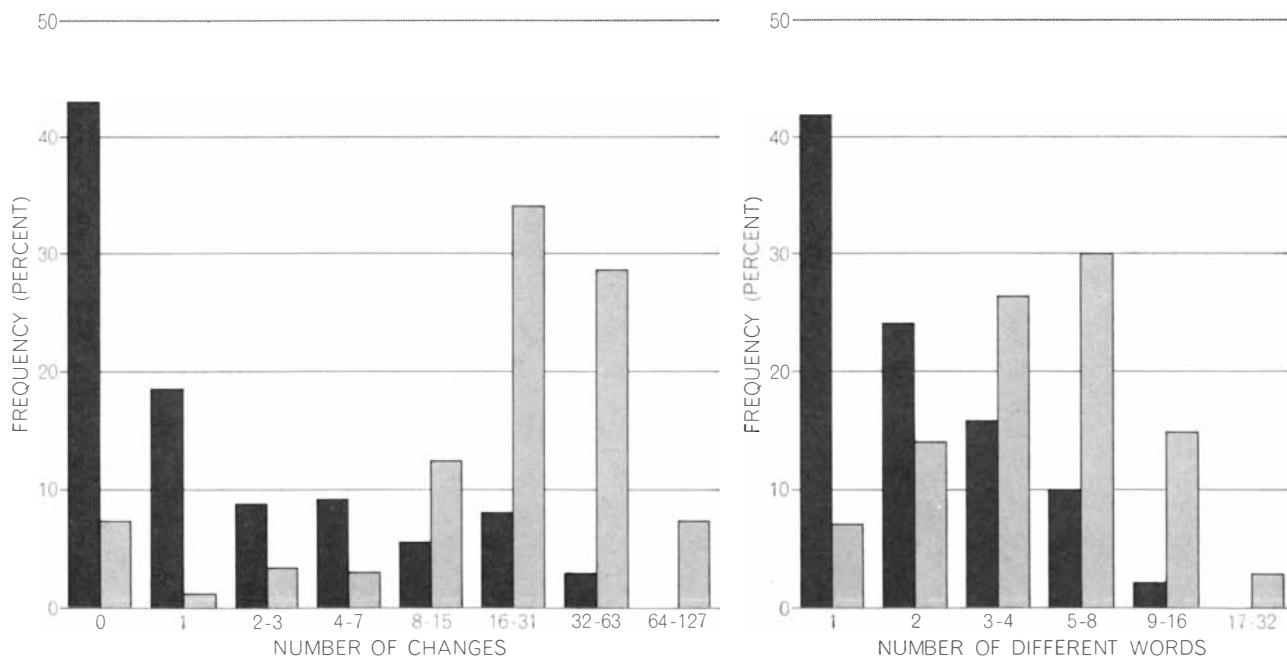
AGE DIFFERENCES in the frequency of verbal transformations are shown for two of the age groups tested. The bars indicate the number of changes from one form to another (left) and the num- ber of different forms (right) perceived during three-minute tests by subjects 18 to 25 (gray) and 62 to 86 years old (black). Differences reflect changes in the perceptual processing of speech.

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We want to be useful
...and even interesting

Fast film for simple needs

This young model is demonstrating the KODAK INSTAMATIC® M22 Movie Camera, lowest-priced movie camera currently manufactured in the U.S.A.* She is having fun, unaware that fun is not the sole purpose of movie-making. Educators are beginning to believe in the magic observed when classes of inarticulate kids whom nobody has ever trusted with anything produce a motion picture epic on a theme like "Por Qué Juanito Llegó Tarde."

This may be of interest to you as a citizen, but you may have an entirely different and professional use for the camera in an austere time for scientific instrumentation. You may want to see which arm a chimpanzee is using and not need a lens that can count abdominal segments in an arthropod, but you may think you don't have enough light. Be advised that the fastest of available movie films, daylight index 400, can now be obtained in 50-foot super 8 cartridges for processing locally to a black-and-white positive. KODAK 4-X Reversal Film 7277 is the name. Make your first cartridge of it an exposure series at various apertures. Of all current Kodak movie cameras, only the lowest-priced one permits manual setting of the 14mm lens from $f/2.7$ down to $f/26$. (For automatic speed setting by the notch on the cartridge, this film can be used in certain of the more elaborate cameras of other manufacturers. Except at extraordinary frame rates or relative apertures, the film is too fast for bright sunlight.)

If you know a place where football is taken very seriously, the athletic department there may have KODAK 4-X Reversal Film on hand. Otherwise, look for the Kodak trademark in the Yellow Pages under "Audio Visual Equipment and Supplies."

*Can be picked up for less than $34 at a nearby counter. Forgive us if this suggestion has failed to reach you in time for the gifting season.

TV, popular or not

"Videoplayer" is not a trademark. It's a generic noun you won't find in the dictionary yet. Better known are various proprietary designations of companies intending to compete in the business of TV that enters the home via purse or pocket, not antenna or cable. The little cartridge simply drops into the videoplayer you will have attached to your set.

The idea is too big to fit under anybody's particular tent. We needed a generic descriptor in stating *our* position. Which

is that the best thing to have in the cartridge is super 8 movie film. For very fundamental reasons: super 8 material is extant in vast profusion and is also very inexpensive to create fresh *(for example, with the camera shown at left)*. For subject material that interests more than a single family or classroom, a multitude of processors across the land stand willing, able, and eager to deliver as few as 5 uniform, standardized super 8 copies for distribution. To make the print order 500,000 instead of 5 is also possible with super 8, but economics does not *demand* a huge audience.

Don't we all keep telling ourselves that we are individuals, that we don't necessarily share our neighbor's preferences in all things, that life at the broadest common denominator sometimes palls?

Otherwise, why a videoplayer at all?

The shape of the land

December. Low cloud covers much of America. Soon the snowdrift contours will be the shape of the land. Ski-time. Not a good time for photographic air survey to help plan how to use the land for other outdoor recreation or other needs of an urbanized society. And where not to try using it. Not a good time even if arrangements with good aerial survey houses could be made instantaneously. Good time is a short period in the spring just before the trees leaf out. If you miss that, you may wait nearly a year for a try in the fall. Let us send you *right now* the names of the aerial survey houses we know. Most of them also do business in prints from existing aerial photographs. Just possibly the photography you need has already been done.

For the names ask Dept. 926, Eastman Kodak Company, Rochester, N.Y. 14650.

Perhaps we are rushing you. Perhaps all you can profitably use at the moment is the new Kodak Publication M-76, "Photo-interpretation for Land Managers," available from photographic dealers or for $1.50 from our Dept. 454 (instead of 926). It even tells of non-proprietary sources for air survey photographs.

Prices subject to change without notice.

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SCIENCE AND

The Nobel Prizes

By awarding the Nobel peace prize to an agronomist the Nobel committee of the Norwegian Parliament has found a way to broaden the range of both the scientific and the peacemaking activities recognized by the executors of Alfred Nobel's will. The award for peace was given to Norman E. Borlaug "as the prime mover in the 'green revolution' [and] for his great contribution toward creating a new world situation with regard to nutrition." The Nobel memorial prize in economics, first awarded last year, went to Paul A. Samuelson "for the scientific work through which he has developed static and dynamic [economic] theory." The Nobel prize in medicine and physiology was awarded to Julius Axelrod, Sir Bernhard Katz and Ulf von Euler "for their discoveries concerning the humoral transmitters in the nerve terminals and the mechanisms for their storage, release and activation." The prize in physics was given jointly to Hannes Alfvén "for fundamental work in magnetohydrodynamics" and to Louis Néel "for fundamental work and discoveries concerning antiferromagnetism and ferrimagnetism." The prize in chemistry went to Luis F. Leloir "for his discovery of sugar nucleotides and their role in the biosynthesis of carbohydrates."

Borlaug, who was born in Iowa and received his doctorate in plant pathology at the University of Minnesota, is head of the wheat program at the International Maize and Wheat Improvement Center in Mexico, set up by the Rockefeller and Ford foundations in cooperation with the Mexican government. The two foundations have also established the International Rice Research Institute in the Philippines and similar institutes in Nigeria and Colombia expressly to improve the productivity of tropical agriculture.

Beginning in 1944 Borlaug and his coworkers sought to breed improved varieties of wheat for Mexico by crossing Japanese dwarf strains with local Mexican varieties. The varieties introduced into the crosses eventually included strains from Africa, Australia, South America and half a dozen states in the western U.S. The goal was to obtain new high-yielding varieties with high disease resistance and good milling and baking properties. Dwarfism was also introduced to minimize top-heaviness and allow the heavy application of fertilizer.

The first of the improved varieties were widely planted in Mexico in the late 1950's. In the early 1960's, when India had to import large tonnages of wheat, Borlaug began testing his new varieties there and selected several that would do well. They were quickly adopted, along with improved irrigation methods and greatly expanded use of fertilizers and pesticides. About 80 percent of the Punjab "wheat basket" is now planted to the new grain and yields are estimated at two or three times the old level. India and Pakistan have both increased their wheat production more than 50 percent.

Samuelson, born in Gary, Ind., attended the University of Chicago and received his doctorate in 1941 at Harvard University. His Ph.D. thesis, published six years later as *Foundations of Economic Analysis,* is regarded as a classic in its field. It and subsequent works were founded on the unifying hypothesis that nearly everyone is trying to maximize (or minimize) something. He also provided new methods for handling a central problem of his discipline: How does a particular sector of the economy return to equilibrium after one or more variables have been disturbed? "After Samuelson's work," says a colleague, "it is harder for economists to be nonrigorous and still be respectable." A

THE CITIZEN

contributor to virtually every branch of economics, Samuelson is regarded as an active developer and expositor of Keynesian economic theory.

Axelrod, born in New York City, was graduated from the College of the City of New York in 1933, obtained a master's degree from New York University in chemical pharmacology in 1941 and a Ph.D. at George Washington University in 1955, at the age of 43. In the same year he was named chief of the pharmacology section of the National Institute of Mental Health. By then he had already published major papers on how drugs interact with the nerve transmitter substances epinephrine and norepinephrine. Using transmitters with radioactive labels, he showed that narcotics such as cocaine and tranquilizers such as reserpine modify the way the neurotransmitters are stored at the nerve terminals. Subsequently he showed how steroid hormones, associated with stress, control the conversion of norepinephrine to epinephrine in the adrenal gland.

Katz, born and educated in Leipzig, moved to England in the mid-1930's, where he began studying the transmission of nerve impulses at University College London under A. V. Hill. After working briefly in Australia and serving as a radar operator in World War II, he returned to London and learned micropipette techniques for studying the large nerve cells of the squid. These studies, largely in collaboration with Paul Fatt, led to the discovery that the nerve transmitter substances such as acetylcholine are stored at the nerve endings in tiny packets, or quanta, each of which has a certain probability of being released on the arrival of a nerve impulse. These findings are now central to all theories of impulse transmission at nerve junctions.

Von Euler, born in Stockholm, has had a long association with Nobel prize winners. His father, Hans von Euler, received the prize for chemistry in 1929. Ulf von Euler obtained his medical degree in 1930 from the Royal Caroline Institute (which administers the prizes for physiology and medicine) and has been on the faculty ever since. He has also collaborated at different times with two Nobel prize winners: Sir Henry Dale and Bernardo Houssay. Since 1953 he has

served on committees responsible for making Nobel awards and since 1966 he has been president of the Nobel Foundation. Colleagues believe that, if anything, these associations delayed his own award. In 1940 von Euler identified norepinephrine as the transmitter substance in the sympathetic nervous system. Later he demonstrated that the adrenal gland increases its output of epinephrine when the nerve to the gland is stimulated. Recently he has studied how norepinephrine is taken up, stored and released by vesicles in the nerve endings.

Alfvén, born and educated in Sweden, has recently been dividing his time between the University of California at San Diego and the Institute of Technology in Stockholm. The work that won him the Nobel prize concerns the behavior of ionized gases—atoms and molecules stripped of electrons—in the presence of a magnetic field. (He gave an early account of this work in the May 1952 issue of Scientific American.) When Alfvén began his studies of such gases, also known as plasmas, they were regarded as being highly esoteric. Subsequently it was appreciated that a knowledge of plasmas is essential for understanding the behavior of stars and the structure of galaxies. Alfvén's work became of direct practical use with the effort to control thermonuclear reactions by building magnetic "containers" to hold plasmas at temperatures of millions of degrees. Alfvén predicted that under certain conditions plasmas would propagate waves with unusual characteristics. Such "magnetohydrodynamic" waves have now been discovered and studied in many systems, ranging from the size of crystals in the laboratory to "whistler" waves in the earth's ionosphere.

Néel, who heads a staff of some 300 at the University of Grenoble, has supplied the theory that underlies much of the technology of magnetic materials developed in the past 25 years. Pierre Curie had investigated the temperature at which ordinary ferromagnetic materials, if heated, lose their magnetic properties (the Curie temperature). Ferromagnetic materials such as iron, nickel and cobalt are magnets because their individual atoms have unbalanced electron spins that give rise to a small magnetic moment. These moments align themselves spontaneously and also respond to an external magnetic field. Certain other materials such as oxides of nickel and manganese have atomic magnetic moments that also align themselves spontaneously, but because the magnetic mo-

ments in individual molecules line up in opposite directions they cancel and produce no external evidence of magnetization. These are called antiferromagnetic materials. Néel found a way to measure the temperature at which such compounds become magnetically disordered; it is now called the Néel temperature. Néel also studied a class of antiferromagnetic materials in which one set of magnetic moments adds up to a larger value than the equal number of moments of opposite sign. Known as ferrimagnetic materials, they include the ferrites widely used as the recording medium in magnetic tape and in the magnetic-core memories of computers. They combine unusual magnetic properties with Néel temperatures that run as high as 350 to 450 degrees Celsius.

Leloir was born in Paris while his Argentine parents were visiting France. He attended medical school in Buenos Aires and then spent 10 years in the laboratory of Houssay, who won the Nobel prize for medicine and physiology in 1947. Leloir is director of the Institute of Biochemical Research–Campomar Foundation. In the late 1940's and early 1950's, when Leloir made the discoveries that brought him the Nobel prize, the institute was quartered in a small house on the outskirts of Buenos Aires. Leloir traced the biochemical pathway used by the living cell to convert glucose, a simple sugar, into more complex carbohydrates such as starch and glycogen. Since test-tube experiments in glassware had indicated that glucose-1 phosphate, an activated form of glucose, will form glycogen by direct polymerization, it was thought the cells of plants and animals might use the same starting material. Leloir showed, however, that the cell needs a more highly activated form of glucose: uridine diphosphoglucose. Later he and others found that uridine can be replaced by other nucleotides, such as adenosine and thymidine. These activated substances are the sugar nucleotides mentioned in the Nobel citation. They are now seen to play an important role in determining blood groups and the structure of bacterial cell walls.

NOAA as in Noah

A new agency designed to provide a focus and an administrative center for the Federal Government's activities relating to the ocean and the atmosphere has gone into operation. It is the National Oceanic and Atmospheric Administration of the Department of Commerce; it has already become known as

"Noah" from the initials NOAA. The agency came into being as a result of a reorganization plan proposed by President Nixon this past summer and recently approved by Congress. In transmitting the proposal the President said: "The Government's environmentally related activities have grown up piecemeal over the years. The time has come to organize them rationally and systematically." NOAA, he said, would meet needs for "better understanding of the total environment" and for "exploration and development leading to the intelligent use of our marine resources."

Most of the new agency's functions were under the Environmental Science Services Administration (ESSA). They include the Weather Bureau, which is now called the National Weather Service; the National Environmental Satellite Service; the Coast and Geodetic Survey, which becomes the National Ocean Survey and also takes over from the Army Corps of Engineers the U.S. Lake Survey; the Environmental Research Laboratories, and the Environmental Data Service. Other components of NOAA include the National Marine Fisheries Service; the Office of Sea Grant, which provides support for marine research programs; the Data Buoy Project Office, which is developing a system of automatic buoys for obtaining continuous marine environmental data; the Marine Minerals Technology Center, and the National Oceanographic Instrumentation Center.

Advances in Alchemy

Physicists at the University of Oxford and the University of California at Berkeley have found a new way to change one chemical element into another. The newly discovered mechanism, called proton decay, involves the emission of a proton by a comparatively unstable "exotic" nucleus synthesized inside a heavy-ion accelerator. The discovery brings to four the number of known modes of radioactive transmutation of the elements. The other three modes are alpha decay (the emission of an alpha particle, or a helium nucleus), beta decay (the emission of a beta particle, or an electron) and spontaneous fission (the unprovoked splitting of certain very heavy nuclei).

Although the possibility of proton decay was postulated more than 50 years ago, it is only now that experimental equipment capable of making and detecting the kinds of nuclei in which the reaction would be expected to occur

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is becoming available. The successful search for the reaction was begun last year by Joseph Cerny of Berkeley during a sabbatical at Oxford. Working with the variable-energy heavy-ion cyclotron at Harwell in England, Cerny and his colleagues (K. P. Jackson, C. U. Cardinal, H. C. Evans and N. A. Jelley) looked for evidence of the reaction in metastable nuclei of cobalt 53, which they created by bombarding nuclei of calcium 40 with nuclei of oxygen 16. When two of these nuclei merged, one proton and two neutrons were emitted, leaving a neutron-deficient cobalt-53 nucleus, which then apparently decayed by the emission of a proton into an iron-50 nucleus.

For various reasons the experiments in England were not conclusive, and after returning to Berkeley, Cerny repeated them with the more powerful 88-inch cyclotron at the Lawrence Radiation Laboratory. In these experiments (carried out in collaboration with J. E. Esterl, R. G. Sextro and R. A. Gough) Cerny was able to observe clear and unequivocal evidence of the direct emission of protons by the cobalt-53 nuclei.

As a method for the transmutation of the elements, proton decay is closely analogous to alpha decay in that the proton is not energetically bound to the nucleus by strong nuclear forces but rather is held in temporarily by barriers arising from other physical effects. As other exotic radioactive nuclei are produced in the laboratory, proton decay is expected to become a common occurrence among nuclei that are comparatively short-lived and at least moderately deficient in neutrons.

Gigahertzian Broadcasting

The length of the radio waves currently used in communications runs from about three centimeters to 100,000 meters; the corresponding frequencies are 10 gigahertz (10 billion cycles per second) and three kilohertz (3,000 cycles). Even this large range of frequencies is strained to provide room for the multitude of radio communication channels needed by an advanced society. L. C. Tillotson of the Bell Telephone Laboratories proposes that the time is now ripe to consider using for such purposes the radio waves ranging from one millimeter (300 gigahertz) to one centimeter (30 gigahertz).

Until recently, Tillotson writes in *Science,* a number of difficulties stood in the way of putting radio communications in the millimeter-wave region.

Sources of power for such transmissions have entailed high initial cost, short operating lifetime and burdensome power-supply requirements. Moreover, transmission losses increase with increasing frequency, and millimeter-wave transmissions are particularly vulnerable to water in the atmosphere.

Now, according to Tillotson, "the advent of solid-state oscillators and amplifiers" has considerably improved the power situation. In addition it has become possible to cope with transmission losses by means of solid-state repeaters on the ground or in a network of artificial satellites. Tillotson describes a possible application exploiting the sharp antenna beams that would result if antennas of reasonable size were mounted on a precisely stabilized space platform in earth orbit. Each beam would cover only a small portion of the earth's surface. This arrangement, he writes, would make possible "communication between a satellite and many earth stations with the use of only one frequency assignment." Conversely, "one assignment can be used between an earth station and many satellites." When such an arrangement is "combined with the broad bandwidths available at these frequencies, a system of very large potential capacity results."

Chopped Pulses

When one is driving in a fog at night, the headlights seem unable to penetrate the fog because so much of their light is scattered back to the eye by tiny droplets of water. The same phenomenon, known as veiling luminance, makes it difficult to use artificial light to see under water. One can now overcome veiling luminance to a remarkable extent with a stratagem that electronically manipulates pulses of laser light. The basic idea is that when an underwater object is illuminated with a laser pulse, the light that returns ahead of the light that is reflected from the object is chopped off. In this way the light scattered by particles in front of the object is eliminated, bringing the object into much clearer view.

Writing in the journal *Optical Spectra,* Anthony Immarco and Tarald Oigarden give an account of their work with the Kollsman Instrument Corporation during the development of a "gated" underwater optical system for the Navy. Their light source was a laser emitting 30 intense pulses of green light per second; each pulse lasted only a hundred-millionth of a second. The returning

light was detected by an image-intensifier, which was switched at such a rate that it received only the light from a five-foot-deep part of the entire illuminated field. The image of this area was then converted into a television signal and fed to a display screen.

The five-foot "spotlit" area could be "moved" closer to or farther away from the receiving apparatus by means of a delay line linking the laser to the image-intensifier switch. Immarco and Oigarden report that the range-gated images remained clear up to a distance of 125 feet from the receiver, compared with a maximum range of some 40 feet for conventional underwater viewing systems.

Where the Fault Lies

Californians are understandably apprehensive about seismic activity along the 800-mile-long San Andreas fault. In addition to the 1906 quake that rattled San Francisco with a magnitude measuring 8.3 on the Richter scale, no fewer than 25 seismic disturbances with magnitudes of 5.0 or greater have occurred at various places along the fault since the 1930's. Robert E. Wallace of the U.S. Geological Survey has now calculated the probable times when the fault will be the site of further earthquakes greater in magnitude than 5.0.

Writing in the *Geological Society of America Bulletin,* Wallace notes that predictions based on earthquake data collected in the past few decades are necessarily handicapped by the short-term nature of the data. The geological history of the San Andreas fault, however, extends some 25 million years into the past and indicates that the rate of slip along the fault line has been relatively constant. Using this and other information to construct "recurrence curves," Wallace estimates that the interval between two successive magnitude-6 quakes somewhere along the length of the fault should be five years, the interval for magnitude-7 quakes 15 years and the interval for magnitude-8 quakes 102 years. Noting that his estimate may be in error by at least a factor of two, Wallace concludes that the recurrence interval for a magnitude-8 quake may lie anywhere between 50 and 200 years. Thus San Franciscans may take a certain amount of comfort from the fact that, although an earthquake of the magnitude of the 1906 one may be 14 years overdue, it is equally likely that such an earthquake will not occur until the year 2106.

Some things are changing for the better.
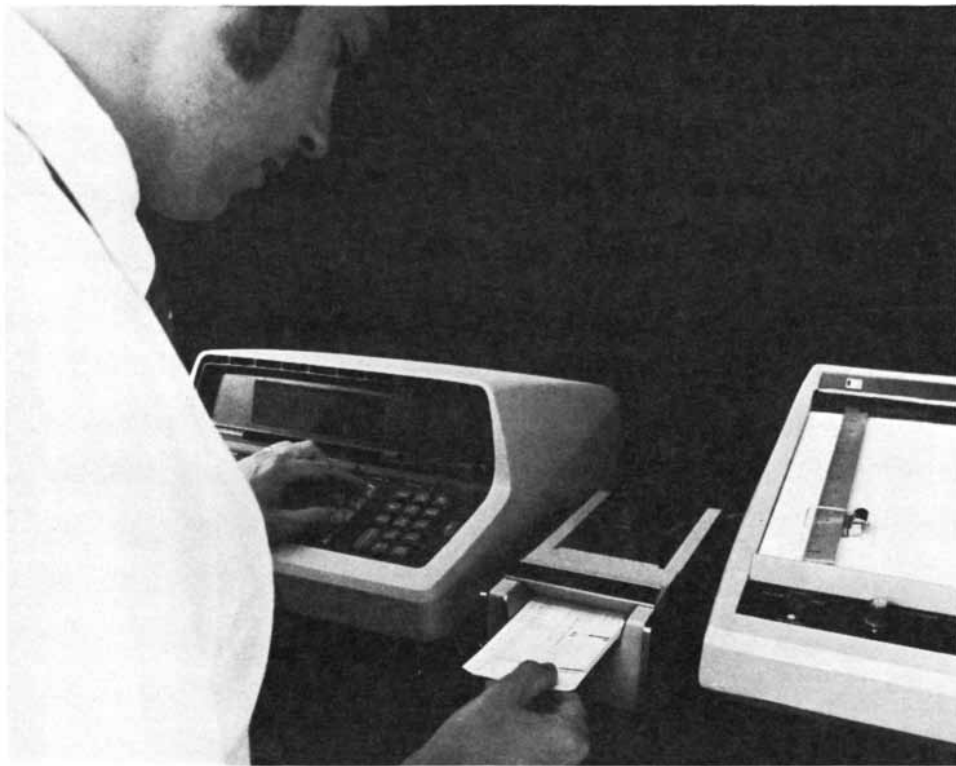
Turn your desk calculator into an on-line data handling system

Let's assume that you now perform scientific and engineering computations on the HP 9100 Calculator, entering data off-line on its keyboard.

But now you'd like to get the answers automatically, on-line, by letting your data-gathering instruments communicate directly with your data processing system. You might think the time has come for a large investment in a computer.

Not so. With the new HP 2570 Coupler/Controller, you can now tie many of your HP measuring instruments (more than 40 models including voltmeters, counters, GC integrators, quartz thermometers) to the 9100 and get reduced data directly. By simple cable connections.

You can even tie a teletype to the 2570 and get complete reports of your experiment, formatted as you like them and prepared automatically during the experiment, on a typewritten sheet or punched paper tape. Or on the calculator X-Y Plotter.

We'd be happy to send you a 24-page Bulletin that explains how the 2570 can expand the capabilities of your 9100 for on-line data handling and even for automatic test systems. Write for "Calculator-Based Instrumentation Systems." Price of the Coupler is only $1625. Interfaces cost $450 – $1500 per device.

Keep an eye on solid-state displays: they're moving fast

If you haven't been paying very close attention in the last several months, some fast-moving developments in solid-state displays based on GaAsP light-emitting diodes (LED's) have undoubtedly escaped your attention.

Earlier this year, HP introduced an alphanumeric display that incorporates 35 LED's per character, arranged in a 5 x 7 dot pattern. There are two outstanding advantages to this design: it can display highly readable letters and symbols as well as numbers, and it is suitable for dynamic as well as static operation. In static operation, all of the diodes that are needed to form a character are *on* continuously; in a dynamic display, the LED's are scanned one row or column at a time, at high speed. If the scanning rate approaches 100 times per second, the eye sees only the complete character and there is no flicker. The scanning technique not only permits sharing the same character generator and scanning circuits by several displays but also greatly reduces the number of interconnections.

HP scientists have just announced the development of a monolithic display which is fabricated from a single GaAsP chip into which seven LED's are diffused. Its seven-segment character (contrasted to the previous 35 dot matrix) is suitable only for number generation. Counterbalancing this, its fabrication from a single chip is fully automated, a fact that has already reduced its price to $7 per character (compared to $30 for the alphanumeric) and promises a further reduction to $2 in large quantities.

All HP solid-state displays are hermetically sealed, IC-compatible and have a life expectancy of at least 100,000 hours. We'll be glad to send you technical data on any of them.
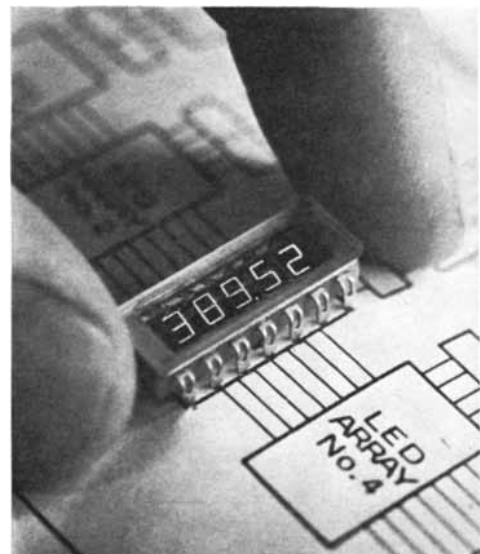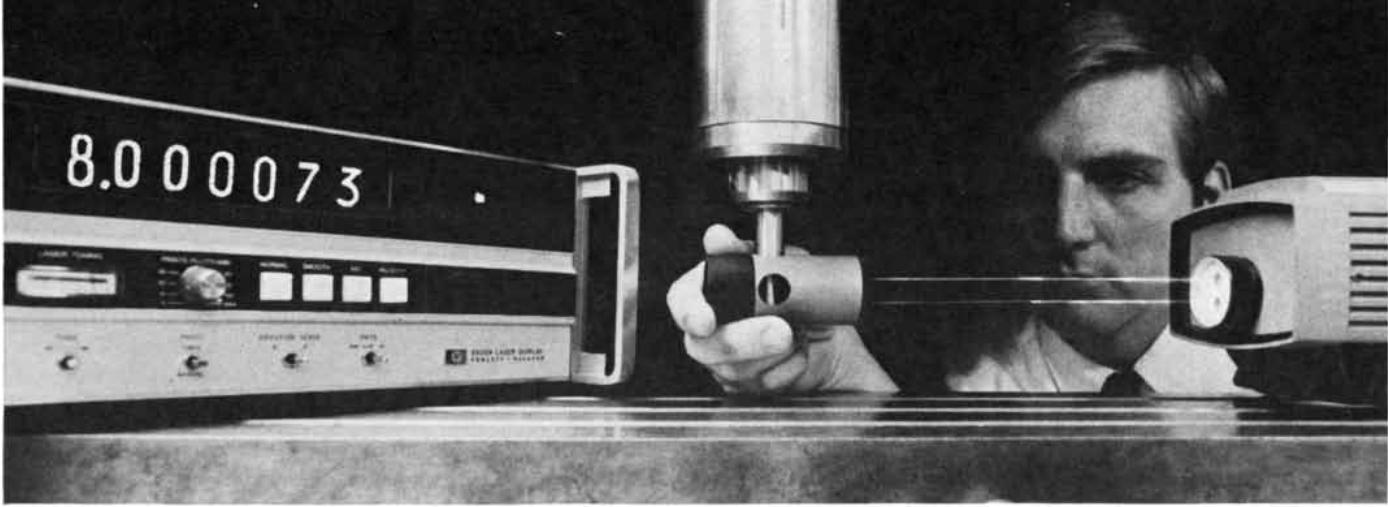
For interferometers, two frequencies are better than one

All interferometers built since Michelson's original experiments in the 1890's use two light beams of the same frequency. They measure distance by counting the cycles of beam intensity in the reflected light caused by alternate constructive and destructive interference of the two beams, as the reflector is moved. Direction is measured by detecting the phase difference between two portions of the measuring beam. These two signals are used to drive a counter one way or the other, after dc amplification.

And there's the rub. Any variation in the intensity of the light source due to atmospheric disturbances or normal dc amplifier drift, can cause erroneous readings or put the system out of commission.

A new interferometer completely avoids this problem by the simple expedient of operating entirely on ac. This was made possible by the development, in the HP Laboratories, of an entirely new laser which oscillates

on two frequencies simultaneously. An axial magnetic field Zeeman splits its main spectral line into two frequencies, 1.8 MHz apart and of opposite circular polarization (thus easily distinguishable).

One of these frequencies (f_1) is isolated in a reference path. The other (f_2), isolated in a measuring path, is bounced off an external reflector and recombined with f_2 at the interferometer. If the external reflector remains stationary, the difference between the two is exactly 1.8 MHz. But when the reflector is moved, the measuring beam's frequency is Doppler-shifted at a rate of about 1 MHz for a 1 foot-per-second reflector velocity, and the difference between these two frequencies becomes ($f_1 \pm \Delta f - f_2$).

Movement is determined by sensing differences between the Doppler signal and the constant reference signal ($f_1 - f_2$) and counting the cycles on separate registers. A subtractor keeps a running count of the differences in quarter-wavelengths of light, while a built-in IC calculator converts wavelengths to units of length.

Besides a radical decrease in susceptibility to air turbulence, the HP Model 5525A Interferometer ($11,500) measures distance to 1 microinch resolution, requires no warmup and tunes itself automatically. These characteristics suggest great utility in metrology laboratories, for measurements from microinches to 200 feet, as well as machine tool use. The August 1970 issue of the HP Journal tells the whole story: write for your copy.

New tool for on-line system analysis

Very recently at a large power station in England, a system analysis of an attemperator or temperature control loop was completed on-line, without disturbing plant output in any way. As the control characteristic of the loop was displayed on a screen during the experiment, adjustments were made to optimize the control system and the results were displayed immediately.

The job of the control system engineer —to predict how the system will react

to a given input pulse — has not always been so easy. If he tests the system with an impulse that is large enough to produce a measurable response, plant output is changed in a way that cannot be tolerated.

Some progress was made when control system analysts discovered the power of cross-correlation. With this mathematical technique, a test noise signal is applied to system input at such low levels that system output is not changed beyond normal background disturbances. Yet by cross-correlating the test noise with the system output over a relatively short period, the engineer is able to extract the impulse response of the system; background disturbances do not interfere because they are uncorrelated with the test noise.

At first, cross-correlation did not help because it could only be accomplished after the fact, through off-line digital computation. What made the difference in the English experiment was the availability of two new HP instruments: a Model 3721A on-line correlator that's about as easy to use as an oscilloscope, and a Model 3722A precision noise generator that synthesizes repeatable pseudo-random noise, ideally suited to system analysis. The correlator costs $8325 and the noise generator $2650. On request, we'll be glad to send you a packet of information on these two instruments, correlation and the on-line experiment.

If you're involved in the techniques of digital analysis or correlation, we can offer a new product-oriented handbook, "Discrete Signal Analysis," which will help. For this 96-page booklet or any of the other material mentioned, write to: Hewlett-Packard, 1508 Page Mill Road, Palo Alto, California 94304; Europe: 1217 Meyrin-Geneva, Switzerland.
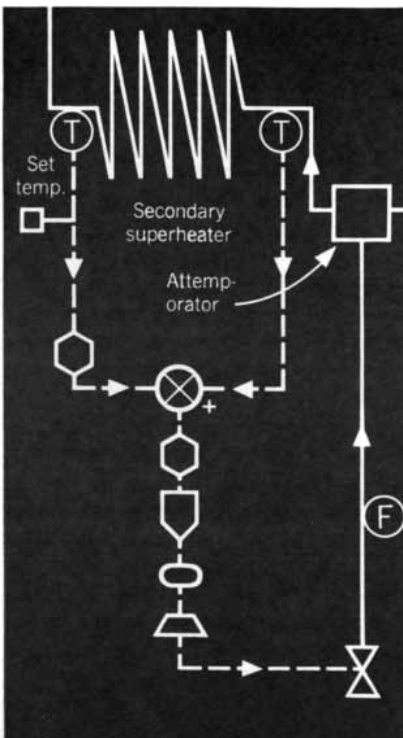
HEWLETT hp *PACKARD*

Measurement, Analysis, Computation

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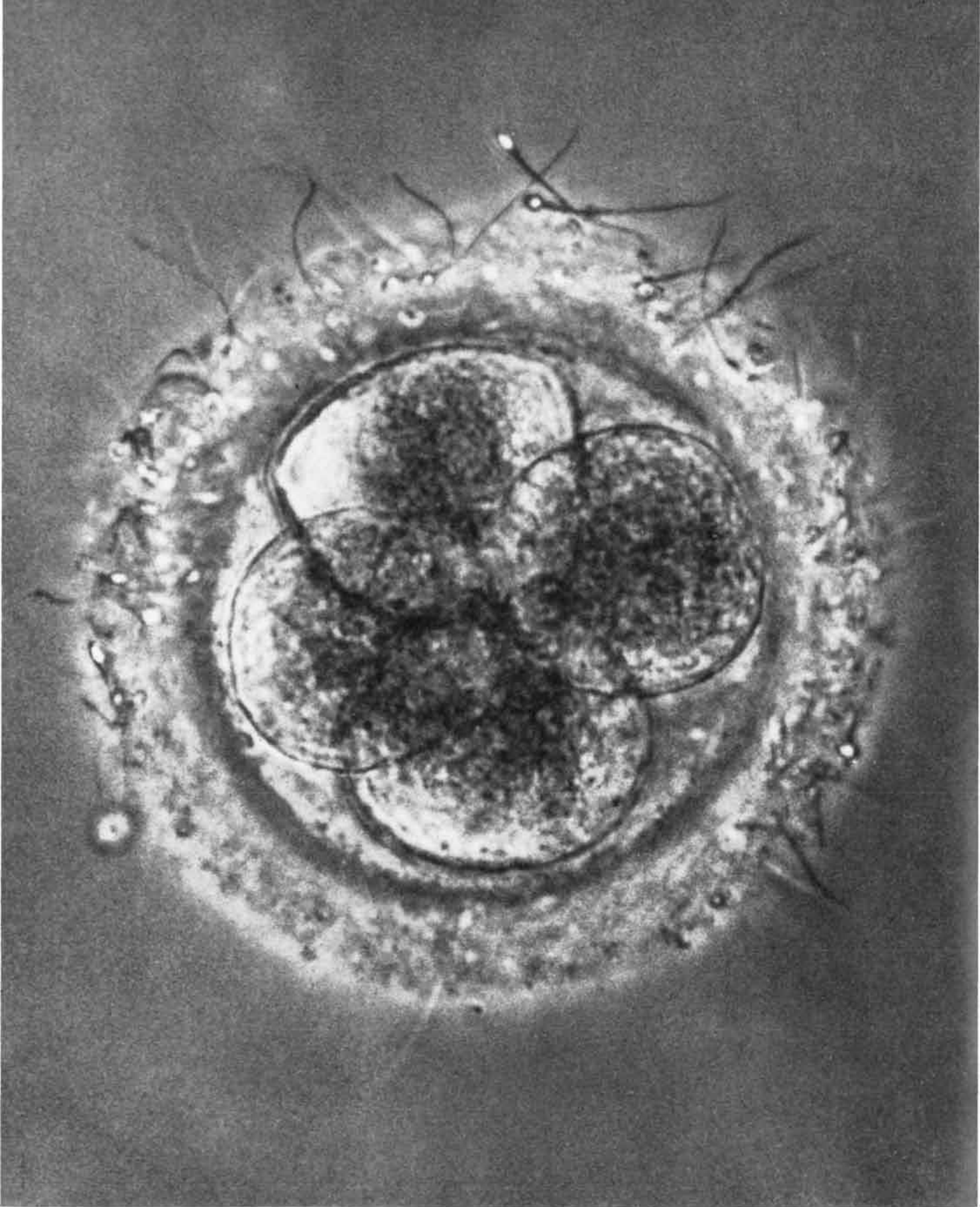
HUMAN EGG that was fertilized in the laboratory has developed to the four-cell embryonic stage in a culture medium. A number of spermatozoa can be seen in the zona pellucida, which is the out-er membrane of the egg. The fertilized egg has cleaved first to two cells and then to four. The four cells can be seen inside the mem-brane. The following stage would be an embryo with eight cells.

HUMAN EMBRYOS IN THE LABORATORY

It is now possible to make human eggs mature, to fertilize them in vitro and to grow them in a culture medium through early embryonic stages. Such procedures may help to alleviate infertility and fetal abnormalities

by R. G. Edwards and Ruth E. Fowler

The fertilization and the subsequent development of the human egg are normally inaccessible to observation. Much effort has been directed toward understanding the sequence of events in invertebrate animals such as the sea urchin and the frog and also in many species of mammal. The study of laboratory species such as the mouse and the rabbit has provided a great deal of information about fertilization.

Mammalian oöcytes, or immature eggs, must reach a particular stage of development before they can be fertilized. Normally they mature in the ovary. It is possible to induce maturation by administering certain reproductive hormones to the female animal, and it is also possible to stimulate maturation artificially by putting the oöcytes in a culture medium. In laboratories at the Oldham General Hospital in Lancashire and at the University of Cambridge human eggs have now been successfully brought to maturity, fertilized in vitro and cultured in vitro to the blastocyst stage of development, which is the stage immediately preceding the beginning of normal implantation of the fertilized egg in the uterus. We foresee that this work will have important physiological and clinical consequences. Since it will be possible to observe in the laboratory (1) the maturation of the egg through the stages just preceding ovulation, (2) the fertilization of the egg and (3) its development to the blastocyst stage, the nature of these events should become much clearer. Clinically it should be possible with these procedures to circumvent certain causes of infertility and to avert the development of embryos that otherwise could be expected to grow abnormally.

Still further possibilities can be imagined. Eggs fertilized in the laboratory and cultivated to the blastocyst stage could be transferred back to the mother with an excellent chance of completing development normally. Since there would be several blastocysts from one couple, a degree of selection could be exercised in deciding which one to return to the mother. For example, the sex of the baby could be predetermined.

The Maturing Egg

A human female possesses at birth her total stock of oöcytes, and they have completed the earliest stages of meiosis: the special process of cell division whereby the number of chromosomes in the egg is halved. Meiosis takes place in two stages commonly known as meiosis I and meiosis II. Oöcytes enter and complete the first stages of meiosis I between the fourth and the seventh month of fetal life. They then enter a prolonged period known as the dictyotene stage. During that stage the nucleus of the egg has certain distinctive characteristics and is called the germinal vesicle. The oöcyte remains in the dictyotene stage for many years—from before the female is born until just before its ovulation in the adult. The dictyotene stage can therefore persist for 40 years or more in the oöcytes that are the last to be ovulated.

In the dictyotene stage the oöcyte is enclosed in a layer of cells that constitutes the primordial follicle. Early in each menstrual cycle several follicles become larger; this growth is stimulated by the follicle-stimulating hormone (FSH), which is released by the pituitary gland. Usually only one of the eggs within the enlarged follicles is ovulated. Ovulation itself is triggered by a midcycle surge of the luteinizing hormone (LH), which is also secreted by the pituitary gland.

The luteinizing hormone stimulates the oöcyte to resume meiosis. The germinal vesicle regresses and the chromosomes become more distinct. The oöcyte goes through the stages termed diakinesis I, metaphase I, anaphase I and telophase I. There follows an unequal division of the oöcyte, producing a large secondary oöcyte and a small first polar body. Meiosis then progresses to metaphase II, which is the stage when the oöcyte is ovulated.

The maturation of oöcytes to the metaphase II stage of meiosis is necessary before normal fertilization can occur. An effort to fertilize eggs in the laboratory therefore calls for eggs that either have matured naturally or can be induced to mature in vitro. Recovering single oöcytes from a woman before, during or after oöcyte maturation has presented almost insuperable problems because the time of ovulation is unpredictable and the recovery of single eggs is technically difficult.

Fortunately there are now other methods of obtaining mature human ova. A simple one is to remove the oöcytes from their follicles during the dictyotene stage and put them in a suitable culture medium. Many of them will progress through meiosis to metaphase II. The studies that led to these procedures were undertaken with animal eggs almost 40 years ago. In several culture media the progression of meiosis in animal oöcytes takes the same length of time as maturation within the ovary following stimulation by the luteinizing hormone.

Human ovarian tissue is often excised for clinical reasons, and several oöcytes can usually be recovered from such tissue. When the oöcytes are put in a culture medium, the germinal vesicle regresses after about 25 hours and metaphase II is reached about 11 hours later.

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Establishing the length of these periods was important for later studies involving the stimulation of oöcytes within the female.

Chromosomal Errors

Mouse and human oöcytes maturing in culture have provided excellent material for studying the earliest stages of human development. For example, the study of the stages of meiosis has helped us to understand the causes of chromosomal imbalance in many human fetuses and offspring. The scale of this phenomenon can be judged from the fact that almost a third of all detected spontaneous abortions involve a fetus with an abnormal number of chromosomes. More than 60 percent of the fetuses are trisomic (having an additional chromosome) or monosomic (lacking a chromosome). Some of these fetuses are not aborted and survive to birth and later; examples include offspring with the syndrome of mongolism.

Human somatic cells, as distinct from sperm and egg cells, have 46 chromosomes, half from the father and half from the mother. There are thus 23 pairs, one member of each pair being inherited from the father and one from the mother. When the cell reproduces by the process of division known as mitosis, these homologous chromosomes replicate and separate, so that each of the two daughter cells has a full complement of 46 chromosomes. During meiosis the sperm and egg cells become haploid, that is, have half the chromosome complement of other cells, so that when a sperm with 23 chromosomes combines with an egg having the same number, the fertilized egg will be a diploid cell with 46 chromosomes.

During meiosis homologous chromosomes come together and lie side by side. At this stage adjacent chromatids—the individual strands of a chromosome—often break and recombine, resulting in the exchange of some genetic material between paternal and maternal chromosomes. In this process, which is called recombination, the points of crossing over between pairs of homologous chromosomes are called chiasmata [*see illustrations on page 48*].

In collaboration with S. A. Henderson of the University of Cambridge the stages of meiosis following these events were investigated. Mouse oöcytes were used initially in order to establish guidelines for work with human oöcytes. It was fortunate that the stage called diakinesis could be studied, because chiasmata can be analyzed at this stage and other forms of association between pairs of homologous chromosomes can be detected. Chiasmata are considered to be of particular importance for holding homologous chromosomes together so that they will be correctly oriented in anaphase, when the chromosomes are segregated, or pulled apart to form the chromosome complement of each daughter cell.

The study showed that the number of chiasmata per oöcyte declined with increasing age of the mother. There was also an increase with age in the number of chromosomes that had separated from their partner. Such separated chromosomes are called univalents, and they can arise through the failure of chiasmate association. This type of anomaly could lead to an abnormal segregation of chromosomes at anaphase and so to the formation of chromosomally unbalanced embryos.

A few homologous chromosomes held together without chiasmata. This form of association might be strong enough to allow orderly segregation at anaphase, but it might also lead to abnormality. In any event, the pairing of homologous chromosomes became weaker with advancing maternal age. Moreover, the number of chiasmata per oöcyte was lower than the mean found in sperm precursor cells.

It is curious that chromosomal errors are found more often in the formation of eggs than in the formation of sperm. In sperm the development of univalent chromosomes appears to be limited to the X and Y pair of chromosomes, which determines sex. It seems likely that abnormal segregation of the sex chromosomes can occur in either the ovary or the testis, whereas other errors of chromosome segregation occur uniquely in
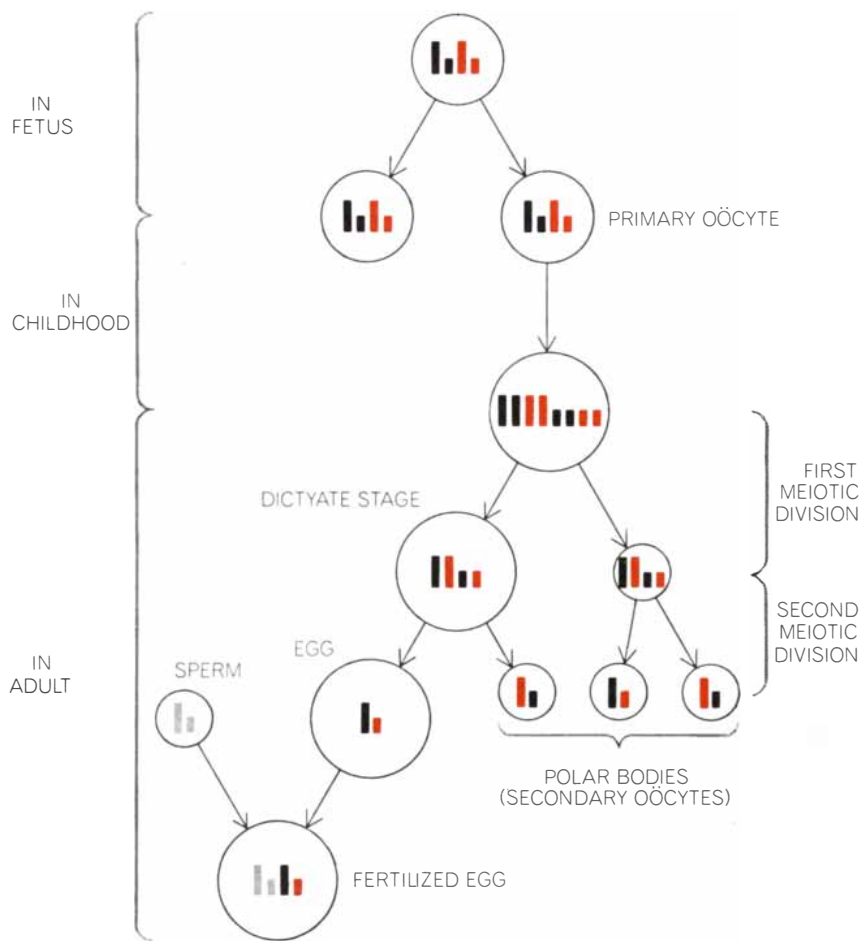
MEIOTIC DIVISIONS are required before an egg can be fertilized. They begin when the female is a fetus and are completed when she is an adult. Before meiosis the oöcyte, or immature egg (*top*), is diploid, having a set of chromosomes from the father (*color*) and a set from the mother (*black*). In meiosis successive divisions produce an egg that is haploid, meaning that it has half the standard complement of chromosomes. When an egg and a spermatozoon join at fertilization, the cells of the resulting embryo are again diploid.

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ZYGOTE — POLAR BODIES, PRONUCLEI, MID-PIECE OF SPERM, ZONA PELLUCIDA

FIRST CLEAVAGE — NUCLEI

FOUR CELLS

EIGHT CELLS

16 CELLS

MORULA

INNER CELL MASS

BLASTOCYST

BLASTOCOEL

TROPHOBLAST
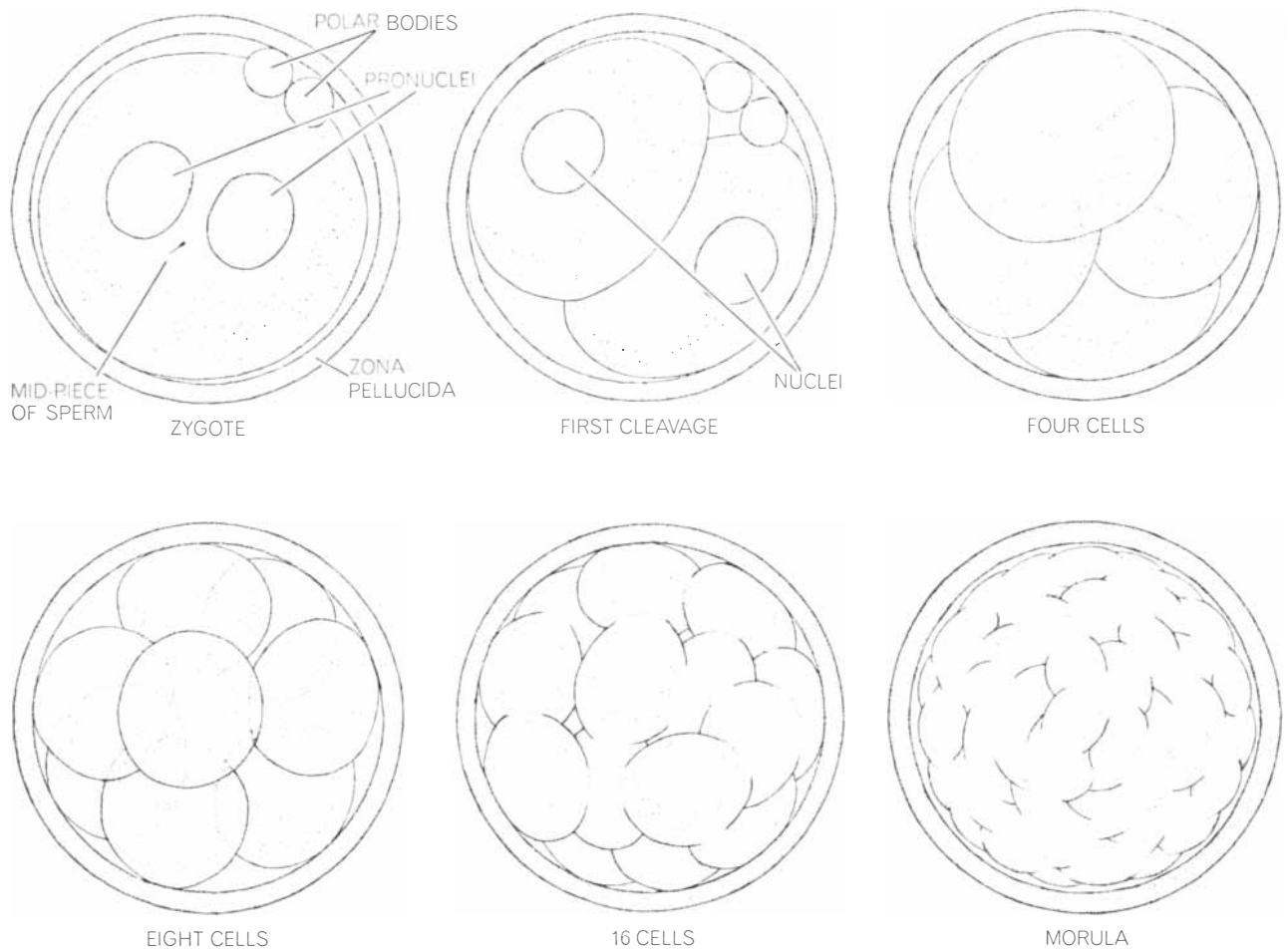
EARLY EMBRYONIC STAGES following fertilization of a human egg are depicted to the blastocyst stage. After fertilization the head and the tail of the spermatozoon separate. The head enlarges into a pronucleus and moves near the pronucleus of the egg. The first cleavage produces two cells; the second, four; the third, eight; the fourth, 16. By this stage the outlines of the cells are becoming indistinct. The morula has approximately 32 cells, but the boundaries are becoming more indistinct as the cells appear to fuse. In the early blastocyst, which has approximately 64 cells, a cavity called the blastocoel has appeared. It is surrounded by a group of cells at one pole called the inner cell mass and by a single-cell layer called the trophoblast. The inner cell mass eventually differentiates into the specialized tissues of the body. The overall size of the egg changes little until the blastocyst stage is reached.
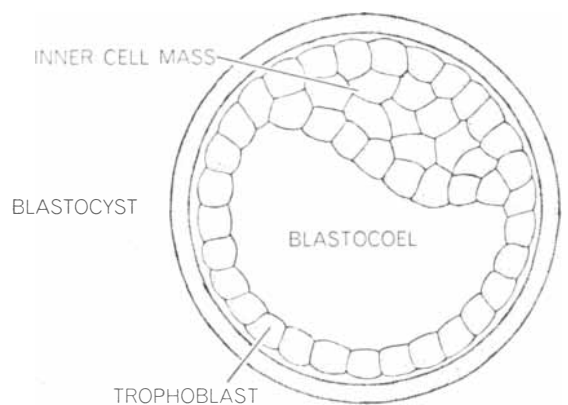
the oöcyte. Other kinds of evidence, including statistical and clinical data, support this interpretation.

Why do univalent chromosomes arise in the oöcyte? The following explanation by Henderson and one of us (Edwards) is based on the assumption that oöcytes are apparently formed sequentially in the fetal ovary, and the ones that are formed late are ovulated later in the reproductive life of the woman. Errors in chromosomal pairing are more frequent toward the end of the period of oöcyte formation than at the beginning. Hence oöcytes ovulated later in life have fewer chiasmata and more univalent chromosomes, so that chromosomal error in the fetus or in the infant is correlated with increasing age of the mother. If the "production line" hypothesis is correct, there is little hope of preventing mongolism or other trisomic conditions unless only young women bear children.

Other interpretations of the origin of human trisomy have been advanced. They rely on changes occurring in oöcytes during the years of maternal aging or on delayed fertilization of the eggs after ovulation.

Fertilization in Vitro

Oöcytes are ready for fertilization when they reach metaphase II. Fertilization in vitro has often been difficult to achieve even with the eggs of laboratory

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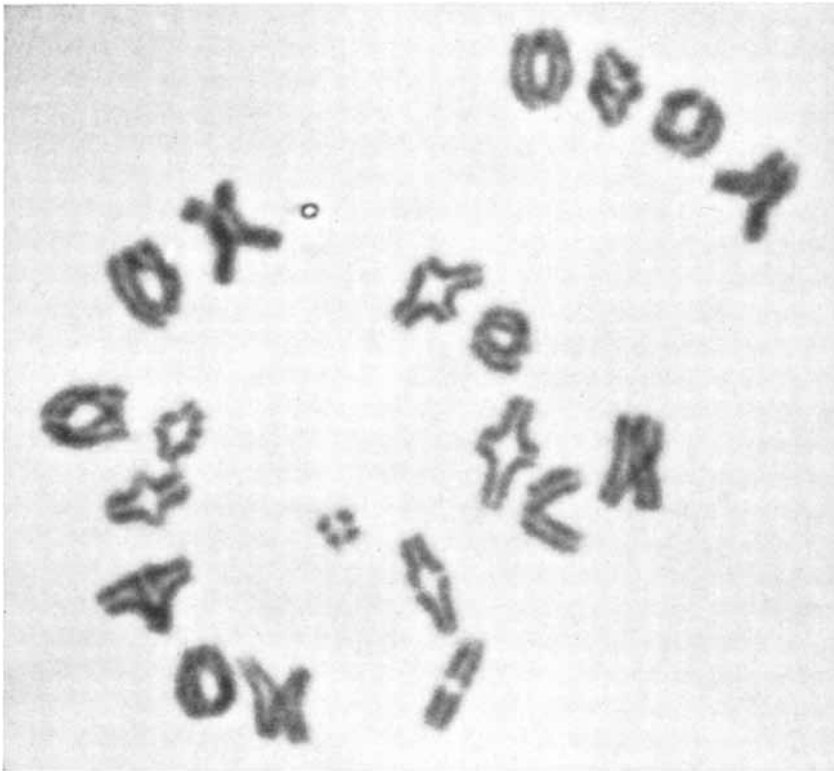
CHROMOSOME PAIRING in oöcytes is important in the development of normal embryos. Pairs of homologous, or similar, chromosomes are normally joined by linkages called chiasmata, as are the chromosomes in this mouse oöcyte. Most pairs in the shape of a cross have a single chiasma; chromosomes in the shape of an oval have two chiasmata.
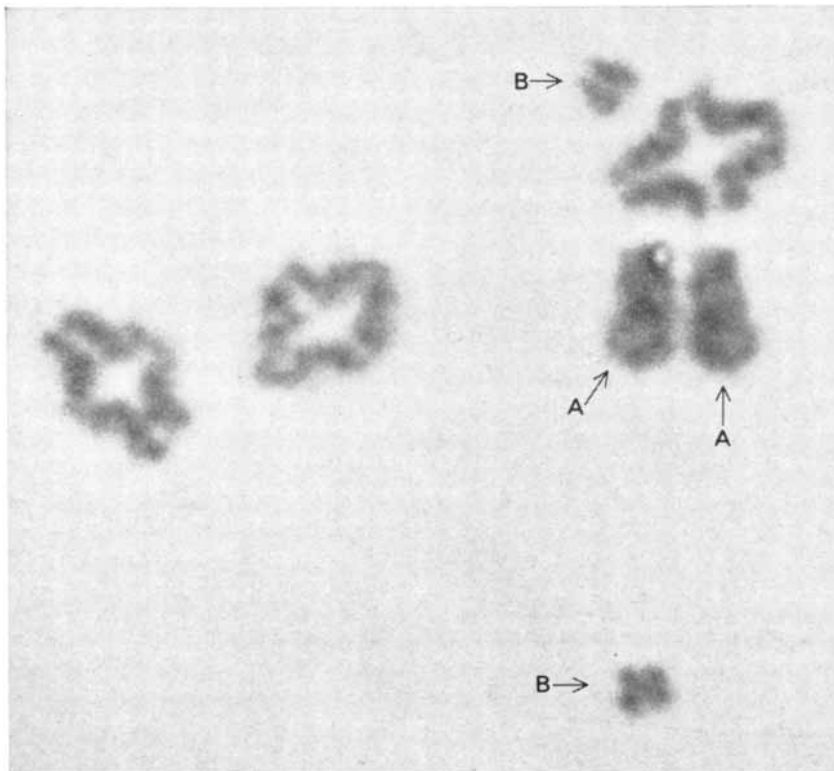
ABNORMAL PAIRINGS appear in chromosomes from mouse oöcyte. Abnormalities (arrows) are univalents, or chromosomes that have separated from their partner. One pair (A) shows a form of secondary association; members of other pair (B) are widely separated.

animals such as the rabbit. It has been widely accepted that sperm must undergo certain changes in the uterus or the oviduct before they are able to penetrate the outer membrane of the egg: the zona pellucida. These changes are termed capacitation.

Recent studies have called into question the role of uterine changes in spermatozoa during capacitation. Hamster eggs have been fertilized in vitro with spermatozoa taken directly from the male seminal tract. Moreover, oöcytes withdrawn from their follicle just before ovulation could be fertilized. The vagina, uterus and oviduct were therefore unnecessary for the fertilization of hamster eggs.

There was a further theoretical difficulty in the way of the fertilization of human eggs, arising from the fact that it was necessary to use ejaculated sperm. The seminal plasma was believed to contain decapacitating factors, that is, substances that inhibit capacitation. We dealt with this problem by washing the semen twice gently by centrifugation.

In collaboration with B. D. Bavister of the University of Cambridge and P. C. Steptoe of Oldham General Hospital sperm thus obtained were added to oöcytes that had been matured in vitro for 36 hours. The fertilizing medium had been devised by Bavister. From the initial experiments onward distinct evidence of fertilization was consistently seen [see illustration on pages 50 and 51]. The criteria we employed to determine whether or not fertilization had been achieved included penetration of spermatozoa through the zona pellucida, enlargement of the sperm head in the cytoplasm of the oöcyte, formation of the second polar body in the oöcyte during telophase II, identification of the mid-piece of the fertilizing spermatozoon in the oöcyte cytoplasm and the formation of male and female pronuclei in the egg. The male and female pronuclei fuse just before the egg begins to cleave (dividing first into two cells and then four and then eight and so on). In several oöcytes we identified two polar bodies, the mid-piece and the pronuclei, which is complete morphological evidence of fertilization.

We also observed anomalies in a number of eggs. Spermatozoa sometimes failed to pass completely through the zona pellucida. Some eggs had several pronuclei. This condition can arise from fragmentation of the female pronucleus or from penetration of the egg by more than one spermatozoon. In these early studies the oöcytes had been transported some distance after their recovery from

	IN FETAL OVARY	IN ADULT OVARY	IN EGG AND POLAR BODIES
a			
b			
c			
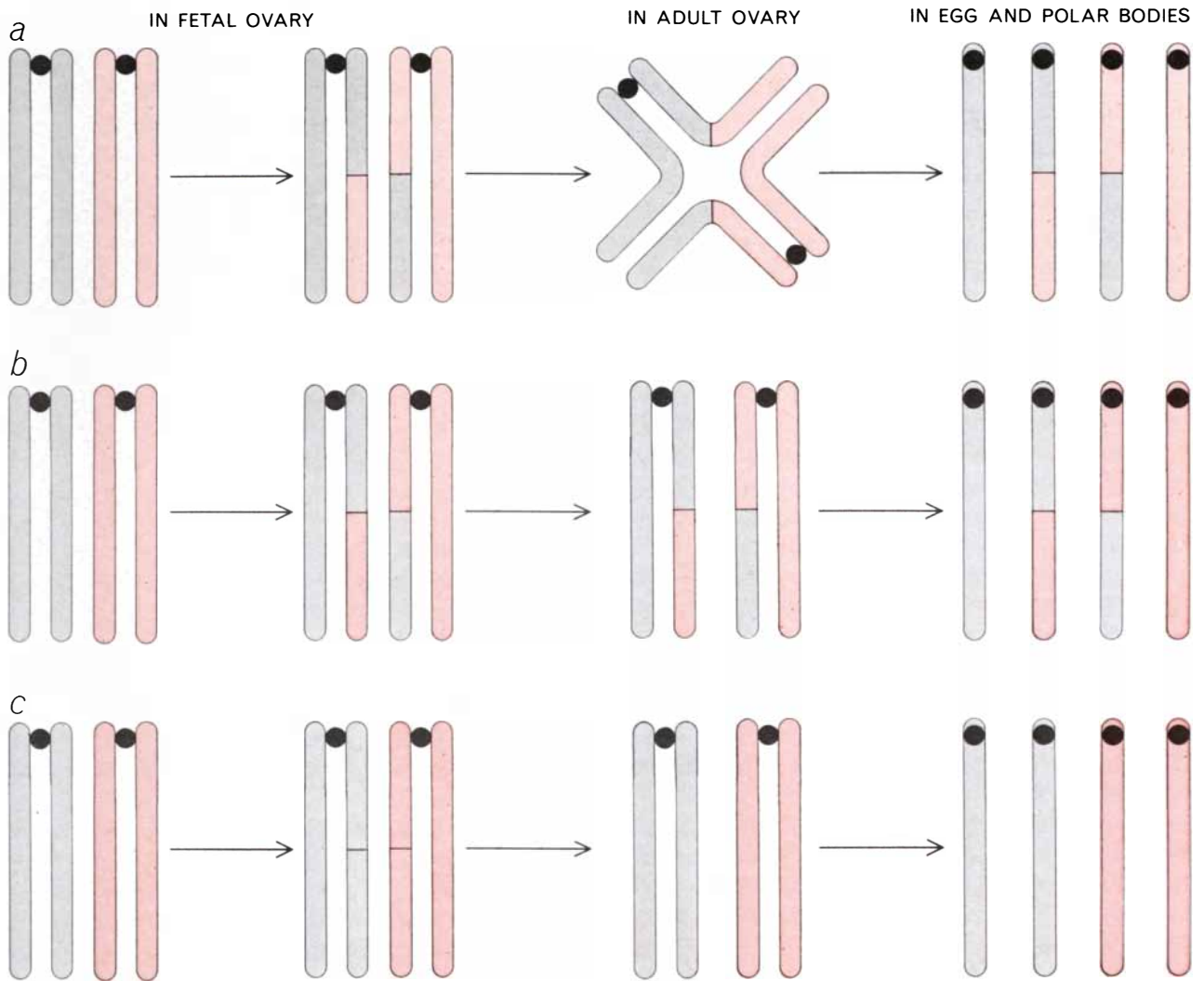
CHROMOSOMAL ERRORS are depicted schematically. In normal behavior (*a*) a single crossover between homologous chromosomes in the fetal ovary is portrayed by means of the exchange of colored and gray parts. The result is that in the adult ovary, in the stage of meiosis known as diakinesis, the homologous chromosomes are held together by one chiasma (*center*). Segregation of chromatids (*right*) into egg and polar bodies is then normal. If the chiasmatic association is lost (*b*), univalents result. Segregation might be normal, as shown, but could be abnormal and lead to chromosomally unbalanced gametes. If chiasmata never occur (*c*), the kind of abnormal segregation depicted might result. Examination of eggs with chromosomal errors will often reveal type of chiasmatic mistake.

excised ovarian tissue. Later studies, making use of oöcytes collected and matured close at hand, did not reveal such anomalies.

The achievement of human fertilization in vitro, with confirmatory observations on a few cow oöcytes, has enlarged the stock of information on capacitation and decapacitation revealed by the fertilization of hamster eggs in vitro. It is apparent that capacitation is restricted to the immediate environment of the oöcyte. It could involve follicular fluid, the cumulus cells surrounding the oöcyte or the oöcyte itself. Indeed, structural changes in the acrosome (the tip of the head of the spermatozoon), which are believed to occur after capacitation, are detected as the sperm penetrate the cumulus cells. Workers in other laboratories are attempting to isolate the protein of the follicular fluid for studies on capacitation.

An alternative explanation, however, seems equally valid. On the basis of histochemical and biochemical tests it now seems that the acrosome acts as a lysosome, that is, it contains a substance that dissolves the outer membrane of the egg. One might therefore search for agents that destabilize the lysosomal membranes, bringing about the release of the lysing substance. Among the most potent agents are progestogens such as the steroid hormone progesterone, which is secreted by the ovaries during the later part of the menstrual cycle, and it is known that progestogens can be synthesized by the granulosa cells that surround the egg. Progestogens are also present in follicular fluid, and their concentration might increase just before ovulation. Critical experiments are required before these matters can be resolved. It would seem a wise precaution, however, to remove the cells surrounding the oöcyte before testing agents suspected of inducing capacitation.

Oöcytes by Surgery

Having achieved fertilization, we next took up the problem of the consistent failure of oöcytes matured in vitro to develop to full term after transfer to host females. Such oöcytes from rabbits, pigs and cattle displayed anomalous fertilization and abnormal pronuclear development and cleavage whether they were fertilized in vitro or in vivo. No

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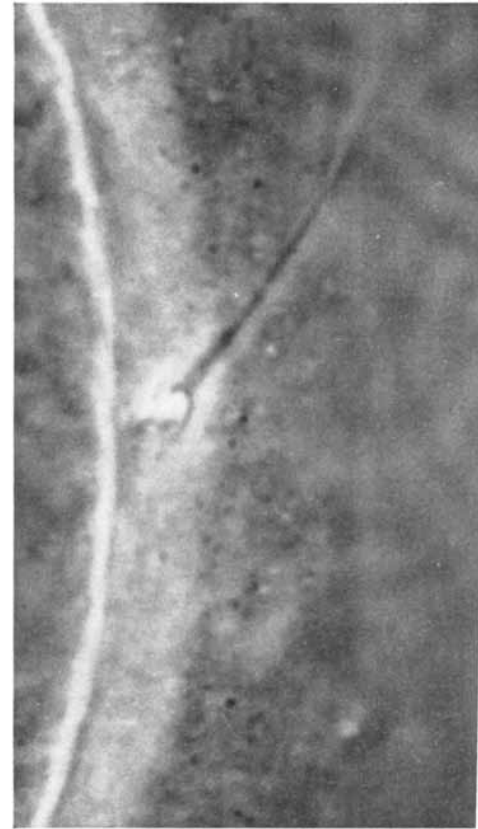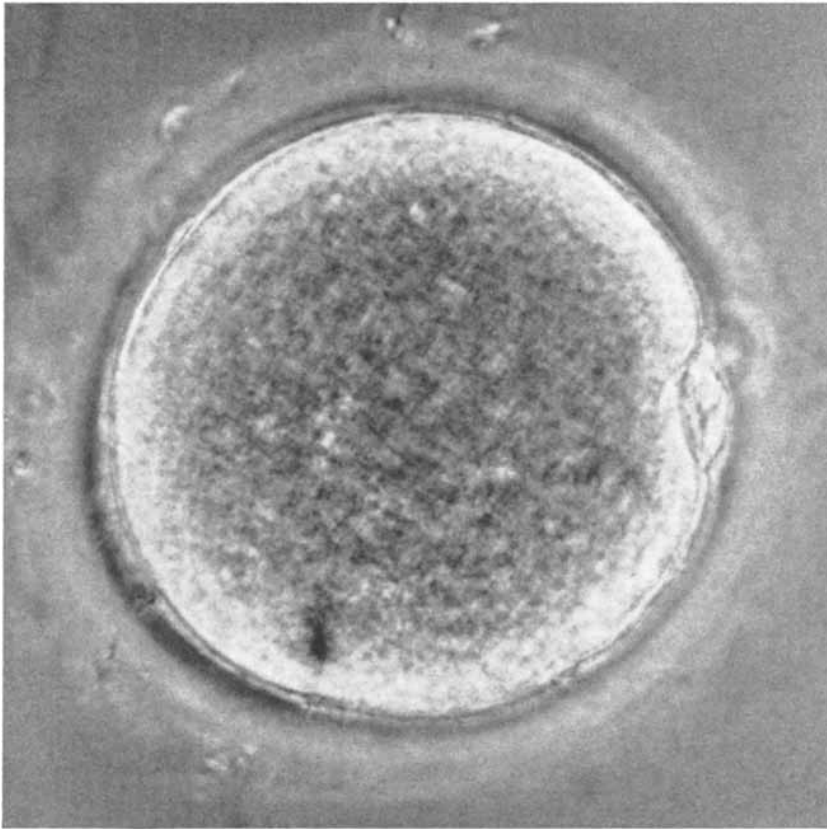
EVIDENCE OF FERTILIZATION can be obtained in a number of ways. At left is an unfertilized human egg, with an extruded first polar body on its right side. In the next photograph a spermatozoon (right) has penetrated the zona pellucida so that its head and mid-piece lie in the space between the egg proper and the zona pellucida. The sperm tail extends outside the zona pellucida and was

viable embryos were found. We had this result with pronucleate human ova.

Viable rabbit embryos can be produced in vitro by injecting the mother with pituitary gonadotrophins (FSH and LH) to bring about the maturation of oöcytes, which are then removed just before ovulation. Clinical methods were therefore needed for obtaining human oöcytes just before ovulation. Our patients were childless couples who hoped our research might enable them to have children.

What had to be done was to give the women human gonadotrophins in order to control the menstrual cycle, to initiate the development of several follicles and to induce maturation of the oöcytes. The techniques for achieving these results with animals are well developed. We also knew for animals the right time to recover oöcytes in metaphase I, since the moment of ovulation is known exactly. In contrast, the situation regarding the number of maturing follicles and the time of ovulation in women was almost totally obscure.

Steptoe and one of us (Edwards) therefore undertook to induce follicular maturation and ovulation in women and to develop surgical methods for removing oöcytes from the follicles. The method of treatment with gonadotrophin was based on the wide experience that has been gained in treating women who fail to ovulate. The present patients differed in that they had a menstrual cycle and were highly responsive to gonadotrophins.

An acceptable surgical method for recovering the oöcytes was developed by Steptoe and others. Called laparoscopy, it is a relatively minor operation; even though it requires general anesthesia the patient seldom remains in the hospital for more than 24 hours. The abdomen is artificially distended with an inert gas to provide room to view and work on the internal organs, and minor incisions are made in the abdominal wall to allow the passage of instruments. Among the instruments is a slender telescope that provides a clear view of the surgical field. Initially the ovarian follicles were aspirated with a hypodermic syringe, but later an aspiration device was developed that provides controlled vacuum pressure, easy manipulation and a small chamber where the aspirated material can be collected for immediate examination.

The complete schedule of treatment is as follows. The patient is given three injections of 300 international units of human menopausal gonadotrophin between the third and the ninth day of her menstrual cycle. The hormone stimulates the growth of the follicles. The maturation of follicles and oöcytes is induced by a single injection of 5,000 international units of human chorionic gonadotrophin between the ninth and the 11th day of the cycle. In order to recover the oöcytes just before ovulation, laparoscopy is performed some 32 hours after this injection; ovulation would occur at about 36 hours, as judged by the timing of oöcyte maturation in vitro.

Examination of the ovaries during the operation revealed enlarged follicles, many with a thinning wall indicating that ovulation was imminent. Initially we obtained oöcytes from about a third of the follicles that were penetrated, but improvements in technique have raised this figure to more than a half. Examina-

beating vigorously when the photograph was made. The third photograph shows a later stage of fertilization; the egg has been fixed and stained to show the mid-piece and tail of the spermatozoon in the egg, with the sperm head beginning to swell. Eventually it will form the male pronucleus. Male and female pronuclei can be seen in the living egg at right; extruded polar bodies are also visible.
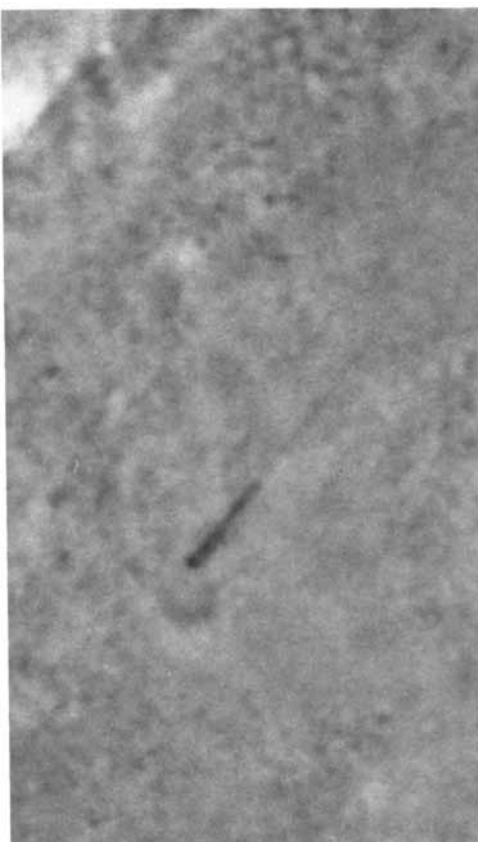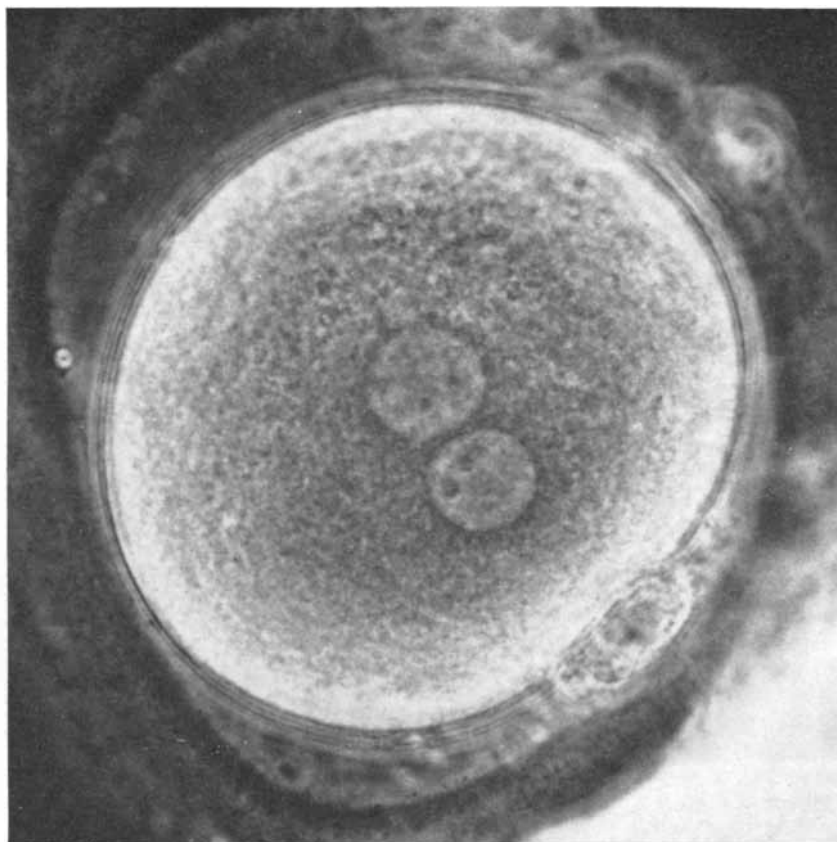
tion of the meiotic stages of the oöcytes collected revealed that about half of them were in diakinesis or metaphase I, which are the transient preovulatory stages of meiosis. The remaining oöcytes had not been stimulated and were beginning to become atretic, that is, to degenerate. From a single patient as many as three or four preovulatory oöcytes were recovered.

Early Embryos in Vitro

There was now every reason to believe the preovulatory oöcytes thus obtained would provide excellent material for studies on fertilization and cleavage. The oöcytes would be ready for fertilization three or four hours after aspiration. The eggs were placed in Bavister's medium, and sperm were added to reach a concentration of from one to two million per milliliter. Within two hours the cumulus cells surrounding the oöcytes began to separate and form a layer on the surface of the dish, leaving the oöcyte surrounded by only a few cells. Occasionally, however, the cells remained tightly packed around the oöcyte, particularly when the oöcytes were atretic.

Since fertilization had already been achieved fairly consistently in our earlier work, only a few preovulatory oöcytes were used for examination under the microscope for evidence of fertilization 12 hours after the addition of spermatozoa. Three were clearly fertilized as judged by the criteria we have described. The rest of the ova were used for studies on cleavage. As the investigators gained experience the pronuclei in many of these ova could be identified under low magnification without removing them from the culture medium.

These eggs were used to find out what media were capable of sustaining early cleavage. At first media were used that had succeeded with animal eggs, since almost nothing is known about the metabolic requirements of human eggs. Fortunately information exists on the metabolic needs of mouse embryos, and simple defined media (wherein the chemical structure and amount of each component are known) had been developed for their culture by such workers as R. L. Brinster of the University of Pennsylvania, J. D.

Biggers of Johns Hopkins University and W. K. Whitten of the Jackson Laboratory in Maine. With these media it had proved possible to fertilize mouse ova in vitro, grow them to the two-cell stage and obtain viable offspring when they were placed in a recipient female; this was shown by our colleague D. G. Whittingham. It is particularly important to include pyruvate or lactate in the medium to serve as a source of energy for the embryo during early cleavage. Serum albumen is also beneficial, and glucose is added later in cleavage.

The cleavage of human ova in these defined media, and also in complex media (which had a more complicated chemical composition) such as Ham's F 10 and medium 199—both widely used in tissue-culture laboratories—was studied by one of us (Edwards), Steptoe and Miss J. M. Purdy of the University of Cambridge. These media were fortified with serum. The cultures were maintained under 5 percent carbon dioxide in air or under 5 percent carbon dioxide, 5 percent oxygen and 90 percent nitrogen—both being standard gas phases for many tissue cultures. The pH

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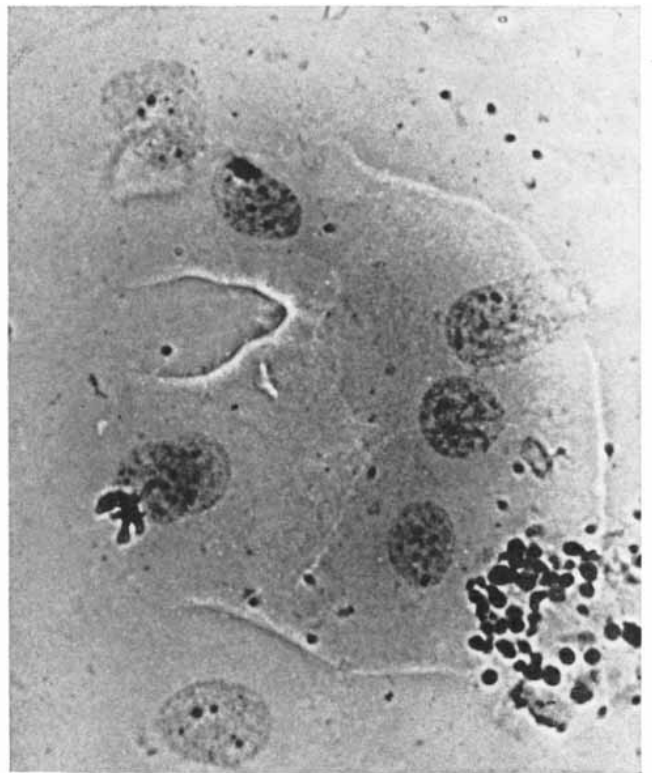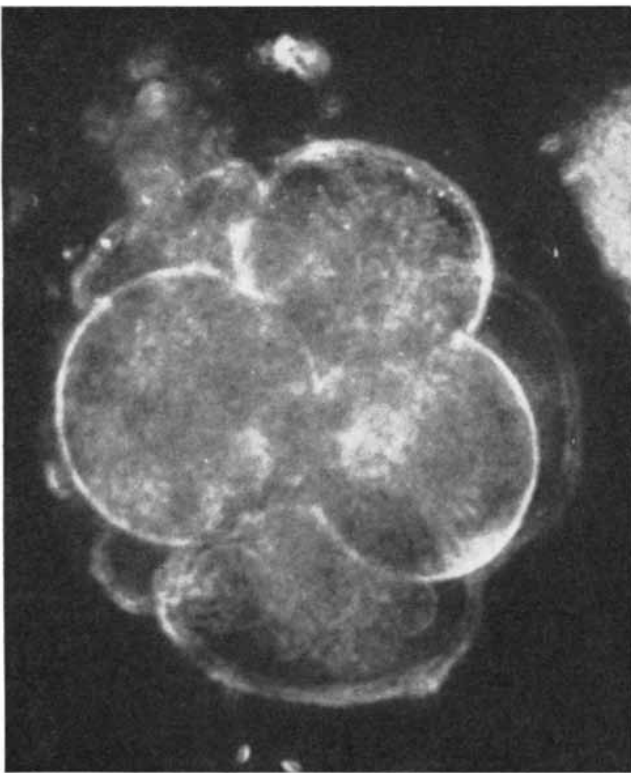
FERTILIZED HUMAN EGG developed to the eight-cell stage in a culture medium. At left the embryo appears as it was photographed after it had stopped growing. When it was subsequently flattened and stained, eight nuclei could be seen (*right*). The cluster of cells near the embryo at top right in first photograph is the remains of corona cells that adhered to outside of the egg prior to fertilization.
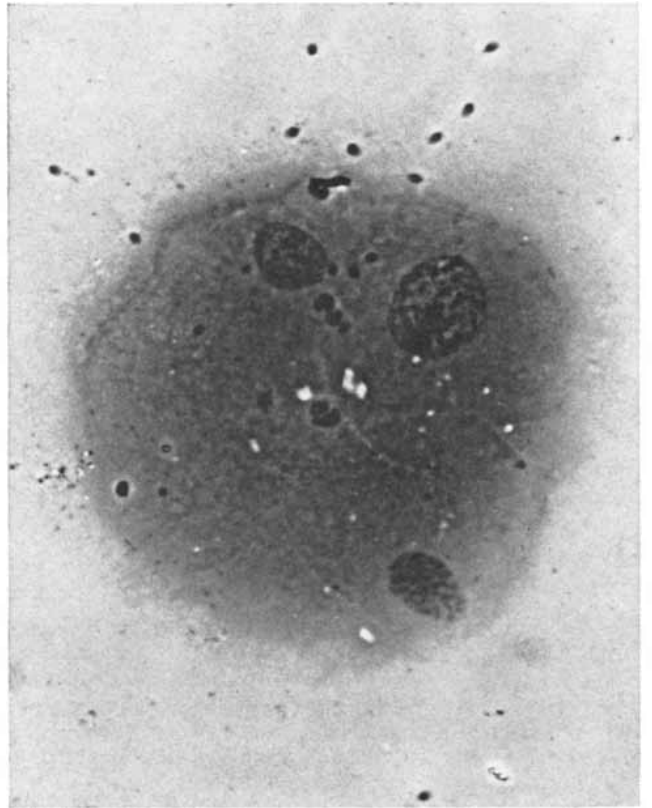
NORMAL AND ABNORMAL DEVELOPMENT of a fertilized human egg are sometimes difficult to distinguish. The egg at left gave the impression of being a normal eight-cell embryo while it was alive, but when it stopped growing and was flattened and stained, it showed only three nuclei (*right*). Presence of only three nuclei rather than eight showed that cleavage had been abnormal.

was standardized at 7.3, but the media were made up with various osmotic pressures.

After fertilization in Bavister's medium the ova were placed in different media for cleavage. At an osmotic pressure of 280 milliosmols per kilogram ova cleaved regularly and evenly in defined media but seldom proceeded beyond the eight-cell stage. Perhaps the most successful results in culturing mouse embryos have been obtained by Whitten with a lower osmotic pressure in the medium. Encouragement to adopt similar methods came when measurements showed the osmolarity of human follicular fluid to be between 270 and 280 milliosmols per kilogram. These conditions, however, proved disastrous for human ova. Cleavage was highly abnormal; the eggs divided unevenly or fragmented during cleavage.

The primary aim of the work was to sustain embryonic cleavage rather than to analyze the metabolic needs of cleaving ova. Therefore complex media were tested. They have proved superior to the simple media. The most successful one employed so far is Ham's F 10 supplemented with human or calf serum. (It might well be significant that this medium contains large amounts of pyruvate.)

In this medium some of the ova developed beyond the eight-cell stage into early morulae and blastocysts [*see illustration on page 47*]. Cleavage in most embryos was regular, the blastomeres (cells resulting from cleavage) being even-sized and the embryos seemingly healthy. The first cleavage occurred between 18 and 39 hours after insemination, although these are approximate estimates. The second and third cleavages occurred between 38 and 46 and 51 and 62 hours respectively. Morulae with 16 or 32 cells or more showed the "fusion" of cells so characteristic of other mammalian morulae, such as those of the mouse. The availability of embryos in these stages is of major importance to our future work.

Significance of the Work

Various kinds of clinical and scientific work are now possible. The transfer of 16-cell embryos (or older ones) directly into the uterus could assist women with occluded oviducts to have their own children. In normal pregnancy the human embryo probably enters the uterus at about the 16-cell stage; hence embryos transferred at this stage or later stages should have an excellent chance of survival. Tests on the patients indicate
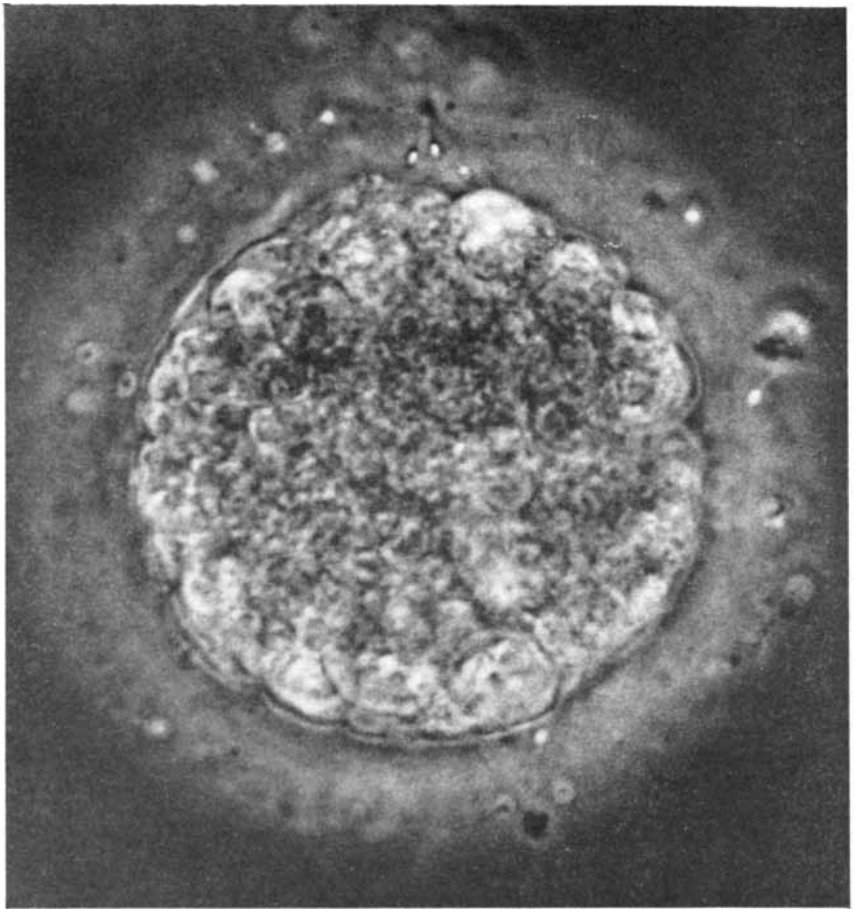
ABNORMAL EGG exhibited a form of fragmentation that can easily be misinterpreted as cleavage after a human egg has been fertilized. When this fertilized egg was subsequently flattened, it disintegrated. There were no nuclei, showing that there had been no cleavage.

that uterine conditions are probably favorable for implantation to occur.

Other objectives are in sight. A deeper understanding of early human reproduction is needed to help in the development of new methods of contraception and in gaining insight into those already in use. At present little is known about such events in man as capacitation, cleavage and implantation.

Several embryos will probably be grown for each couple, since it would be difficult to work with fewer. The embryos replaced in the mother could be chosen for various characteristics. Choosing male or female blastocysts is one possibility that has already been achieved with rabbits, in collaboration with our colleague R. L. Gardner. A few trophoblast cells excised from the blastocyst served to sex the rabbit; we ascertained if the sex chromatin body, which appears only in the nuclei of female cells, was present in cells of the trophoblast. (A better alternative to the control of sex ratios in offspring would be to separate X-bearing and Y-bearing spermatozoa before fertilization, but there has been little success with this approach in spite of intensive effort.)

Sexing blastocysts could be advantageous to families known to carry sex-linked genes such as the one responsible for hemophilia. Most of these genes are recessive, and so they are mostly expressed in male offspring. Placing female embryos in the mother would avoid the birth of affected males, although half of the female children would be carriers of the gene. Averting the birth of children with sex-linked disorders demands the identification of female carriers. At present the technique known as amniocentesis is used to withdraw a small number of cells from the amniotic fluid in order to type the embryo, and an abortion is induced if necessary. One drawback of this method is that fetuses cannot be typed until about the fourth month of pregnancy or later.

The identification of preovulatory and nonovulatory (degenerating) follicles just before ovulation will open the way to investigation of the differences be-

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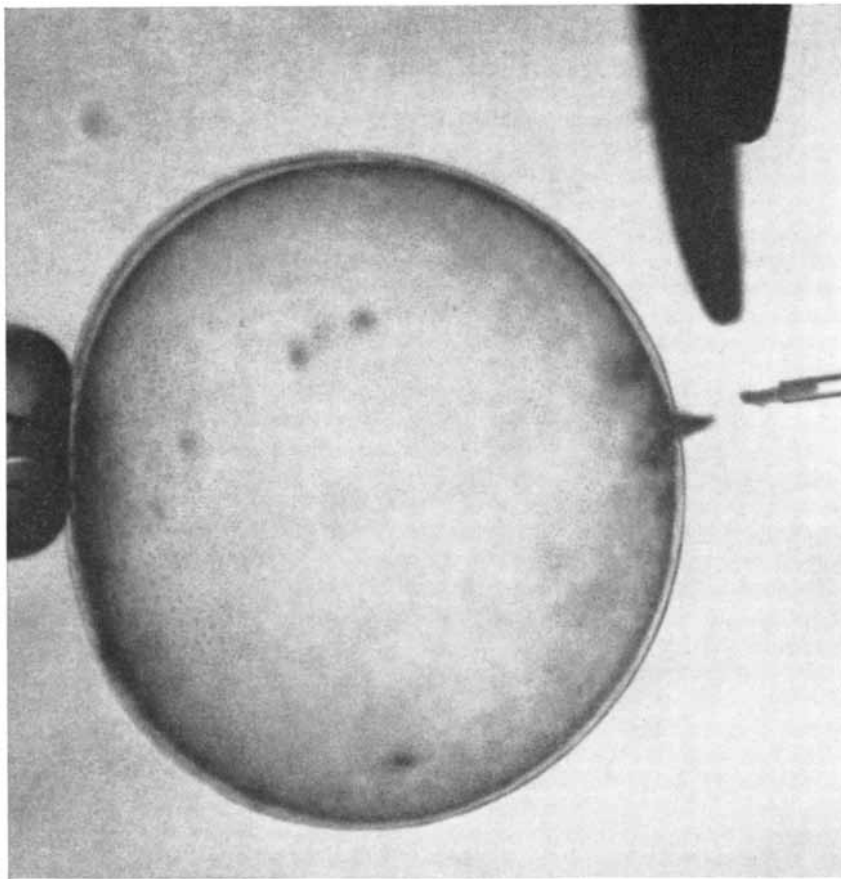
MANIPULATION OF BLASTOCYST is carried out on a rabbit embryo. The embryo, which has reached the blastocyst stage in vitro, is held with a large suction pipette (*left*) while another pipette is used to excise a small piece of trophoblast. By means of the excised trophoblast it is possible to determine whether the growing embryo is male or female.
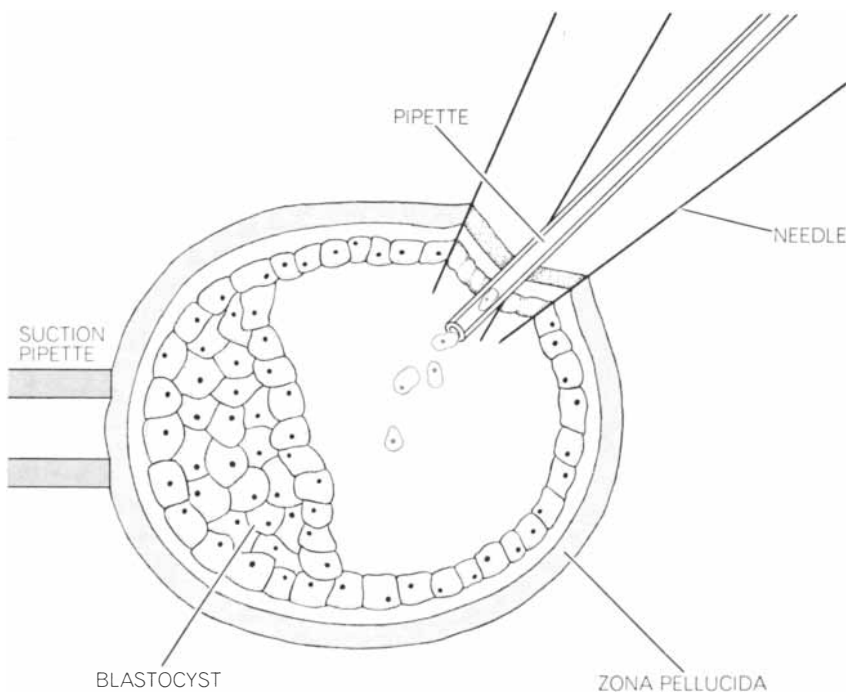
COLONIZATION OF EMBRYO with cells from another embryo is depicted. Descendants of the injected cells partially colonize the host fetus, resulting in a combination of traits.

tween the two and lead to an understanding of the factors that initiate the maturation of the follicle. We are currently studying the levels of luteinizing hormone, estrogens and progestogens in follicular fluids. A great deal of information can now be obtained on ovarian and uterine function. The analysis of uterine fluids might reveal the secretion of specific proteins significant in implantation and the development of the human embryo. Information about follicular maturation, uterine fluid and embryonic metabolism is needed both for the elucidation of basic processes and in the search for new methods of contraception.

Other possibilities, growing out of work with mouse embryos, belong to the realm of experimental embryology rather than clinical medicine. Mouse blastocysts have been used frequently to study the effect of modifying embryonic development. Gardner, for example, has cut mouse blastocysts in half, removed pieces from them and excised or replaced certain cells.

Most remarkable, a single cell from a donor embryo can be injected into a mouse blastocyst, resulting in the colonizing of large parts of the developing embryo by descendants of the single cell. This type of evidence suggests that there must be few truly embryonic cells even at the blastocyst stage. Other evidence is accumulating to indicate that major pathways of cellular differentiation are determined when there are relatively few cells in the embryo. The extensive colonization of embryonic tissues by donor cells could profoundly influence subsequent fetal development in such beneficial ways as masking the effect of deleterious genes in the host embryo. Already bone-marrow infusions have been used with some success in children suffering from a disease wherein the normal immune response fails to develop properly.

Still other investigations could be undertaken to extend the study of early human development. Mouse eggs have been induced to develop parthenogenetically, or without fertilization, and haploid cell cultures were obtained from outgrowths of some of the embryos. The availability of preovulatory human oöcytes should allow similar work with human cell lines, to the benefit of many studies of human cellular genetics.

We are well aware that this work presents challenges to a number of established social and ethical concepts. In our opinion the emphasis should be on the rewards that the work promises in fundamental knowledge and in medicine.

Fish used to be scared when we looked

Not long ago, the oil industry usually looked for offshore oil with dynamite.

They exploded it underwater and recorded the telltale echoes on a seismograph.

When carefully done, this did little or no harm to aquatic life. But fish were sometimes scared and fled to quieter waters. Fishermen frowned.

Now, the Esso Production Research Company (a Jersey affiliate) has invented a substitute for dynamite. We have nicknamed it the popper and you can see one in our picture. It doesn't go bang like dynamite. It simply goes pop.

The device is beautifully simple. A mixture of propane and oxygen is ignited by a spark plug inside a rubber sleeve. The pop inflates the sleeve like an instant balloon.

This sudden expansion is strong enough to give a seismic echo, but not so strong that it hurts the fish.

But fishermen aren't the only people to cheer.

Dynamite is often tricky stuff to handle.

for oil. Now they couldn't care less.

The popper is much safer. Exploration crews have less danger to contend with.

What's more, a crew using a popper can do an underwater survey six times faster than a crew using dynamite. They can work night and day in rough weather. Whereas a dynamite crew needs daylight and comparative calm. And our popper gives a better seismic picture in the bargain.

Esso Production Research has now made the popper available to the oil industry around the world.

Good news for oilmen. Great news for fish. Quite an invention.

Standard Oil Company (New Jersey)

Esso

Optical Interference Coatings

The same phenomenon that is responsible for the iridescence of various natural surfaces, including peacocks' tail feathers, is exploited to produce a host of modern optical components

by Philip Baumeister and Gerald Pincus

What do oil slicks, soap films, oyster shells and peacock feathers have in common? The familiar iridescent patterns of color reflected from all these surfaces are natural manifestations of the same phenomenon: optical interference in a thin layer. Although the principles of optical interference have been understood for more than a century, it has been only in the past few decades that this knowledge has been exploited for technological ends. The oldest, simplest and still the most common application of an optical interference film is as a single-layer antireflection coating, such as those used to reduce the reflectance of camera lenses.

In recent years more complicated optical interference coatings have been developed in which many layers of different materials are deposited on an optical surface. Stacks of such films are used not only as antireflection coatings but also as filters, polarizers, beam-dividers and highly reflecting mirrors. These coatings are indispensable components of not a few modern optical systems, such as lasers, color television cameras and infrared missile-guidance systems. This article explains the rudiments of optical interference and discusses in detail a number of current devices that make use of this phenomenon.

Optical interference in a thin film can be explained in terms of the wave theory of light. When a light wave traveling in a certain medium, say air, en-

counters a medium with a different refractive index, say glass, a portion of the incident wave is reflected at the interface [see top illustration on next page]. The amplitude of the reflected wave, which is equivalent to the electric-field strength, is computed from an equation developed in 1816 by the French physicist Augustin Jean Fresnel. The equation yields a value called the amplitude-reflection coefficient, which depends on the ratio of the refractive indexes of the two mediums; in the case of air and glass, for example, the amplitude of the reflected wave is .203 (or about 20 percent) of the amplitude of the incident wave.

The human eye and most other photodetectors do not respond to the amplitude of a light wave directly but rather to its intensity, which is equal to the square of the amplitude; thus the intensity of the reflected wave in the foregoing example is $(.203)^2$, or 4.1 percent, of the intensity of the incident wave. This is the ordinary reflection that occurs at each surface of a pane of window glass.

Now, suppose one wishes to reduce this reflectance by coating the glass surface with an antireflection coating, say a single layer of magnesium fluoride [see bottom illustration on next page]. A portion of the incident wave is then reflected at each of the two interfaces. There is a difference in the phase of the two waves because of the time it takes for the wave to penetrate the film, reflect from the film-glass interface and emerge into

the air again. This phase difference depends on the film's thickness (measured in wavelengths of the incident light) and also on the film's refractive index. It is convenient to express the phase difference in terms of the "optical thickness" of the film, which is defined as the product of its physical thickness times its refractive index.

When a film's optical thickness is a quarter of a wavelength, the phase difference between the two reflected waves is 180 degrees; in other words, they are completely out of phase. This means that the net amplitude of the reflected wave is a minimum because, to use the language of physical optics, the two waves add destructively. The amplitude of the wave reflected from the air-film interface is .16 and the amplitude at the film-glass interface is .048. The net amplitude of the reflected wave is approximately .16 minus .048, or .11, and its intensity is $(.11)^2$, or .012, which is equivalent to 1.2 percent of the incident wave.

This minimum reflectance is attained at only one wavelength. At wavelengths shorter than the minimum the reflectance increases until the film's optical thickness is a half-wave. At this point the phase difference is 360 degrees and the waves that reflect at the two interfaces of the film add constructively, or in phase, to produce a maximum amplitude. Thus the net amplitude of the reflected wave is approximately .16 plus .048, or .208. At other wavelengths the reflectance lies between the minimum and the maximum value.

The wavelength at which the minimum reflectance occurs depends on the thickness of the film. For example, if its optical thickness is a quarter-wave in the green portion of the spectrum, the reflectance is a minimum there. Such coatings appear purplish in reflected

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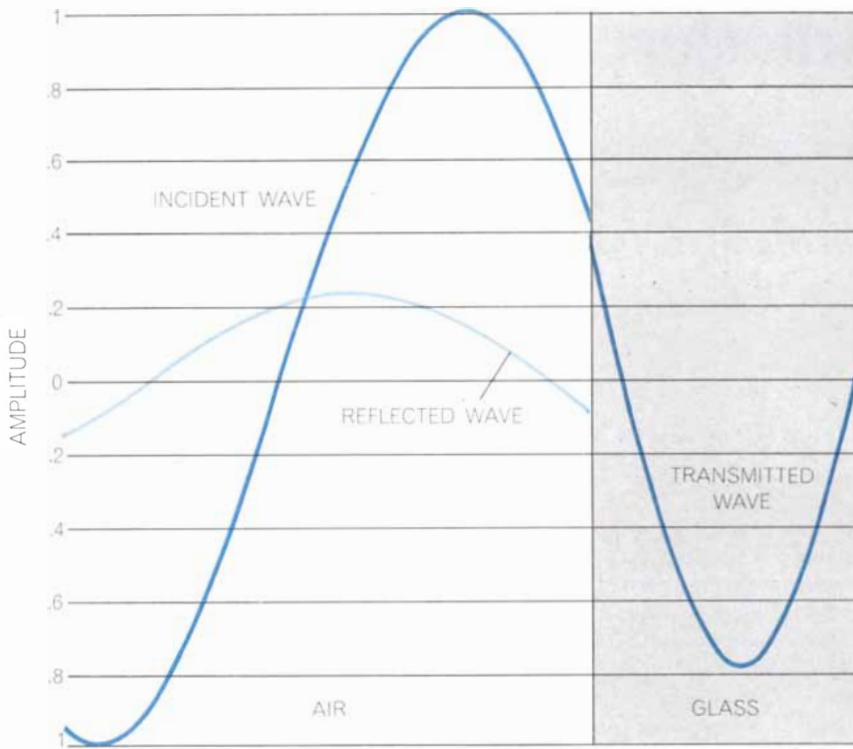
UNCOATED GLASS SURFACE reflects a portion of an incident light wave at the interface between the air and the glass. The amplitude of the reflected wave, which is equivalent to the electric-field strength, is dependent on the ratio of the refractive indexes of the two mediums; in this particular case the amplitude of the reflected wave is .203 (or about 20 percent) of the amplitude of the incident wave. The wavelength of the transmitted wave is shorter inside the glass because the wave's velocity there is less than it is in the air.
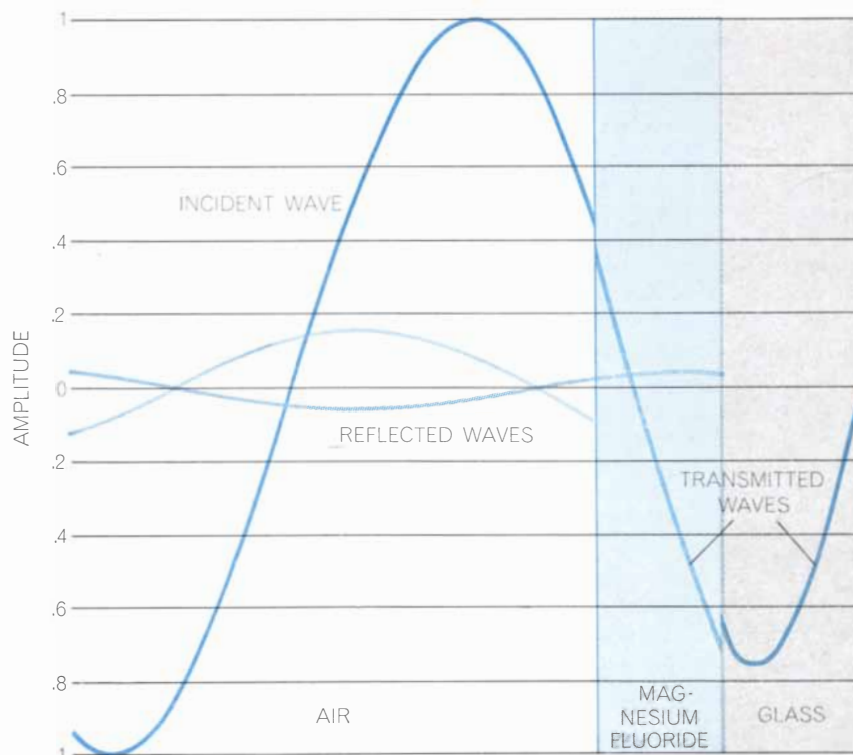
COATED GLASS SURFACE is covered by a single antireflection layer of magnesium fluoride with an optical thickness equal to a quarter of a wavelength of the incident light. The reflectance is reduced because the two reflected waves are exactly out of phase. The amplitude of the wave reflected from the air-film interface is .16 and the amplitude at the film-glass interface is .048. Hence the net amplitude of the reflected wave is approximately .16 minus .048, or .11, which is equivalent to 11 percent of the amplitude of the incident wave.

light and are deposited on camera lenses for use with black-and-white film. If the lenses are to be used for color photography, then the magnesium fluoride layer is made slightly thinner so that the reflectance minimum is in the blue part of the spectrum. These coatings have an amber hue in reflected light.

The single layer of magnesium fluoride reduces the reflectance to low values, but not to zero. The minimum reflectance depends on the refractive index of both the glass and the film. If the film's index is the square root of the index of the glass, then the waves that reflect from each interface of the film are equal in amplitude and they exactly cancel. This would require that the refractive index of the film equal $\sqrt{1.51}$, or 1.23. Unfortunately it is not possible to deposit durable films with such a low refractive index, and thus magnesium fluoride represents a compromise: a film with a fairly low refractive index (1.38) that is hard and durable.

In the foregoing discussion only the reflectance of the coating was considered. How is the transmittance determined? Although there are equations by which the transmittance can be computed, it can also be found by noting that if the coating is nonabsorbing, then the reflectance and transmittance must add to 100 percent. This follows from the conservation of energy. For example, the minimum reflectance of the coated glass mentioned above is 1.2 percent. Since the absorptance of the coating is negligible, its transmittance is 100 percent minus 1.2 percent, or 98.8 percent.

This method of computing the coating's reflectance by adding the waves that are reflected at each interface is called "vector addition of amplitudes." Although the method is used here to compute the reflectance of a single layer, it can be extended to two or more layers. Its advantage is that it furnishes an intuitive and simple model of how the coating functions. The disadvantage is that it is an approximation that becomes less and less accurate as the number of layers increases and also as the differences in the refractive indexes get larger. How good an approximation is the method in the case of the magnesium fluoride coating? We can obtain some estimate of its accuracy for this material, since it can be rigorously shown that when the optical thickness of the layer is a half-wave, the reflectance is the same as that of the bare substrate. By vector addition of amplitudes one obtains a reflectance of $(.208)^2$, or 4.3 percent, in contrast to the exact result of 4.1 percent.

The commercial production of opti-
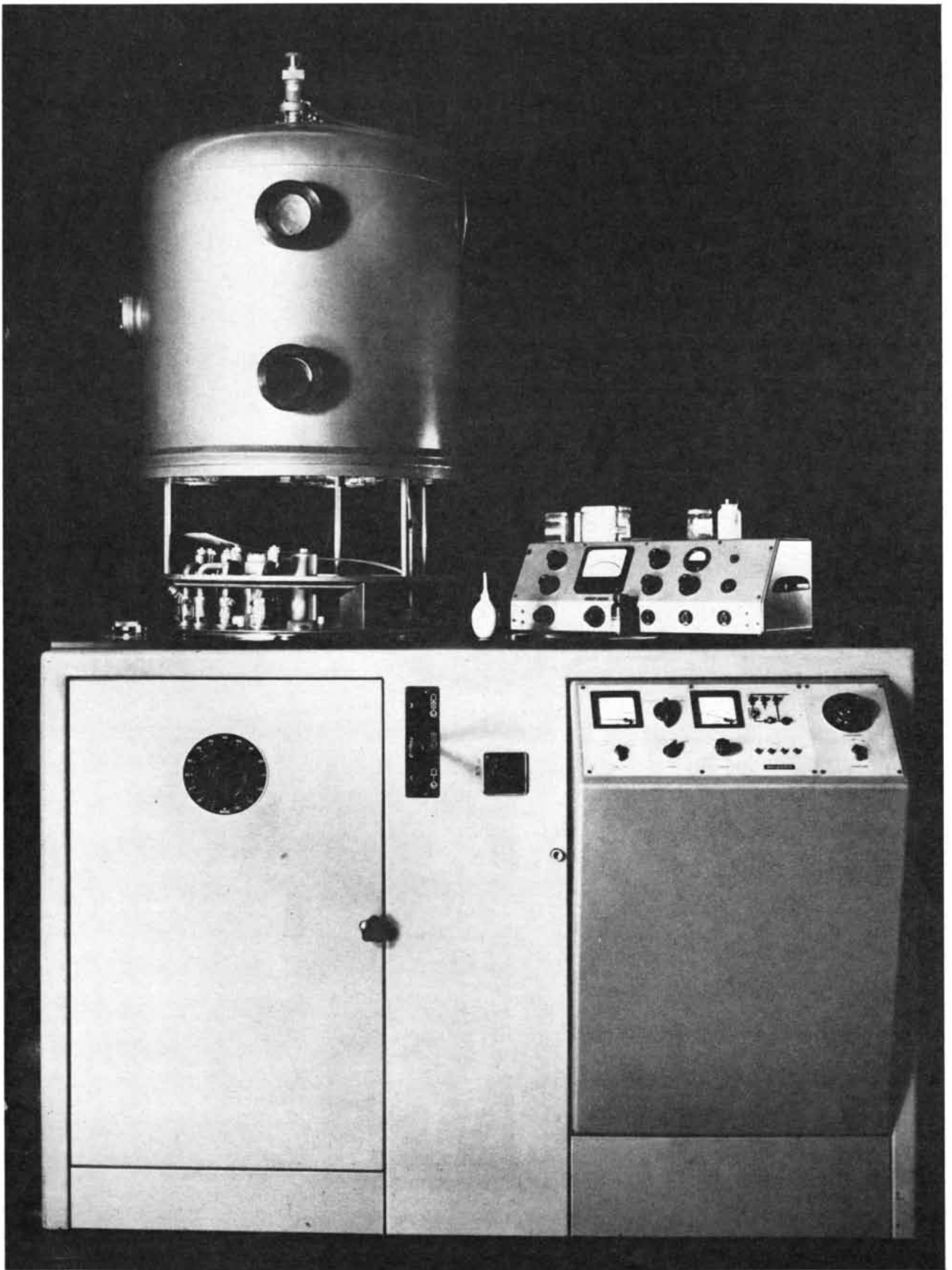
PRODUCTION COATING UNIT for depositing optical interference films on lenses and other optical components by evaporation in a vacuum was photographed at Boxton-Beel, Inc. The apparatus consists essentially of a metal bell jar (shown in the raised, or open, position), pumps to produce the vacuum, a rack for holding the substrates to be coated and electrically heated evaporation sources.

cal interference coatings was not undertaken until the 1930's, when suitable pumps and vacuum materials were developed for depositing the films by evaporation in a vacuum. The problem is to deposit these thin layers in a uniform thickness over a substrate, which in some instances is as much as several meters across. The film should be hard and durable and its thickness should be controlled to an accuracy of within 5 percent. Although it is possible to produce such films by chemical deposition or by the process called sputtering, the most widely used method is evaporation in a vacuum.

The apparatus for the deposition of these films consists of a metal bell jar, a rack for holding the substrates that are to be coated and an electrically heated evaporation source [*see illustration on preceding page*]. In addition there is a heater above the substrates so that they can be heated during the deposition of the film. Attached to the bottom of the chamber is an oil diffusion pump and a mechanical pump that exhaust the air from the enclosure.

Let us follow the steps for depositing a magnesium fluoride film on a batch of camera lenses. First, the lenses are washed to remove grease and other contaminants from the surface. Then they are loaded into the rack in the bell jar, which typically holds 40 lenses. The pumps remove the air from the chamber until the pressure is less than 1/7,600,-000 of atmospheric pressure. This pressure can also be expressed as 100 microtorr; one microtorr is a millionth of the pressure of a mercury column one millimeter in height. While the chamber is being exhausted, the heaters are warming the substrates so that they reach a temperature of 150 degrees Celsius by the time film is deposited. This deposition onto a heated substrate produces a film that is very durable.

Depending on the speed of the pumps, it typically takes 10 minutes to reach a pressure of 100 microtorr. The operator then turns on the evaporation source and the magnesium fluoride evaporates when it reaches the proper temperature. At this pressure the mean free path of a molecule (the average distance it travels before it collides with another molecule) is greater than the dimensions of the bell jar. This means that most of the molecules of the vapor travel directly from the source to the substrate without colliding with any of the residual gases in the chamber. As these molecules hit the substrate, some stick and sublime (change directly from a vapor into a sol-
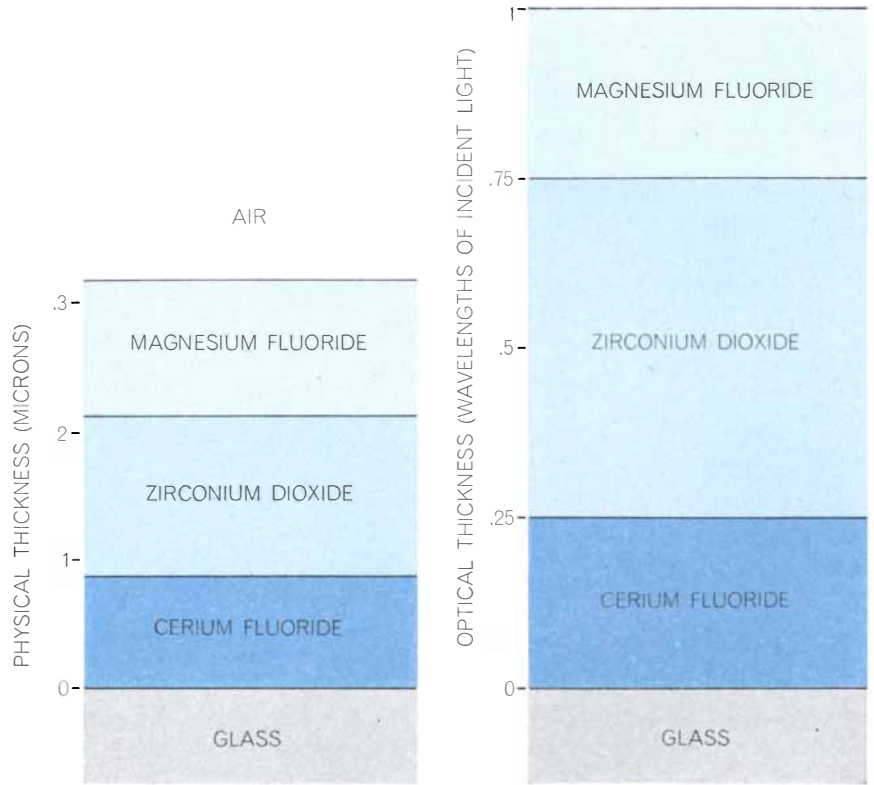
THREE-LAYER ANTIREFLECTION COATING is represented at left in terms of its physical thickness in microns and its optical thickness in wavelengths of the incident light. (The coating's optical thickness is the product of its physical thickness times its refractive index.) Reading from the glass substrate upward, the cerium fluoride layer (*bottom*) has an optical
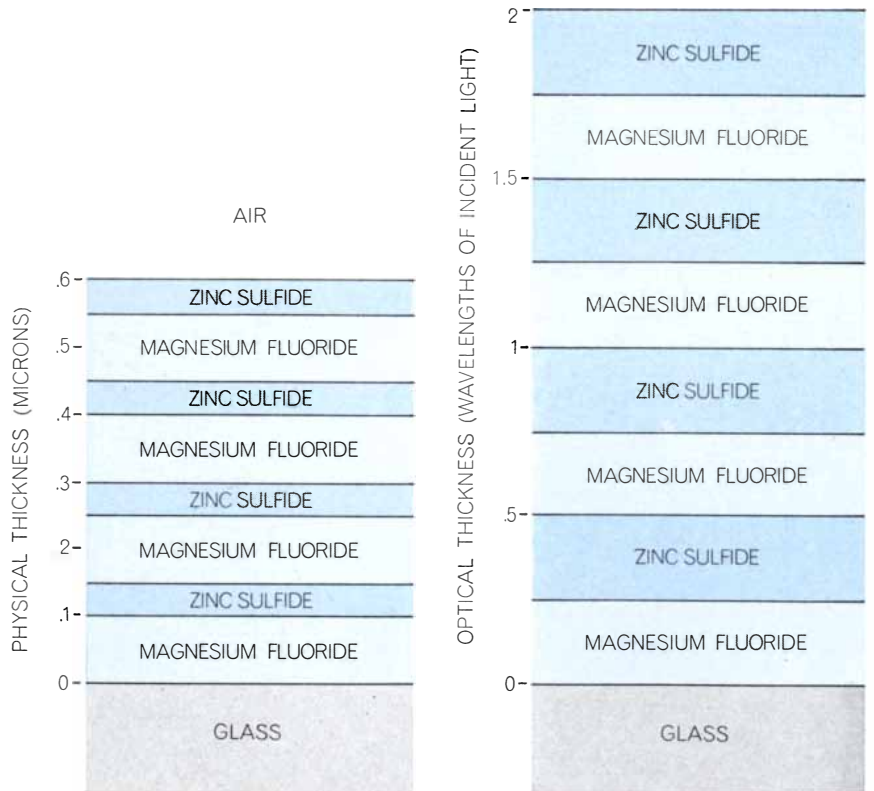
DIELECTRIC MIRROR is produced by stacking optical interference films in such a way as to enhance a surface's reflectance. (A mirror of this type is called dielectric because it is composed entirely of films that are nonconductors of electricity.) The coating at left, as in the illustration above shown in terms of both physical thickness and optical thickness, consists of eight alternating layers of magnesium fluoride (with a refractive index of 1.38)
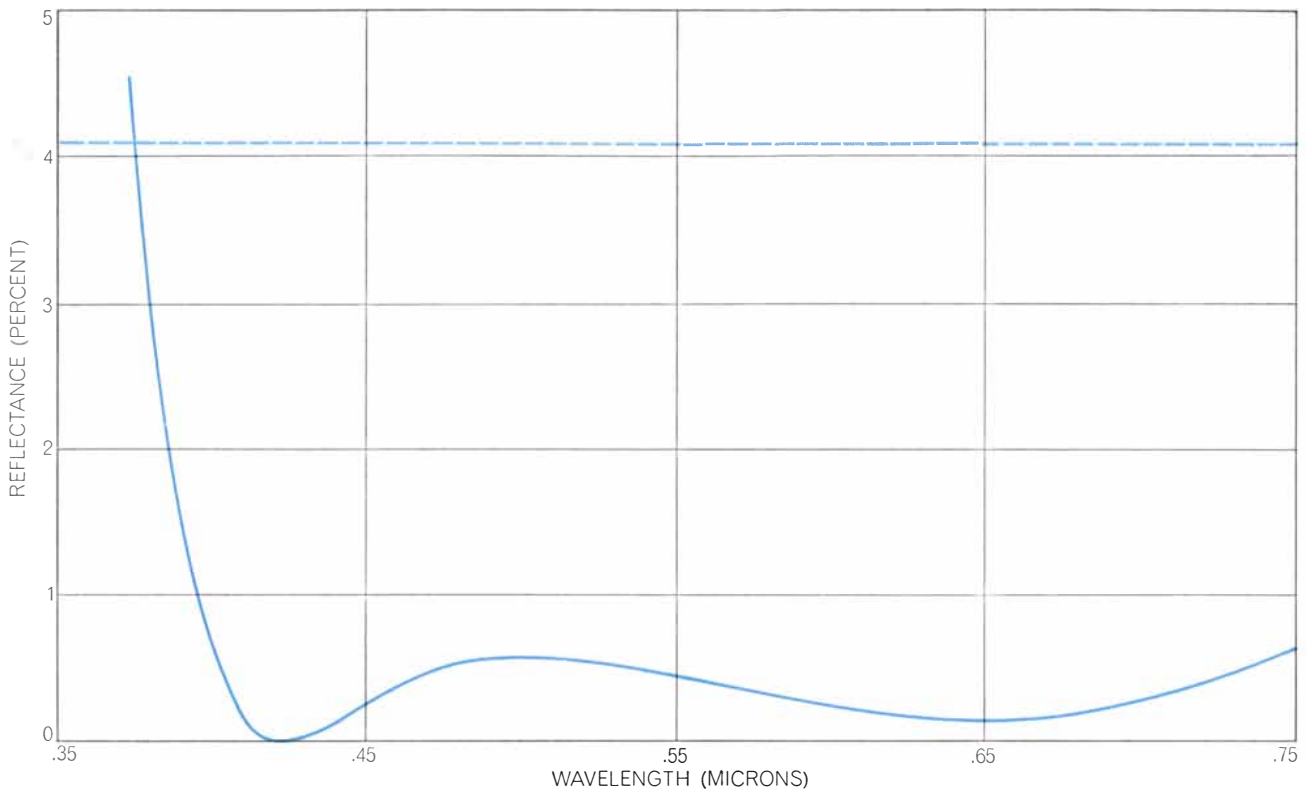
thickness of a quarter-wave and a refractive index of 1.63, the zirconium dioxide layer (*middle*) has a half-wave optical thickness and a refractive index of 2.1, and the magnesium fluoride layer (*top*) is a quarter-wave thick and has a refractive index of 1.38. As the curves at right show, the reflectance of a glass surface covered with such a three-layer coating (*solid colored curve*) is considerably lower than the reflectance of an uncoated glass surface (*broken colored curve*) over most of the visible portion of the spectrum.
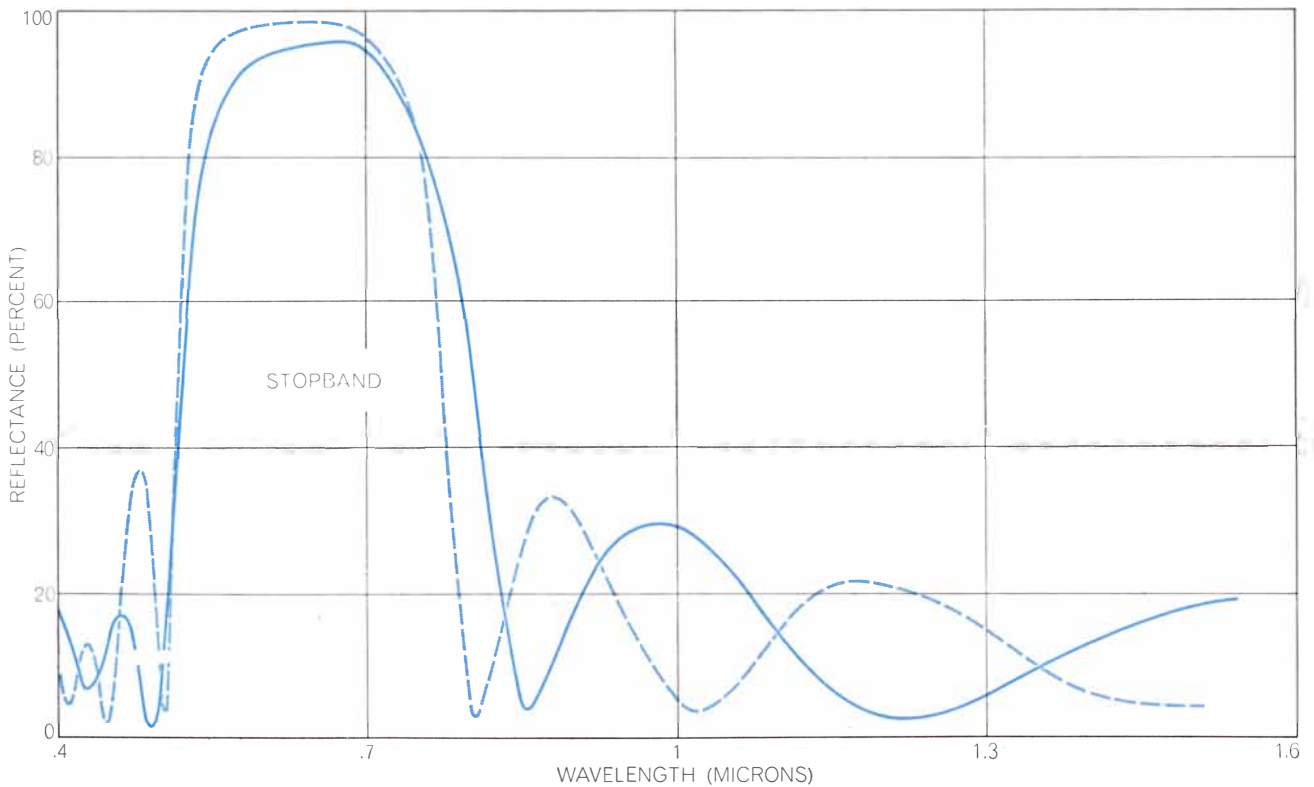
and zinc sulfide (with a refractive index of 2.32). This particular coating is called a quarter-wave stack because the films all have the same optical thickness of a quarter of a wavelength at the "tuned" wavelength of .63 micron. As the solid colored curve in the graph at right shows, the maximum reflectance of the coating at .63 micron is bracketed by a spectral region of high reflectance called a "stopband." The broken colored curve shows the effect of adding two extra layers to form a 10-layer stack of magnesium fluoride and zinc sulfide; the maximum reflectance is thereby increased from 96 to 98.5 percent, but the spectral width of the stopband is unchanged.

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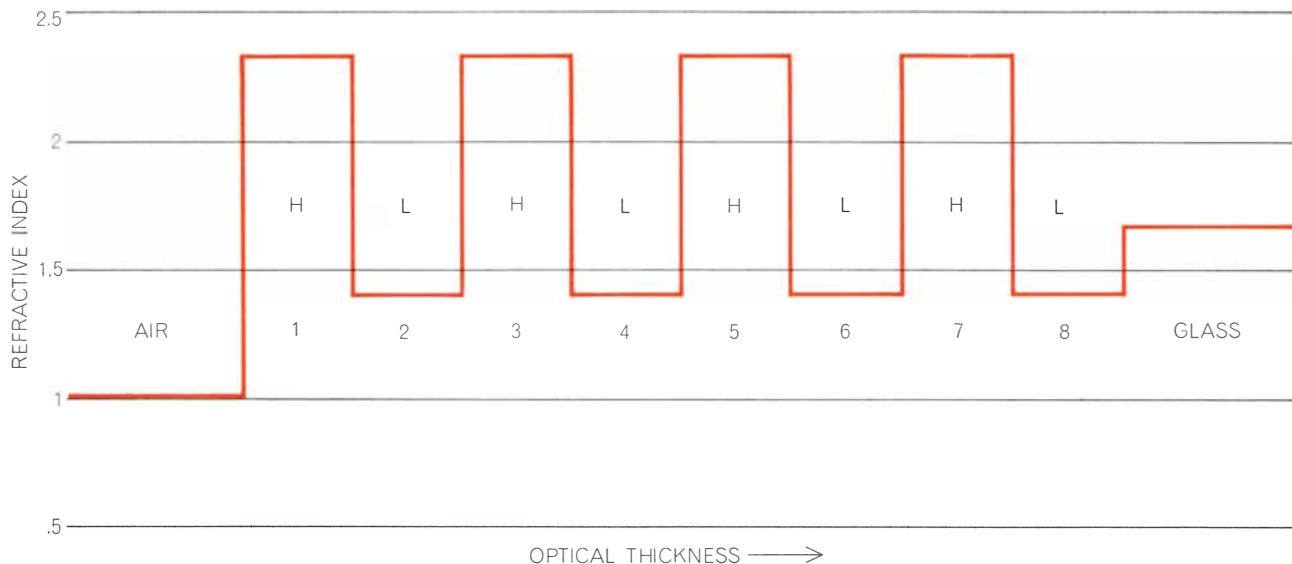
QUARTER-WAVE STACK can be viewed as a periodic medium in which a particular sequence of refractive indexes is repeated many times. In this example of the eight-layer quarter-wave stack shown in the bottom illustration on the preceding two pages the high-index layer is represented by the symbol *H* and the low-index layer by the symbol *L*. The basic period, *HL*, is repeated four times.

id). Soon a layer of solid magnesium fluoride forms on the surface and the operator is able to judge its thickness by observing its color in reflected light. The deposition continues until the film attains the proper thickness, at which time the evaporation source is turned off. Air is readmitted to the chamber and the substrates are removed. If they are to be coated on both sides, they are turned over in the rack and the process is repeated.

Such production coating units for manufacturing antireflection coatings were perfected in the early 1940's, and it was not long before the advantage of "coated optics" was fully recognized. During World War II, Britain, Germany and the U.S. coated most of their military optical equipment with such films. These coatings were considered to be so important that coating machines were installed on U.S. battleships so that the optical elements in range finders could be recoated at sea if necessary. This single-layer coating is effective and inexpensive to produce; it is still popular today.

In the early 1960's serious development was started on another type of antireflection coating: one with three layers [*see top illustration on preceding two pages*]. Although the theoretical design of such a coating was known in the 1940's, the techniques were not available for depositing films with the proper refractive index. In this coating the film adjacent to the substrate has an optical thickness of a quarter-wave and a refractive index of 1.63. The center layer has a half-wave optical thickness and a refractive index of 2.1. The layer adjacent to the air is a quarter-wave of magnesium fluoride with a refractive index of 1.38. The reflectance of this coating is lower than a single-layer one over most of the visible spectrum.

In spite of the superiority of this three-layer coating, its acceptance has been slow, for several reasons. First, it is considerably more difficult to produce than the single-layer coating. The optical thickness and refractive index of all three layers must be controlled with the utmost precision. During the deposition of these layers it is no longer possible to control their thickness by visually judging the color. Rather, the thickness is measured photometrically by a separate instrument. A three-layer antireflection coating also scatters more light than the single-layer coating does and has an absorption in the blue part of the spectrum that is as large as 1 percent. On the other hand, the three-layer coating definitely has a lower reflectance than the single-layer coating, and it is used in many optical instruments in which the advan-
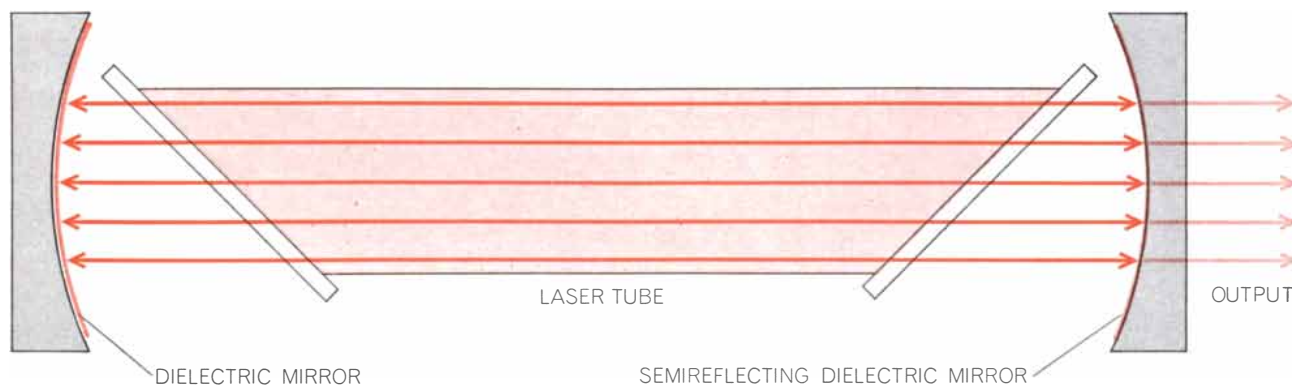
HELIUM-NEON LASER makes use of optical interference in its dielectric mirror, which is the only means available to obtain the nearly 100 percent reflectance required for such a laser to operate, given its typical power amplification of approximately 1 percent.

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tage of higher transmittance outweighs the higher cost and other disadvantages we have mentioned.

Various other types of antireflection coating exist, including a two-layer narrow-band antireflection coating, which is often used in laser optical systems, and several different three-layer and four-layer coatings, which are deposited on infrared optical components.

The antireflection coatings described so far reduce the reflectance of a surface. Stacks of optical interference films are also used to enhance a surface's reflectance and thus produce a mirror. In order to distinguish such coatings from conventional metal mirrors, they are called dielectric mirrors because they are composed entirely of films that are dielectrics, that is, nonconductors of electricity. These coatings are also used as band-pass filters and beam-dividers.

A typical dielectric mirror consists of eight layers that alternate between an index of 1.38 and one of 2.32 [*see bottom illustration on pages 62 and 63*]. The low-index layers are magnesium fluoride and the high-index layers are zinc sulfide. This type of coating is called a quarter-wave stack, because the films all have the same optical thickness of a quarter of a wavelength at .63 micron in the red portion of the spectrum. If the films' refractive indexes do not change appreciably with wavelength, then the maximum reflectance of the coating occurs at this "tuned" wavelength of .63 micron.

The maximum reflectance is bracketed by a region of high reflectance that extends from .52 to .75 micron. This spectral region is called a "stopband." Outside this region the reflectance oscillates between the maximum and the minimum value. If the films were non-absorbing, the spectral transmittance would be equal to 100 percent minus the reflectance. In practice, however, there is a small amount of absorption and scattering in the layers, which degrades the performance of the mirror. This absorption and scattering must be minimized in order to produce mirrors with a reflectance that is close to 100 percent.

The maximum reflectance depends on the refractive indexes of the films and on the number of layers. For a given number of layers the maximum reflectance in the stopband gets larger as the ratio of the refractive indexes increases. For example, if films of titanium dioxide with a refractive index of 2.40 were substituted for the zinc sulfide layers, the maximum reflectance would increase from 96 to 97 percent. For a stack that

contains given materials the reflectance in the stopband increases as more layers are added to the stack. For instance, the addition of two extra layers to form a 10-layer stack of magnesium fluoride and zinc sulfide increases the maximum reflectance from 96 to 98.5 percent. The spectral width of the stopband, however, depends only on the refractive index of the two films that are used in the stack and is independent of the number of layers.

This phenomenon of a stopband, as a spectral region in which the incident wave is strongly reflected, is best explained in terms of a wave propagating in a periodic medium. In this case the periodic medium is a particular sequence of refractive indexes that is repeated many times. For example, suppose the refractive-index profile of a quarter-wave stack is plotted against optical thickness, and the high-index layer is represented by the symbol *H* and the low-index layer by the symbol *L;* the basic period is then *HL* [*see top illustration on page 64*]. The eight-layer coating described above has four such *HL* periods and the 10-layer stack has five.

The spectral region of the stopband is determined by calculating the change in the wave's amplitude as it propagates through a basic period. If at a particular wavelength the wave is attenuated, a stopband exists at that wavelength. Since the medium is nonabsorbing, the only way for the wave to be attenuated is for it to be reflected. In the case of the quarter-wave stack this happens when the optical thickness of the basic period is a half-wave. At other wavelengths the wave's amplitude will sometimes increase and sometimes decrease as it propagates through a basic period. A "passband" is said to exist at those wavelengths.

The phenomenon of a stopband is not limited to a periodic medium in which the basic period consists of layers that are optically homogeneous, that is, with a constant refractive index. It also occurs in optically inhomogeneous layers, in which the refractive index changes in the direction of propagation. In general a stopband is found in any medium in which there is a periodic modulation of the wave's propagation velocity.

Nature has provided several striking examples of such a periodic structure, for instance in the colors of birds and in mother-of-pearl. Both exhibit iridescence, which is produced by a structure in which there is a periodic variation of the refractive index. How can the observer distinguish such colors from absorption colors such as those produced
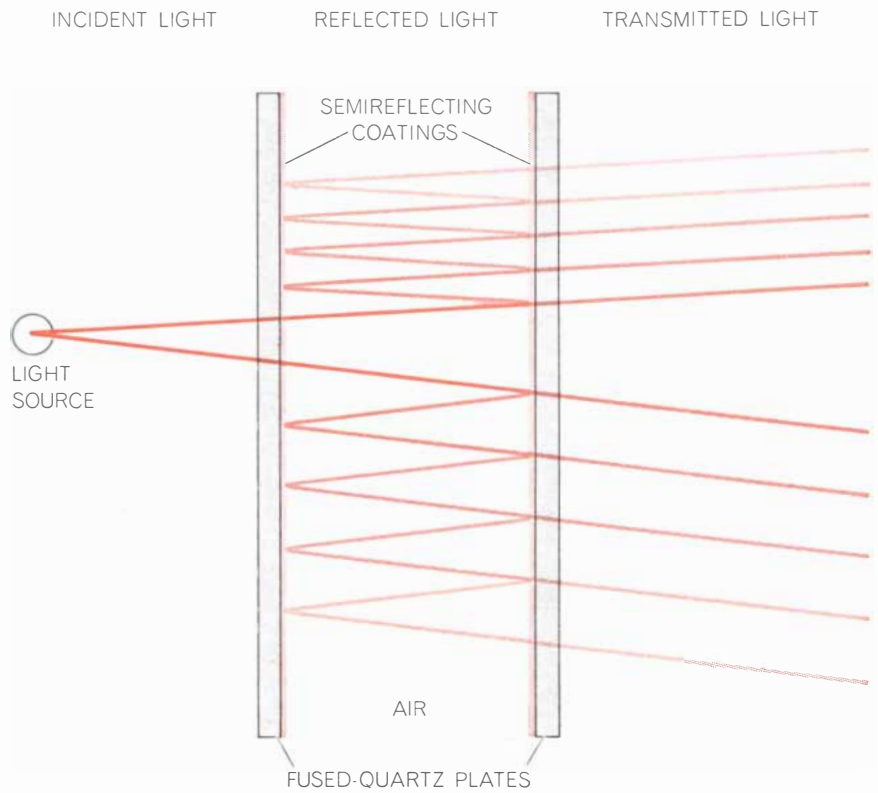
FABRY-PERÔT INTERFEROMETER, the essential parts of which are shown in this diagram, can be equipped with semireflecting dielectric mirrors in order to maintain a high reflectance while reducing the absorptance of the coated fused-quartz flats that form the interferometer's optical cavity. The object is to increase the transmittance and hence the efficiency of the device, which is used to measure the spectral profile of a light source.
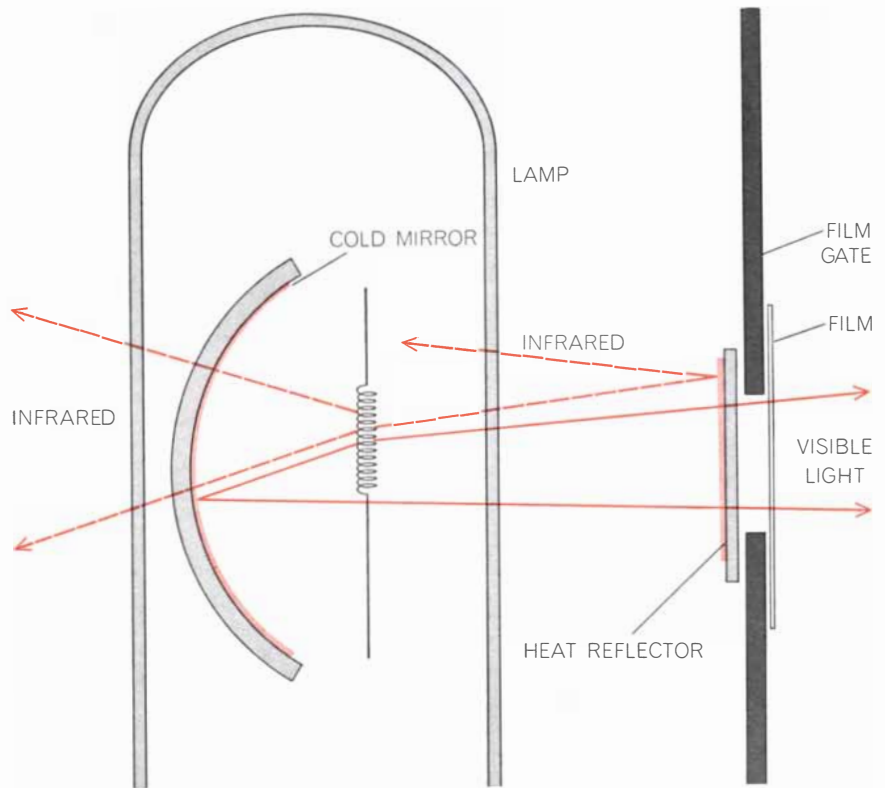
MOTION-PICTURE PROJECTOR employs coated optics for two different functions: as a heat-reflector between the projection lamp and the film gate in order to reflect heat radiation in the infrared portion of the spectrum away from the film and as a "cold mirror" be-
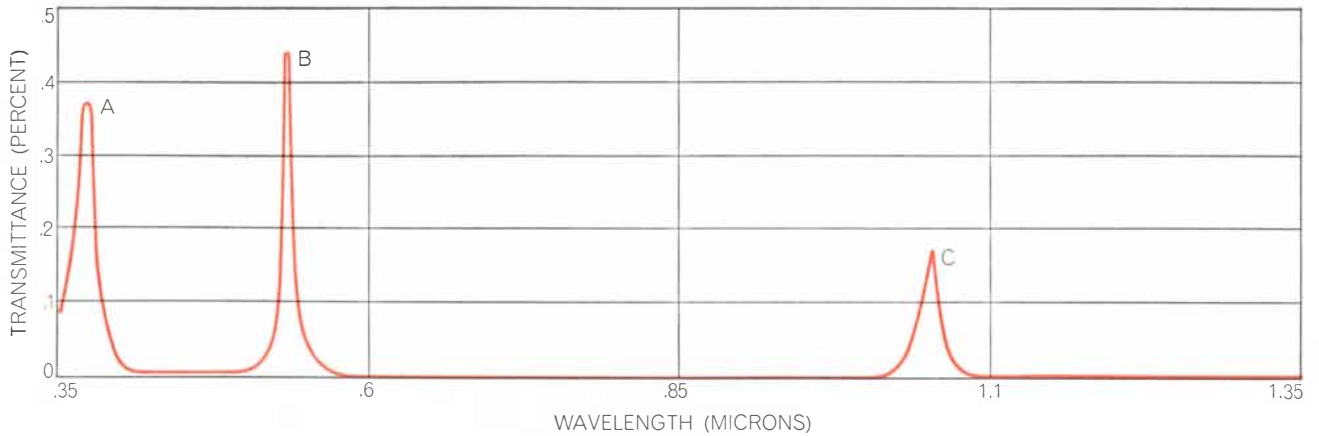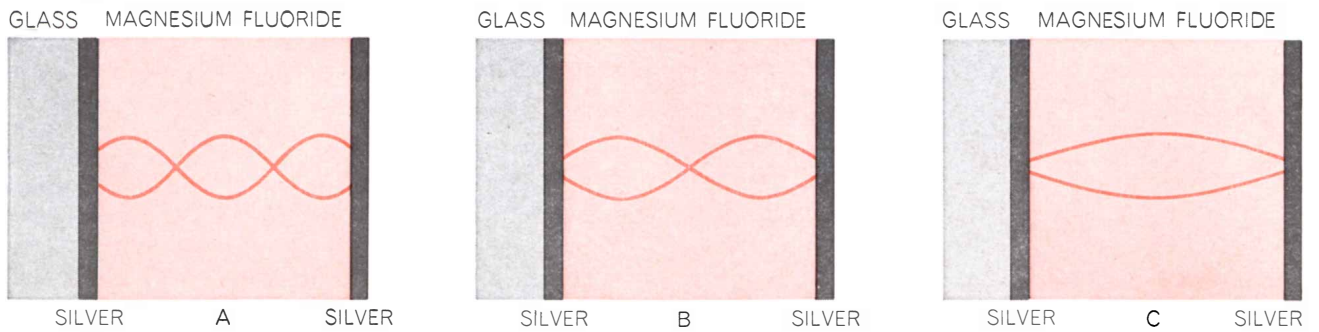
SOLID OPTICAL CAVITY composed of magnesium fluoride can be used instead of air between the semireflecting plates in a Fabry-Perôt interferometer; in this case the wavelengths of the transmittance bands depend on the thickness of the spacer layer. The first-order, second-order and third-order transmittance peaks correspond respectively to one half-wave of incident light at 1.06 microns (C), two half-waves at .537 micron (B) and three half-waves at .370 micron (A). When a standing wave is set up in such a cavity, the wave penetrates into the metal and hence is shown with the node about 30 degrees out of phase below the surface of the metal.
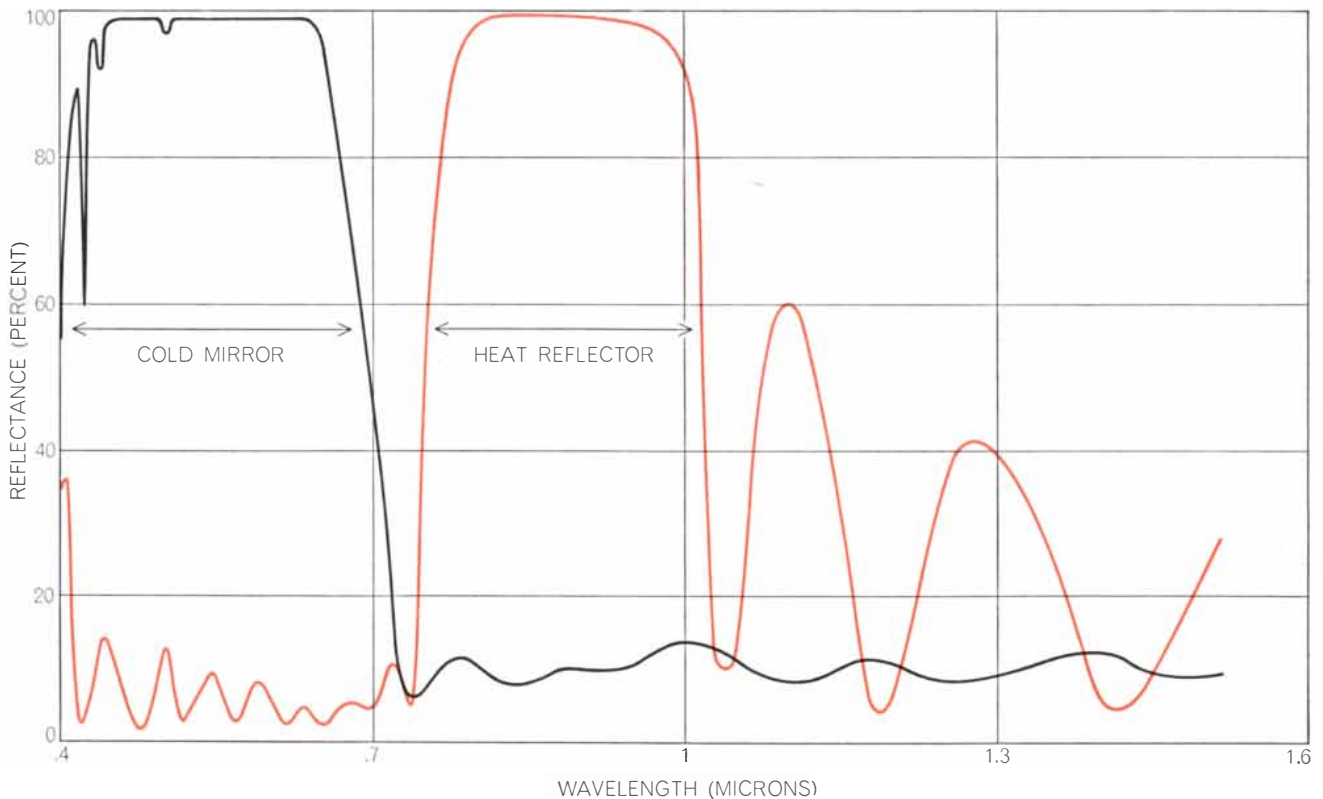
hind the filament in the lamp in order to reflect visible light toward the film while allowing the infrared to pass harmlessly into the lamp housing (diagram at left). The reflectance curves of the two coated surfaces are at right; the black curve represents the cold mirror; the colored curve represents the heat-reflector. The transmittance of both coatings is very nearly one minus the reflectance.

67
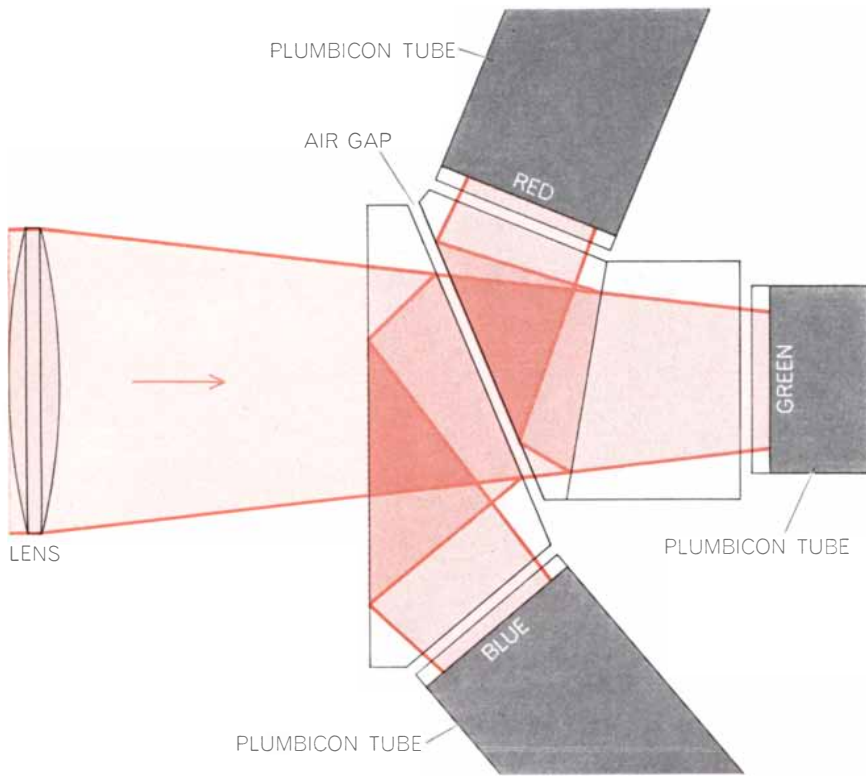
COLOR TELEVISION CAMERA consists essentially of three components: an objective lens, a beam-splitter assembly and three separate Plumbicon tubes to convert the light into an electronic signal. Light reflected from the scene being televised is split into red, green and blue channels by the dielectric band-pass filters deposited on the faces of the prisms in the beam-splitter assembly. The signals from the red, green and blue Plumbicon tubes eventually produce the corresponding colors on the picture tube in the television receiver.
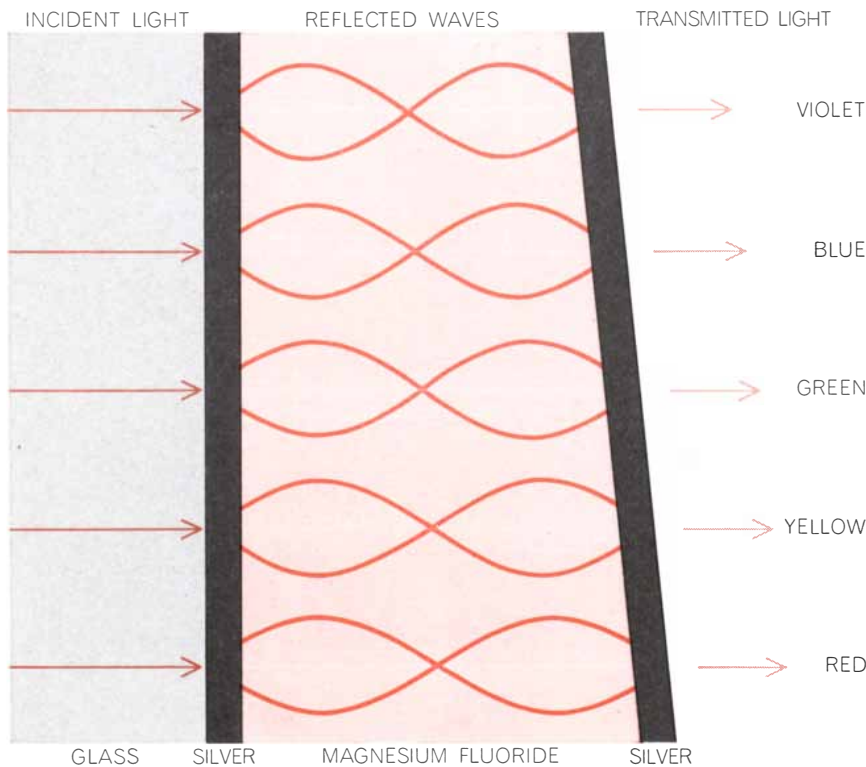
WEDGED SPACER LAYER of solid magnesium fluoride is employed between two semireflecting silver films in this band-pass filter. Different wavelengths are transmitted at various positions across the filter. The thickness of the spacer layer is greatly exaggerated.

by chemical dyes or inks? One method is to notice that interference color changes as the illumination changes its angle. For example, by examining the color of a peacock feather with a single tungsten lamp as a light source, one can see how the colors change as the light's angle of incidence becomes oblique. The color shift is always to shorter wavelengths: the reds become yellows, the yellows become greens and the greens become blues. Several species of beetles and many butterflies exhibit similar interference colors in their wings. This periodic structure has also been clearly seen in electron micrographs of the platelets of hummingbird feathers.

Dielectric mirrors differ in two respects from conventional metal mirrors: they can attain a higher reflectance and their absorptance is considerably smaller. Several optical instruments take advantage of these attributes. For instance, in the Fabry-Perôt interferometer, which is an optical cavity consisting of two parallel fused-quartz flats, the inner surface of each plate is coated with a semitransparent mirror [see top illustration on page 66]. This instrument has been used for many years to measure with high resolution the spectral profile of emission lines. Before 1950 it was customary to coat the plates with silver, which typically has a reflectance of 90 percent, a transmittance of 6 percent and an absorptance of 4 percent. The reflectance of 90 percent is adequate for most purposes, and even when dielectric coatings are used in lieu of the silver, a reflectance in excess of 90 percent is rarely employed.

Although the silver coating suffices for many applications, the absorption loss at each plate reduces considerably the overall transmittance of the interferometer. In computing the transmittance of the interferometer, it is meaningless to consider only the coating's absorptance. Rather, the transmittance is determined by the ratio of the coating's absorption to its transmittance. As the ratio decreases, the coatings are more efficient and the transmittance of the interferometer increases. For example, the interferometer with silver coatings had an absorption/transmittance ratio of 4:6, which reduces its transmittance to 36 percent.

In the quest for greater efficiency, many spectroscopists had dielectric coatings deposited on their interferometer plates in the early 1950's. A typical dielectric mirror with a reflectance of 90 percent would have an absorptance of .5 percent and a transmittance of 9.5

Solving subtraction problems with addition
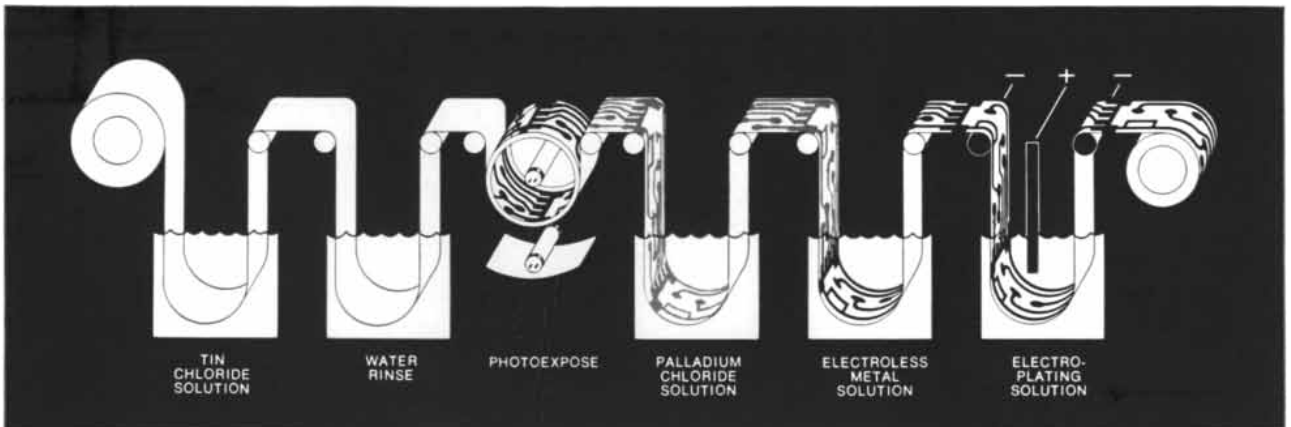
Schematic of PSMD with flexible substrate: After dipping in tin chloride solution, substrate is rinsed off, leaving tin oxide coating; exposed to UV light, dipped into palladium chloride solution, electroless metal solution, and electroplated.
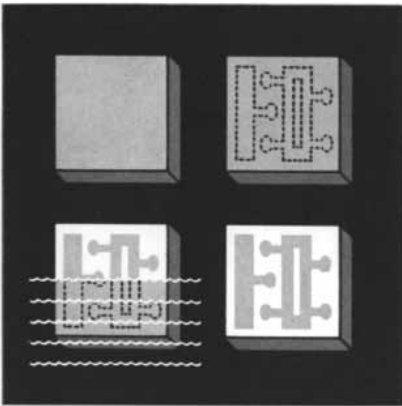
Usual method of making circuits requires coating substrate with photo-resist, exposing, eliminating exposed photo-resist, and etching away uncovered copper.

Most people make printed circuits by putting a layer of copper on a substrate and etching away the unwanted part. But engineers at Western Electric's Engineering Research Center in Princeton, N.J., have devised a way to do exactly the opposite: add copper only where it's wanted. "Photo Selective Metal Deposition," now being introduced into Western Electric factories, works this way:

The substrate is coated with tin oxide, then dipped in a palladium chloride solution. Tin oxide reduces the palladium ions to palladium metal, so the surface now has a coating of palladium. If the substrate is dipped in an

electroless copper bath, this palladium causes the copper to plate.

But the plating depends upon the presence of palladium, which depends upon the reducing ability of tin oxide. And *that* is destroyed by exposure to ultraviolet light.

So. We expose the coating to ultraviolet light through a mask of the circuit before dipping it into the palladium chloride. We thus get palladium —and hence copper—only on the unexposed portions. (Because chemical plating is slow, we can add electroplating if we want thick copper quickly.)

Now, our engineers have gone to considerable time and trouble to develop this new process because while the subtractive method makes perfectly fine circuits, it also makes problems. The copper salts formed by the etching-away process are quite poisonous and must be disposed of. To put down that initial layer of copper you need copper foil, which is expensive. Reclaiming the copper unused is laborious and can be expensive. *Not* reclaiming it means throwing away up to 70% of the copper you start with.

Considering the number of printed circuits Western Electric makes for the Bell System, these become major problems indeed. But by adding where we used to subtract, we not only solve those problems, we eliminate them.

We also get other benefits. The
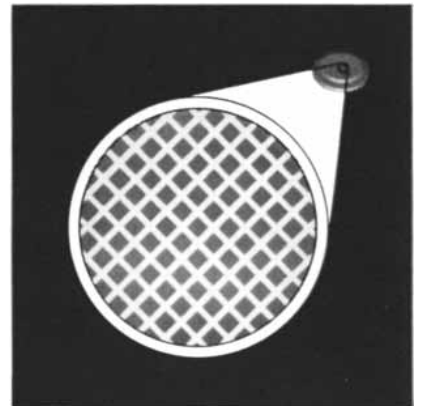
Grid used in Picturephone® camera, produced experimentally by PSMD: It has 8 micron lines on 1 mil centers.

process can be used for one or both sides of rigid or flexible substrates, and with other metals beside copper. The pattern can be peeled off certain substrates, giving us an excellent way to make intricate connections. And, because the light used for exposure is UV (higher in the spectrum = shorter wavelength = better detail), resolution is good enough for us to make the kind of thing shown just above.

Exactly the kind of development most pleasing to us at Western Electric.

Ⓐ Western Electric

Gifts that won't sit under the Christmas tree.

The Colorpack II. Beautiful color pictures in a minute, at a beautiful price. Electronic shutter and electric eye for automatic exposures. Sharp 3-element lens. Drop-in pack-film loading. Built-in flash for 4-shot flashcubes. Under $30.

The Model 320. The most economical in our popular line of folding cameras. Coupled rangefinder-viewfinder lets you focus as you shoot. Electronic shutter and electric eye read and set exposures automatically–even for flash. Detachable camera cover and carrying strap. Under $60.

The Model 330. A lot more gift for a little more money. Built-in mechanical timer automatically tells you when your picture's ready. Transis-

torized electronic shutter. Precise triplet lens that can use optional filters. Double-image rangefinder-viewfinder for easy focusing. Under $80.

The Model 340. One of the most sophisticated cameras you can give for under $100. Takes indoor black-and-white shots without flash. Built-in development timer. Foldaway rangefinder-viewfinder. Four film speed settings. Handles a whole list of optional accessories such as close-up and portrait attachments. Under $100.

The Model 350. How automatic can you get? Built-in electronic timer ''beeps'' when your picture is perfectly developed. Takes auto-

matic time exposures up to 10 seconds. Electronic shutter and electric eye. Single-window Zeiss Ikon rangefinder-viewfinder. Handsome all-metal body with brushed chrome finish. Under $160.

The Model 360. The most self-sufficient camera in the world. Snap-on electronic flash. (At 1/1000th of a second it can stop the action at a teenage party.) Recharges on ordinary house current. Electronic development timer. Triplet lens and Zeiss Ikon rangefinder-viewfinder. Four exposure ranges: Two color, two black-and-white. Under $200.

Polaroid Land Cameras

Polaroid®

percent. This much lower absorption/transmittance ratio means that the transmittance of the device is 90 percent.

In some applications the interferometer plates are still coated with either silver or aluminum films. Such films have the advantage that their reflectance is relatively constant with wavelength, in contrast to the quarter-wave stack, whose reflectance changes rapidly in certain spectral regions. It is possible to design dielectric coatings that have a broader region of high reflectance than the conventional quarter-wave stack, but they are more difficult to deposit.

Dielectric mirrors are important components of many lasers, particularly gas lasers. A gas laser consists of two parts: an amplifier and an optical cavity [*see bottom illustration on page 64*]. The amplifier is a tube containing a plasma, a gas that is excited by an electric discharge. A typical plasma tube has a power amplification of 1 percent. This means that a wave with an initial intensity of 100 units has an intensity of 101 units after it has traversed the tube once. In a laser the tube is inserted into an optical cavity that resembles a Fabry-Perôt interferometer. When the amplified wave reflects from one of the mirrors, it suffers a power loss proportional to 100 percent minus the reflectance. If the power loss exceeds the amplification of the plasma tube, the laser will not function. In this example, if the reflectance of the mirror is not greater than 99 percent, the laser will not operate. The small amplification of 1 percent is not untypical of many gas lasers and hence they would simply not function without dielectric mirrors, which are the only means available for obtaining a reflectance close to 100 percent.

Dielectric coatings with a periodic structure are also used extensively as band-pass filters. In principle such a filter should exhibit a substantial transmittance in the spectral region of its passband and a large rejection elsewhere. The stopband of the periodic structure provides the rejection, so that the only problem in producing a band-pass filter is to alter its design slightly in order to optimize its passband transmittance. For example, consider the spectral transmittance of a filter that is designed to reflect the heat radiation in the infrared portion of the spectrum and to transmit visible light. Most of the layers have an optical thickness of a quarter-wavelength at .89 micron, where the stopband is located. A few of the layers are of a different thickness in order to improve the transmittance in

the visible portion of the spectrum. Such a heat-reflector is often placed in front of the film gate in a motion-picture projector in order to reflect the heat away from the motion-picture film. It is considerably more effective than heat-absorbing glass, which is also used.

Another widely used band-pass filter has a high reflectance throughout the visible portion of the spectrum and a low reflectance in the infrared. This coating, which is called a cold mirror, is deposited on the reflector that is positioned behind the tungsten projection lamp in a motion-picture projector. A substantial portion of the lamp's radiation is in the form of heat, which is invisible to the human eye but which heats and sometimes damages the motion-picture film. The cold mirror reflects the visible light toward the film and allows the infrared to pass into the lamp housing. This arrangement is particularly effective when it is used in conjunction with a band-pass filter of the heat-reflector type [*see bottom illustration on pages 66 and 67*].

Band-pass filters are also important components of color television cameras, which consist essentially of an objective lens, a beam-splitter assembly and separate Plumbicon tubes that convert light

into an electron signal [*see top illustration on page 68*]. Three channels record the primary colors of the scene being televised. The light is split into red, green and blue channels by the dielectric band-pass filters deposited on the faces of the prisms in the beam-splitter assembly. For example, the blue-channel coating is a dielectric mirror that reflects in the blue part of the spectrum and transmits at longer wavelengths in the green and red. The signals from the red, green and blue Plumbicon tubes eventually excite the red, green and blue colors on the face of the picture tube in the television receiver.

These band-pass filters and dielectric mirrors can be fabricated to operate at practically any wavelength from the ultraviolet to the far-infrared portion of the spectrum. The wavelength at which they function is controlled by making the films thicker or thinner. The chief difficulty is that in the ultraviolet and the far infrared there are not many materials that are transparent and that can be used as thin films. Many of the problems have been overcome, however, and it is now possible to buy band-pass filters at wavelengths in the range from .2 micron to 18 microns as "off the shelf" items from commercial firms. These infrared filters
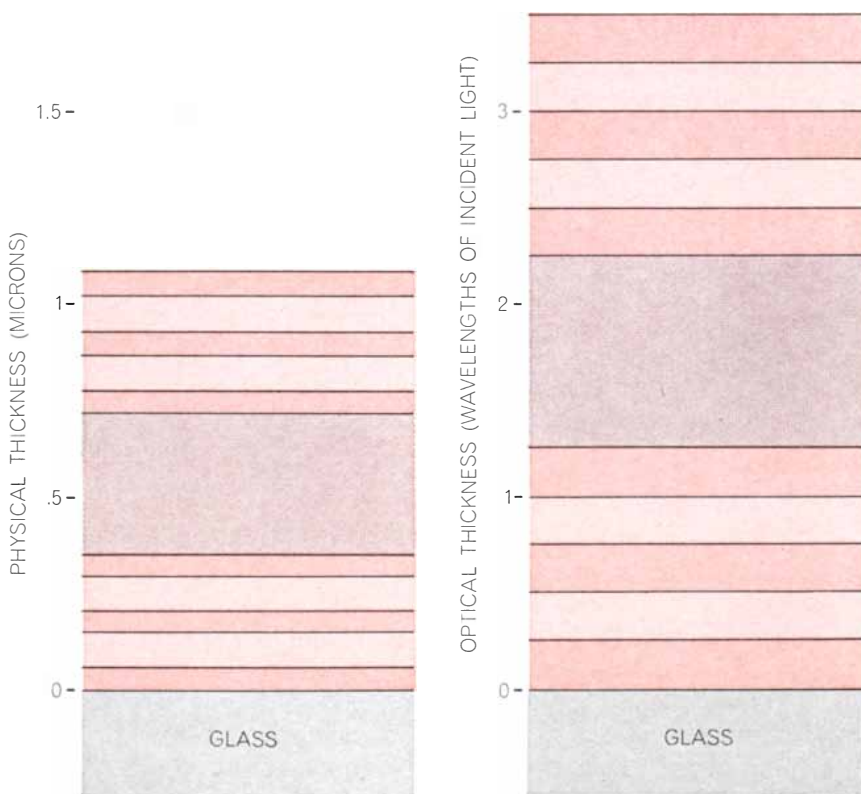
ALL-DIELECTRIC BAND-PASS FILTER is constructed by replacing the silver mirrors in the conventional arrangement with dielectric mirrors. A representative filter of this type consists of a five-layer quarter-wave stack, a spacer layer and another five-layer quarter-

are important components of instruments such as the carbon dioxide laser, infrared gas analyzers, guidance systems for missiles, horizon-seekers for satellites and so on.

Band-pass filters that have a much narrower passband than the filters described above are also available. The simplest of these filters functions on the same principle as the Fabry-Perôt interferometer; it consists of two semitransparent silver films separated by a "spacer layer" of magnesium fluoride [*see top illustration on page 67*]. Whereas the optical cavity in the Fabry-Perôt interferometer is filled with air, however, the optical cavity in the filter consists of the solid magnesium fluoride spacer layer. The transmittance of such a filter is at a maximum when the optical thickness of the spacer layer is an integral number of half-waves. The wavelength of the passband can also be varied by changing the thickness of the spacer layer. For example, if the spacer layer in a given filter is in the form of a wedge, then different wavelengths are transmitted at various positions across the filter [*see bottom illustration on page 68*]. Thus by moving such a filter past a pair of slits, it is possible to construct a simple monochromator.

This type of filter was first produced in Germany in the late 1930's. Since it was the first type of filter to function according to the principles of optical interference, it was originally called an interference filter. Since that time, however, many other types of optical interference coatings have been produced, and hence it is no longer meaningful to describe any one particular type as an interference filter. Although the spectral width of the passband of such a filter is not particularly narrow, these filters are often used when a large attenuation outside the passband is required.

By analogy with the Fabry-Perôt interferometer, it is possible to replace the silver mirrors with dielectric mirrors and thereby construct an "all dielectric" band-pass filter. A representative filter of this type would consist of a quarter-wave stack, a spacer layer and another quarter-wave stack [*see illustration below*]. Compared with the band-pass filters that incorporate silver films, this all-dielectric filter has a greater peak transmittance in its passband and also a narrower spectral passband width, which in some filters is as narrow as a few angstroms.

These narrow-band filters are used in solar coronagraphs, spectrum-analyzers and other instruments where it is necessary to isolate a narrow region of the spectrum. For example, a laser range finder illuminates a target with laser light and determines its range from the time delay in the reflected beam. This instrument will function in broad daylight because its receiver contains a narrow-band filter that transmits the laser radiation and reflects almost all the sunlight.

This article has described some of the simpler types of optical interference coatings and a few applications. Some of the coatings that are produced today by commercial manufacturers are similar to these simple designs and many others are considerably more complex, incorporating as many as 100 layers. The design and construction of these coatings are challenging and now represent a thriving branch of optical engineering. The active research in this subject embraces such topics as new methods of designing coatings, the investigation of new coating materials and the improvement of the durability and hardness of the coatings. The technology of optical interference coatings has expanded rapidly in the past 20 years and there is every reason to expect that it will continue to do so.
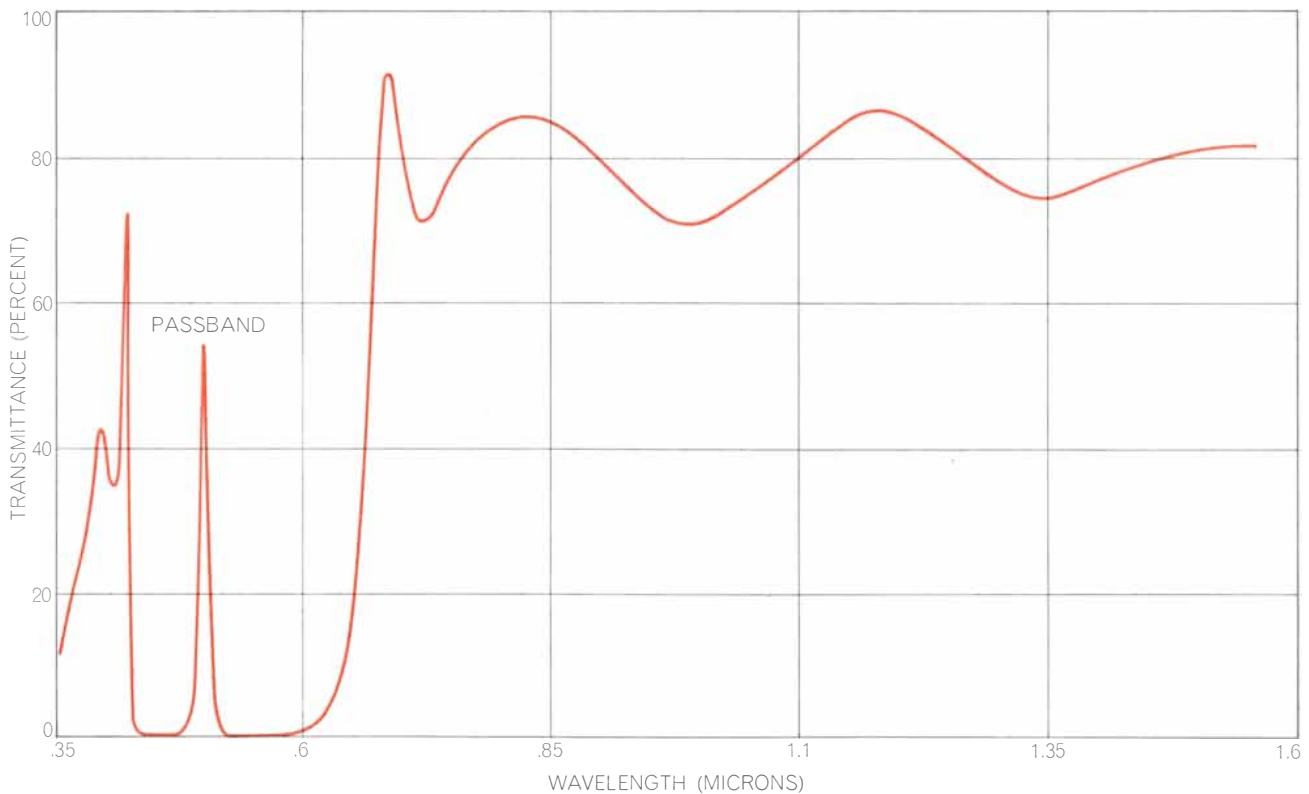
wave stack (*diagram at left*). As the transmittance curve at right shows, such an all-dielectric filter has a narrower spectral bandpass width than a band-pass filter containing silver films. The passband in this case is located at approximately .5 micron. The unwanted radiation at wavelengths shorter than .4 micron and longer than .6 micron must be removed by means of auxiliary filters.
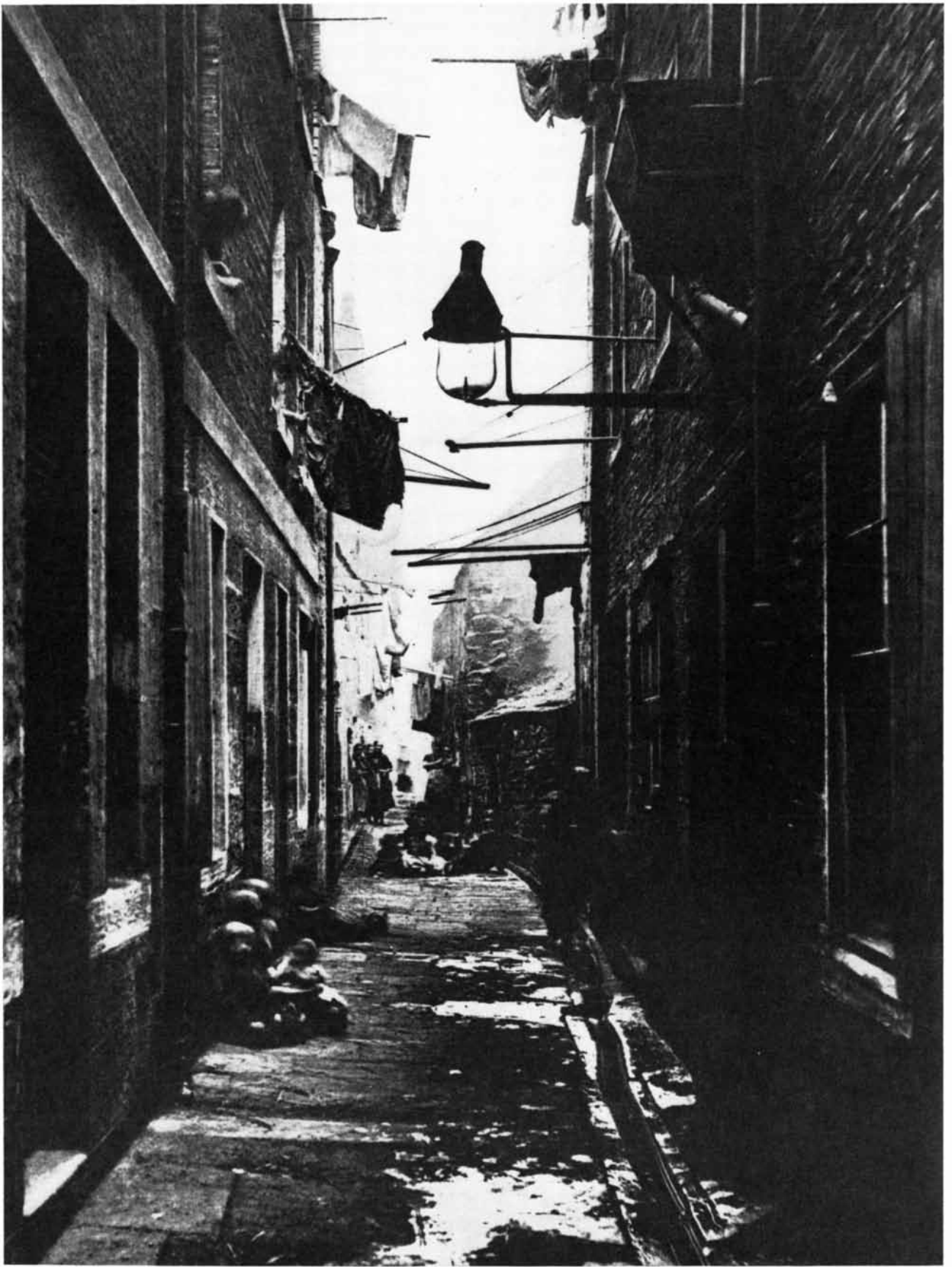
DARK ALLEY in Glasgow, photographed in about 1870, is typical of the environment in which rickets was once endemic. In such a setting children received little ultraviolet radiation, which is nec- essary for the synthesis of the hormone that prevents rickets. Along the left side of the alley are two groups of children. Images are blurred because the children moved during the time exposure.

RICKETS

Although it is still widely regarded as a dietary-deficiency disease resulting from a lack of "vitamin D," it results in fact from a lack of sunlight. In smoky cities it was the first air-pollution disease

by W. F. Loomis

The discovery of the cause and cure of rickets is one of the great triumphs of biochemical medicine, and yet its history is little known. Indeed, it is so little known that even today most textbooks list rickets as a dietary-deficiency disease resulting from a lack of "vitamin D." In actual fact rickets was the earliest air-pollution disease. It was first described in England in about 1650, at the time of the introduction of soft coal, and it spread through Europe with the Industrial Revolution's pall of coal smoke and the increasing concentration of poor people in the narrow, sunless alleys of factory towns and big-city slums. This, we know now, was because rickets is caused not by a poor diet but by a deficiency of solar ultraviolet radiation, which is necessary for the synthesis of calciferol, the calcifying hormone released into the bloodstream by the skin. Without calciferol not enough calcium is laid down in growing bones, and the crippling deformities of rickets are the consequence. Either adequate sunlight or the ingestion of minute amounts of calciferol or one of its analogues therefore prevents and cures rickets, and so the disease has been eradicated.

That seems a clear enough story, and yet the textbooks speak of diet and vitamin D. How can that be? What happened is that the investigation of rickets proceeded along two quite independent lines. Intuitive folk medicine and then medical studies pointed in the direction of sunlight and calciferol. At the same time, however, common assumptions about poverty and poor nutrition and then studies by nutritionists pointed in the direction of diet and vitamin D. Now, with the inestimable advantage of hindsight, it is possible to trace these two chains of thought, to disentangle them and set the historical record straight.

Now that one knows what to look for, the evidence of a climatic influence on rickets can be discerned quite early. In the early 19th century G. Wendelstadt published *The Endemic Diseases of Wezlar,* a German town of 8,000 population with exceptionally narrow streets and dark alleys. The town was infamous for rickets, he wrote, with entire streets where in house after house individuals crippled by rickets could be found. "The children must sit indoors...which ends in death or if they continue to live, they develop thick joints, cease to be able to walk or have deformed legs. The head becomes large and even the vertebral column bends. It comes to pass that such children sit often for many years without being able to move; at times they cease to grow and are merely a burden to those about them." This terrible picture of an entire town afflicted with severe rickets leads one to guess that many of William Hogarth's sketches of frightfully deformed men and women may have depicted the crippling effects of rickets in London in the 18th century.

As early as 1888 the English physician Sir John Bland-Sutton found unmistakable evidence of rickets in animals in the London zoo—chimpanzees, lions, tigers, bears, deer, rabbits, lizards, ostriches, pigeons and many other species. He noted that "in spite of every care and keeping them in comfortable dens" lions in London developed rickets, whereas "in Dublin, Manchester, and some other British towns, lions can be reared successfully in captivity." It is clear in retrospect that the pall of coal smoke over London was the causative factor.

The geographical relation between rickets and cities was clearly noted in 1889 by the British Medical Association. After a survey of the incidence of the disease in the British Isles the association published maps [*see illustration on page 79*] that supported its major conclusion: There was widespread and severe rickets "in large towns and thickly peopled districts, especially where industrial pursuits are carried on," whereas rickets was almost totally absent in rural districts. Specifically, the report added, "almost the whole of London and the greater number of its outlying suburbs" reported severe rickets among rich and poor alike.

Solar ultraviolet may be blocked by many means, among them being the industrial smog in London and the sunless alleys of Wezlar, but beneath such specific industrial and urban conditions there is a major underlying factor: the far northern location of the entire European land mass. The area is made habitable by the benign influence of the Gulf Stream, yet its winter sun, hanging low in the sky, is almost without potency in effecting the crucial conversion of 7-dehydrocholesterol into calciferol. Elsewhere in the world, lands as northerly as Europe are largely uninhabited—the Aleutian Islands, for example, or Labrador or northern Siberia. The long, dark winters of Europe therefore powerfully predisposed European infants toward rickets during the winter months.

The seasonal variation was noted as early as 1884 by M. Kassowitz in Germany, who attributed it to the prolonged confinement of infants indoors during the winter. Then in 1906 D. Hansemann noted that nearly all German children who were born in the fall and died in the spring had rickets; those who were born in the spring and died in the fall were free of the disease. Noting the progressive rise of rickets during the winter months, he concluded that rickets was primarily a disease of "domestication,"
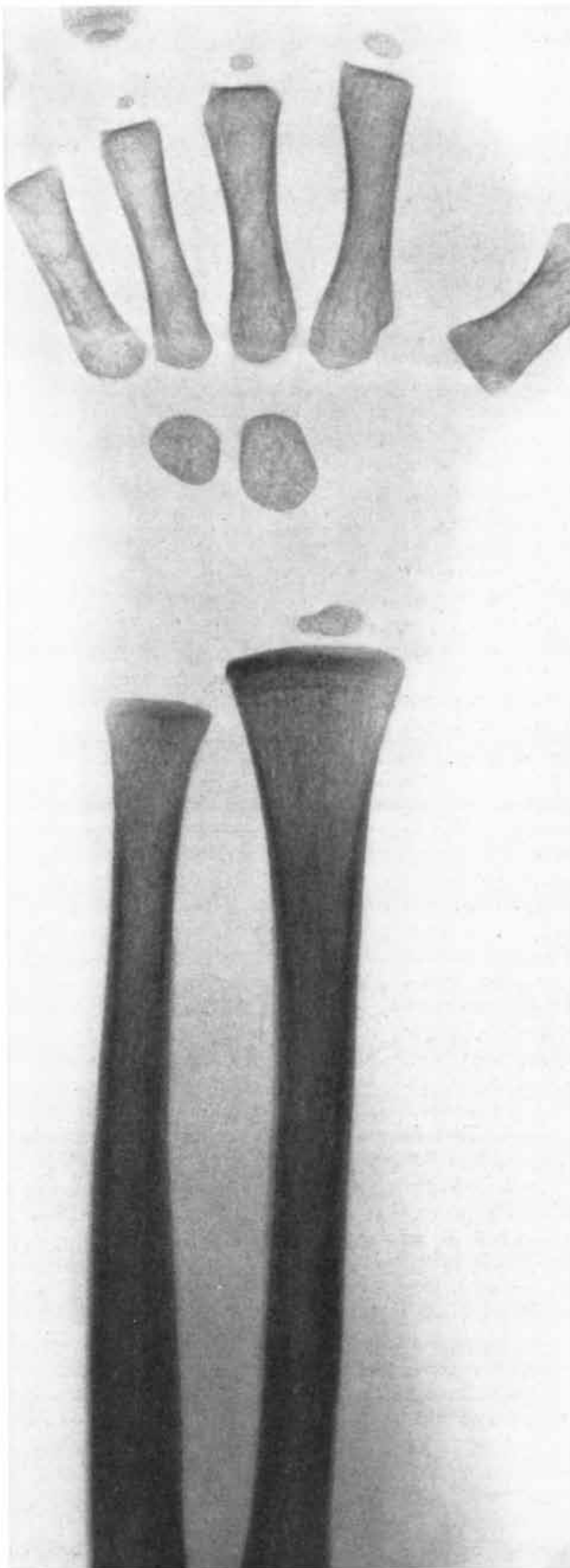
EFFECT OF RICKETS is deformation of bone for want of the calcifying hormone calciferol, which is synthesized on ultraviolet radiation. An X ray of normal arm and hand bones in an 18-month-old child (*left*) is compared with an X ray of the bones of a child of the same age with rickets (*right*). The disease can be prevented or cured by sunlight or the ingestion of small amounts of calciferol.

for "I have learned that rickets never exists in wild tribes or in animals [that] live in complete freedom. Once caught, however, most of these formerly wild animals—and especially monkeys—show great disposition towards rickets. Hardly one young captured animal can avoid this danger. By observing rickets in people, who do not get this disease to such a degree as monkeys, one can also see that it is a sickness of *domestication*. We can say that in living locked indoors, with thick, heavy walls and windows facing brick walls in other houses, the natural habitat of a child is being disturbed—namely the outdoors." In 1909 G. Schmorl strongly documented this marked seasonal variation in the frequency of rickets with a series of 386 postmortem examinations carried out on children under four years old.

Perhaps the most brilliant investigation into the nature of rickets was made in 1890 by Theobald Palm, an English medical missionary who went to Japan and "was struck with the absence of rickets among the Japanese as compared with its lamentable frequency among the poor children of the large centres of population in England and Scotland." He wrote to other medical missionaries around the world, collated the results and was amazed to find that rickets was essentially confined to northern Europe and was almost totally absent from the rest of the world.

Dugald Christie wrote him from Mukden, for example, as follows: "I have met with not a single case of rickets during a residency of six years in Manchuria," and this in spite of the fact that there were "no sanitary conditions whatever" and the only articles of diet were millet, rice, pork and vegetables. C. P. Smith reported from Mongolia that he had not seen any rickets. "We have 10 months in the year of almost constant sunshine. In summer the children go practically naked, and even in winter, with the rivers frozen into a solid mass of ice, I have seen children running about almost naked, that is during the day while the sun is shining." From Java a Dr. Waitz reported what was a known fact there: European children suffering from rickets recovered from the malady within a few months of moving to Java and without any medical treatment.

From data such as this Palm deduced that rickets was caused by the absence of sunlight. "It is in the narrow alleys, the haunts and playgrounds of the children of the poor, that this exclusion of sunlight is at its worst, and it is there that

the victims of rickets are to be found in abundance." He proceeded to recommend "the systematic use of sun-baths as a preventive and therapeutic measure in rickets."

The first successful attempt to induce rickets experimentally in animals was made at the University of Glasgow in 1908 by Leonard Findlay. He published conclusive pictures of puppies that had been confined in cages and developed rickets; unconfined animals did not become rachitic. His results convinced him that the cause of rickets was not any

CORRELATION OF RICKETS with industrial areas and smoke from the burning of coal appeared in data assembled in 1889 by the British Medical Association. The map, which shows in gray the principal concentrations of rickets, is based on maps of England and Scotland prepared by the association. Since diets in these areas were in general better than those in poorer surrounding areas, the distribution of rickets is not what one would expect if the disease were of dietary origin. In actuality the cause was smoke that obscured sunlight.

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defect in the diet, but he did not come to quite the right conclusion; he suggested that rickets was caused by "confinement, with consequent lack of exercise." More accurate was a brilliant experiment by Jan Raczynski of Paris in 1912. Raczynski pointed to lack of sunlight as the principal etiological factor in rickets. Two puppies, "newborn in the month of May from the same mother, were reared for six weeks, the first in sunlight from morning to evening, the second in deep shade in a large, well-ventilated cage. Both were fed in the same manner, that is exclusively on the milk of their mother." After six weeks the puppy kept out of the sunlight was markedly rachitic, a diagnosis confirmed by chemical analysis of its bones, which were found to contain 36 percent less calcium phosphate than the bones of the puppy that had been raised in the sun. Raczynski concluded that sunlight played a principal role in the etiology of the disease.

In 1918 Findlay returned to the problem with the assistance of Noel Paton. They did experiments with 17 collie puppies from two litters and reported that "all those kept in the laboratory showed signs of rickets to a greater or less degree. One which had been confined and had had butter was most markedly affected. It was unable to walk. Another of the confined animals which had had no butter was least affected." They concluded: "Pups kept in the country and freely exercised in the open air, although they had actually a smaller amount of milk fat than those kept in the laboratory, remained free of rickets, while the animals kept in the laboratory all became rickety." Findlay and Paton fed butter to some of their animals to check on the effect of diet, since the idea that rickets was a dietary-deficiency disease was already taking hold and milk fat was known as an important source of vitamin A. Their results argued against such a theory, of course. Moreover, it is known today that the adverse effect of butter they observed was due to the fact that "florid," or severe, rickets develops best in well-fed puppies; a poorly fed animal develops only mild rickets since the defect in calcification does not have as much effect in an animal whose bones are not growing. Rather than being a dietary-deficiency disease, therefore, florid rickets required a good diet, complete with vitamins A, B and C; only then could the puppy grow rapidly and hence develop incapacitating rickets.

Findlay's group had by now become known as the "Glasgow school," as opposed to the "London school" of nutritionists. Their competing theories led to two important studies of human rickets, one in Scotland and one in India.

Margaret Ferguson studied 200 families living in Glasgow among whom marked rickets existed and decided that inadequate air and exercise appeared to be the most potent factors. "Over 40 percent of the rachitic children had not been taken out, while only 4 percent of the nonrachitic children had been confined indoors." It is clear now that being out of doors was the chief variable, for both sets of children were free to exercise at will.

The most clear-cut investigation was conducted by Harry S. Hutchinson in Bombay. He found no rickets at all among poor Hindus who subsisted on a pitifully inadequate diet but who worked outdoors all day "and while at work left their young infants at some nearby point in the open air." In contrast, he found that rickets was exceedingly common among the well-fed Moslems and upper-caste Hindus, whose women usually married at the age of 12 and entered purdah, where the ensuing infants usually remained with their mother for the first six months of life in a semidark room in the interior of the house. Hutchinson found that infants of both sexes kept in purdah suffered severely from rickets; the girls, who entered purdah when they were married, recontracted the disease then. He concluded that "the most important etiological factor in the production of rickets is lack of fresh air, sunlight, and exercise." He then proceeded to cure 10 such cases of purdah-induced rickets by taking the patients out into the open air, "showing that removal of the cause removes the effect. All other factors remained constant and no medicine was given."

Although it was becoming increasingly clear by 1919 to many physicians that sunlight had the power both to prevent and to cure rickets, no method of providing summer sunlight during European winters was available. Not only were such winters generally cloudy, with an ineffective sun less than 30 degrees from the horizon, but also the cold usually required exposure of children to the sun in glassed-in solariums whose windowpanes, it is now known, effectively filtered out the required ultraviolet rays. Folk custom had taught northern European mothers to put their infants out of doors even during January for "some fresh air and sunshine." The trouble was that in large cities with narrow streets even this became ineffective because of the intervening buildings and the pall of smoke.

With natural sunlight ineffective, doctors such as E. Buchholz in Germany turned to artificial illumination such as that provided by the carbon-filament electric bulb. Since the ultraviolet component of such light is very small, the treatments did little good. Then in 1919 a Berlin pediatrician, Kurt Huldschinsky, tried the light from a mercury-vapor quartz lamp, which includes the ultraviolet wavelengths, on four cases of advanced rickets in children. He obtained complete cures within two months.

Huldschinsky's discovery of the subtle fact that it is the invisible portion of the sun's rays that prevents rickets solved the problem of this disease for all time. In addition to providing a truly effective method of curing the disease, he proceeded to show that an endocrine hormone must be involved. He irradiated one arm of a rachitic child with ultraviolet. Then he showed, with X-ray pictures, that calcium salts were deposited not only in the irradiated arm but in the other arm as well. This proved that on irradiation the skin released into the bloodstream a chemical that had the needed power to induce healing at a distance—in other words, a hormone.

After World War I, Huldschinsky's findings were extended by Alfred F. Hess in New York. He showed that sunlight alone had the power to cure rickets in children. He then showed that this was true also of rats that had been made artificially rachitic by means of a low-phosphate diet. In June, 1924, Hess found that ultraviolet irradiation rendered linseed or cottonseed capable of curing rickets. Similar results were obtained on whole rat rations later that year by Harry Steenbock. Hess proceeded to show that a crude cholesterol and plant sterols, as well as the skin, acquired the property of curing rickets when irradiated by ultraviolet light. In 1927 Otto Rosenheim and Thomas A. Webster showed that the plant sterol ergosterol (derived from ergot, a fungus) became enormously antirachitic when irradiated with ultraviolet light. This is the process that has now become routine: Some .01 milligram per quart of ergocalciferol—or what is called "vitamin D_2"—is added to almost all the milk sold in the U.S. and most European countries.

A description of the nature of the skin hormone naturally released by irradiated skin was finally provided in 1936 by Adolf Windaus of the University of Göt-

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SEASONAL VARIATION in the frequency of rickets appeared in a series of 386 postmortem examinations of children with rickets conducted by G. Schmorl in 1909. Children were classified according to whether they had an active case of rickets at the time of death (*color*) or a "healing" case (*black*). It was clear that the severity of the disease increased in the fall and decreased with spring.
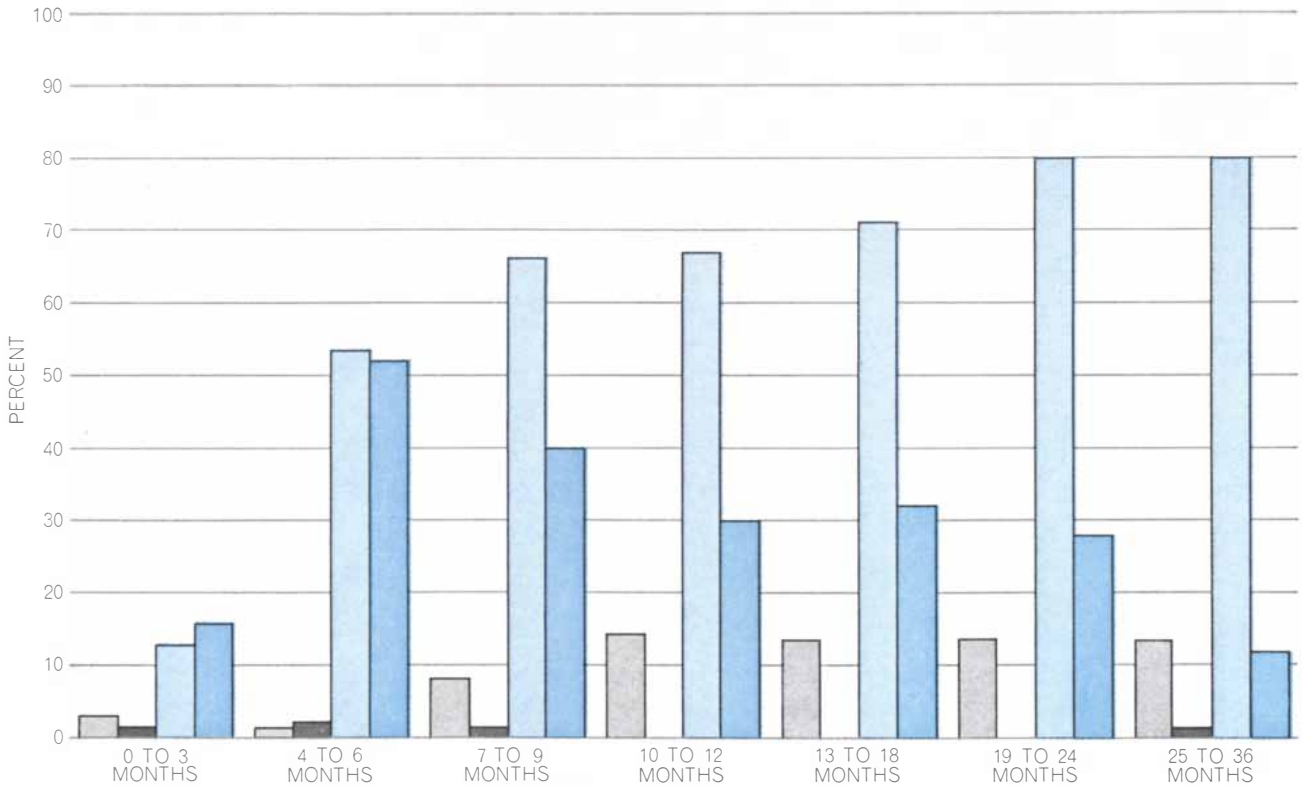
EFFECT OF LATITUDE on the incidence of rickets among children of various ages in Puerto Rico (*gray*) and New Haven (*color*) was demonstrated in a survey that was reported in 1933. The incidence is apparently related to the amount and strength of sunlight at 18 degrees of latitude and at 42 degrees. The light bars indicate clinical diagnosis of rickets, dark bars X-ray diagnosis.

FOOD	WINTER	SUMMER
MILK	0	.025
BUTTER	0	4
CREAM	0	.1
EGG YOKE	.4	1.2
OLIVE OIL	0	0
CALF LIVER	0	0

CALCIFEROL IN FOOD is charted. The substance, which is often called vitamin D, is essentially absent from foodstuffs other than fish, particularly in winter. The numerals give the percentage of the minimum daily protective dose of calciferol in a gram of each food.

tingen. He demonstrated that 7-dehydrocholesterol is the natural prehormone that is found in the skin and showed how it becomes calciferol on ultraviolet irradiation.

The hormonal nature of calciferol had been recognized to some degree as early as 1923 by such an authority as the American pediatrician Edwards A. Park, who wrote a careful summary of the history of rickets in *Physiological Reviews*. He summarized his view of the complex situation by saying that rickets is best compared to the endocrine-deficiency disease diabetes rather than to the genuine vitamin-deficiency diseases such as scurvy, pellagra, xerophthalmia and beriberi. Hess shared this view. In the first sentence of a 1929 monograph he stated that rickets "must be regarded as essentially a climatic disorder."

How, then, has the London school's view that rickets is due to a deficiency of "vitamin D" prevailed even up to the present day? Why is the error almost universally found in modern textbooks of endocrinology, physiology, biochemistry and medicine and further propagated by the words printed on every carton of milk sold in the U.S. and many other countries: "400 U.S.P. units vitamin D added per qt."? The remainder of this article will attempt to explain briefly the origin of the mistake.

Modern studies such as those of G. A. Blondin of Clark University support the long-suspected fact that fish, unlike birds and mammals, are able to synthesize calciferol enzymatically without ultraviolet light. Shielded by water, fish receive essentially no ultraviolet (290-to-320-millimicron) radiation, and yet the bluefin tuna has up to a milligram of calciferol per gram of liver oil—enough to provide a daily protective dose of calciferol for 100 children. Cod-liver oil contains less than 1 percent as much, enough to protect against rickets if it is consumed in amounts equal to four grams per day. It is an effective antirachitic medicine because of calciferol's unusual stability: an oil or fat containing the hormone preserves its efficacy for a long time.

In the north of Europe fish has always been a staple of diet, and so the normal diet tended to protect children against rickets. Slowly, over the years, the people of Scandinavia and the Baltic regions became aware of the specific therapeutic value of cod-liver oil as a preventive and even as a cure for rickets. By the end of the 19th century this therapy had come to the attention of physicians, but it was not generally accepted because a number of variables made the evaluation difficult: the advent of spring, chance exposure to sunlight or some unrelated retardation of growth that reduced the severity of the rickets could mask the effect of the cod-liver oil. It remained for Hess to make the unequivocal demonstration. In 1917 he conducted a controlled test with Negro children in New York City, among whom rickets was severe and almost universal, and proved the prophylactic value of routine administration of cod-liver oil.

It was a significant finding but it helped to turn investigators away from sunlight and toward diet. In 1919, the very year in which Huldschinsky pointed directly to ultraviolet radiation as the crucial factor in preventing rickets, the British nutritionist Edward Mellanby re-

INDOOR LIVING had a marked effect on rickets in India, according to a survey conducted by Harry S. Hutchinson in Bombay. He found a high incidence (*left*) among rich, well-fed Moslems, whose married women entered purdah and whose infants remained indoors; less among well-to-do Hindus (*middle*), whose children got outdoors more; none among poor Hindus (*right*), who had bad diets but who worked (and whose babies played) outdoors.

RICKETS PER 1,000 CASES

MOHAMMEDANS   UPPER-CLASS HINDUS   OTHER HINDUS

A   UNDER 20
B   20 TO 24
C   25 TO 29
D   30 TO 34
E   35 AND OVER

THE INPUT/OUTPUT STRUCTURE OF THE ECONOMY
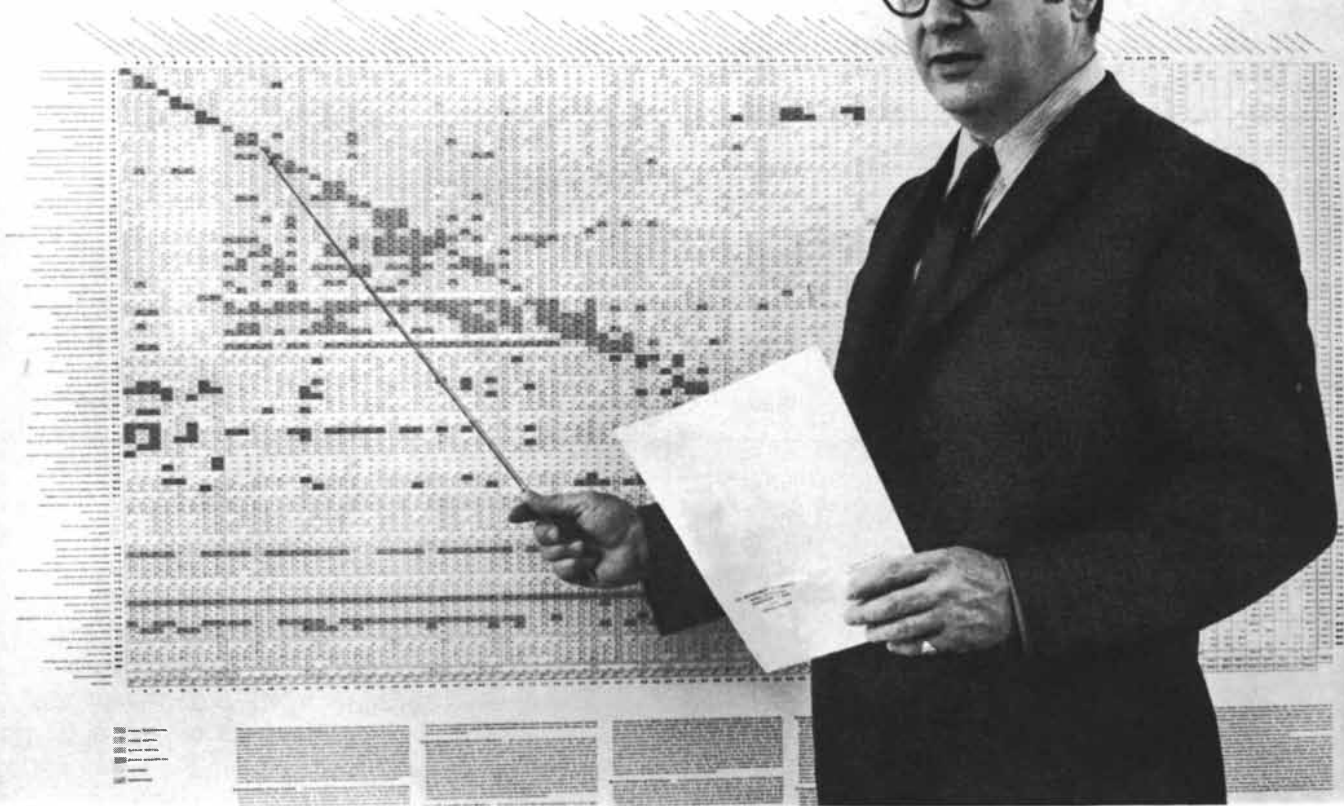
WHAT DOES IT TAKE TO PRODUCE A $1000-BILLION GNP?

The Editors of SCIENTIFIC AMERICAN have prepared a wall chart, based upon the latest Federal input/output table, displaying the interindustry flows of raw materials, intermediate products and business services required to carry the U.S. economy to the benchmark Gross National Product of $1000 billion.

Input/output tables provide management, government administrators, economists and market analysts with a powerful new tool for forecasting and measuring the indirect as well as the direct interindustry relationships that structure our industrial economy.

This handsome and informative wall chart (70" x 46", in eight colors) offers a unique entry into the rapidly developing discipline of interindustry (or input/output) analysis. Based upon input/output tables issued by the Office of Business Economics of the U.S. Department of Commerce, the chart can be used as a teaching tool and for study of practical and theoretical questions about the U.S. economy.

The chart presents an interindustry matrix of 99 rows and 99 columns; each of the nearly 10,000 cells in the matrix shows (1) the direct input/output coefficient, (2) the "inverse" coefficient and (3) the interindustry dollar flow for a $1000-billion Gross National Product. The input/output coefficients as published by OBE have been recomputed by the Harvard Economic Research Project to reflect gross domestic output. The 370 sectors of the detailed tabulations have been selectively aggregated to 99 sectors to provide maximum feasible detail for the wall chart. Where the ratio of input to output exceeds 1/100, the cell is tinted in the color-code of the industrial bloc from which the input comes. This device, combined with triangulation of the matrix, brings the structure of interindustry transactions into graphic visibility.

Offprints of five SCIENTIFIC AMERICAN articles on the technique of input/output analysis accompany the chart. The articles are:

Input/Output Economics
  by Wassily W. Leontief

The Economic Effects of Disarmament
  by Wassily W. Leontief and Marvin Hoffenberg

The Structure of Development
  by Wassily W. Leontief

The Structure of the U.S. Economy
  by Wassily W. Leontief

The Economics of Technological Change
  by Anne P. Carter

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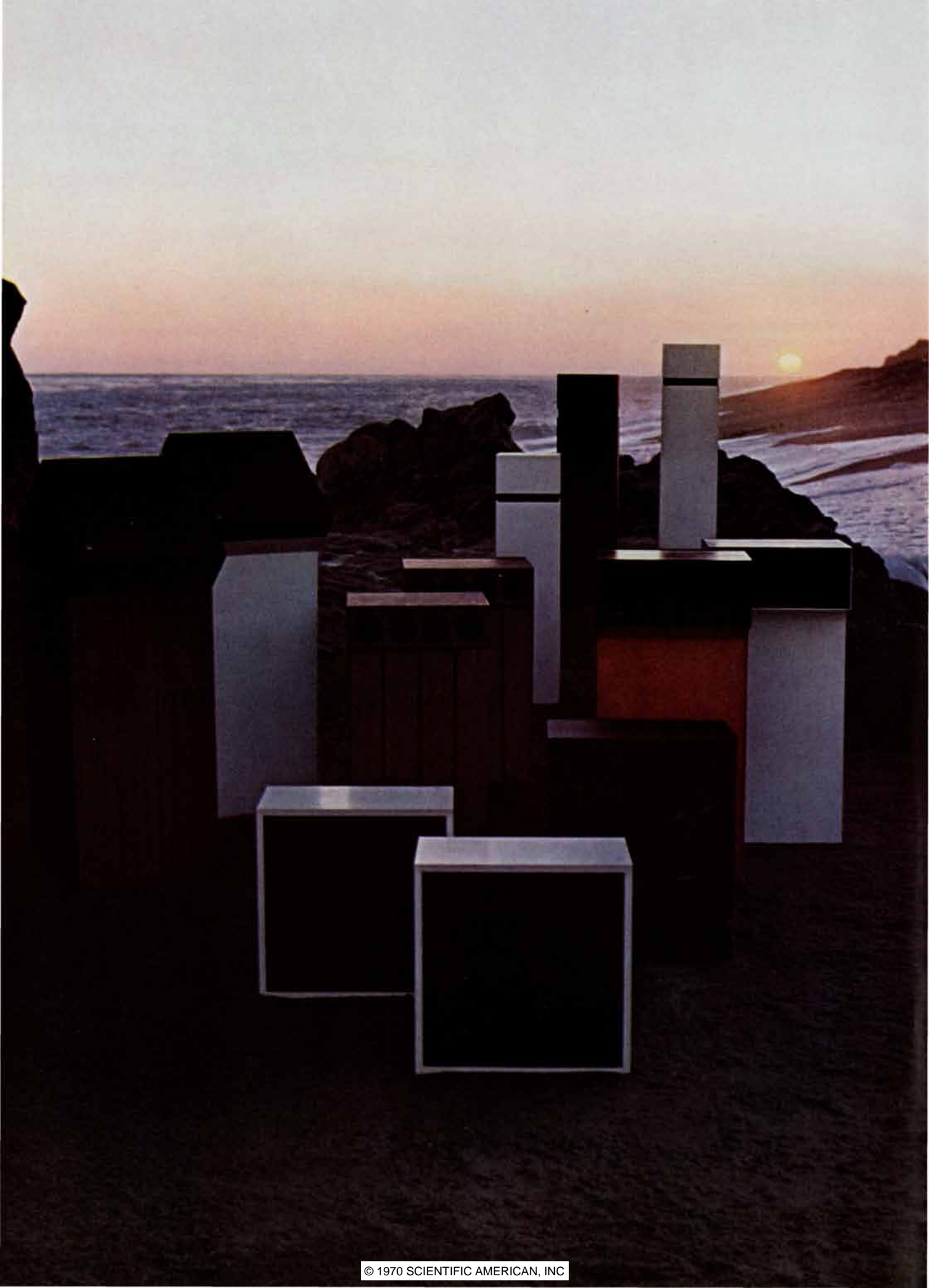
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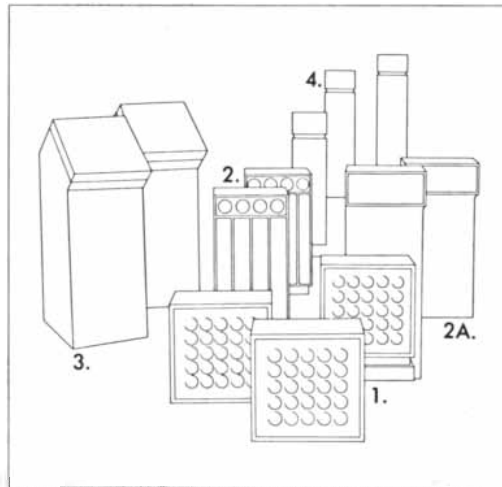
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ported on what he called a "rachitogen-ic" diet. Working in London, under its pall of industrial smoke, Mellanby found that puppies would rapidly develop flor-id rickets on a diet reinforced with yeast, milk and orange juice—a natural find-ing, considering that Bland-Sutton had shown that almost all the animals in the zoo in industrial London suffered from rickets. Mellanby's announcement of the "production" of rickets in dogs by means of a particular diet was in line with the new "vitamine" theories of Frederick Gowland Hopkins and Casimir Funk; Mellanby suggested that the efficacy of cod-liver oil was "most probably" due to vitamin A, which was presumably missing in his "rachitogenic" diet. The diet finding was greeted with enthusi-asm—even though Findlay had produced rickets in dogs 11 years earlier by simply keeping them indoors.

Park has pointed out that the report of Mellanby's "first experiments was mea-gre and would probably have awakened little interest, had not the British Medi-cal Research Committee endorsed the work and publicly committed itself to the view that rickets was a deficiency disease due to a lack in the diet of 'anti-rachitic factor.' " It is clear enough to-day that Mellanby's idea that the cod-liver oil factor was probably vitamin A was wrong, but it is not generally rec-ognized that *no* specific medicine such as cod-liver oil can be called a dietary vitamin unless it is present in normal foods in significant amounts. (Orally ad-ministered thyroid, for example, cannot be regarded as a "vitamin T" even though patients with insufficient thyroid of their own are cured by thyroid ex-tract. Both endocrine secretions require external factors, incidentally: ultraviolet radiation in the case of calciferol and iodine in the case of thyroxine.)

In 1921 the American nutritionist El-mer V. McCollum, who had just accom-plished the separation of fat-soluble vi-tamin A from water-soluble vitamin B, turned his attention to the rickets prob-lem, putting his laboratory rats on Mel-lanby's "rachitogenic" diet. At first he could not produce rickets; being noctur-nal animals, rats have become adapted to survival without direct sunlight and are resistant to rickets. Eventually Henry C. Sherman and Alwin M. Pappen-heimer came on the trick of artificially giving rats a diet low in phosphate. Un-der this artificial stress the bones of young rats failed to calcify—unless they were placed in direct sunlight or were given cod-liver oil.

McCollum went on to establish the difference between the active factor in cod-liver oil and vitamin A in 1922 by showing that, after having been aerated and heated, cod-liver oil could still cure rickets but had lost its ability to cure xerophthalmia, which is due to lack of vitamin A. On this basis he called the cod-liver oil factor "vitamin D." Final recognition of the uniqueness of fish-liver oils came from the finding that ani-mal fats such as butter and lard have essentially no calciferol, particularly in winter; the conclusion was clear that no nonfish diet of any kind could protect against rickets in a sunless environment. It was quite clear then that cod-liver oil was a medicine and not a food.

Nevertheless, McCollum had called it "vitamin D," and in the flush of enthusi-asm for these new-found dietary factors the name acquired general acceptance. Semantic confusion now entered the pic-ture in overwhelming force. Circular verbal proof made it evident that if "vi-tamin D" cured rickets, then rickets was a vitamin-deficiency disease! All the careful work demonstrating that rickets

was primarily a climatic disorder was forgotten in the enthusiasm for the latest "vitamin." Chemists such as Windaus set about the task of deciphering its chemi-cal structure. When Windaus received the Nobel prize in chemistry in 1928, it was "for his researches into the constitu-tion of the sterols and their connection with the vitamins"—a curious citation in view of the fact that all biologically ac-tive sterols are manufactured by the body and are hormonal in character, whereas none of the known vitamins have a steroid structure. Even the dis-covery that calciferol was produced nat-urally in the skin in the presence of ultra-violet did not wipe out its classification as a vitamin or the definition of rickets as a dietary problem. Meanwhile the addi-tion of ergocalciferol to milk had essen-tially eradicated the disease in Europe and America. Ironically, its effectiveness tended to buttress the dietary concept of the disease.

It took time for the correct view to emerge. In 1927 the chairman of the American Medical Association's section on the diseases of children remarked that "cod-liver oil is our civilization's excel-lent, economical and practical substitute —at least during the colder and darker half of the year—for exposure to sunlight. Is it not strange that the established vita-min deficiencies such as xerophthalmia, beriberi and scurvy are so rare in infants fed human milk from mothers and that rickets is so common? The great primary importance of the actinic [chemically ac-tive] rays to normal growth is evidenced by the fact that rickets occurs most se-verely and most frequently at the end of winter, and especially in those infants whose skins are pigmented. These obser-vations strongly suggest that in human infants vitamins do not play a primary role in the development of rickets...."
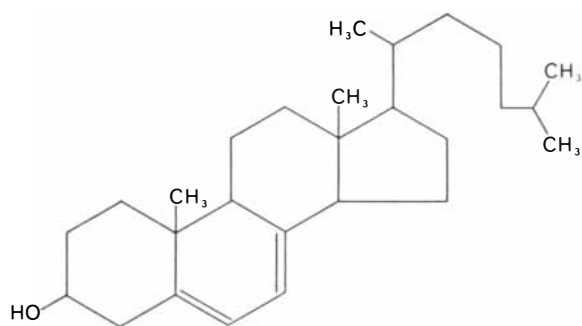
7 DEHYDROCHOLESTEROL
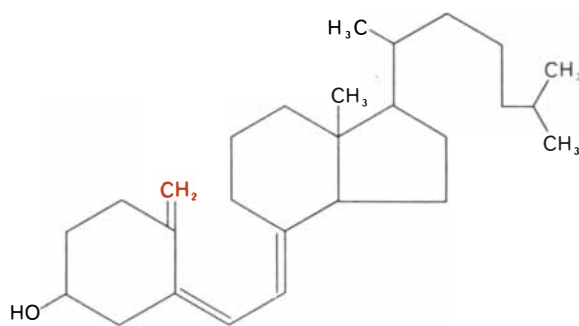
CALCIFEROL

CHEMICAL STRUCTURES of calciferol (*right*) and its precursor, 7-dehydrocholesterol (*left*), are closely related. The precursor is in the skin, and ultraviolet radiation from the sun is crucial in effecting its conversion to calciferol, which then enters the blood.

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The fact that cod-liver oil, which contains the so-called 'vitamin D,' cures rickets does *not* prove that rickets observed in human infants primarily is a vitamin-deficiency disease."

It is interesting to consider the essential difference between the methods of the Glasgow school and those of the London school. Whereas the Glasgow school studied rickets in humans as well as in animals, and from a medical point of view, the London nutritionists studied it only in animals, believing only the results of their experiments and essentially ignoring such brilliant medical studies as those of Palm and Hutchinson. The methodological differences between clinical medical research and beginning biochemistry are therefore behind the whole tangled story, and it is only today, 50 years later, that hindsight can explain the errors of those days.

A word should be said in answer to those who may ask what difference it makes whether calciferol is called a hormone or a vitamin. The answer lies in the point of view from which one approaches this vital calcifying factor needed for the healthy development of the skeleton. Calling calciferol "vitamin D" at least suggests that it forms the nucleus of some cellular coenzyme, as is the case with many vitamins. Calling calciferol a hormone, on the other hand, explains why three hormones, calciferol, thyrocalcitonin and the parathyroid hormone are linked together in the delicate control of the level of calcium in the blood [see "Calcitonin," by Howard Rasmussen and Maurice M. Pechet; SCIENTIFIC AMERICAN, October]. Since no other cases of hormones and vitamins working together are known to medicine, it should not be surprising that calciferol turns out to be a steroid hormone whose production rate is under physiological control rather than being left to the vagaries of diet.

Other leads opened up by the hormonal view include the evolutionary development of the hormone. Fish synthesize it without ultraviolet light. Amphibians, reptiles, birds and mammals each apparently have some ultraviolet-receptive area of the body where the hormone is made, such as the ears of rabbits and the feet of birds. By and large, northern animals avoid rickets by living out of doors and by bearing their offspring in the spring, so that they are exposed to the summer sun during their growing period. Truly arctic animals, such as the polar bear and the seal, that live the year round in an area of deficient ultra-

violet obtain their calciferol orally from their staple diet of fish. (The same was true of the Eskimos, who were entirely free of rickets until they were placed on a European diet by missionaries—when they too rapidly developed the disease.)

The recognition of calciferol as an ultraviolet-dependent hormone gives fresh meaning to a number of seemingly unrelated physiological and cultural adaptations. Tropical man probably avoids the dangers of too much calciferol production by virtue of his dark skin; the melanin granules in the outer layers protect the lower layers of the skin. European man, on the other hand, needed to use all the scanty ultraviolet light available, and consequently was gradually selected for an unpigmented skin such as is present in extreme degree in the blond-haired, blue-eyed, fair-skinned and rosy-cheeked infants of the English, north German and Scandinavian peoples. Indeed, the northern European idea of female beauty fits this picture: a girl with trim ankles, straight legs, fair skin and rosy cheeks must never have suffered from rickets and hence would probably bear strong sons and daughters if chosen as a mate. The very phrase "a fair young damsel" implies that a girl who is beautiful in the eyes of northern beholders is the possessor of an unpig-

MEDIUM
LIGHTEST
MEDIUM DARK
MEDIUM LIGHT
DARKEST

EVOLUTION OF SKIN COLOR may have been related to the requirement for calciferol. The map shows the distribution of human skin colors before the migrations that began in

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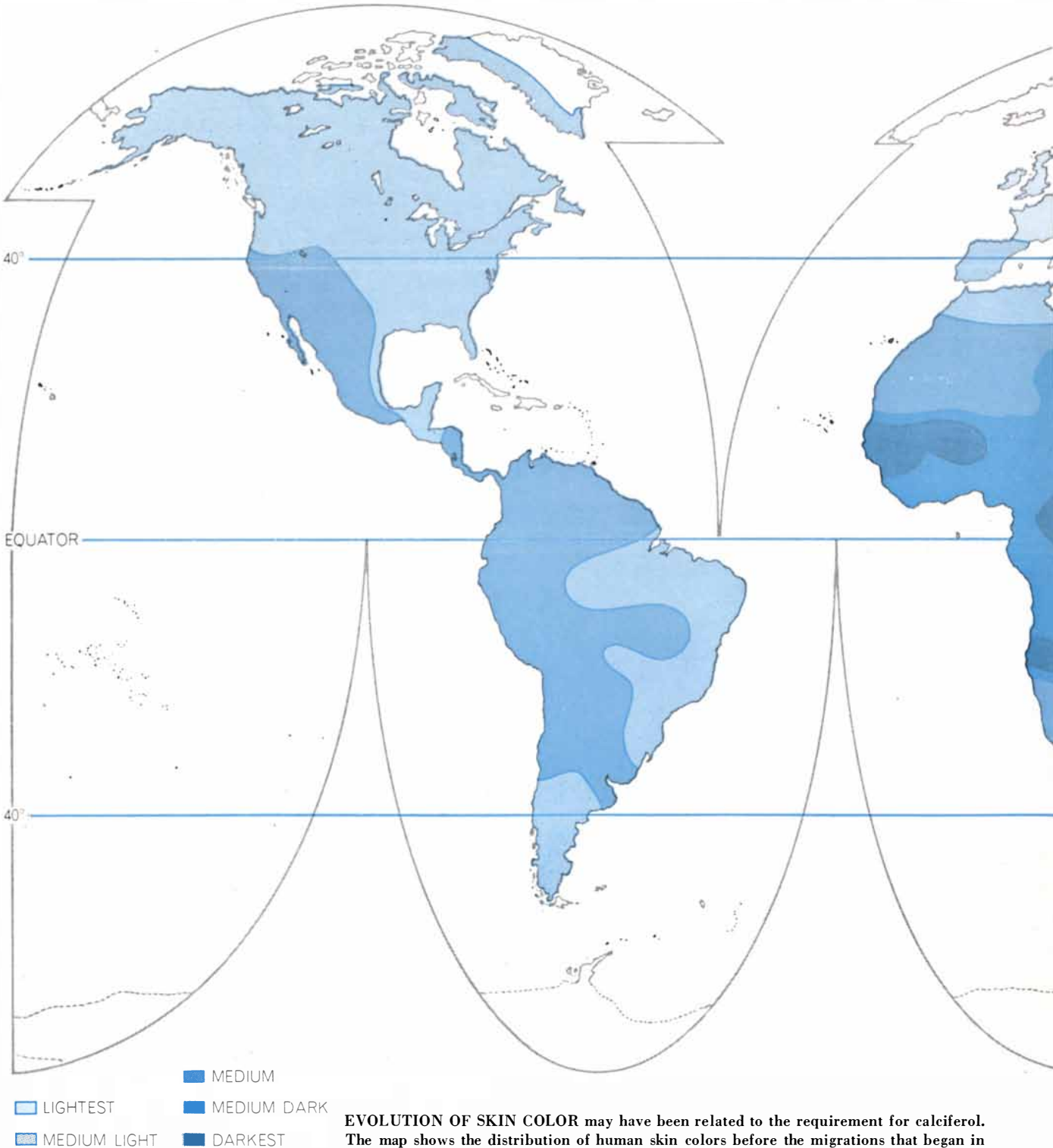
mented skin! Delicate wrists are further proof of the absence of a history of rickets, as is a free-swinging walk, which is only possible in the absence of the pelvic deformities of rickets that would later endanger the process of childbirth.

June weddings tend to bring the first baby in the spring; an infant born in the fall was almost certain to have rickets by the time he was six months old. The fish-on-Friday tradition was as adaptive as the scurvy-preventing eating of an apple a day. Taking the baby out of doors even in the middle of winter for "some fresh air and sunshine" became a northern folk custom. Pink cheeks are visible evidence of the thinness of the unpigmented skin in the one area left uncovered in babies wrapped up warmly and placed out of doors in winter. The ability of outdoor-living Europeans to become deeply bronzed by the sun prevents the synthe-sis of too much calciferol in summer; it is significant that this seasonal pigmentation is induced by the identical 290-to-320-millimicron radiation that produces calciferol. Clearly northern European man, bronzed in summer but crocus white in winter, has an epidermis well adapted to the seasonal variation in ultraviolet radiation. Only with the advent of industrial smog did rickets appear in England and northern Europe.
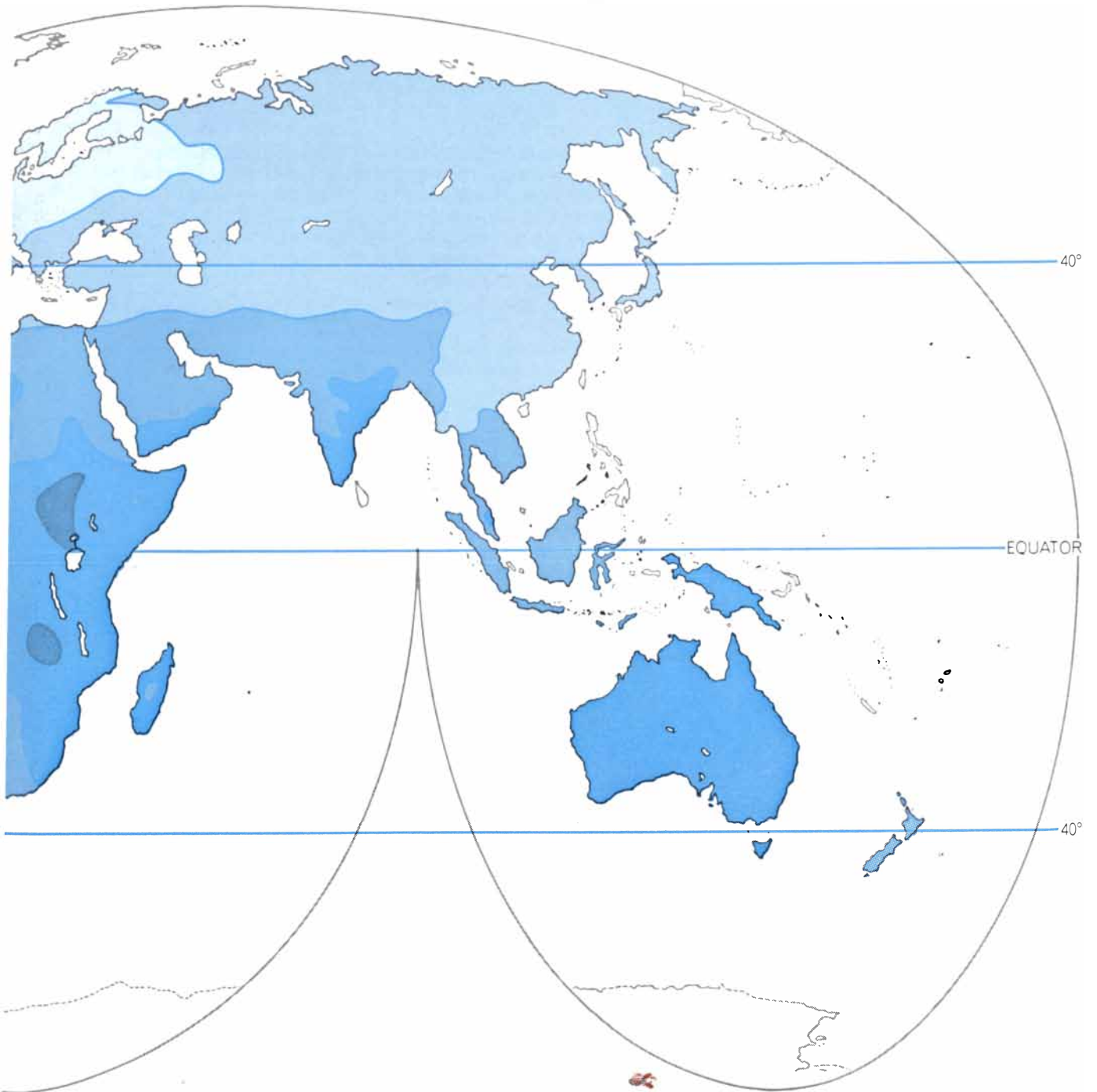
the 16th century. Dark skin presumably protected against over-production of calciferol. In Europe, much of which is at very high latitudes, man needed all the ultraviolet he could get, particularly in winter, and was presumably selected for unpigmented skin.

PERMANENT MAGNETS

New alloys of cobalt with rare-earth elements have
magnetic properties so superior to those of former
materials that they constitute virtually a new class

by Joseph J. Becker

Hidden somewhere inside a great variety of electrical and electronic devices is a permanent magnet, and often not one but several. The only magnets most people ever see, however, are the ones that hold the refrigerator door closed or that catch the lid of a freshly opened tin can. Hidden though they may be, magnets exert a large influence on the design and performance of every device in which they are used. The more powerful the magnet for a given size is, the smaller it can be for a given job. (The old-fashioned telephone receiver was not given its elongated shape so that it would be convenient to hold but to accommodate the long tungsten-steel magnet needed to make it work.)

Within the past few years a new class of materials for making permanent magnets has been developed, based on cobalt and some of the rare-earth elements. The improvement over other materials is so great that the cobalt-rare-earth magnets stand in a class by themselves. In terms of their resistance to demagnetization the new materials are from 20 to 50 times superior to conventional magnets of the Alnico type, and their magnetic energy is from two to six times greater. As a result the cobalt-rare-earth magnets should eventually find their way into applications for which other materials could not even be considered.

Elements that are ferromagnetic, such as iron, cobalt and nickel, have atoms in which one electron shell contains fewer than the maximum number of electrons. In such unfilled shells there are one or more unbalanced electron spins, giving rise to a small magnetic moment and making the atom itself a tiny magnet. Ordinarily in a large collection of such atoms the atomic magnets point in various directions and cancel one another. If a sample of ferromagnetic material

is placed in a magnetic field, however, the individual atomic magnets tend to line up so that when the sample is removed from the field, it retains a net residual magnetism, with an observable north and south pole. The total magnetization (M) of a piece of material is the sum of the contributions of all the elementary atomic magnets. If all the atomic magnets are parallel and pointing in the same direction, the magnetization in that direction reaches its saturation, or maximum, value.

Magnetic materials are traditionally divided into two categories: "hard" and "soft." A hard material is difficult to magnetize and demagnetize; thus it is what one ordinarily wants in a "permanent" magnet. A soft material has the opposite property: it is easily magnetized and demagnetized. The softer the material is, the better it is suited to certain electrical devices, such as a transformer, in which the magnetization must be reversed many times per second.

If one plots these different characteristics on a graph in which the imposed magnetic field (H) forms the horizontal axis and the total magnetization M forms the vertical axis, one obtains a characteristic curve, resembling a thick S, known as a hysteresis loop [see top illustration on page 95]. For a hard material the value of M will not move far from zero (if it happens to be at zero) until the imposed field H reaches a substantial value; then M rises steeply. When the field is turned off, M remains high; the material remains magnetized. To return M to zero the direction or polarity of the imposed field must be reversed. The value of the field that returns M to zero is the "intrinsic coercive force" (H_{ci}). If the strength of the reversed field is raised still further, the material will finally become fully magnetized with the

opposite polarity, and again it will remain magnetized when the field is removed. In other words, a hard magnetic material is like a heavy box resting on a rough floor that requires a hard push to move it from one place to another, and once there needs another hard push to move it back again. A soft magnetic material is like the same box on rollers: it is easy to move from one position on the floor (state of magnetization) to another.

A hard material has a wide hysteresis loop; a soft material has a thin one. Since each traversal of a loop represents energy lost, a narrow loop is desirable in devices in which magnetization must be reversed frequently (as in a transformer). The designer of magnetic materials is usually trying to make his materials either harder or softer. The intrinsic coercive force, which determines the width of the hysteresis loop, can range from less than a hundredth of an oersted in alloys used in telephone equipment to tens of thousands of oersteds in the new cobalt-rare-earth materials. For comparison, the earth's magnetic field is about half an oersted.

Magnetic materials are often described by hysteresis loops in which the vertical axis is expressed in terms of total magnetic flux density (B) rather than simply in magnetization (M). Total flux density includes the contribution of both magnetization and magnetic field (H). Because total flux density is more directly related to the performance of many electrical devices, engineers tend to use it rather than the value M. A materials physicist, on the other hand, is more likely to think in terms of M, since it describes what the material itself does in response to a magnetic field. In considering new materials such as the cobalt–rare earths both values are useful.

Engineers who wish to assign a value to the hardness of permanent magnets
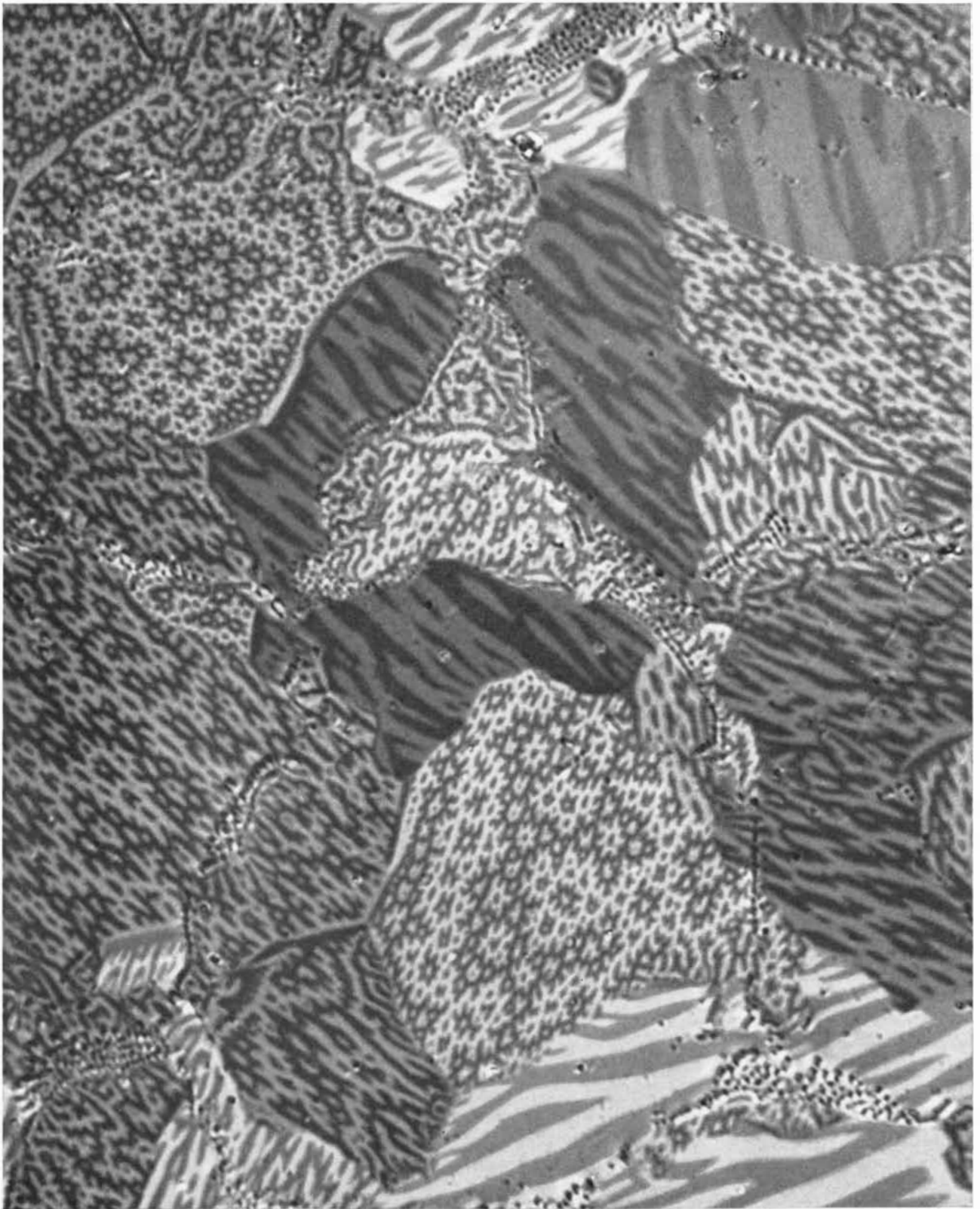
MAGNETIC-DOMAIN STRUCTURE in many ferromagnetic materials can be made visible with polarized light. In this micrograph of one of the new permanent-magnet materials, cobalt-samarium, each region with a particular type of pattern is a grain in the casting. When polarized light is reflected from the polished surface, the plane of polarization is rotated slightly one way or another, depending on the direction of magnetization within each domain, and this can be converted into a pattern of light and dark areas. Within each grain the dark and light regions are oppositely magnetized. In the grains with a cogwheel pattern the direction of magnetization is roughly perpendicular to the surface, alternately in and out. The cogwheels are hexagonal because the crystal lattice of cobalt-samarium is hexagonal and the domain boundaries of the material prefer certain orientations. The micrograph, which is shown here at an enlargement of 500 diameters, was made by Curtis R. Rodd and Andrew S. Holik of the General Electric Company.
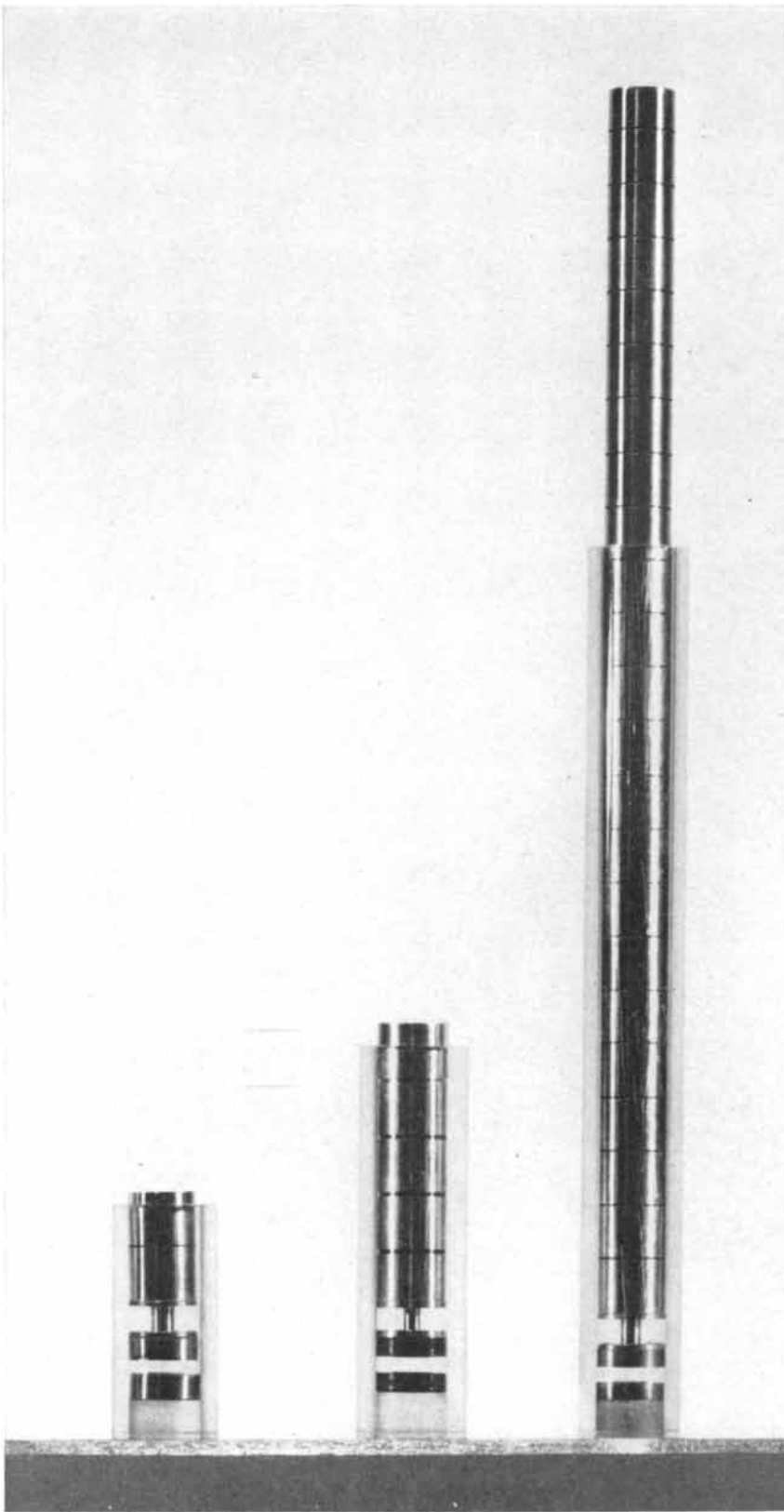
REPULSIVE FORCE of different kinds of magnets can be compared by placing two disks of each material with like poles adjacent and adding weights until the gaps between the disks are compressed to the same size. In this photograph the disks supporting the column of weights at the left are made of Alnico, the disks in the middle are of barium ferrite and those on the right are of cobalt-samarium. For the sake of clarity the lower disk in each pair is resting on a plastic base and the upper disk is separated from the column of weights by a short rod. Plastic cylinders surround the weights to keep them from toppling over. The weights supported by the three magnetic materials are in the ratio 2:5:23.

traditionally concentrate on the upper-left-hand quadrant of a B v. H hysteresis loop, where B and H have opposite polarities [see bottom illustration on opposite page]. The value of the imposed field that reduces total flux density to zero is called simply the coercive force (H_c). In this quadrant each point on the loop represents some value of B times H. The point where this value reaches a maximum is known as the maximum energy product $(BH)_{max}$. This maximum has been used for years as an index of quality for permanent magnets.

In soft materials and in most hard materials before the advent of the cobalt–rare earths, the ordinary coercive force H_c and the intrinsic coercive force H_{ci} were practically identical. The field that reduces the total flux density B to zero does so by permanently demagnetizing the material. In the cobalt–rare earths, however, the intrinsic coercive force can be much larger than the ordinary coercive force, with important consequences.

Consider two hard magnets of equal lifting power: one an ordinary Alnico magnet and the other made from the new rare-earth materials. If a field equal to the coercive force is applied to each magnet, the results are remarkably different. Once the Alnico magnet has been driven to zero flux density and the field is removed, the flux rebounds only slightly; for all practical purposes the magnet can be considered demagnetized [see illustration on page 96]. This happens because the coercive force H_c is nearly the same as the intrinsic coercive force H_{ci}. The Alnico magnet would now be useless unless it were remagnetized by a large field.

When the experiment is repeated with a hard magnet made of cobalt–rare earths, one observes that a field equal to this material's coercive force will again drive the flux density to zero, just as in the case of the Alnico magnet, but when the field is removed, the flux rebounds almost to its original value. The explanation lies in the fact that the cobalt–rare earths have values for intrinsic coercive force that are many times larger than their values for ordinary coercive force. As a consequence a demagnetizing field can drive the flux density to zero (or even below zero) without affecting the material's intrinsic magnetization M. This resistance to permanent demagnetization does not appear in the quantity "maximum energy product," but it is at least as important. The cobalt–rare earths have values of intrinsic coercive force from 20 to 50 times greater than

those of conventional permanent magnets [*see illustration on page* 97].

The ability of the new rare-earth materials to resist demagnetization should make it possible to design more powerful and efficient permanent-magnet motors than ever before. The armature of a permanent-magnet motor is like that of any other direct-current motor. The difference is in the field portion of the motor, which is a permanent magnet instead of a structure of iron wound with copper wire. Because they consume no power for excitation of the field, permanent-magnet motors are widely used in battery-operated devices. They are limited in size and power, however, by the requirement that the maximum armature current must not demagnetize the field magnets. The extraordinary resistance to magnetization of the cobalt–rare earths should greatly raise this limitation.

The mechanism that makes a magnet hard can be described theoretically in terms of magnetic "domains." It was proposed as early as 1907 and demonstrated experimentally in the 1930's that ordinary ferromagnetic materials are subdivided into the microscopic regions called domains [*see illustration on page* 93]. Within each domain the individual atomic magnets are parallel; whichever way they happen to point determines the direction of magnetization of that domain. The boundaries between domains are not fixed but can move in response to a magnetic field. They move in such a way that domains whose magnetization is in the direction of the field grow at the expense of the others. The total externally measured magnetization, which is the sum of the domain magnetizations, thus increases. The motion of domain boundaries can cause large changes in magnetization.

To make a magnetic material soft, the motion of domain boundaries should be made as easy as possible. Soft magnets are characteristically fabricated from a material with a uniform structure, free from inclusions and annealed to relieve strains. For a long time it seemed logical that hard materials should have directly opposite properties. Thus early carbon steels were quenched to produce a structure called martensite, consisting of a microscopic tangle of plates and needles of a very hard, highly strained material. The Alnico alloys, introduced in the late 1930's, owe their magnetic properties to the metallurgical precipitation of a finely dispersed intercrystalline second phase.

Around 1950 several investigators (including the French physicist Louis Néel, who is sharing the 1970 Nobel prize in
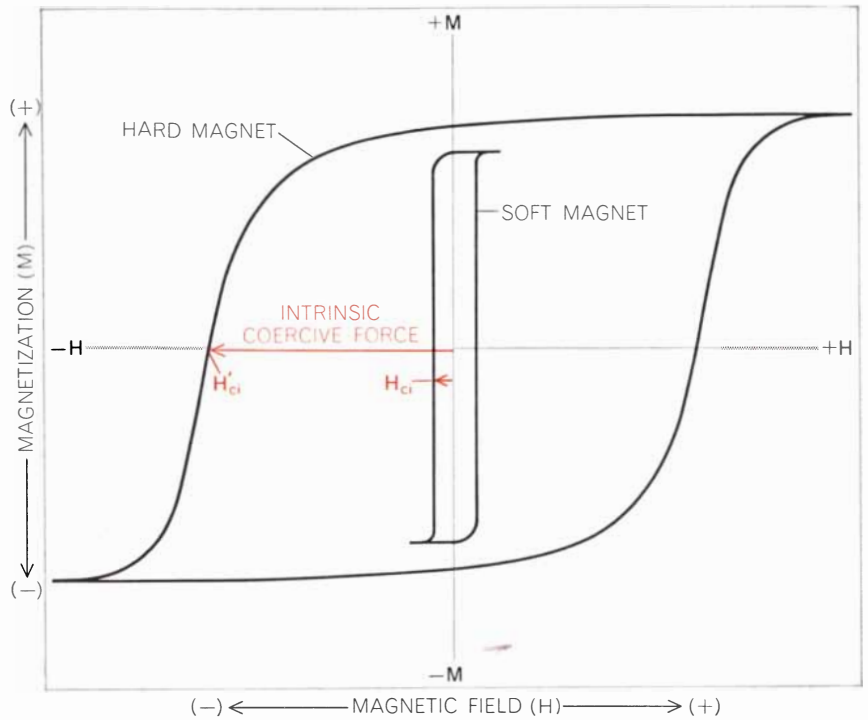
HYSTERESIS LOOP characterizes the behavior of all magnetic materials when their magnetization M is measured as function of an imposed magnetic field H. A "hard" magnet strongly resists a change in the direction of its magnetization. Thus in a hard material the value of M cannot be driven to zero until the imposed field H reaches a substantial value, designated the intrinsic coercive force. For the hardest material known this force (H'_{ci}) can be 10 million times as high as the intrinsic coercive force (H_{ci}) for the softest material.
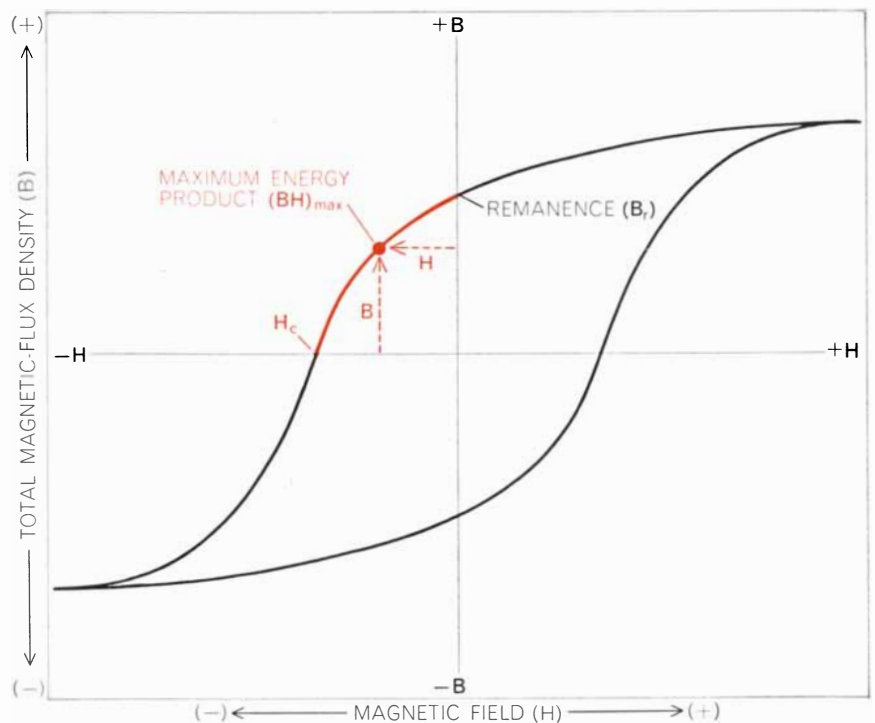
QUALITY OF PERMANENT MAGNET is usually expressed numerically by the "maximum energy product" $(BH)_{max}$. It designates the point in the second quadrant of the hysteresis loop where the product of total magnetic flux density B and magnetic field H reaches a maximum. The signs of B and H are ignored for this purpose. The remanence B_r is the flux remaining when H is zero. The coercive force H_c corresponds to the value of H needed to reduce B to zero. Coercive force H_c need not equal intrinsic coercive force H_{ci}.

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physics for his many contributions to magnetism) proposed a new theory for the design of hard-magnet materials, arguing that if ferromagnetic particles were made small enough, there would be no room for domain boundaries. Coercive forces might be very high because reversal of magnetization would have to take place by rotation of magnetization of the entire particle, which should be more difficult than the displacement of domain boundaries. The size of the particles needed to implement this new theory depended on the material selected. For iron the size could not exceed a few hundred angstroms, comparable to the dimensions of a medium-size virus. Ideally the particles should be highly elongated to make rotation of the magnetization still more difficult.

Ingenious efforts to prepare such particles have led to useful materials, but their properties fall far short of the spectacular predictions made by some early proponents of the fine-particle theory. Irregularity of particle shape appears to be the fundamental stumbling block. Perfectly smooth, elongated particles of the right dimensions might still produce coercive forces approaching 10,000 oersteds, as the theory predicts, but no one knows how to make them.

As hopes for this particular theory faded, attention shifted to another way crystalline materials can resist magnetic rotation. All ferromagnetic crystals are anisotropic, meaning that the magnetization prefers to follow certain crystallographic directions—the "easy" axes—and energy is required to rotate the magnetization to some other direction. The magnitude of the anisotropy varies widely from material to material. If a material could be found combining large anisotropy with a reasonably large magnetization, it might qualify as a good hard-magnet material if it were also in fine-particle form. The coercive force would be limited only by the value of the anisotropy. Furthermore, there were theoretical reasons for believing that the effective particle size would be large enough for it to be achieved simply by grinding the bulk material. This line of reasoning had for several years guided a search for anisotropic materials among the intermetallic compounds of iron, cobalt, manganese and nickel with a va-

riety of elements such as boron, phosphorus, germanium, aluminum and tin. Some of the materials turned up were interesting but not really outstanding.

Then in 1966 Gary Hoffer and Karl Strnat of the Air Force Materials Laboratory published some remarkable measurements of a single crystal of an intermetallic compound containing five atoms of cobalt for each atom of yttrium: Co_5Y. The material has a substantial magnetization value and an anisotropy several times larger than that of any previously known material. Its anisotropy is so high that its resistance to demagnetization could conceivably be as high as 200,000 oersteds, or more than 100 times the value of typical Alnico materials.

Initial experiments with bulk quantities of Co_5Y, however, were disappointing. Not only was the material difficult to prepare but also attempts to increase its coercive force by mechanically reducing it to small particles seemed to be self-defeating. The coercive force would rise to about 2,000 oersteds and then fall again with further grinding. Evidently the grinding was deforming the crystal structure so much that the inherent anisotropy was being destroyed.

The author, working at the General Electric Research and Development Center, and the Air Force group collaborated closely in an investigation of Co_5Y and related compounds. It had been known for some years that compounds analogous to Co_5Y could be prepared by substituting lanthanum or other rare earths for yttrium. In 1967 we jointly announced that the cobalt-samarium compound Co_5Sm developed far higher coercive forces than any of its near relatives and that it looked extremely promising even at that early stage.

The pace of development has been very rapid since then, with studies going forward in many laboratories. The fabrication of good magnets requires the solution to a number of basic processing problems. Once the material is reduced to a powder of favorable size it must be aligned by a strong magnetic field so that the easy magnetic axes of all the particles are made parallel. Once that is done the powder must be compacted into a dense form. This final and important step can be accomplished either by mechanical pressure or by a sintering process. Both have been successful.

The Philips Research Laboratories in the Netherlands, the Raytheon Corporation and General Electric have all announced the successful fabrication of cobalt-samarium permanent magnets with an intrinsic coercive force of from 10,000

REMANENCE (B_r) — B_0

COBALT-RARE EARTH MAGNET

CONVENTIONAL ALNICO MAGNET

H'_c

H_c

B_0
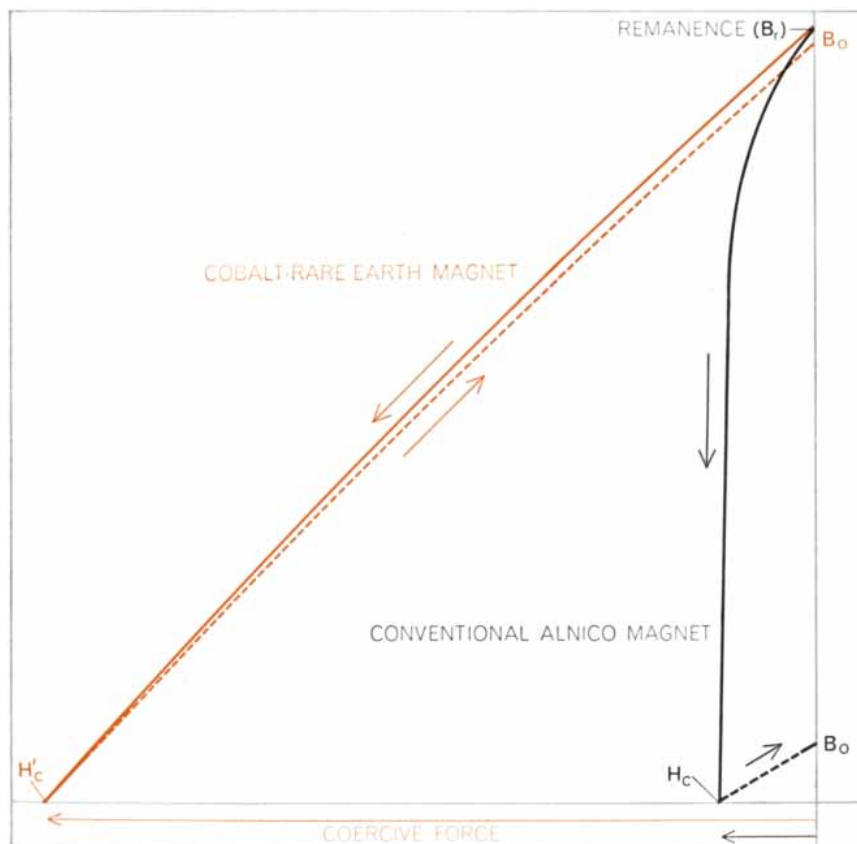
COERCIVE FORCE

RESPONSE TO DEMAGNETIZING FIELD equal to a magnet's coercive force can be quite different in two materials. When a force equal to the coercive force (H_c) is removed from a magnet of the Alnico type, the flux "rebounds" to a negligible value, B_0. The magnet must be remagnetized. When the much larger coercive force (H'_c) is removed from the new cobalt-rare-earth magnets, the flux returns almost fully to the initial magnetic remanence B_r.
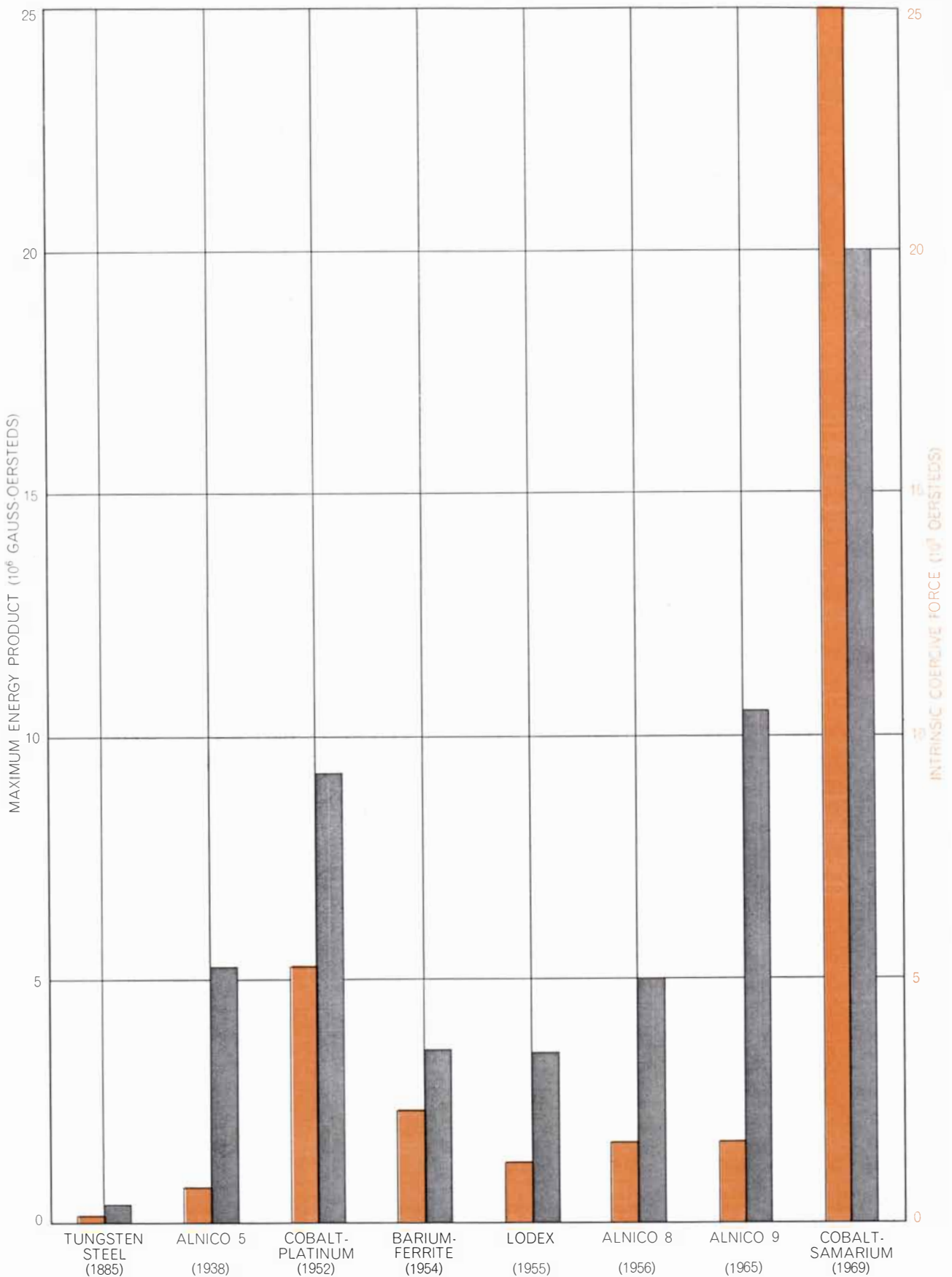
TWO INDEXES OF MAGNET QUALITY, intrinsic coercive force (*color*) and maximum energy product (*gray*), reveal the wide margin by which the new cobalt-samarium materials outperform their predecessors. The dates represent the first commercial ap-

pearance of magnets with the properties shown. The cobalt-platinum alloy of 1952 had the best combination of properties for many years but it costs several thousand dollars per pound. The raw materials for cobalt-samarium magnets cost about $40 per pound.

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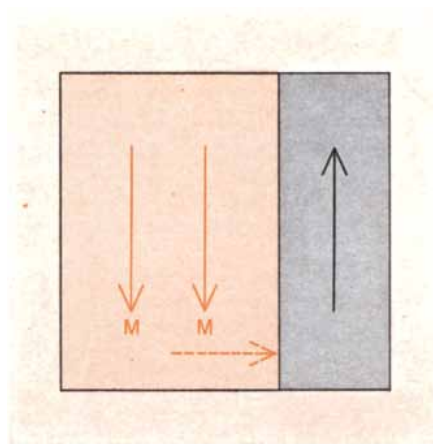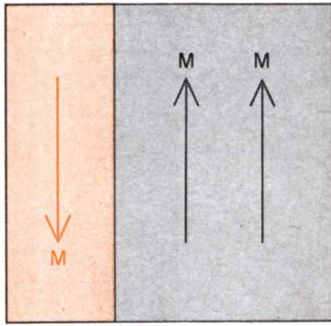
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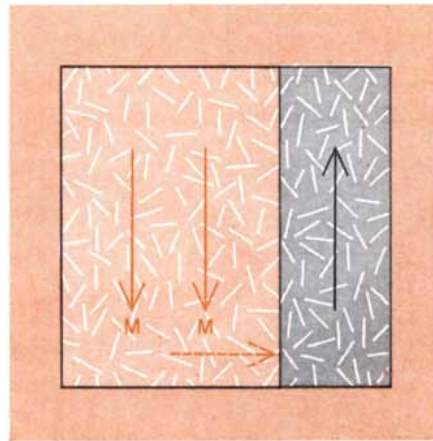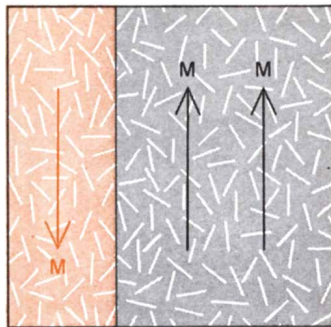
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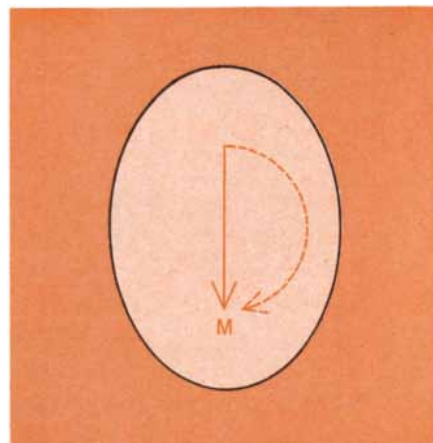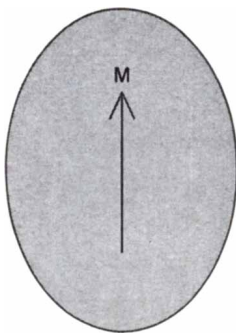
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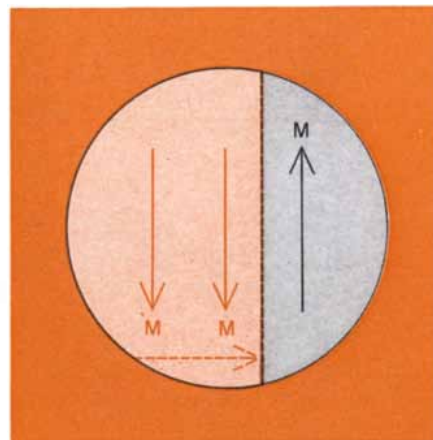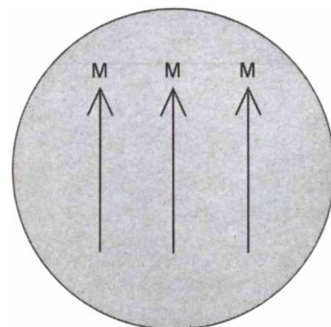
to 30,000 oersteds and with a maximum energy product of from 16 million to 20 million gauss-oersteds. Such intrinsic coercive forces are some 30 times higher than the forces found in typical Alnico alloys, and the maximum energy products are about three times as great. This represents a remarkable amount of progress since the original discovery of the anisotropy of Co_5Y in 1966.

As one might expect, the new materials are still expensive. At the moment, using laboratory quantities of pure metals, the raw-material cost of cobalt-samarium magnets is around $40 per pound. Even at this price there are applications where the superior performance of the new magnets is well worth the cost.

Rare-earth elements are not really very rare, however; the chief cost in their preparation is in separating them from one another. One effort to reduce the cost of rare-earth magnets involves using rare-earth mixtures, called "mischmetal," in place of pure elements in combination with cobalt. Mischmetal, the mixture of rare-earth metals that results from reducing the mixed ore, has long been used as a deoxidant in steelmaking and, more familiarly, in flints for cigarette lighters. In this form the rare earths cost only a few dollars per pound. Up to now, however, efforts to make good magnets with mischmetal have not been successful.

MECHANISM OF RESPONSE to an applied magnetic field is depicted schematically for four kinds of magnetic materials. In each case the original dominant direction of magnetization (left) is shown by black arrows. When a field H of the opposite direction is applied (right), the dominant direction of magnetization is reversed, as shown by colored arrows inside the material. The strength of the applied field needed to effect reversal is suggested by color intensity and by the length of the colored arrows labeled H. In soft-magnet steels (a) domain walls move easily in response to a small applied field. Early hard-magnet alloys (b) were heated and quickly quenched to create a complex internal structure that impeded movement of domain walls. The next two diagrams (c, d) represent individual fine particles in newer materials greatly magnified. In Alnico-type alloys (c) the particles are too small to have domain walls. Magnetization can be reversed only by fields high enough to force the magnetization to rotate against the anisotropic properties of the crystal, which favor magnetization in the direction of the "easy" axis. In the newest cobalt-rare-earth materials (d) domain walls are not ordinarily present, but they can be nucleated and moved by fields of suitable strength.

Another approach, which could lead indirectly to lower costs, has been to develop the desired microstructure by means of metallurgical reactions rather than through mechanical preparation. It may be possible to treat an alloy in such a way that particles of the desired size and shape simply precipitate out in the solid state. In fact, this is how Alnico and certain other alloys are now prepared. Workers at the Bell Telephone Laboratories and at Matsushita in Japan have reported attempts to apply this technique with the cobalt–rare earths. They find that by adding copper to these materials they can obtain a satisfactory structure by careful heat treatment. So far, however, they have not been able to make magnets with a maximum energy product much above 10 million gauss-oersteds (half the value attainable with cobalt-samarium alone) because of the rather large fraction of nonmagnetic copper present. On the other hand, the heat-treatment process has been successful even when samarium has been replaced with cerium, which is a good deal cheaper.

It seems clear that future development will proceed along two lines. One is the continued search for materials with still higher energy product and coercive force, for tasks where minimum size and weight and maximum performance are of the first importance and cost is secondary. What one would like to find are materials having even higher values of magnetic saturation than cobalt-samarium. The original report on cobalt–rare earths noted that cobalt-praseodymium was superior to cobalt-samarium in this respect. The other line of investigation will be to develop materials approaching the performance of cobalt-samarium but at significantly lower cost.

There is no satisfactory theory that links the magnetization process in the rare-earth materials to their composition. We do not know why cobalt-samarium develops permanent-magnet properties that are so superior to those attainable with, say, cobalt-praseodymium or cobalt-cerium, even though they are chemically, metallurgically and magnetically similar in basic properties.

The critical step in determining the coercive force seems to be the successful nucleation of a magnetic-domain boundary in the presence of a reversing magnetic field [see illustration on opposite page]. The development of this idea, both theoretically and experimentally, has already contributed to our understanding of these unusual new materials. In my laboratory, for example, we have shown that smoothing the surface of cobalt-
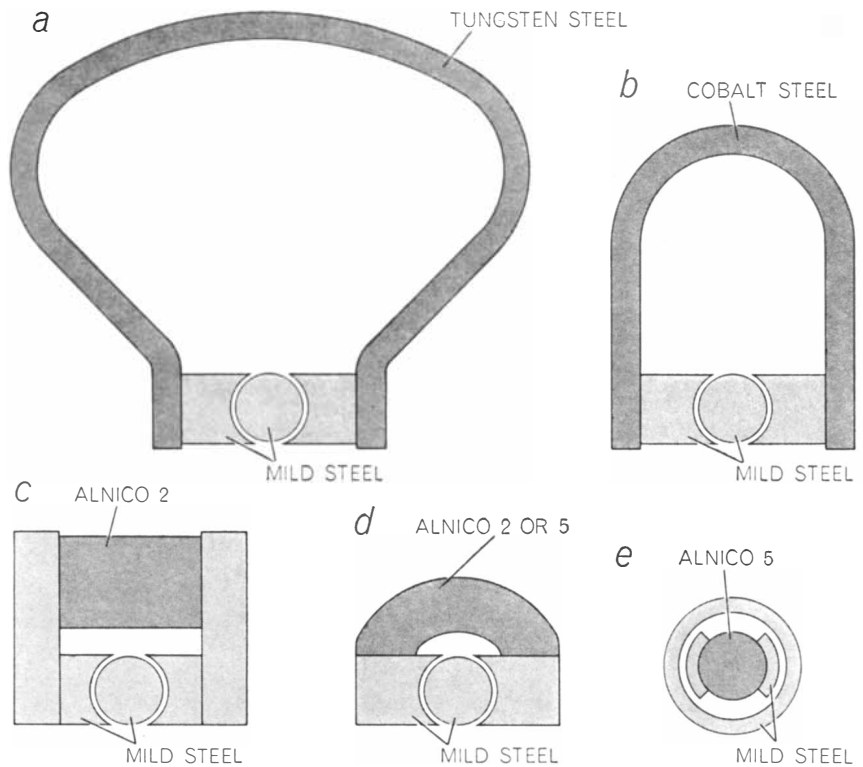
MORE COMPACT D'ARSONVAL METERS are made possible by stronger permanent-magnet materials. In the meters depicted here the current to be measured passes through a coil (*not shown*) that rotates in the narrow space between the mild-steel pieces. In this space there is a magnetic field provided by the permanent magnet. In four of the meters (*a, b, c, d*) the magnet is outside the mild-steel pieces. In the fifth meter (*e*) the magnet is so small that the design is turned inside out; the gap for the coil now surrounds the magnet.

yttrium particles can raise their intrinsic coercive force by a factor of more than 30 [see illustration on next page]. Presumably the smoothing removes surface irregularities that would facilitate the nucleation of reverse domains.

I have already mentioned one promising use for materials with high intrinsic coercive force: large permanent-magnet electric motors. What other applications can one see in the future? The ability to resist demagnetizing forces is important, for instance, in microwave amplifiers of the traveling-wave type, which are widely used in telecommunications and on virtually all the communication satellites. In such amplifiers an electron beam travels through a hollow cylinder made up of several dozen doughnut-shaped permanent magnets. The magnet structure serves to focus the electrons into a narrow beam. The permanent magnets are stacked with like poles adjacent (north next to north and south next to south), with the result that each magnet tends to demagnetize its neighbor. The requirements of this application are so severe that to obtain the necessary energy product in combination with high coercive force it was often

necessary to use a cobalt-platinum alloy costing thousands of dollars per pound. In comparison cobalt-samarium magnets not only are cheap but also have twice the magnetic energy product and are five times more resistant to demagnetization.

The fact that like poles of a magnet repel each other is the basis of many suspension devices that are virtually frictionless. In many watt-hour meters, for example, the rotating shaft is suspended in a magnetic bearing, because any friction in the meter would tend to make it read too low. The moving-coil meter, widely used for measuring current and voltage, reflects the design changes that have been brought about as the maximum energy product of magnets has increased over the past several decades [see illustration above].

The ability of permanent magnets to support large loads without physical contact may one day be exploited in suspension systems for high-speed trains. Fanciful as such a scheme may sound, it has the great virtue that permanent magnets consume no power and thus would provide a fail-safe system. If one wanted to support a 10-ton car with ferrite magnets (which would be lighter and more powerful than Alnico magnets), one

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would need two sets of magnets, one under the car and one in it, with a combined weight of perhaps 4,000 pounds. If cobalt-samarium were used, the combined weight of it needed to hold up a 10-ton car would be only 1,000 pounds. It is assumed in both calculations, of course, that the weight of the magnetic unit in the car has to be supported along with the weight of the car itself. Thus the ferrite magnet would have to support a total weight of 11 tons, whereas the cobalt-samarium would have to support only 10.25 tons.

These calculations are no more than rough estimates. Many other suspension schemes for high-speed vehicles are under consideration. Compared with air cushions or electrodynamic systems, however, this one has the virtue of simplicity. Its practicality would depend on the economic production of miles of permanent-magnet track at a cost not greatly exceeding that for steel rails. This is at least conceivable for ferrites, perhaps barely so for cobalt–rare earths or some of their descendants. In any case the implications for the permanent-magnet industry of a demand for magnetically repelling railroad track are quite staggering.

SMOOTHING OF PARTICLES increases the coercive force of the new cobalt-samarium materials. The sharp-edged particles at the top exhibit a coercive force of 103 oersteds; the particles at bottom, smoothed chemically, have a coercive force of 3,340 oersteds. The particles are enlarged 600 diameters in this micrograph made in the author's laboratory.

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THE MULE

This man-made animal is nearing extinction under the impact of mechanization. Its biology goes considerably beyond the mere fact that it is the result of a cross between a donkey and a horse

by Theodore H. Savory

Late in the 19th century the American Populist leader Ignatius Donnelly said of his Democratic opposition: "The Democratic party is like a mule—without pride of ancestry or hope of posterity." The phrase is memorable, but it is both unfair and inaccurate. It is unfair because, although a mule is the result of a cross between a male donkey and a female horse, the care with which the breeder chooses both parents is quite enough to afford the offspring a genuine pride of ancestry. It is inaccurate because, although male mules are sterile and indeed without hope of posterity, female mules can and do successfully produce foals. Donnelly was also gratuitously unkind: few of the hybrids created by man have been economically more valuable or biologically more interesting than the mule.

The origin of the mule is difficult to determine, but the practice of breeding the animals is at least 3,000 years old. So is the breeding of the hinny: the offspring of the reciprocal cross, between a female donkey and a male horse. Mules were known in the Holy Land before the time of King David, replacing the donkey as the royal beast. We read in II Sam. (13:29): "Then all the king's sons arose, and every man gat him up upon his mule, and fled." The animal was well known to Homer; not only does a famous line in the *Iliad* conjure up the animals in motion but also the poet records the arrival of mules from Henetia in Asia Minor, where breeding them was a local specialty. Mules were also bred in Homeric Greece and were widely used as draft animals and in farming. In later days they were raised in many areas of the Peloponnesus, particularly in Arcadia, and harness races for mules, started at Olympia in 500 B.C., continued to be run for more than 50 years. The Greek word for mule was *hemionus*, that is,

"half-ass," and the word for a female donkey was *muchlos*, whence came the Latin *mulus* and the English *mule*.

Mules were cosmopolitan animals long before the Renaissance; as early as A.D. 1274 Marco Polo praised the Turkoman mules he encountered in central Asia. By the 18th century the breeding of mules was a flourishing industry in Italy, Spain and France. For many years the chief European center was the French province of Poitou, where every year some 50,000 animals were bred. Heavy-draft mules were in demand for farm work, and a local breed of stud donkey, which had unusually large legs and hooves, was in high favor. The French distinguish between the masculine mule (*le mulet*) and the feminine (*la mule*). Two other phrases have been contributed to that language by the mule industry. The hinny is known as *le bardot*, and the phrases are *être le bardot*, which we might render as "to be a laughing-stock," and *passer pour bardot,* meaning "to crash the gate."

In America and Britain the mule was not much appreciated until late in the 18th century. In Britain the chief demand for mules was for service in the army in India and elsewhere abroad. Among the first in America to encourage the use of mules was George Washington, who had been given a large Spanish ass, named "Compound," by the king of Spain. In 1786 Washington advertised the animal's services in a Philadelphia journal. Compound's stud fee for serving horses was a third less than it was for serving donkeys; the father of his country, foreseeing the value of mules to the American farmer, chose this practical means of making his opinion known.

A large number of donkeys were subsequently brought to America from Spain. In the decade between 1850 and 1860 alone the number of mules in the

country increased 100 percent. More than 150,000 mules were foaled in the year 1889; by then the animals had almost entirely replaced horses for farm work in many areas.

In the years before Mendel's discoveries made known the principles of heredity, experimental hybridists failed to grasp the essentials of their results because they were described in broad, overall terms rather than being focused on some single pair of contrasting characteristics. Hence the mule was the subject of a number of vague and even inaccurate generalizations. For example, it was said, as it still is today by a few dog-fanciers, that the contribution of the female to its offspring was negligible and that the male parent was the one that must be critically selected. In contrast, the mule breeders of Kentucky always brought the best cart-horse mares to stud and found that this practice consistently gave the best results.

A generality with somewhat more truth to it is the dictum that the mule resembles its male parent at its extremities, namely in the ears, the legs and the tail. Spanish donkeys, frequently used as studs, are notable for their rather delicate legs and feet, which may account for another general comment: that the mule has the appearance of a horse's body mounted on the legs of an ass. The grain of truth in the first dictum led, as we have seen, to the use of a line of donkeys with unusually large legs and hooves as the studs in Poitou. Another descriptive comment, once common among British troops, is that mules look like asses in front and like horses behind. Underlying all such remarks is the fact that by selective breeding the mule can to some extent be tailored to suit whatever purpose is intended.

In height at the withers mules range

between 12 and 17½ hands (between four feet and five feet 10 inches). The coat is uniformly colored, without "stockings" or blazes, and the neck and croup are shaped like those of a horse. The head, the ears, the tail and the short mane all resemble a donkey's. Like the legs of the donkey, the mule's legs do not show on their inner surface the growths of callus at knee and hock, called "chestnuts," that are characteristic of horses. The mule brays like a donkey.

The mule has more than its share of admirable qualities. It is courageous and intelligent, hard of hide, sure of foot, sound of constitution and able to resist changes in climate and withstand thirst and hunger better than the horse. Such perfection must necessarily be marred by a few minor drawbacks. The mule is markedly sensitive around the head and does not enjoy having its ears fondled; in this respect it differs from the horse and resembles its male parent. It will not accept injustice or irrational treatment but meets them with instant rebuff. The common phrase "a kick like a mule" shows how well known is the animal's major means of protest. The mule can also be self-willed to the point of unreasonableness, as is attested by "stubborn as a mule." Like their masters, however, mules acquire the unattractive traits of stubbornness and ill temper only when they have been badly brought up. They are essentially sensitive spirits in robust bodies, and when their early training has been sympathetically carried out, their behavior is incomparable.

The hinny, the hybrid of a female donkey and a male horse, grows in a smaller uterus, which may in part account for its lesser value. Its distinctive character was known to Pliny, who described it as *effrentis et tarditatis*, meaning "unrestrained and slow of movement." The animal is more like a horse in general appearance, just as the mule is more like its male parent. Never as popular as the mule, the hinny has been bred in Ireland more than elsewhere. It has great stamina, trots well and is long-lived; owners of a first-class hinny are always enthusiastic about it.

Mules are bred for three basic tasks: pack work, draft work and riding. The amount of work the animal can do varies with each role. The largest mules bred, certain crosses between dray mares and Poitou donkeys, stood between 17 and 17½ hands high; they were favored for riding. Harnessed for draft work, the mule is not at its best before the plow, and the slow labor of agriculture in hot countries is more satisfactorily done by oxen. Teams of mules, however, are effi-
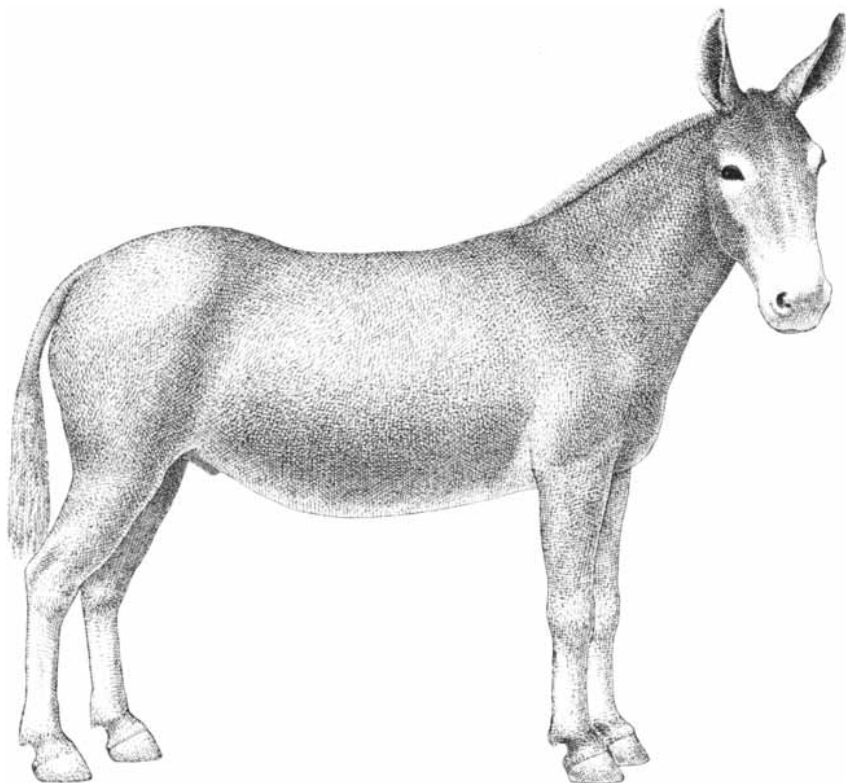
FAMILIAR HYBRID, the mule is the offspring of a female horse that has been mated with a male donkey. Mules resemble their male parent in size and shape of ears, legs and hooves, shape of tail and shortness of mane. Mules can range between 12 and 17½ hands in height.
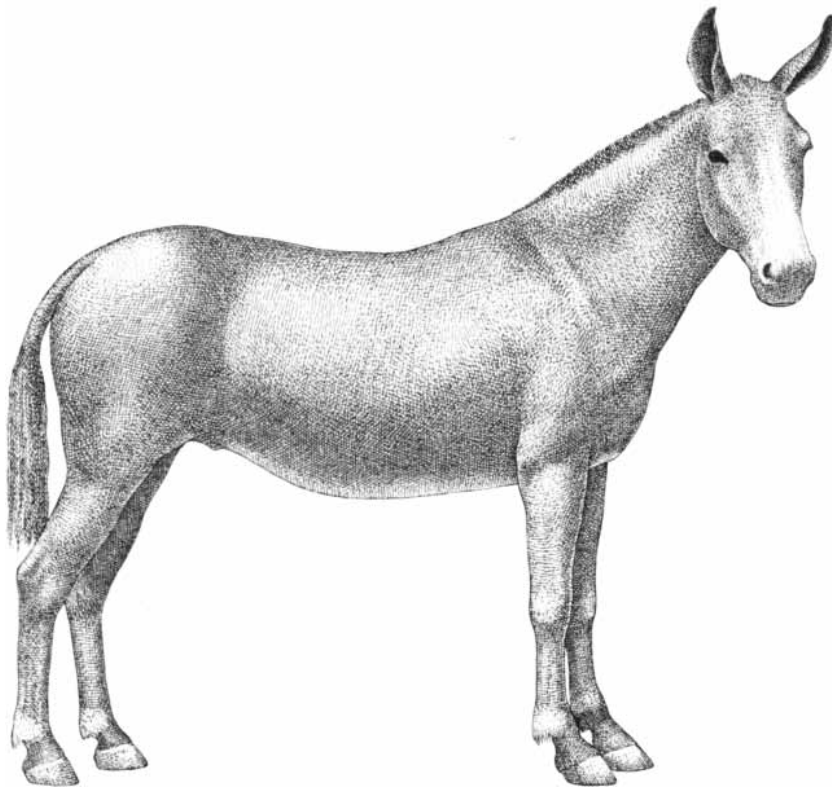
LESS FAMILIAR HYBRID, the hinny is the offspring of the reciprocal cross, the mating of a female donkey with a male horse. Hinnies are more horselike in appearance than mules. Far less frequently bred than mules, they are long-lived animals and noted for stamina.

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cient wagon animals and have been used to haul loads everywhere from the snows of Antarctica to the superheated desert of Death Valley [*see top illustration on pages 106 and 107*].

It is as pack animals that mules of ordinary size, from 13 to 14½ hands, come into their own. Starting when they are four or five years old, they will continue to work well until they are 18 or 20. Carefully loaded, a mule can carry 300 to 350 pounds, including the weight of the packsaddle, and it normally covers 20 to 25 miles in a day's march. When the animals are pressed, they can do a good deal better. During the Indian wars in the American Southwest a number of mule endurance records were set. In 1882 a company of scouts and one pack train, loaded 200 pounds to the mule, set out from the San Carlos Agency in Arizona on a three-day forced march; at the end of that time the pack train had covered 280 miles. During the Garza campaign on the Rio Grande that same year, a company of the Third Cavalry and another pack train covered 108 miles in 16 hours, bettering the record for a day's march set the year before in New Mexico by a pack train that had traveled 85 miles under the desert sun in 12 hours.

As pack animals mules can be led or driven. Driving is usually the better way; the mule's hearing is acute, and it is readily controlled by voice. Thus it is said, "You can talk to a horse, but you can chat and whisper to a mule." In the American West both the acuteness of the mules' hearing and the animals' tendency to form into "herds" under a dominant leader led to the perfection of the "bell mare" method of driving. An experienced mare, a bell slung around her neck, was the lead animal on the trail. The mare dominated the mules, so that following her was a natural herd action. Even when the mare was out of sight ahead, the mules farthest to the rear could follow the sound of the bell, moving contentedly behind in single file.

The mule's small hooves give it a surefootedness that is invaluable in mountainous terrain. This was one reason for the large number of mules with the British forces in India. As readers familiar with Kipling's poem "Screw-guns" will remember, they were the usual means of transport for the light artillery. They were often shod as horses are. The custom of protecting their feet in some way or other is at least as old as Shakespeare's day. In *Henry VI: Part II* he writes of "my foot-cloth mule," a reference to the contemporary habit of wrapping the hooves with fabric.

One of the favorable qualities characteristic of the mule is its quick power of recovery after strenuous effort. If a day's work has pushed it close to the limit of its strength, a night's rest seems to restore it completely and morning finds it ready to undertake another day's labor. In this respect the mule is quite different from the horse. The mule's advantage lies in its disproportionate strength, a strength that is found in the anatomy of its hindquarters. This muscular development of the mule is of much greater practical value than show-ring conformation of shoulders and withers.

Manuals of animal management point out that mules and horses fundamentally need the same care. Although they say that mules can endure hunger and thirst better than horses can, and that mules are commonly supposed to eat less, they should receive the same rations as horses when subjected to the rigors of active service. A heavy-draft mule, for example, might be given 12 pounds of oats, 16 pounds of hay and eight pounds of straw a day; these quantities may be varied considerably for mules of a different type and in different circumstances.
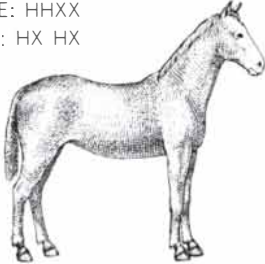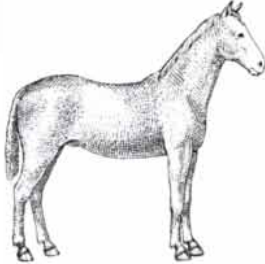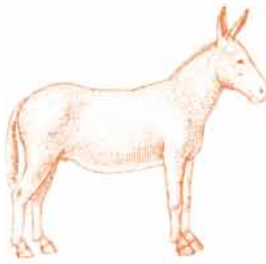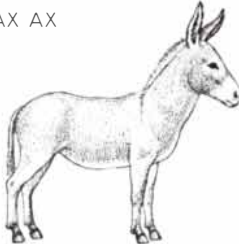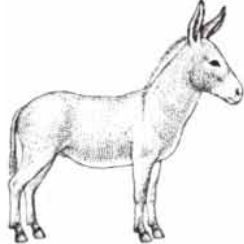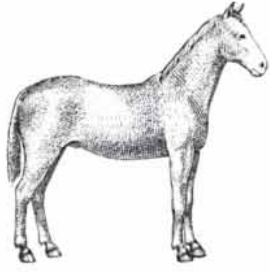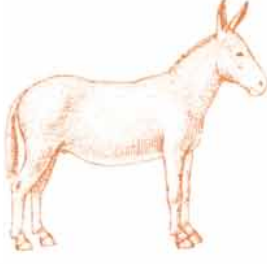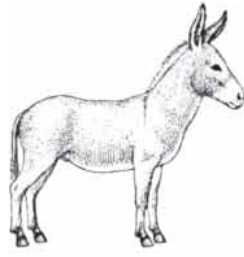
As recently as 1966 British army instructions devoted six pages to the mule. Among other things, the reader was informed that in selecting a mule one should look for those with straight backs. The pages included information on feeding, watering, general care on the march or in fording or swimming rivers, and proper procedures in other emergencies of service. Perhaps with inspirational intent a statement is included that the Chinese have a reputation for taking great care of their mules. Nor is the humanitarian touch omitted: "When unsaddled," the instructions state, "mules should be allowed to roll, a proceeding they thoroughly enjoy."

Everyone who is interested in the history of Antarctic exploration is familiar with the tragic end of Robert Falcon Scott and his party, but few remember that the sledges of the relief expedition that reached Scott's tent were drawn by mules. As an alternative to Manchurian ponies seven mules had been sent from India to Ross Island in 1912. They were brought to first-rate condition, and on October 30 they set out on their journey, each mule pulling a sledge load of 700 pounds. They soon showed the mulish characteristic of refusing to eat when disturbed. It is recorded that they neglected their rations of corn but at times ate sugar, tea leaves and tobacco ash. On one occasion two of them devoured a headrope between them. For 30 days the mules virtually starved themselves, two reaching the limit of their endurance and dying. The other five returned safely to Cape Evans, where sad to relate they were shot in January, 1913.

During World War I many men made the acquaintance of mules for the first time, and many mules had their first encounter with partially trained drivers. The consequences were inevitable: only the more fortunate animals were given
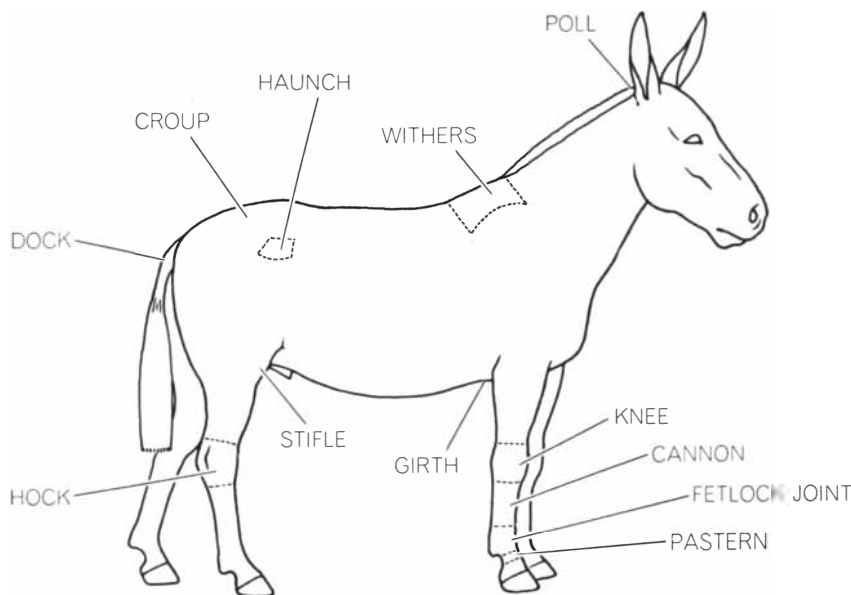
SELECTED FEATURES of equid anatomy are indicated on this outline drawing of a mule. The mule differs from the horse in its donkey-like appearance and in lacking the growths of callus, known as "chestnuts," found on the inner surface of horses' legs at hock and knee.

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POSSIBLE CROSSES between horses and donkeys are indicated in this diagram, along with the natural (*black*) or hybrid (*color*) offspring to be expected from each cross. The genotypes and gametes of the parents are also shown. In addition to the sex-determining *X* and *Y* chromosomes, the nonsex chromosomes are indicated by the letter *H* for the horse and the letter *A* for the donkey. Male mules and hinnies have been omitted because both are sterile. Issue from the cross between hinny and horse is unknown.

TWENTY-MULE TEAM hauls two freight wagons and a tank wagon in train through the forbidding terrain of Death Valley in California. The freight wagons are 16 feet long; their rear wheels are seven feet in diameter. Each weighs nearly four tons and can

the expert and kindly treatment to which they always respond. Their services were well appreciated and ended only too often in events belying the tradition that "one never sees a dead mule." The others responded to their amateur stablemen with their teeth and heels, a form of reprisal the British soldier accepted with good humor. Such encounters were the inspiration for a *Punch* cartoon in 1916 showing a group of tethered mules. The animals are depicted in escalating stages of mirth as one of their number takes vengeance first on a corporal, then on a veterinarian, then on a staff officer and finally on the regimental commander.

A lasting example of how mules have impressed their character on the minds of the men who have known them is a monument that stands in the Swiss town of Sion. Mules have long been the mainstay of agriculture in that region. The time came not long ago when the last mule was superseded by machine, whereupon the farmers of the neighborhood joined together and erected the memorial that will for years to come testify to the debt they and their forebears owed to generations of hardworking mules.

I have not yet forgotten the circumstances that required me to hear three times the same lecture on the care of mules that was given to each section of a Royal Field Artillery battery many years ago. On each occasion the veteri-

MULE TRAIN of the U.S. Eighth Cavalry Service Troop moves out of Camp Marfa in Texas loaded with supplies for a squadron of the regiment (*rear*) bound for border duty in the Big Bend area of the Rio Grande in 1918. Mounted man at far right is the pack-

carry 10 tons of cargo. The water tank holds 1,200 gallons. The 20-mule teams were used in the 1880's to carry borax from Death Valley to the railroad at Mojave, 165 miles away. The United States Borax & Chemical Corporation uses the team as its trademark.

nary officer, emphasizing his advice with more than a little eloquence, had the following to say about watering a mixed body of horses and mules:

"Horses are more
Particular about their food and less
Particular about their water than mules;
Mules are less
Particular about their food and more
Particular about their water than horses;
Hence,

If you have to water
A mixed force
Of horses and mules,
Water your mules first."

Perhaps the officer did not notice that his advice, if it is printed as it is above, comes near to being poetry. It is said that "poetry is memorable speech," and this speech was memorable. I have often wondered who wrote it.

A more conscious poetic effort involv-

ing the mule appears, as I have noted, in the *Iliad*. The scene comes as a party from the Greek camp ascends the mountains to gather wood for the fallen Patroclus' funeral pyre. The lines, as rendered by A. T. Murray, run:

"...and before them went the mules;
And ever upward, downward, sideward
and aslant they fared."

Here is the sound in Greek of the sec-

master; next to him is the cook, who leads the "bell mare" for the mules to follow. Packers bring up the rear at far left. A cavalry pack train set the record for a day's march during a campaign in the Rio Grande area in 1882 by covering 108 miles in 16 hours.

ond line, the stress of the meter (dactylic hexameter) indicated by the accents: Pólla d'anánta katánta páranta te dóchmia t'élthón. It is an almost perfect onomatopoetic reproduction of the clatter of mules' hooves on a mountain trail.

What is the exact reason for the sterility of the male mule? In 1913 H. Federley showed that this condition results from a failure of sperm production by meiosis, the type of cell division that gives rise to germ cells. Specifically the failure occurs at the stage of synapsis, when the chromosomes of maternal and paternal origin come together. Male mules and male hinnies will readily mount female mules, hinnies, horses or donkeys, but there is no record that such mating has ever resulted in offspring. As a matter of fact, male mules and male hinnies are usually gelded early in life, since such mating behavior is pointless and a nuisance in the stable and the pasture. This guarantees that the animals are without hope of posterity.

Female mules, however, are less consistently sterile than males, and when they are served by male horses or donkeys, they may sometimes conceive. Conception is usually followed by a slipping, or miscarriage, of the fetus, but very occasionally a foal is carried to its full term of 10½ months. The rarity of this accomplishment is recognized in the old Latin phrase *cum mula peperit* ("when a mule foals"), which might be rendered today as "once in a blue moon." Such occasional foals are of two kinds. If the sire was a donkey, they are mules like their mother; if it was a horse, they are horses like their father.

Fertility is even rarer among female hinnies than among mules, or perhaps records of hinny foals are scarcer because there have always been fewer hinnies in existence. Served by a horse, a female hinny produces nothing. Served by a donkey, she bears a typical donkey.

The instances of fertility among female hybrids of both crosses between the donkey and the horse are so few that it is impossible to be certain that they represent a general truth. If one accepts the risks of arguing from the particular to the general and the few facts are taken at their face value, however, the reproductive pattern can be interpreted in terms of simple genetics, as follows.

Let the nonsex chromosomes of the horse be represented by H and those of the donkey by A. When the sex chromosomes X and Y are added, a genetic formula for male and female horses will respectively be $HHXY$ and $HHXX$, and the formula for male and female donkeys will be $AAXY$ and $AAXX$. The breeding of mules can then be written: $AAXY \times HHXX = AHXX$ (female) or $AHXY$ (male). The breeding of hinnies would be written: $AAXX \times HHXY = AHXX$ (female) or $AHXY$ (male).

The subsequent mating between a male horse and a female mule should therefore follow the pattern $HHXY \times AHXX$, with the offspring either $AHXX$, $AHXY$, $HHXX$ or $HHXY$, which is to say both sexes of mules and horses. The failure of such matings to produce either $AHXX$ or $AHXY$, that is, either of the mule sexes, can be explained by assuming that true mule ova (AX) are not present in female mules. This leads to the conclusion that the ova of the mule carry only horse chromosomes. Similarly, the absence of horses from crosses between a donkey and a hinny is understandable if the ova of a hinny contain only donkey chromosomes. All the possible matings between horses, donkeys, mules and hinnies of both sexes are summarized in the illustration on page 105.

All of this does not, however, explain why the cross between a male horse and a female hinny yields no foals (which in theory would be mulelike). The probable truth is that opportunities to try this mating have arisen too seldom. Unlike fruit flies or mice, horses and donkeys are not suitable animals for experiments in genetics. They breed too slowly, they produce only one offspring at a time even when the breeding is successful, and they are too expensive to keep merely for research purposes. These considerations underlie the reason for each individual mule or hinny's being the offspring of a specially contrived mating. To complicate matters further, it is a curious fact that once a male donkey has served a female donkey, it is often reluctant to transfer its attentions to a female horse.

Under the impact of mechanization the mule has been steadily disappearing from agriculture, industry and transportation. This trend will undoubtedly continue. Worldwide mule-breeding statistics are not readily accessible, but the following figures for the U.S. are indicative. In 1920 the mule population was about 5.43 million. By 1931 the number had fallen to 5.13 million, by 1948 to 2.54 million and by 1954 to 1.6 million. A graph of these figures shows that the last three points lie on a straight line, indicating the complete extinction of mules in the U.S. sometime around 1958. This has not yet come to pass, but the outcome is unmistakable. In many ways it will be regrettable. Mules have played a worthy role in human affairs over much of the world for a considerable period, and they deserve a fate better than such an obscure drift toward oblivion.

PACK MULE'S PATIENCE is extolled in a sketch by Frederic Remington. It appeared in the March 1891 issue of *Century Magazine,* accompanying an article about the Indian wars.

"HE'S KICKED THE CORPORAL!"

"HE'S KICKED THE VET.!!"

"HE'S KICKED THE TRANSPORT OFFICER!!!"

"HE'S KICKED THE COLONEL!!!!"

MULE HUMOR during World War I, as imagined by a cartoonist for the British comic weekly *Punch*, shows a cluster of mules in escalating degrees of mirth as one of their number, who is out of sight, kicks at military personnel of successively more exalted rank.

MATHEMATICAL GAMES

The paradox of the nontransitive dice
and the elusive principle of indifference

by Martin Gardner

Probability theory abounds in paradoxes that wrench common sense and trap the unwary. Many of them have been discussed in "Mathematical Games." This month we consider a startling new paradox involving the relation called transitivity and a group of paradoxes stemming from the careless application of what is called the principle of indifference.

Transitivity is a binary relation such that if it holds between A and B and between B and C, it must also hold between A and C. A common example is the relation "heavier than." If A is heavier than B and B is heavier than C, then A is heavier than C. The three sets of four dice shown "unfolded" in the illustration below were designed by Bradley Efron, a statistician at Stanford University, to dramatize some recent discoveries about a general class of probability paradoxes that violate transitivity. With any of these sets of dice you can operate a betting game so contrary to intuition that experienced gamblers will find it almost impossible to comprehend even after they have completely analyzed it.

The four dice at the top of the illustration are numbered in the simplest way that provides the winner with the maximum advantage. Allow someone to pick any die from this set. You then select a

die from the remaining three. Both dice are tossed and the person who gets the highest number wins. Surely, it seems, if your opponent is allowed the first choice of a die before each contest, the game must either be fair or favor your opponent. If at least two dice have equal and maximum probabilities of winning, the game is fair because if he picks one such die, you can pick the other; if one die is better than the other three, your opponent can always choose that die and win more than half of the contests. This reasoning is completely wrong. The incredible truth is that regardless of which die he picks you can always pick a die that has a 2/3 probability of winning, or two-to-one odds in your favor!

The paradox (insofar as it violates common sense) arises from the mistaken assumption that the relation "more likely to win" must be transitive between pairs of dice. This is not the case with any of the three sets of dice. In each set the relation "more likely to win" is indicated by an arrow that points to the losing die. Die A beats B, B beats C, C beats D—and D beats A! In the first set the probability of winning with the indicated die of each pair is 2/3. This is easily verified by listing the 36 possible throws of each pair, then checking the 24 cases in which one die bears the highest number.

The other two sets of four dice, also designed by Efron, have the same nontransitive property but fewer numbers are repeated in order to make an analysis of the dice more difficult. In the second set the probability of winning with the indicated die is also 2/3. Because ties are possible with the third set it must be agreed that ties will be broken by rolling again. With this procedure the winning probability for each of the four pairings in the third set is 22/34, or .647.

It has been proved, Efron writes, that 2/3 is the greatest possible advantage that can be achieved with four dice. For three sets of numbers the maximum advantage is .618, but this cannot be obtained with dice because the sets must have more than six numbers. If more than four sets are used (numbers to be randomly selected within each set), the possible advantage approaches a limit of 3/4 as the number of sets increases.

A fundamental principle in calculating probabilities such as dice throws is one that goes back to the beginnings of classical probability theory in the 18th century. It was formerly called "the principle of insufficient reason" but is now known as "the principle of indifference," a crisper phrase coined by John Maynard Keynes in *A Treatise on Probabil-*
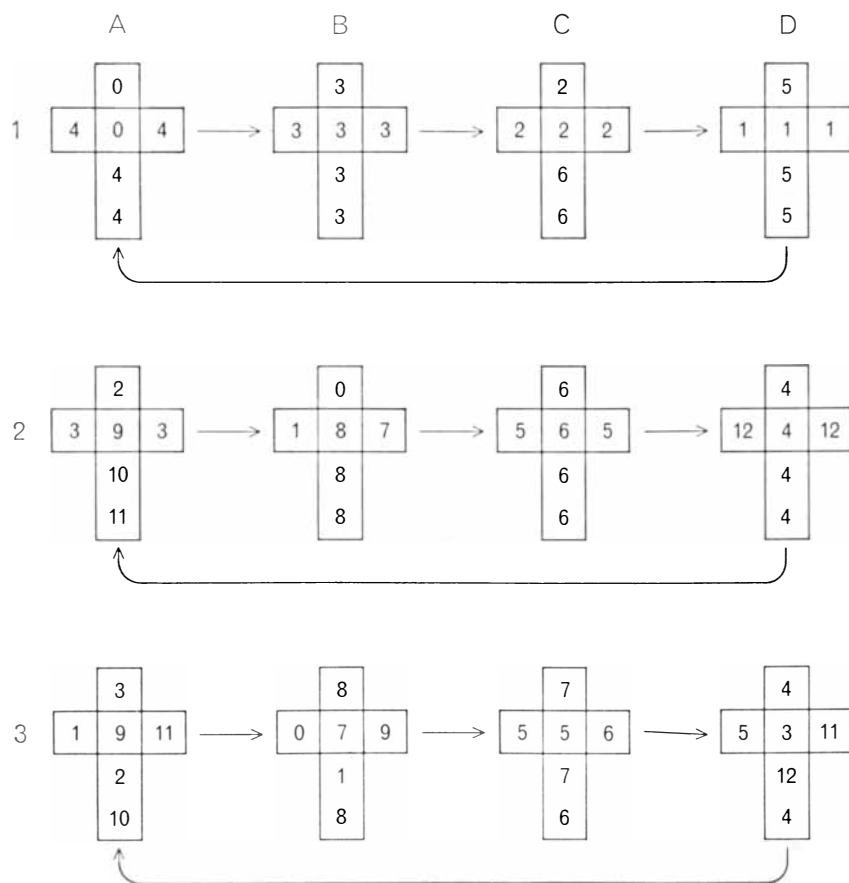
Nontransitive dice

ity. (Keynes is best known as an economist, but his book on probability has become a classic. It had a major influence on the inductive logic of the late Rudolf Carnap.) The principle is usually stated as follows: If you have no grounds whatever for believing that any one of *n* mutually exclusive events is more likely to occur than any other, a probability of $1/n$ is assigned to each.

For example, you examine a die carefully and find nothing that favors one side over another, such as concealed loads, noncubical shape, beveling of certain edges, stickiness of certain sides and so on. You assume that there are six equally probable ways the cube can fall; therefore you assign a probability of 1/6 to each. If you toss a penny, or play the Mexican game of betting on which of two sugar cubes a fly will alight on first, your ignorance of any possible bias prompts you to assign a probability of 1/2 to each of the two outcomes. In none of these samples do you feel obligated to make statistical, empirical tests. The probabilities are assigned a priori. They are based on symmetrical features in the structures and forces involved. The die is a regular solid, the probability of the penny's balancing on its edge is virtually zero, there is no reason for a fly to prefer one sugar cube to another and so on. Ultimately, of course, your analysis rests on empirical grounds, since only experience tells you, say, that a weighted die face would affect the odds, whereas a face colored red (with the others blue) would not.

Some form of the principle of indifference is indispensable in probability theory, but it must be carefully qualified and applied with extreme caution to avoid pitfalls. In many cases the traps spring from a difficulty in deciding on what are the equally probable cases. Suppose, for instance, you shuffle a packet of four cards—two red, two black—and deal them face down in a row. Two cards are picked at random. What is the probability that those two cards are the same color?

One person reasons: "There are three equally probable cases. Either both cards are black, both are red or they are different colors. In two cases the cards match, therefore the matching probability is 2/3."

"No," another person counters, "there are *four* equally probable cases. Either both cards are black, both are red, card *x* is black and *y* is red or *x* is red and *y* is black. More simply, the cards either match or they do not. In each way of putting it the matching probability clearly is 1/2."
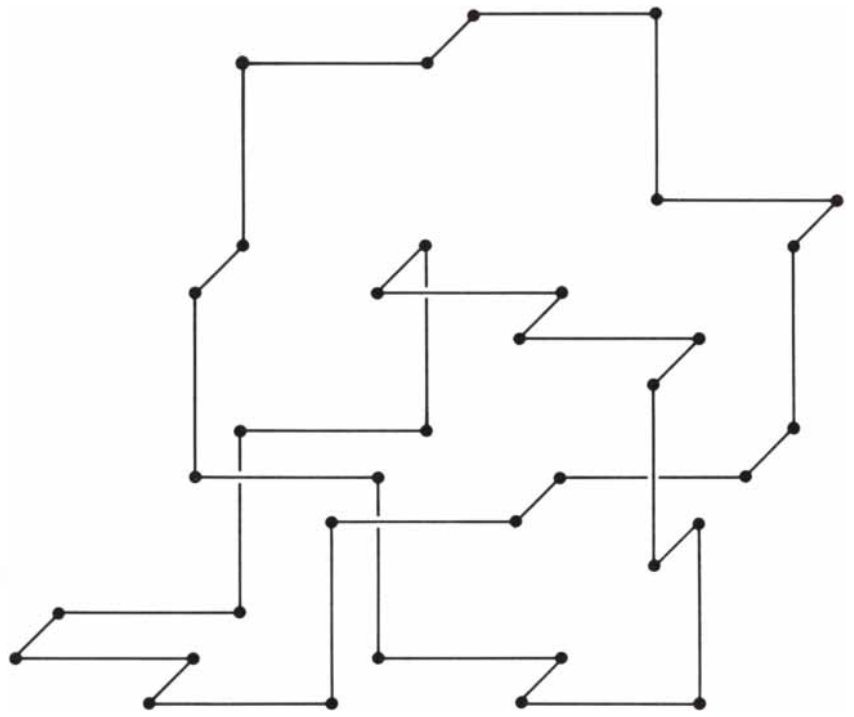
Solution to the knot problem

The fact is that both people are wrong. (The correct probability will be given next month. Can the reader calculate it?) Here the errors arise from a failure to identify correctly the equally probable cases. There are, however, more confusing paradoxes—actually fallacies—in which the principle of indifference seems intuitively to be applicable, whereas it actually leads straight to a logical contradiction. Such cases result when there are no positive reasons for believing *n* events to be equally probable and the assumption of equiprobability is therefore based entirely, or almost entirely, on ignorance.

For example, someone tells you: "There is a cube in the next room whose size has been selected by a randomizing device. The cube's edge is not less than

one foot or more than three feet." How would you estimate the probability that the cube's edge is between one and two feet as compared with the probability that it is between two and three feet? In your total ignorance of additional information, is it not reasonable to invoke the principle of indifference and regard each probability as 1/2?

It is not. If the cube's edge ranges between one and two feet, its volume ranges between 1^3, or one, cubic foot and 2^3, or eight, cubic feet. But in the range of edges from two to three feet, the volume ranges between 2^3 (eight) and 3^3 (27) cubic feet—a range almost three times the other range. If the principle of indifference applies to the two ranges of edges, it is violated by the equivalent ranges of volume. You were

$1 = [\sqrt{\pi}]$	$11 = [(\pi \times \pi) + \sqrt{\pi}]$
$2 = [\sqrt{\pi} \sqrt{\pi}]$	$12 = [\pi \times \pi] + [\pi]$
$3 = [\pi]$	$13 = [(\pi \times \pi) + \pi]$
$4 = [\pi + \sqrt{\pi}]$	$14 = [(\pi \times \pi) + \pi + \sqrt{\pi}]$
$5 = [\pi \sqrt{\pi}]$	$15 = [\pi \times \pi] + [\pi + \pi]$
$6 = [\pi + \pi]$	$16 = [(\pi \times \pi) + \pi + \pi]$
$7 = [\pi^{\sqrt{\pi}}]$	$17 = [\pi \times \pi \times \sqrt{\pi}]$
$8 = [(\pi \times \pi) - \sqrt{\pi}]$	$18 = [\pi \times \pi] + [\pi \times \pi]$
$9 = [\pi \times \pi]$	$19 = [(\pi \times \pi) + (\pi \times \pi)]$
$10 = [\pi \times \pi] + [\sqrt{\pi}]$	$20 = [\pi\sqrt{\pi}] [\pi + \sqrt{\pi}]$

How the first 20 integers can be "pied"
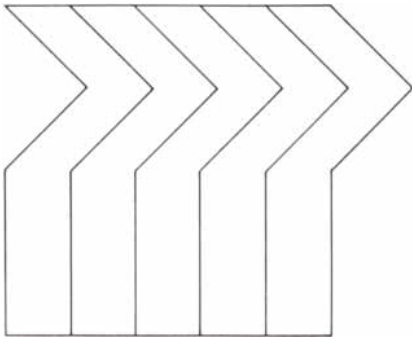
Solution to dissection problem

not told how the cube's "size" was randomized, and since "size" is ambiguous (it could mean either the cube's edge or its volume) you have no clues to guide your guessing. If the cube's edge was picked at random, the principle of indifference does indeed apply. It is also applicable if you are told that the cube's volume was picked at random, but of course you then have to assign a probability of 1/2 to each of the two ranges from one to 14 and from 14 to 27 cubic feet, and to the corresponding ranges for the cube's edge. If the principle applies to the edge, it cannot apply to the volume without contradiction, and vice versa. Since you do not know how the size was selected, any application of the principle is meaningless.

Carnap, in attacking an uncritical use of the principle in Harold Jeffreys' *Theory of Probability*, gives the following example of its misuse. You know that every ball in an urn is blue, red or yellow, but you know nothing about how many balls of each color are in the urn. What is the probability that the first ball taken from the urn will be blue? Applying the principle of indifference, you say it is 1/2. The probability that it is not blue must also be 1/2. If it is not blue, it must be red or yellow, and because you know nothing about the number of red or yellow balls, those colors are equally probable. Therefore you assign to red a probability of 1/4. On the other hand, if you begin by asking for the probability that the first ball will be red, you must give red a probability of 1/2 and blue a probability of 1/4, which contradicts your previous estimates.

It is easy to prove along similar lines that there is life on Mars. What is the probability that there is simple plant life on Mars? Since arguments on both sides are about equally cogent, we answer 1/2. What is the probability that there is simple animal life on Mars? Again, 1/2. Now we are forced to assert that the probability of there being "either plant or animal life" on Mars is $1/2 + 1/2 = 1$, or certainty, which is absurd. The philosopher Charles Sanders Peirce discredited the principle of indifference by a similar argument proving that the hair of inhabitants on Saturn had to be either of two different colors. Many variants of this fallacy can be found in Chapter 4 of Keynes's book. It is easy to invent others.

In the history of metaphysics the most notorious misuse of the principle surely was by Blaise Pascal, who did pioneer work on probability theory, in a famous argument that became known as "Pascal's wager." A few passages from the original and somewhat lengthy argument (in Pascal's *Pensées*, Thought 233) are worth quoting:

" 'God is, or he is not.' To which side shall we incline? Reason can determine nothing about it. There is an infinite gulf fixed between us. A game is playing at the extremity of this infinite distance in which heads or tails may turn up. What will you wager? There is no reason for backing either one or the other, you cannot reasonably argue in favor of either....

"Yes, but you must wager.... Which will you choose?... Let us weigh the gain and the loss in choosing 'heads' that God is.... If you gain, you gain all. If you lose, you lose nothing. Wager, then, unhesitatingly that he is."

Lord Byron, in a letter, rephrased Pascal's argument effectively: "Indisputably, the firm believers in the Gospel have a great advantage over all others, for this simple reason—that, if true, they will have their reward hereafter; and if there be no hereafter, they can be but with the infidel in his eternal sleep, having had the assistance of an exalted hope through life, without subsequent disappointment, since (at the worst for them) out of nothing nothing can arise, not even sorrow." Similar passages can be found in many contemporary books of religious apologetics.

Pascal was not the first to insist in this fashion that faith in Christian orthodoxy was the best bet. The argument was clearly stated by the fourth-century African priest Arnobius the Elder, and non-Christian forms of it go back to Plato. This is not the place, however, to go into the curious history of defenses and criticisms of the wager. I content myself with mentioning Denis Diderot's observation that the wager applies with equal force to other major faiths such as Islam. The mathematically interesting aspect of all of this is that Pascal likens
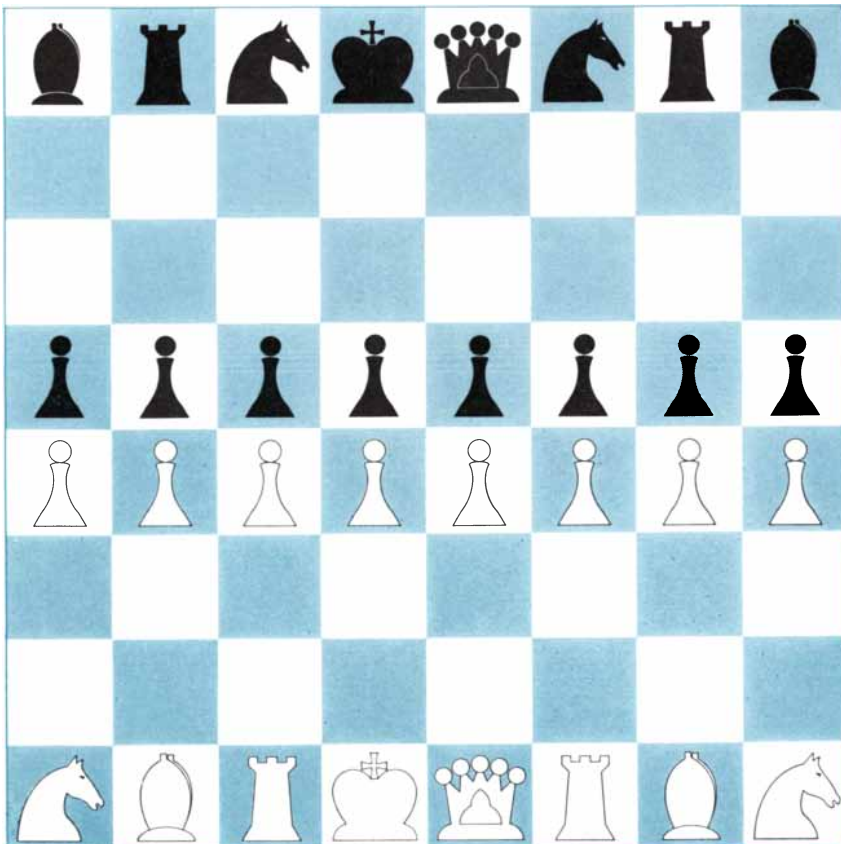
A solution to the chess problem
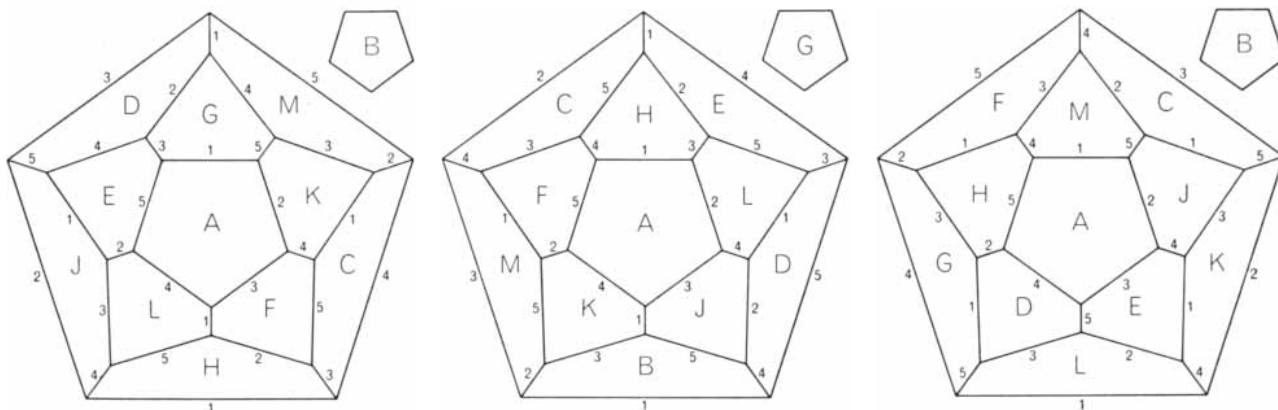
Three basic solutions to the dodecahedron-quintomino problem

the outcome of his bet to the toss of a coin. In other words, he explicitly applies the principle of indifference to a situation in which its application is mathematically senseless.

The most subtle modern reformulation of Pascal's wager is by William James, in his famous essay *The Will to Believe,* in which he argues that philosophical theism is a better gamble than atheism. In a still more watered-down form it is even used occasionally by humanists to defend optimism against pessimism at a time when the extinction of the human race seems as likely in the near future as its survival.

"While there is a chance of the world getting through its troubles," says the narrator of H. G. Wells's little read novel *Apropos of Dolores,* "I hold that a reasonable man has to behave as though he was sure of it. If at the end your cheerfulness is not justified, at any rate you will have been cheerful."

Here are the answers to the 10 short problems that were given last month.

1. The shortest knotted chain known that meets the conditions specified last month has 36 links [*see top illustration on page 111*]. It is reproduced from Max Delbrück's paper "Knotting Problems in Biology," in *Mathematical Problems in the Biological Sciences: Proceedings of Symposia in Applied Mathematics,* Vol. 14, 1962, pages 55–68. I shall report later if any reader finds a shorter chain.

2. The bottom illustration on page 111 gives Fitch Cheney's best answer to the problem of expressing the integers 1 through 20 by using pi—as few times as possible—and the symbols specified last month. He was able to express all integers from 1 through 100 without going beyond four pi's. I am not interested in receiving solutions for integers beyond 20, but I shall report later on

any improvements (fewer pi's) on the expressions shown here.

3. The large polygon in the top illustration on the opposite page can be cut into five congruent polygons as shown. The method obviously enables one to dissect the polygon into any desired number of congruent shapes. L. Vosburgh Lyons first published this problem in *The Pallbearers Review* for July, 1969, page 268.

4. The 32 chess pieces can be placed so that 36 "moves" are needed to transfer the pieces to a correct starting position with black at the top and white at the bottom [*see bottom illustration on opposite page*].

5. The Texas oilman's bank deposit problem reduces to the Diophantine equation $2,584x + 4,181y = 1,000,000$. It can be solved by Diophantine techniques such as the continued-fraction method explained in July. The first two deposits are $154 and $144.

The shortcut, given that x and y start the longest possible Fibonacci chain terminating in 1,000,000, rests on the fact that the longer a generalized Fibonacci series continues, the closer the ratio of two adjacent terms approaches the golden ratio. To find the longest generalized Fibonacci chain that ends with a given number, place the number over x and let it equal the golden ratio. In this case the equation is

$$\frac{1,000,000}{x} = \frac{1 + \sqrt{5}}{2}.$$

Solve for x and change the result to the nearest integer. It is 618,034. Because no other integer, when related to 1,000,000, gives a closer approximation of the golden ratio, 618,034 is the next-to-last term of the longest possible chain of positive integers in a generalized Fibonacci series ending in 1,000,000. One can now easily work backward

along the chain to the first two terms. (This method is explained in Litton Industries' *Problematical Recreations,* edited by Angela Dunn, Booklet 10, Problem 41.)

6. Contrary to most people's intuition, the most probable position of the first black ace (in a shuffled deck) is the top card.

The situation can be grasped easily by considering simpler cases. In a packet of three cards, including the two black aces and, say, a king, there are three equally probable orderings: *AAK, AKA, KAA.* It is obvious that the probability of the first ace's being on top is 2/3 as against 1/3 that it is the second card. For a full deck of 52 cards the probability of the top card's being the first black ace is 51/1,326, the probability that the first black ace is second is 50/1,326, that it is third is 49/1,326, and so on down to a probability of 1/1,326 that it is the 51st card. (It cannot, of course, be the last card.)

In general, in a deck of n cards (n being equal to or greater than 2) the probability that the first of two black aces is on top is $n - 1$ over the sum of the integers from 1 through $n - 1$. The probability that the first black ace is on top in a packet of four cards, for instance, is 1/2.

The problem is given by A. E. Lawrence in "Playing with Probability," in *The Mathematical Gazette,* Vol. 53, December, 1969, pages 347–354. As David L. Silverman has noticed, by symmetry the most likely position for the *second* black ace is on the bottom. The probability for each position of the second black ace decreases through the same values as before but in reverse order from the last card (51/1,326) to the second from the top (1/1,326).

7. The three essentially distinct solutions of the dodecahedron-quintomino puzzle are shown on Schlegel diagrams

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in the illustration on the preceding page. They were first published by John Horton Conway, the inventor of the problem, in the British mathematical journal *Eureka* for October, 1959, page 22. Each solution has a mirror reflection, of course, and colors can be interchanged without altering the basic pattern. The letters correspond to those assigned last month to the 12 quintominoes. The letter outside each diagram denotes the quintomino on the solid's back face, represented by the diagram's perimeter.

Conway found empirically that whenever the edges of 11 faces were correctly labeled, the 12th face was automatically labeled to correspond with the remaining quintomino. He did not prove that this must always be true.

Because the regular dodecahedron is the "dual" of the regular icosahedron, the problem is equivalent to coloring the edges of the regular icosahedron so that at its 12 vertexes the color permutations correspond to the permutations of colors on the 12 quintominoes.

8. The scrambled quotation is "There is no frigate like a book/To bear us lands away." It is an altered version of the first two lines of a poem by Emily Dickinson; the word "bear" should be "take."

9. There is certain to be at least one column of blank spaces on that typed page. Assume that the sentence is n spaces long, including the first space following the final period. This chain of n spaces will begin each typed line, although the chain may be cyclically permuted, beginning with different words in different lines. Consequently the first n spaces of every line will be followed by a blank space.

10. Only the following eight triplets have a product of 36: 1, 1, 36; 1, 2, 18; 1, 3, 12; 1, 4, 9; 1, 6, 6; 2, 2, 9; 2, 3, 6, and 3, 4, 3. Speaker A certainly knew his own house number. He would therefore be able to guess the correct triplet when he was told it had a sum equal to his house number—unless the sum was 13, because only two triplets have identical sums, $1 + 6 + 6$ and $2 + 2 + 9$, both of which equal 13. As soon as A was told that B had an oldest child he eliminated 1, 6, 6, leaving 2, 2, 9 as the ages of B's three children.

In last month's answers to "life's" problems the swastika's fate was given incorrectly. As D. M. Saul of the University of Illinois was the first to point out, it vanishes on the sixth move. In October I summarized the destinies of 11 pentominoes incorrectly. Five (not six) vanish quickly and four (not three) become traffic lights.

THE AMATEUR SCIENTIST

How to make an isoteniscope: an apparatus for measuring the boiling point of fluids

Conducted by C. L. Stong

A number of substances can be identified by measuring their boiling temperature. For example, oleic acid and stearic acid are chemically similar animal fats that to the eye appear identical, but oleic acid boils at 286 degrees Celsius and stearic acid boils at 383 degrees C. Either one can be identified by heating it to a boil in an open vessel at sea level and measuring the temperature with a thermometer. The altitude where the measurement is made is significant because the boiling temperature of a fluid is determined not only by the nature of the substance but also by the pressure exerted on the surface of the fluid by the atmosphere.

As a fluid is heated some of its molecules acquire enough energy to escape through the surface and exert a vapor pressure in the space above the liquid. The temperature at which this pressure equals the pressure exerted by a column of mercury 760 millimeters high is by definition the boiling point of the fluid. Chemists routinely measure the boiling point of certain fluids with an isoteniscope, an apparatus that excludes the atmosphere. With an isoteniscope the experimenter can investigate a number of properties of fluids, including their vapor pressure at any temperature, the theoretical boiling point of fluids that would be destroyed if heated to boiling, the individual pressures exerted by each gas in a mixture of gases and related information of interest, particularly to those who experiment with such instruments as gas lasers and gas chromatographs. An isoteniscope that amateurs can make at home has been designed by Walter Averett, a chemist of Vicksburg, Miss. He discusses its construction and operation as follows:

"In effect the isoteniscope consists of a closed vessel supplied with a sensitive gauge for measuring vapor pressure and a means for heating or cooling the vessel to a desired temperature. The specimen is placed in the vessel and frozen. Air is then exhausted from the system with an air pump. The specimen is warmed just to thawing. At this temperature some air absorbed by the specimen escapes and is removed by the pump after the specimen is frozen again. Customarily the specimen is frozen, thawed and exhausted several times to remove all the absorbed air. Finally, the frozen specimen, now free of unwanted gases, is thawed and warmed to a selected temperature. There a measurement is made and the vapor pressure in the space above the specimen is recorded.

"Measurements are similarly made and recorded at several arbitrarily selected higher temperatures. The tabulated results show that vapor pressure increases with temperature for all substances and by an amount that is characteristic of each substance. One need not heat a fluid to its boiling point to learn the temperature at which it boils. The boiling point can be determined graphically by plotting vapor pressure against temperature at several temperatures below boiling and extrapolating the graph to find the temperature that would correspond to a vapor pressure of 760 torr, or one atmosphere.

"The isoteniscope consists of a 10-milliliter flask connected through a tapered glass joint to a manometer [*see illustration on opposite page*]. A bypass tube that includes a stopcock connects the sample side and the outlet side of the manometer and is used for equalizing pressure between the two. The outlet side of the manometer also includes a stopcock for isolating the apparatus from the vacuum system and a tapered glass joint for connection to the accessory apparatus.

"The accessory apparatus includes a mercury manometer for measuring a maximum pressure of 760 torr; a ballast flask of about one-liter volume that cushions abrupt changes in air pressure; an air pump; a needle valve for isolating the pump from the system; a needle valve for admitting air to the system; a thermostatically controlled water bath for maintaining the isoteniscope at a desired temperature, and a cathetometer for measuring pressure as indicated by the mercury manometer [*see illustration on page 118*]. The system can be simplified if the experimenter is willing to sacrifice accuracy in the final results. For example, a meter stick can be substituted for the cathetometer for measuring the height of the mercury column. A reasonably effective substitute for the unsilvered Dewar flask can be made by nesting a pair of ordinary beakers and circulating thermostatically controlled water between the two. An adequate vacuum pump can be improvised from the compressor of a refrigerator if the check valve is removed from the inlet port of the compressor by the procedure described in *The Scientific American Book of Projects for the Amateur Scientist* (Simon and Schuster, Inc., 1960). The dimensions of the apparatus are not critical.

"I made the mercury manometer from barometer tubing that has a bore three millimeters in diameter. One end of the tube is heated in a gas burner until the bore closes. A *U* bend is made 800 millimeters from the closed end. When you make the bend, heat the glass until the bore shrinks at that point to a diameter of about one millimeter. The constriction limits the velocity of mercury in the tube and is intended to prevent the mercury from striking the closed end of the manometer with sufficient impact to fracture the glass should the vacuum be accidentally broken during operation. A right-angle bend is made in the open end of the manometer about 600 millimeters from the constriction. Shops that repair neon signs can construct the apparatus for those who do not go in for glassblowing.

"The manometer was filled by connecting the open end to a mercury still that contained some six ounces of metal. The system was evacuated to the limit of

the mechanical air pump. During the filling operation the manometer was placed horizontally but tilted so that the closed end was at the lowest point. The closed end was chilled with ice. Condensed mercury filled the tube progressively from the closed end. The still was shut down when mercury had accumulated about two centimeters beyond the constriction. When the manometer was removed from the still and placed upright, a void appeared at the closed end. This space is a vacuum and must be present.

"Depending on the barometric pressure of the atmosphere, the net difference in the level of mercury between the two arms of the manometer is about 760 millimeters. If a perfect vacuum were now created in the open end of the manometer, mercury in the closed arm would fall and mercury in the open arm would rise until the net difference would be zero, indicating zero pressure in the open arm. To make a pressure measurement you need to measure the level of metal in only one arm, because as metal rises in one arm it falls an identical distance in the other. To find the net difference measure the movement in either arm and multiply by two.

"A still can be improvised from a Pyrex distillation flask that has a ground neck mating with a tapered glass joint. The distilling operation should be conducted in a fume hood because the fumes of mercury are toxic. Incidentally, another potential hazard is the ballast flask. Apply a layer of adhesive tape to the ballast flask for confining glass fragments in case the vessel shatters while it is evacuated.

"The manometer that forms part of the isoteniscope is partly filled with oil. It indicates inequalities of pressure between the space above the specimen and the space in the manifold. The device is more responsive to changes in pressure than the mercury manometer because the density of the oil is much lower than the density of mercury. I used fluorocarbon oil to minimize the possibility of error arising from the chemical reaction of the oil with vapor from the specimen. The oil is known as Fluorolube MO-10 and is available from the Hooker Chemical Company.

"The vapor pressure of fluorocarbon oil is low, but the oil may contain air and volatile lighter oils. To remove these substances I exhausted the filled manometer to the limit of the air pump. There was considerable frothing as absorbed air escaped. A beaker of hot water was then raised around the U-tube, and pumping was continued until the oil stopped bubbling. The glass was also tapped lightly to encourage the release of additional gas. Subsequently I learned that the oil absorbs gases from acid specimens, particularly at elevated temperatures. For this reason I routinely degassed the manometer between tests and after a few runs refilled it with new oil.

"The isoteniscope must be maintained at a temperature as nearly constant as reasonably possible. Ordinarily the temperature is deliberately varied through a range during a test, but the temperature must be closely controlled at selected points. The isoteniscope is rigidly mounted with enough neighboring space so that the specimen flask can be immersed by raising a vessel of water under the apparatus.

"This arrangement enables the experimenter to conveniently submerge the specimen in refrigerant or in a constant-temperature bath. Depending on the nature of the specimen, I do the freezing with either a slurry of dry ice in acetone or with liquid nitrogen. Frozen specimens are warmed by a water bath.

"Originally I submerged the apparatus so that water covered the stopcock in the bypass line, but I discovered that I could not keep the stopcock vacuum-tight at elevated temperatures. I had to lower the water level to clear the stopcock, thus exposing a small section of the vapor line to the atmosphere. The top of the vessel was covered with a
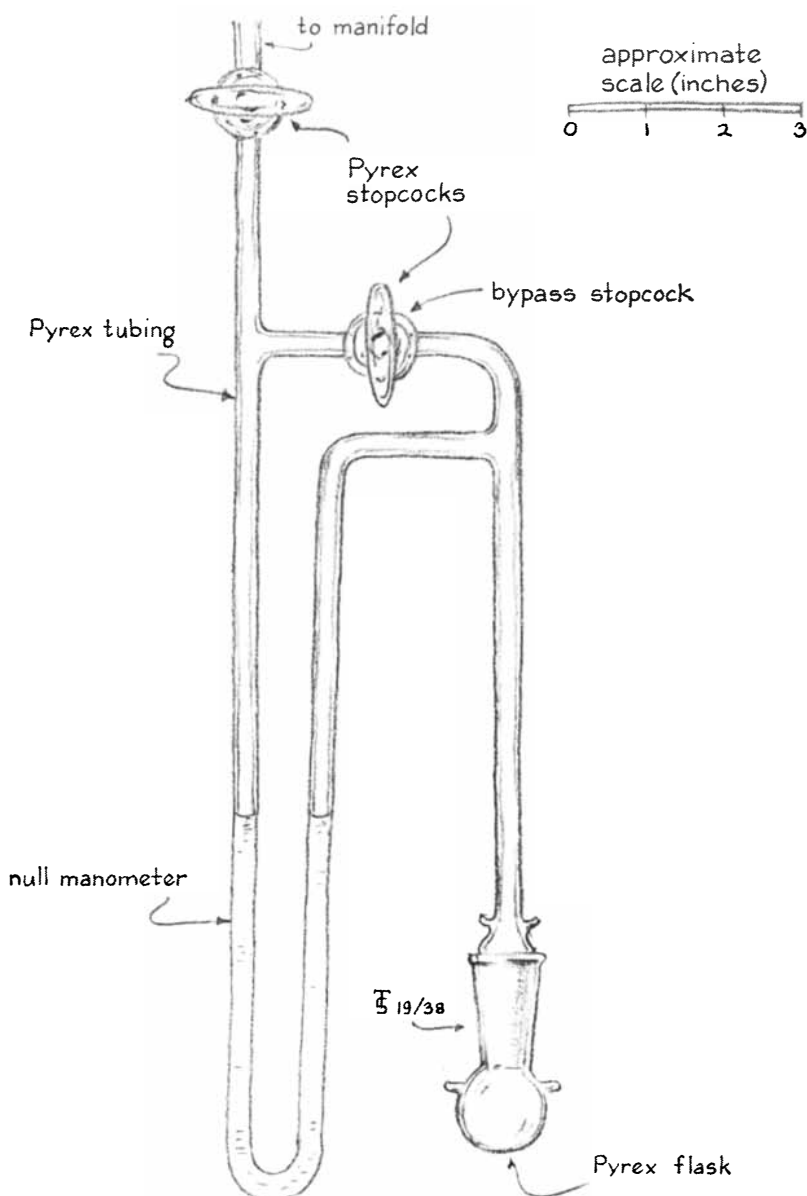
Walter Averett's isoteniscope

sheet of aluminum foil to reduce the exchange of heat between the bath and the room.

"After the apparatus has been assembled the system must be tested for air leaks. Initially I used Kel-F grease No. 90 on all stopcocks and ground-glass joints. It turned out that the grease tended to leak when the apparatus was operated at 85 degrees C., the maximum temperature in my experiments. The problem was solved by coating the ground joint of the specimen flask with a mixture of Kel-F grease and Type 25–20M grease, a product of the Halocarbon Products Company. Avoid using excess grease: thick layers tend to flow and invite a leak. When the system has been exhausted to the limit of the pump and sealed off, the rise of pressure over a period of 12 hours should not be more than two millimeters.

"The procedure for a test run will be apparent if I give an example in which the boiling point of nitric acid is determined. It is next to meaningless to try to obtain a specimen of pure nitric acid, heat it to boiling and measure the boiling point with a thermometer, because

the acid continuously decomposes as it is heated. On the other hand, it is relatively easy to measure the vapor pressure of the acid at several temperatures below boiling, to make a graph by plotting vapor pressure against temperature and so by extrapolation to estimate what the temperature of the mixture would be at a pressure of 760 torr.

"With a pipette fill the specimen flask almost to the top with acid. The object of almost filling the flask is to minimize the empty space in the isoteniscope. (The flask could be filled with a substance that is normally solid at room temperature, such as paraffin wax, by melting the wax.) Exhaust the system to the limit of the air pump.

"With the bypass stopcock open freeze the acid by immersion in liquid nitrogen. (Were the specimen an aqueous solution the freezing could be accomplished by a slurry of dry ice.) Close the valve to the air pump and warm the specimen until it becomes slushy. This procedure will release absorbed air and carbon dioxide but not any significant amount of nitric acid, water or nitrogen dioxide because the freezing point of the

mixture ranges from −20 to −40 degrees C.

"Repeat the freezing, thawing and pumping three times. Make a test to determine if the specimen has been adequately degassed by again freezing the acid and, after closing the valve to the air pump, closing the stopcock in the bypass. Any gas released by the specimen will be indicated by the oil manometer.

"Record the level of the mercury in the closed-end arm of the mercury manometer. Make the reading by observing the top of the meniscus in relation to the meter stick. If a cathetometer is used, set the hairline of the telescope even with the top of the meniscus. This reading represents zero pressure.

"Remove the freezing bath and let the specimen warm. As the temperature rises vapor will be released by the specimen and will displace the oil in the oil manometer. Carefully crack the needle valve that opens to the atmosphere. Admit just enough air to establish equilibrium in the two legs of the oil manometer. The adjustment is a bit tricky, but you will soon develop the knack of admitting air at a rate that establishes and
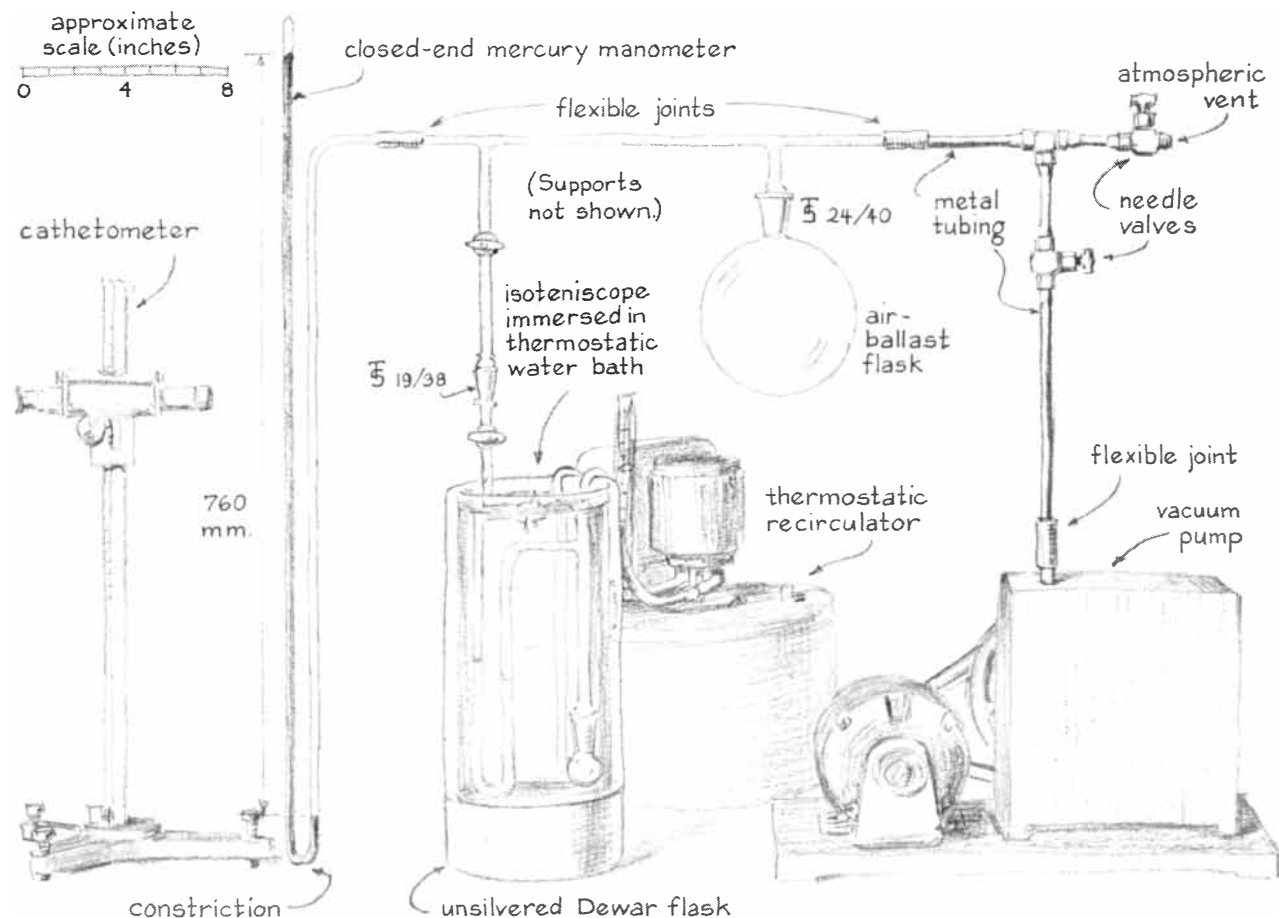
Accessories for the isoteniscope

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maintains the equilibrium. If air is admitted too rapidly, oil may be blown into the specimen, ruining the test.

"It is assumed that the specimen is surrounded by a water bath at some minimum temperature above freezing and that this temperature is measured by a thermometer. When the oil manometer remains in equilibrium for a few minutes, you can assume that the temperature of the specimen equals that of the water bath. At that temperature read the pressure as indicated by the mercury manometer and record the temperature and the pressure.

"Raise the temperature of the water bath a few degrees. As the specimen warms and liberates vapor again admit air to maintain equilibrium in the oil manometer. After the specimen has reached the higher temperature read the vapor pressure as indicated by the mercury manometer. With nitric acid I usually measure the pressure in intervals of 10 degrees from 0 to 80 degrees C.

"If the specimen were a stable liquid, such as water, the measurement would now be complete. A graph of the results could be made and extrapolated to find the boiling point. As previously mentioned, however, nitric acid continuously decomposes when it is heated. As the temperature rises the specimen becomes a mixture of nitric acid, nitrogen dioxide, nitrogen tetroxide and other oxides of nitrogen plus water. The proportions of nitrogen dioxide and nitrogen tetroxide change with both temperature and pressure. Indeed, the proportions can change even though the specimen is held at constant temperature, with the result that the vapor pressure may change at constant temperature. Hence the pressure readings as recorded can only be a best approximation at a given temperature.

"An interesting check of chemical decomposition can be made by recording a series of measurements as the specimen is cooled from an elevated temperature. If the specimen is stable, the resulting measurements will match those made when the specimen was warmed. If the specimen decomposes, the pressures will be somewhat greater during the cooling run. A graph of the results of both the heating run and the cooling run will take the form of a hysteresis loop [see top illustration at right]. The area enclosed by the loop varies with the extent of the decomposition.

"Because of the decomposition the pressure measurements actually are measurements of partial pressures. The total pressure is the sum of the vapor pres-
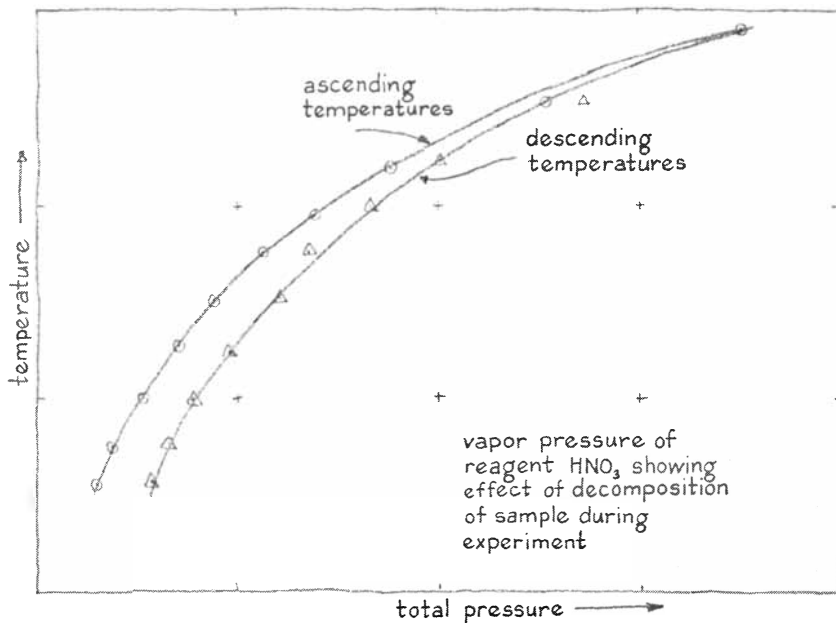
Results of a measurement of chemical decomposition

sures of each of the components in the mixture. The measurements are not misleading in the case of decomposing nitric acid because one is interested in the behavior of the mixture. Measurements could be misleading if one were under the false impression that one was testing a pure solution of nitric acid in water.

"When the vapor pressures have been recorded for the selected temperatures, the next step is to draw a graph of the results. I prefer a plot of the type first suggested in 1923 by the chemist Edwin R. Cox. It displays pressure v. temperature, but the temperature axis is laid off in units of vapor pressure of a standard substance [see illustration below]. For example, the vapor pressure of water is well established: 760 torr of water vapor appears at 100 degrees C., hence the temperature point of 100 degrees C. on the plot can be designated as 760 torr. At each lower temperature water has a known vapor pressure, and so the axis can be calibrated in units of pressure that are equivalent to units of temperature. If the vapor pressure of the specimen is plotted against these pressure
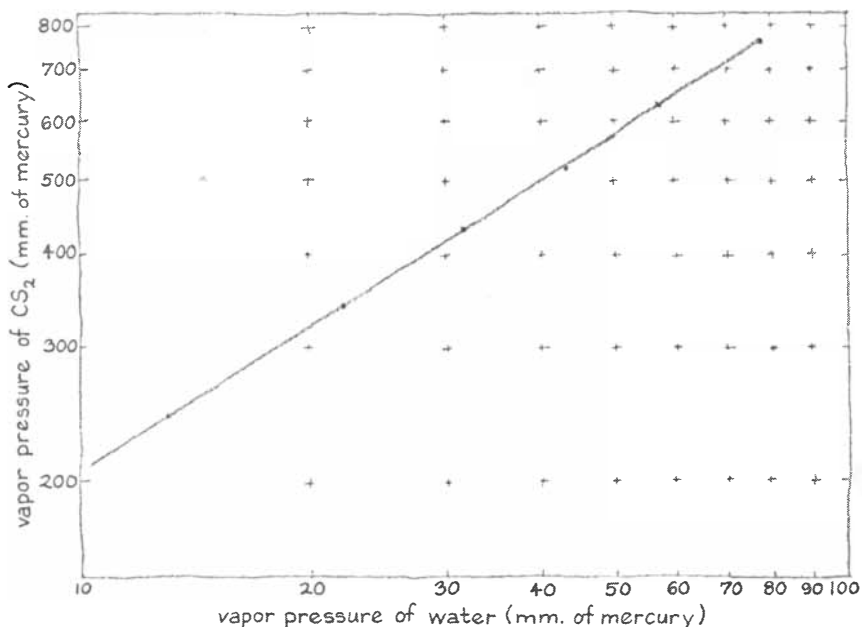
Pressure v. temperature, with temperature in units of vapor pressure of a standard substance

total pressure (mm. of mercury)

— + — .21% NO$_2$, 83.6% HNO$_3$ —□— .48% NO$_2$, 83.6% HNO$_3$
— • — .30% NO$_2$, 84.0% HNO$_3$ —△— 1.49% NO$_2$, 81.7% HNO$_3$
— × — .44% NO$_2$, 83.6% HNO$_3$ —⊙— 2.52% NO$_2$, 81.5% HNO$_3$
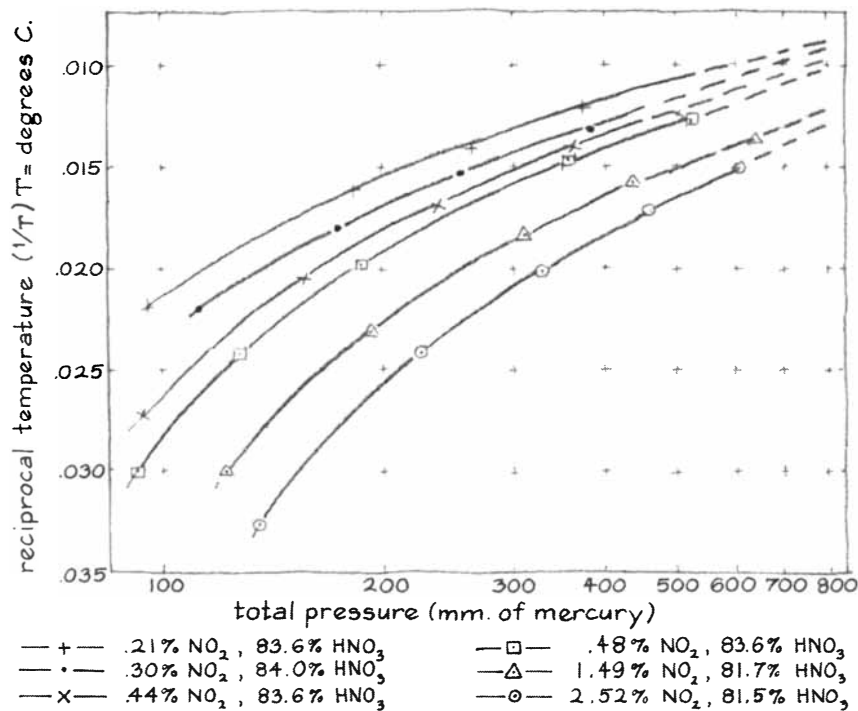
Pressure plotted against the reciprocal of temperature

total pressure (mm. of mercury)

vapor pressure of water (mm of mercury)

—⊙— 2.52 % NO$_2$, 81.5% HNO$_3$ — × — .44 % NO$_2$, 83.6% HNO$_3$
—△— 1.49 % NO$_2$, 81.7% HNO$_3$ — • — .30 % NO$_2$, 84.0% HNO$_3$
—□— .48 % NO$_2$, 83.6% HNO$_3$ — + — .21 % NO$_2$, 83.6% HNO$_3$
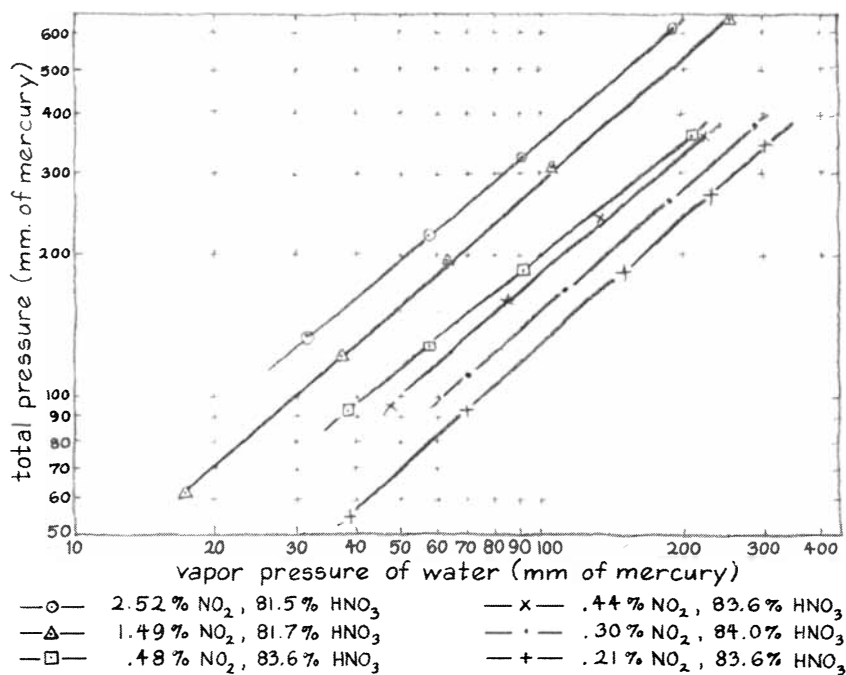
Plots of pressure v. temperature for a nitric acid system

equivalents of temperature, a straight line results. A plot of vapor pressure against temperature is not linear, but a graph in the form of a straight line results when two vapor-pressure curves are plotted against each other. The Cox chart lends itself nicely to extrapolation because it is easier to extend a straight line than a curved one. A little time spent in plotting the data will soon lead

the experimenter to the form of plot that seems most useful to him. Another form often used is the plot of vapor pressure against the reciprocal of temperature.

"In addition to its usefulness as an instrument for measuring vapor pressure the isoteniscope is a handy tool for preparing gas mixtures according to a set of prescribed partial pressures. My work in gas chromatography and infrared

spectrophotometry requires the preparation of gas standards of known composition. I find it convenient to use a manometric method, wherein a sample bulb is evacuated and then a specified gas is admitted to obtain a certain pressure.

"A Bourdon gauge is adequate in the general range of .25 atmosphere and higher, but the reading error soon becomes impossibly large at lower pressures. For example, my gauge is calibrated for a vacuum ranging from 0 to 30 inches of mercury, but there are only three divisions in the interval from 0 to five inches, which corresponds to about 40 torr per division. In contrast, the isoteniscope is reasonably accurate to .5 torr.

"Assuming that the air pump exhausts the system to zero pressure, the introduction of gas to a pressure of 76 torr amounts to .1 atmosphere, and the system contains 10 percent of the amount of gas it is capable of holding at a pressure of one atmosphere. Another gas can be introduced to bring the pressure up to exactly one atmosphere, in which case the concentration of the first gas would be 10 percent by volume. (It is assumed that the temperature remains constant, that no chemical reaction occurs, that there is no association or dissociation and that the gas compressibility can be neglected.)

"Thus by using gas sources such as cylinders or lecture bottles any desired mixture of compatible gases can be prepared, including helium-neon, helium-argon, helium–carbon dioxide and similar mixtures used in gas lasers. My infrared spectrophotometer has a cylindrical Pyrex cell, 10 centimeters long by about five centimeters in diameter, with a sodium chloride window at each end and with two sidearms complete with stopcocks and 18/9 ball joints. If the Dewar flask and the sample flask are eliminated from the isoteniscope and its associated equipment, a simple adapter makes it possible to connect one sidearm of the infrared cell to the 19/38 joint where the sample flask would normally be. One or more gas cylinders can be attached to the other sidearm of the cell through a manifold.

"The entire system is then evacuated, up to the leaktight valve on the gas cylinder, and the vacuum pump is isolated. The bypass stopcock is closed, the cathetometer is set to read the calculated pressure and gas is slowly bled into the cell while air is admitted to the vacuum side to keep the oil manometer in balance. When the mercury meniscus reaches the correct point, the calculated pressure of the gas will have been intro-

duced into the cell. The sidearm stopcocks are closed and the gas cylinder is removed, or additional gas is added to the next calculated pressure.

"The bypass stopcock can then be opened and air can be bled in until the vacuum in the system has been relieved. This can be done so that the corrosive gas will not escape from the system. A liquid-nitrogen trap can be installed to protect the manometer. A trap should be used in any event to protect the vacuum pump, unless some other expedient can be devised."

BOOKS

by Philip and Phylis Morrison

I n the 19th century the word "children" meant people up to the age of their majority; nowadays one tends to think of children as being people below the highest primary school grades. The books we have selected here by no means appeal exclusively to grade school youngsters. We have not omitted books for young children, but we have included many aimed at the enthusiasms and the need for new paths of readers of college age.

Men of the Past and Present

DWELLERS OF THE TUNDRA: LIFE IN AN ALASKAN ESKIMO VILLAGE, by Aylette Jenness. With photographs by Jonathan Jenness. Crowell-Collier Press ($5.95). On the shelving coast of the cold Bering Sea, a day's walk across the boggy tundra of summer from any neighbor at all, live 150 of our fellow citizens: the people of a village here called Makumiut. "There was a village, set on a hill beside a river, where the river enters the sea," begin the old Eskimo tales. This small, intimate, deeply felt book, with its intense photographs sharpening the clarity of the text, tells the story of the villagers and their pursuit of happiness. Grandmother Chahnak was born near Makumiut 70 years ago. Her son Edward is a highly successful hunter, the richest man in the village; his cache house is 10 feet high at the ridge, sheathed in corrugated aluminum and crammed with muskrat skins, kegs of seal oil and bundles of delicious oily smoked salmon. But canny Edward drinks too much, starting on home brew at an open house in his store and ending sullen, ill, weak and repentant only after he has finished the whisky sent by airfreight from Anchorage. Another family, the Tuliks, are losers: their skiff foundered, their dogs died, their new baby died in the night after the doctor who

prescribes by radio had authorized the chartered plane to carry the infant to the hospital in the morning. "Norma Tulik visits around more than most women." Her children cry easily and often; they are dirty; their cabin does not have room even for a table. The condition of mankind is not uniform for the hunters in those too big spaces, for the women housebound in their too little houses, for the happy, fat, passive, secure infants and for the hard-hit young people, living between childhood and responsibility in two vastly different worlds. It is not all sorrow; there is delight and hope and joy in the year and in the book. Still, the burden of real life is heavy here. This book is a compact, wise, respectful account of that load.

ESP, SEERS & PSYCHICS: WHAT THE OCCULT *REALLY* IS, by Milbourne Christopher. Thomas Y. Crowell Company ($6.95). The most articulate "professional illusionist" of the day, and a man at home in the library no less than on the stage, Christopher has taken the role of the skeptic with verve and learning. The confusion of eyewitnesses, fraud, unconscious motions, imprecise reporting and willful exaggeration: such are the true causes behind thought-reading, calculating horses, table tilting, the Ouija board, poltergeists and the oracles of television ("Jeane Dixon & Co."). Barefoot fire walking, on the other hand, is a real exercise in heat transfer; anyone can do it over a bed of well-burned glowing embers for a few light, quick, confident steps. Just as real is surviving burial alive, if your time underground is not too long. Acquired voluntary control of the "autonomic" nervous system, now verified in the laboratory, is likely to play some part, although Christopher ignores it.

The feats of the spiritualistic medium, the most famous being D. D. Home in the late 19th century and Eusapia Palladino some 50 years ago, are painstakingly reduced mainly to ingenious trickery and misdirection. Among other things, Home could make himself taller and

shorter at will. So could a contemporary vaudevillian, Clarence E. Willard, who at 84 could still stretch five inches while he talked, his feet flat on the floor. He had frequently performed under medical observation; he had learned by diligent practice, inspired by "watching tigers extend their reach in a circus." The main method of this delightful and convincing book, as it has always been for critics of such uncontrolled phenomena, is that of William of Occam. We cannot now prove just what Home did, but we can exhibit the same effects and argue that it is more economical to assume the same causes.

The largest topic touched on is extrasensory perception. Christopher, citing the remarkable work of C. E. M. Hansel, a psychology professor now at University College of Swansea in Wales, describes the use of supersonic whistles and of synchronized counting to pass a little information about those cards through undetected sensory channels. (Children can hear the whistle but elderly experimenters cannot!) There is an excellent bibliography of works in French and English, a fine set of historical advertisements and comment on wonder-workers past and present. In 1966 Christopher was present at the Bombay walk-on-water of a well-known yogi. "With complete confidence [the white-bearded mystic] stepped on the surface of the water. As the huge audience gasped, Rao sank immediately to the bottom."

POTS AND ROBBERS, by Dora Jane Hamblin. Simon and Schuster ($4.95). The clever title conceals a central theme: this is a book about Italy and the Italians. That is a land where two or three millenniums of culture lie in the ground or in the grotto. The quick, more numerous and no less able and energetic than the dead, search out, steal, remove, forge, deal in and above all enjoy the works of their ancestors. The author, in a book for teen-agers and anyone else, tells from her firsthand experiences as a bureau chief in Rome for *Life* what the raffish side of archaeology is like today in Italy,

the "most exuberant and hospitable of nations." There are heroes, for example the highway engineer Erno Bellante, who found the grotto of Tiberius from a few remarks passed with a local boy at Sperlonga. The scholarly superintendent in Rome, who had the official responsibility for antiquities, concurred; he too knew of the grotto and the connection with Tiberius. The highway workmen with Bellante, however, were a new resource. Their 1957 pioneering led to the now famous art treasures of Sperlonga. Then there is Carlo Lerici, who introduced to Italian archaeology geophysical instruments, camera probes and sampling drill rigs, which increase the productivity of archaeological discovery by orders of magnitude.

There are thieves great and small, and detectives in the same range. We meet Alfredo Fioravanti, who 50 years ago, with a couple of friends in the small kilns of the family pottery shop in Orvieto, made the three big terra-cotta "Etruscan" figures so long justly admired at the Metropolitan Museum in New York. This is a genuinely entertaining, wonderfully lively book, telling a dozen fast tales of crime, international wheeling and dealing, worldliness, ingenuity, science and devotion to country. It is all true and, even better, it is well told.

THE FIRST ARTISTS, by Dorothy and Joseph Samachson. Doubleday & Company, Inc. ($4.95). The rock and cave paintings *Homo sapiens* has done all over the world form one of the strongest networks that bind humankind together over time and space. This smoothly written book for grade school and teen-age readers gives an introductory account of the pictures, their discovery, the mediums, the techniques, the conjectures about meaning and above all some 100 photographs of the images themselves. Shown in color are 16 of the most famous paintings, mainly those at Lascaux and Altamira, but also some in Africa, Australia and New Mexico. (Only South America is slighted here, as it is in much of the professional literature.) The up-to-date interpretations are given; indeed, the book is more inclusive than nearly all the lengthier works. There is an index, but a bibliography is badly missed. The book fittingly begins its main account with the story of five-year-old Maria de Sautuola, who first looked up at the bison on the ceiling at Altamira, only a dozen yards beyond where her father was sifting the soil of the floor for stone artifacts. She lived to see Altamira recognized as high art of ancient man,

but her father, Don Marcelino, died repudiated as a dupe or a fraud by most of his colleagues.

CAPTAIN COOK & THE VOYAGE OF THE *ENDEAVOUR* (1768–1771), by Captain Frank Knight. Thomas Nelson Inc. ($4.95). This is the bicentenary of the voyage of the bark *Endeavour,* which first made Australia and New Zealand known to Europe. (A few earlier explorers had touched those shores but none had established their nature and extent.) The master of the voyage was the son of a farm laborer, a self-made cartographer and writer, a man of the Enlightenment, reasonable, humane and broad. This is his fascinating journal of the voyage, abridged for teen-agers from the recent multivolume edition of Professor J. C. Beaglehole. It is well presented, with good maps and drawings of the ship, of kangaroos, of Botany Bay and more. Captain Knight knows the sea and Cook's navy; the guidance he gives us is always clear and helpful. The voyage has tragedy in it; Europe and Polynesia were too far apart for even Cook's fairness to join them peacefully. "Mr. Gore fired a musket at them, and from what I can learn killed this man who took the cloth. I must own that it did not meet with my approbation because I thought the punishment a little too severe for the crime."

THE FANTASTIC MIRROR: SCIENCE FICTION ACROSS THE AGES, by Benjamin Appel. Pantheon Books ($3.95). The classics of science fiction are excerpted here, from the often-mentioned but little-read Lucian, a few pages of whose second-century *True History* are given, up to a Russian story by Valentina Zhuraleva, paired with a 1947 piece by Murray Leinster. On the way we read extracts from Kepler and Swift, Poe and Verne, Twain and Wells, and half a dozen other less notable but nonetheless excellent examples. The author is a novelist and a writer of many books for young readers; he displays his stories well as mirrors of what each generation saw in science. Between Verne and Twain and even the gloomy Poe there was a bond of buoyant hope. Today fear and dreadful war dominate the imagination, yet the book ends quite movingly with two writers, Russian and American, who hold out the hope of the "utopian planet men call Peace." This is absorbing reading for young teen-agers, who may seek their librarian's aid for more of the real thing as Appel urges them to do. The many illustrations are well chosen; it is a bit unfortunate that the sources of some

are not clear. The Verne projectile train shown is a kind of dream within the dream, not the "real" projectile at all.

ADVENTURES IN DISCOVERY, edited by Tom Purdom. Doubleday & Company, Inc. ($4.95). Ten original essays, each on a single topic in science, narrow or broad, make up this book. They are without exception excellent: the authors are 10 professional writers of fiction, mainly science fiction. They know and love science, and they embed their stories in a context of motive and concern. The names are familiar: Willy Ley and Hal Clement, Isaac Asimov and James Blish, Poul Anderson and L. Sprague de Camp, and more. There are nuggets of surprise here too. Hot water freezes faster than cold in most refrigerators, just as Aristotle and Roger Bacon explained it would. (The container melts its way into more intimate contact with the cooling surface.) A short piece on the epidemiology of serum hepatitis by Harry Harrison is an extraordinarily crisp "process of deduction." Swedish "orienters," the sharp, athletic young men and women who make a sport of finding their way to mapped checkpoints through the forests of the northern winter, came down with that serious disease 150 times more frequently than the average of the entire population. Danish orienters had not a single case. The same sport, similar people only a long ferry ride away. Why? You will have to read the book to find out.

INDIAN SIGN LANGUAGE, by William Tomkins. Dover Publications, Inc. ($1.25). A facsimile reprint of the fifth edition (1931) of a work very much marked by its place and time. Mr. Tomkins lived "when a boy...on the edge of the Sioux Indian Reservation in Dakota Territory.... He worked on the cow range." Here he is shown, a young man in 1890, stern on his cow pony Blaze. The period style and trappings (witness a letter from Sir Robert Baden-Powell and a final poem not unlike "Home on the Range") enfold an alphabetically arranged dictionary of almost 800 signs of the "Universal Indian Sign Language of the Plains Indians of North America." The equivalents also appear in French and German; there is a drawing for each sign and a sentence of instruction. Exercises and the needed grammar are included, and an interesting case is made for the probable relation of the Plains *lingua franca* to the pictographs widespread in the West. The famous moon-and-disk form conjectured by some au-

thors to refer to the supernova of 1054 is here given the rather concordant meaning "shining, bright." Altogether a good buy, although many values have been transformed since the author ("Sign Talking Eagle") was adopted by the Sioux.

Technology

TECHNOLOGY IN THE ANCIENT WORLD, by Henry Hodges. With drawings by Judith Newcomer. Alfred A. Knopf ($10). The history of technology has not before this excellent book been thus set down for the youthful or the general reader. There are fascinating volumes on this or that period or craft; there are also excellent multivolume works prepared in Britain and in France covering the entire subject. The present author and his gifted illustrator have made one readable, modest book tell the story overall. Nor is the story skimped; naturally some richness of detail is gone and, more serious, the sources are more or less suppressed. The book does have many photographs and original drawings.

The narrative begins with an introduction to how we know about the old crafts and about the environment in which they grew. It continues more or less chronologically from flint tools to the end of the Roman Empire, including agriculture, the evolution of writing and of cities, trade and shipping, the civil and mechanical works of Greece and Rome and a chapter very agreeably surveying the rest of the world: "barbarian" Europe, India, China and the New World. The pace is lively and the tone sure. Ancient bureaucracy gets no charity from Hodges; weighing very lightly a good deal of evidence, he is committed to the superior inventiveness of unstable periods in history. Materials engage his interest most easily; it is clear that he prefers chemistry to physics. One marvelous gadget is a bronze sickle with a wooden handle cunningly fitted to the user's thumb and fingers that "would undoubtedly win an award at any design center." It was made by an alpine peasant craftsman 3,000 years ago.

FIRST ON THE MOON: A VOYAGE WITH NEIL ARMSTRONG, MICHAEL COLLINS AND EDWIN E. ALDRIN, JR., written with Gene Farmer and Dora Jane Hamblin. Epilogue by Arthur C. Clarke. Little, Brown and Co. ($7.95). WHERE THE WINDS SLEEP: MAN'S FUTURE ON THE MOON, A PROJECTED HISTORY, by Neil P. Ruzic. Doubleday & Company, Inc. ($5.95). Putting aside the cant and the hyperbole, it *was* a giant step 18 months ago, first upward and then down into the dusty Sea of Tranquillity. These two books celebrate that step, without sidelong looks, cost-benefit analysis or even judicious balance. They are all sincere praise and merited wonder, and they will be good reading for many a young dreamer and doer.

First on the Moon is the "exclusive and official" account, the personal record of the "grandest voyage in history." In form it is first of all a smooth and sensible reporter's story setting the context and chronology of Apollo. Interviews with a few key people among the hundreds of thousands of men and women who made Apollo work merge into long quotations from the three astronauts, who give their biographies compactly. On this base is set a well-knit narrative of the flight itself, mainly in verbatim tapings from the long microwave conversations, edited with an accuracy greater than the newspapers could achieve at the time. The three men fit similar rubrics: all are about 40, cheerful husbands and fathers, fighter pilots become test pilots. They differ a good deal in this closer look. Armstrong is dedicated, deep, earnest; Aldrin, a Ph.D., held a lonely Communion service on the moon and walked without fanfare in a Houston procession the first Palm Sunday after Dr. King was killed in Memphis; Collins, the Army brat without any hometown, is iconoclast enough to look up at the television camera during solemn prayer aboard the carrier, precisely toward the chair where his wife far off in Texas was watching their home screen.

The finest single moment and the role one somehow wants to dream into—less awesome than that of the chosen who went to the moon—belongs to young Steve Bales. He was one of the quiet, tense watchers in Mission Control. It was he who in a few seconds found reason to ignore the computer's overload alarms in those last moments of landing because they "were not recurring often enough, *not quite often enough.*" He was right, and *Apollo 11* came back safely.

The epilogue to *First on the Moon,* and the whole of the smaller *Where the Winds Sleep,* treat the same theme: how men can hope to use the moon. Arthur Clarke puts the case as well as it can be put, and Neil Ruzic, with a good deal of insight into men and nature, writes a mock history of mankind on the moon: after 75 years a few tens of thousands of them are in residence, engaged in astronomy, vacuum technology for the clean assembly of devices and the production of pure materials, even low-gravity therapy. "Some say man came to the moon to do science.... Others [to] feel the low gravity so he could live longer.... But man really came to the moon to fly." They fly like birds with fabric wings in airy domes!

Where the Winds Sleep is plausible, thoughtful and engaging. Its title is from a sea poem by Matthew Arnold. There is an index, which is missing from the Apollo book.

THE GREATEST DEPTHS: PROBING THE SEAS TO 20,000 FEET AND BELOW, by Gardner Soule. Macrae Smith Company ($5.95). HISTORIC SUBMARINES, by F. W. Lipscomb. Illustrated by Malcolm MacGregor. Praeger Publishers ($10). In the summer of 1969 Jacques Piccard and his crew in their Swiss-built submarine, the *Ben Franklin,* drifted in the Gulf Stream as silently as the plankton for 30 days. At depths of between 600 and 2,000 feet they made about 50 miles a day. Piccard took along a copy of *Twenty Thousand Leagues under the Sea,* and like Captain Nemo he could view the sea through portholes from his wardroom table. The *Glomar Challenger* drills into the bottom with a four-mile string of pipe; she is able to penetrate the bottom with her diamond drill bit and bring up a sample core from half a mile into the ooze and rock. She is kept in position by her six propellers, which are controlled by signals from sonar beacons dropped to the solid bottom before the drill string goes down. Full of computerized feedback controls and receivers for satellite navigation and weather mapping, she is a ship of "unbelievable technical sophistication," the realization of Mohole dreaming. Men first went deep in a simple steel sphere, let down on a cable, as William Beebe was a generation ago, or buoyed up by a gasoline-filled "balloon," as the men of the *Archimède* and the *Trieste* were. These latter craft have reached the bottom in the deepest trenches of both great oceans. Soule, a science journalist with a long interest in the sea, has written a fascinating account of the quest for the ocean deeps. By taking aim at a specific topic he has given deep-sea research an interest and immediacy that will ensnare any reader.

Commander Lipscomb, a knowing veteran submarine officer of the Royal Navy, has compiled a detailed brief history of the submarine not as a benign tool of deep-sea exploration but as a stealthy means of destruction. He provides period illustrations in black and

white of the long history of the attempt of men outgunned at sea to attack shipping from vessels awash or below the waves, from the time of James I through Robert Fulton to the Confederate navy. The modern submarine, however, was born in the 20th century, and the rest of these large pages bear elegant, hard-edged, colorful paintings of 16 submarines, each against a white background, from a pioneer French boat of 1900 to a Polaris submarine launched in 1959. The Japanese sent out five aircraft-carrying submarines in 1945 to attack the Panama Canal. The war ended too soon for them, but one such diesel-electric boat, the I-400 shown here, carried the bombers and was as long and large as a Polaris submarine.

THE COMPLETE WALKER, by Colin Fletcher. Alfred A. Knopf ($7.95). His credentials are authentic: Fletcher has walked as surveyor across the Kenyan highlands, hiked the length of California across the deserts and along the high Sierra ridge and legged it through the entire Grand Canyon of the Colorado, alone, cheerful, reflective and most thoughtfully equipped. He writes as well as he walks, like a new Thoreau faced with the evaluative responsibilities of Consumers Union. His choice of equipment and supplies is based on intimate experience, experimental trial, clear thinking and all the data he can get. Failure of a plastic bottle can mean death by thirst; his is a serious technology. His central taste, however, is philosophic: "I like to walk alone.... If you choose, sensibly, to travel in twos...or twenties, ... everything I have to say still applies. You miss something, that's all. You never quite learn for instance that one of the riches a wilderness has to offer is prolonged and absolute silence. There is one notable exception to my rule. When you and your companion are newly in love ... the bond enriches everything you see. And that is the best walking of all."

Learn about flashlights and maps, binoculars and oregano, conservationists and calorie lists, polyethylene tube tents, how to ask questions of total strangers (and gauge their reliability) and how to establish empathy with rattlers. "It yawned.... Finally, with such obvious contentment...it laid its head gently on the pillow of its clean and beautifully marked body."

In a year or so this book has become a practical guide for a great many young backpackers. Its wit and its depth of thought and feeling extend its value beyond that of a handbook, but first-rate handbook it remains, complete with checklists, brand names, retail stores and addresses of walkers' organizations.

ELECTRONIC FLASH, STROBE, by Harold E. Edgerton. McGraw-Hill Book Company ($22.50). That jeweled crown of a milk-drop splash was first photographed by Professor Edgerton in 1937. He had been working with sparks and arcs for about five years until he found the convenience and power of those fast puffs of photons made by the plasma columns in inert-gas lamps, triggered by a quick voltage pulse along the lamp wall and nourished by a hefty condenser discharge. That technique is now an industry, familiar in machine shop, textile mill, photographer's studio, big lighthouses, a couple of satellites that flash on command and wherever there are fluttering wings or spinning dancers.

This expensive book is Edgerton's own account, on a practical and personal engineering level, of the circuit theory of electronic flash, its detailed design over a variety of systems, with a practical look at the applications for which so many devices now exist. The theory of electric discharge is still of little use in the design of flash lamps; the lamps themselves lie outside the scope of the book. A good xenon tube—the best gas because of its daylight-like color—delivers tens of photons per gas atom in a normal flash. Its flash time is controlled mainly by circuit features. The usual modern portable flash unit, with its efficient electrolytic condenser for energy storage, is fast enough (200 or 300 microseconds) for "people and other slow subjects," but paper condensers and special circuit arrangements to cut afterglow are needed for subjects such as hummingbird wings and bullets. A practical bright short flash is made by an arc guided along a quartz tube open to the air; air has only a brief and reddish afterglow. The biggest flashes are xenon ones for night aerial photography.

The book includes a list of suppliers, and a set of 12 "experiments and experiences" that can be repeated with a fair amount of equipment. For certain young experimenters, or for an advanced amateur who has the necessary resources, this book and its warm and open invitation to enter the art will be a treasure.

THE MOTOR BALLOON "AMERICA," by Edward Mabley. The Stephen Greene Press, Brattleboro, Vt. ($4.95). The readers of a *Scientific American* issue in October, 1910, could study diagrams and photographs of the dirigible that would be headed for Europe from Atlantic City within the coming weeks on the first of all human transoceanic flights. The Paris-built airship was hydrogen-filled, with subdividing bags within her non-rigid envelope 75 yards long; she was powered with two gasoline engines and equipped with a wireless. She carried six dashing voyagers and Kiddo the Cat. Her captain was a newspaperman in the tradition of Henry M. Stanley. He did not merely report news; with financial support from a set of newspapers, all with big Sunday supplements to fill, his profession was rather to make it. William Wellman, elegant in top hat, wing collar and white mustache, was a man of genuine courage and talent; it was by no means his first gallant expedition. He had tried for the North Pole several times both by sledge and by dirigible, but Robert E. Peary had just won that race. The balloon was lost, but all her company were rescued by a steamer 400 miles off Cape Hatteras. The story is a period piece, with wires of congratulation from President Roosevelt and Admiral Peary, and plenty of fine writing such as the following by Wellman: "Tears stood in the eyes of the unemotional engineer when he realized we were communicating to the shore back and forth with Signor Marconi's wizard will-o'-the-wisp whisperings, through the misty miles."

The New York Times, a backer, carried six full pages on the rescue; *The Chicago Tribune,* not a sponsor, remarked editorially: "What gets us is how a perfectly sane cat ever consented to go." The author was a boy excitedly watching the takeoff that foggy morning from the boardwalk; we share his pleasure in the writing of this delightful true tall tale 60 years later.

Physical and Earth Sciences

HOW TO MAKE & FLY PAPER AIRPLANES, by Captain Ralph S. Barnaby, U.S.N. (Ret.). Bantam Books (75 cents). FLYING KITES, by James Wagenvoord. Collier Books ($2.95). Captain Barnaby is a redoubtable paper-airplane designer who proved himself by winning the first prize in aerobatics in the International Paper Airplane Competition sponsored by *Scientific American*. He writes and draws as well as his small craft fly, and he has been making paper airplanes ever since the Wrights were flying larger versions made of wood and canvas. He holds United States Soaring Certificate Number One. His little book, an absolute best-buy reprint, outlines briefly but

richly the principles of stable flight and is sure to induce a "feel" for the forces on a model in the air. Careful directions follow for a variety of designs, including the champion model itself. Barnaby's law—"Regardless of direction or technique of launch, a paper airplane will invariably come to rest at the most inaccessible landing site"—seems a worthy corollary to the great general laws of experience. Get the book, and some paper.

The kite book is another genuine value in home aeronautics. It includes a good account of the history of this delectable art (although it is ignorant of the giant Japanese kites), with many illustrations. Its special strength is in the people and places caught up in the renascence of kite-flying in this country in the 1960's. The efforts to send a kite across the Atlantic, with its string dragging a plastic pail as a sea anchor, will one day succeed. There are a dozen careful designs for kites, of which the version of the Scott Sled, given with very practical details, and the folded-sheet-of-paper minimal kite catch the eye.

ROCKS AND MINERALS, by E. P. Bottley. G. P. Putnam's Sons ($5.95). A widely informed collector's guide to the stuff of the earth, this is a beautifully made book, giving the reader a couple of dozen museum-quality samples of colorful minerals, glowing and rich on the page. It is even better than that; other photographs, mainly black-and-white aerial views, exhibit those handsome larger samples, such as the chalk cliffs of Dover, that men live on and mine. The hardness table and the geologic periods are the most technical topics presented in a brief text that is an easy and pleasant path to a view of physical geology.

THE SCIENCE OF CLOUDS, by R. A. R. Tricker. American Elsevier Publishing Company, Inc. ($6.95). THE HEAT'S ON, by A. Harris Stone and Bertram M. Siegel. Illustrated by Peter P. Plasencia. Prentice-Hall, Inc. ($3.95). INVESTIGATING SCIENCE WITH RUBBER BANDS, by Laurence B. White, Jr. Addison-Wesley Publishing Company ($3.50). LET'S-TRY-IT-OUT: LIGHT & DARK, by Seymour Simon. Illustrated by Angeline Culfogienis. McGraw-Hill Book Company ($4.50). These four books, spanning a wide range of age and interest, share the happy aim of presenting a connected and meaningful series of experiments in their several subjects. *The Science of Clouds*, by a wide margin the most advanced, is an introduction by way of lecture-table experiments to the physics of the atmosphere: how we know air holds

water and has weight, "fogs and smogs," rainbows, storms and more. The clear text ends with a fresh and attractive list and guide of "simple things to make, to think about, and to do." This is no cookbook manual but a genuinely helpful set of suggestions, richer than anyone will be able to complete. There are excellent photographs in color, and a really wonderful idea—with examples—for making photographs of clouds in three dimensions by snapping two pictures as the clouds move past your camera for the two shifted views. It is a book for readers of junior high school age up, demanding not much formal science but an amateur's interest and energy.

The Heat's On, intended for fifth- or sixth-grade boys and girls (with a little help from their friends and parents), treats of finding out about heat "by experimenting with its effects on matter." What sort of matter? Why, fingertips and thermometers, ice cubes and sugar cubes, candle flames and matches, cold drinks and freshly baked bread. The approach is made chiefly through rather gentle hints on what to do and plenty of leading questions, with an easily read text and simple, lighthearted pictures. This is one of more than a dozen books in which the senior author has mined the same rewarding vein; a few of the proposals in this one are quantitative, and a couple are by no means simple to carry out. If a youngster has access to a small basement shop, however, metal rods may not seem costly apparatus.

The rubber-band book captures better than any of the others the delights of curiosity, making much out of little by trial and thought. Here one finds music from the vibrations, muscle models from the stretching, chemistry by way of a coin-tarnish test for sulfur, thermodynamics out of kinks and heating, a rubber-band navy (the bands float and can be driven by surface tension)—even mathematics, its curves and surfaces arising out of taut bands. Almost all the proposals are easily workable for the experimenting fifth-grader, for whom this clear, brief book is written.

The light-and-dark book is for children in the earliest grades. (Older brothers and sisters would be first-rate tutors in its lore.) Its smooth drawings and easy text call attention to darkness and to light, to the "light birds" a mirror can make on the wall on a sunny day and to making and watching shadows of every shape and size, ending with that great shadow in which we all sleep—the night.

THE WILD YOUNG DESERT, text and photographs by Ann Atwood. Charles

Scribner's Sons ($4.95). The publisher puts "all ages" where the intended grade level is mentioned. The publisher is right too; the beautiful photographs of ocher mountain, rose red canyon, dune, butte, sand grain, fawn and golden cactus blossom glow beside a text both precise and poetic—a calm, loving couple of pages that give the biography of a desert. The book is a gem, in no way inferior to the very best of the genre of large, expensive and handsome books that proudly occupy many a shelf at six times the price.

Mathematics and Games

COMMUNICATING WITH A COMPUTER, by A. B. Bolt and M. E. Wardle. Cambridge University Press ($1.95). BASIC FOR BEGINNERS, by Wilson Y. Gateley and Gary G. Bitter. McGraw-Hill Book Company ($3.95). These two paperbacks stand on the lowest rungs of the ladder to the clicking Parnassus of digital-computer mastery. *Communicating with a Computer,* aimed at teachers but also very useful for inexperienced but enterprising students from junior high grades on up, is a British product. It begins with a most useful, and quite uncommon, system for programming computations on an ordinary keyboard desk calculator. Flow diagrams with loops and access to paper memory are the main technique. Such planning is both fully practical and a first-rate way to see just what computers and programmers do even without access to someone's pile of electronic chips. The book contains a little tour de force, worth the price in itself, in the form of schemes for making the classroom simulate a computer, with each student following his fixed petty instructions and the entire room producing as its output a table of cubes digit by digit in successive approximations. A broad outline of computers and their uses is included, with the sensible observation that a knitting pattern is in fact a symbolic program with loops and decision boxes, workable by a great many women and girls who might not easily recognize themselves as being inclined strongly to logic and mathematics.

BASIC for Beginners is a readable self-instruction for the beginning student of the computer language BASIC, widely used at time-sharing teletypewriter terminals, particularly in schools and colleges. The book is sensitive to accent and dialect; BASIC is now spoken by so many machines and people that it begins to sound rather different from its clipped New England origins. A couple of pages tell the beginner how to handle "string data," the nonnumerical program entries

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Ford's new Pinto. The little carefree car.

Pinto is one little car that can free you from car cares, big and little. From cares about high price and big gas bills. From cares about maintenance and repairs, power and stability, roominess and quiet.
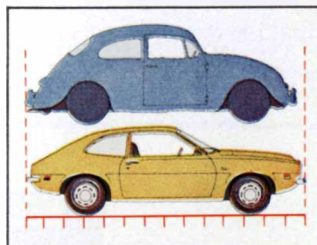
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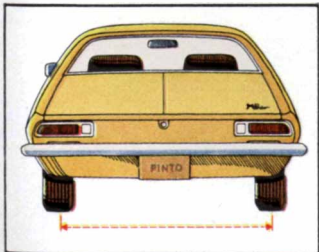
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Do it yourself and save. Pinto is designed so you can do most servicing yourself. The Do-It-Yourself Manual shows you how. A Do-It-Yourself Key helps you do everything from gauge the spark-plug gap to adjust the headlight beam.
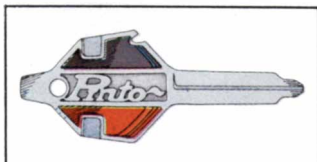
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possible in many dialects of BASIC. Dry and apt comment from the machine, easy alphabetizing of lists of names and many other unexpected powers arise from this modest skill, which is important particularly because "students get a great deal of pleasure and motivation in writing programs which involve manipulation of such data." Twelve of the 16 computers whose abilities are listed in detail here can manage this friendly union with human language. The comparison table and facsimile programs for doing one simple computation as formed and listed by 14 different systems give the appendix to this book a special value for people coming to a decision about what system to employ. The book is a helpful introduction to the instruction manual of any specific BASIC system rather than a substitute. It yields 10 hours' study of basic BASIC.

ONE MILLION, by Hendrik Hertzberg. Simon and Schuster ($3.95). One million crisp black dots comprise the profound text of this book. They march in long rows, each dot a neat round disk of ink, 50 dots to the line, 100 lines to the page, 10,000 dots to the two-page spread, 100 such spreads. To be sure, 500 or 600 of the dots have straggled to the page margins, each along a light marker line, which leads to an account of some set with the cardinal number that dot stands for. The examples range widely. The second dot marks the phrase "2—Population of the Garden of Eden"; one much later signals "919,799—Votes cast for Eugene V. Debs, imprisoned candidate of the Socialist party, in the 1920 U.S. Presidential election." Seven pages that are not so dotty contain the author's convincing and imaginative justification for his marvelous book: "To experience, visually and concretely, a number which is very large, and yet awesomely small [is] an aid to comprehension and to contemplation." The book deserves plenty of such use. If "each dot represents a year (and the whole book the life-span of mankind), history begins with the last two pages." One hopes for school corridors lined with the pages of the book, or with their homemade equivalent, with those additional dots marked that have personal meaning for the student. Let no one lightly extend the book to a billion! That would take more than 10 yards of bookshelves crammed with copies of this large, flat paperback. You could do it with sand grains in a large sandbox, or with all the picture elements of a very long television commercial, or with the halftone dots in three or four big volumes of printed pictures. In none of these examples can one perceive the individual elements with much success. The book designers, Gemini-Smith, Inc., have made a small flickering piece of op art out of every page and both covers.

SECRET WRITING: THE CRAFT OF THE CRYPTOGRAPHER, by James Raymond Wolfe. McGraw-Hill Book Company ($5.50). The familiar "black chamber" of an earlier age, when a suite of back offices housed the crew of patient clerks and ingenious puzzlers who worked on the messages of the enemy, has expanded wildly. More than $1 billion a year is spent by the National Security Agency in its giant computer complex "breaking secret messages sent by other countries." Wolfe is a free-lance writer, a retired naval officer, with both vocational and amateur experience in the making and breaking of codes and ciphers. He has written an exciting book, a savory mixture of mathematics and the most raffish part of diplomatic history, a first-class introduction to the art of the cryptographer. He manages to include an account of most of the main cipher systems, from a simple shift along the alphabet to a double-transposition cipher used in Italy by both German and American forces as a high-security field cipher. It is still "probably the most resistant of all 'pencil-and-paper' ciphers."

There is plenty of history and some rumor, told with that slightly weary cynicism that always goes with the intelligence outlook. Algebraic and mechanical devices, clever systematic schemes of multiple-message analysis, and a quite sophisticated (if not always complete) introduction to the use of statistical methods endow the book with an unusually high degree of realism. Not officially privy to the latest wrinkles, Wolfe is free to speculate convincingly on the kind of computer-made one-time quasi-random keys that must make up the most modern ciphers. The entire book is a wry pleasure, whether read for its virtuoso logic, ironies and inversions of loyalty or for the nature of the external evidence—observations of recent events and their correlation with code words—that makes possible the breaking of code-book messages beyond the reach of any algebra.

AFTERMATH, 1, 2, 3 and 4, by Dale Seymour, Mary Laycock and Verda Holmberg. Creative Publications, Palo Alto, Calif. ($3.50 per volume). POLYHEDRA MODEL KIT. Creative Publications ($3). These are similar mathematical comic books by a skillful team of author-teachers. Each presents about 100 logical puzzles, numerical problems, cartoon-strip homilies, intricate designs of knots and monograms, optical illusions—a potpourri of recreational and appealing tasks aimed broadly at grade school readers. A sample: "The trellis in the . . . corner is one of the other eight as seen from the back side. Which one?" Each trellis is a weaving of six strips, three vertical and three horizontal, drawn in strong black line. The cartoonist Bob Larsen and the designer Ruth Heller have given their book that curious stilted, half-grotesque look of the comic book (although all black and white), but always lightheartedly and without vulgarity. It is a genre familiar to children that merits the friendly epithet "corny." These are first-class aids both to students who like mathematics and to students who fear it. Wisely, all solutions are given.

The kit supplies light cardboard punchings, printed in bright colors, of the developed surfaces of all five Platonic solids, easy to paste together. There are a variety of edge lengths. Mimeographed proofs of the completeness of the set are included. This is the best value among the commercial kits available.

THE AMAZING MAZE, by Harry Hartwick. Illustrated by Ruffins/Taback. E. P. Dutton & Co., Inc. ($4.95). Small readers with a taste for sitting a little while to do a puzzle should be delightfully caught in the text and picture pages of this color-wash, ink-drawing book. Mainly in green tones that evoke the bushes and hedges of which real garden mazes are so playfully built, the artist and the cheerful and intimate author present more than a dozen mazes to enter with the eraser end of your pencil (so as not to mark the solution visibly, of course). Each maze—famous ones such as those at Hampton Court and Versailles or more workaday ones such as those built for the hardworking rat partners of many a psychology professor—is drawn with some evocation of period or place. The entire book is a small pleasure for eye, hand and mind. The reader is encouraged to make mazes of his own. "Can you find your way into the center of each, and back out again? Some rats can."

Specific Forms of Life

CHIPMUNK PORTRAIT, by B. A. and H. K. Henisch. With drawings by H. S. Wilsher. The Carnation Press, State College, Pa. ($5.95). "Chipmunks refuse to dwindle into pets. Their mysterious and complicated lives touch man's here and there, never to become engulfed. Wrapped in the dignity of indepen-

dence, their trim, determined figures dot his gardens, self-absorbed, self-reliant, self-contained." So closes this delightful and meaty book, an admiring study of the doughty chipmunk. About half of the pages tell of the chipmunk as a literary figure, of his discovery by western Europeans (the chipmunk's range is from eastern Europe across northern Asia and North America) and of his celebration in myth and legend among the Russians, the Hopi, the Chippewa and the Navaho. The rest of the book is a close and entertaining account of three years of one chipmunk family in a central Pennsylvania garden. Chipmunks have a real "concern for quality control." Thoreau remarked that they leave only poor hazelnuts behind. In old Russia "chipmunk nuts" sold for higher prices than those gathered by men. The book has 45 closeup photographs of the small beasts, 28 attractive line drawings and a number of other photographs. This is a scholarly work, not intended for early readers, but it will be irresistible to anyone who has wondered about these animals.

PUCK OF THE DUSK, by Paul Annixter. Illustrated by Gilbert Riswold. Charles Scribner's Sons ($4.50). BATS: WINGS IN THE NIGHT, by Patricia Lauber. Random House ($1.95). Men—and their children—live by day, bats by night. That separation alone suffices to make the bat a creature of mystery and romance. Puck is a small red bat whose life story from birth to mating flight is told in graceful prose. On every page the text runs, sometimes in white type, sometimes in dark, right across a rich set of pastels done in the hues and tones of dusk. The result is a book of extraordinary harmony; young readers and the read-to might well learn through it to understand and trust the darkness. The second book is a straightforward, simply written account of bats of the entire world, with many photographs of bats with faces endearing or fearsome, bats echo-ranging on moths, swarming from caves and hanging like tiny furry umbrellas. Bats have finally got a good press among both adult and young readers over the past several years.

A SNAKE-LOVER'S DIARY, by Barbara Brenner. Young Scott Books ($4.25). MY DEAR DOLPHIN, by Cynthia de Narvaez. Photographs by Jerry Greenberg. American Heritage Press ($3.95). Two journals, each written by a mother, tell of children's intimacy with animals. Mrs. Brenner, who has become a snake-lover under the influence of two snake-loving sons, takes on the difficult task of writing a first-person diary in the character of a boy of about 12. The story is believable and full of action, as Carl finds his first garter snake in spring. By fall he has been struck—on the boot—by a small rattler, and he has come to watch, to understand, to love and even to mourn snakes he has found. The writing is didactic enough, full of honest (mainly northeastern U.S.) snake lore but somewhat arch. There are excellent photographs.

My Dear Dolphin describes two spring weeks the author-mother—it is her first-person journal we are reading—and her children, a boy of four and three girls up to 12, spend with four bottle-nosed dolphins, professional entertainers in a Florida pool. The story rings true, and the photographs document a remarkable family friendship. The dolphins each choose a favorite human friend; they organize games: leapfrog, boat-towing tag and the ball games of catch and keepaway. Underwater swimming by people worries the dolphins, and they prevent it. Dolphins go to great lengths and will suffer much to avoid injuring people; the animals rarely fight, although there was one slashing dolphin quarrel overnight during the two-week visit. The two opponents were afterward "on friendly terms at last." The book is written with high enthusiasm, a little wearing on the reader but entirely understandable. The family has returned once, and promises to be back again. "When we left them, they were clowning with a ball and a baseball hat, trying to make us laugh."

HILDEGARDE AND MAXIMILIAN, by Fernando Krahn. Delacorte Press ($3.50). THE WAY OF AN ANT, by Kazue Mizumura. Thomas Y. Crowell Company ($3.95). CATCH A WHALE BY THE TAIL, by Edward R. Ricciuti. Pictures by Geoffrey Moss. Harper & Row, Publishers ($2.50). OLLY'S POLLIWOGS, by Anne and Harlow Rockwell. Doubleday & Company, Inc. ($3.95). These are four books on animals (and people) for young listeners or beginning readers, all handsomely illustrated. The nuances of the titles amount in each case to a review; read them again. Hildy the Red and Max the Yellow are two ladybugs (or a Lord and Lady Bug) who meet on a top hat, marry, give up a planned voyage to the moon and instead raise 10 children. The text is in pica typewriter, the drawings are aptly whimsical and faintly grotesque. The book is thoroughly unsound entomologically and delightful. *The Way of an Ant* is another anthropomorphic story, but it is delicate in text and picture, evocative and tranquil, with beautiful watercolors of the flowers and trees on which the ant's truly scaled figure climbs high. In *Catch a Whale by the Tail* the men really catch a young beluga by the tail and fly her to New York, there to live with noisy, playful Robert so that "soon there may be a baby whale in the big tank at the aquarium." The whales are a paper white species that is very showy in ultramarine water. Most realistic is the story of Olly and his father, who live in Connecticut and find frogs' eggs in the pond. They watch the eggs hatch in their dimestore aquarium, until finally half a dozen little frogs are let go in the garden grass. The large pen-and-wash drawings are attractive, and people who live in a wooded suburb can follow the book as a small guide to their own husbandry of leopard frogs.

GALLS AND GALL INSECTS, by Ross E. Hutchins. Dodd, Mead & Company ($3.75). A master of the closeup lens, Dr. Hutchins has once again set before the reader a new look at the life of insects. Here we see the interplay of wasps and oaks, or aphids and grapes, that has led the plant to build a complex organ, the gall, in response to a specific chemical signal emitted by the insect. The insect changes too; these species often have a strange "alternation of generations"—say one generation of winged females followed by half a dozen broods all wingless but of both sexes—in their complex adjustments to the parasitic life. All around the fields and woods, on goldenrod or sumac, blackberry or rose, the galls appear. Tiny posts or cones, spherical or woolly, sometimes oozing strange honeydew from an oak, they are an unusual class of collector's items that this book ought to do much to popularize. Youngsters who like to seek odd treasures in field and wood will like the book.

MAMMOTHS, MASTODONS AND MAN, by Robert Silverberg. Illustrations by Dale Grabel. McGraw-Hill Book Company ($5.50). The amateur paleontologists seized with the problem of those huge bones and great tusks were no mean group: they include Thomas Jefferson and Benjamin Franklin, Lewis and Clark, Otto von Guericke, the sphere-making mayor of Magdeburg, even Bernal Díaz, the plain soldier who wrote the wonderful story of Cortez' conquest. The first men in America to identify the big fossil teeth as those of elephants were "native Africans"—slaves in Carolina around 1730. Real professionals such as Georges Cuvier and Henry Fairfield Osborn are in the picture too. The tale is understandably a little difficult to follow when it comes to the confused, and often

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relabeled, family tree of all these "large thick-set animals with trunks." It is a splendid story everywhere else, both in the domain of the evolution of species and in the growth of ideas of man's place in time.

Men hunted the mammoths and the mastodons; some men drew them from life. Fifty thousand tusks of such beasts, held in the natural deep freeze of the Siberian permafrost, were sold for hairbrushes and billiard balls in London in the 19th century. In a museum in Leningrad there has been a stuffed mammoth, woolly hide and all, since the marvelous find of the botanist Mikhail Ivanovich Adams in 1806. An even more complete animal arrived there, its meat said to be fresh enough to eat, in 1902. Hunters may have ended the mammoths and the mastodons in the declining days of the animals 5,000 or 6,000 years ago. There is even a slim chance that a few mammoths survive today somewhere in the Siberian forest. In 1920 a French diplomat reported talking with a hunter who told of seeing big elephants there.

Biology in General

THE LIFE OF THE JUNGLE, by Paul W. Richards. The World Book Encyclopedia and McGraw-Hill Book Company ($4.95). "The luxuriant evergreen forests of the tropical lowlands . . . are what most people mean by 'jungle.'" Here it is: the strangler fig, the emerald tree boa with its new-caught blue tanager, the red-capped mushrooms, the peering land crab, the yellow tree frog, the encrusted orchids—all the life of that ancient three-dimensional world which is the tropical rain forest. Professor Richards is a veteran of 40 years' study of the rain forest; the text bears the mark of real knowledge, and it is easy to read. The color photographs are large, numerous and well chosen. The book calls for a less factual supplement, perhaps *Green Mansions*. With this text to support the romance, any teen-age reader is likely to start planning his visit to the rain forest. Nearest to the continental U.S. is the Caribbean National Forest around El Yunque, not very far from San Juan, Puerto Rico.

SYMBIOSIS: A BOOK OF UNUSUAL FRIENDSHIPS, by Jose Aruego. Charles Scribner's Sons ($3.95). Cheerful, funny big pictures with a few sentences of text celebrate animal friendships. Here is the zebra, who hears so well, herding together with the sharp-eyed ostrich. How can any lion sneak up? Or take the ratel

and the honey guide. That bird will squawk his friend, an African badger, to the beehive on a stump. The thick-skinned badger enjoys the honey and shakes off the angry bees, while his bird partner gets the beeswax it likes so much. There are nine of these true and amusing tales for children who can listen or have begun to read.

THE INFLATED DORMOUSE AND OTHER WAYS OF LIFE IN THE ANIMAL WORLD, by Anne Feldman and Jean Ely. The Natural History Press ($3.95). English literature has shown that dormice are sleepy little beasts, and the title animal of this book of words and pictures is getting ready to sleep out the dull winter. This dormouse, however, "has spent the last several weeks preparing for its long nap by eating and eating and eating and. . . ." Full of hazelnuts, it looks like a well-made three-inch sphere of fur with whiskers and tiny paws. This delightful large, thin volume displays pictures of about 50 different species of animals, each with one or more paragraphs of informal, meaningful comment on the special nature of the particular form. The pictures are nothing short of marvels, collected from many sources. They range from the shot of a pair of polar bears loping onto an icy shore to the mother wolf spider bearing hundreds of baby spiders on her back like some living fur. There is a skillful grasshopper mouse calmly eating an *Eleodes* beetle headfirst, with the beetle's rear end pushed into the soft earth. That is the knack of eating these bugs; if you are careless about the two ends, the bug can spray you with an explosively driven irritant. There is an English beach, "not Coney Island on a hot July day" but just as crowded with shorebirds called knots. A heaping dozen of rock-python eggs are here, with one baby snake's head sticking out of the newly bitten slit in its parchment shell. "Mother snake has gone away and will not be back." The endearing and even spectacular pictures, the intelligent comment genuinely aimed at children add up not only to enjoyment but also to a surprising degree of understanding about the adaptiveness of the world of life. This is a first-rate book for children who can listen or for young readers.

HUNTING FOR DINOSAURS, by Zofia Kielan-Jaworowska. The M.I.T. Press ($7.95). HUNTING FOSSILS, by Martin L. Keen. Illustrated by George Solonevich. Julian Messner ($4.50). The last photograph of *Hunting for Dinosaurs* shows the author sitting on the airport bench

in Ulan Bator with her Mongolian colleagues, waiting for the plane home to Warsaw. She is a paleontologist, and the leader of three expeditions into the waterless regions of the Gobi Desert seeking bones. The story is attractive; the expeditions, using six-wheel-drive Polish trucks but never such items as radio, have the personal scale and intimacy that larger enterprises lack. There are a dozen people, more or less—men and women, scientists, students, guides, a motor mechanic and a doctor. (The doctor was chosen among those physicians "prepared to act as cook for 15 persons under field conditions. . . . There was no call for his professional services . . . but he proved to be an excellent and conscientious cook . . . and a pleasant companion." On a trip to Mongolia you might stay in a yurt hotel; one is shown here. There are lamaseries and sandstorms, live yaks and fossil tyrannosaurs. The travelers brought home many tons of bones and a fine story. There are strong drawings by Maciej Kuczynski in a volume of unusually handsome design.

Hunting Fossils is a simple primer of paleontology for grade school readers. It exhibits many vivid, perhaps somewhat imaginative, reconstructions of fearsome ancient scenes. It is unusually successful at giving the reader a sense of the evidence, the logic and the arguments of the fossil-hunter. Then it goes on to induce the reader, if he can travel a little, to hunt for himself, not, of course, in the Gobi Desert but in the stone fences, the old quarries and the road cuts not far from home. There is a list of addresses state by state of survey offices that will send information on where to go, and of museums and college departments.

OUR TERRARIUMS, by Herbert H. Wong and Matthew F. Vessel. Illustrated by Aldren A. Watson. Addison-Wesley ($4.35). DISCOVERING THE OUTDOORS: A NATURE AND SCIENCE GUIDE TO INVESTIGATING LIFE IN FIELDS, FORESTS AND PONDS, edited by Laurence P. Pringle. The Natural History Press ($4.50). THE POND ON MY WINDOWSILL, written and illustrated by Christopher Reynolds. Foreword and appendix by John C. Pallister. Pantheon Books ($4.95). These three books all treat of an active approach to life. *Our Terrariums*, for beginning readers, tells in short phrases with large pictures how to make an animal's home in a big jar—a terrarium. Indeed, it carefully describes two: one for a toad, damp and green like the garden where the toad was found, and one for a lizard, dry and more open like

the empty lot where they found the lizard. Honestly done, it aims at theory for small thinkers. *Discovering the Outdoors,* intended for naturalists up to 12 or so, is an anthology of expert pieces on a variety of projects. Take one of the more than two dozen. "Face to Face with Wild Mice," by Christopher Hale, tells in seven pages, with good pictures, how and why to make, set, open and record the take from live traps for small mammals. This is within the reach of children who have space, time and inclination, but it will absorb a year's hard work. That is the danger—and the value—of such an anthology. It is a rich menu, well suited for clubs, schools and libraries. *The Pond on My Windowsill,* appealingly written by an expert British naturalist and artist, bears out its title in a warm and personal way. The pond is not a fishpond. It is an aquarium full of water beetles and caddis flies, leeches and snails and shrimps. Not a fish or a frog in the lot; no room. The expert appendix translates the British species into their very similar American equivalent. The level is for people able to find the ponds and spend long hours collecting by themselves, say junior high school.

Exploring with a Microscope, by Seymour Simon. Random House ($2.95). Life in a Drop of Water, by George I. Schwartz, with photographs by the author. The Natural History Press ($4.50). The dots in a halftone, the letters on a page, the fat droplets in milk are well-known and admirable first steps into the world of the small. Simon's inexpensive book begins just so, and rather rapidly urges the grade school microscopist on to snowflakes and salt crystals, insects and living protozoa. The pictures are excellent, and the book is easy to read, easier than the tasks it tempts you to try. *Life in a Drop of Water* is a more advanced treatment. Its photographs (one through the microscope made by van Leeuwenhoek himself) are wonderful, and they manage to convey the sense of one man's work rather than the picture gallery one usually sees. The classical photographs and drawings are not neglected, however. Diatoms and dinoflagellates, protozoa and rotifers—the entire microworld of fresh water and salt passes before the eye. Yet these marine plankton were taken at a spot no more exotic than a jetty in the inlet between Rockaway and Long Beach on Long Island. The book is "a long and enticing invitation to enter this world." Its audience is anyone who has already played around a little with the microscope.

ANNUAL INDEX

The following index lists all the authors and articles that appeared in SCIENTIFIC AMERICAN *during 1970. Also indexed are "Mathematical Games," "The Amateur Scientist" and longer book reviews.*

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