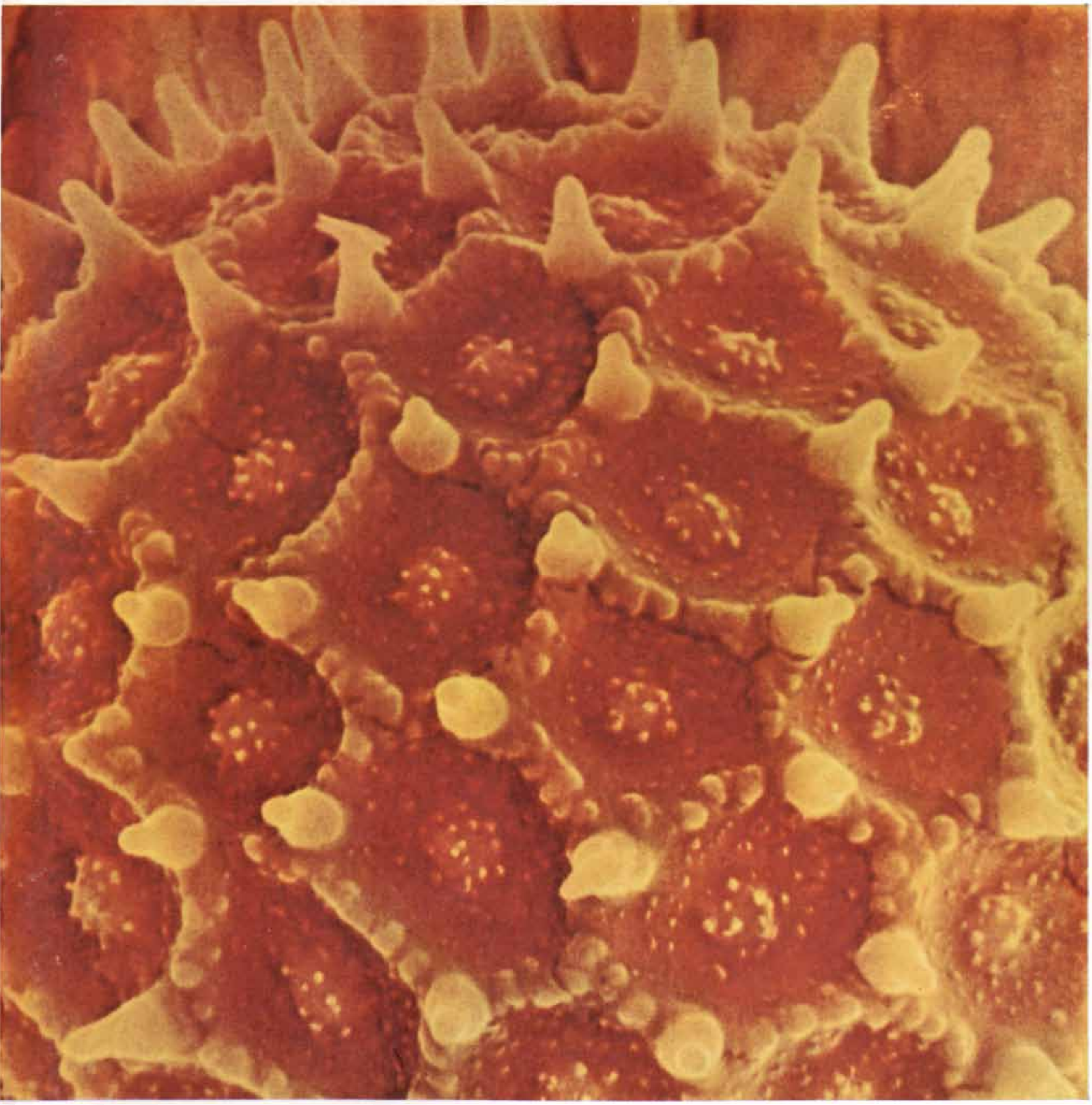
SCIENTIFIC AMERICAN



POLLEN GRAIN

SEVENTY-FIVE CENTS

April 1968

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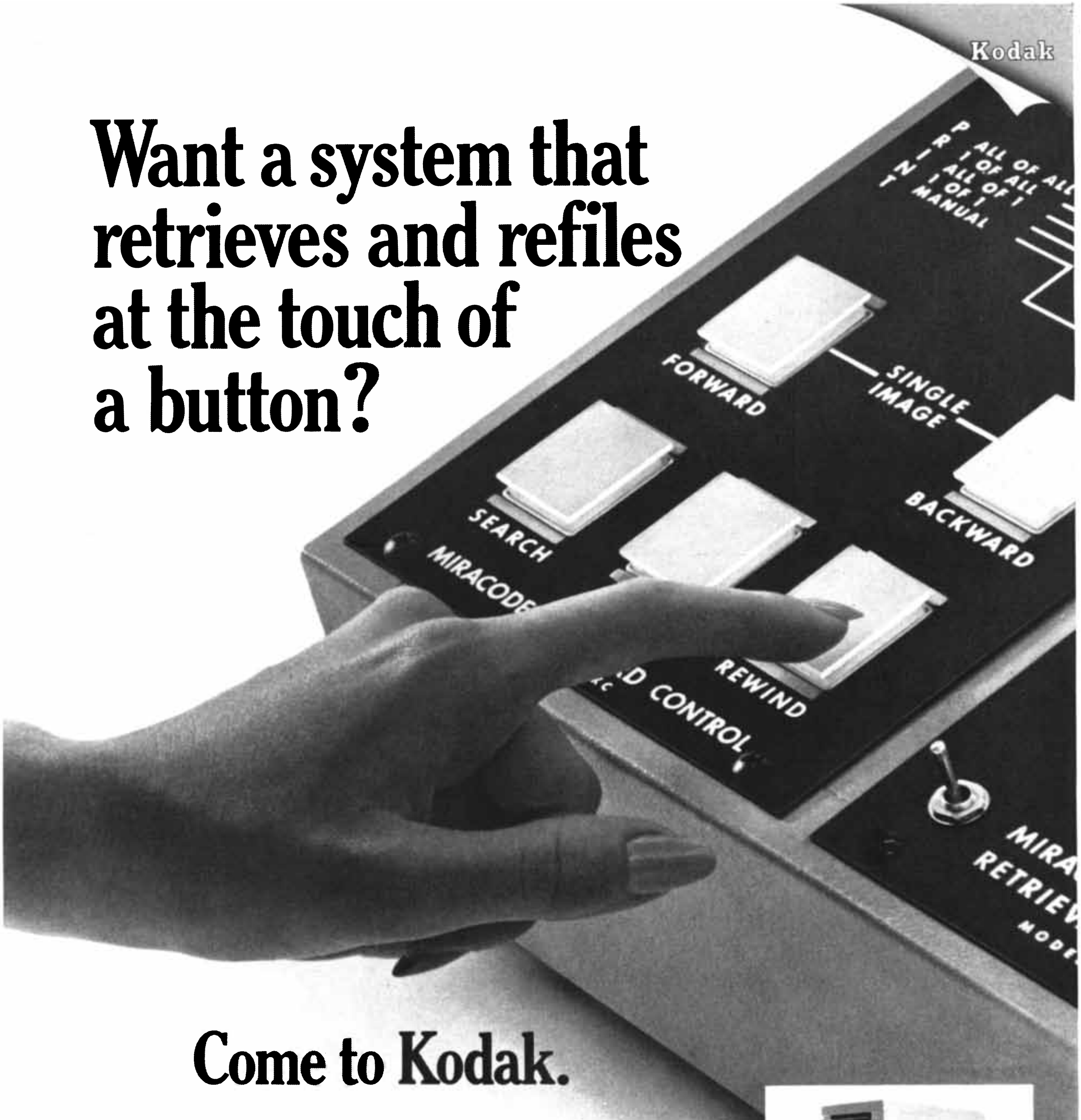

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These fingers once trembled uncontrollably.
The affliction, Parkinson's disease or "shaking palsy." Its cause, a bit of diseased tissue deep within the brain—making the hands tremble uncontrollably.
For years, doctors tried many ways of destroying the troublesome spot. Today, in carefully selected patients, operations for Parkinson's disease are performed safely and successfully with a new type of surgery based on cryogenics—the science of extreme cold—that was pioneered by Union Carbide.
Working with surgeons at Saint Barnabas Hospital, New York City, Union Carbide designed equipment by which the intense cold of liquid nitrogen, at 320 degrees below zero F., is applied with pinpoint exactness to the diseased tissue. Instantly frozen and destroyed, the uncontrollable trembling ceases.
Medical science is finding more and more uses for intense cold—another example of how Union Carbide takes familiar things and puts them to new and beneficial uses.
UNION CARBIDE
THE DISCOVERY COMPANY

Established 1845 **SCIENTIFIC AMERICAN** April 1968 Volume 218 Number 4

ARTICLES

DEPARTMENTS

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THE COVER

The electron micrograph on the cover shows the highly sculptured surface of a pollen grain from the common morning glory (*Ipomoea purpurea*) enlarged 2,400 times (see "Pollen," page 80). The remarkable three-dimensional quality of the micrograph is characteristic of pictures made with the recently developed scanning electron microscope. In this instrument the electron beam sweeps the surface of the specimen rather than passing through it, as the beam does in the conventional electron microscope. Electrons scattered backward from the beam, together with secondary electrons emitted by the specimen, are then collected, amplified and projected on the face of a cathode-ray tube. When the photograph of the tube image was printed, a filter was used to add the characteristic yellow color of pollen.

THE ILLUSTRATIONS

Cover photograph by Paul Curtis and Patrick Echlin

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SCIENCE/SCOPE

The extraordinary longevity of Hughes-built synchronous communications satellites is causing a continuing downward revision of cost estimates for operating satellite networks. Syncom II, originally designed for one year of service, is still at work five years later. The Hughes satellites, including two Syncoms, three Intelsats (Early Bird, Lani Bird, Canary Bird), and two Applications Technology Satellites, now have a combined service life of over 17 years. Every satellite in synchronous orbit around Earth was built by Hughes.

Every target in Vietnam is a shooting target -- even the Army's Mark 1B satellite communications ground terminals. A 20-minute attack in the middle of one muggy night recently left nearly 60 bullet and shrapnel holes in the terminal's huge nylon radome and also hit the antenna and one of the cargo vans housing electronics gear -- but failed to put the Mark 1B out of business.

Twelve of the Mark 1B terminals, positioned around the globe, are providing fast, reliable voice and teletype communications via DOD's satellite network. Hughes has built a total of 14 for the Army Satellite Communications (SATCOM) Agency, to be used by the Army, Navy, and Air Force.

The American Meteorological Society's 1968 award for outstanding service to meteorology was presented recently to Santa Barbara Research Center, a Hughes subsidiary, for building the spin-scan cameras that have been photographing the earth's cloud cover from the Applications Technology Satellites.

First black-and-white photo of the earth's full face was made December 11, 1966, from ATS-B over the Pacific. New multi-color camera aboard ATS-C, over the Atlantic, took the first simultaneous full-color photo November 10, 1967.

Programmers needed for Europe and California: Hughes has immediate openings for operational and compiler-language programmers, systems analysts, management information system specialists, and software/hardware interface specialists, to work on large-scale operational command-and-control systems. Please send your resume to: Mr. J.C. Cox, Hughes Aircraft Company, Culver City, California. Hughes is an equal opportunity employer.

A compact Laboratory Tiltmeter developed by Hughes is so sensitive it can measure a tilt of only 1/100-millionth of an inch in a span of 10 inches. Its basic sensor differs from earlier circular-bubble devices in that the bubble moves beneath a high-precision quartz optical flat instead of a convex surface.

Tiltmeter's basic sensor can also be attached to instruments weighing up to two tons. Only one is needed because its electrical output signals are proportional to integrated tilt around either of two horizontal axes. Signals actuate a powerful electro-pneumatic servo system to level the instrument.

Creating a new world with electronics

HUGHES

HUGHES AIRCRAFT COMPANY

LETTERS

Sirs:

Professor Colwell ["Remote Sensing of Natural Resources," by Robert N. Colwell; SCIENTIFIC AMERICAN, January] is undismayed by the thought of an unmanned, computer-carrying satellite surveying the natural resources of a region, computing cost/benefit ratios, making decisions and telemetering the decisions to the ground. To me this is a thoroughly frightening prospect—all the more so since the prestigious School of Forestry at Berkeley could mount just such a program.

Certainly there are some situations so simple that this approach would work. My concern is with the usual case.

We have some experience with mechanizing decision-making and in evaluating the results. In the interests of efficiency we have given directives to various agencies, removed personal initiative and personal responsibility and reduced the process to an algorithm insofar as it is possible with fallible components (people). Now consider the results:

We tell the Highway Department to worry about roads—and they try to run freeways through redwood parks and historic waterfronts. We give the Bureau of Reclamation a mandate to worry about water—and they are destroying the lower Colorado River, straightening its curves, burying its plant and animal life beneath wide swaths of mud, rendering a formerly beautiful riparian ecosystem useless, sterile, ugly—and this in spite of agreements to stop work until the relevant state agencies and concerned citizens' groups could present their case. One could magnify examples ad nauseam.

I foresee in Colwell's approach only an exacerbation of this dysfunctional procedure. Because the computer can be made to arrive at the same decision from the same data each time, we regard its decision as somehow better than the more equivocal sort that people are likely to make. The trouble is that the data are incomplete, "costs" and "benefits" are inadequately defined, the decision is questionable—and with a bit of efficiency the action is initiated and the landscape torn into, all without being touched by human minds.

The data incomplete? Of course. Show me an economist who will venture a dollar answer to the question that should be central to all our resource planning: "What is the cost to our grandchildren if we let our children grow up with increasing alienation from the natural world?" On such questions hinges the shaping of the human character and the survival of human traits as we know them. The important questions have barely been phrased.

Dr. Colwell, if you must have computers in space, may I at least write the programs?

FERREN MACINTYRE

Scripps Institution of Oceanography
University of California, San Diego
La Jolla, Calif.

Sirs:

I apologize for my lateness in writing about Harriet Zuckerman's article "The Sociology of the Nobel Prizes" [SCIENTIFIC AMERICAN, November, 1967], but I am about two months behind in my reading of your magazine.

I was working in Paris at the time when the 1965 award in medicine and physiology was conferred on three Frenchmen. As this was the first such award made in that country since the war, it was received with enthusiasm and a period of vigorous introspection occurred among French scientists. One of the fortnightly seminars held in my laboratory began with an address on the environment most favoring the winning of Nobel prizes.

When comments were invited, I achieved instantaneous unpopularity when I remarked that the American economy had been little perturbed by the war, and that Switzerland had not been occupied, whereas France had been invaded, Britain had had to give her undivided attention to avoiding the same fate, and the wings of scientific thought in Germany had been clipped to the officially approved pattern. The same social pressures that restricted the activities of scientists in Europe caused many of those scientists to remove to the U.S.

No objective appraisal of the sociological background of scientific achievement during the past three decades, of which Nobel prizes are one index, could be made without considering the political scene. One significant factor that cannot be disregarded is the cultural background of the winners.

SIDNEY C. ALFORD

Department of Agricultural Chemistry
University of Tokyo
Tokyo

Sirs:

I read with considerable interest the article by Riccardo Giacconi titled "X-Ray Stars" in the December 1967 issue of *Scientific American.*

My attention was drawn in particular to pages 42 and 43, displaying the collimating system used. The concepts of this system were developed (invented) by John F. McGrath of our company and are covered by U.S. Patent No. 3,324,-294.

The first collimator developed on this principle was used in an XUV spectrometer built by our company and flown on an Orbiting Geophysical Observatory (OGO) spacecraft in 1964.

We are sorry that no credit and/or reference was given to the inventor of the collimator principles used in the instrument described in this otherwise very interesting article.

PIETER R. WIEDERHOLD

Manager
Space Physics Division
Comstock & Wescott, Inc.
Cambridge, Mass.

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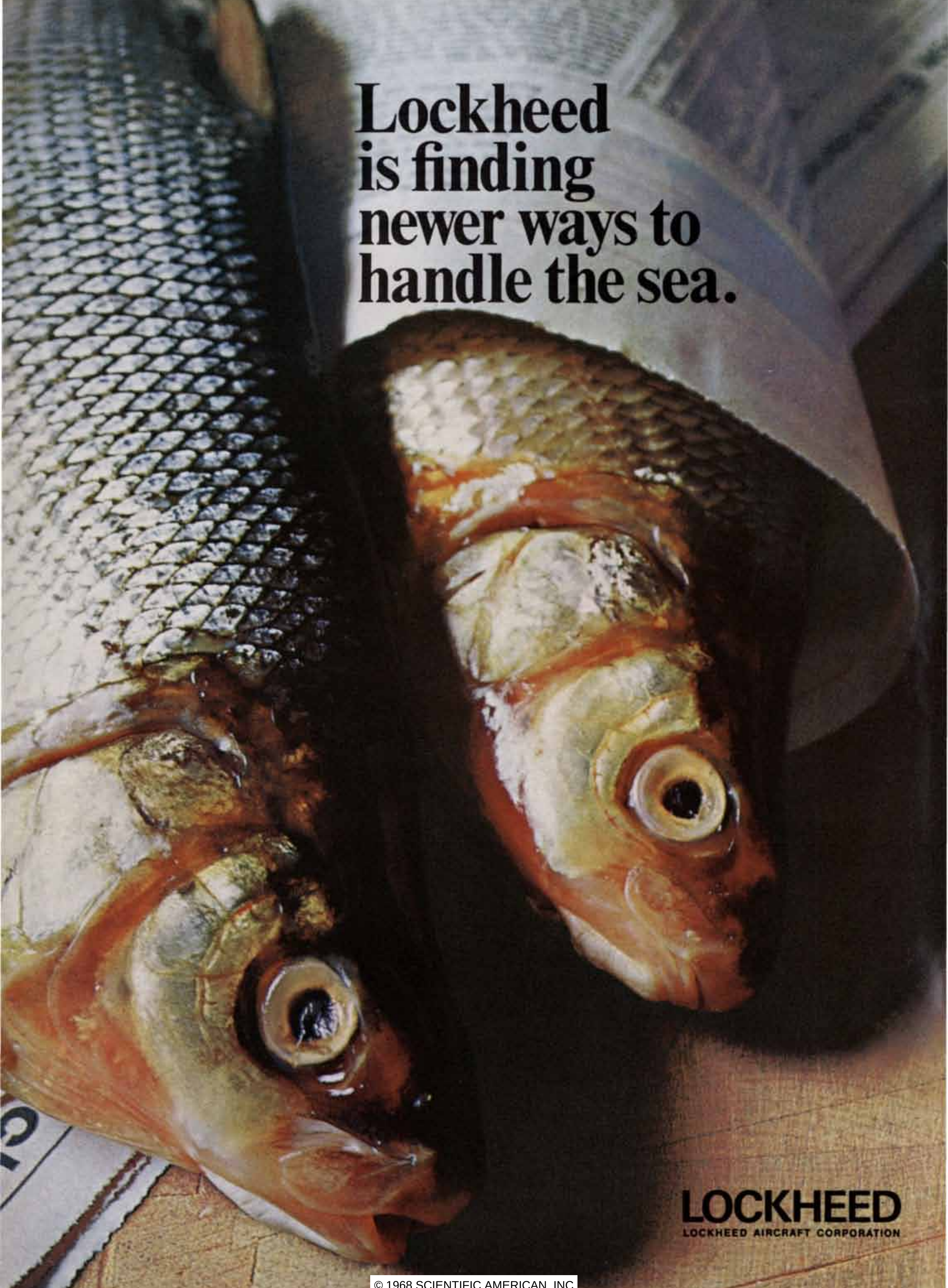

Lockheed
is finding
newer ways to
handle the sea.
LOCKHEED
LOCKHEED AIRCRAFT CORPORATION

Fouling prevention. How to handle fouling by marine life—microorganisms that attach themselves to underwater structures and grow into creatures such as barnacles—is a problem as old as the history of ships. Now, through a better understanding of these organisms' behavior, a new and effective way to prevent attachment has been found by Lockheed scientists. It involves physical-chemical changes made on a surface to create a repellent environment. While current antifouling systems (mainly poison-containing paints) usually work only for a year or less, the new method keeps surfaces clean indefinitely.

Metal experiment panels, 2 modified and 2 control, illustrate antifouling effectiveness after long submersion.

Deep-diving submarines. A prerequisite for finding newer ways to handle deeper parts of the sea is the development of more capable underwater vehicles. To this end, Lockheed is developing deep-submergence craft for various missions.

Although the undersea, or inner space, environment differs greatly from aerospace environments, considerable technology already gained in aerospace programs is finding application in deep-diving vehicles. Instrumentation, controls, structural materials and integration of systems within limited envelopes are examples. Rapid advances also are being made in other areas.

One is the development of syntactic foam, a flotation material carried to provide buoyancy. The foam is composed of hollow glass microspheres—millions per cu. ft.—in a resin base. It must survive tremendous pressures while having maximum buoyancy. Experiments to decrease its density without sacrificing structural integrity involve adding more voids of various controlled sizes. While the current state-of-the-art in syntactic foam is 44 lbs. per cu. ft., a 35- to 25-lbs.-per-cu.-ft. material is in the offing. When perfected, it will offset heavier payloads and withstand diving to greater depths.

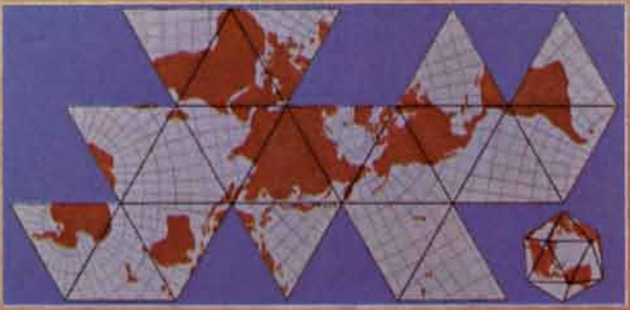
The near future will see fuel cells replace batteries as deep-submersible energy sources, reducing weight and greatly extending underwater operating time. Fuel cells powered by hydrazine now are under test by Lockheed. Others using hydrogen and oxygen also show promise.

Deep Quest. Launched in June, 1967, this Lockheed-funded vehicle is designed for research at depths to 8,000 ft. Its bispherical pressure hull quarters a 2-man crew plus 2 scientists. The vessel can perform a variety of tasks, including ocean-floor mapping, taking bottom samples and proving out advanced modes of instrumentation and communication.

DSRV. The Deep Submergence Rescue Vehicle is scheduled to become operational early in 1969. With a depth capability of 3,500 ft., rescuing men from distressed submarines will be its primary mission. It will mate with a submarine's escape hatch, clearing away debris with an articulated manipulator if necessary. Measuring 49 ft. long, it has room for 24 evacuees besides a crew of 3. Rechargeable silver-zinc batteries will give it 12-hr. endurance at 3 knots and a maximum speed of 5 knots. Designed to fit into a C-141 jet transport, DSRV will give the U.S. Navy worldwide, rapid rescue capability.

Improved wave forecasting technique. Lockheed scientists have been working to improve wave prediction techniques. While developing computerized methods of forecasting (involving wave speed, direction, fetch, and wind-over-water inputs), they devised a new tool—a gnomonic map projection of the earth onto an icosahedron. This special map displays vast ocean areas almost without distortion.

The icosahedron's orientation relative to the earth sphere was optimized for wave studies through a long series of computerized computations. This placed as many vertices of the icosahedron's 20 triangular faces as possible on land, as many edges as possible along shorelines. So each face displays either mostly land or mostly water, with a minimum number of faces covering the ocean areas.



Gnomonic projection. Above: unfolded. Below: icosahedral form.

The triangular faces of the icosahedron are broken up by a superimposed grid based on a 60° coordinate system. Each grid point represents a hexagonal area of ocean. Each triangular face has 2 of its sides coincident with 60°-grid-system axes, while its 3rd side falls precisely along a line of grid intersections. This arrangement permits all grid points on the globe to be connected by great circles—and in any of 12 directions.

With the map's multiple-projection presentation of a near-distortion-free g id point reference, oceanographers now can study and predict wave action over the entire world's surface with higher precision.

Light-imaging. Lockheed has found a way to pierce the eternal darkness that envelopes most of the ocean floor: a light-imaging system designed for use on deep-submersible vehicles such as Deep Quest and DSRV.

Light beamed from nose of submersible is picked up by sensor at stern.

As the vehicle slowly cruises, a narrow beam of high-intensity light scans the bottom. A receptor on the ship's underside "sees" the lighted area and transmits an image to a viewing screen that shows a real-time, contour picture.

Light-imaging, now in development, could prove extremely valuable for search, mapping and research operations. By using light in a new way, it gives men sight even where fish are blind.

The activities described here are only a few of the current Lockheed R&D projects in Oceanology. If you are an engineer or scientist interested in this field of work, Lockheed invites your inquiry. Write: K. R. Kiddoo, Lockheed Aircraft Corporation, Burbank, California 91503. An equal opportunity employer.

50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

APRIL, 1918: "The world has witnessed in the past two weeks the greatest struggle of armed forces that has ever occurred since history began its record. There is no doubt that we are at 'the decisive moment of the war,' as the Kaiser has so vehemently proclaimed, though the decision may ultimately not be exactly as he wishes it. Today and for days the Allied lines in Picardy have been under pressure and have been bent back over a front of more than 50 miles, but they are very far from being broken. The defensive strength of the lines and the success in holding them intact will depend entirely on the well-known resistance already offered by the British and the French, aided by the American and Portuguese contingents. The German attacks have been pressed with a view to an early decision and with no account whatever taken as to loss of lives. This battle appears to be the last desperate throw of the dice; if it does not go well, there will undoubtedly be internal disruption of some sort."

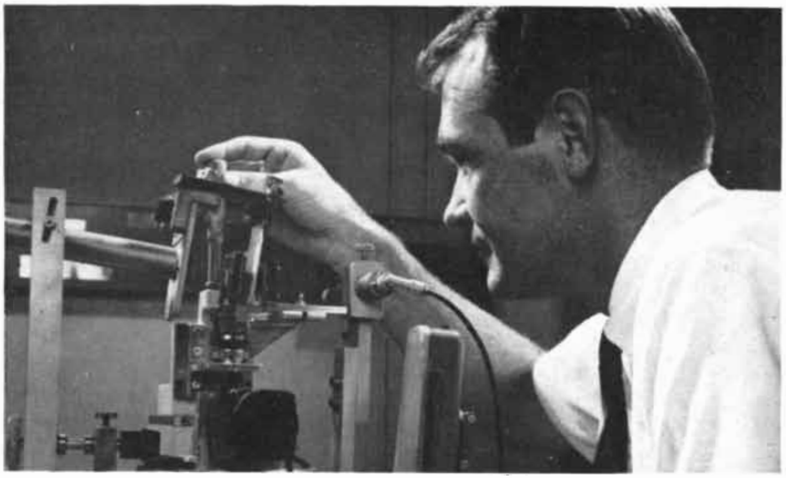
"Are spiral nebulae external galaxies? This question has been actively debated by astronomers during the past few years, and a timely summary of evidence pro and con is presented by Dr. Crommelin in a recent number of *Scientia*. 'Most of the evidence,' says Dr. Crommelin, 'seems to favor the extra-galactic position of the spirals; but if we once adopt this, it follows that they are of dimensions quite comparable to those of our galaxy. This, combined with the resemblance of shape, justifies us in concluding, at least as a plausible assumption, that they are similar formations.' Recent evidence also indicates that some of the globular star clusters are as distant as the spirals. Hertzsprung has suggested that the globulars are star systems in a settled state, whereas spirals are the result of the interpenetration and mutual capture of two globular clusters."

"Much attention was attracted not long ago to the novel exploit of 'harnessing a volcano,' as it was carried out near

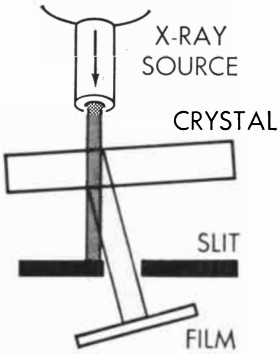
Report from

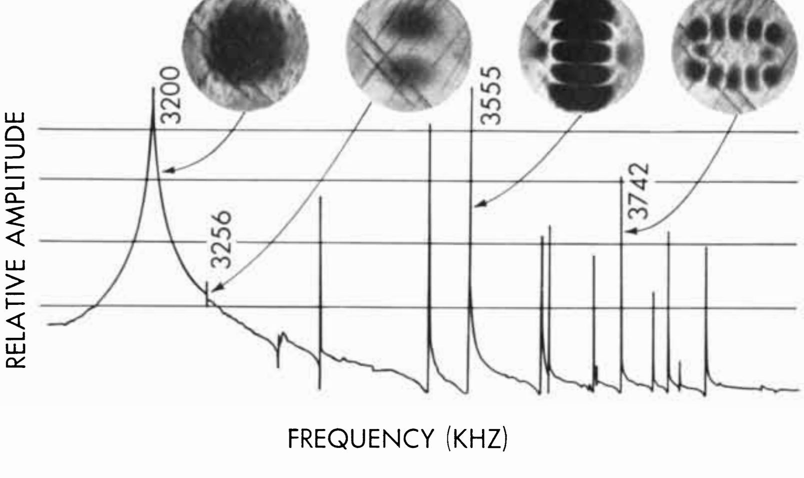
BELL LABORATORIES

The Anatomy of Vibrating Crystals



William J. Spencer with equipment for detecting vibrational modes. Through sloped tube, left, X-rays strike crystal (in frame at center of apparatus). A portion of beam is diffracted by the crystal (drawing, right) and passes through the slit. The main X-ray beam is stopped at the edge of the slit. During exposure, crystal and film are driven from left to right so that entire crystal area is photographed. The X-ray beam is set at a particular angle to the crystal (the Bragg angle), which for good crystals produces a diffracted intensity greater than at other orientations. Vibrating the crystal reduces destructive interference and increases diffracted-beam intensity.





X-ray photographs of a crystal showing four modes of vibration selected from the many modes indicated by the resonance peaks on the curve. Dark areas are due to displacement antinodes in the vibrating quartz disk. Diagonal lines are intrinsic crystal-lattice defects.

In modern amplifiers, filters, and oscillators, piezoelectric crystals are widely used to select signals at certain frequencies. Such crystals —of quartz, for example—provide electronic selectivity because of their ability to convert electric waves into mechanical waves, and mechanical waves back into electric waves, at certain resonant frequencies. For any particular application, the principal resonant frequency is determined by the size and geometry of the crystal, but in addition to this principal vibrational mode, the crystal will vibrate in a number of other modes.

To suppress these unwanted resonances, they must first be identified. And until recently we did this by observing patterns created when a crystal, coated with a fine powder, is vibrated at high intensity. Since the powder collects where the crystal surface is stationary, a vibrational pattern or mode is revealed. But the pattern at such high signal levels may not correspond to the modes produced at the lower signal levels of actual operation.

Recently, however, W.J. Spencer, at the Bell Telephone Laboratories location in Allentown, Pa., has used X-ray diffraction as an accurate and flexible method of observing vibrational amplitude under realistic conditions. The new method depends on the fact that the intensity of diffracted X-rays is extremely sensitive to distortion of the crystal lattice. The transmission of the rays is greater through vibrating regions of a crystal, and this darkens such areas on the X-ray film. Stationary regions are light.

Vibration amplitudes of less than a millionth of an inch are easily observed. Thus, we obtain a quick, sensitive photographic record of displacement associated with any crystal resonance under conditions simulating actual use. This technique helps us design better filters for the Bell System.

Bell Telephone Laboratories
Research and Development Unit of the Bell System

Volterra in Tuscany, where volcanic heat has been successfully utilized as a source of power. Now a similar plan is on foot in the vicinity of Naples, where the heat of the dormant volcano known as Solfatara is to be tapped in the same way and used for generating electric power and for other industrial purposes. The well-known volcanologist F. A. Perret is aiding this undertaking with his advice and incidentally hopes to get interesting scientific information in connection with the proposed borings."

"An interesting new field of research, to which the practical requirements of aeronautics will doubtless lend importance, has been suggested by Dr. L. A. Bauer, viz., a magnetic survey of the air analogous to those which have been made on land and sea. The data of such a survey will be needed by every air pilot who steers by compass. Investigations of the change in the earth's magnetic field with altitude were made in balloons by Gay-Lussac and Biot in 1804 and again, half a century later, by Glaisher. However, says Dr. Bauer, the available observations to date do not possess the requisite refinement, and it is to be hoped that someday a non-magnetic airship and the necessary instrumental appliances will be available for conducting a magnetic survey of the atmosphere similar to that which has been carried out over the oceans by the non-magnetic ship *Carnegie*."

"It is surprising to learn that a magnificent folio volume, a translation of the first Latin edition (1556) of *De re metallica*, by Georgius Agricola, containing hundreds of footnotes and cross-references revealing a vast amount of scholarly research, was published in London in 1912 by Herbert C. Hoover and (Mrs.) Lou H. Hoover. Since that time Mr. Hoover has attained world-wide celebrity for his philanthropic work in Belgium and in this country, exhibiting a genius for organization that is not usually looked for in a classical scholar."

SCIENTIFIC AMERICAN

APRIL, 1868: "Prof. Nobel of Hamburg, not entirely content with his former discovery, nitro-glycerin, has brought out another explosive, to which he has given the name 'dynamite.' Instead of being an oily liquid, liable to leak from the vessel in which it is confined and produce a spontaneously inflammable mixture with rags, shavings and other packing material, this powder resembles snuff in appearance. In a loose, non-compressed condition it does not explode but burns slowly with little smoke, an invaluable property in working closed mines or tunnels. A detonating cap is required to explode it. Recent California papers contain accounts of the prodigious power of this powder, demonstrated in some experiments tried in that state. They recommend it highly as being vastly more explosive and requiring much less drilling or preparation of the rock than gunpowder."

"The owners of the *Great Eastern*, mourning not only a non-appearance of dividends but also a very heavy expense in keeping the big ship in existence, are in a sad state of perplexity, not knowing what is to become of their unproductive property. At the recent annual meeting of the shareholders the directors' report deplored the failure of the company to complete its contract with the new French cable company, the latter refusing to honor the terms of the agreement, and the whole affair is now before the law courts for adjudication. As far as the future is concerned, the chairman tried to persuade the company that the prospects were encouraging, as there were other cables to be laid and he was certain that their ship was the only one which could accomplish such an undertaking successfully. One hopeful proprietor suggested that the Leviathan should be converted into an immense floating hotel, but the plan was promptly voted down. The shareholders are certainly deserving of public sympathy."

"Mr. George Bartlett left this city on the evening of April 8th to visit a sister residing in Providence, R.I. The next afternoon he lay down to recover from the fatigue of his journey, and soon afterward he was found to be dead. Thus suddenly passed away a steadfast friend and a zealous promoter of science and the arts. Mr. Bartlett was for several years an editor on this paper, and in this capacity he won the high regard of all those who were associated with him. His contributions to the paper were remarkable for their clearness of expression and aptness of illustration; they were always entertaining as well as instructive. He had the ability from education and natural endowments to make his name illustrious in literature and science, and he lacked only the personal ambition to do so. He printed very little over his own name, and thus his real worth was known only to his friends."

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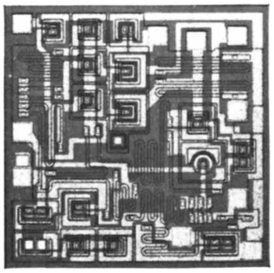

In 1967, one major supplier had an integrated circuit sales growth rate more than double anyone else.

THE AUTHORS

ROBERT ROSENTHAL and LENORE F. JACOBSON ("Teacher Expectations for the Disadvantaged") are respectively professor of social psychology at Harvard University and principal of an elementary school in the South San Francisco Unified School District. Rosenthal was graduated from the University of California at Los Angeles in 1953 and obtained a Ph.D. there in 1956. He taught at the University of Southern California, U.C.L.A., the University of North Dakota and Ohio State University before going to Harvard in 1962. Miss Jacobson was graduated from San Francisco State College in 1946, received a master's degree at Sacramento State College in 1951 and obtained the degree of Ed.D. from the University of California at Berkeley in 1966. She writes: "The arts were my prime interest aside from teaching school until I began my doctoral work. Since then my extra-job energies have been devoted to educational research, and I suspect that I'm permanently hooked."

JOSEPH K. STONE ("Oxygen in Steelmaking") is manager of the Steel Plants Development Department of Kaiser Engineers, a division of Kaiser Industries Corporation. His entire career has been in the steel industry, beginning in 1936 when he received a bachelor's degree in metallurgical engineering from Lehigh University. The scope of his work has ranged from the metallography of alloy steels to the development of pilot plants for making steel by pneumatic methods. Since 1956 he has been concerned mostly with the L-D, or basic oxygen, process that he describes in his article; he writes that he has been "involved in the preliminary development, conceptual design or start-up of most of the L-D plants in the U.S."

SVEN R. HARTMANN ("Photon Echoes") is associate professor of physics and an Alfred P. Sloan research fellow at Columbia University. He was graduated from Union College in 1954 and received a doctorate in physics from the University of California at Berkeley in 1961. After a year as a research physicist at Berkeley he joined the Columbia faculty. His special interests are magnetic-resonance effects, relaxation effects and echo effects. He recently took up small-boat sailing on the Hudson River and Long Island Sound; describing himself as "a novice," he says "I race and lose."

PATRICK M. HURLEY ("The Confirmation of Continental Drift") is professor of geology at the Massachusetts Institute of Technology. He was born in Hong Kong and lived there until he was nine years old. After being graduated from the University of British Columbia in 1934 with a degree in mining engineering he spent three years mining gold in British Columbia. He obtained a Ph.D. from M.I.T. in 1940 and has been on the faculty there since 1946. He serves as a consultant to industry and government on mineral resources and development. Hurley writes that in addition to his studies of continental drift his recent work "has been on the absolute abundance of minor elements in the earth and on the rate of separation of the crust from the earth's interior."

W. E. VAN HEYNINGEN ("Tetanus") is master of St. Cross College of the University of Oxford and reader in bacterial chemistry at the university's Sir William Dunn School of Pathology. Born in South Africa, he was graduated from the University of Stellenbosch in 1931 and took a master's degree there in 1932. He holds two doctorates from the University of Cambridge: a Ph.D., obtained in 1936, and an Sc.D., which was granted in 1952. Describing his college, he writes: "St. Cross College came into being in October, 1965, and I am its first master. It is a college for graduate students only, who come to take advanced degrees, and we are interested in all subjects, but we do have a preponderance of scientists. It is our mission in life to make the application of knowledge academically respectable."

PATRICK ECHLIN ("Pollen") is head of the electron microscopy laboratory in the department of botany at the University of Cambridge and a fellow of Clare Hall. He obtained a teacher's certificate at Goldsmiths' College of the University of London in 1954 and a bachelor's degree in botany at University College London in 1957. For the next five years he was a Fulbright Scholar at the School of Medicine of the University of Pennsylvania, where he received a Ph.D. in medical microbiology in 1961. In addition to pollen his research interests include the biology of blue-green algae (he was the author of the article "The Blue-Green Algae" in the June 1966 issue of SCIENTIFIC AMERICAN) and the origins of photosynthesis. He writes that outside of his work his interests include "photography, gourmet cooking and the camping variety of world-wide travel."

H. E. WULFF ("The Qanats of Iran"), who died in Pakistan on December 31, was senior lecturer in engineering at the University of New South Wales in Sydney, Australia. Before World War II, as principal of the Technical College at Shiraz in Iran, he collected information on the preindustrial technologies of Iran. Two years ago he published the results of this work in a book, *The Traditional Crafts of Persia*. From 1966 until his death Wulff was leader of a team doing research in the early technologies of South Asia for the Smithsonian Institution and the University of New South Wales. He described the work as "trying to rescue from oblivion the knowledge of early technological activities."

JACK COLVARD JONES ("The Sexual Life of a Mosquito") is professor of entomology at the University of Maryland. He was graduated from Auburn University in 1942 and received a master's degree there in 1947. In 1950 he obtained a Ph.D. from Iowa State University. From 1950 to 1958 he was at the National Institutes of Health, investigating the anatomy, histology and physiology of *Anopheles quadrimaculatus*, the southeastern malaria mosquito, and also studying the mode of action of various insecticides on the hearts of those insects. He has been at the University of Maryland since 1958. Of his work there he writes: "Teach general and advanced insect physiology. Conduct research on the anatomy and physiology of the reproductive system of mosquitoes and on the structure and function of insect blood cells in general. Interest in comparative hematology extends from 1946 to present. Interest in the circulatory system of insects in general extends from 1950 to present." Jones plans to begin studying the alimentary canal of mosquitoes in the near future.

KINGSLEY DAVIS, who in this issue reviews *Population Growth and Land Use*, by Colin Clark, is director of International Population and Urban Research and professor of sociology at the University of California at Berkeley.

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Teacher Expectations for the Disadvantaged

It is widely believed that poor children lag in school because they are members of a disadvantaged group. Experiments in a school suggest that they may also do so because that is what their teachers expect

by Robert Rosenthal and Lenore F. Jacobson

One of the central problems of American society lies in the fact that certain children suffer a handicap in their education which then persists throughout life. The "disadvantaged" child is a Negro American, a Mexican American, a Puerto Rican or any other child who lives in conditions of poverty. He is a lower-class child who performs poorly in an educational system that is staffed almost entirely by middle-class teachers.

The reason usually given for the poor performance of the disadvantaged child is simply that the child is a member of a disadvantaged group. There may well be another reason. It is that the child does poorly in school because that is what is expected of him. In other words, his shortcomings may originate not in his different ethnic, cultural and economic background but in his teachers' response to that background.

If there is any substance to this hypothesis, educators are confronted with some major questions. Have these children, who account for most of the academic failures in the U.S., shaped the expectations that their teachers have for them? Have the schools failed the children by anticipating their poor performance and thus in effect teaching them to fail? Are the massive public programs of educational assistance to such children reinforcing the assumption that they are likely to fail? Would the children do appreciably better if their teachers could be induced to expect more of them?

We have explored the effect of teacher expectations with experiments in which teachers were led to believe at the beginning of a school year that certain of their pupils could be expected to show considerable academic improvement during the year. The teachers thought the predictions were based on tests that had been administered to the student body toward the end of the preceding school year. In actuality the children designated as potential "spurters" had been chosen at random and not on the basis of testing. Nonetheless, intelligence tests given after the experiment had been in progress for several months indicated that on the whole the randomly chosen children had improved more than the rest.

The central concept behind our investigation was that of the "self-fulfilling prophecy." The essence of this concept is that one person's prediction of another person's behavior somehow comes to be realized. The prediction may, of course, be realized only in the perception of the predictor. It is also possible, however, that the predictor's expectation is communicated to the other person, perhaps in quite subtle and unintended ways, and so has an influence on his actual behavior.

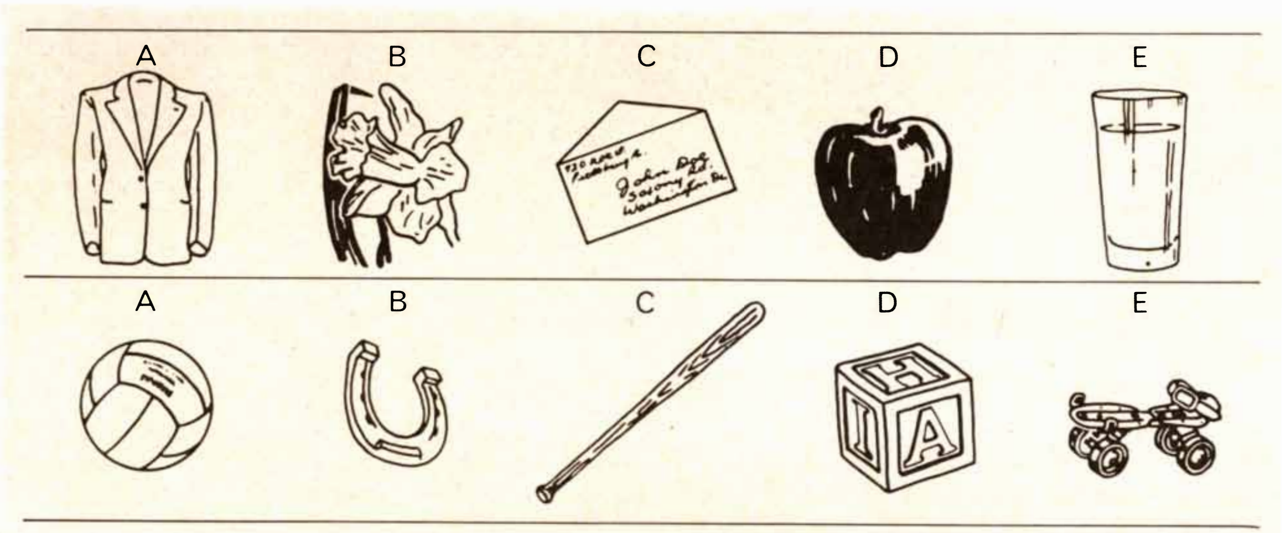
An experimenter cannot be sure that he is dealing with a self-fulfilling prophecy until he has taken steps to make certain that a prediction is not based on behavior that has already been observed. If schoolchildren who perform poorly are those expected by their teachers to perform poorly, one cannot say in the normal school situation whether the teacher's expectation was the cause of the performance or whether she simply made an accurate prognosis based on her knowledge of past performance by the particular children involved. To test for the existence of self-fulfilling prophecy the experimenter must establish conditions in which an expectation is uncontaminated by the past behavior of the subject whose performance is being predicted.

It is easy to establish such conditions in the psychological laboratory by presenting an experimenter with a group of laboratory animals and telling him what kind of behavior he can expect from them. One of us (Rosenthal) has carried out a number of experiments along this line using rats that were said to be either bright or dull. In one experiment 12 students in psychology were each given five laboratory rats of the same strain. Six of the students were told that their rats had been bred for brightness in running a maze; the other six students were told that their rats could be expected for genetic reasons to be poor at running a maze. The assignment given the students was to teach the rats to run the maze.

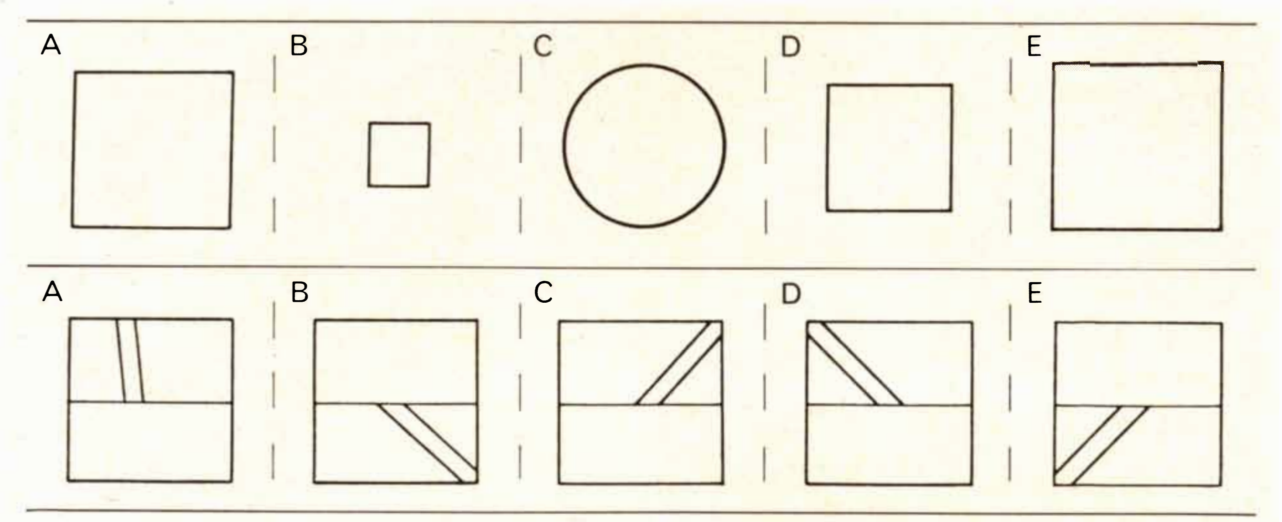
From the outset the rats believed to have the higher potential proved to be the better performers. The rats thought to be dull made poor progress and sometimes would not even budge from the starting position in the maze. A questionnaire given after the experiment showed that the students with the allegedly brighter rats ranked their subjects as brighter, more pleasant and more likable than did the students who had the allegedly duller rats. Asked about their methods of dealing with the rats, the students with the "bright" group turned out to have been friendlier, more enthusiastic and less talkative with the animals than the students with the "dull" group had been. The students with the "bright" rats also said they handled their animals more, as well as more gently, than the students expecting poor performances did.

Our task was to establish similar conditions in a classroom situation. We wanted to create expectations that were based only on what teachers had been told, so that we could preclude the possibility of judgments based on previous observations of the children involved. It was with this objective that we set up our experiment in what we shall call Oak School, an elementary school in the South San Francisco Unified School District. To avoid the dangers of letting it be thought that some children could be expected to perform poorly we established only the expectation that certain pupils might show superior performance. Our experiments had the financial support of the National Science Foundation and the cooperation of Paul Nielsen, the superintendent of the school district.

Oak School is in an established and somewhat run-down section of a middle-sized city. The school draws some students from middle-class families but more from lower-class families. Included in the latter category are children from families receiving welfare payments, from low-income families and from Mexican-American families. The



VERBAL ABILITY of children in kindergarten and first grade was tested with questions of this type in the Flanagan Tests of General Ability. In the drawings at top the children were asked to cross out the thing that can be eaten; in the bottom drawings the task was to mark "the thing that is used to hit a ball." The tests are published by Science Research Associates, Inc., of Chicago.



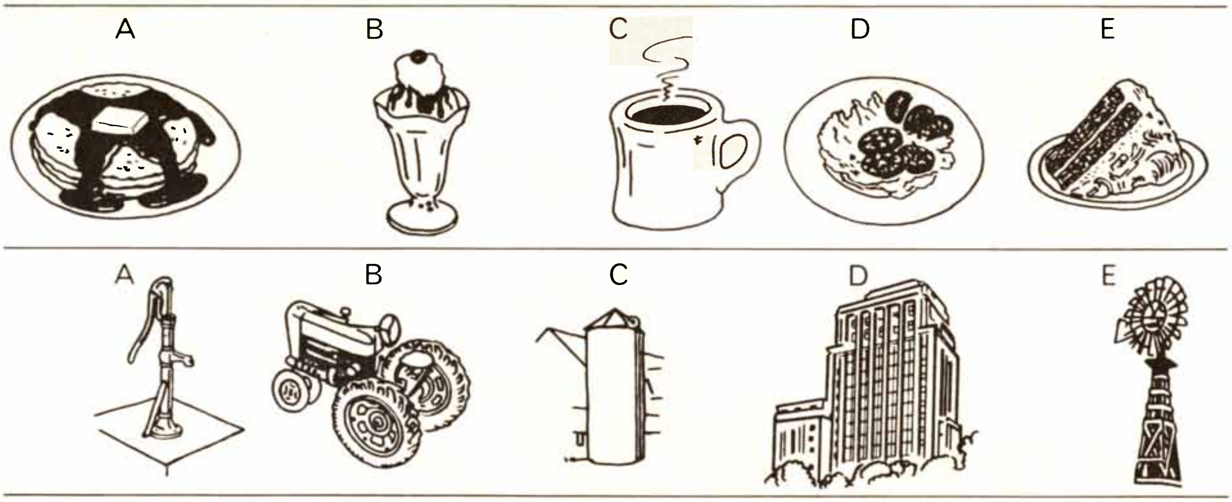
REASONING ABILITY of children in kindergarten and first grade was tested with abstract drawings. The children were told that four of the drawings in each example followed the same rule and one did not. The task was to mark the exception. In the drawings at top the exception is the circle; at bottom all the drawings except the first one have parallel lines that terminate at a corner.

school has six grades, each organized into three classes—one for children performing at above-average levels of scholastic achievement, one for average children and one for those who are below average. There is also a kindergarten.

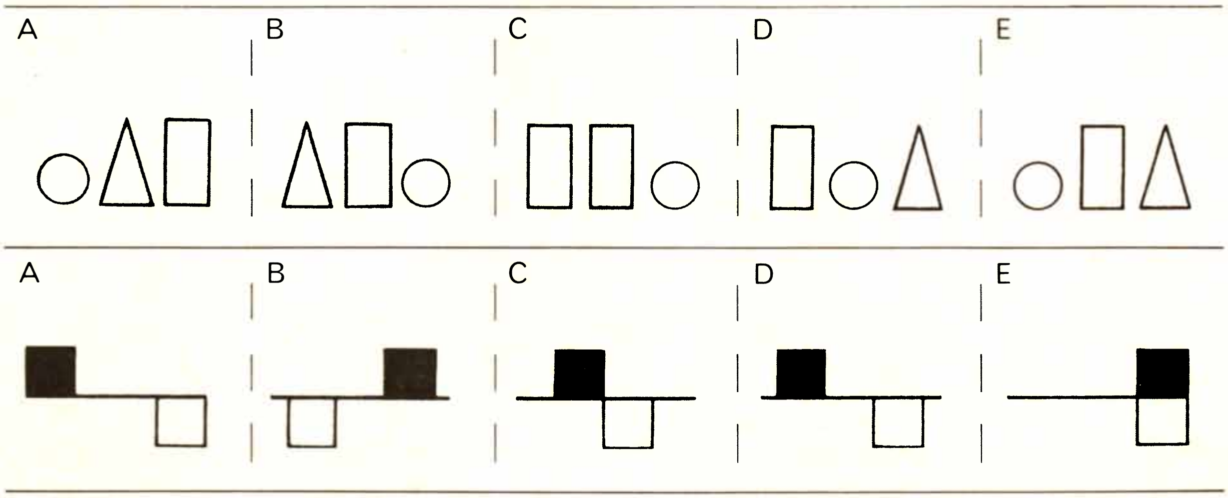
At the beginning of the experiment in 1964 we told the teachers that further validation was needed for a new kind of test designed to predict academic blooming or intellectual gain in children. In actuality we used the Flanagan Tests of General Ability, a standard intelligence test that was fairly new and therefore unfamiliar to the teachers. It consists of two relatively independent subtests, one focusing more on verbal ability and the other more on reasoning ability. An example of a verbal item in the version of the test designed for children in kindergarten and first grade presents drawings of an article of clothing, a flower, an envelope, an apple and a glass of water; the children are asked to mark with a crayon "the thing that you can eat." In the reasoning subtest a typical item consists of drawings of five abstractions, such as four squares and a circle; the pupils are asked to cross out the one that differs from the others.

We had special covers printed for the test; they bore the high-sounding title "Test of Inflected Acquisition." The teachers were told that the testing was part of an undertaking being carried out by investigators from Harvard University and that the test would be given several times in the future. The tests were to be sent to Harvard for scoring and for addition to the data being compiled for validation. In May, 1964, the teachers administered the test to all the children then in kindergarten and grades one through five. The children in sixth grade were not tested because they would be in junior high school the next year.

Before Oak School opened the follow-



ADVANCED TESTS were given to children in second and third grades and grades four through six. Two examples from the test of verbal reasoning for grades four through six appear here. In the example at top the children were asked to "find the beverage." In the bottom example the instruction that the pupils received from the teacher was "Find the one you are most likely to see in the city."



REASONING TEST for children in grades four through six was based on the same principles as the test for younger children but used more sophisticated examples. At top the exception is *C*, which has no triangle. In the example at bottom the exception is *E*, because in all the other drawings the black and white squares are not aligned vertically. The tests were used to measure pupils' progress.

ing September about 20 percent of the children were designated as potential academic spurters. There were about five such children in each classroom. The manner of conveying their names to the teachers was deliberately made rather casual: the subject was brought up at the end of the first staff meeting with the remark, "By the way, in case you're interested in who did what in those tests we're doing for Harvard...."

The names of the "spurters" had been chosen by means of a table of random numbers. The experimental treatment of the children involved nothing more than giving their names to their new teachers as children who could be expected to show unusual intellectual gains in the year ahead. The difference, then, between these children and the undesignated children who constituted a control group was entirely in the minds of the teachers.

All the children were given the same test again four months after school had started, at the end of that school year and finally in May of the following year. As the children progressed through the grades they were given tests of the appropriate level. The tests were designed for three grade levels: kindergarten and first grade, second and third grades and fourth through sixth grades.

The results indicated strongly that children from whom teachers expected greater intellectual gains showed such gains [*see illustration below*]. The gains, however, were not uniform across the grades. The tests given at the end of the first year showed the largest gains among children in the first and second grades. In the second year the greatest gains were among the children who had been in the fifth grade when the "spurters" were designated and who by the time of the final test were completing sixth grade.

At the end of the academic year 1964–1965 the teachers were asked to describe the classroom behavior of their pupils. The children from whom intellectual growth was expected were described as having a better chance of being successful in later life and as being happier, more curious and more interesting than the other children. There was also a tendency for the designated children to be seen as more appealing, better adjusted and more affectionate, and as less in need of social approval. In short, the children for whom intellectual growth was expected became more alive and autonomous intellectually, or at least were so perceived by their teachers. These findings were particularly striking among the children in the first grade.

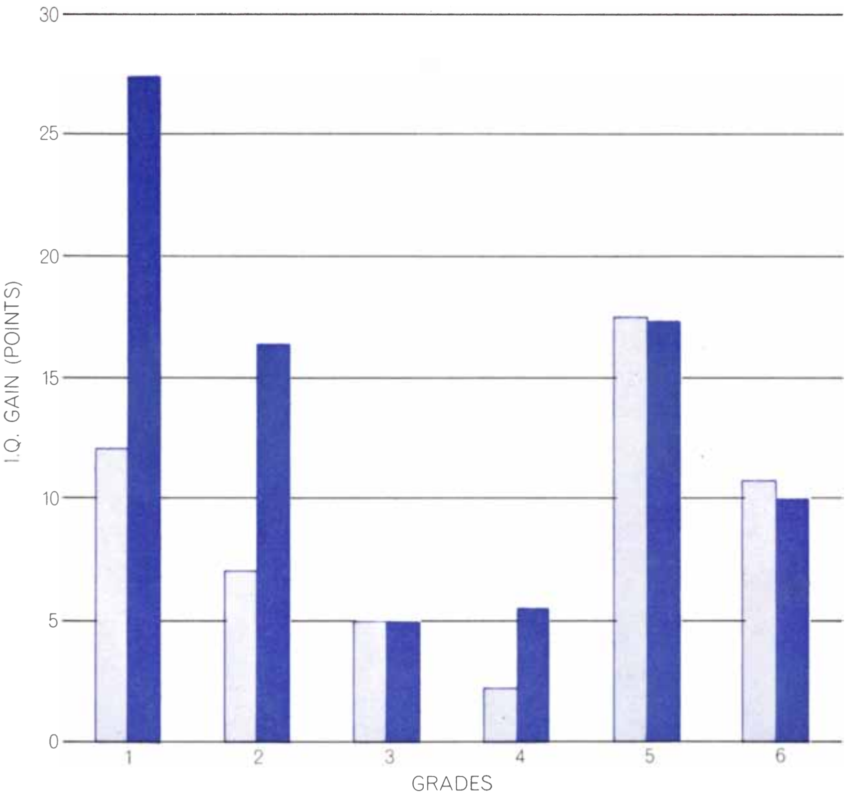
An interesting contrast became apparent when teachers were asked to rate the undesignated children. Many of these children had also gained in I.Q. during the year. The more they gained, the less favorably they were rated.

From these results it seems evident that when children who are expected to gain intellectually do gain, they may be benefited in other ways. As "personalities" they go up in the estimation of their teachers. The opposite is true of children who gain intellectually when improvement is not expected of them. They are looked on as showing undesirable behavior. It would seem that there are hazards in unpredicted intellectual growth.

A closer examination revealed that the most unfavorable ratings were given to the children in low-ability classrooms who gained the most intellectually. When these "slow track" children were in the control group, where little intellectual gain was expected of them, they were rated more unfavorably by their teachers if they did show gains in I.Q. The more they gained, the more unfavorably they were rated. Even when the slow-track children were in the experimental group, where greater intellectual gains were expected of them, they were not rated as favorably with respect to their control-group peers as were the children of the high track and the medium track. Evidently it is likely to be difficult for a slow-track child, even if his I.Q. is rising, to be seen by his teacher as well adjusted and as a potentially successful student.

How is one to account for the fact that the children who were expected to gain did gain? The first answer that comes to mind is that the teachers must have spent more time with them than with the children of whom nothing was said. This hypothesis seems to be wrong, judging not only from some questions we asked the teachers about the time they spent with their pupils but also from the fact that in a given classroom the more the "spurters" gained in I.Q., the more the other children gained.

Another bit of evidence that the hypothesis is wrong appears in the pattern of the test results. If teachers had talked to the designated children more, which would be the most likely way of invest-



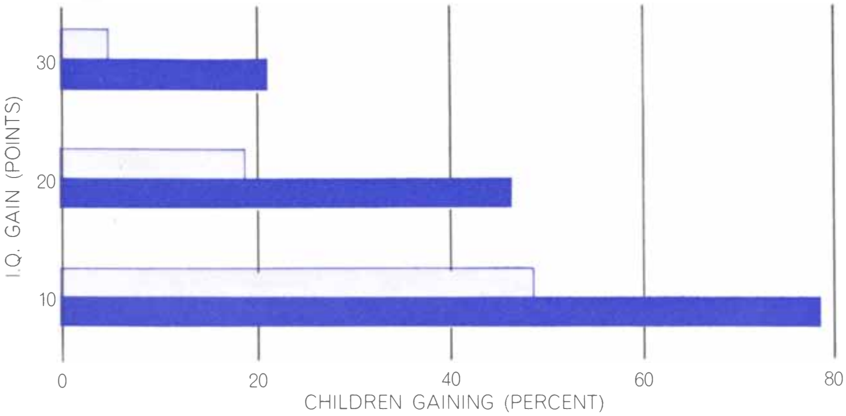
GAINS IN INTELLIGENCE were shown by children by the end of the academic year in which the experiment was conducted in an elementary school in the San Francisco area. Children in the experimental group (*dark bars*) are the ones the teachers had been told could be expected to show intellectual gains. In fact their names were chosen randomly. Control-group children (*light bars*), of whom nothing special was said, also showed gains.

ing more time in work with them, one might expect to see the largest gains in verbal intelligence. In actuality the largest gains were in reasoning intelligence.

It would seem that the explanation we are seeking lies in a subtler feature of the interaction of the teacher and her pupils. Her tone of voice, facial expression, touch and posture may be the means by which—probably quite unwittingly—she communicates her expectations to the pupils. Such communication might help the child by changing his conception of himself, his anticipation of his own behavior, his motivation or his cognitive skills. This is an area in which further research is clearly needed.

Why was the effect of teacher expectations most pronounced in the lower grades? It is difficult to be sure, but several hypotheses can be advanced. Younger children may be easier to change than older ones are. They are likely to have less well-established reputations in the school. It may be that they are more sensitive to the processes by which teachers communicate their expectations to pupils.

It is also difficult to be certain why the older children showed the best performance in the follow-up year. Perhaps the younger children, who by then had different teachers, needed continued contact with the teachers who had influenced them in order to maintain their improved performance. The older children, who were harder to influence at first, may have been better able to maintain an improved performance autonomously once they had achieved it.



CHILDREN IN LOWER GRADES showed the most dramatic gains. The chart shows the percent of children in the first and second grades by amount of their gains in I.Q. points. Again dark bars represent experimental-group children, light bars control-group children. Two lower sets of bars include children from higher groups, so that lowest set sums results.

In considering our results, particularly the substantial gains shown by the children in the control group, one must take into account the possibility that what is called the Hawthorne effect might have been involved. The name comes from the Western Electric Company's Hawthorne Works in Chicago. In the 1920's the plant was the scene of an intensive series of experiments designed to determine what effect various changes in working conditions would have on the performance of female workers. Some of the experiments, for example, involved changes in lighting. It soon became evident that the significant thing was not whether the worker had more or less light but merely that she was the subject of attention. Any changes that involved her, and even actions that she only thought were changes, were likely to improve her performance.

In the Oak School experiment the fact that university researchers, supported by Federal funds, were interested in the school may have led to a general improvement of morale and effort on the part of the teachers. In any case, the possibility of a Hawthorne effect cannot be ruled out either in this experiment or in other studies of educational practices. Whenever a new educational practice is undertaken in a school, it cannot be demonstrated to have an intrinsic effect unless it shows some excess of gain over what Hawthorne effects alone would yield. In our case a Hawthorne effect might account for the gains shown by the children in the control group, but it would not account for the greater gains made by the children in the experimental group.

Our results suggest that yet another base line must be introduced when the intrinsic value of an educational innovation is being assessed. The question will be whether the venture is more effective (and cheaper) than the simple expedient of trying to change the expectations of the teacher. Most educational innovations will be found to cost more in both time and money than inducing teachers to expect more of "disadvantaged" children.

For almost three years the nation's schools have had access to substantial Federal funds under the Elementary and Secondary Education Act, which President Johnson signed in April, 1965. Title I of the act is particularly directed at disadvantaged children. Most of the programs devised for using Title I funds focus on overcoming educational handicaps by acting on the child—through remedial instruction, cultural enrichment and the like. The premise seems to be that the deficiencies are all in the child and in the environment from which he comes.

Our experiment rested on the premise that at least some of the deficiencies—and therefore at least some of the remedies—might be in the schools, and particularly in the attitudes of teachers toward disadvantaged children. In our experiment nothing was done directly for the child. There was no crash program to improve his reading ability, no extra time for tutoring, no program of trips to museums and art galleries. The only people affected directly were the teachers; the effect on the children was indirect.

It is interesting to note that one "total push" program of the kind devised under Title I led in three years to a 10-point gain in I.Q. by 38 percent of the children and a 20-point gain by 12 percent. The gains were dramatic, but they did not even match the ones achieved by the control-group children in the first and second grades of Oak School. They were far smaller than the gains made by the children in our experimental group.

Perhaps, then, more attention in educational research should be focused on the teacher. If it could be learned how she is able to bring about dramatic improvement in the performance of her pupils without formal changes in her methods of teaching, other teachers could be taught to do the same. If further research showed that it is possible to find teachers whose untrained educational style does for their pupils what our teachers did for the special children, the prospect would arise that a combination of sophisticated selection of teachers and suitable training of teachers would give all children a boost toward getting as much as they possibly can out of their schooling.

OXYGEN IN STEELMAKING

The injection of pure oxygen into a mixture of molten iron and scrap greatly speeds up the refining of steel. A process based on the use of oxygen is rapidly replacing the open-hearth method of steelmaking

by Joseph K. Stone

The making of steel, one of man's oldest arts, has been advanced by many important refinements since Sir Henry Bessemer inaugurated its modern technology more than a century ago, but it is certain that none of those improvements has had a more dramatic impact on the industry than one that is now being introduced in steel mills the world over. It involves the use of gaseous oxygen in the treating of iron to convert it into steel. The injection of oxygen speeds up every steelmaking process, reduces the cost of steelmaking and improves the quality of the steel. A new process based on the use of oxygen, introduced on a broad scale within the past 16 years, is replacing the open-hearth method so rapidly that it is expected to become the leading steel-production technique in the U.S. within the next few years. Its effects on the steel industry have been profound.

One related effect already in evidence is a huge increase in the production of oxygen. In 1950 the total consumption of processed oxygen by the U.S. iron and steel industry was about 18 billion cubic feet; last year it was 185 billion cubic feet, and it is expected to reach 295 billion cubic feet in 1972. The use of oxygen in steelmaking has created a demand for oxygen by the ton rather than by the pound. Until the mid-1950's oxygen was marketed in the U.S. mainly in bottles—standard steel ones containing 220 cubic feet of the gas. Today it is being produced at steelmaking centers and stored and used in tonnage quantities (24,160 cubic feet to the ton).

Large-scale production has of course reduced costs; whereas the price of oxygen by the bottle amounts to $150 to $200 per ton, in bulk from large plants it costs less than $10 per ton. The lowered cost has intensified interest in the potential uses of oxygen for other promising applications in the iron and steel industry, notably for the smelting of iron in blast furnaces. Such uses could eventually enlarge the market for oxygen enormously.

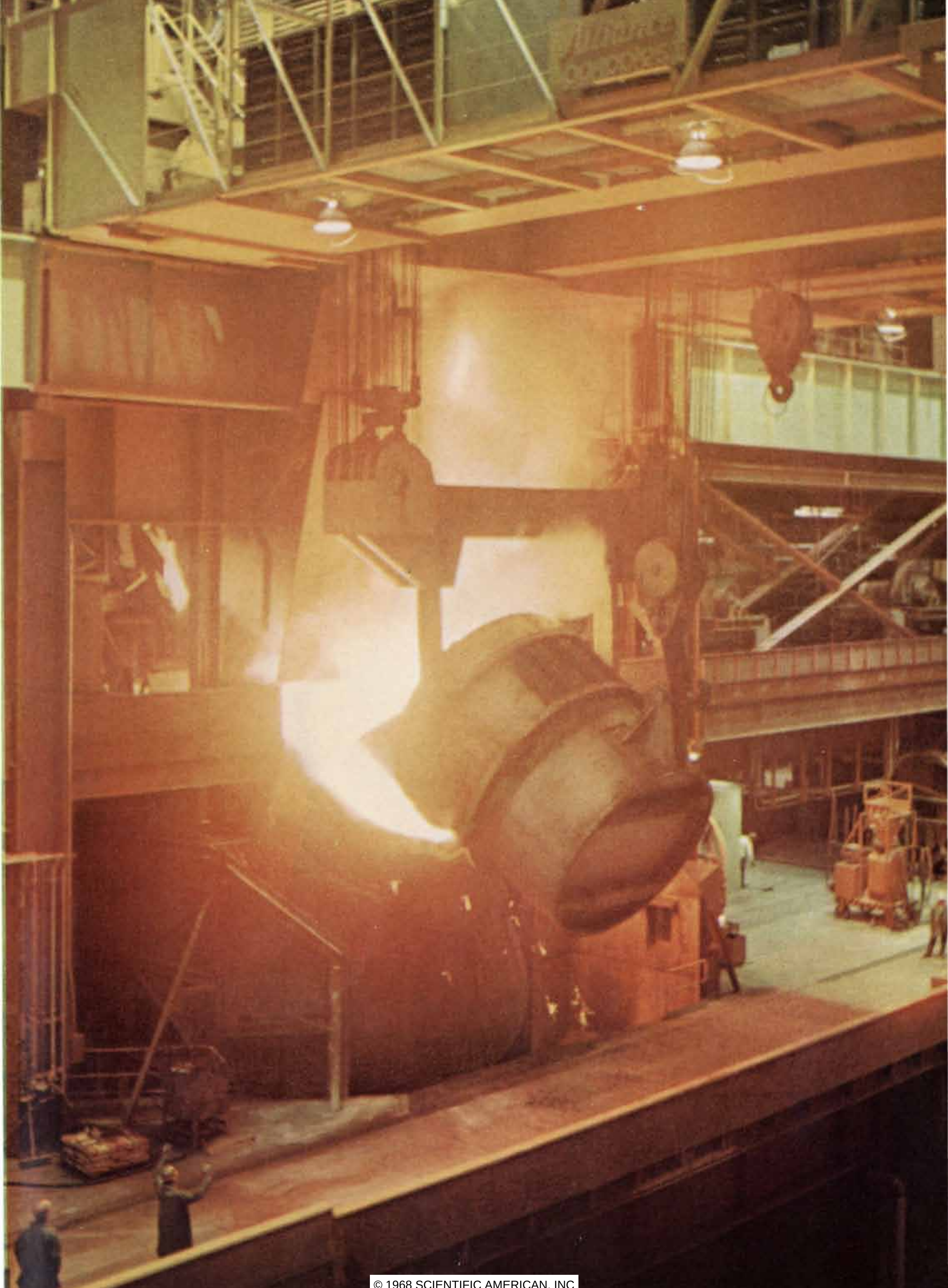
The conversion of iron to steel depends essentially on removal of carbon and other impurities from the iron by combustion. When Bessemer invented his epoch-making converter—a furnace in which air is blown through molten iron—he recognized that the process might be improved by using oxygen rather than air, and he proposed doing so as one of several alternatives. At the time, however, there was no known way to produce the gas in quantity; pure oxygen was just a laboratory curiosity. In fact, oxygen did not become available commercially until Carl Linde of Germany showed at the turn of the century that it could be obtained at a reasonable cost by the liquefaction and distillation of air. The efficient heat exchanger that made tonnage production of the gas practicable and sufficiently reasonable in cost for use in metallurgical operations was developed in the late 1920's.

A few metallurgists, notably Frank W. Davis of the U.S. Bureau of Mines and Robert Durrer of Germany, then began to urge steelmakers to look into the possibilities of oxygen. Many attempts were made to develop new processes, but it was not until 1952 that a new method of steelmaking using high-purity oxygen came into commercial use. In the U.S., where the steel industry had invested heavily in conventional open-hearth furnaces and regarded oxygen as too expensive for large-scale utilization, little attention was paid to these early proposals. In Germany and elsewhere in Europe, however, some steelmakers began to experiment.

Most of the steel in Europe was produced by Bessemer converters of the "basic" type (using a basic, or alkaline, furnace lining and a slag composed predominantly of lime), which had been invented by Sidney G. Thomas and Percy C. Gilchrist of Britain. The experimenters tried blowing mixtures of air and oxygen, instead of air alone, through the molten iron in the converter. Their tests ran into serious trouble. Oxygen, by producing higher temperatures, accelerated the destruction of the bottom of the furnace and the tuyeres, or nozzles, through which the gas is introduced—a process that is troublesome enough in such furnaces when ordinary air is used for blowing.

Nevertheless, European steelmakers continued to experiment with oxygen both before and after World War II. Particularly active and persistent efforts were made in a steel center at Linz in Austria. During the war the Germans built a large complex in Linz consisting of modern blast furnaces, open-hearth and electric furnaces for steel conversion, and a nitrogen-producing plant that generated oxygen as a by-product. When, after the war, the Austrian government nationalized the plant, the plant engineers decided to take advantage of the existing oxygen production to carry

BASIC OXYGEN FURNACE is shown on the opposite page receiving a charge of molten iron. Earlier the furnace, which is in a plant operated by the Weirton Steel Division of the National Steel Corporation, was given a charge of scrap metal. When the scrap and iron are in, the vessel is tilted upright and oxygen is blown into the mixture to facilitate the process of combustion by which the mixture is converted to steel.



BASIC OXYGEN STEEL PLANT is operated by the Armco Steel Corporation in Ashland, Ky. The two sloping tubes emerge from the top of the main building, which contains two basic oxygen furnaces, and carry gases from the operating furnace down to the precipitators, which are to the left of the stack. Precipitators clean gas by removing solid material from it before it enters the stack.

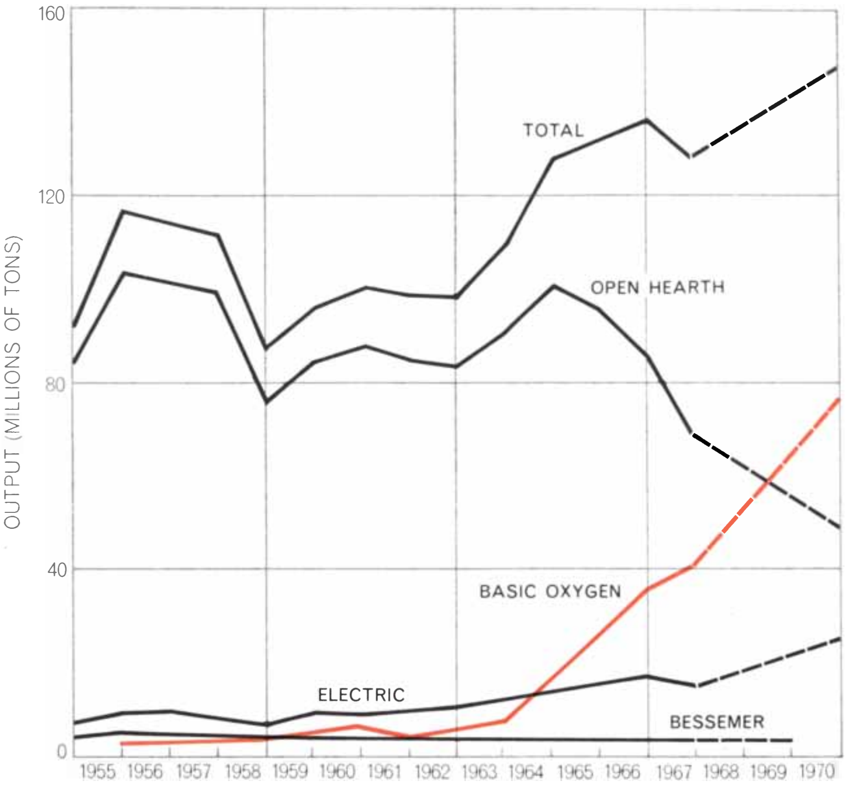
REFINING OF STEEL takes place during a "blow" in a basic oxygen furnace in the Great Lakes Steel Division of the National Steel Corporation. After the pear-shaped furnace has been tilted to receive scrap metal and molten iron it is returned to a vertical position and a water-cooled lance, dimly visible in the small bright space at the top of the photograph, is lowered into the furnace. Through the lance pure oxygen at high pressure is blown into the furnace. Process can produce 300 tons of steel in less than an hour.

out a systematic program of studies. As it happened, the fact that their steel furnaces were of the open-hearth instead of the basic Bessemer type turned out to be crucially important. An essential physical difference between the open-hearth furnace and the Bessemer converter is that in the open hearth the fuel and air are burned over the top of the iron melt instead of being blown through the bottom of the furnace.

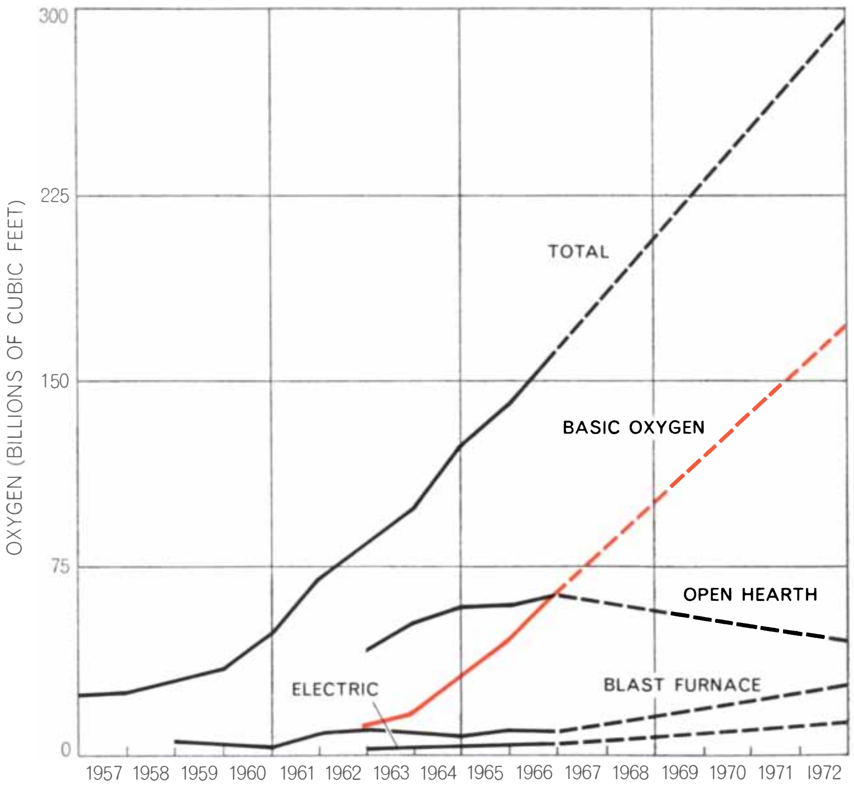
The Austrian experimenters at first simply blew oxygen into the space above the iron melt in an open-hearth furnace. They succeeded in accelerating the conversion of iron to steel, but the increased flame temperature destroyed the roof of the furnace and the regenerators (for preheating air) became clogged with dust. Next they tried feeding oxygen into an electric furnace; again the heat proved destructive, ruining the electrode holders. The Linz engineers then consulted Durrer, who, with a colleague, Heinrich Hellbruegge, was experimenting in Switzerland using oxygen in a two-ton converter and in an electric furnace. Durrer and Hellbruegge were injecting a jet of oxygen into the molten iron through a water-cooled lance placed just above the surface of the iron.

The first trials of this system failed in experiments at Linz designed to follow Durrer's instructions. The heat destroyed the lance; the stream of oxygen blown deep into the melt caused damage to the bottom and other refractories of the vessel, and the treatment failed to remove enough of the phosphorus impurity from the iron. The Linz engineers, as a result of information gleaned from an accident, departed from the views prevailing at the time. They reduced the impact pressure of the oxygen jet by using a different nozzle and raising the lance farther from the surface of the melt so that the oxygen jet did not penetrate deeply into it. This new concept worked splendidly. The bottom of the vessel was undamaged; the lance survived; carbon monoxide gas generated by the burning of carbon in the iron stirred the melt; phosphorus was effectively removed, and the experiment produced steel of good quality.

From their initial experiments in a two-ton vessel the Linz engineers went on to further tests with larger units, and in 1952 they installed the system on a commercial scale, using vessels of 35-ton capacity. The following year a second plant of the same kind went into operation at Donawitz in the ancient ironmaking district of Styria in Austria. The system has since been called the



STEEL PRODUCTION in the U.S. is charted by major processes, with estimates for the next few years indicated by broken lines. The rapidly gaining basic oxygen process is also widely known as the L-D process after the Austrian communities of Linz and Donawitz, where the first plants using the system on a commercial scale were built about 16 years ago.



USE OF OXYGEN by the American iron and steel industry has risen sharply, mainly because of growth of L-D process. Blast furnaces are used to smelt iron ore into pig iron.

L-D process, from the initials of the towns where the first two plants were installed.

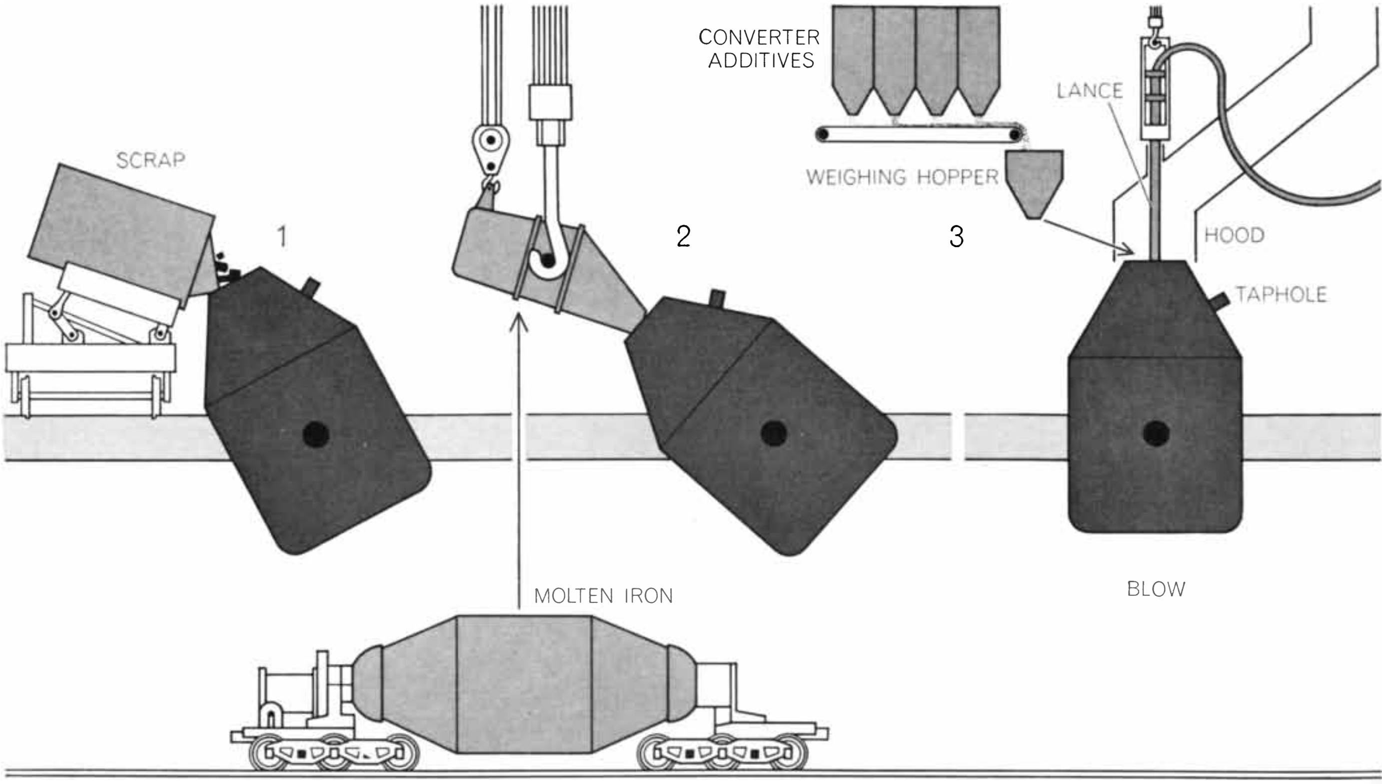
In sum, it took nearly a quarter of a century to develop the L-D process to a commercial scale, if one takes as a starting date the discovery of techniques for making cheap oxygen by the ton. After many failures the discoveries at Linz in 1949 led to the construction of the first commercial-scale plant in 1952.

In its prevailing present form the L-D furnace is a pear-shaped, tiltable vessel resembling a Bessemer converter, typically with a capacity of 150 tons. Such a vessel is charged with 52 tons of scrap steel and 120 tons of molten iron (at about 2,350 degrees Fahrenheit). The iron is poured from a ladle into the L-D furnace after the scrap has already been charged. The entire charging process takes less than four minutes. The vessel is then returned to the upright position, and the lance, a tube some 50 feet long and 10 inches in diameter, is lowered through the mouth until its tip is from four to eight feet above the surface of the white-hot metal. Cooled by water circulating around it at the rate of about 400 gallons per minute, the lance withstands the great heat of the fiery furnace. Through the lance pure oxygen under a pressure of 150 pounds per square inch pours into the melt at the rate of 10,000 cubic feet per minute, making a great roar and generating a tremendous flame as it strikes the molten charge. The resulting oxidation, burning part of the iron and nearly all its impurities—carbon, silicon, manganese and phosphorus—liberates a large amount of heat. A flux consisting of 10 tons of lime, some fluorspar and mill scale is added to form a slag that absorbs the oxides of the metallic impurities; the carbon is removed as carbon monoxide, which is burned (with a large flame) to carbon dioxide as it mixes with the air on emerging from the mouth of the vessel.

The refining process takes only about 20 minutes. When the carbon has been consumed, the fire goes out. The operator withdraws the lance, tilts the vessel and has a look at the molten steel. If he has calculated correctly, he has 150 tons of highly refined steel ready to pour. A thermocouple and a spectrograph tell him the temperature and the composition of the steel. If all is correct, he proceeds to tap the product by tilting the vessel so that the molten metal pours through a taphole into a ladle. Measured proportions of manganese, silicon, carbon and alloys are added to deoxidize the steel and meet the required chemical specifications. The ladle then moves off to pour the steel into ingots or castings. The operator, after inspecting the furnace lining for signs of wear, starts a new cycle. Fifty minutes later another "heat" of steel will be ready.

Unlike an open-hearth furnace, the L-D converter requires no fuel; it derives all the necessary heat from the original molten charge and the combustion of its impurities by the injected oxygen. The L-D furnace uses about half as much steel scrap as most open hearths do. It produces 150 tons of high-quality steel in less than an hour, whereas the conventional open hearth used to take nearly 12 hours for a 150-ton heat and produced steel at the rate of about 16 tons an hour. The cost of the L-D process itself, exclusive of raw materials, is about $10 per ton less than that in an old, inefficient open hearth and $2 per ton less than the cost in open-hearth plants using the most efficient present methods of operation—which call for copious amounts of oxygen.

Small wonder that most of the steel-



BASIC OXYGEN PROCESS consists of the five steps depicted here schematically as they would be carried out in a plant such as the one shown in the illustration on page 25. The basic oxygen furnace is tilted (*1*) to receive a charge of scrap metal, which is followed (*2*) by a charge of molten iron. The furnace is tilted upright (*3*) and the lance is lowered into it for the 22-minute "blow," which oxidizes such impurities as silicon, phosphorus, manganese and sulfur. Additives such as burned lime are put into the converter during the

producing countries found it profitable to invest in plants for the new process and quickly converted to the L-D system. Japan is among the leading producers, making 65 percent of its steel in L-D shops. It is estimated that by 1970 the L-D process will account for more than 40 percent of the total world production of raw steel, including that of the U.S.

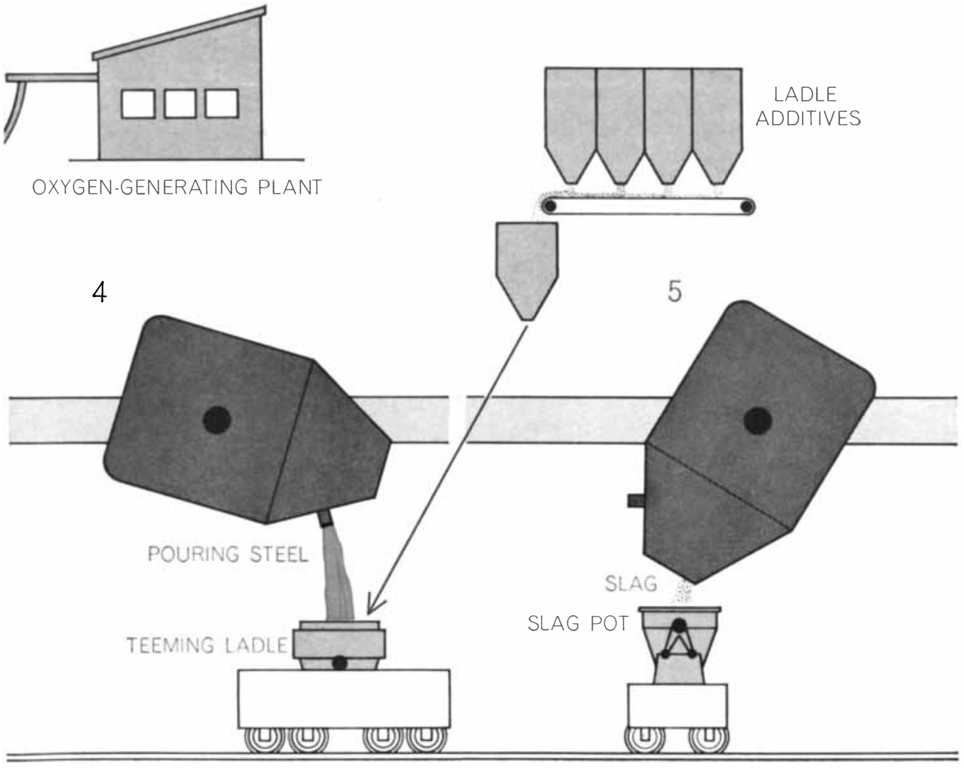
At first the U.S. was slow to adopt the process. The reasons are understandable. Whereas Europe and Japan emerged from World War II with steel plants that, where they were not destroyed by the war, were often pitifully antiquated (much of their production was in small Bessemer converters), the U.S. had built up a huge investment in the then superior open-hearth system, with a capacity of 75 million tons a year, or 90 percent of the nation's total steel production. There were 90 open-hearth plants, averaging nine or 10 furnaces each. The open-hearth process seemed ideally suited to the American economy. It consumes a great deal of scrap, which is plentiful in this highly industrialized country; it can use pig iron in either solid or liquid form and can consume some iron ore as a feed, and its need for fuel (two to five million B.T.U.'s per ton of steel produced) is not a serious drawback on a continent so abundantly supplied with petroleum, natural gas and coal. Furthermore, the first reports of the L-D success in Austria were not impressive to most American steelmakers. Why should their vast steel mills, based on furnaces capable of producing hundreds of tons in a single batch, replace their furnaces with the 35-ton units of which Linz was so proud?

The American industry after the war continued to invest for the most part in improvement of the open-hearth shops, enlarging the furnaces, developing better refractories to strengthen their resistance to high temperatures and introducing oxygen into the open hearth to enhance its performance. The continuing reports from Europe, however, soon convinced American steelmakers that the L-D process was a major breakthrough. The modest 35-ton furnace's output of 50 tons of steel an hour at Linz was a startling advance over the rate of production in American open-hearth furnaces. The American open-hearth operators therefore began to give attention to the possibility of improving their production with more liberal use of oxygen. They found that enriching the combustion of air with oxygen did in fact speed steel production, but it also burned out the furnace roof and filled the air-preheating system with dust, just as it had in early experiments at Linz. They then tried feeding oxygen into the furnace through the doors with steel pipes; this method, however, consumed the pipes too rapidly, cluttered up the shop with hoses and required constant attention. Nevertheless, by the use of oxygen and various improvements in operation, the largest and most efficient open-hearth shops managed to reduce the furnace heat time from 12 hours to as little as five hours and to achieve a production rate of more than 40 tons of steel an hour.

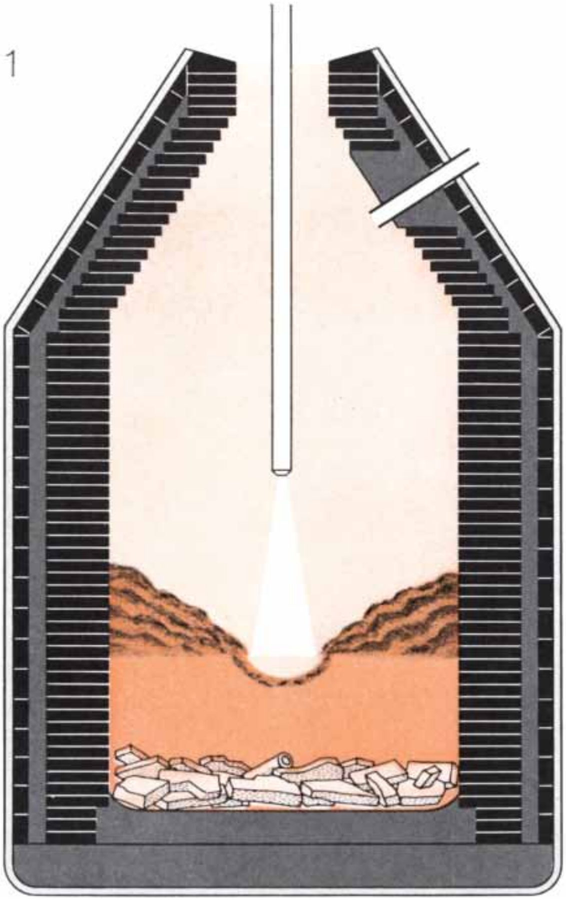
This was still far from satisfactory in comparison with the much faster production in Europe's L-D furnaces. Consequently a few mills borrowed the idea of the water-cooled lance and applied it to the open hearth, feeding oxygen together with natural gas into the furnace. The Steel Company of Canada and the Ford Motor Company (in its steel mills) pushed this technique farthest and attained a steel-production rate of 100 tons an hour. As this was still considerably short of the goal, Ford finally went all the way and built an L-D plant, which began operating in 1964. It attained a production rate of 300 tons an hour, and Ford tore down its open hearths.

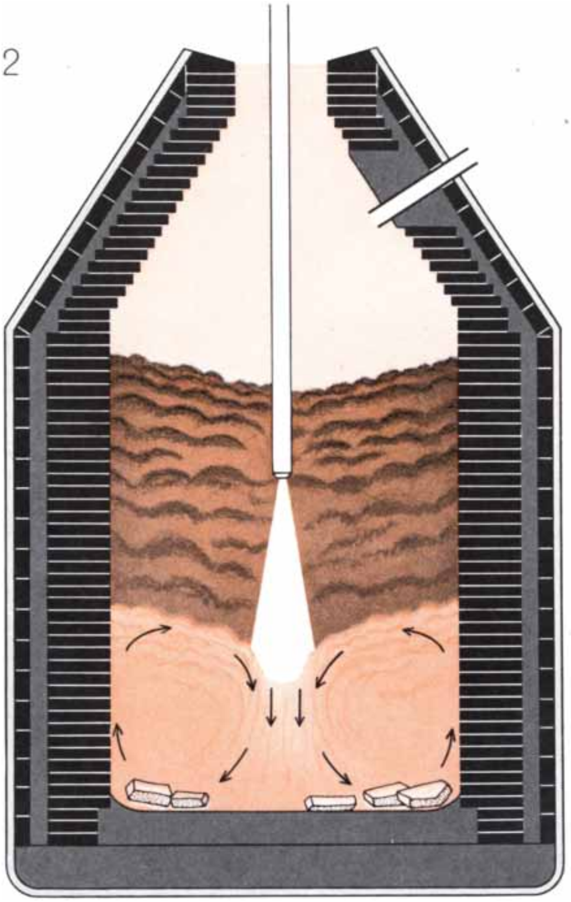
Throughout the nation the open-hearth mills are now yielding steadily to the competition of the L-D technique, which in the U.S. is called the "basic oxygen process" (BOP). About a dozen open-hearth shops have been scrapped or put on permanent standby. In 1967, 40,500,000 tons of steel in the U.S., about a third of the nation's total steel production, was made in new furnaces by the basic oxygen process. By 1970 this process will probably account for at least half of the total.

Although the open hearth still dominates the industry, it survives mainly because it has itself gone over to a large reliance on oxygen. The new open-hearth furnaces built within the past decade or so are equipped with lances or water-cooled roof jets that feed the metal bath with up to 1,300 cubic feet of oxygen per ton of steel produced (compared with 1,800 cubic feet per ton in L-D furnaces). Even so, they cannot match the rate of output or the low cost per ton of steel produced in L-D shops.



early part of a blow to assist in the formation of a slag containing the oxidized impurities. After the blow the furnace is tilted to one side (4) and the refined steel is poured off through a taphole. Substances such as carbon and manganese are added to the ladle to bring the batch of steel to precise specifications. In the final step (5) the slag is poured from furnace.





STAGES OF REFINEMENT of a mixture of scrap and iron into a batch of steel are represented as they appear inside a furnace during a blow. The stages are (*1*) about 15 seconds after the beginning of the blow, (*2*) approximately midway in the 22-minute operation,

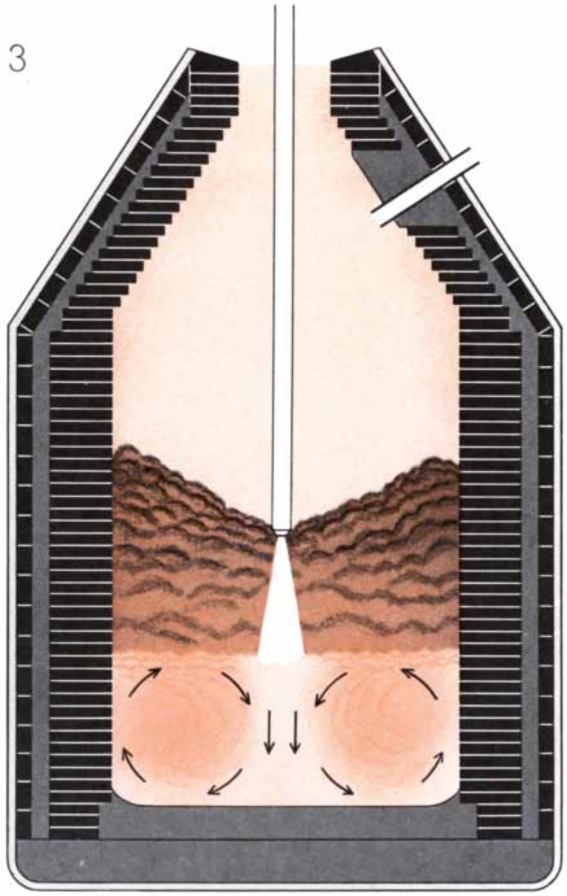
Moreover, in using oxygen the open hearth generates a very dirty plume of smoke from the furnace stack, which in a large mill may necessitate a $10 million investment in equipment to clean up the smoke sufficiently to comply with antipollution ordinances. In an L-D shop the elimination of smoke is much less costly.

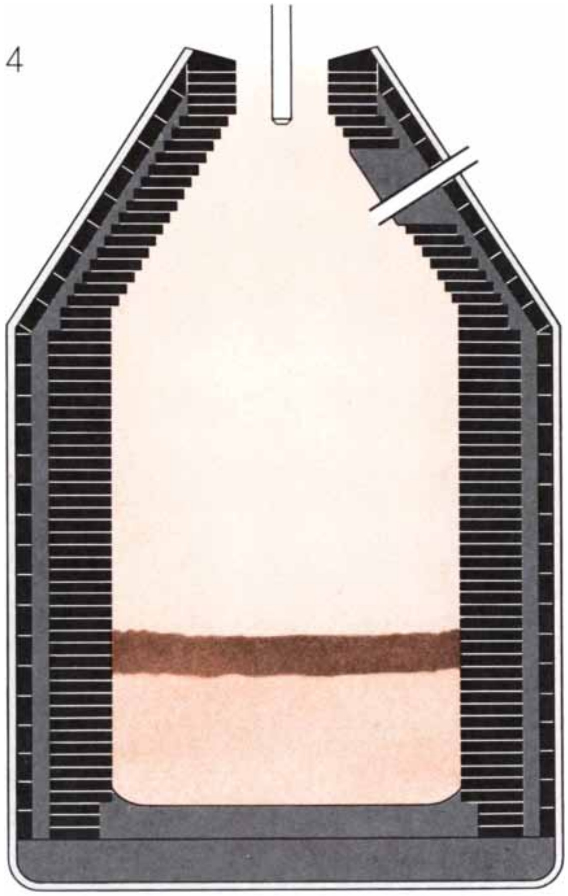
The present position of the open-hearth furnace is reminiscent of that of the sailing ship when steamships came in or that of the steam locomotive when the diesel locomotive arrived. Just as the sail and the steam locomotive eventually had to yield to their more potent and more efficient new competitors, so the open hearth seems destined to become obsolete in the near future. No doubt some of the large new open-hearth units, boosting their production by the use of oxygen, will continue to be important producers for at least 10 more years, but their days are certainly numbered.

Current estimates forecast that by 1972 basic oxygen furnaces in the U.S. will be producing about 96 million tons of raw steel a year (and consuming about 173 billion cubic feet of oxygen), and the production from open hearths will decline to 33 million tons of steel (with a consumption of 44 billion cubic feet of oxygen).

In contrast to the open hearth, the electric-furnace technique for making steel has been promoted to a more favorable position by the advent of the basic oxygen process. It has proved to be both feasible and helpful to inject oxygen into an electric furnace: the oxygen lance speeds up steel production in such a furnace, reduces the electric-power requirement by providing heat from combustion and raises no particularly difficult operating problems. The electric furnace has also benefited economically from the popularity of L-D furnaces, because its charge, or raw material, is mainly scrap. The wide adoption of the L-D process, which uses only about half as much scrap as most open hearths do, has sharply reduced the demand for steel scrap and consequently its price. At the lower prices for the raw material, the electric furnace has become competitive with other steelmaking processes, not only in the manufacture of special alloy steels (which has been its forte) but also in the production of ordinary steels. It has been predicted that the electric-furnace output of steel, now only about 15 million tons a year, will rise to 31 million tons by 1970, with a consumption of more than 12 billion cubic feet of oxygen.

Oxygen is being given a growing role in the finishing of steel. When steel comes from the furnace and is rolled into various semifinished products—slabs, blooms and billets—it is often pocked with defects that must be removed before it is rolled into its final form, such as sheet metal for automobile bodies. These defects are now "scarfed" out of the surface by a burning operation based on the use of oxygen. The surface of the steel slab is heated, then attacked with an oxygen blast that burns the iron imperfections to iron oxide and sweeps the oxide away as a slag. The operation used to be performed with hand torches, but to save time the oxygen blast is now applied to the entire surface, cleaning up the surface at the expense of burning away only 1 percent of the metal. In this and other finishing operations the Amer-





(3) a minute or two before the oxygen is shut off and (4) 30 seconds after the end of the blowing operation. The lance is being withdrawn in the final illustration; the step is necessary so that the furnace can be tipped to pour off first the steel and then the slag.

ican steel industry already uses some 18 billion cubic feet of oxygen a year—equal to the steel industry's entire consumption of commercial oxygen for all purposes in 1950!

Remarkable as all these developments in steelmaking are, they still tell only part of the story of the impending importance of oxygen in the iron and steel industry. Its role in the making of iron could become as important as in the making of steel, and could generate a far greater volume of consumption. For nearly half a century imaginative metallurgists have been advocating the use of oxygen to improve the efficiency of the smelting of iron ore in the blast furnace. The idea has been tested in Europe and in the U.S. with rather promising results. Now that oxygen plants to produce the cheap oxygen envisioned by Davis in 1924 have been built to supply oxygen to the L-D process, use of the same oxygen for smelting iron ore becomes practical. As a result the earlier proposals for the use of oxygen in blast furnaces are being reexamined.

In the blast furnace the production of one ton of iron requires blowing in two and a half tons of air. Basically it is only the one-half ton of oxygen in that air that does the work. If a practical system were devised to perform the smelting with air enriched in oxygen, the furnace could be smaller, cheaper to build and more efficient. Various approaches are being tried, some of them adding a fuel or steam along with the oxygen. These tests have generally shown that oxygen can in fact accelerate the production of iron, reduce the amount of coke required and bring about other improvements in efficiency. A number of problems remain to be solved before oxygen-enriched smelting can be considered feasible for general adoption. Oxygen is already being used on a trial basis in a few furnaces, however, and in 1966 they consumed some nine billion cubic feet of the gas.

The potential market for oxygen in blast furnaces, assuming that a suitable process can be developed, is astronomical. A modest addition of oxygen that would enrich the blown-in air from the normal 21 percent oxygen content to 26 percent would call for supplying 2,700 standard cubic feet of oxygen per ton of iron produced. This is one and a half times the amount used for each ton of steel in the L-D process. For the present annual iron production of about 90 million tons in the U.S. some 240 billion cubic feet of oxygen would be required, more than three times the amount now consumed for L-D steelmaking. And the demand of course would be considerably greater if the oxygen enrichment of the air blown into the blast furnace were extended by more than 5 percent.

The manufacture of iron and steel is undergoing great changes, which have been brought about by the use of oxygen in large quantities in the L-D process. The availability of oxygen in tonnage quantities has led to its use in the existing open hearths. The result has been better and cheaper steels.

The use of tonnage oxygen in steelmaking is likely to serve as an example to inspire other new applications of oxygen to other metallurgical and chemical processes. The improvements that result seem certain to have important technical and economic consequences all over the world.

PHOTON ECHOES

Experiments in which two light pulses are aimed at one end of a ruby crystal and three light pulses are detected emerging from the other end are explained in terms of the crystal's inherent "phase memory"

by Sven R. Hartmann

For the past few years my colleagues and I at Columbia University have been investigating a curious optical phenomenon called the photon echo. Our basic experimental technique is quite simple. When we illuminate a ruby crystal with two short bursts of coherent light from a ruby laser, we sometimes observe not two but three equally spaced light pulses emerging from the other end of the crystal! The first two output pulses are simply the original laser pulses transmitted through the crystal. The third pulse, on the other hand, is spontaneously emitted by the crystal as a delayed by-product of the passage of the first two pulses. It is this third light pulse that we refer to as the photon echo. (In quantum theory the photon is the quantum, or energy unit, of light.)

The photon-echo experiment is one of a large class of echo experiments in which the excitation of a system by two energy pulses separated by a certain time interval (t) leads to the spontaneous emission of a third energy pulse t seconds after the second excitation pulse. The effect of the first pulse is to induce a macroscopic excitation in the irradiated system that is quickly (but only apparently) dissipated. The second pulse, t seconds later, modifies the state of the excited system in such a way that its previous excitation experience is in effect "recalled." When the time elapsed after the transmission of the second excitation pulse is equal to the time separation of the two excitation pulses, the macroscopic excitation induced by the first pulse is re-formed by the irradiated system and a signal is thereby radiated to the outside world. As a general rule the amplitude, or intensity, of the echo signal decreases as the time interval between the first two pulses is increased.

The detailed behavior of such echo signals yields important information about the relaxation characteristics of a system (that is, the ways in which a system returns to normal after being subjected to a shock). Moreover, the inherent memory represented by the echo has been recognized for some time as being potentially useful as a storage system for a computer.

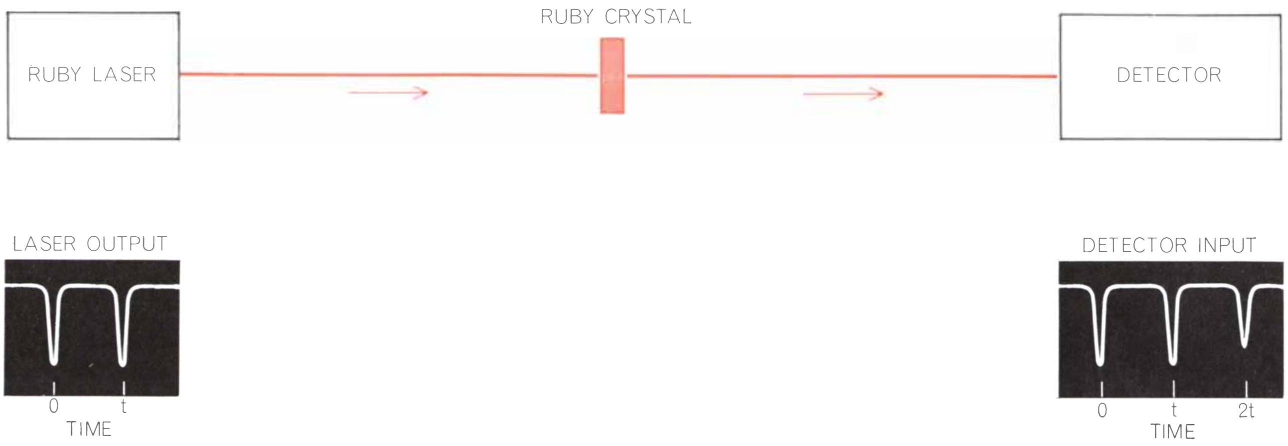
Although the photon-echo experiment is easy to describe, its explanation is rather subtle and should best follow a short discussion of some of the earlier echo experiments.

The earliest-known echo effect—called the nuclear-spin echo—was discovered in 1950 by E. L. Hahn at the University of Illinois in the course of some nuclear-magnetic-resonance experiments. Hahn found that when he applied two resonant bursts of an oscillating magnetic field to a sample containing a large number of paramagnetic atomic nuclei placed in a large constant magnetic field, the paramagnetic nuclei generated an echo signal. The echo-generating mechanism in this case is comparatively easy to visualize. A paramagnetic nucleus is one that has a magnetic moment parallel to its axis of spin. Such a nucleus behaves rather like a tiny spinning dipole magnet. When a paramagnetic nucleus is placed in a magnetic field, its magnetic moment precesses around the direction of the magnetic field in much the same way that the axis of a spinning top precesses around the direction of the earth's gravitational field. In a crystal lattice, however, the spins of many nuclei interact with one another and with the lattice so that they eventually become polarized with their magnetic moments effectively lined up along the magnetic field. If one now applies a small circularly polarized magnetic field that is rotating at the frequency of the precessing nuclei in a plane perpendicular to the constant magnetic field, the nuclei will undergo a complicated motion as they precess around the resultant of the rotating field and the constant field [*see illustration on pages 34 and 35*]. An important characteristic of this motion is that at any instant the angle between the direction of the magnetic moments and the direction of the transverse rotating magnetic field remains the same.

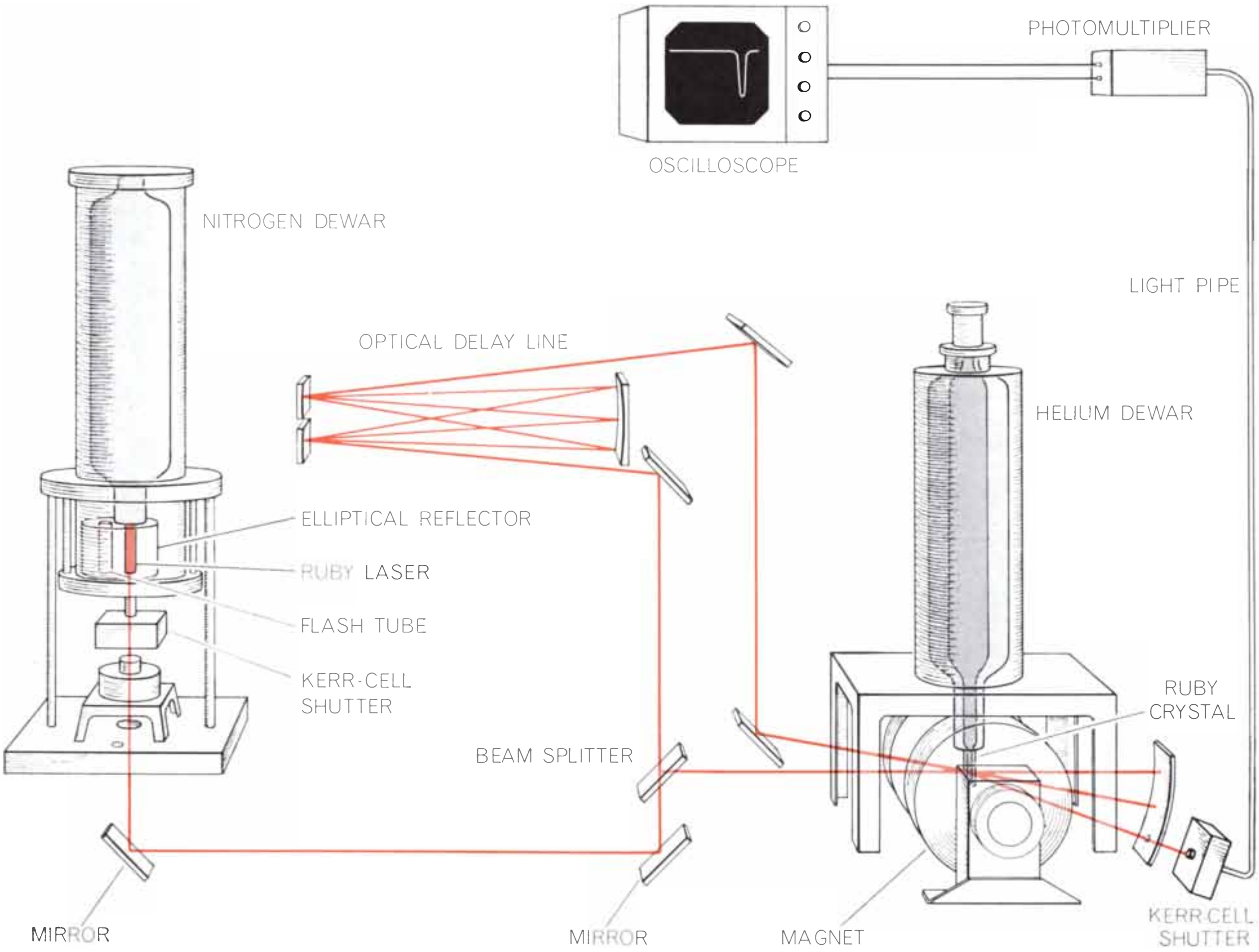
The downward spiral motion executed by each nuclear magnetic moment eventually brings it into the transverse plane, whereupon the rotating magnetic field is turned off. The magnetic-field pulse in this case is called a 90-degree pulse, since the magnetic moment precesses through an angle of 90 degrees around the direction of the transverse rotating field. The magnetic moments of all the nuclei in the sample are now oriented at right angles to the constant magnetic field and are rotating together in the transverse plane at the resonance frequency. As a result the coil that houses the sample will have induced in it an electrical signal, just as a motor generator induces an electric current in its coil.

The induced signal is quickly reduced to zero, however, since there is a spread in the resonance frequencies of the nuclear spins owing to spin-spin interactions and inhomogeneities in the applied magnetic field. As time progresses the individual magnetic moments will precess at different rates and hence fan out in the transverse plane. Since the magnetization of the sample is the vector sum of all the nuclear magnets, it is clear that the net magnetization will soon disappear.

If a second resonant magnetic-field



PRINCIPLE OF PHOTON-ECHO EXPERIMENT is illustrated by this schematic diagram. Two short bursts of coherent light from a ruby laser (*left*) are directed at a ruby crystal (*center*); under the right conditions three light pulses are detected emerging from the other end of the crystal (*right*). The third pulse is the spontaneously emitted photon echo. The stylized oscilloscope traces at bottom show that the time interval between the second excitation pulse and the echo is equal to the interval between the two excitation pulses.

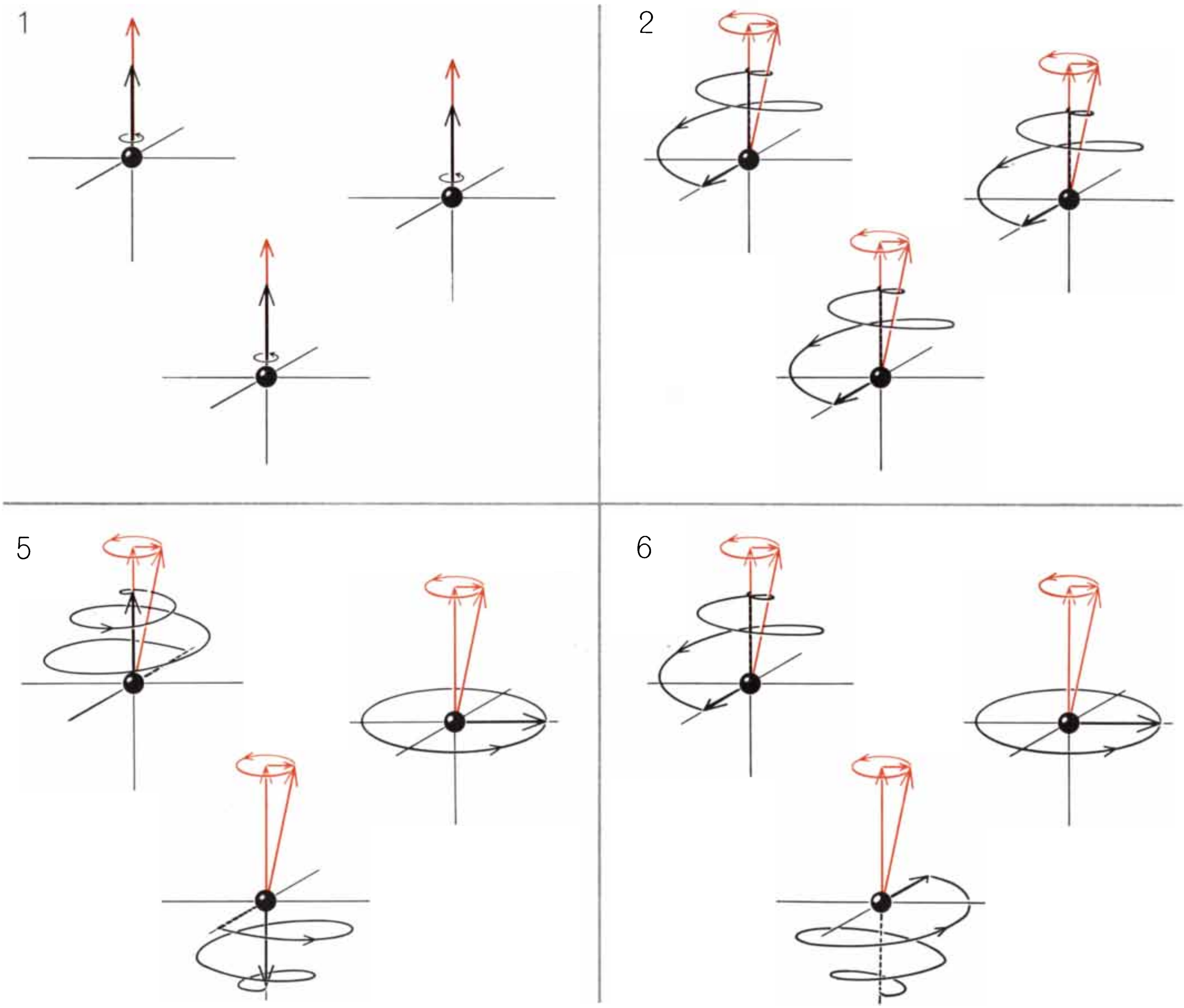


ACTUAL EXPERIMENTAL SETUP used by the author and his colleagues at Columbia University to study the photon echo is depicted here. To ensure against thermal excitations the ruby crystal is cooled to 4.2 degrees Kelvin (degrees centigrade above absolute zero) by suspending it from the base of a Dewar vessel containing liquid helium; the ruby laser is cooled to 77 degrees K. by means of another Dewar vessel containing liquid nitrogen. The ruby laser rod is mounted in an evacuated elliptical cavity at one of the foci; a flash tube at the other focus is used to optically "pump" the ruby rod. A Kerr-cell shutter serves to provide short, intense pulses. Two pulses are obtained by passing the light through a beam splitter, allowing the reflected light to impinge directly on the ruby crystal while diverting the transmitted light into an optical delay line. When the second pulse emerges from the delay line (between 30 and 400 billionths of a second later), it too is directed at the ruby crystal. Because the output pulses are not parallel, the two excitation pulses can be blocked by a screen in order to prevent them from desensitizing the photomultiplier used to detect the echo. The echo pulse passes through a hole in the screen and along a flexible "light pipe"; the detected signal is displayed on an oscilloscope.

pulse is now applied with twice the intensity of the first (or with the same intensity but for twice as long as the first), then each magnetic dipole will again precess in a spiral motion around the resultant of the rotating field and the constant field. In this case, however, the pulse is called a 180-degree pulse, since each magnetic moment precesses 180 degrees around the direction of the transverse rotating field. The important feature of the new dipole configuration is that the relative phase angle of any two dipoles is exactly the negative of what it was before the second pulse. Accordingly the dipoles that precess fastest are now last, whereas the ones that precess slowest are now first. It is clear that after a time interval equal to the time it took for the dipole moments to fan out in the first place they will all be precessing together again in the transverse plane. As soon as this macroscopic oscillating dipole moment is reformed, the coil housing the sample will again detect a temporary electrical signal. This signal is the nuclear-spin echo.

The occurrence of a spin echo usually requires that the local magnetic fields at the various lattice sites remain more or less constant during the time the echo is formed, so that the phase "memory" is easily restored. Nuclear-spin echoes have been detected in many solids, liquids and gases, and they are usually characterized by a simple dependence of echo amplitude on pulse-separation time. The decay of the echo yields information regarding spin-spin interactions, which are very difficult to study in any other way.

The preceding analysis for a nuclear-

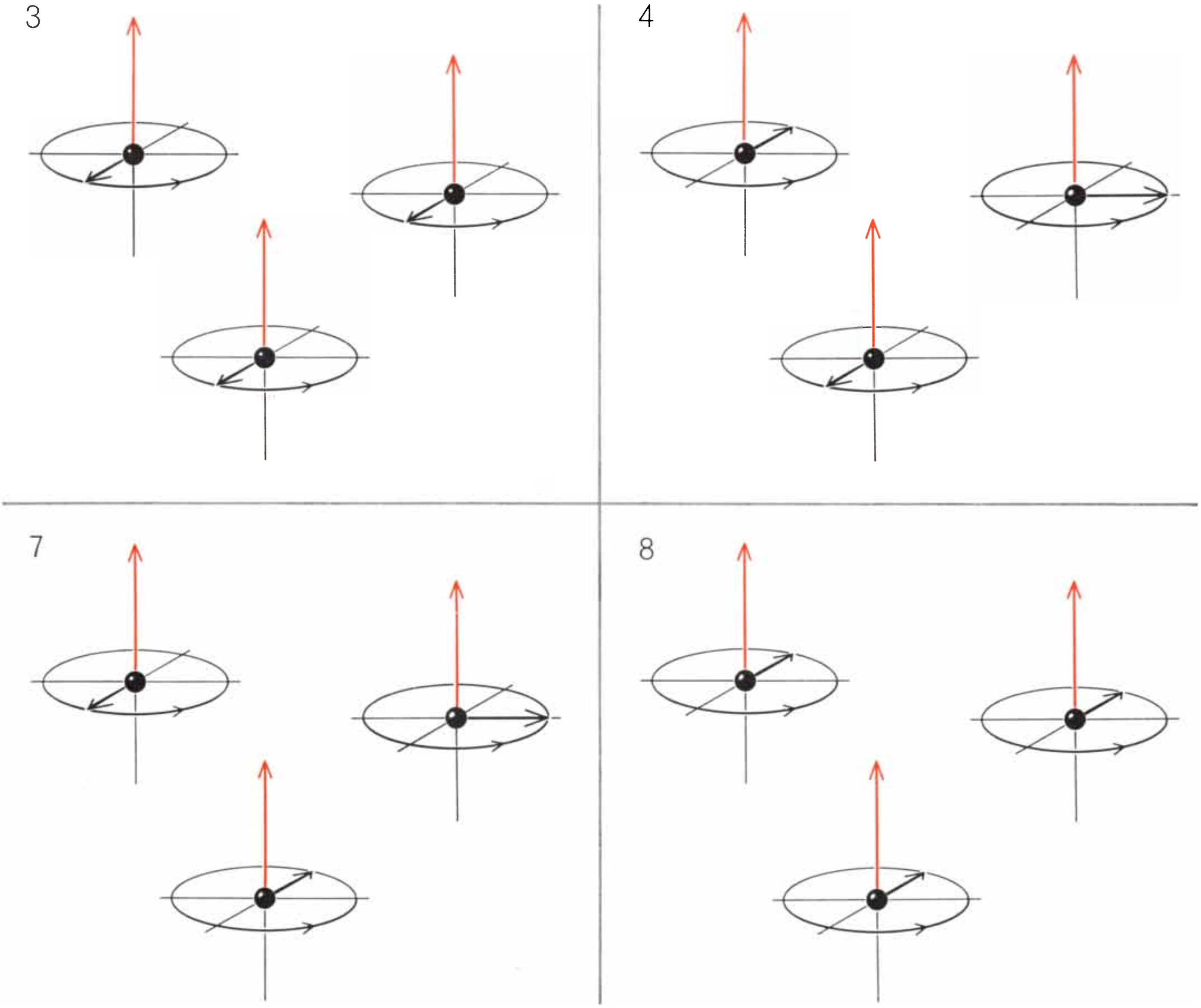


ECHO-GENERATING MECHANISM is demonstrated for the comparatively simple case of the nuclear-spin echo, a phenomenon that is similar in many respects to the photon echo. When a crystal containing a large number of paramagnetic atomic nuclei is placed in a large constant magnetic field (*vertical colored arrows*), the nuclei ultimately become polarized so that their magnetic moments (*heavy black arrows*) are all effectively lined up along the magnetic field (*1*). If one now applies a small circularly polarized magnetic field (*horizontal colored arrows*) that is rotating at the precession frequency of the nuclei in a plane perpendicular to the constant magnetic field, the nuclei will precess around the resultant of the two magnetic fields (*2*). The downward spiral motion executed by each nuclear dipole moment eventually (after several hundred turns) brings it into the transverse plane, whereupon the rotating magnetic field is turned off (*3*). The magnetic moments of all the nuclei in the sample are now oriented at right angles to the constant magnetic field and are rotating together in the transverse plane at the resonant frequency. As a result the coil that houses the

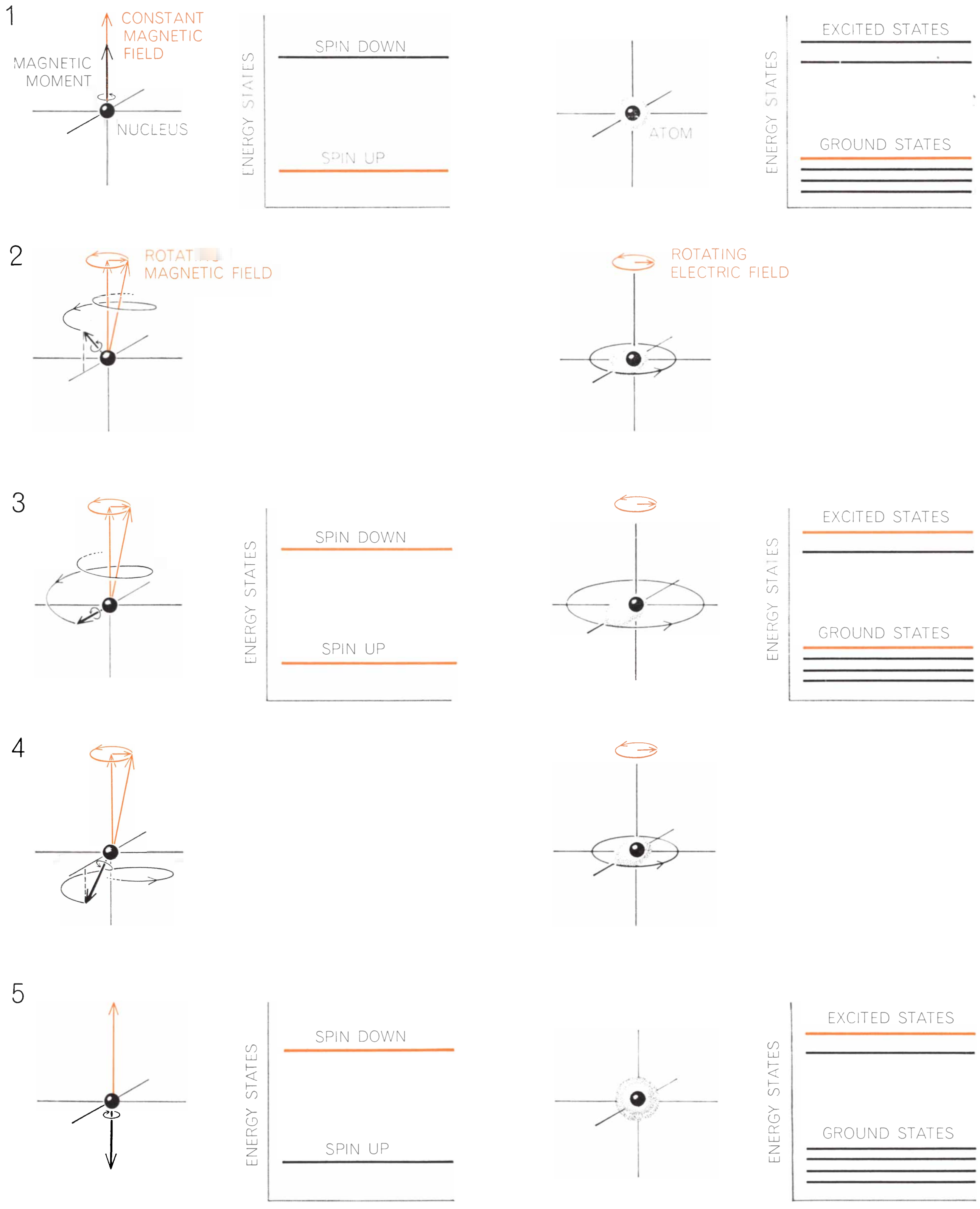
spin echo was made for a particular pulse sequence that had the effect of rotating the magnetic moments through angles of 90 degrees and 180 degrees successively. Almost any other pulse sequence will lead to an echo; the other echoes are weaker, however, and not as easy to explain. Although we have considered only the interaction of the nuclear magnetic moment with an applied magnetic field, the same analysis holds for other nuclear interactions as well.

Electrons also spin and have a magnetic moment; accordingly one can observe electron-spin echoes. The behavior of these echoes is quite striking in that one usually observes large fluctuations in the intensity of the echo as the separation between the excitation pulses is increased. These fluctuations in intensity are caused by the fact that the local magnetic field at each electron site is disturbed by the precessing nuclear magnetic moment of the neighboring atoms. Nonetheless, it is possible to obtain strong electron-spin echoes, since the time variation of the local fields has some regularity to it; by spacing the excitation pulses carefully with respect to the precession period of the neighboring nuclei one can enable the electron spins to recover their "lost" phase.

So far we have considered only echoes produced by easily visualized precessing magnets. If we generalize our results, however, we find that we are dealing with systems that contain a finite number of energy levels capable of being excited by a direct resonant interaction. For example, the simple case of echoes produced by protons in water



sample will have induced in it an electrical signal. The induced signal is quickly reduced to zero, however, since spin-spin interactions and inhomogeneities in the applied magnetic field will cause the individual magnetic moments to precess at different rates and hence fan out in the transverse plane (*4*). If a second resonant magnetic-field pulse is now applied for twice as long as the first, then each magnetic moment will precess around the initial direction of the resonant field by an angle of 180 degrees and end up once again in the transverse plane (*5, 6*). (If a magnetic moment happens to be coincident with the initial direction of the resonant field, it simply continues to rotate in the transverse plane at the resonant frequency.) The important feature of the new dipole configuration is that the relative phase angle of any two dipole moments is exactly the negative of what it was before the second pulse (*7*). After a time interval equal to the time it took for the dipole moments to fan out in the first place, they will all be precessing together again in the transverse plane (*8*). The coil housing the sample will again detect a temporary electrical signal representing the nuclear-spin echo.



SIMILARITY between the permitted energy states of a nucleus spinning in a magnetic field (*left*) and of an isolated impurity atom in a crystal lattice (*right*) led to the prediction of the photon echo. As the energy-level diagrams accompanying the drawings show, both systems can be regarded as two-level systems capable of being excited by a direct resonant interaction. (Occupied states are indicated by colored lines, unoccupied states by black lines.) In the case of a proton excited by a rotating magnetic field the "spin up" and "spin down" energy states are coupled by an interaction of the proton's magnetic dipole moment with the applied magnetic fields. In the case of a chromium impurity ion in a ruby crystal excited by circularly polarized light, two of the ion's many energy levels are coupled by an interaction of the ion's electric dipole moment with the rotating electric-field vector of the light. The electric dipole moment of the atom arises from the induced polarization of its electric-charge distribution represented by the positive nucleus and the negative electron cloud. The nuclear-spin echo is detected as an electrical signal; the photon echo, as a light pulse.

can be analyzed in terms of an ensemble of two-level systems, since protons have only two energy states (corresponding to "spin up" and "spin down") that can be coupled by an interaction of the proton's magnetic dipole moment and an external magnetic field. Using the methods of quantum mechanics, one can readily show that in such a situation one should expect to obtain a spin echo.

Another situation that is formally similar to that of a proton in a magnetic field is that of an isolated atom, either in a gas or as an impurity in a crystal lattice. Such atoms are characterized by certain well-defined energy states, and these states can always be coupled by some interaction. An example of such a system is the chromium impurity that makes an aluminum oxide crystal a ruby. When the chromium impurity ions in ruby are excited by circularly polarized light, it is possible to consider the chromium system as an ensemble of two-level systems coupled by an interaction of the electric dipole moments of the ions with the rotating electric-field vector of the circularly polarized light. The transition between the two levels is accomplished by irradiating the chromium ions with resonant light pulses that are capable of exciting only two of the ions' many energy levels, making it possible to neglect the rest. This formal connection between the chromium-atom systems and the nuclear systems leads to the prediction of an echo phenomenon similar to the nuclear-spin echo. The echoes produced by the chromium ions will be light pulses formed by a macroscopic oscillating electric dipole moment without the need for any applied constant field to provide an axis for the dipoles to precess around. The small wavelength of the expected radiation with respect to the size of the sample also suggests a new kind of echo phenomenon.

Our group at Columbia, consisting of Isaac D. Abella, Norman A. Kurnit and myself, began our search for this new echo in 1964. We quickly decided that the experiment should be performed using a ruby laser as a light source and a ruby crystal as the medium in which to form the echo. To ensure against thermal excitations that would relax the echo and prevent us from observing it, we cooled the ruby crystal to 4.2 degrees Kelvin (degrees centigrade above absolute zero) in a bath of liquid helium. The cooling of the ruby crystal to such low temperatures caused us some inconvenience: we then had to cool the laser crystal, since the frequency of the excitation pulse from the ruby laser is temperature-dependent. This dependence arises from the fact that as the temperature increases, thermal excitations shake the chromium atoms in their environment and modify their effective interactions with the neighboring atoms. Fortunately we had to cool the laser crystal only to 77 degrees K., the temperature of liquid nitrogen.

The ruby laser rod was supported from the base of a nitrogen-filled Dewar vessel and was contained in an evacuated elliptical cavity at one of the foci [*see bottom illustration on page 33*]. At the other focus of the cavity a flash lamp was placed to optically "pump" the ruby rod. In order to obtain short, intense pulses a Kerr-cell shutter was employed to "*Q*-switch" the ruby; this enabled us to obtain high-energy pulses with a small cross section and a duration of about 15 billionths of a second. Two pulses were obtained by passing the light through a beam splitter, which is nothing more than a thin flat plate that partially reflects and partially transmits light that impinges on it. The reflected light is aimed directly at the ruby crystal, and the transmitted light is diverted into an optical delay line. The optical delay line consists of an arrangement of spherical mirrors that provides a long optical path for the second light pulse so that it emerges delayed by a time equal to the distance traveled divided by the velocity of light. Typical delay times were between 30 and 400 billionths of a second. When the second pulse emerges from the delay line, it is aimed at the same point on the ruby crystal where the first pulse struck.

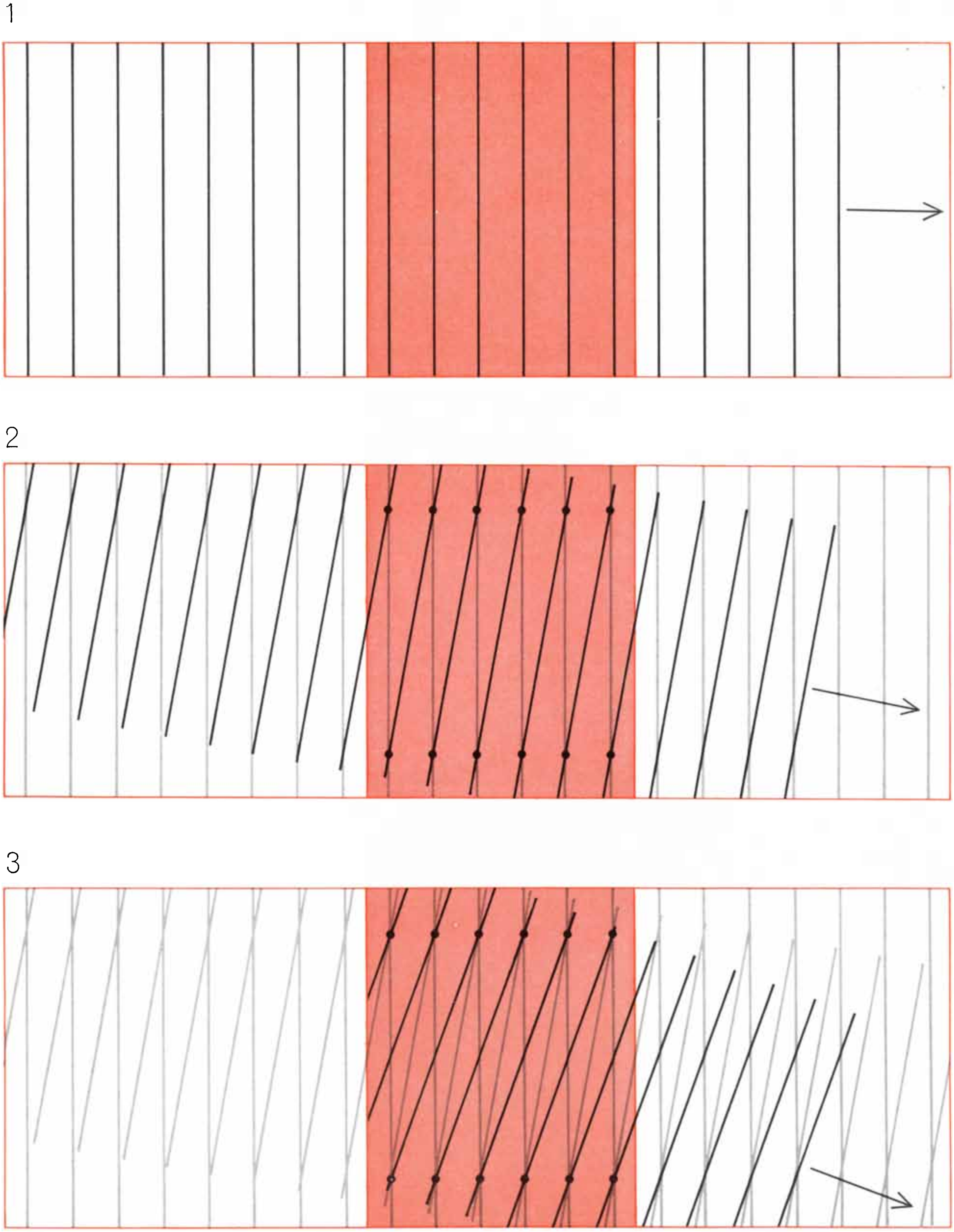
We wanted the light pulses to be as closely spaced in time as possible to avoid relaxation effects. This caused a problem, because the initial pulses can desensitize the photomultiplier used to detect the echo. That is what happened even when we put a Kerr-cell shutter in front of the photomultiplier to try to block the excitation pulses and allow only the echo through. Here we were fortunate because a calculation showed that, when the light pulses are not parallel, the echo is radiated in a direction different from that of either of the excitation pulses. This effect enables us to use nonparallel light pulses and to block the path of the excitation pulses by placing a screen in front of the photomultiplier, allowing only an opening for the echo to get through.

The calculation that led to this conclusion is quite straightforward, and its essence can be explained simply. The first pulse, whose lines of constant phase lie in parallel planes, stimulates a spatial excitation with a similar plane-wave character. The second pulse, which strikes the crystal from a slightly different angle, superposes its corresponding planes of constant phase on those of the first pulse. The echo will then be propagated in a direction that is perpendicular to the planes in which the rephased dipole moments are in phase. These planes are obtained by requiring that the phase angle of the first excitation pulse vary twice as fast spatially as the phase angle of the second excitation pulse [*see illustration on next page*].

The experiment described above was performed repeatedly without success until we decided to apply a large magnetic field. All studies of electron-spin relaxation in the "ground" state and the excited states of ruby had been conducted with high magnetic fields, and although extrapolation of these results indicated that for our experiment a magnetic field was not necessary, we decided to play it safe and apply a magnetic field anyway. Because of the crystal structure of ruby there is a direction called the optic axis in which the index of refraction is independent of polarization. It seemed that if we did apply a magnetic field, then for reasons of "symmetry" we should apply it along the optic axis. We did so and we immediately detected the photon echo. We found that as the spacing between the excitation pulses was increased, so was the spacing between the excitation pulse and the echo [*see illustration on page 40*]. When we turned off the magnetic field, the echo disappeared. We also found to our surprise that when the applied magnetic field was rotated a few degrees away from the optic axis, the echo disappeared.

After we had convinced ourselves that we had detected an actual photon echo and not some spurious reflection, we submitted a paper to *Physical Review Letters* for publication. I mention this because shortly after it was submitted we found that we were unable to obtain any more photon echoes! A week passed with no success until we found that the trouble was caused by the extreme sensitivity of the orientation of the magnetic field with respect to the optic axis. We had again doubled the time between the excitation pulses and the importance of the field orientation had drastically increased. The crystal and the magnetic field had to be aligned to within a degree, which was difficult to do with our experimental configuration.

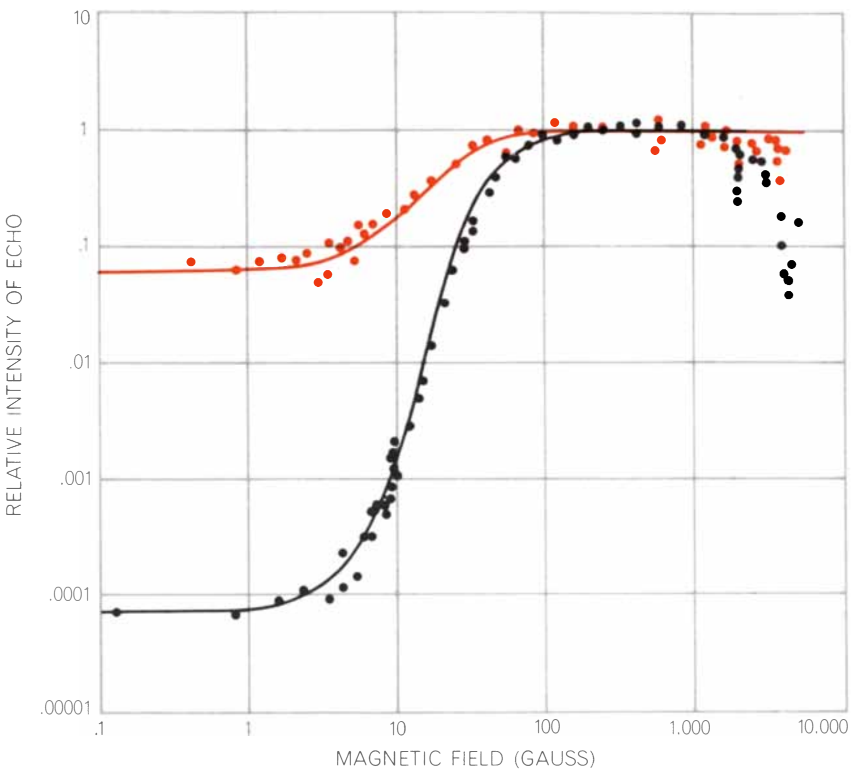
In subsequent experiments we have shown that one can obtain photon ech-



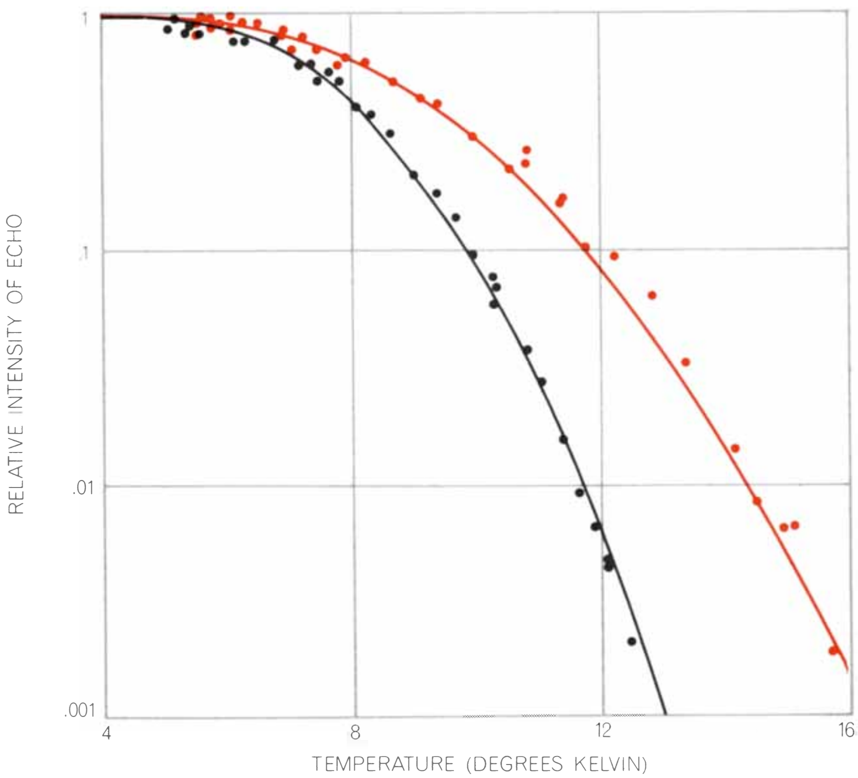
PHOTON ECHO IS PROPAGATED in a direction different from either of the two excitation pulses when the excitation pulses are not parallel. The first light pulse, whose lines of constant phase lie in parallel planes, stimulates a macroscopic excitation in the ruby crystal with a similar plane-wave character (*1*). The second pulse, which strikes the crystal from a slightly different angle, superposes its corresponding planes of constant phase on those of the first pulse (*2*). The echo will then be propagated in a direction perpendicular to the planes in which the rephased dipole moments are in phase (*3*). These planes are obtained by requiring that the phase angle of the first excitation pulse vary twice as fast spatially as the phase angle of the second excitation pulse. The black dots in *2* and *3* indicate one family of points for which the rephased dipole moments of the macroscopic excitation will have the same phase.

oes in the absence of a magnetic field. The magnetic field inhibits the neighboring aluminum nuclei from "flipping" the electron spin of the chromium ion or modulating the energy separation of the atomic states that are responsible for the echo. By making the time separation between the excitation pulses small enough, however, it is possible to observe an echo signal before it has time to relax completely. A sharp rise in echo amplitude takes place at an applied magnetic field of about 10 gauss, which is approximately the magnetic field at the chromium lattice sites attributable to the aluminum neighbors [*see top illustration at right*]. The dips at higher fields are due to "level crossings" in the ground state and arise because the ruby system is not an ideal two-level system but rather a more complicated system with four levels in the ground state alone.

The critical dependence of the orientation of the magnetic field with respect to the optic axis is now being studied in our laboratory with the help of electron-spin echoes. In an experiment with Daniel Grischkowsky we found that the ordinary electron-spin echoes of chromium ions in ruby are also strongly dependent on the orientation of the magnetic field. A detailed analysis of this simpler problem has shown that the critical dependence on orientation is due to an enhanced quantum-mechanical interaction that arises when the component of the precessing nuclear moments of the aluminum atoms that lies in the average direction of the spin of the chromium electron fluctuates in time. Accordingly the echoes last longest when the aluminum nuclei precess around an axis that is parallel to the average spin direction of the chromium ions, a condition that is not met when the applied magnetic field is either too weak or tilted away from the optic axis. Although the aluminum nuclei are effectively free, the chromium ion is strongly perturbed by the crystalline fields, with the result that its magnetic moment only points along the magnetic-field direction when it is parallel to the optic axis, whereas at lower applied magnetic fields the nonuniform dipolar field of the chromium ion makes a sizable contribution to the magnetic field at the aluminum sites, with the result that the aluminum nuclei then precess about nonparallel axes. The occurrence of the echo dips at higher fields is thus caused in part by the extreme sensitivity of the spin orientation of the chromium ion with respect to the magnetic-field direction in the



SHARP RISE in the amplitude, or intensity, of the photon echoes emitted by an excited ruby takes place at an applied magnetic field of about 10 gauss, which is approximately the magnetic field at the chromium lattice sites that can be attributed to the neighboring aluminum atoms. The dips at higher fields are due to "level crossings" in the four-level ground state of the ruby. The two sets of points were obtained for experiments in which the pulse separations were 34 billionths of a second (*color*) and 75 billionths of a second (*black*).



RELAXATION EFFECTS can be studied by means of photon echoes. In this example the intensity of the two sets of echoes decreases as the temperature of the ruby is raised. The pulse separations for the two sets were 50 billionths of a second (*black*) and 103 billionths of a second (*color*). Quantized lattice vibrations called phonons cause the echo to decay.

energy region of the level crossings in the ground state.

The main use of the photon echo, like all other echo phenomena, is in the study of relaxation effects. As the temperature of the ruby sample is raised, for example, the amplitude of the echo decreases [*see bottom illustration on preceding page*]. The quantized lattice vibrations called phonons interact with the excited chromium atoms and cause energy-level transitions that make the echo decay. A detailed study of this process enables one to understand the nature of the interaction of the chromium atoms and phonons.

It is not just the relative directions of the excitation pulses that are important; their relative polarizations are important also. If the two excitation pulses are plane-polarized at a certain angle with respect to each other, then it can be shown that the echo is plane-polarized with respect to the first pulse at an angle that is twice as large as the angle between the excitation pulses. This circumstance enables one to select the echo in another way: by polarizing the excitation pulses at 90 degrees with respect to each other and then using a polarizer in front of the detector to eliminate the light from the second pulse. By doing this and letting the excitation pulses propagate in parallel directions, we obtained multiple echoes. In this case the echoes were so strong that they themselves acted as excitation pulses and produced further echoes. Up to three echoes were observed in this way. These echoes had not been seen previously since the directions in which they were propagating were not the same and only the first echo was reaching the detector.

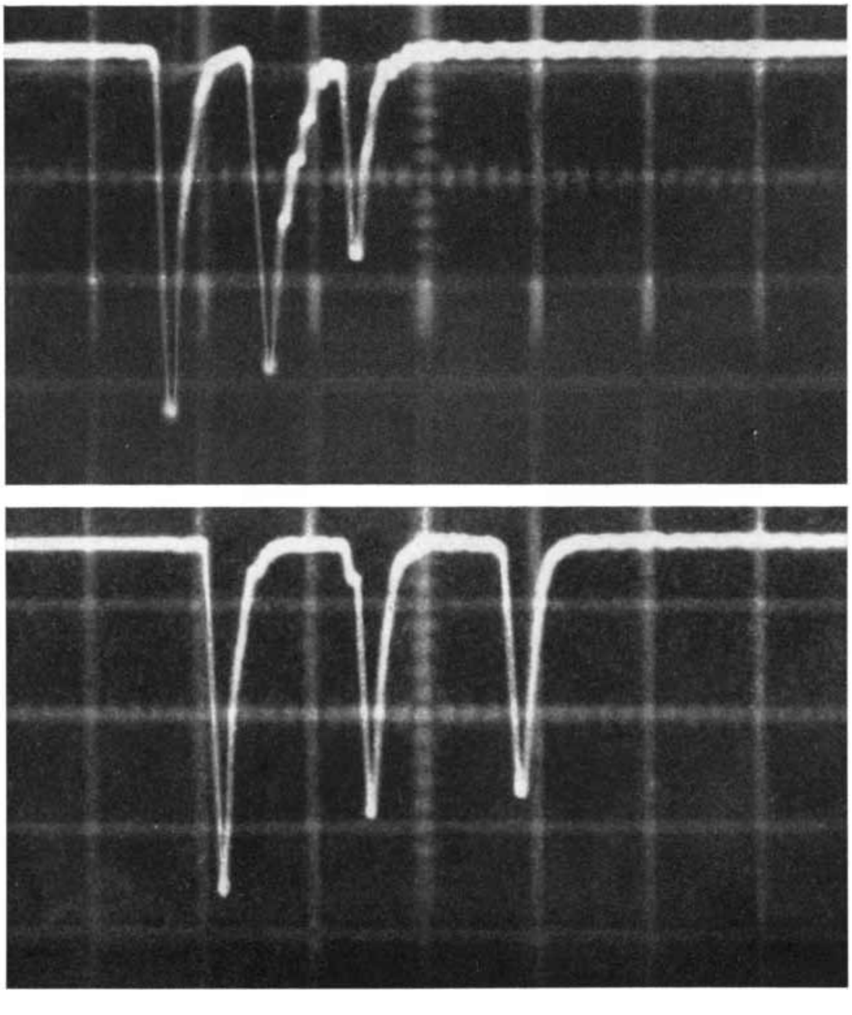
It is now tempting to excite any system with two resonant shocks in the hope of seeing an echo, even when one may not be certain beforehand that an echo is theoretically possible. For example, if one generates a plasma, or ionized gas, in a large magnetic field, the free electrons in the plasma will travel in helical paths whose axes are along the direction of the magnetic field. The frequency of the circulating electrons, called the cyclotron frequency, depends only on the value of the magnetic field and not on the velocity of the electrons. Now we again have a resonant magnetic system as we had with the nuclear spins, and one may wonder whether we can obtain echoes.

The answer is that we can, as was shown by Daniel E. Kaplan and Robert M. Hill of the Lockheed Research Laboratories, who employed a pulsed microwave generator to excite the cyclotron resonance. Their result was quite mystifying, however; a quick calculation shows that no echo should really be expected in this situation. The process by which cyclotron echoes are formed turns out to be different from the process associated with the spin or photon echoes. When nuclear magnets are excited by a resonant pulse of energy, one can at most invert the nuclear spins—any further increase in the energy of the excitation serves to bring them back to their initial state, and this in fact plays a central role in the formation of ordinary nuclear-spin echoes.

On the other hand, the resonant excitation of an electron in its cyclotron orbit can result in a continual increase in the electron's energy (or the radius of its cyclotron orbit). In contrast to the photon echo the cyclotron echo is explained in terms of a "bunching" of electrons in momentum space that is unbalanced by a velocity-dependent relaxation mechanism. This echo phenomenon offers a convenient way to study relaxation processes due to collision processes in a plasma.

Two-pulse echoes are not the only possible type. By exciting a system with three or more pulses one can obtain a whole series of additional echoes. Some of these echoes are produced by the mechanism described in this article; others are produced by different mechanisms and therefore decay with a different characteristic relaxation time.

With the advent of "mode-locked" lasers that can produce light pulses of extremely short duration (on the order of a ten-trillionth of a second), one can now visualize the possibility of using the photon-echo technique to make measurements of very short relaxation phenomena under almost ideal conditions or alternatively of using photon echoes for computational operations or for information storage in an extremely fast computer.



OSCILLOSCOPE TRACES of the photomultiplier response to two series of light pulses, each consisting of two excitation pulses and an echo, show that as the spacing between the excitation pulses was increased (*top to bottom*), so was the spacing between the second excitation pulse and the echo. Time increases to right at 100 billionths of a second per division.

In hope of doing each other some good

Science and Industry, Romeo and Juliet, ham and eggs—common speech employs certain close associations. Ham *is* good with eggs, Romeo and Juliet *did* feel close, but just how close are Science and Industry today? The question is a live one for young scientists trying to make up their minds which way to go. They wonder whether industry really needs them or just likes to think so.

There was a time when identity of interest between science and industry was widely taken for granted and a time before that when such congruence was a fresh idea. Kodak's history dates back to that olden time. Lord Kelvin—a mighty name in the history of physics—paid us enough attention to take over the vice-chairmanship of our Board of Directors in 1899. The eminent chemist Sir William Ramsay, isolator of the noble gases, persuaded one of his more scintillating students to cast his lot with industry, with the result that the young man became our research director in 1912 and embarked on making color photography as easy and ubiquitous as it is today.

Thus was the house built and the pattern set. To work in the house, a degree in chemistry or physics or in their engineering counterparts has been particularly desirable as a ticket of admission, largely because it is then easy to find useful tasks the bearer can do as he learns what the business is all about.

Paper on which are printed one's personal name and some words of truth has been the ultimate product for only a tiny fraction of the technical people in industry. The percentage shrinks because that's really what the campuses are for, and the campuses are booming with money and people. We cheer and even help.

Still, the scientist who decides to go with us is not renouncing his opportunities to be challenged by his subject. As long as he feels the challenge and responds to it, we have the wherewithal (in both problems and rewards) to keep him happy. **Here's the sneaky part, though:** if when looking inside himself 5, 10, 15 years later he discovers that he is less interested in the subject than he had thought he was, the bottom doesn't fall out. We count, in fact, on that to happen in most but not all cases. That's how we get the people who run the house, joining on an equal footing those who had felt nonacademic from the start. That's also the process that makes room for fresh talent from the campuses.

The process ought to be more widely understood.

An inner envelope

If color slides from 135- or 120-size film constitute serious business for you, buy a supply of a new item which the Kodak dealer has just laid in: KODAK Special Processing Envelope for KODAK High Speed EKTACHROME Film. Then, when you encounter a situation that makes you wish that this fastest of Kodak color films were yet 2½ times as fast, the special processing envelope will make it so. You may be unable to detect any sacrifice in quality. We make film and do processing on the assumption that you turn to color photography not just to relieve the monotony of black-and-white but to re-create more accurately the perceptions engendered on viewing the subject.

Put the exposed roll into the envelope and the envelope into the appropriate KODAK *Prepaid Processing Mailer. Affix postage and mail to our nearest processing station, which needs no instructions on what to do and has been fully paid through purchase of the envelope and mailer for return to you of the resultant mounted slides with the special processing service.*

—and a minor in Photo-Interpretation

United Nations

When setting off to the isle of Jamaica for some fun, forget about looking up the place where this picture was taken. The establishment is supposed to improve the quality of life on the island. That's no fun.

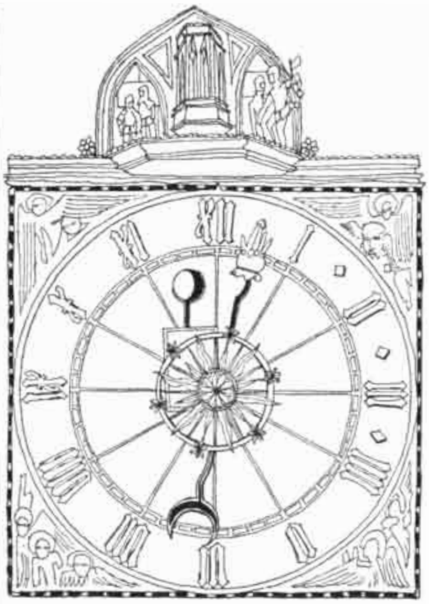
Ruth Masters is working here with aerial photography. The United Nations is helping the citizens of Jamaica learn to use it more effectively both for mapping and for "P.I.," which is a military term. Photo-interpretation, a fallout from the art of war, is now rapidly moving into a new phase. People are getting into it who know nothing about war. They operate on the understanding that objective study of the physical environment must guide improvement of the economic, social, and psychological environments. Yet what's good economically may be bad for the body or the spirit, whether or not your choice in theologies tells them apart. The physical world does matter.

There is a citizen of Norway at the U. N. Secretariat in New York who argues that peaceable photo-interpretation should now drop its guise as a separate craft, that students preparing themselves to serve in fields from political science to limnology, from geology to anthropology, need firsthand knowledge of photo-interpretation if they are to do a better job for humanity, including themselves.

The man may be addressed as follows:

Chief, Cartography Section
Resources and Transport Division
Department of Economic and Social Affairs
United Nations, N.Y. 10017

Do you have any questions for him?



SCIENCE AND

Open Oceans

A draft of a treaty that would ensure orderly exploitation of the oceans and would curb military activities in undersea areas has been presented to the Senate by Senator Claiborne Pell, Democrat of Rhode Island. He urged consideration of the treaty because of "the probable danger of anarchy in the Ocean Space of this globe" arising from the fact that technology has brought advanced nations "to the verge of total undersea capability at any depth of the world ocean." International cooperation in the oceans, the Senator said, "is of comparable importance to that achieved in the field of outer space."

The treaty, which was believed in Washington to be the first one prepared by a member of Congress rather than by the Executive Branch, would establish free access to ocean space by all nations. Exploration and exploitation of the natural resources of the ocean bottoms would be regulated by licenses issued under the authority of the United Nations. Nations would be prohibited from emplacing on the ocean bottoms "any objects containing nuclear weapons or any kinds of weapons of mass destruction." Such areas could be used, however, for the temporary stationing of military submarines and for the emplacement of devices to detect or track submarines.

Fastest Pulse in the Galaxy

A celestial object that emits radio pulses so frequent and so precisely timed that they were at first thought to have a technological origin has been reported in *Nature* by workers at the Mullard Radio Astronomy Observatory of the University of Cambridge. The radio pulses repeat at the precise interval of $1.3372795 \pm .0000020$ second. Indeed, the timing of the pulses is so regular that one can detect from them whether the earth in its orbit is moving toward the source or away from it. This and other evidence made it clear that the signals did not originate from an artificial source within the solar system. The rapid discovery of three similar sources in other parts of the sky also makes it unlikely that the emissions are anything but natural. The best guess at present is that the pulses are generated by the stable oscillations of white-dwarf stars. The workers who reported the discovery are A. Hewish, S. J. Bell, J. D. H. Pilkington, P. F. Scott and R. A. Collins.

Precisely timed pulsations are not unknown among variable stars. For example, many variables of the RR Lyrae type have pulsation periods of about half a day, and over many years of observation these periods are found to be constant to one part in 10^8. Such stars are said to have a high Q circuit, meaning that they are resonating at a natural frequency with only a tiny loss of energy on each cycle. The natural frequency of such a star (or of any body) varies as the square root of the density; the higher the density, the higher the frequency. If the sun were to start resonating at its natural frequency, it would have a period of about an hour. The period of 1.34 seconds of the new radio object suggested that if it were a variable star, its density would be enormous. Such would be the case in a white-dwarf star or a neutron star. Neutron stars have been proposed on theoretical grounds but have never been directly observed. In them matter would be so dense that most of its electrons would have been forced onto protons to form neutrons.

In a recent study at Princeton University, D. W. Meltzer (now at the University of Rochester) and Kip S. Thorne (now at the University of Chicago and the California Institute of Technology) calculated the pulsation periods for stars with central densities from 10^5 to 10^{19} grams per cubic centimeter (covering the range from white dwarfs to neutron stars). A minimum period of about eight

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seconds was computed for a white dwarf consisting of iron with a density of 10^7 grams per c.c. A neutron star, being of much higher density, would pulsate much more rapidly: about 1,000 times per second. Thorne is now reviewing his calculations with James Ipser of Cal Tech; they believe that neutron stars are still ruled out as candidates but that pulsation periods as brief as a second might be possible for dwarfs composed of elements other than iron.

As for the mechanism of pulsation, Thorne suggests that a young white dwarf may still retain an envelope of hydrogen that occasionally becomes hot enough for nuclear burning to occur for a short time. This could set the star "ringing," and the pulsations might go on for hundreds or thousands of years. In the case of a neutron star the phenomenon of collapse by which the star is formed might provide the energy needed to start it pulsating. Shock waves from the pulsations may accelerate electrons and give rise to the radio emissions.

A tentative identification of the 1.34-second object has been reported in *Nature* by Martin Ryle and Judy A. Bailey of the Mullard Radio Astronomy Observatory. They believe it is a blue star of 18th magnitude that appears close to the calculated radio position on Palomar Sky Survey plates. They estimate that the star is between 150 and 300 light-years away. Astronomers at the Mount Wilson and Palomar Observatories believe that if the object exhibits a 1.34-second period in the visible part of the spectrum, the pulsations should be detectable with the 200-inch Palomar telescope.

Antarctica's Ancient Amphibian

The first evidence that land vertebrates once lived in Antarctica has been uncovered by a group of geologists from the Institute of Polar Studies at Ohio State University. The evidence is a fossilized fragment of the lower jaw of a freshwater amphibian, probably about four feet long, that lived more than 200 million years ago. Animals closely related to the Antarctic amphibian, a salamander-like creature known as a labyrinthodont, lived at the same time in Africa, Australia and Madagascar. This provides another impressive argument for the theory that Antarctica was at one time joined to these three land masses (and probably to South America and India as well), forming a single giant continent that has been named Gondwanaland. Some 200 million years ago rifts formed in Gondwanaland and the land masses we now know drifted apart (see "The Confirmation of Continental Drift," by Patrick M. Hurley, page 52).

The jawbone fragment of the labyrinthodont was found last December in a succession of sediment layers 2,500 feet thick that form a cliff near the upper Beardmore Glacier, 325 miles from the South Pole. The bone was lying in the bed of an ancient stream, surrounded by fossil freshwater plants of the early Triassic period. Below it in the cliff, and therefore older, were such typical Gondwanaland plants as the fern *Glossopteris*.

The Ohio State party was led by Peter J. Barrett of New Zealand. The fossil fragment was identified by Edwin H. Colbert, curator of vertebrate paleontology at the American Museum of Natural History. He believes that the discovery in Antarctica of a freshwater land vertebrate closely related to species known to have existed elsewhere is even more convincing evidence for Gondwanaland than the existence of similar plant life in the same regions, because one can imagine spores being carried across salt-water barriers but scarcely a freshwater animal. Presumably Antarctica was not centered over the South Pole when the labyrinthodont was alive but drifted there from a more tropical latitude.

Health and Smoking (Discontinued)

Between 1959 and 1965 the number of American men who smoked cigarettes declined by about 22 percent, according to a survey of more than a million men and women conducted by the American Cancer Society. Whereas 45.8 percent of men over 30 smoked in 1959, only 35.8 percent smoked in 1965. Among women the comparable figures were 25.8 percent and 22.6 percent, for a relative decrease of 12.4 percent.

A study of individuals who reported their smoking habits over the six-year period confirmed what might have been expected: the habit is harder to break the more one smokes. Among men who smoked less than half a pack a day in 1959, 47.5 percent reported in 1965 that they had given up smoking. Among two-pack-a-day smokers (20 to 39 cigarettes) 24 percent had quit. And among the heaviest smokers (40 or more cigarettes a day) only 18.6 percent were able to stop—but this is still almost one man in five.

The study also shows that the cigarette habit is harder to break the younger one is when one begins smoking. Among men who began smoking before they were 15 years old, 47.3 percent reported no change in their consumption; 13.5 percent said they were smoking more and 23.2 percent had stopped. Among men who began smoking after age 24, the comparable figures were 36.5, 11.4 and 38.5 percent. The results of the survey are reported in the *American Journal of Public Health* by E. Cuyler Hammond and Lawrence Garfinkel of the American Cancer Society.

The Genetic Code (Concluded)

The quest to assign a meaning to all 64 triplet "words" in the genetic code is apparently ended with the finding that the triplet UGA is a "period" that results in the termination of a protein chain. Thus UGA plays the same role as two other triplets, UAG and UAA, that had previously been found to terminate protein synthesis. The other 61 triplets, or codons, designate one or more of the 20 amino acids the living cell links in various sequences to make protein molecules.

The letters U, G and A stand respectively for the nitrogenous bases uracil, guanine and adenine; another base, cytosine (C), is the fourth in the set of four "letters" that can be assembled into 64 different triplet sequences. When they are attached to a backbone consisting of alternating units of ribose sugar and phosphate, the four bases, in various triplet sequences, form molecules of messenger ribonucleic acid (messenger RNA). These molecules transcribe the genetic message of the genes and convey it to the site of protein synthesis. A single molecule of messenger RNA, however, usually carries the information needed for making more than one kind of protein molecule. The question therefore arose: What is the signal, presumably embodied in a codon, that tells the cell machinery when one protein molecule is finished and another is to be started?

A study of mutants of the bacterium *Escherichia coli,* conducted in many laboratories, finally supplied the answer. It was found that after mutation the messenger RNA for a particular protein sometimes formed two short protein chains instead of one long chain. This happened when one of the codons in the messenger RNA mutated to become UAG or UAA. Prior to mutation the codon might have been any other triplet differing in the first, second or third position, for example GAG, UGG or UAU. Before mutation these triplets specified a particular amino acid; after mutation to UAG or UAA they no longer specified any amino acid and thus the protein chain terminated. UAG and UAA were termed nonsense codons.

Last year workers at the Laboratory of Molecular Biology at the University of Cambridge found evidence that the unassigned triplet UGA also acted as a nonsense codon, but they were not quite sure that it was fully equivalent to UAG or UAA as a chain-terminator. This was subsequently demonstrated by David Zipser of Columbia University. He produced *E. coli* mutants in which the change of one letter in a particular codon led to the formation of a single long protein chain instead of two short ones. By analyzing his results Zipser could show that the mutation had changed UGA into UGG (the codon for the amino acid tryptophan) and that UGA therefore must have acted as a chain-terminator.

Fourth Enzyme Structure

Carboxypeptidase is the fourth enzyme (and sixth protein) whose three-dimensional structure has been mapped in detail by X-ray crystallography. Carboxypeptidase cleaves molecules of food protein by hydrolyzing peptide bonds. Perhaps the chief novelty of the carboxypeptidase investigation is that the molecule's overall structure has been elucidated well in advance of its amino acid sequence. The molecule consists of a single chain of 307 amino acid units, 25 percent more than the next-largest enzyme (chymotrypsin) to be mapped by X-ray methods. The amino acid sequence of only the first third of the carboxypeptidase chain has so far been established with certainty; the sequence of the middle third is still tentative and the sequence of the remainder is unknown.

William N. Lipscomb and his co-workers at Harvard University were able to overcome this disadvantage by pushing their X-ray analysis to approximately atomic dimensions: two angstrom units. The analysis of only one protein, myoglobin, has been carried to a higher resolution (1.5 angstroms), and myoglobin has only half as many amino acid units as carboxypeptidase does. The X-ray map of carboxypeptidase is so detailed that Lipscomb has been able to identify about 80 percent of the amino acids, taking into account their position in the chain as well as their shape. About 30 percent of the molecule consists of heli-


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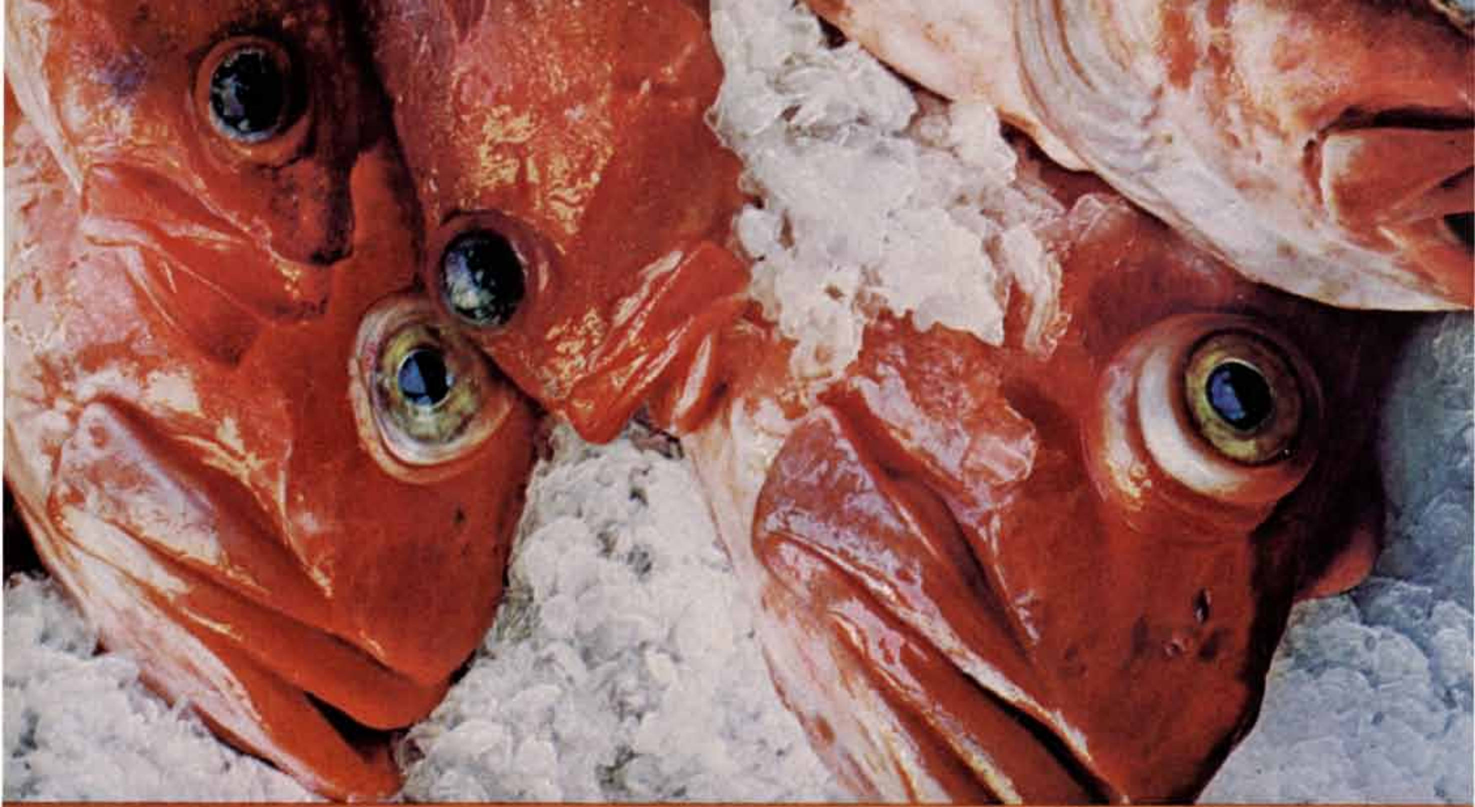

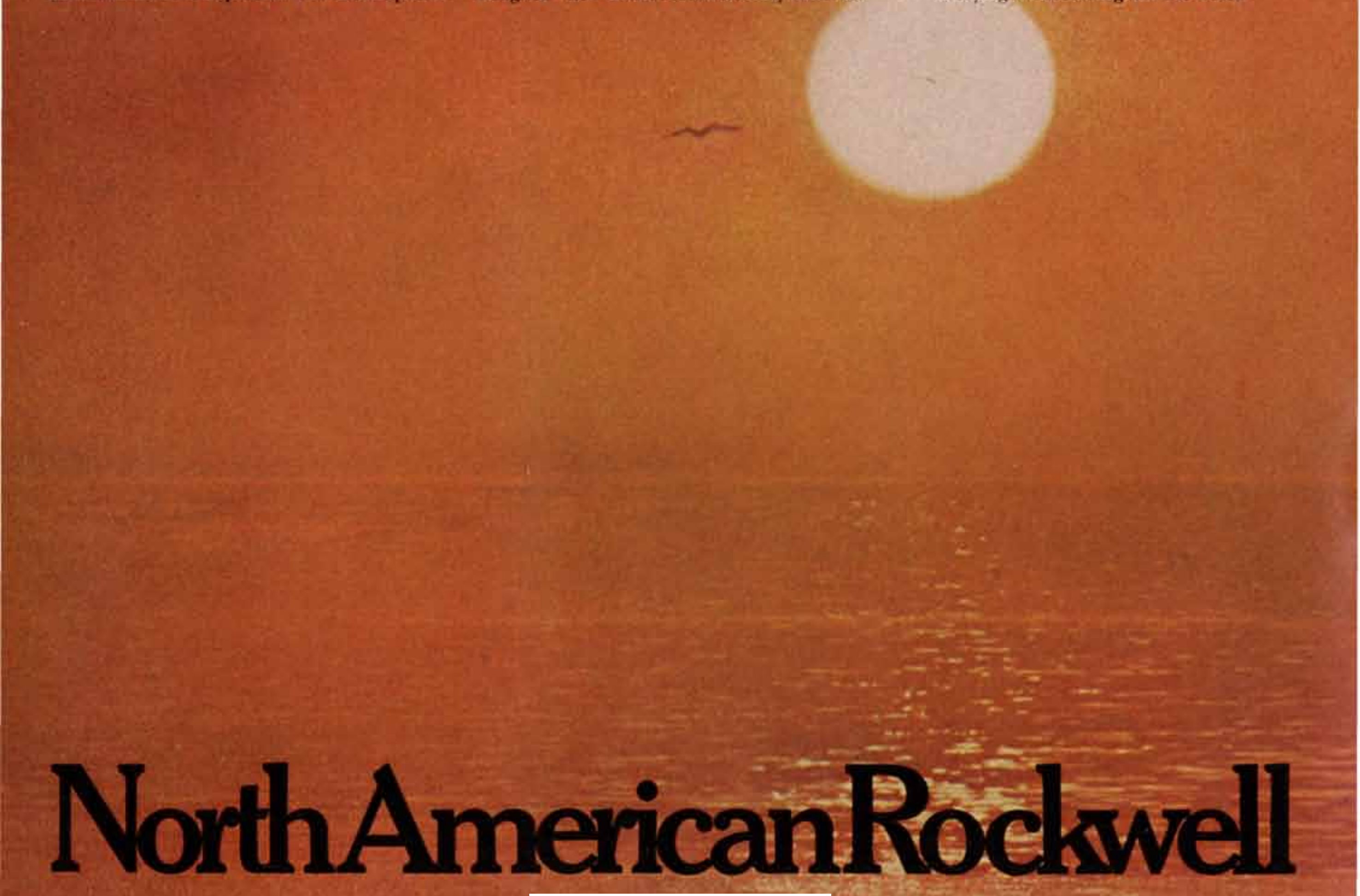

cal regions, chiefly the alpha helix of 3.6 amino acid units per turn. This is roughly equal to the proportion found in the molecule of lysozyme but much less than the 75 percent in myoglobin. Another configuration, the "pleated sheet," accounts for some 20 percent of the carboxypeptidase molecule. There are four pairs of pleated-sheet sections, including parallel arrangements never before observed.

A major goal of enzyme investigations is to discover how enzymes work. Carboxypeptidase forms a complex with many simple substrates consisting of two or three amino acid units. X-ray studies of one such complex show that the carboxypeptidase molecule changes shape significantly when the substrate is present and being split by hydrolysis. A particular portion of the enzyme shifts 14 angstroms—about a quarter of the width of the whole molecule—to engage part of the substrate. This is the largest displacement yet seen in X-ray studies of enzymes and supports the "induced fit" model of enzyme action.

Investigators who have worked with Lipscomb in his six-year study include G. N. Reeke, J. A. Hartsuck, Martha L. Ludwig, F. A. Quiocho and T. A. Steitz. The Harvard group collaborated closely with Hans Neurath of the University of Washington, whose laboratory has been analyzing the amino acid sequence of the enzyme. Bert L. Vallee of the Harvard Medical School has been participating in studies of the enzyme's mode of action.

Falling Birthrate

The birthrate of the U.S. reached its lowest level in history last year, according to the National Center for Health Statistics of the Department of Health, Education, and Welfare. The rate was 17.9 live births for every 1,000 persons in the population. It compared with the previous low of 18.4, which was reached in 1966 and in the depression years of 1933 and 1936. The highest rate of recent times was 26.6 in 1947, soon after the end of World War II. Last year the absolute number of births also declined: it was 3,533,000, compared with 3,606,000 in 1966.

Arthur A. Campbell, chief of the Natality Statistics Branch of the center, said the decline resulted from two major changes in the timing of births among women of childbearing age. The younger women of the group are tending to have babies somewhat later than was the case a decade ago, and the older women are tending to stop having babies somewhat sooner. Campbell also noted that there appears to be a trend toward smaller completed families of two or three children instead of three or four as in the past.

Factory-made Rain

Since 1925 it has been raining more than it used to in La Porte, Ind., and more than in nearby cities; there has been more thunder and a lot more hail. It now seems probable that the "La Porte anomaly" is caused by heat from the Chicago industrial complex some 35 miles west, or upwind. The anomaly had been noted some time ago and the link to Chicago had been suggested: In 1962 Glenn E. Stout of the Illinois State Water Survey pointed out that the rising curve of precipitation at La Porte generally matched a curve for annual steel production in the Chicago area and that production peaks were associated with periods of high precipitation. The possibility remained, however, that the weather anomaly was "fictional," the result of errors in observation or factors affecting the exposure of precipitation gauges.

Stanley A. Changnon, Jr., of the State Water Survey therefore reviewed precipitation, thunderstorm and hail records for La Porte and compared them with records for nearby communities. He reports in the *Bulletin of the American Meteorological Society* that the agreement among the three kinds of records makes observer bias unlikely. Most of the increase in precipitation has been in the warm season of the year, whereas any overexposure of gauges would have affected snowfall more than rain. The precipitation curve for La Porte, Changnon found, matches a curve for days of smoke and haze in Chicago—a reflection of industrial activity. Moreover, regional patterns for thunderstorms and hail support the high values at La Porte. Changnon concludes that the La Porte weather anomaly is real.

Industrial activity increases air temperature, the amount of water vapor and the number of smoke and dust particles that can serve as nuclei for condensation or freezing and thus increase rainfall. Which factor is responsible for La Porte's weather? The increases in thunderstorms and hailstorms as well as warm-season rain suggest that what is special at La Porte is additional convective activity, or upward movement of warmed air. Changnon notes too that La Porte often had thunder or hail in the early morning when nearby communities did not. Of the various possible factors, a "thermal island" created by industrial heat would have a relatively great effect in the ordinarily cool morning hours. On the basis of such data Changnon suggests that heat from industry is the primary cause of the convective activity responsible for the La Porte anomaly.

Sexual Behavior and Mongolism

The declining frequency of sexual relations that is characteristic of older, long-married couples may explain the high incidence of mongolism in children born to older women. This hypothesis is proposed in an article in *Nature* by James German of the Cornell University Medical College. The congenital anomaly called mongolism, which involves mental retardation and certain physical signs, occurs about once in 650 births. The rate is about one in 3,000 in women under 30 but rises to one in 40 births in women 45 and over. Since 1959 mongolism has been associated with a chromosomal abnormality: the baby's cells have an excess of chromosomal material, usually in the form of an extra chromosome, Number 21. The chromosomal error was assumed to be the result of some kind of deterioration of the female germ cells in older women. German believes delayed fertilization may be a more likely explanation.

The human egg, having left the ovary, remains fertilizable for about 24 hours, German points out. On the basis of animal studies, it is likely that the egg begins to deteriorate before it becomes infertile; the deterioration can include a disarrangement of chromosomes. Male spermatozoa maintain their fertilizing potential for about 48 hours. If intercourse occurs at least about every two days, therefore, an egg entering the Fallopian tube is likely to be met by a fresh spermatozoon and to be fertilized before it begins to deteriorate. If coitus occurs only sporadically, or regularly but infrequently, delayed fertilization is possible. In general the frequency of marital coitus decreases with age, and so the older woman would be more likely to bear a mongoloid child.

German suggests that his hypothesis could be checked by surveys concentrating on frequency of sexual intercourse rather than on age. Is the incidence of mongolism higher in those women, young or older, who have infrequent relations than in those who have frequent and regular coitus? Among older women, is the incidence lower for those who have been married recently and who might as a group be expected to be more active sexually than those married for a long time? In this connection German cites one survey in which the duration of marriage was recorded for mothers of mongoloid children. Among older women there was "a striking lack of marriages of short duration," although a group of older mothers ordinarily includes many women who married late in life.

If his hypothesis should prove to be correct, German writes, it will show that human disease can be the result of a seemingly normal pattern of behavior rather than of damage from some inhospitable environment or of a spontaneous error of nature. Moreover, the way would be open to a reduction in the incidence of mongolism.

Pre-Neolithic Danubians

To the total of about half a dozen villages known to have thrived without benefit of organized farming 7,000 to 9,000 years ago in the Near and Middle East can be added one more from a new area: Central Europe. The village is near Lepenski Vir ("the whirlpool of Lepena") on the Yugoslav bank of the Danube about a mile above the point where the Boljetinska River joins the main stream. This is an area where the Danube narrows to run through a steep-walled canyon on its way to the Iron Gates; the site was discovered in the course of salvage archaeology in an area that will soon be flooded by a hydroelectric project. Last summer and fall Dragoslav Srejović of the University of Belgrade excavated a three-yard-thick cultural deposit covering a steeply pitched, 100-yard stretch of beach in the canyon. The upper half of the deposit proved to contain remains typical of the Starčevo culture, a Neolithic horizon in the Balkans that flourished some 7,000 years ago.

The lower half of the Lepenski Vir site, the contents of which give no hint that its inhabitants possessed domesticated plants or animals, includes the remains of some 30 rectangular one-family dwellings with hard lime-plastered floors and central hearths. Fifteen human burials have been unearthed. Among the animal remains are fishbones, the tusks of wild boar, a set of large stag antlers, the bones of small carnivores and the skull of a bovine animal.

The greatest surprise at Lepenski Vir was the discovery of some 40 decorated stone objects, many of which came from the lower level at the site. Made from red or gray sandstone with designs incised in negative relief, the stone objects are usually spherical and range from the size of a fist to more than a foot and a half in diameter. Motifs range from quizzical human faces to geometric meanders that resemble the decorations executed on bone by the hunting peoples of postglacial Europe a few millenniums earlier.

Carbon-14 dates for the site are not yet available. The sophistication of the pre-Neolithic village suggests, however, that the main elements in the revolution that reached Europe from the Near East were more the specific techniques of food production than any broad fundamentals of social organization.

Bypassed Spinal Cord

When someone suffers a completely severed spinal cord, it is generally assumed that he has permanently lost the use of muscles controlled by nerves branching from the cord below the break. Studies at a rehabilitation center in England now suggest that in such a person the muscles themselves can provide pathways between regions below the break and the brain. At a recent meeting of the Royal Society of Medicine, Sir Ludwig Guttmann of the Stoke Mandeville Hospital pointed out that muscle systems such as the latissimus dorsi are connected at the lower end to the pelvis, the rib cage or the spine and at the upper end to parts of the skeleton that may be above a break in the spinal cord; by the same token these muscle systems have nerve connections with the cord above the break. The latissimus dorsi itself extends to the pelvis, but it is normally involved in movements of the arm. Under Guttmann's care, patients with severed spinal cords have learned to use the muscle to move the paralyzed pelvis instead. This movement in turn improves the tone of paralyzed muscles in the hip and knee.

Guttmann also described how nerve-muscle systems below a break in the spinal cord and totally isolated from the brain can be trained to function. For example, reflex arcs can be established that will stiffen and lock the extensor muscles of the legs so that, after a number of practice sessions, injured persons are able to stand upright on their paralyzed legs for as long as half an hour. Suggesting that other nerve-muscle reflexes should be investigated in the hope of similarly reconditioning respiratory, eliminative and sexual function in spinal-injury paralysis, Guttmann concluded with a quotation from the pioneer neurophysiologist Sir Charles Sherrington: "Each and every part of the animal is integrative."

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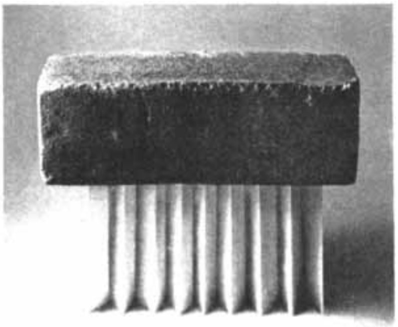

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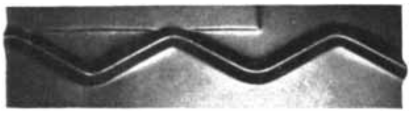

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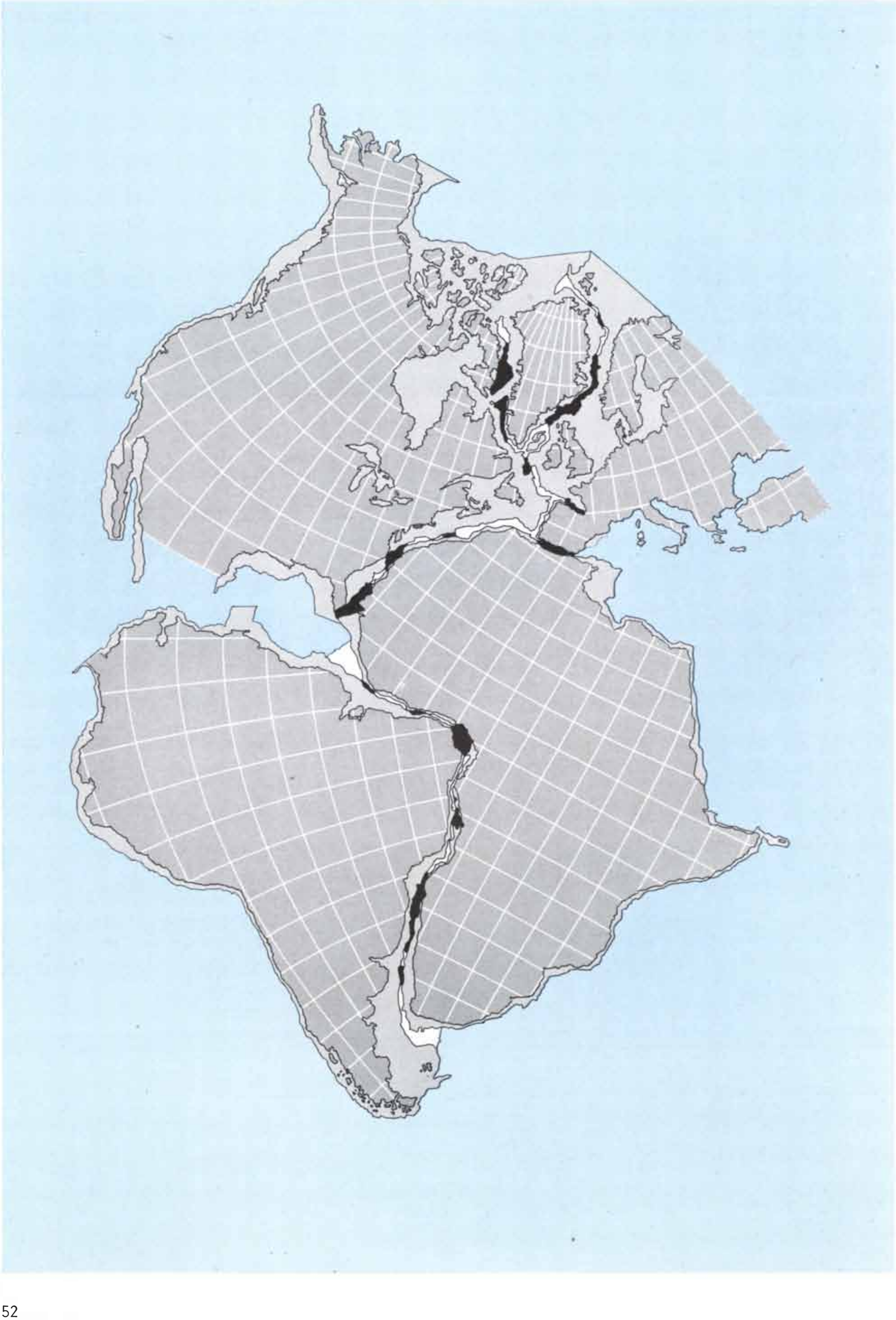


The Confirmation of Continental Drift

After years of debate many lines of evidence now favor the idea that the present continents were once assembled into two great land masses: Gondwanaland in the south, Laurasia in the north

by Patrick M. Hurley

As recently as five years ago the hypothesis that the continents had drifted apart was regarded with considerable skepticism, particularly among American investigators. Since then, as a result of a variety of new findings, the hypothesis has gained so much support that its critics may now be said to be on the defensive. The slow acceptance of what is actually a very old idea provides a good example of the intensive scrutiny to which scientific theories are subjected, particularly in the earth sciences, where the evidence is often conflicting and where experimental demonstrations are usually not possible.

As long ago as 1620 Francis Bacon discussed the possibility that the Western Hemisphere had once been joined to Europe and Africa. In 1668 P. Placet wrote an imaginative memoir titled *La corruption du grand et du petit monde, où il est montré que devant le déluge, l'Amérique n'était point séparée des autres parties du monde* ("The corruption of the great and little world, where it is shown that before the deluge, America was not separated from the other parts of the world"). Some 200 years later Antonio Snider was struck by the similarities between American and European fossil plants of the Carboniferous period (about 300 million years ago) and proposed that all the continents were once part of a single land mass. His work of 1858 was called *La Création et Ses Mystères Dévoilés* ("The Creation and Its Mysteries Revealed").

FIT OF CONTINENTS (*opposite page*) was optimized and error-tested on a computer by Sir Edward Bullard, J. E. Everett and A. G. Smith of the University of Cambridge. Over most of the boundary the average mismatch is no more than a degree. The fit was made along the continental slope (*light gray*) at the 500-fathom contour line. The regions where land masses, including the shelf, overlap are black; gaps are white.

By the end of the 19th century geology had come seriously into the discussion. At that time the Austrian geologist Eduard Suess had noted such a close correspondence of geological formations in the lands of the Southern Hemisphere that he fitted them into a single continent he called Gondwanaland. (The name comes from Gondwana, a key geological province in east central India.) In 1908 F. B. Taylor of the U.S. and in 1910 Alfred L. Wegener of Germany independently suggested mechanisms that could account for large lateral displacements of the earth's crust and thus show how continents might be driven apart. Wegener's work became the center of a debate that has lasted to the present day.

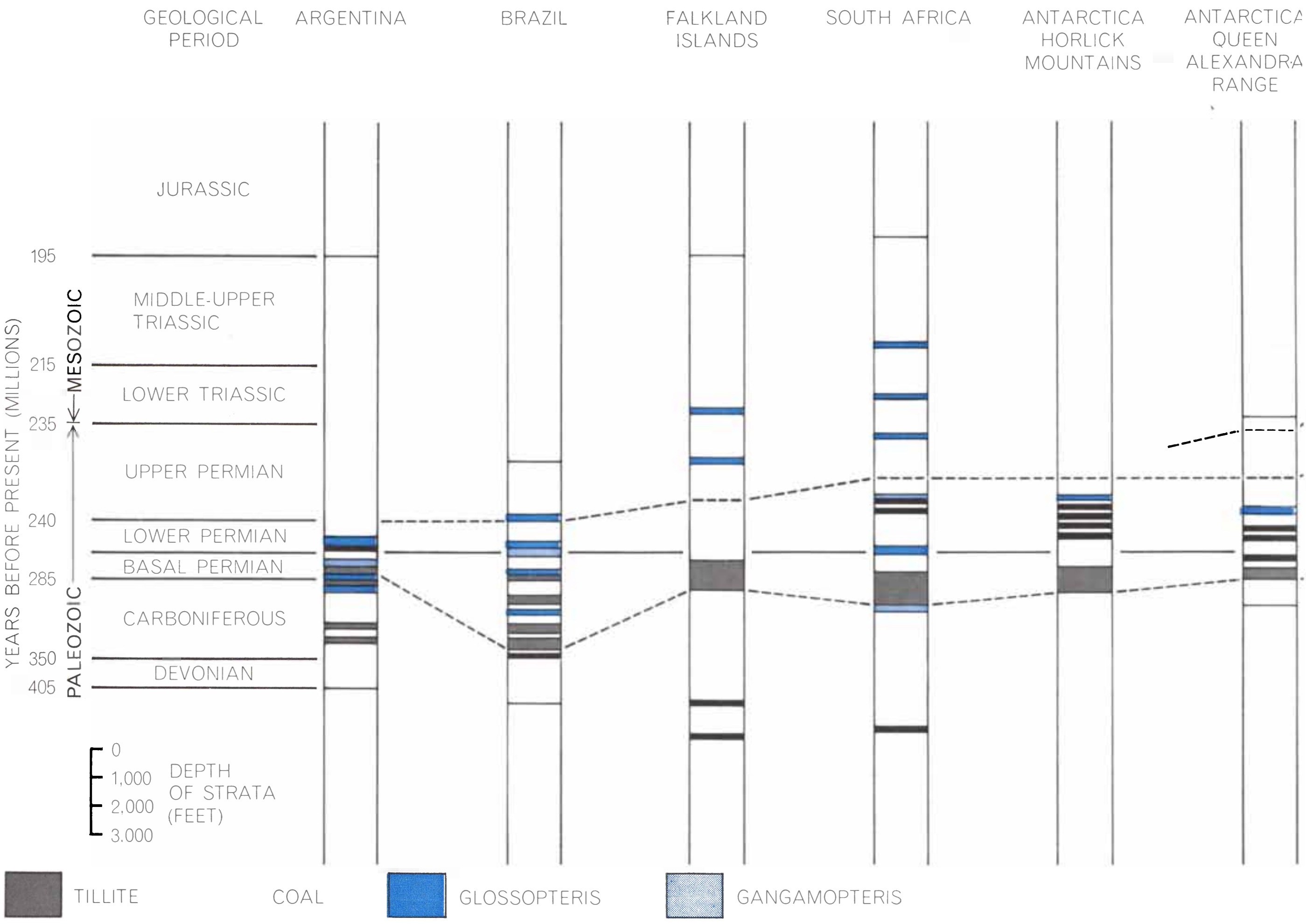
Wegener advanced a remarkable number of detailed correlations, drawn from geology and paleontology, indicating a common historical record on the two sides of the Atlantic Ocean. He proposed that all the continents were joined in a single vast land mass before the start of the Mesozoic era (about 200 million years ago). Wegener called this supercontinent Pangaea. Today the evidence favors the concept of two large land masses: Gondwanaland in the Southern Hemisphere and Laurasia in the Northern.

In the Southern Hemisphere an additional correlation was found in a succession of glaciations that took place in the Permian and Carboniferous periods. These glaciations left a distinctive record in the southern parts of South America, Africa, Australia, in peninsular India and Madagascar and, as has been discovered recently, in Antarctica. The evidence of glaciations is compelling. Beds of tillite—old, consolidated glacial rubble—have been studied in known glaciated regions and are unquestioned evidence of the action of deep ice cover. In addition many of the tillites rest on typically glaciated surfaces of hard crystalline rock, planed flat and grooved by the rock-filled ice moving over them.

This kind of evidence has been found throughout the Southern Hemisphere. In all regions the tillites are found not only in the same geological periods but also in a sequence of horizontal beds bearing fossils of identical plant species. This sequence, including the geological periods from the Devonian to the Triassic, is called the Gondwana succession. The best correlations are apparent in the Permocarboniferous beds, where two distinctive plant genera, *Glossopteris* and *Gangamopteris*, reached their peak of development. These plants were so abundant that they gave rise to the Carboniferous coal measures, which are commonly interbedded in the Gondwana succession [*see top illustration on next two pages*].

The South African geologist Alex L. du Toit and others have sought out and mapped these Gondwana sequences so diligently that today they provide the strongest evidence not only that these continental areas were joined in the past but also that they once wandered over or close to the South Pole. It is inconceivable that the complex speciation of the Gondwana plants could have evolved in the separate land masses we see today. It takes only a narrow strip of water, a few tens of miles wide at the most, to stop the spread of a diversified plant regime. The Gondwana land mass was apparently a single unit until the Mesozoic era, when it broke into separate parts. Thereafter evolution proceeded on divergent paths, leading to the biological diversity we observe today on the different continental units.

Wegener and Du Toit published their work in the 1920's and 1930's. The de-



GONDWANA SUCCESSION is the name given to a late Paleozoic succession of land deposits found in South America, Africa, Antarctica, India and Australia. The succession contains beds of tillite (glacial rubble), coal deposits and a diversity of plants arranged in such a way that perhaps 200 million years ago the different areas must have been a single land mass known as Gondwanaland, or at

bate for and against drift became polarized largely between geologists of the Southern Hemisphere and the leaders of geophysical thought in the Western Hemisphere. Eminent geophysicists such as Sir Harold Jeffreys of the University of Cambridge voiced strong opposition to the hypothesis on the grounds that the earth's crust and its underlying mantle were too rigid to permit such large motions, considering the limited energy thought to be available.

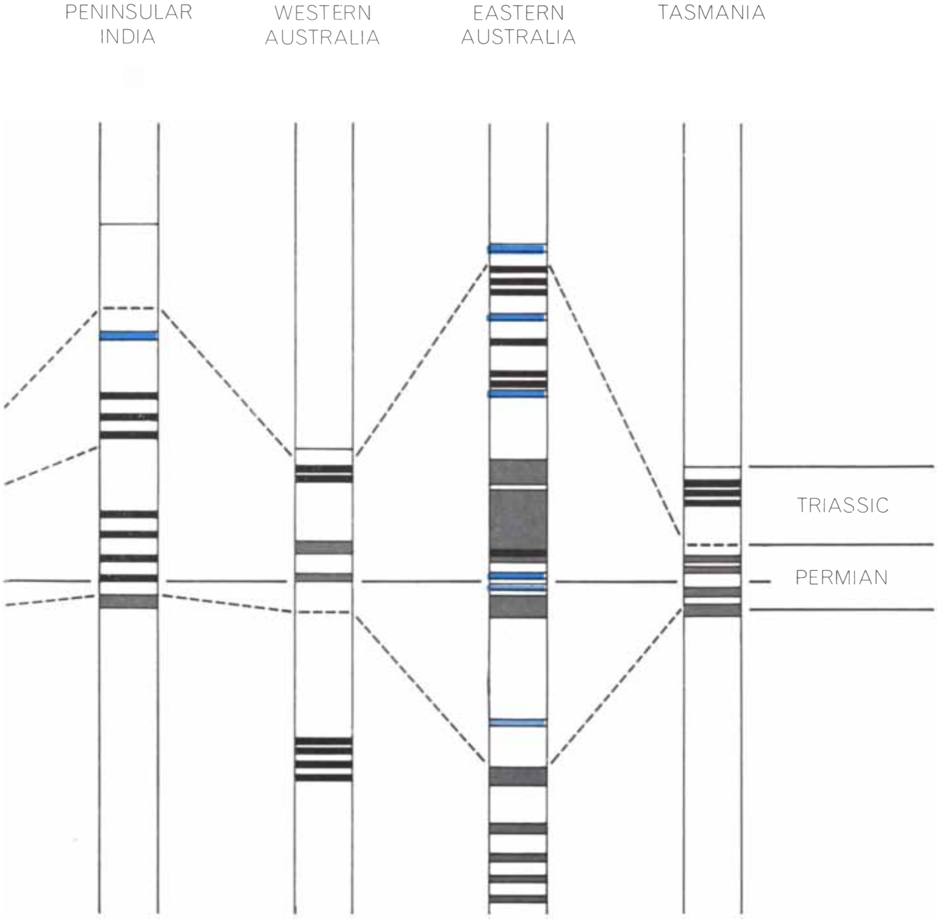
Not all felt this way, however. In the late 1930's the Dutch geophysicist F. A. Vening Meinesz proposed that thermal convection in the earth's mantle could provide the mechanism. His ideas were supported by his gravity surveys over the deep-sea trenches and the adjacent island arcs of the western Pacific. The results implied that some force was maintaining the irregular shape of the earth's surface against its natural tendency to flatten out. Presumably the force was somehow related to thermal convection. Arthur Holmes of the University of Edinburgh added his weight to the argument in favor of the hypothesis, and he was followed by S. W. Carey of Tasmania, Sir Edward Bullard and S. K. Runcorn of Britain, L. C. King of South Africa, J. Tuzo Wilson of Canada and others [see "Continental Drift," by J. Tuzo Wilson; SCIENTIFIC AMERICAN, April, 1963]. The historical and dynamical characteristics of the earth now engaged the attention of many more geophysicists, and today the interplay of all branches of geology and geophysics generates the excitement of a new frontier area.

Continents and Oceans

Although the general nature of the earth's crust is familiar to most readers of *Scientific American*, it is worth reviewing and summarizing some of its major features while asking: How do these features look in the context of continental drift? The earth's topography has two principal levels: the level of the continental surface and the level of the oceanic plains. The elevations in between represent only a small fraction of the earth's total surface area. What maintains these levels? Left alone for billions of years, they should reach equilibrium at an average elevation below the present sea level, so that the earth would be covered with water. Instead we see sharp continental edges, new mountain belts, deep trenches in the oceans—in short, a topography that appears to have been regularly rejuvenated.

The continental areas are a mosaic of blocks that are roughly 1,000 kilometers across and have ages ranging from about 3,000 million years to a few tens of millions. In Africa there appear to be several ancient nuclear areas, or cratons, surrounded by belts of younger rocks. Most of the younger belts have an age of 600 million years or less, contrasting sharply with an age of 2,000 million to 3,000 million years for the cratons.

A closer look at the younger belts tells us that although much of the material is



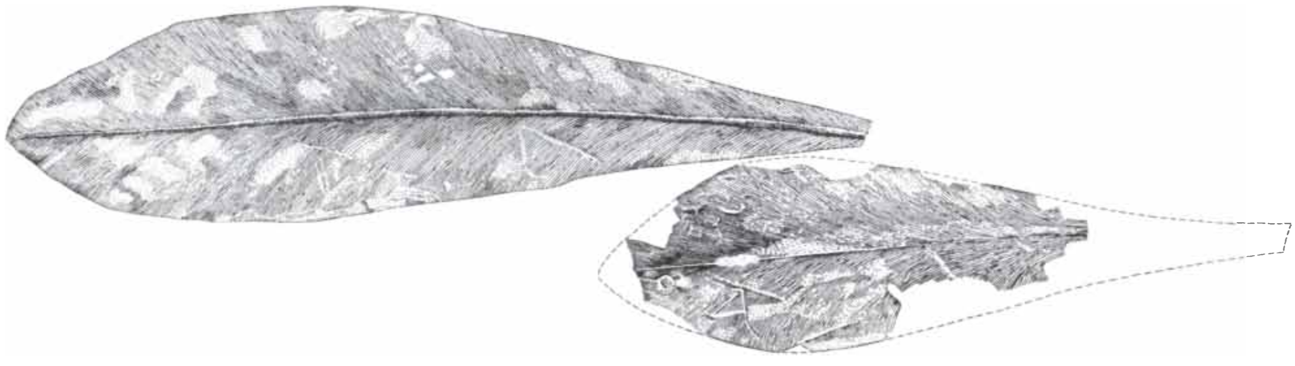
the very least a closely associated mass connected by land bridges. Only two of several major plant genera are plotted here: *Glossopteris* and *Gangamopteris*. The depths of the various deposits have been arbitrarily aligned between the lower and the basal Permian.

apparently new, there are large blocks that have the same age as the cratons. It looks as if the earth's surface has been warped and folded around the ancient continental masses, catching up segments of the crust and intruding younger igneous rocks into the folds. In some places the ancient material has been altered beyond recognition, but elsewhere it has been left fairly undisturbed and its antiquity can be determined by radioactive-dating methods. These composite belts are termed zones of rejuvenation. When they are eroded down to sea level, all we see, as far as topography is concerned, is another part of the continental platform. Geological mapping, however, reveals the belt structure clearly. A closer look at the cratons shows us that they too have the structure of preexisting mountain belts that have been carved into segments, with the younger material always cutting across the older structural pattern.

We see the process in action today. Our young mountain belts have not been eroded to sea level but show high elevations that are clearly apparent; we do not need geological surveys to observe them. It is only when we see the global distribution of these mountain belts on land areas, together with the distribution of rifts and their associated ridges under the oceans, that we begin to perceive the possibility that vast motions of the earth's surface may be their cause [*see illustration on next two pages*].

The earth is also encircled by belts of geological activity in the form of volcanoes, earthquakes and high heat flow, and observable motions in the form of folded rocks and the large displacements known as faults. In recent years the direction of displacements that are not observable on the surface has been deduced by the study of seismic waves arriving at various points on the earth's surface from earthquakes. It is now possible to tell the direction of slippage in the zones of rupture within the solid rocks of the earth's near-surface regions, so that the directions of the forces can be obtained.

If one looks at a map such as the one on the next two pages, one is immediately struck by the large scale and systematic distribution of these lines of geologic activity. Some of the systems are coherent over distances of several thousand kilometers. This immediately suggests the large-scale motion of material in the earth's interior. It does not, however, necessarily imply motions extending a similar distance into the interior. It is



TYPICAL GONDWANA FLORA are *Glossopteris communis* (*leaf at left*) and *Gangamopteris cyclopteroides* (*right*), two species of fern that are identified in the Gondwana succession illustrated at the top of these two pages. The fossils from which these drawings were made were uncovered in the central part of Antarctica in 1961–1962 by William E. Long of Alaska Methodist University.

possible to have sheets of rigid material supporting stresses and fracturing over great distances if the underlying material is less rigid.

The topography of the ocean floors has been rapidly revealed in the past two decades by the sonic depth recorder. The principal systems of ridges and faults have been mapped in considerable detail by such oceanographers as Bruce C. Heezen and Maurice Ewing of Columbia University and H. W. Menard of the Scripps Institution of Oceanography. The layers of sediment on the sea floor have also been explored by such methods as setting explosive charges in the water and recording the echoes. It became a great puzzle how in the total span of the earth's history only a thin veneer of sediment had been laid down. The deposition rate measured today would extend the process of sedimentation back to about Cretaceous times, or 100 to 200 million years, compared with a continental and oceanic history that goes back at least 3,000 million years. How could three-quarters of the earth's surface be wiped clean of sediment in the last 5 percent of terrestrial time? Furthermore, why were all the oceanic islands and submerged volcanoes so young? The new oceanographic investigations were presenting questions that were awesome to contemplate.

In the early 1960's Harry H. Hess of Princeton University and Robert S. Dietz of the U.S. Coast and Geodetic Survey independently proposed that the oceanic ridge and rift systems were created by rising currents of material which then spread outward to form new ocean floors. On this basis the ocean floors would be rejuvenated, sweeping along with them the layer of sedimentary material. If such a mechanism were at work, no part of the ocean basins would be truly ancient. Although this radical hypothesis had much in its favor, it appeared farfetched to most.

Tracking the Shifting Poles

During this time a group of physicists and geophysicists were studying the directions of magnetism "frozen" into rocks in the hope of tracing the history of the earth's magnetic field. When an iron-bearing rock is formed, either by crystallization from a melt or by precipitation from an aqueous solution, it is

WORLDWIDE GEOLOGICAL PATTERNS provide evidence that the major land masses have been driven apart by a slow convection process that carries material upward from the mantle below the earth's crust. The dark-colored lines identify the crests of oceanic ridges that are now believed to coincide with upwelling regions. These ridges are crossed by large transcurrent fracture zones. The broken lines show the approximate limits of the oceanic rises. The light gray areas identify the worldwide pattern of recent mountain belts, island arcs, deep trenches, earthquakes and volcanism that apparently mark the downwelling of crustal material. The slightly magnetized in the direction of the earth's magnetic field. Unless this magnetism is disturbed by reheating or physical distortion it is retained as a permanent record of the direction and polarity of the earth's magnetic field at the time the rock was formed. By measuring the magnetism in rocks of all ages from different continents, it has been possible to reconstruct the position of the magnetic pole in the past history of the earth. Great impetus was given to this study by P. M. S. Blackett and Runcorn, who with others soon found that the position of the pole followed a path going backward in time that was different for each continent [*see top illustration on next page*].

The interpretation of this effect was that the continents had moved with respect to the present position of the magnetic pole, and that since the paths were different for each land mass, they had moved independently. Because it was unlikely that the magnetic pole had wandered very far from the axis of the earth's rotation, or that the axis of rotation had changed position with respect to the principal mass of the earth, it was concluded that the continents had moved over the surface of the earth. Moreover, since the shift in latitude of the southern continents was generally southward going backward in time, the motions were in accord with the older evidence pointing toward a Gondwanaland in the south-polar regions. In short, the magnetic evidence supported not only the notion of continental drift but also the general locations from which the continents had moved within the appropriate time span.

This was still not enough to sway the preponderance of American scientific opinion. Finally, at the annual meeting of the Geological Society of America in San Francisco in 1966, came the blows that broke the back of the opposition. Several papers put forward startling new evidence that related the concepts of ocean-floor spreading and continental drift, the cause of the oceanic-ridge and fault systems and the direction and time scale of the drift motions. In addition, the development of new mechanisms explaining displacement along faults brought into agreement some of the formerly contradictory seismic evidence.

In the study of rock magnetism it was observed that the earth's magnetic field not only had changed direction in the past but also had reversed frequently. In order to study how frequently and when the reversals occurred three workers in the U.S. Geological Survey—Allan Cox, G. Brent Dalrymple and Richard R. Doell—carefully measured the magnetism in samples of basaltic rocks that they dated by determining the amount of argon 40 in the rocks formed by the decay of radioactive potassium 40. They noted a distinct pattern of reversals over some 3.6 million years [see "Reversals of the Earth's Magnetic Field," by Allan Cox, G. Brent Dalrymple and Richard R. Doell; SCIENTIFIC AMERICAN, February, 1967]. Their finding was soon confirmed when Neil D. Opdyke and James D. Hays of Columbia University found the same pattern in going downward into older layers in oceanic sediments. It was thus established that the polarity of the magnetic field had universally reversed at certain fixed times in the past.

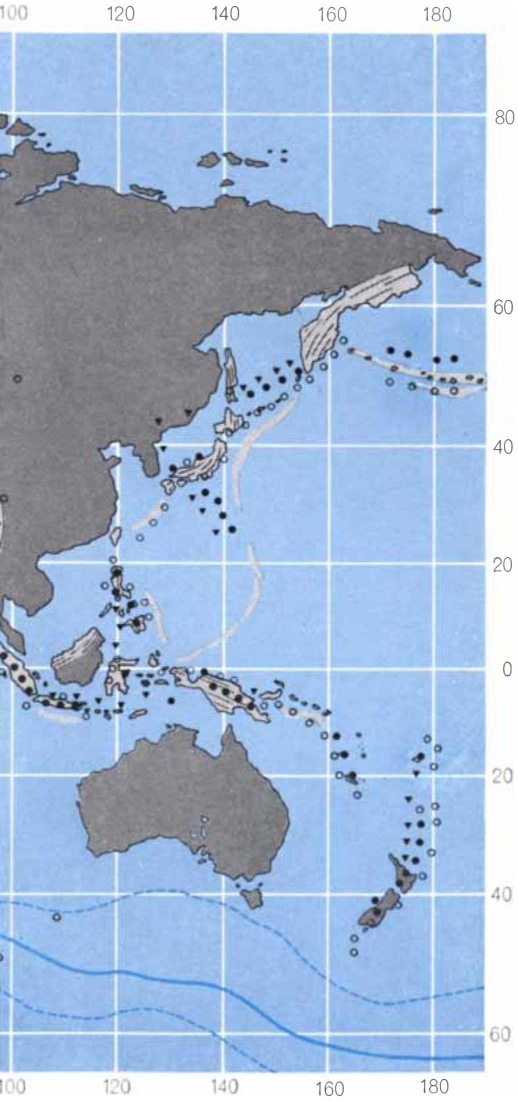
Meanwhile an odd pattern of magnetism in the rocks of the ocean floors had been detected by Ronald G. Mason and Arthur D. Raff of the Scripps Institution of Oceanography. Using a shipborne magnetometer, they found that huge areas of the ocean floor were magnetized in a stripelike pattern. Putting together these patterns, the discovery of magnetic reversals and Hess's idea that the oceanic ridges and rifts were the site of rising and spreading material, F. J. Vine, now at Princeton, and D. H. Matthews of the University of Cambridge proposed that the hypothesis of the continuous creation of new ocean floors might be tested by examining the magnetic pattern on both sides of an oceanic ridge. The extraordinary discovery that the pattern was symmetrical with the ridge was demonstrated by Vine and Tuzo Wilson, who studied the two sides of a ridge next to Vancouver Island.

The history of the magnetic field going back into the past was laid out horizontally in the magnetism of the rocks of the sea floor going away from the ridge in both directions. It appeared that new hot material was rising from the rift in the center of the ridge and becoming magnetized in the direction of the earth's field as it cooled; it then moved outward, carrying with it the history of magnetic reversals. Since the dates of the reversals were known, the distance to each reversed formation gave the rate of spreading of the ocean floor [*see bottom illustration on next page*].

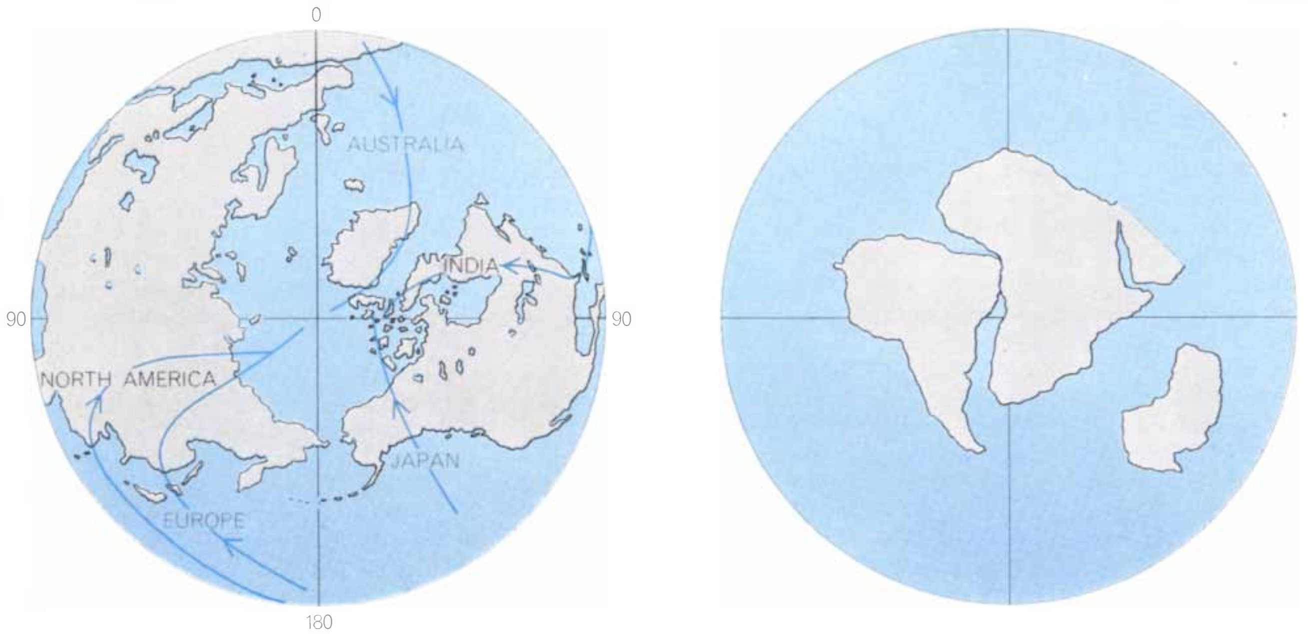
This important piece of work was quickly followed up by James R. Heirtzler, W. C. Pitman, G. O. Dickson and Xavier Le Pichon of Columbia, who have now shown that the ridges of the Pacific, Atlantic and Indian oceans all exhibit similar patterns. In fact, these workers have detected recognizable points in the history of magnetic reversals back about 80 million years, or in the Cretaceous period, and have drawn isochron lines, or lines of equal age, over huge strips of the ocean floors. Hence it is now possible to date the ocean floors and perceive the direction and rate of their lateral motion simply by conducting a magnetic survey over them. The implications for the study of drifting continents are immediately apparent.

These and other new findings do not unequivocally call for continental drift. It might be possible to have sea-floor spreading without drifting continents. Nonetheless, the directions and rates of motion for both sea-floor spreading and continental drift are entirely compatible. Above all, the principal objection to a hypothesis of continental movement has been removed.

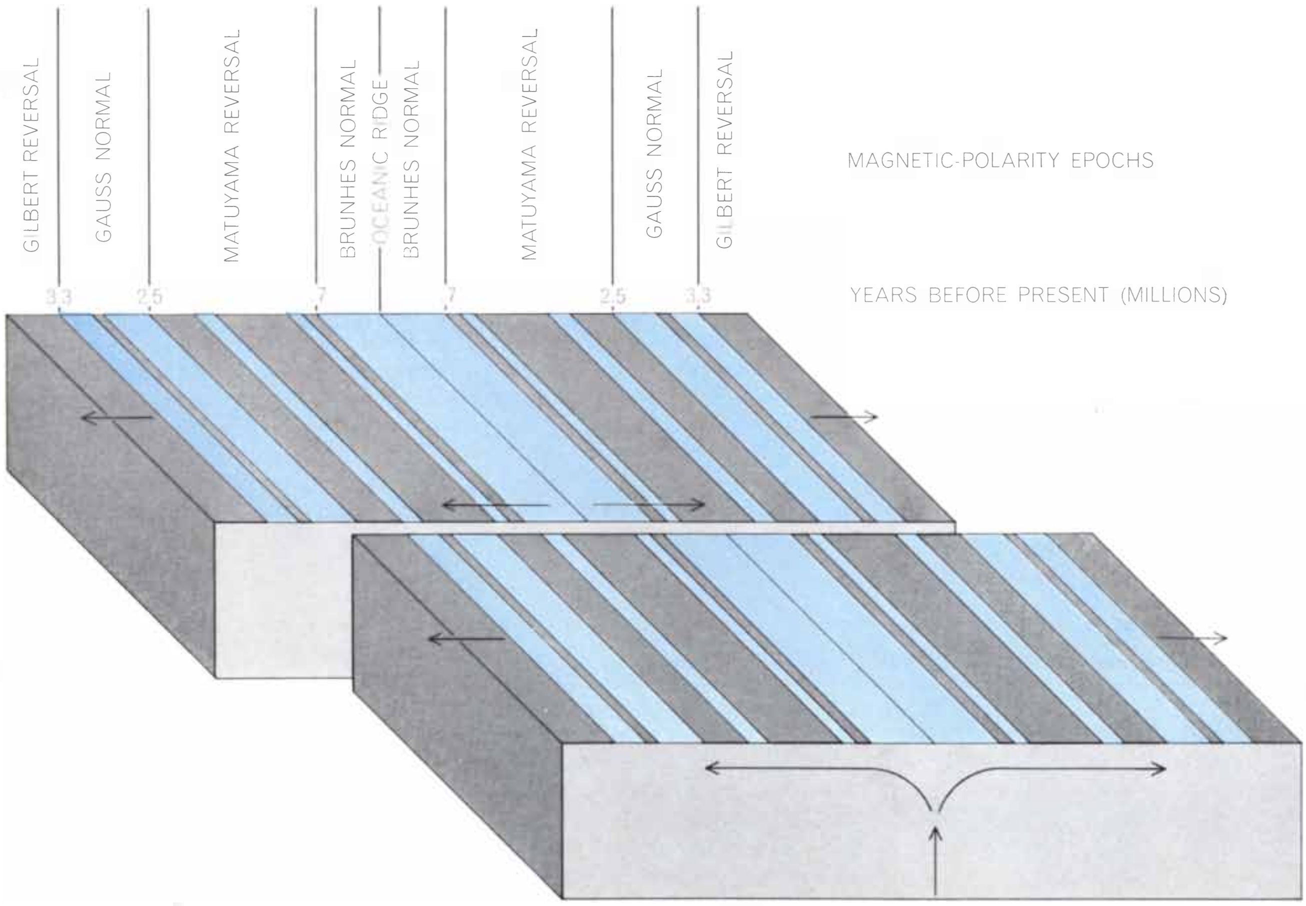
Looking back, it is interesting to ob-



downwelling seems to coincide with the occurrence of deep earthquakes (*triangles*) and earthquakes of intermediate depth (*solid dots*). Upwelling zones seem to coincide only with shallow earthquakes (*open dots*).



NORTH MAGNETIC POLE would appear to have wandered inexplicably during the past few hundred million years (*colored lines at left*), on the basis of "fossil" magnetism measured in rocks of various ages in various continents. The diagram is based on one by Allan Cox and Richard R. Doell of the U.S. Geological Survey. The pole could hardly have followed so many different tracks simultaneously; evidently it was the continents that wandered. K. M. Creer of the University of Newcastle upon Tyne found that the tracks could be brought together if South America, Africa and Australia were grouped in the late Paleozoic as shown at the right.



EVIDENCE FOR SEA-FLOOR SPREADING has been obtained by determining the polarity of fossil magnetism in rocks lying on both sides of oceanic ridges. In the diagram rocks of normal, or present-day, polarity are shown in color; rocks of reversed polarity are in gray. The displacement of the two blocks represents a transcurrent fracture zone. The symmetry suggests that the rocks welled up in a molten or semimolten state and gradually moved outward. The diagram is based on studies by a number of workers.

serve how each new piece of evidence presented in the past was met by counterevidence. Wegener's reconstruction, for example, was countered by numerous geologists who took exception to his detailed arguments. The arguments for the Permocarboniferous Gondwana glaciations were countered by Daniel I. Axelrod of the University of California at Los Angeles and others in this country. They contended that most species of fossil plant tend to be restricted to zones of latitude that hold for the continents in their present position, a fact that is hard to reconcile with the presumed pattern of glaciation. The idea that the great Gondwana land masses drifted in latitude has also been opposed by F. G. Stehli of Case Western Reserve University; his studies suggest that ancient fauna were most diverse at the Equator, and that the Equator defined in this way has not shifted.

Another Test of the Hypothesis

Any hypothesis must be tested on all points of observational fact. The balance of evidence must be strongly in its favor before it is even tentatively accepted, and it must always be able to meet the challenge of new observations and experiments. My own interest in the problem of continental drift was stimulated at a 1964 symposium in London sponsored by the Royal Society and arranged by Blackett, Bullard and Runcorn. At that time Bullard and his University of Cambridge associates J. E. Everett and A. G. Smith presented an elegant study of the geographic matching of continents on both sides of the North and South Atlantic. They had employed a computer to produce the best fit by the method of least squares. Instead of using shorelines, as had been done in earlier attempts, they followed the lead of S. W. Carey; he had chosen the central depth of the continental slope as representing the true edge of the continent.

The fit was remarkable [*see illustration on page 52*]. The average error was no greater than one degree over most of the boundary. My colleagues and I at the Massachusetts Institute of Technology now began to think of further testing the fit by comparing the sequence and age of rocks on opposite sides of the Atlantic.

Radioactive-dating techniques for determining the absolute age of rocks had reached a point where much could be learned about the age and history of both the ancient cratonic regions and the younger rejuvenated ones. For such purposes two techniques can be used in combination: the measurement of strontium 87 formed in the radioactive decay of rubidium 87 in a total sample of rock, and the measurement of argon 40 formed in the decay of potassium 40 in minerals separated from the rock. A collaborative effort was arranged between our geochronology laboratory and the University of São Paulo in Brazil (in particular with G. C. Melcher and U. Cordani of that institution). We also enlisted the aid of field geologists who had been working on the west coast of Africa (in Nigeria, the Ivory Coast, Liberia and Sierra Leone) and on the east coast of Brazil and Venezuela. The São Paulo group made the potassium-argon measurements of the Brazilian rock samples; we did the rubidium-strontium analyses on samples from all locations.

European geochronologists (notably M. Bonhomme of France and N. J. Snelling of Britain) had done pioneering work on the Precambrian geology of former French and British colonies and protectorates in West Africa. Of special interest to us at the start was the sharp boundary between the 2,000-million-year-old geological province in Ghana, the Ivory Coast and westward from these countries, and the 600-million-year-old province in Dahomey, Nigeria and east. This boundary heads in a southwesterly direction into the ocean near Accra in Ghana. If Brazil had been joined to Africa 600 million years ago, the boundary between the two provinces should enter South America close to the town of São Luís on the northeast coast of Brazil. Our first order of business was therefore to date the rocks from the vicinity of São Luís.

To our surprise and delight the ages fell into two groups: 2,000 million years on the west and 600 million years on the east of a boundary line that lay exactly where it had been predicted. Apparently a piece of the 2,000-million-year-old craton of West Africa had been left on the continent of South America.

In subsequent work on both sides we have found no incompatibilities in the age of many geological provinces on both sides of the South Atlantic [*see illustration on next page*]. Furthermore, the structural trends of the rocks also agree, at least where they are known. Minerals characteristic of individual belts of rocks are also found in juxtaposition on both sides; for example, belts of manganese, iron ore, gold and tin seem to follow a matching pattern where the coasts once joined.

Can such comparisons be made elsewhere? To some extent, yes. Unfortunately the rifting process by which a continent breaks up seems to be guided by zones of rejuvenation between cratons, as if these zones were also zones of weakness deep in the crust. It is necessary for the break to have transected the structure of the continent, cutting across age provinces, if one is to get a close refitting of the blocks. In the North Atlantic this is not the case, but the continental areas on both sides were simultaneously affected by an unmistakable oblique crossing of a Paleozoic belt of geological activity [*see illustration on page 62*]. Actually the belt covers the region of the Appalachian Mountains and the Maritime Provinces of North America, with an overlap along the coast of West Africa, and then splits into two principal belts: one extending through the British Isles and affecting the Atlantic coast of Scandinavia and Greenland and the other turning eastward into Europe. There is a superposition of at least four periods of renewed activity affecting the various parts of this complex. All four are represented on both sides of the North Atlantic, making this correlation extremely difficult to explain unless the continents were once together.

My colleagues H. W. Fairbairn and W. H. Pinson, Jr., and I, as well as other workers, have made age measurements in the northern Appalachians and Nova Scotia for many years, and we have found all four periods well represented in New England. The earliest period of activity (which Fairbairn has named Neponset) is dated about 550 million years ago; it is seen in some of the large rock bodies in eastern Massachusetts and Connecticut, in the Channel Islands off the northern coast of France, in Normandy, Scotland and Norway. The next-oldest period (the Taconic) was about 450 million years ago and is found on the western edge of New England and in parts of the British Isles. The next period, going back about 360 million years, is strongly represented in the entire span of the Appalachians and Nova Scotia (where it is called the Acadian) and in England and Norway (where it is called the Caledonian). Finally, about 250 million years ago, the activity seemed to move into southern Europe and North Africa, where it has been called the Hercynian. This activity, however, also extended into New England; much of southern Maine, eastern New Hampshire, Massachusetts and Connecticut show rocks of this age. Here the event is called the Appalachian.

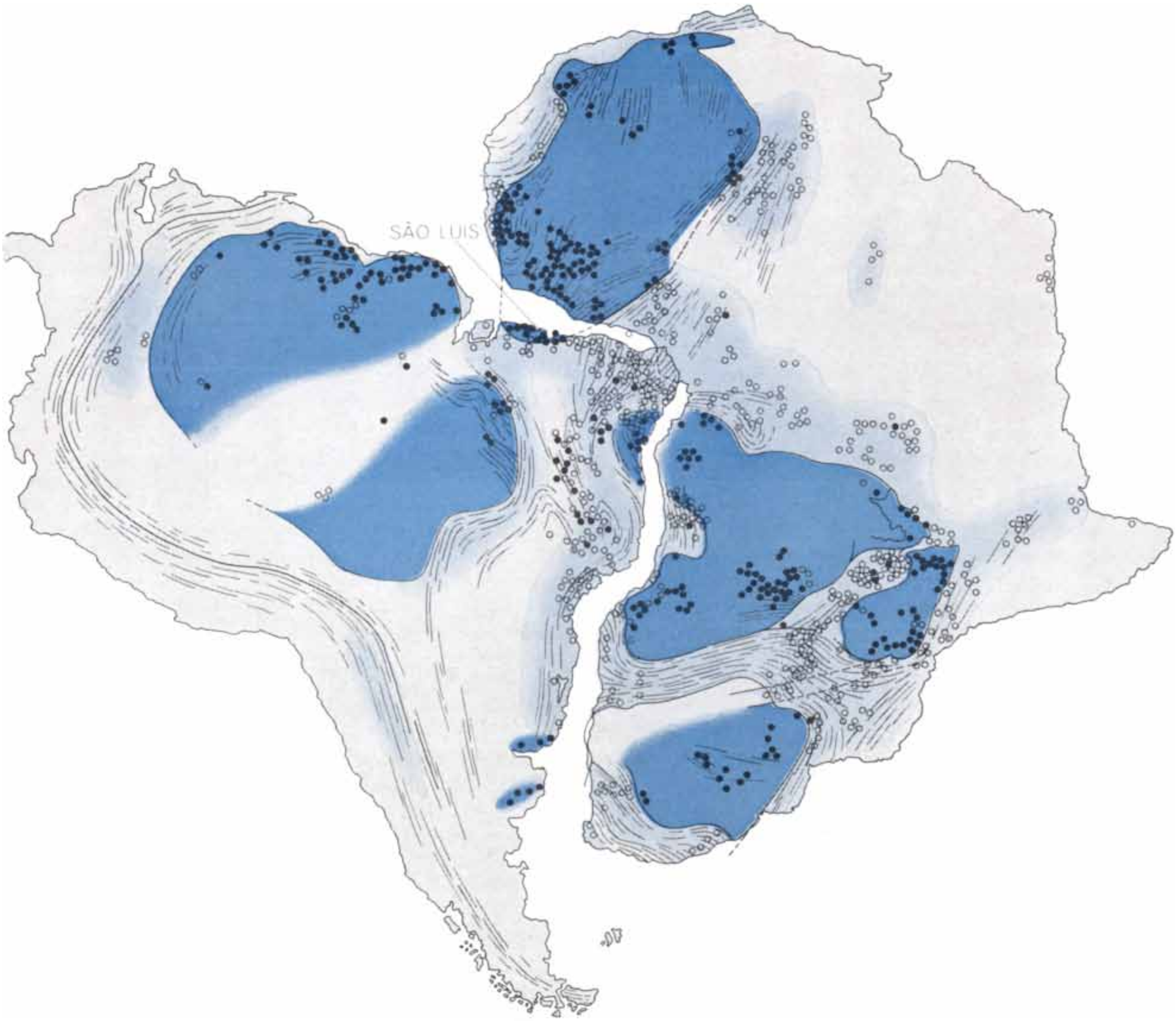
Farther south the Lower Paleozoic section of the northwest coast of Africa (Senegal) appears to continue under the younger coastal sediments of Florida.

This African belt shows large rock units with ages equivalent to the Neponset, and also evidence of the younger events.

The Fitting of Antarctica

The recent extensive geological surveys in Antarctica have been highly rewarding in reconstructing Gondwanaland. Prior to the end of the Permian period the younger parts of western Antarctica were not yet formed. Only eastern Antarctica was present, including the great belts of folded rocks that form the Transantarctic Mountains. These consist of two geosynclines, or sediment-filled troughs: the inner Eopaleozoic and the outer Paleozoic [*see illustration on page 64*]. The inner belt includes late Precambrian and early Cambrian sediments, which were folded and invaded by igneous rocks during late Cambrian or early Ordovician times (about 500 million years ago). Thus the inner belt is similar in age to the widespread event in the rest of Gondwanaland. It is marked by the Cambrian fossil Archaeocyatha, an organism that formed barrier reefs. These coral-like structures are found transecting sediments in bodies known as bioherms. The outer belt, farther within western Antarctica, is a geosyncline filled with Lower Paleozoic sediments. Like the northern Appalachians, it was deformed and invaded by igneous rocks in the middle and late Paleozoic. Later it was covered with a quite representative Gondwana succession, with its glacial deposits, coal and diverse plants.

There seems to be a similar record of events in eastern Australia. The bioherms of the Cambrian Archaeocyatha are found in a belt extending northward from Adelaide and mark the edge of an early geosyncline filled with sediments including late Precambrian and Cambrian ones. Later in time, and farther to the east, great thicknesses of Silurian and Lower Devonian sediments accumulated in the Tasman trough. Compression and igneous intrusion occurred in this Tasman geosyncline mostly in the late Lower Devonian period to the middle Devonian (about 350 million years



TENTATIVE MATCHING of geological provinces of the same age shows how South America and Africa presumably fitted together some 200 million years ago. Dark-colored areas represent ancient continental blocks, called cratons, that are at least 2,000 million years old. Light-colored areas are younger zones of geological activity: mostly troughs filled with sediments and volcanic rocks that were folded, compressed and intruded by hot materials, forming granites and other rock bodies. Much of this activity was 450 million to 650 million years ago, but some of it goes back 1,100 million years. The dots show the sites of rocks dated by many laboratories, including the author's at the Massachusetts Institute of Technology. Solid dots denote rocks older than 2,000 million years; open dots denote younger rocks. The region near São Luís is part of an African craton left stranded on the coast of Brazil.

ago). The later cover of sediments includes a Gondwana succession similar to the one in Antarctica.

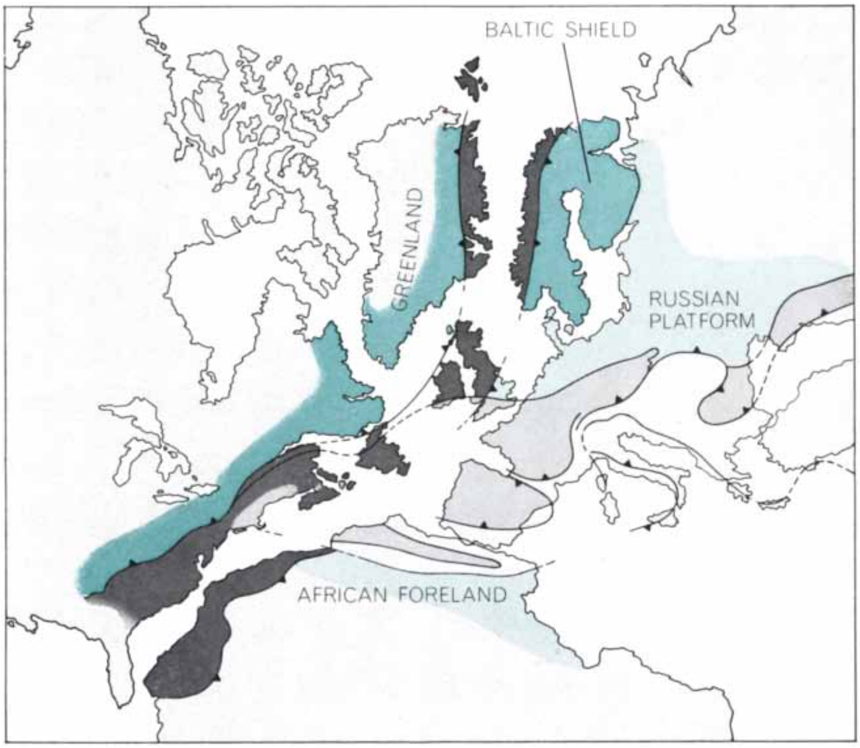
There is also strong evidence for a juncture between Australia and India, particularly in the Permian basins of sedimentation of the two continental blocks and in Gondwana sequences of coal and plants. Limestone beds containing the same Productid shells are found in the upper layers of the sequence on both sides. A correlation also exists between the banded iron ores of Yampi Sound in northwestern Australia and the similar ores of Singhbhum in India.

The illustration on page 64 is a reconstruction of Gondwanaland based on the evidence we have discussed so far. The three land masses—Antarctica, Australia and India—have been fitted together not at their present shorelines but where the depth of the surrounding ocean reaches 1,000 meters. As can be seen, the fit of the edges is good. The detailed fit of this assemblage into the southeastern part of Africa is still debated because most of the edges lack structures that cut across them. Nevertheless, I have included the edge of Africa in the map to show how it might possibly fit on the basis of limited age data from Antarctica.

This arrangement of land masses in the late Paleozoic is extremely tentative. It is now up to the geochronologists to test each juncture more closely for correlations in geologic age, and up to the field geologists to match structure and rock type. One particularly interesting fit may be forthcoming in a study of the boundaries of shallow and deep marine glacial deposits, and of the land tillites around what appears to be the start of an oceanic basin at the time Antarctica was breaking away. This attempt to establish the former position of Antarctica, which is being made by L. A. Frakes and John C. Crowell of the University of California at Los Angeles, may set in place the key piece in the puzzle. A detailed correlation of fossil plants in Antarctica with those of the adjacent land masses, which has been undertaken by Edna Plumstead of the University of Witwatersrand, is similarly limiting the possible position of the blocks.

The Age of the Atlantic

When did Gondwanaland begin to break up? One of the best pieces of evidence for the start of the opening of the South Atlantic is the age of offshore sediments along the west coast of Africa. Drilling through these sediments down to the ancient nonsedimentary rocks



MATCHING OF NORTH ATLANTIC REGIONS is more difficult than in the South Atlantic. This tentative, pre-drift reconstruction of a portion of Laurasia depends on matching ancient belts of similar geological activity. The dark gray belt represents the formation of sediment-filled troughs and folded mountains in the early and middle Paleozoic (470 million to 350 million years ago). The medium gray belt was formed in the late Paleozoic (350 million to 200 million years ago). The latter belt overlapped the region of the former in the northern Appalachians and in southern Ireland and England, but diverged eastward in Europe. Four distinct and superimposed periods of geological activity occur on both sides of the present North Atlantic, providing strong evidence for a previous juncture.

shows that the layer of sediments is quite young: not older than the middle Mesozoic (about 160 million years ago). If the South Atlantic had been in existence for a major part of geologic time, the continent of Africa would unquestionably have developed a large shelf of sediments along the entire length of its western margin. The continental shelf would consist of sediments dating all the way back to the time of the ancient cratons. This is not the case. It looks as though the rift started from the northern edge of western Africa in the middle Triassic and slowly opened to the south until the final separation occurred in the Cretaceous. The east coast of Africa, on the other hand, apparently started to open earlier, in the Permian.

With the acceptance of sea-floor spreading and continental drift the global problems of geology are beginning to be solved. Although the train of thought on such matters is not universally accepted in detail, it is something like the following. Continental areas appear to have greater strength, to a depth of 100 kilometers or so, than ocean basins do, so that they tend to maintain themselves as buoyant masses that are not destroyed by sinking motions. They can, however, be ruptured. Rising material pushes the surface apart; sinking material pulls the surface together and toward the region of sinking. Therefore if a sinking zone is established in an oceanic region, the continents will move toward the zone, and if a rising zone is established under a continent, the continent will split apart and the parts will move away from the zone. When the ocean floor moves toward a sinking zone in an oceanic region, it forms a deep trench bordered by volcanoes, chains of islands or elongated land masses such as the Philippines and Japan. When an ocean floor moves toward a continent, it appears to pass under the continental border, forming a great mountain chain. The mountain chain may be in part piled-up material that was already present and in part volcanic material that rose as the ocean swept its load of sediment, underlying volcanic rock and the continental shelf itself toward and under the edge of the continent. The process leads to a melting of underlying rock and to the intrusion of new volcanic material. The west coast of South America is a good example.

Another example is the thrust of India into Eurasia that formed the Himalayas. It has long been known that there was a large body of water between Africa and Eurasia and that a great thickness of sediments was deposited there at some time during the past 200 million years. This body is known as the Tethys Sea. It was located north of Arabia and extended from the former location of the Atlas Mountains to east of the Himalayas. As I have mentioned, it appears that Gondwanaland not only broke up but also moved northward, with India and Africa pushing up into Eurasia. This motion apparently caused the buckling up of sediments in the Tethys Sea, giving rise to the mountain ranges that now form a contorted chain from the western Atlas range through the Mediterranean, the western Alps, the Caucasus and the Himalayas.

The way the present mountain systems of the earth fall along great circles suggests that the motions in the earth's interior have a large-scale coherence, of the order of the dimensions of the earth itself. The prevailing explanation stems from a new lead in seismology: a zone in the earth at a depth of 100 or 200 kilometers has been found to transmit seismic waves more slowly than the layers above and below it and to absorb seismic energy more strongly. This low-velocity zone is generally thought to consist of a material whose strength is reduced because a small amount of it is molten or because its temperature is approaching the melting point. The surface of the earth may therefore move around on this low-strength layer like the skin of an onion. It is believed the earth loses heat partly by conduction outward and partly by convection currents in the relatively thin layer above the weak zone. These currents, as they have been depicted by Walter M. Elsasser of Princeton and Egon Orowan of M.I.T., form rather flat convection cells.

A hypothesis that is currently popular is that the mechanism of spreading at the oceanic ridges involves the intrusion of hot material into ruptures near the surface. This material is the same as that in the low-velocity zone, lubricated by partly molten rock. A small proportion of the intruded material actually loses some of its melted fraction upward, giving rise to volcanoes and creating a thin layer (about five kilometers thick) of volcanic rock at the surface. The masses of intruded material cool as they move sideways from the central ridge, which is overlain by the thin layer of volcanic rock. This results in the observed distribution of seismic velocities at various

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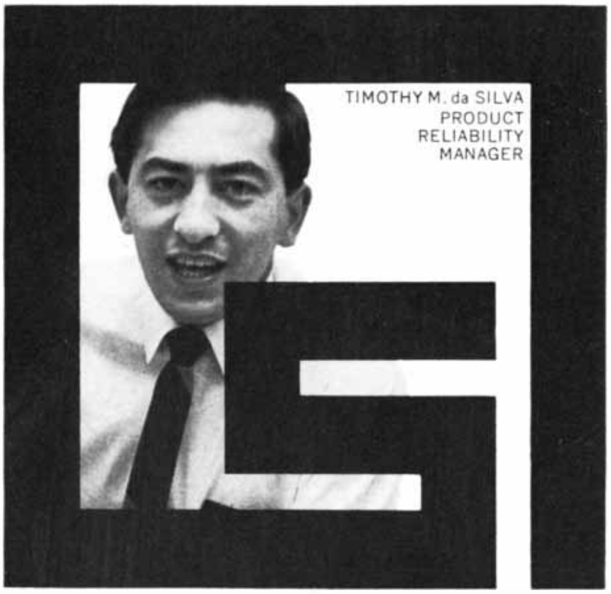

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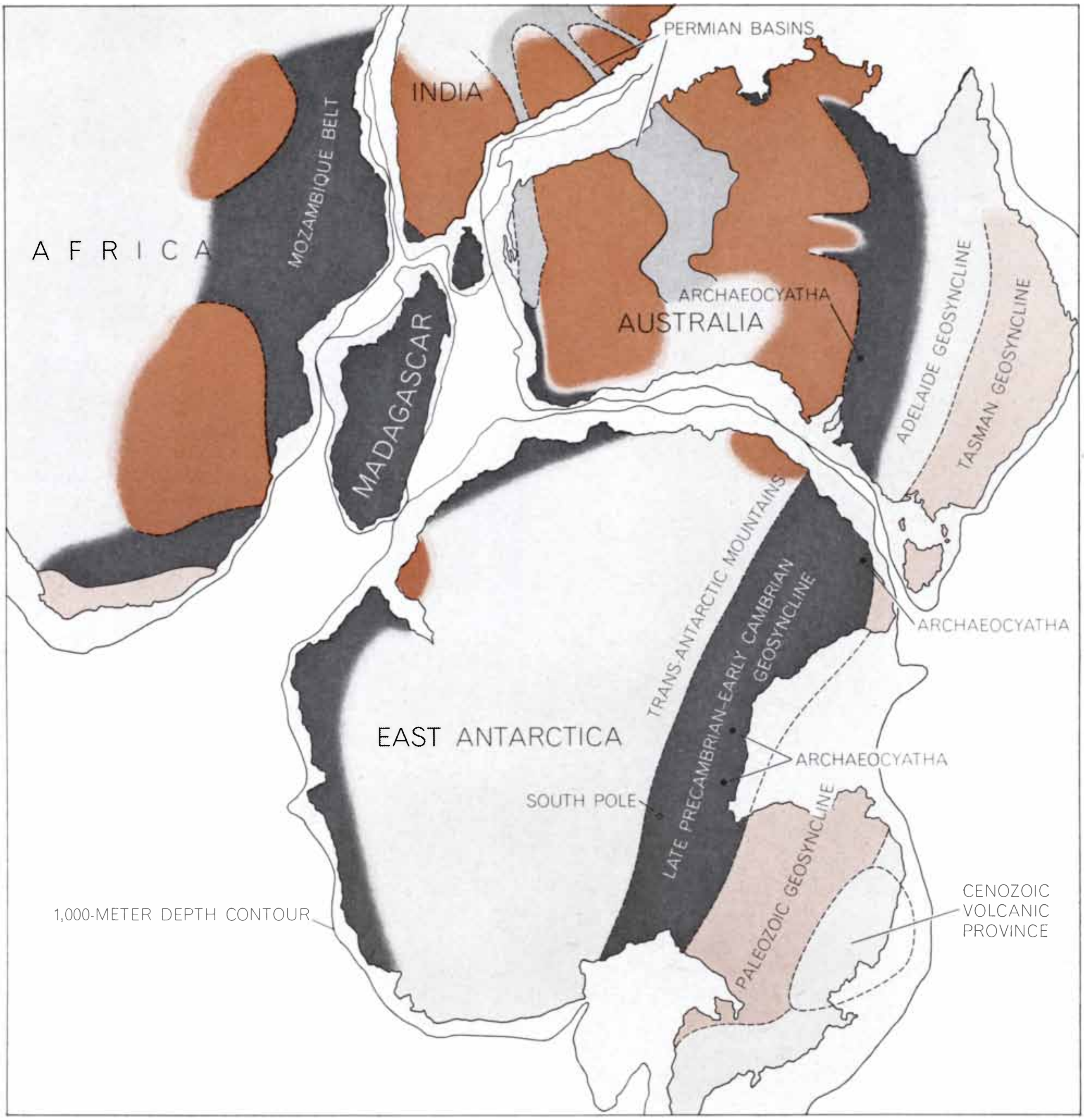
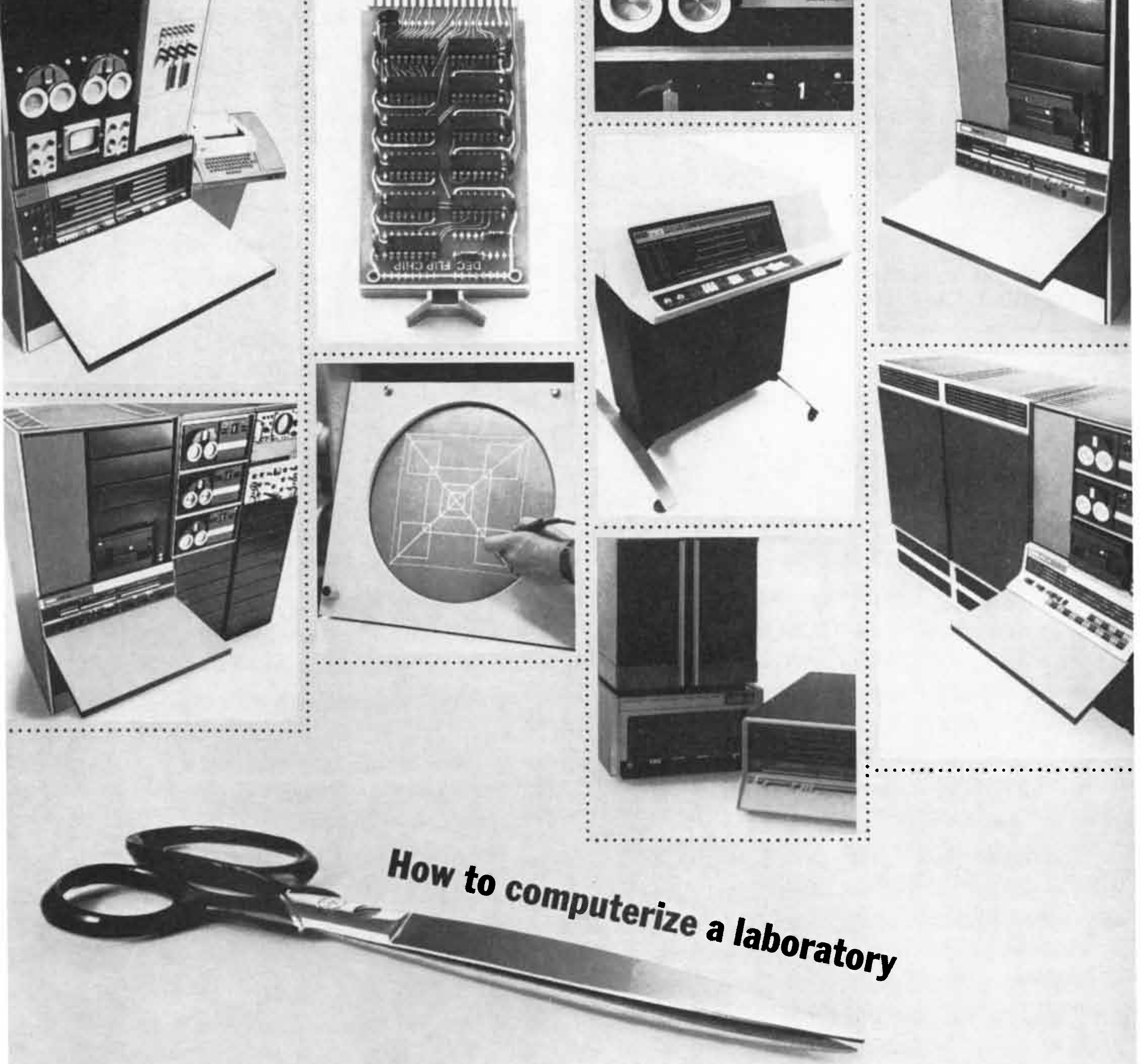
depths, helps to explain why the flow of heat to the surface decreases with distance from the ridge and accounts for the pattern of magnetic reversals. At the sinking end of the convection cell this relatively rigid block of mantle material with its thin cover of basalt (plus a thin cover of new sediment) moves downward on an inclined plane.

It is clear where these concepts will lead. If folded mountain belts are the "bow waves" of continents plowing their way through ocean floors and ramming into other continents, we can use them to show us the relative directions of motion prior to the last great drift episode. If we look at the pre-drift Paleozoic mountain belts, such as the Appalachian belt of North America, the Hercynian of Europe and the Ural of Asia, we find that they are located *internally* in the great continental masses of Gondwanaland and Laurasia. This suggests that these pre-drift supercontinents had been formed by the inward motion of several separate blocks, which came together before they broke apart. Geologists have a new game of chess to play, using a spherical board and strange new rules.



PART OF GONDWANALAND, tentatively reconstructed, brings together East Antarctica, Africa, Australia, Madagascar, India. The fit is at the 1,000-meter depth contour of the continental slope. Late Precambrian and Paleozoic geosynclines, or sediment-filled troughs, in eastern Australia are correlated in age and location with similar troughs along the Transantarctic Mountains. The deep Permian basins of northwest Australia match those of India. Glacial deposits, fauna and metal ores provide other correlations.



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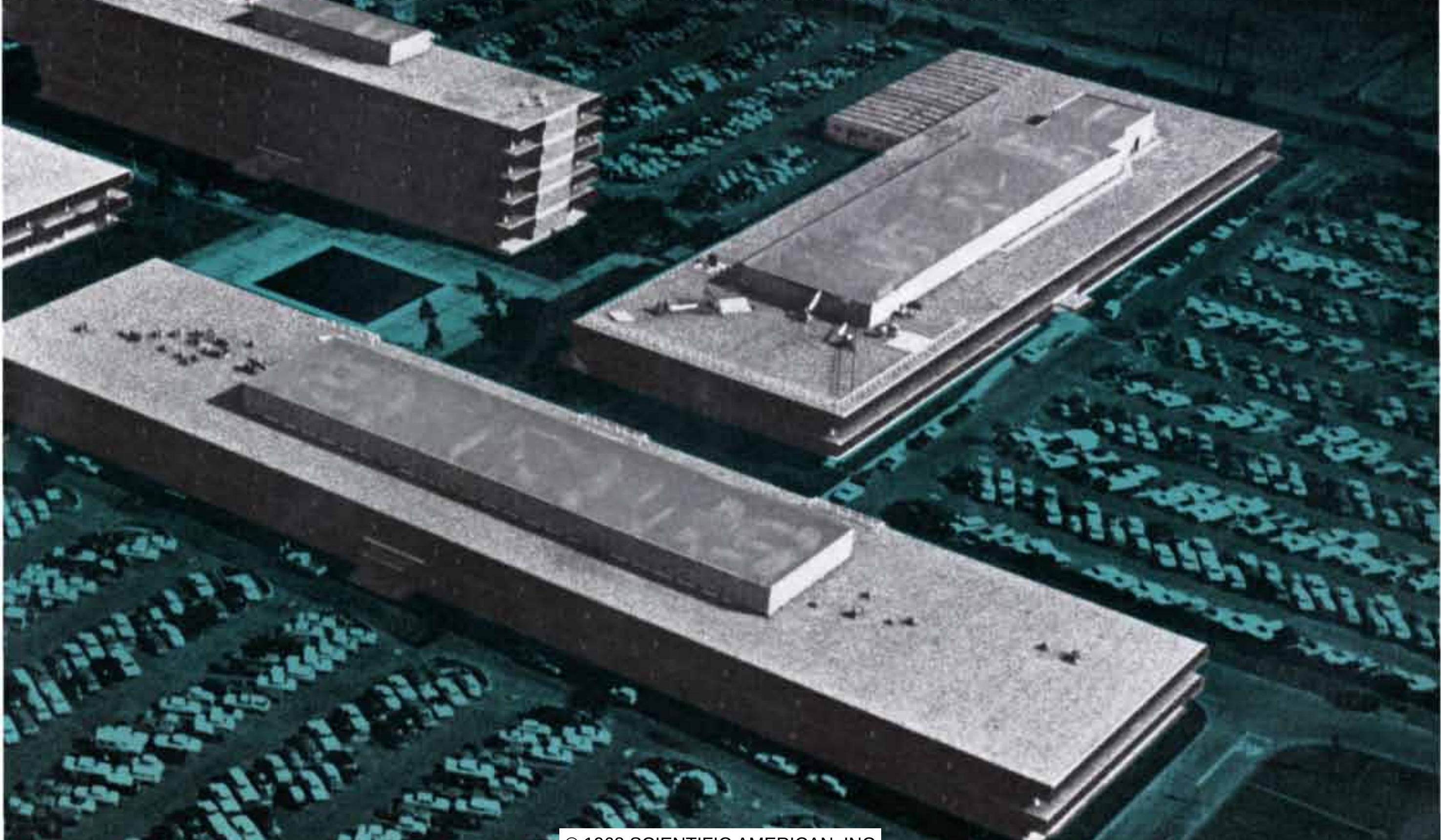


TETANUS

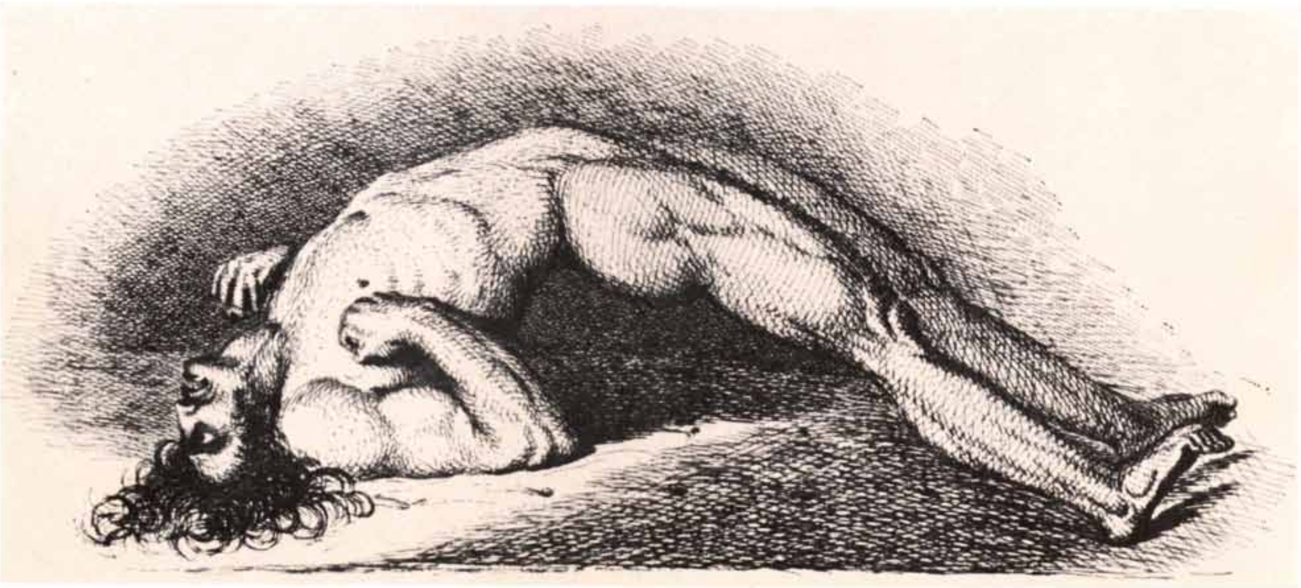
Bacteria that may barely infect a trivial wound can produce enough toxin to cause the severe and often fatal symptoms of this disease. Tetanus is hard to treat, but it could be eradicated by immunization

by W. E. van Heyningen

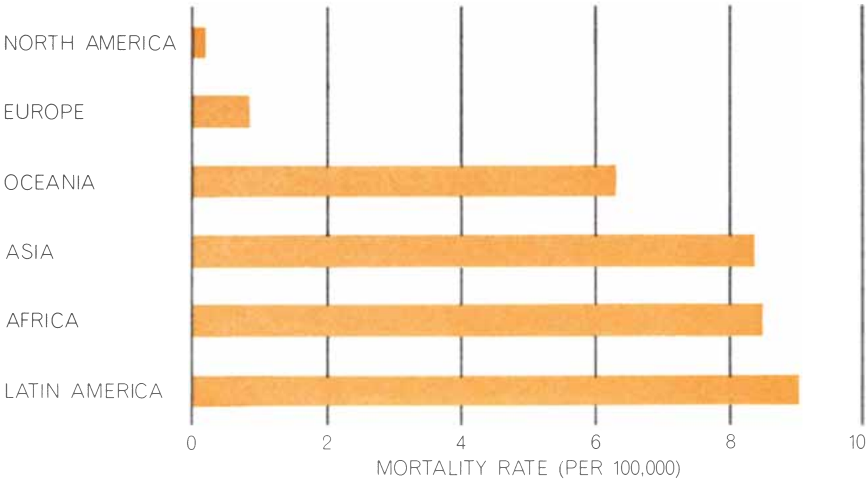
Early in the 19th century the Scottish surgeon Sir Charles Bell made a drawing of a British soldier who had been wounded at the Battle of Corunna, during the Peninsular War in Spain. The soldier was rigid: his back arched, his hands and feet clenched, his jaw set in a terrible grimace—the "sardonic smile" of tetanus, or lockjaw [*see illustration below*]. A victim of tetanus is in a state of spastic paralysis. He is unable to move, although the muscles of his body are contracting with all their strength, because for every muscle pulling in one direction another is pulling as strongly in the opposite direction. Bell's soldier was exerting tremendous energy, pitting himself against himself. He was exhausted but could not possibly rest, and he was suffering intense pain. Soon he would die, because there was no way to save him.

Tetanus is an ancient and ferocious infectious disease that was described by Hippocrates 24 centuries ago. It is a disease of wounding, but not just of serious wounds. Any break in the skin—a superficial scratch or the puncture of a drug addict's needle—is susceptible to the infection. The organism that causes tetanus was identified in 1889; it is the ubiquitous bacillus *Clostridium tetani,* present in soil, dust and clothing. It acts not directly but by producing a nerve toxin that has been isolated and purified and found to be one of the most powerful poisons known. The action of the toxin is now understood in a general way and is being studied at the molecular level. Meanwhile tetanus continues to be one of the world's greatest killers. This need not be, because the disease could be virtually eliminated by an intensive worldwide program of immunization.

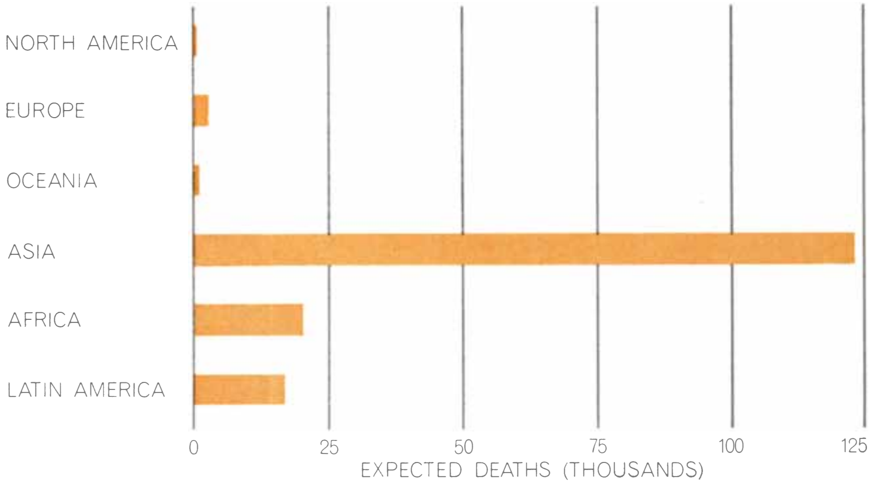
The prevalence of tetanus is masked, as B. Bytchenko of the World Health Organization has pointed out, in part by the fact that the disease does not cause epidemics. It strikes individuals rather than large communities or regions, and is therefore less noticed than infectious diseases such as smallpox, cholera, tuberculosis and malaria. Yet it ranks high among the infectious diseases as a cause of death. Tetanus is badly underreported because in many countries it is not a "notifiable" disease. Bytchenko has calculated that if it were reported on the same basis as smallpox, it would be found to account for some 164,000 deaths a year.



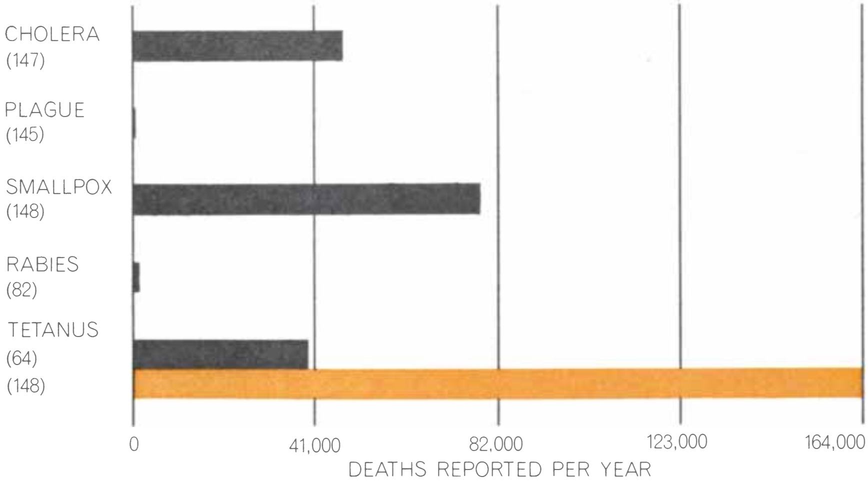
VICTIM OF TETANUS, a soldier wounded at the Battle of Corunna in 1809, is seen in a drawing made by the Scottish surgeon and anatomist Sir Charles Bell and published in 1832 in his book *The Anatomy and Philosophy of Expression.* The patient's muscles are working against one another, leaving him in a state of spastic paralysis; his jaw is set in the "sardonic smile" of tetanus, or lockjaw.



MORTALITY RATES from tetanus vary widely, depending on the stage of development of the region. These rates have been corrected for widespread underreporting of tetanus.



ANNUAL DEATHS, derived from the computed mortality rates, yield the world total of 164,200. Chart data were compiled by B. Bytchenko of the World Health Organization.



MORTALITY FIGURES for five infectious diseases show smallpox as the leading killer (*gray bars*). The number of countries notifying, or reporting deaths from each disease, is shown in parentheses. If tetanus were as widely reported as smallpox, the World Health Organization estimates, it would account for twice as many deaths as smallpox (*color*).

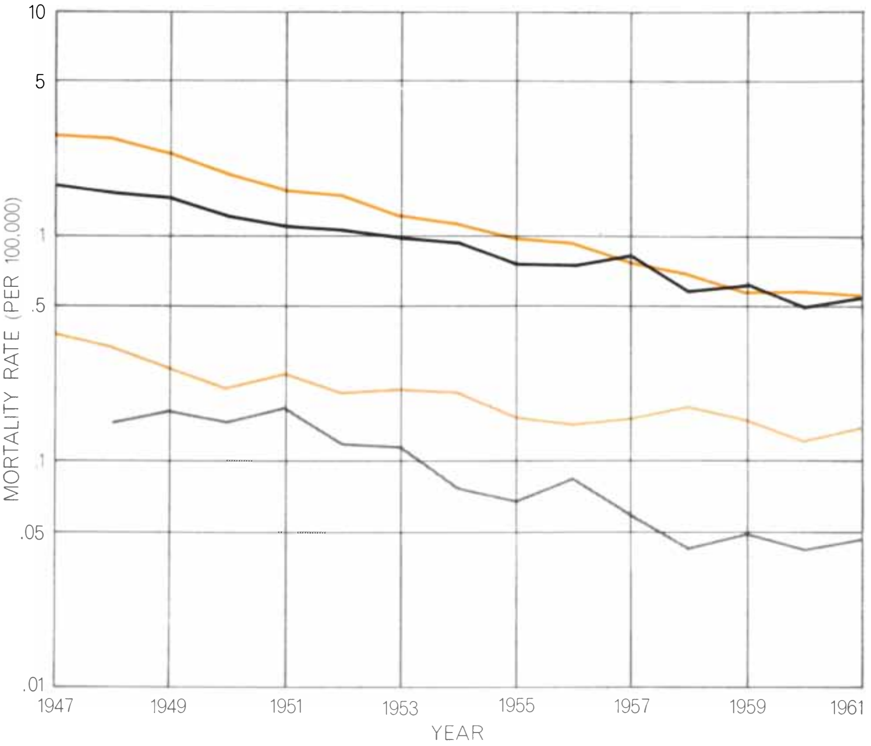
A remarkably high proportion of the victims of tetanus die of it. The recorded percentage has been as high as 97 percent (based on a study of tetanus cases resulting from July 4 celebrations in the U.S. from 1904 to 1907) and is seldom lower than 40 percent. The very lethality of the disease makes its toll less obvious. As R. Veronesi of the University of São Paulo Faculty of Medicine has remarked, if tetanus did not kill people but rather left them paralyzed, "we would see, every 10 years, more than one million tetanus-crippled individuals in the streets of the world, and confronted with this situation perhaps people and governments would ask immediately for measures to control the problem."

Any tabulation of tetanus mortality rates shows tremendous differences between the developed and the developing regions of the world. The rates tend to increase toward the Equator, and indeed tetanus is listed by the World Health Organization among the 10 leading causes of death in a number of tropical countries. The correlation is not with climatic and soil conditions, of course, but with social and economic conditions; tetanus is closely associated with primitive sanitation. A high proportion of the deaths are caused by "tetanus neonatorum," a disease of newborn babies in the first two or three weeks of life. It results from infection of the umbilicus after the cord has been cut with dirty instruments or under insanitary conditions. (In some countries it is even the practice to apply cow dung to the navel.) Umbilical tetanus accounts for 30 to 80 percent of the deaths from tetanus in tropical countries and for as many as 70 percent of all deaths of newborn infants; in one state in Brazil that has about 15 million inhabitants more than 1,000 babies die of umbilical tetanus every year.

Tetanus appears, however, in people of all ages and as a result of all kinds of injuries. Apart from accidental injuries these include negligent surgical operations, vaccination, circumcision, abortion and ear-piercing as well as the injection of drugs. (In the past 11 years 72 percent of all tetanus cases in New York City occurred in heroin addicts; the fatality rate among these cases was 86 percent compared with 38 percent among nonaddict victims of tetanus.)

Clearly tetanus could be avoided to a large extent by the application of simple sanitary measures, for example by persuading (and enabling) children in tropical countries to wear shoes or sandals and thereby avoid many of the daily small wounds that can lead to infection. The effect of improved sanitation was demonstrated in Japan, where the mortality from tetanus declined steadily from 2.9 deaths per 100,000 inhabitants in 1947 to fewer than .5 in 1964. This last figure was about equal to the rate in France, where preventive immunization had been applied on a nationwide scale since 1940, although immunization had not been widely practiced in Japan. The improvement in Japan can be traced in part to a decreasing death rate from tetanus of the newborn, and that in turn may be correlated with an increase in the proportion of babies delivered in hospitals rather than at home (from 2.4 percent in 1947 to 58 percent in 1961).

The attainment of sanitary conditions in the developing countries is easier said than done, of course, and it will not be possible until their economic condition is greatly improved. Immunization, on the other hand, can prevent tetanus no matter how insanitary the environment or how infested the wound. To understand immunization against tetanus we must first inquire into the nature of the disease and how the infecting bacillus brings it about.



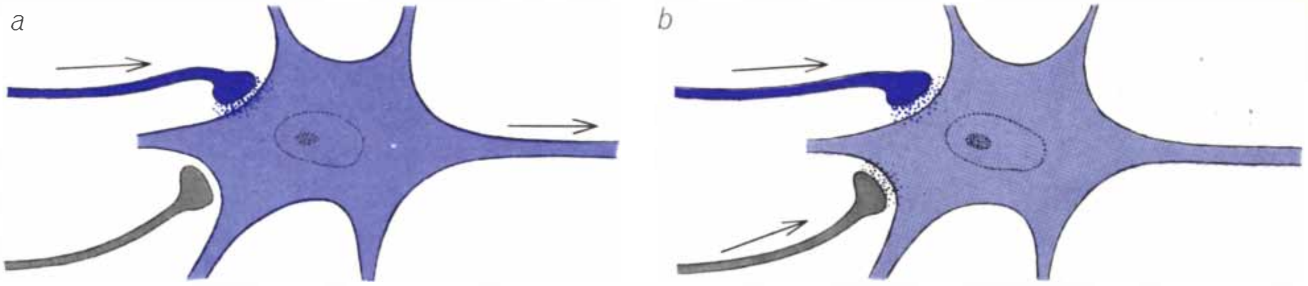
TETANUS DEATH RATE has declined since World War II at roughly the same rate in Japan (*color*), France (*black*), the U.S. (*light color*) and England and Wales (*gray*). Among these countries only Japan was not practicing preventive immunization in those years. The decline there was apparently due to increasingly effective public health and sanitation.

Tetanus is an unusual kind of infection. Not only is the wound that causes it often trivial; there is also no visible pathology that can be detected at postmortem examination. No lesions are produced in the tissues that can be detected even with the electron microscope. The bacillus that infects the wound has hardly any capacity to invade the tissues; it proliferates only to a limited degree, so that the wound hardly appears to be infected. Clearly the mere presence of the infecting organisms cannot account for the violent, widely distributed symptoms of the disease.

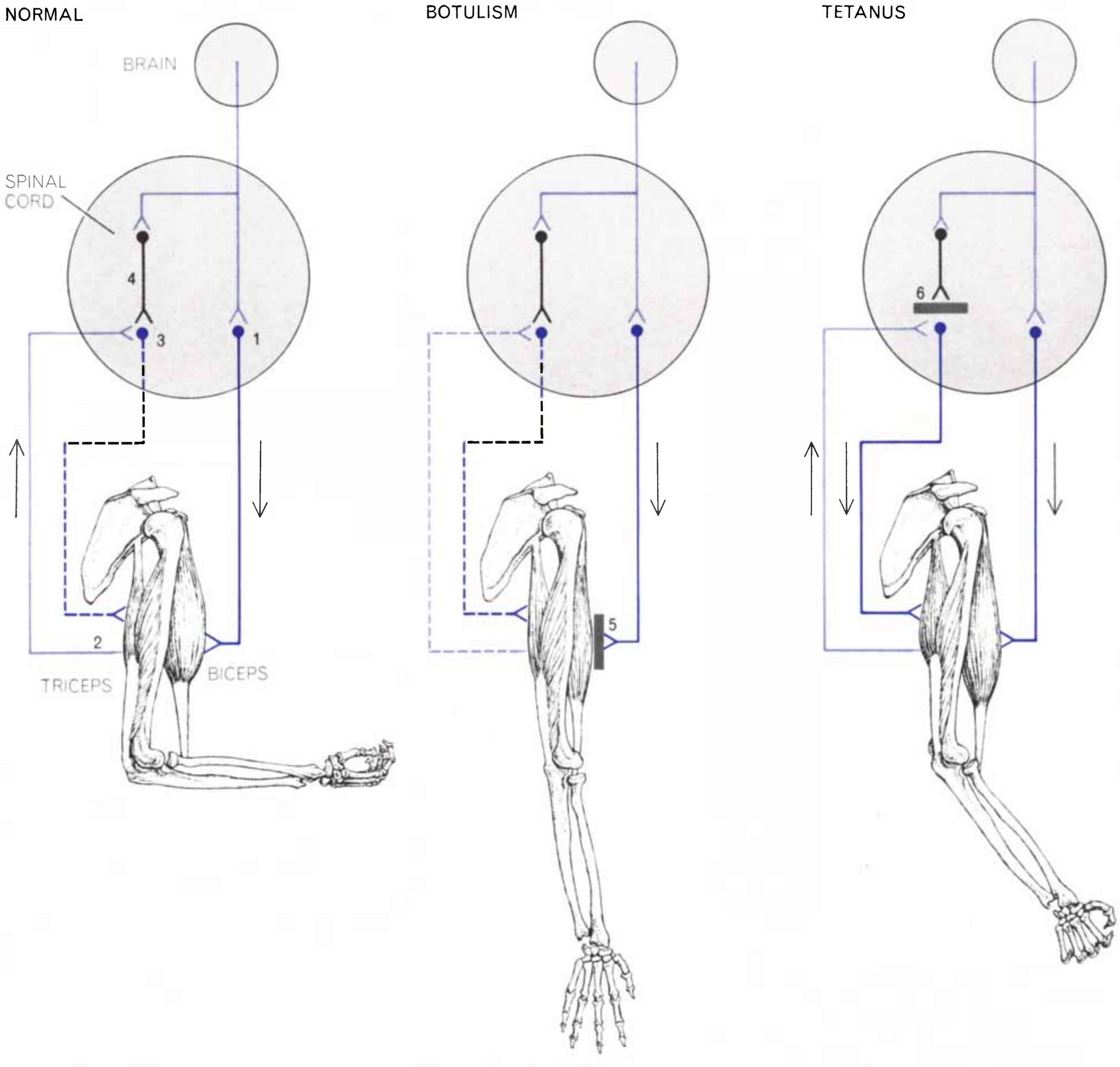
This was apparent even in the early days of the germ theory of disease to Arthur Nicolaier of the University of Berlin. He observed that the organisms (which had not yet been identified) that presumably caused tetanus did not seem to be distributed through the body. He also noted that the symptoms of tetanus were similar to those caused by the potent poison strychnine, and in 1885 he suggested that the organism acted by producing a strychnine-like poison. In 1889 the Japanese bacteriologist Shibasaburo Kitasato, working with Emil von Behring in Robert Koch's laboratory in Berlin, isolated *Clostridium tetani*. The following year a Danish investigator, Knud Faber, confirmed Nicolaier's idea. He reproduced tetanus symptoms in experimental animals by injecting them with filtrates of *C. tetani* cultures from which all the bacilli had been removed. He thus proved that a poison was produced by the germs and was capable of acting independently of them. The first such bacterial toxin, the one produced by the diphtheria bacillus, had been discovered the year before at the Institut Pasteur in Paris by Émile Roux and Alexandre Yersin. In 1896 Émile van Ermengem of the University of Ghent discovered the toxin responsible for the bacterial food poisoning known as botulism. Germ-free filtrates of tetanus bacilli and botulinus bacilli (*Clostridium botulinum*) are extremely toxic: a cubic centimeter may contain enough poison to kill more than a million mice.

When some of these bacterial toxins were isolated and purified during the past 25 years, they turned out to be far more toxic than such poisons as strychnine and arsenic or the snake venoms [*see illustration on page* 77]. An amount of tetanus, botulinus or dysentery toxin weighing no more than the ink in the period at the end of this sentence would be enough to kill 30 grown men; an ounce could kill 30 million tons of living matter; half a pound would be more than enough to destroy the entire human population of the world. (These calculations are theoretical and somewhat theatrical, since they are based on determinations of the smallest injection that will kill a mouse, and the projection to mass killing of men involves some unrealistic assumptions. Botulinus toxin, for example, has been considered seriously as an agent of warfare, but for a number of reasons—including the fact that such toxins are about a million times less toxic when administered by mouth or through the lungs rather than by injection—its military applications would seem to be limited.)

Why the tetanus and botulinus bacilli should produce these immensely potent toxins is a problem of great philosophical and practical interest. Diphtheria toxin and most other bacterial toxins attack and break down the tissues of the animal infected by the parent organism. In doing so they assist the bacteria in their invasion, because the bacteria grow well in disintegrating tissues. The tetanus and botulinus toxins, however, do not attack animal tissues generally. It does not appear to be of any survival value to the tetanus and botulinus bacilli to produce toxins that not only confine their action to nerve tissue but also, as far as can be seen, cause no damage even in this tissue. Yet on evolutionary grounds it is hardly conceivable that the bacilli should



EXCITATION AND INHIBITION of a motoneuron, a nerve cell controlling a voluntary muscle, are shown schematically. Excitatory (*color*) and inhibitory (*gray*) afferent fibers (*at left in each drawing*) form synapses at the surface of a cell body. Impulses from the excitatory fiber (*a*) release a chemical transmitter that causes the motoneuron to fire efferent impulses along its axon (*right side of drawing*). Impulses from the inhibitory fiber release a different transmitter (*b*) that opposes excitation, so that no impulse is fired.



NERVOUS CONTROL of muscles that raise and lower the forearm is diagrammed very schematically. In a normal individual (*left*) impulses from the brain can excite a motoneuron (*1*) to cause the biceps to contract, stretching the triceps. A stretch-sensitive receptor (*2*) in the triceps would thereupon cause a triceps motoneuron (*3*) to fire and oppose the stretching—except that this firing is inhibited by impulses from an inhibitory nerve (*4*). In botulism (*center*) the neuromuscular junction is blocked (*5*), causing flaccid paralysis. In tetanus (*right*) the inhibitory impulses to the triceps motoneuron are blocked (*6*); both muscles contract, causing a spasm.

produce the toxins unless they have some survival value. If we could find out why these toxins are produced, we not only would learn something important about bacterial physiology but also might find clues to the mechanism of the extraordinary action of the toxins on animals.

It is interesting to compare the action of botulinus and tetanus toxins, since they are produced by closely related organisms and since both act on the nervous system and are highly toxic without doing any apparent structural damage. Botulinus toxin prevents muscle activity and thereby causes a flaccid paralysis; tetanus toxin promotes muscle overactivity and thereby causes a spastic paralysis.

Let us consider (in a necessarily oversimplified way) the functions of the voluntary nervous system in raising the forearm. Nerve impulses travel from the brain (or from different sensory regions, such as those in the skin) down a bundle of "afferent" axons, or nerve fibers, to the spinal cord. There the fibers split up and make synapses, or junctions, with motoneurons, the cell bodies of motor-nerve fibers leaving the spinal cord. Each of these "efferent" axons connects with fibers of the biceps muscle of the upper arm. The synapses in the spinal cord are part of the central nervous system; the neuromuscular junctions at the biceps are part of the peripheral nervous system. At each central synapse and at each peripheral junction there is a gap about 200 angstrom units (.00002 millimeter) wide. When an impulse from the brain reaches a central synapse, it causes a chemical substance to be released from the ending, flow across the gap and excite the motoneuron, initiating a new impulse that travels along the efferent fiber to the peripheral neuromuscular junction. There a different chemical transmitter is released from the nerve ending and flows across the gap to the muscle, exciting it and causing it to contract. The excitatory transmitter at the neuromuscular junction is acetylcholine. The transmitters in the central nervous system have not yet been identified.

Now, in the resting state muscle tone is maintained by the constant gentle tension of opposing muscles. For example, the forearm is levered about a fulcrum, the elbow joint, essentially by two sets of muscles: on one side the biceps, whose contraction raises the forearm, and on the other side the triceps, whose contraction pulls the forearm down. When the biceps contracts slightly, the triceps is stretched a little. Stretch-sensitive receptors in the triceps are thereby excited and send impulses up afferent fibers to the spinal cord, where they excite motoneurons that stimulate the triceps in turn to contract and oppose the stretch. The stretch reflex plays a necessary role in maintaining posture and controlling muscle movement, but if every contraction of the biceps were opposed too much by the triceps, there could be no voluntary movement at all because the forearm would be locked in a spastic state. Therefore the afferent impulse that causes the biceps to be excited must at the same time ensure that the triceps will be somewhat relaxed; that is, it must inhibit any stretch-reflex excitation of the triceps. This inhibition is achieved within the spinal cord by the branching of the nerve fiber carrying the impulse from the brain. One branch excites the biceps; the other branch excites a short "interneuron," a nerve cell within the spinal cord that releases not an excitatory but an inhibitory transmitter from its ending. The inhibitory transmitter acts on the triceps motoneuron, opposing the action of the excitatory transmitter released there from the stretch-sensitive afferent nerve. As a result the motoneuron is not excited, the triceps does not contract and the biceps is free to pull the forearm up [*see bottom illustration on opposite page*].

Botulinus toxin acts at the neuromuscular junctions, as A. S. V. Burgen and his collaborators at Middlesex Hospital in London showed in 1949. It prevents the release of acetylcholine, the excitatory transmitter, from the efferent nerve endings; excitatory impulses are blocked before they can reach the muscles, and the result is a state of flaccid, limp paralysis in which no limbs can be moved.

Tetanus, on the other hand, acts in the spinal cord, apparently by suppressing inhibition. (Strychnine seems to act in the same way, it was suggested by Sir John Eccles and his collaborators in Australia in 1957.) In the absence of inhibition the stretch reflex of the triceps goes unopposed, so that when the biceps contracts, the triceps contracts too. The forearm is locked in a state of spastic paralysis, unable to move in any direction.

Some years ago N. Ambache found, at the Institute of Ophthalmology in London, that an injection of either tetanus or botulinus toxin in the eye of a rabbit paralyzes the muscles that contract the pupil in response to light. It is acetylcholine that excites these involuntary muscles, and so at least in this case tetanus exhibits the same kind of action as botulinus. Tetanus toxin may have other such peripheral effects that are usually masked by its dramatic impact on the central nervous system.

Although the neurophysiology of tetanus toxin's action is reasonably clear, not much is known of what goes on at the molecular level. The first clue to a chemical process that may play an important role came from an observation made in 1898 by August von Wasserman and T. Takaki of the Koch Institute for Infectious Diseases. They found that when the toxin is added to nerve tissue, it is bound, or taken up, by the tissue. This binding is specific: no other bacterial toxin (including botulinus toxin) is bound by nerve tissue and no other tissue of the body binds tetanus toxin. In my laboratory at the University of Oxford we have discovered that the site of this binding is apparently in the synaptic membranes of the nerve endings and that the substance apparently responsible for the chemical fixation of toxin is a ganglioside, a fatty substance found mainly in nerve tissue. There are a number of gangliosides, each somewhat different in chemical structure. They are alike in that each has two portions, one composed of water-repellent fatty acids and sphingosine and the other composed of water-soluble sugars. As a result they are readily water-soluble even though they are fatty, and this ambivalence suggests that they may have an important function in cell membranes. We have found that sialic acid, one of the components of the sugar portion, is essential for the fixation of the tetanus toxin; if the sialic acid is removed, the toxin is no longer bound. It is apparent, however, that only certain sialic acid groups are involved in the fixation of toxin and that their position in the ganglioside molecule greatly affects their binding ability [*see illustration on page 76*].

Tetanus toxin may be bound to ganglioside in a ratio that is nearly molecule for molecule, but no detectable change takes place in the ganglioside molecule. The part the binding plays in tetanus is not yet established; it may not be an essential stage in the action of the toxin. As I have mentioned, there are hints that tetanus and botulinus toxins may have fundamentally the same mode of action at the molecular level. If that is the case, then (in view of the fact that botulinus toxin is not bound by nerve tissue) it is possible that what the binding of tetanus toxin by ganglioside does is simply to divert this toxin to the central nervous system.

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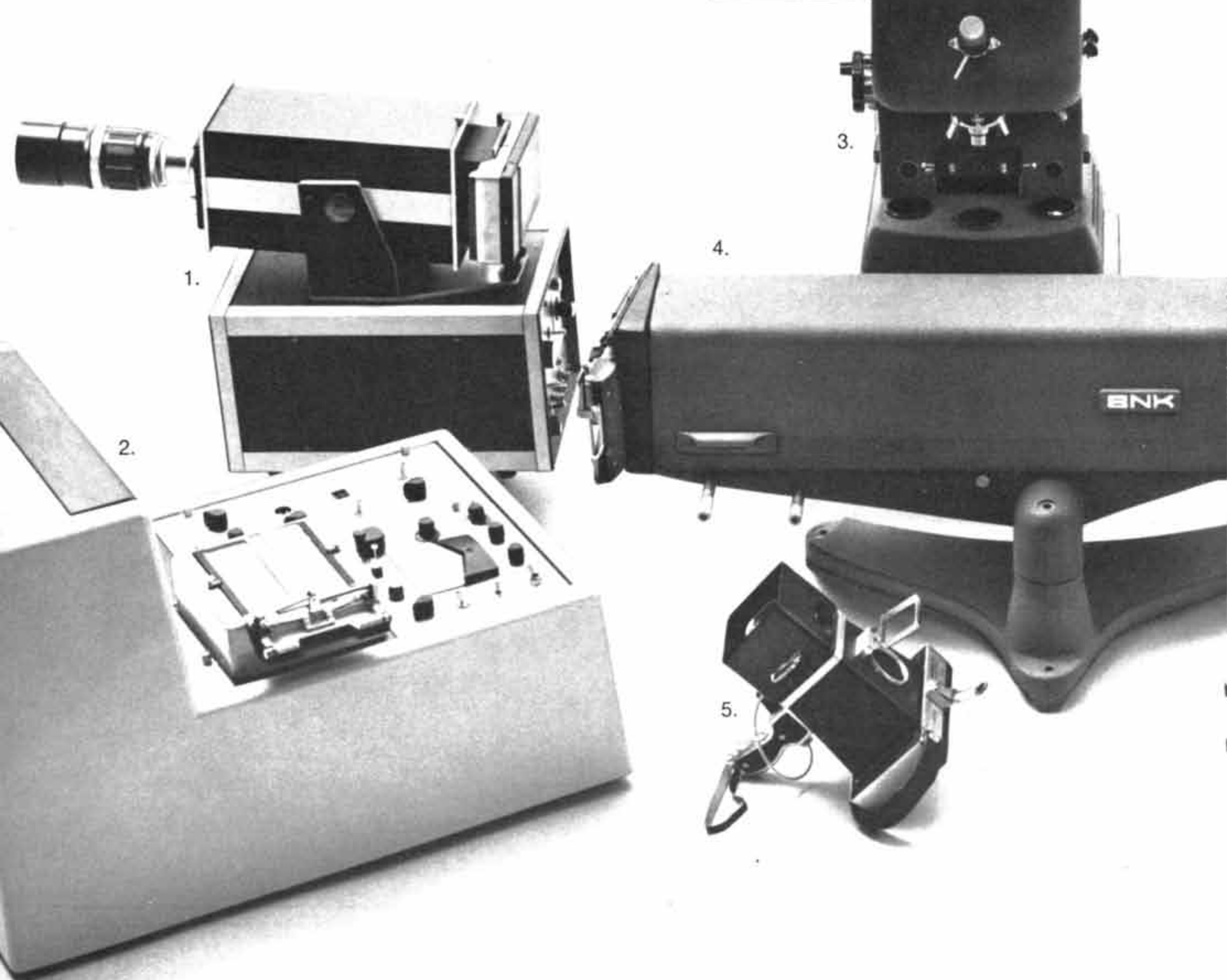

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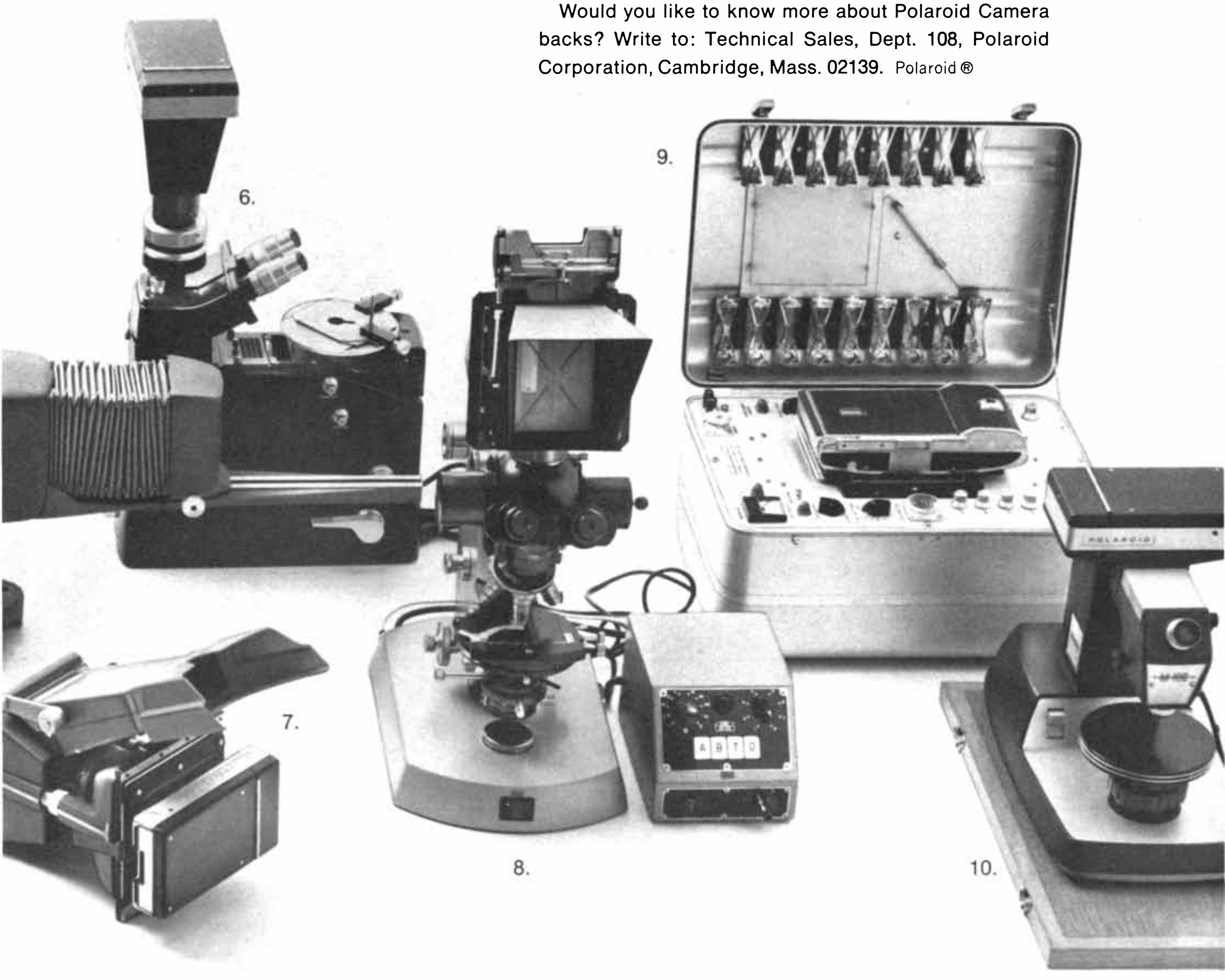
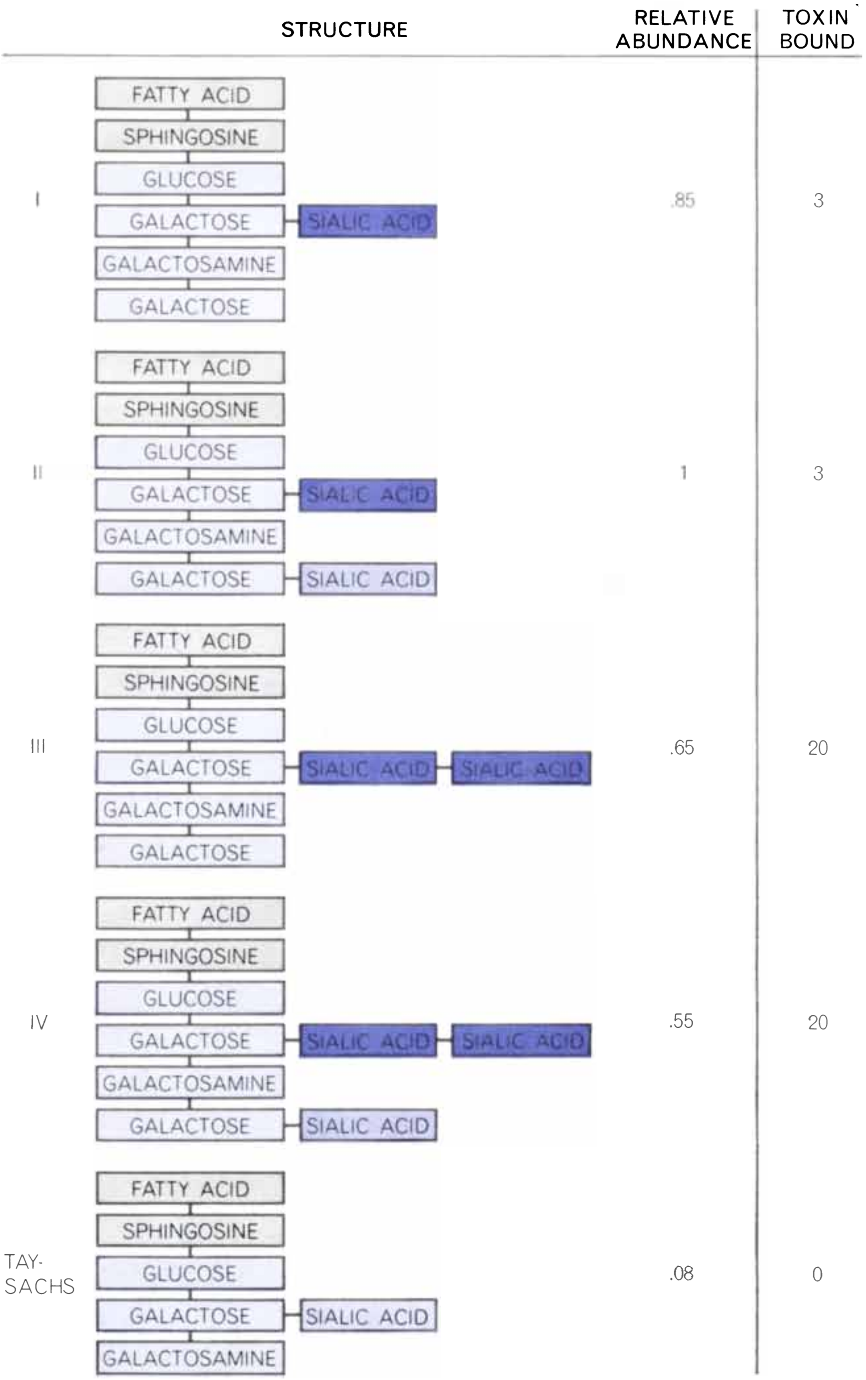


it is quite clear that the toxin is responsible for all the symptoms of tetanus. These symptoms can be mimicked exactly in experimental animals by the injection of purified toxin (and indeed in humans into whose bodies the toxin has been inadvertently introduced in laboratory accidents). Since the disease is entirely due to the toxin, it is technically rather a simple matter to prevent the disease by immunizing against the toxin. Like other bacterial toxins (and the active principles of snake venoms), tetanus toxin is a protein, and proteins are antigenic: when they are injected, they stimulate the formation of antibodies (antitoxins) that neutralize the toxins and prevent them from acting. The discovery of antitoxins to both diphtheria and tetanus toxins was announced by von Behring and Kitasato in 1890. The antitoxin was present in the blood serum of animals that had been immunized by sublethal doses of attenuated toxin, and its neutralizing activity persisted when the immune serum was transferred into other animals. That is to say, unexposed animals could be made "passively" immune by being injected with the serum of "actively" immune animals.

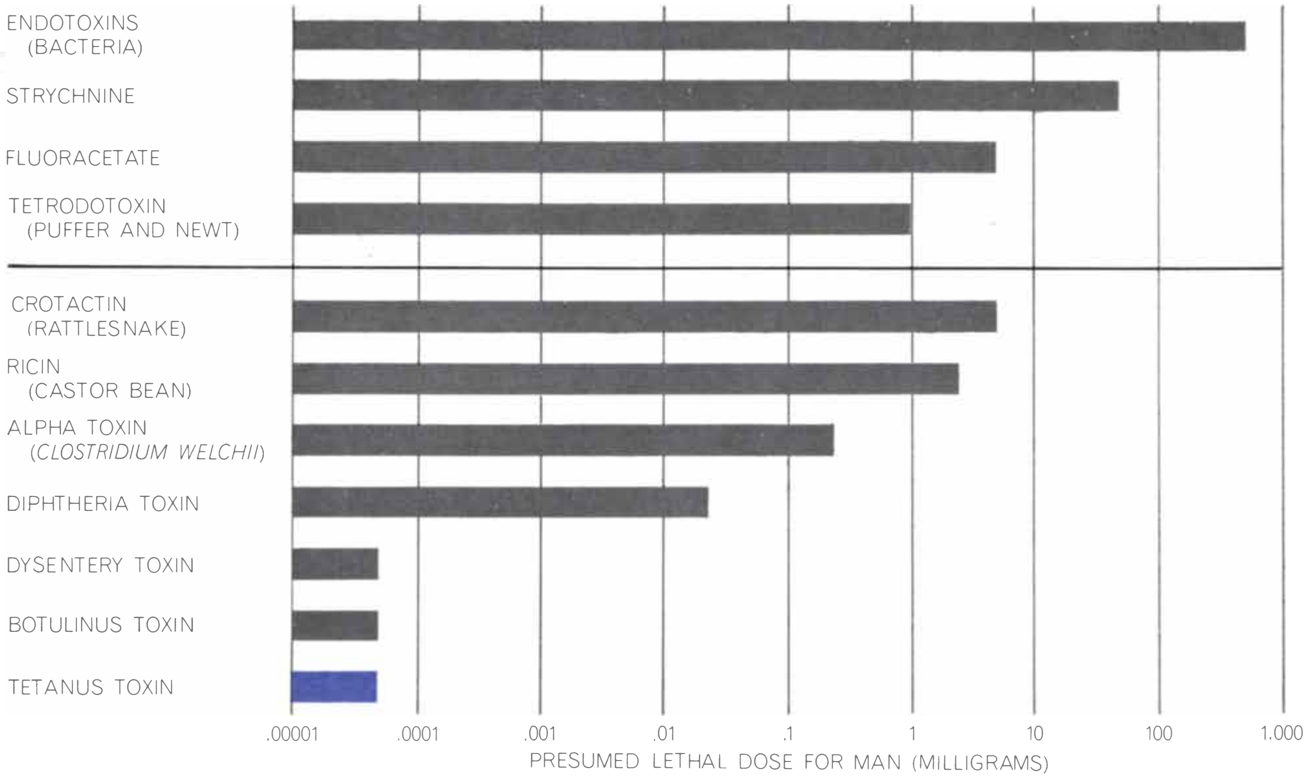
In 1920 W. T. Glenny of the Wellcome Laboratories in London and G. Ramon of the Institut Pasteur in Paris independently discovered that toxin rendered harmless by treatment with formaldehyde could still remain antigenic, or capable of stimulating antibody formation. This nontoxic antigenic material is called toxoid. Antitoxic serum is made on a large scale by hyperimmunizing horses with repeated large doses of toxoid and then refining their blood serum.



GANGLIOSIDES are the substances in nerve tissue that bind tetanus toxin. Here general structures are given for the four gangliosides most abundant in nerve tissue and for one that is increased in Tay-Sachs disease. Each has fatty (*gray*) and sugar (*color*) components. The sialic acid groups are specifically responsible for binding toxin. As shown by the number of grams of toxin bound per gram of ganglioside (*right*), only certain sialic acid groups (*dark color*) take part in this process; the others have no effect on the binding.

Tetanus antitoxin proved its worth in World War I. During the first months of the war nearly eight British soldiers out of every 1,000 who were wounded died of tetanus—an alarmingly high proportion. By the end of 1914 there was an ample supply of antitoxin for immediate injection of all wounded troops at the front and the death rate from tetanus dropped sharply. In the years between the wars it became the practice, wherever possible in the world, to inject all injured patients routinely with antitoxic serum to prevent the development of tetanus. Antiserum has a serious disadvantage, however; it may give rise to serum sickness, an allergic reaction to the foreign (horse) protein in the serum. The risk of fatal serum sickness is much greater in people who have a history of previous injections of serum, whether against tetanus or some other disease. Indeed, it is now recognized that if reasonable sanitary precautions are taken, the risk of tetanus is less than the risk of fatal serum sickness. Moreover, although passive immunization has some value in preventing tetanus, it has become evident that its therapeutic effect once the disease is established is less than was hoped for. Once the toxin has become attached to the susceptible substance in nerve tissue, antitoxin cannot displace or neutralize it. For these two reasons the administration of tetanus antiserum has now been discontinued in many countries.

Direct, active immunization of human populations with tetanus toxoid is a



TOXICITY of the bacterial toxins, including tetanus, is compared with that of other poisons. Crotactin and ricin, like the bacterial exotoxins, are simple proteins. The scale is logarithmic. The dosage figures are theoretical; they assume that the toxin is injected.

much better proposition as a preventive measure. The risk of allergic reaction to the toxoid is negligible. The immunity lasts much longer, since the antibody produced is the subject's own protein, not the protein of a horse. And the immunity is more effective because the antitoxin is present in the body before the toxin produced by infecting bacilli is and can therefore prevent the binding of toxin by nerve tissue.

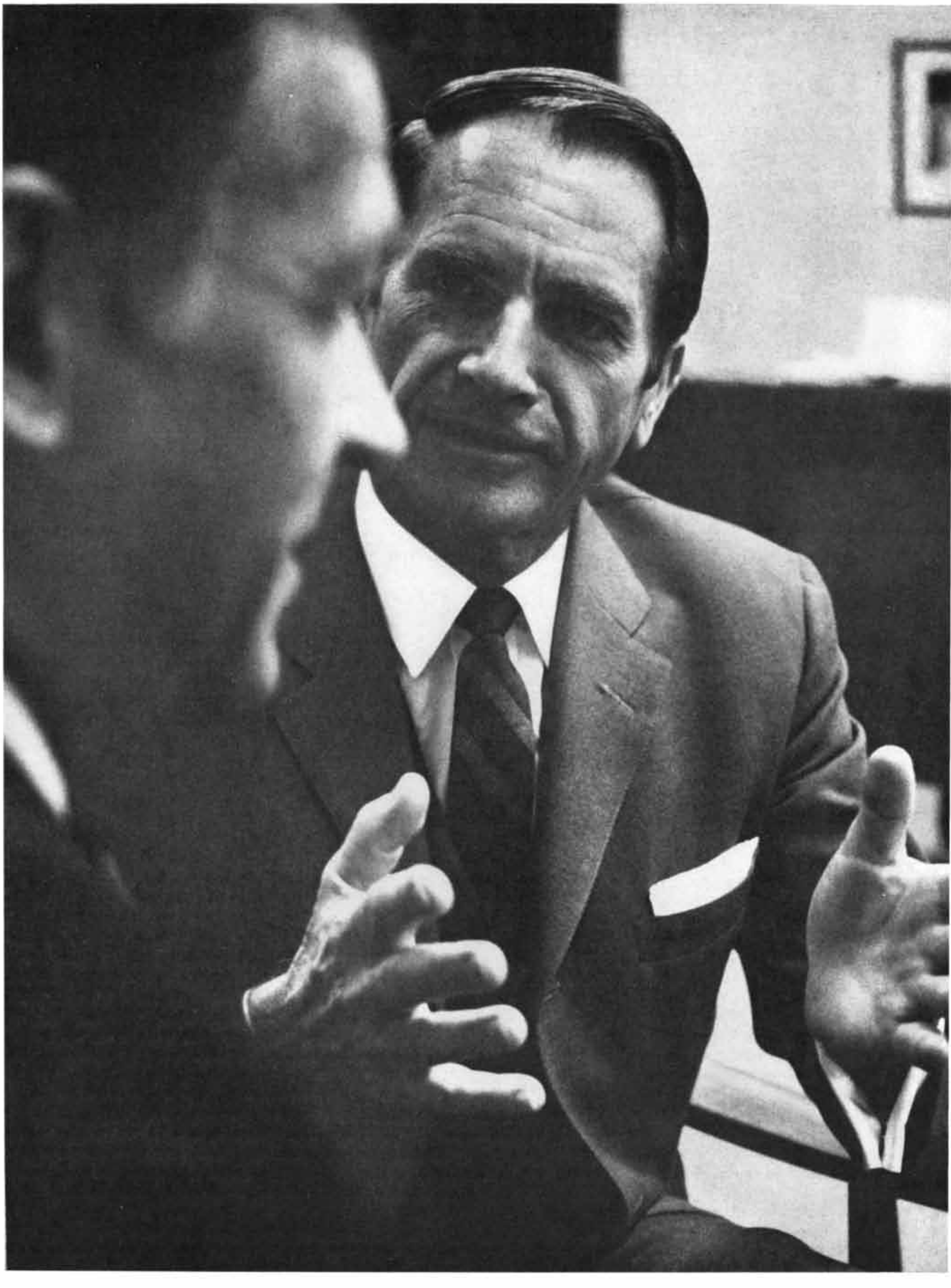
Deaths from tetanus are now rare in the many countries where active immunization of all children and members of the armed forces against tetanus is routinely practiced. The virtual elimination of tetanus in these countries is one of the great triumphs of combined laboratory research and public health services.

To prevent tetanus in communities (and even whole countries) all that is needed is for every member of the community (or the country's population) to receive two injections of tetanus toxoid spaced six weeks apart. A booster dose after six months and an occasional booster thereafter are considered desirable but are probably not essential. Even the unborn can be protected: J. C. Suri, R. MacLennan and K. W. Newell have demonstrated in India, New Guinea and South America respectively that the active immunization of women (whether they are pregnant or not) virtually eliminates umbilical tetanus in children they bear subsequently. In primitive communities, of course, it is often difficult to make sure that an individual receives two injections some weeks apart. For this reason R. Veronesi in Brazil and C. Merceux in France have been investigating the possibility of active immunization by means of a simultaneous multiple injection of concentrated toxoid over a small area on one occasion. Their preliminary tests indicate that active immunity can be achieved in this way even though antitoxin may not be detectable in the blood.

In contrast to prevention, the treatment of tetanus once contracted is a difficult and expensive procedure. Since 1954 it has been the practice in severe cases to treat the patient with D-tubocurarine, a poison that paralyzes the muscles much as botulinus toxin does. This drastic treatment paralyzes the patient so that even his breathing must be assisted by a respirator, but it does prevent the terrible spasms of tetanus. If the patient can be kept alive long enough, the damage caused by the tetanus toxin is eventually repaired and he is completely restored to health.

Unfortunately this heroic form of treatment has not been as successful as expected. It does prevent death from the asphyxia that follows the inhalation of vomit during a major spasm or from the chest complications and oxygen depletion that follow recurrent minor inhalations during lesser spasms. Yet the death rate from tetanus remains high, and indeed the prevention of death from spasm appears to have uncovered other sites of action of tetanus toxin that were not known before. There are signs that the toxin may act on the involuntary nervous system, which controls the heart and blood vessels, among other organs. In Alexander Crampton Smith's hospital wards and laboratories at Oxford, evidence is beginning to accumulate that patients with tetanus may die from heart and circulatory abnormalities that are reflected in such symptoms as increased heart rate and blood pressure and constriction of the blood vessels. The possibility that the involuntary system is implicated in death from tetanus suggests new ways to treat tetanus patients, but more research in this area is needed.

Meanwhile it is far simpler to make sure that everybody is actively immune to the disease. At an international conference on tetanus in Switzerland in 1966 the delegates called on organized medical groups and public health authorities to bring about "universal active immunization against tetanus at the earliest practicable date."



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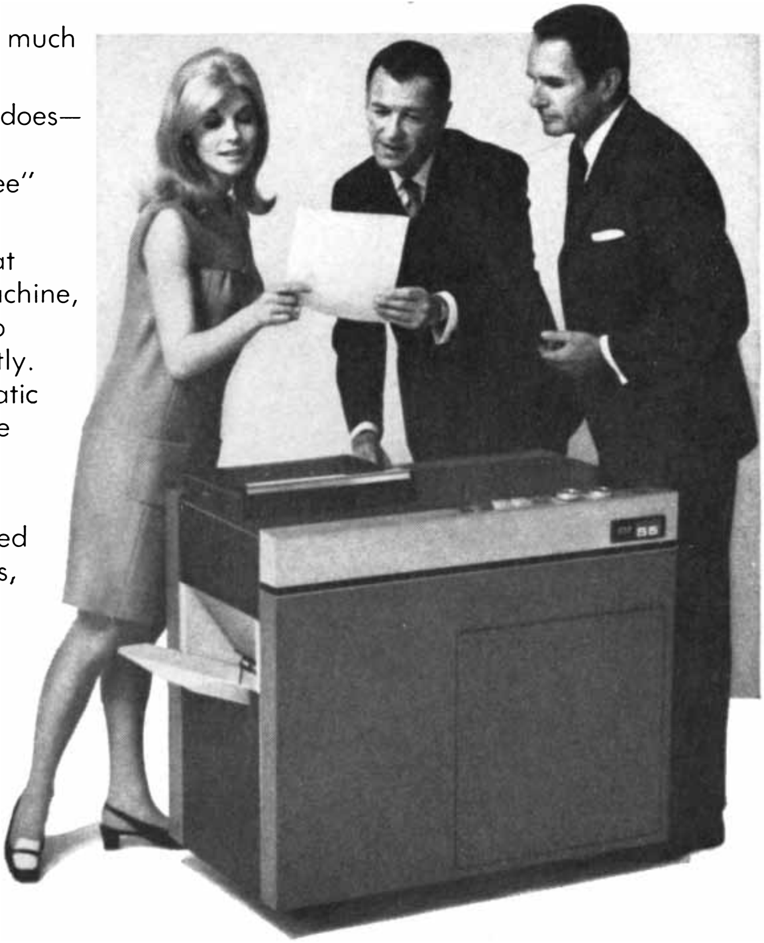

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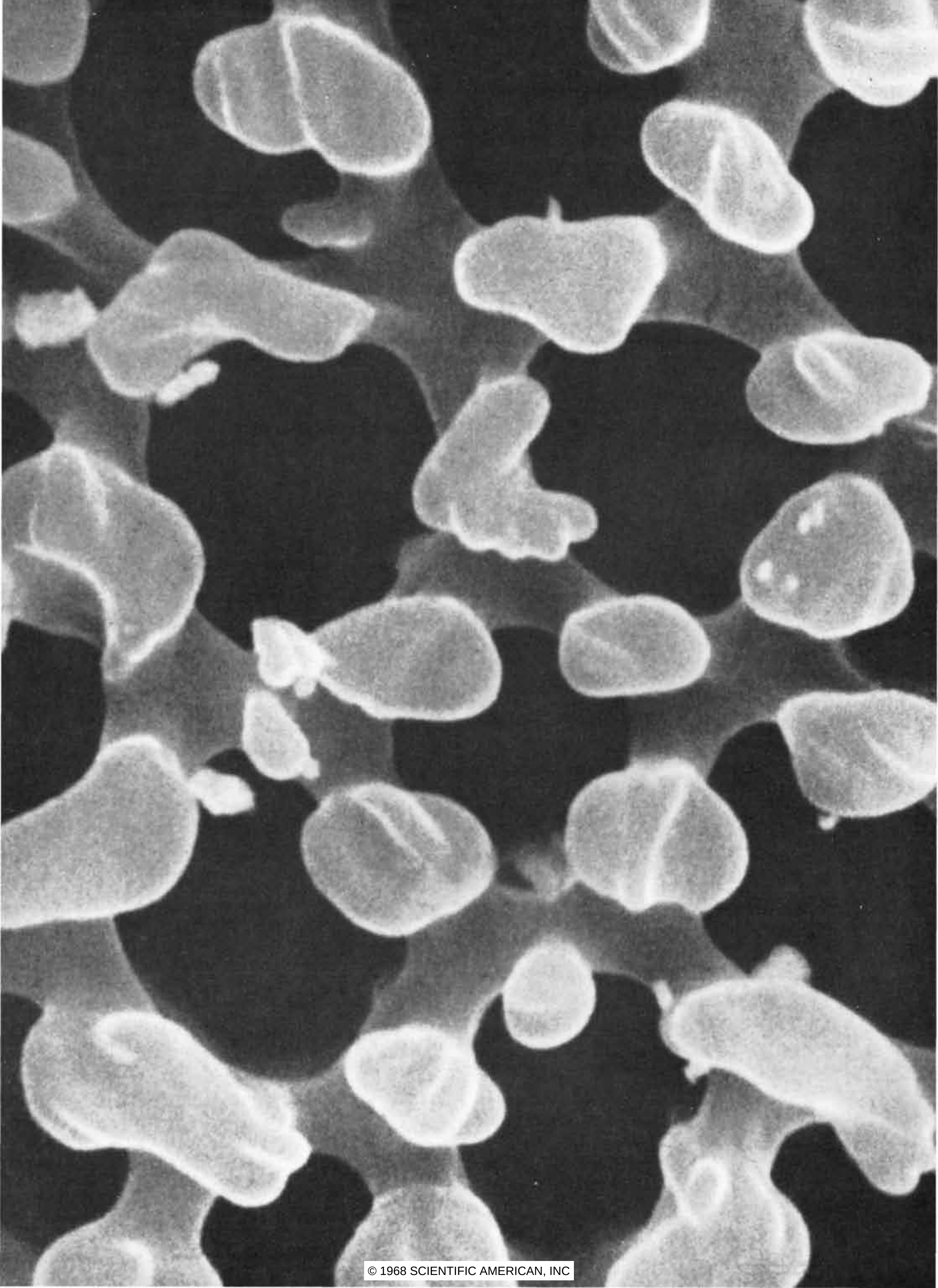


POLLEN

The tiny grains that carry the male genetic material of plants are closely studied with, among other instruments, the scanning electron microscope. Their baroque architecture raises fundamental questions

by Patrick Echlin

Pollen grains, the dustlike cells that transfer the male genetic material in the reproduction of flowering plants, are among the shortest-lived independent bodies in nature, and yet a major component of pollen grains is one of the most enduring natural materials. Few pollen grains remain alive for more than a few days after they have been dispersed; some live only a few hours. With the exception of the pollen of aquatic plants such as *Zostera* (eelgrass), however, all pollen grains are covered with an extremely tough substance called sporopollenin. The sporopollenin outer wall of a pollen grain remains intact in concentrated acids and alkalis at temperatures as high as 500 degrees Fahrenheit. Samples taken from the depths of ancient bogs contain grains of pollen that are clearly recognizable in spite of having been buried for hundreds of thousands of years. (Fossilized pollen grains have been isolated from Cretaceous deposits some 100 million years old.) The durability of pollen, together with the fact that the pollen grains of each plant genus (and even some species) have their own distinctive form, have made pollen analysis an important tool for investigating the vegetation and the climate of the past.

In the Botany School at the University of Cambridge we have been studying the form of pollen grains for a number of years. We have been concerned not only with the differences among grains but also with changes in the grains as they grow to maturity. With the recent development of the reflection scanning electron microscope we have been able to examine pollen grains in unprecedented detail. This kind of microscope differs from the conventional transmission electron microscope in that the electron beam, instead of passing through an ultrathin specimen, scans the surface of an opaque specimen. The scattered electrons, together with secondary electrons emitted by the specimen itself, are then amplified and form an image of the surface in strong relief on the face of a cathode-ray tube [*see illustration on page 84*]. Although the resolution of the scanning microscope is not as high as that of the transmission microscope, its usable depth of focus is much greater and its specimens are simpler to prepare. It is therefore possible to examine a large number of specimens in a relatively short time. Such an instrument is of immense value in the study of specimens as complex as the surfaces of pollen grains.

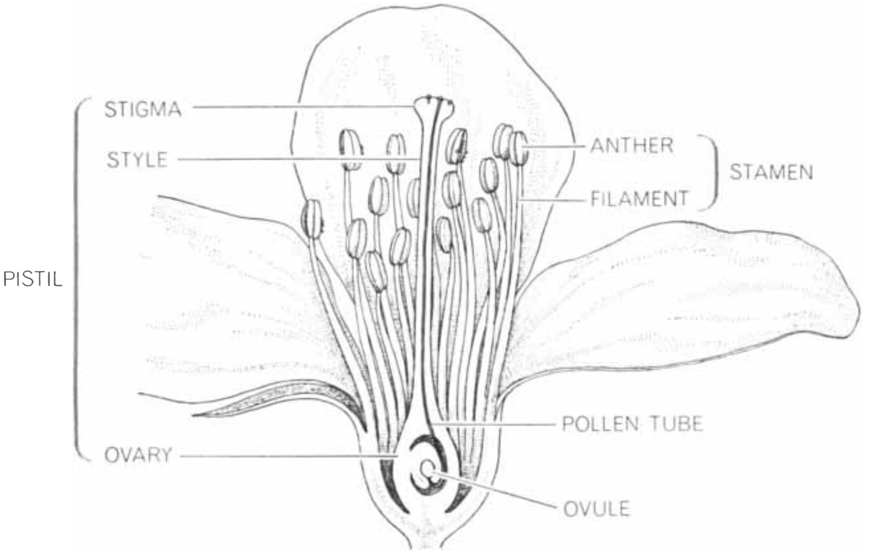
SURFACE OF POLLEN from the geranium is enlarged 11,000 times in a micrograph made with the scanning electron microscope (*opposite page*). The instrument produces a contoured image which shows that the surface of the grain is made up of tiny rods that project upward from an openwork floor.

Before describing what we have learned about the maturation of pollen grains it will be useful to review the role of pollen in plant reproduction and to describe the morphology of the mature pollen grain. Let us begin with the stamen, the male organ of the flower where the pollen is formed [*see top illustration on next page*]. The stamen usually consists of a short stalk or filament, and at its tip is the structure known as the anther. The anther consists of four elongated sacs within which the pollen grows. At maturity the anther bursts open along a predetermined line of cells that are weaker than their neighbors, thereby releasing the pollen.

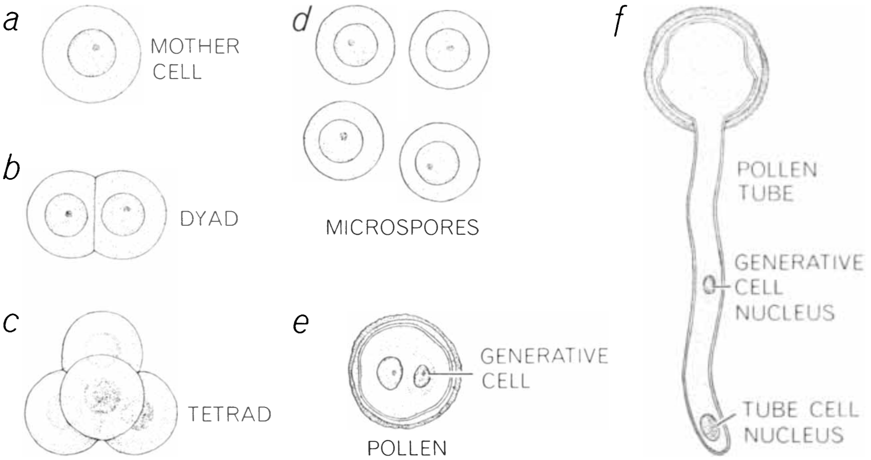
The pollen eventually travels to the female organ of the same flower or of another flower of the same species, a journey that can be accomplished in a variety of ways. The female organ, the pistil, consists of an ovary at the base of a stalk called the style and, at the top of the style, the sticky structure known as the stigma. If the pollination has been successful, the grain adheres to the stigma and fertilization begins. The pollen grain puts forth an extension, the pollen tube, which by the secretion of special enzymes is able to penetrate the surface of the stigma. Then the pollen tube grows downward between the cells of the style until it reaches the ovary, providing a path along which the pollen grain's two nuclei travel. One nucleus fuses with the egg nucleus in the ovule to form the embryo; the other fuses with two "polar" nuclei to give rise to the nutritive endosperm tissue.

Fertilization is only one of two independent functions served by pollen. The other is setting in motion the physiological processes that form the plant's fruit. The chemical constituents of pollen, although they are mainly protein and fat, also include vitamins, free amino acids, pigments and small amounts of two growth hormones: indoleacetic acid and gibberellin. The last two substances induce the production of hormones in the plant's female organ, which in turn stimulate the growth of the ovary wall and the formation of the fruit. The fact that this function of pollen is separate from fertilization is indicated by experiments in which the formation of fruit was induced by dead pollen, pollen extracts and even pollen from other species. Such fruit, however, lacks male nuclei and is therefore sterile.

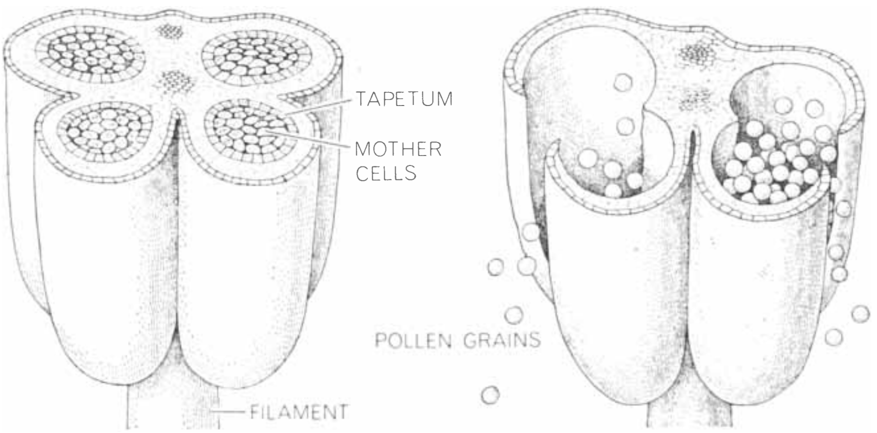
The amount of pollen produced by a single plant varies greatly among species, but even in the most pollen-poor



FLOWER CROSS SECTION shows a cluster of stamens, each with a pollen-filled anther at its tip, surrounding a central pistil with a sticky stigma at the tip and an ovary in the base. One pollen grain adhering to the stigma has grown a long tube (*color*) reaching the ovary.



GRAIN OF POLLEN, beginning as a single cell (*a*), undergoes meiosis (*b, c*) to become a cluster of four microspores called a tetrad. When mature, the tetrad separates into individual microspores (*d*), each of which has two cell nuclei (*e*). If a free pollen grain comes in contact with a stigma, the tube cell becomes involved with the growth of the pollen tube toward the ovary (*f*) and the generative cell then travels down the tube to fertilize the ovule.



ANTHER CROSS SECTIONS show the two kinds of tissue (*left*) that respectively give rise to mature grains of pollen and to the tapetum, or inner wall, of the anther cavity. When mature (*right*), the anther splits open and the loose pollen in its cavities is dispersed.

flowers many thousands of pollen grains are shed for each ovule that is eventually fertilized. In the hazel tree (*Corylus*), for example, the average is 2.5 million grains per fertilized ovule. A single shoot of the hemp plant (*Cannabis*) may produce more than 500 million grains. At the other extreme, even a large flax plant (*Linum*) may produce no more than 20,000 grains.

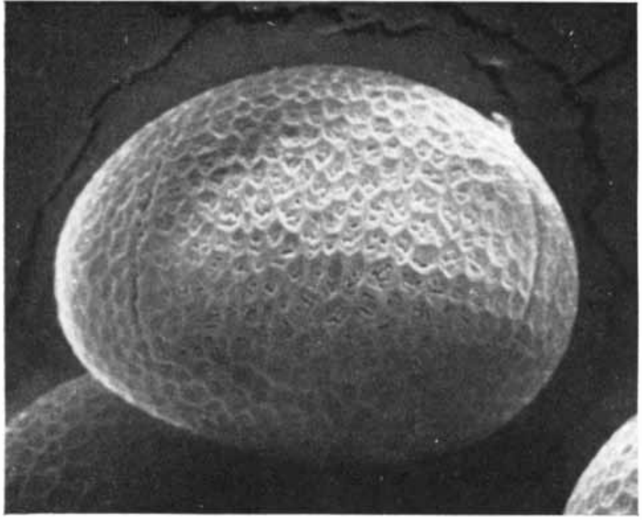
Forest trees, many of which are pollinated by the wind, manufacture large quantities of pollen, the number of grains per acre running into many billions. So much pollen is given off by evergreens that the discharge is sometimes visible as a cloud over the forest, and pollen can be scooped up by the handful from the surface of a forest lake. It has been estimated that the spruce forests of southern and central Sweden produce 75,000 tons of pollen a year.

Pollen grains display a wide range of sizes. Among the largest are the grains of the pumpkin (*Cucurbita*); they may be 250 microns (.25 millimeter) in diameter. At the other end of the scale are the grains of forget-me-not (*Myosotis*), only two to five microns in diameter. Once they are shed the pollen grains of most plants travel separately, but the grains of some species—orchids, for example—remain in clusters.

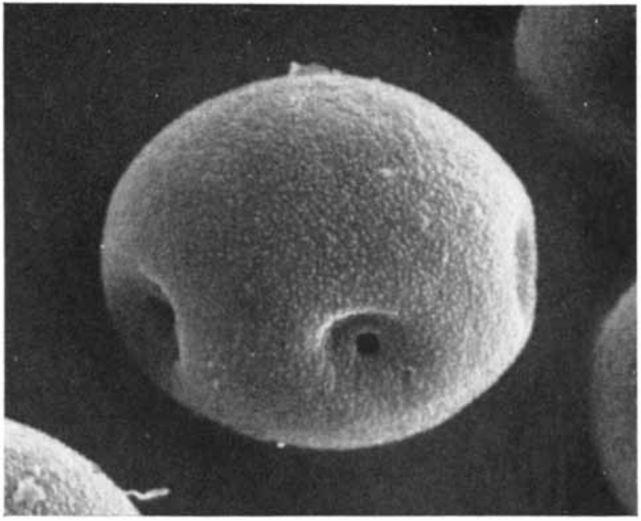
Speaking generally, the size of the pollen grain is related to the means of its dispersal. Grains between 20 and 60 microns in diameter are usually carried from one plant to another by the wind. Grains that are larger or smaller than that are usually transported by insects. Some plants do not depend on either wind or insects: the pollen from each flower's anthers simply falls onto its own stigma.

Plants that are pollinated by insects generally possess some mechanism for attracting the pollinators. One is odor, including not only odors that are pleasant to man but also many that are unpleasant. Another, often combined with odor, is conspicuous color, usually on the petals of the flower but occasionally on other parts of the plant. Visits by pollinators are also encouraged by edible pollen and by nectar. The pollen of insect-pollinated plants cannot easily be blown away by the wind, and it is often located within the flower in such a way that it can be easily reached only by the appropriate insect.

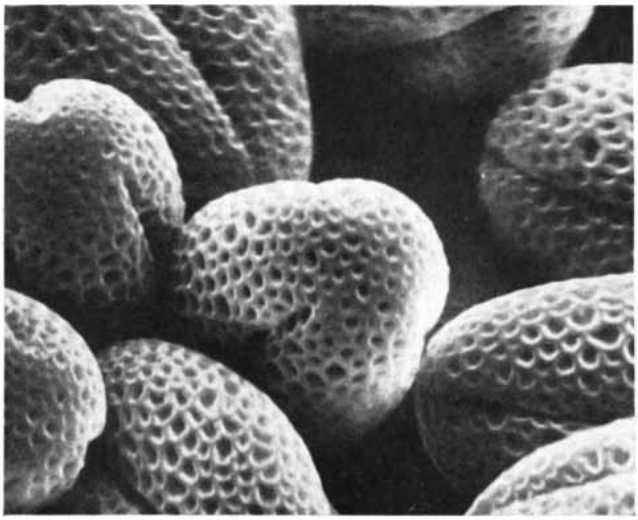
The flowers of wind-pollinated plants are characterized by simplicity of structure. They are not scented or showy, do not produce nectar and usually produce large amounts of powdery pollen. The



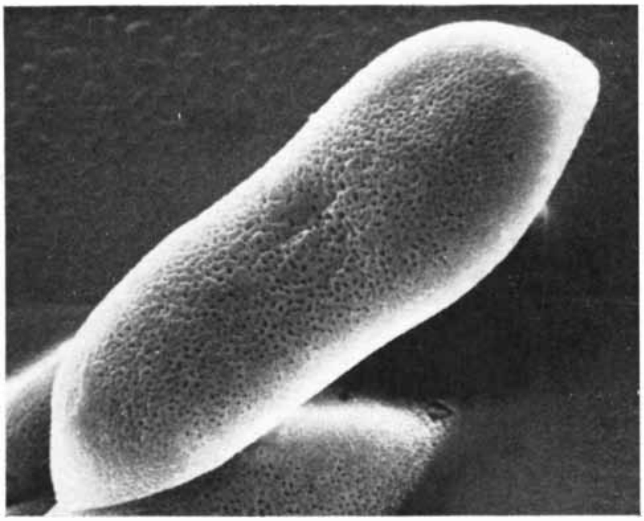
TOUCH-ME-NOT (*Impatiens grandiflora*) pollen is seen magnified 3,500 times. The furrow lines of the grain are faintly visible.



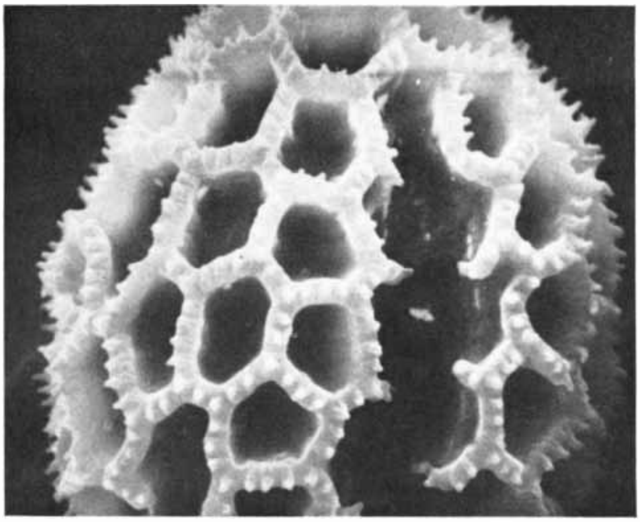
HORNBEAM (*Carpinus*) pollen grain is magnified 2,200 times. The characteristic deep-sunken pores have even deeper center openings.



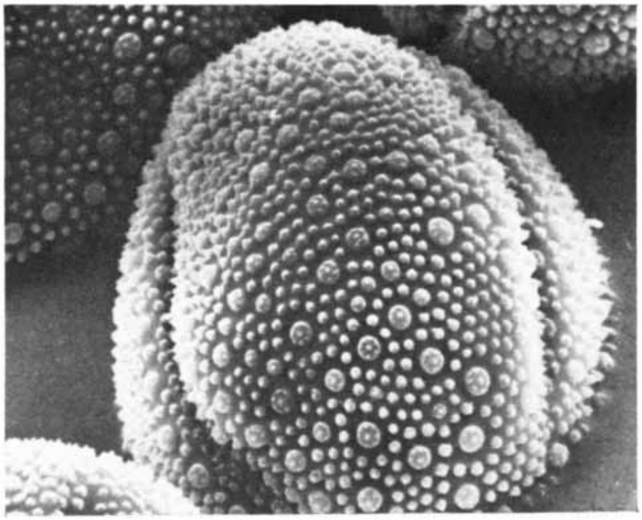
WALLFLOWER (*Cheiranthus*) pollen grains are magnified 2,300 times. They are marked by prominent furrows and many tiny pits.



BLUE-EYED GRASS (*Sisyrinchium bermudiana*) pollen is magnified 1,250 times. The furrow in the oblong grain lies out of sight.



THRIFT (*Armeria maritima*) pollen, magnified 1,400 times, shows a deeply sculptured surface and a furrow marked by broken ridges.

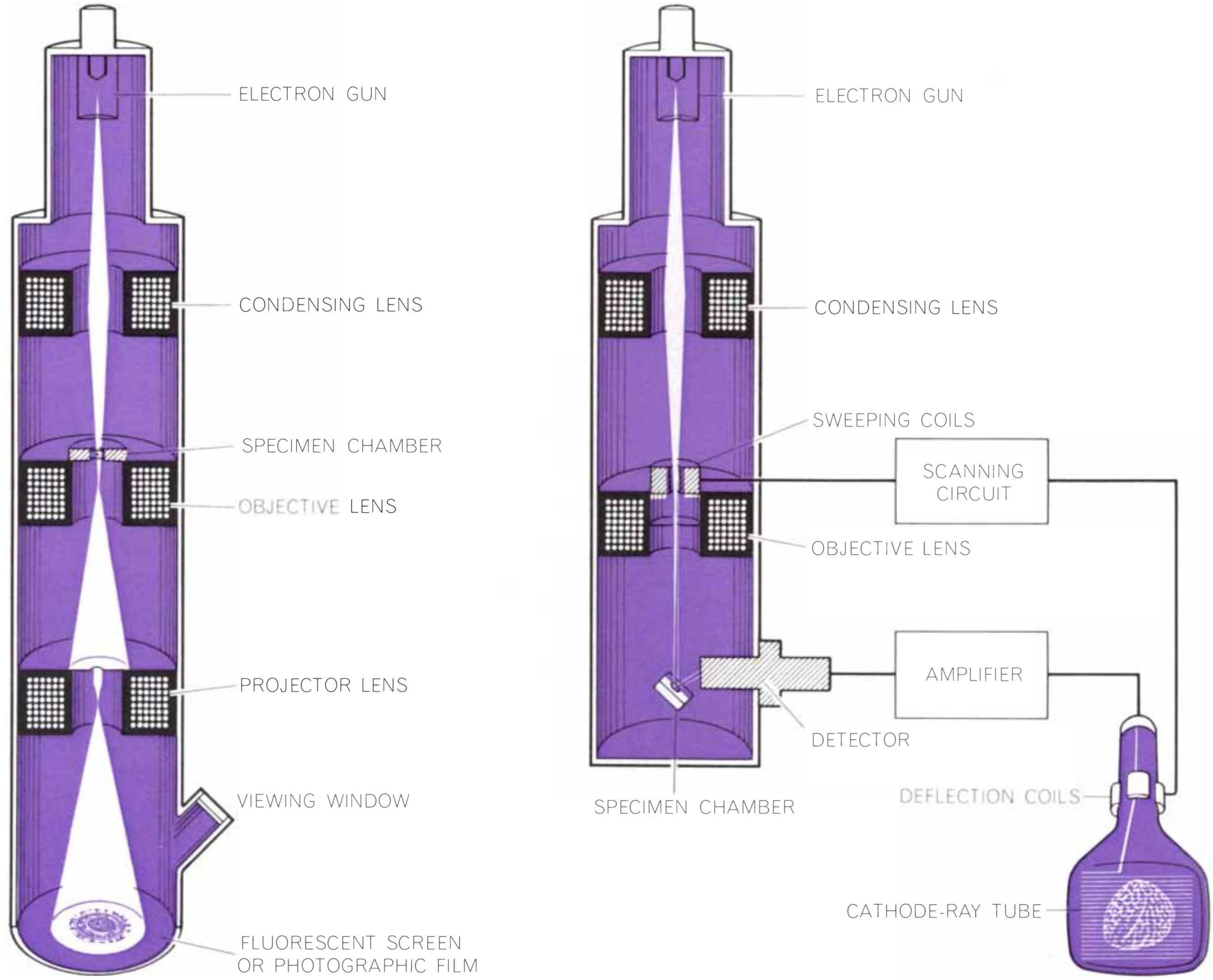


FLAX (*Linum austriacum*) pollen grain is magnified 1,250 times. It displays deep furrows and a surface dotted with small blunt spines.

flowers of many wind-pollinated trees open and release their pollen before the leaves appear, so that pollen transport is not obstructed by the dense mass of foliage that develops later. The wind can carry small grains of pollen a surprisingly long way. Air samples collected over the North Atlantic, more than 400 miles from the nearest land, contained pollen grains of the alder *Alnus viridis*. Peat deposits on the isolated South Atlantic islands of Tristan da Cunha contain pollen grains of the evergreen beech (*Nothofagus*) and the joint fir (*Ephedra*). It is unlikely that either of these plants ever grew on the islands, and the evergreen beech is not found in southern Africa, the closest land. It therefore seems likely that the evergreen beech pollen, and probably the pollen of both plants, was borne to Tristan da Cunha by the prevailing westerly winds from South America, nearly 2,500 miles away. This, of course, is an extreme case; pollen is usually not carried very far by the wind because it is collected and washed out of the air by rain.

Pollen grains are divided into two major classes on the basis of gross morphology. One class is characterized by a single germinal furrow, the other by three germinal furrows. The grains also have a wide range of other morphological characteristics, such as the form and location of the apertures in the grain wall known as pores and other features of wall structure. When pollen grains are arrayed in order of size, it becomes apparent that the walls of the smallest grains are comparatively featureless. The grains of middle size, mostly the windborne pollens, are also generally rounded and smooth. The larger pollen grains typical of insect-pollinated plants, however, are often elaborately sculptured. An example is the pollen grain of the mallow (*Malva*), the surface of which appears in the illustration at top right on page 86. The grain walls of the larger pollens are also sometimes coated with an oily adhesive substance.

How do these variations in surface morphology arise? Is there a point during the growth and maturation of the grain at which its characteristic form appears? What factors are primarily responsible: heredity, influences from the microenvironment or a mixture of both? In an effort to find answers to such questions we have examined the ultrastructure of pollen grains from a number of plants at various stages on the way to maturity. The description of pollen-grain growth that follows is based on our study of pollen from a species of hellebore (*Helleborus foetidus*). With



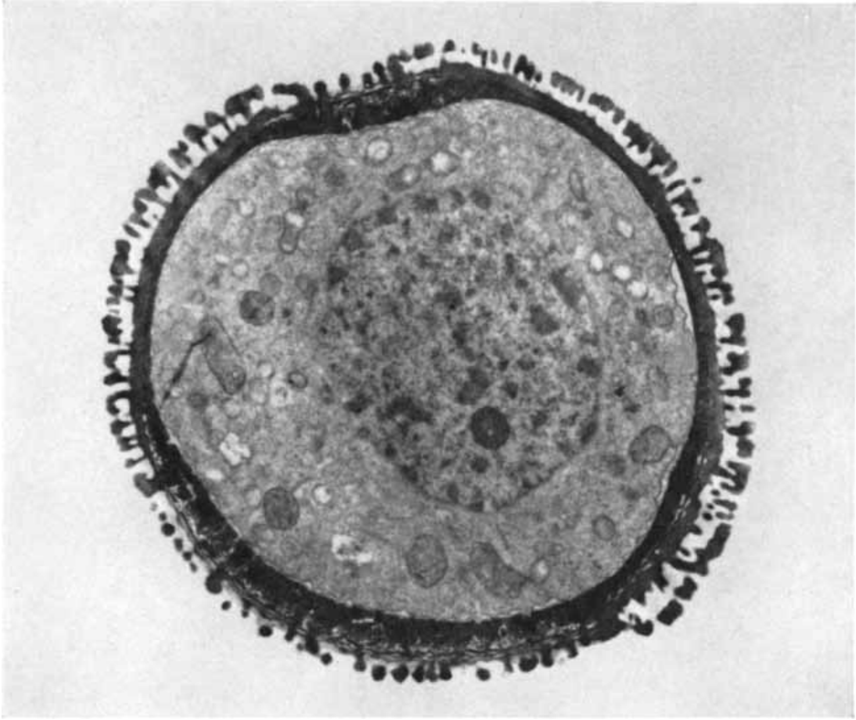
SCANNING MICROSCOPE (*right*) differs from the conventional transmission electron microscope (*left*) in its use of whole specimens rather than thin sections. In both instruments a beam of electrons is used to bombard the object being studied. In the scanning microscope some electrons that are scattered by impact with the specimen and others that are emitted by the specimen during bombardment are collected to form a cathode-tube image characterized by great depth of focus and a three-dimensional appearance.

certain minor differences, the process is the same as the one that has been observed in the pollen grains of other plants.

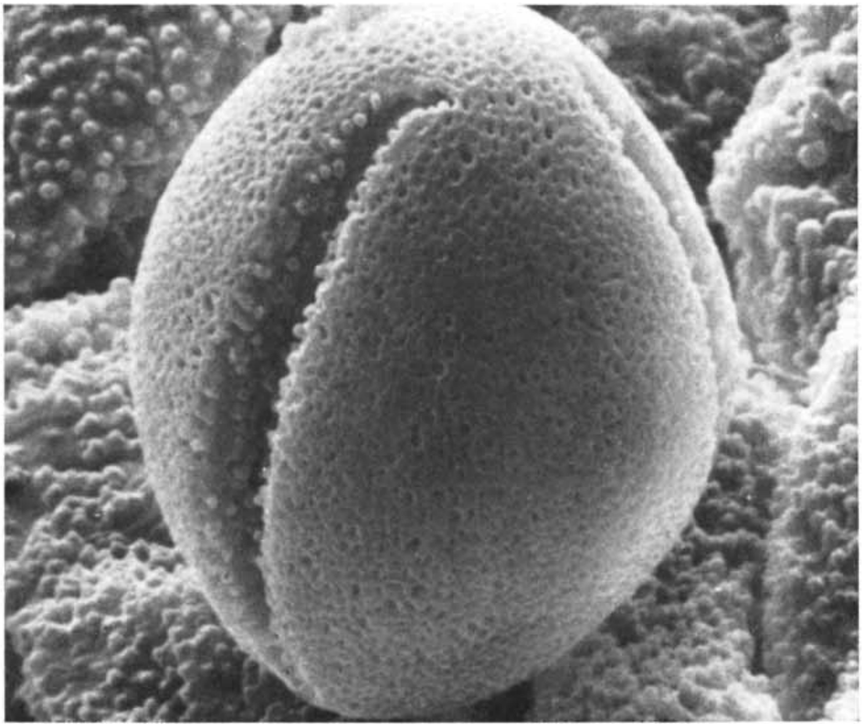
Pollen grains resemble most other living plant cells in that the living cytoplasm of the grain is surrounded by a thin wall of cellulose; in pollen this wall is called the intine. Immediately outside the intine is another layer known as the exine. The principal component of the exine is sporopollenin, the tough substance that gives pollen its remarkable durability. The chemical nature of sporopollenin is somewhat obscure. Gas chromatography indicates, however, that it is primarily a polymer of monocarboxylic or dicarboxylic fatty acids with a fairly high molecular weight.

In a few groups of plants the exine is a fairly uniform sheath. More commonly it is complex and is itself divided into an outer component (the ektexine) and an inner one (the endexine). The inner component, which completely covers the intine, is usually a smooth layer. It is the outer component that forms the structures that give the grain walls their rich detail. These structures are made up of tiny rods called bacula. The rods differ widely in size and may be either isolated or clustered in groups. In some plant genera the tips of the bacula are fused to form a tectum, or roof, that is perforated or sculptured in characteristic ways [*see illustrations at top of next two pages*]. In other genera the bacula have a spinelike appearance, and the tips of the spines can be rounded, pointed or shaped in other ways. Long and short spines on the surface of the tectum may surround crater-like pores, as they do in morning-glory pollen, looking rather like a high-speed photograph of a splashing water droplet. Or the spines may cover the surface of the pollen grain in symmetrical arrays of peaks, as they do in woodsmallow pollen, like some surrealist portrait of a lunar landscape.

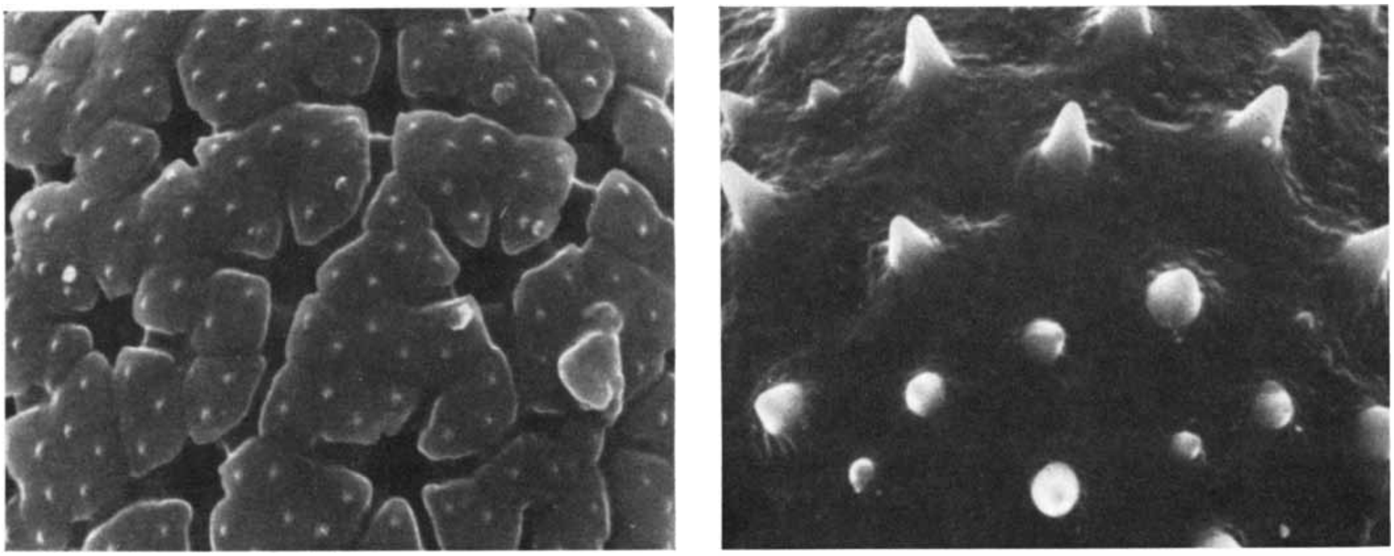
The early stages of pollen growth are intimately associated with the development of the anther, the pollen-producing organ at the tip of the stamen. Precursor cells in the young anther, comprising what is called archesporial tissue, give rise to two distinctively different components. One of them, the primary parietal layer, forms both the outer wall of the anther and its specialized inner wall, called the tapetum. The tapetum, consisting of one or more layers of cells, plays an essential role in the formation of pollen grains: abnormal development of the tapetum invariably



TRANSMISSION MICROGRAPH shows many details of grain structure visible in a transverse section through a mature pollen grain. This is pollen from a hellebore (*Helleborus foetidus*), a member of the buttercup family. Structures visible in the micrograph include the main components of the grain's tough outer coat. The inner layer of the coat, the endexine, is darker than the outer layer, the ektexine, and is quite thick in the vicinity of a furrow (*lower left*). The rodlike elements whose fused ends form both the roof and the floor of the pollen grain's outermost covering are visible as dark upright structures along the entire circumference of the pollen grain. The electron micrograph enlarges the grain 6,200 times.



SCANNING MICROGRAPH shows the external appearance of a pollen grain of the same hellebore species. The smoothness of the outermost grain covering is broken by two deep furrows. The tiny, crater-like openings in the surface are areas in which the tips of rods have not fused completely in forming a roof. The pollen grain is seen magnified 3,400 times.



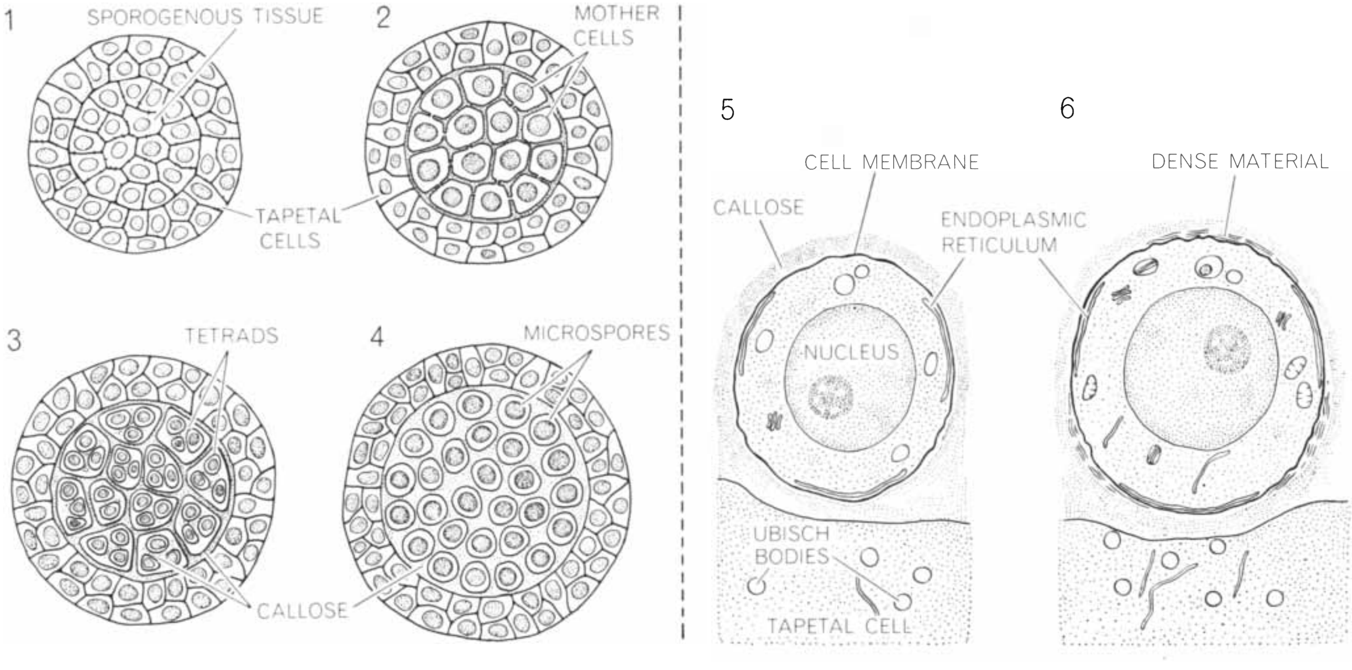
POLLEN SURFACE DETAILS are visible in four scanning micrographs. Magnified 4,500 times (*left*), pollen of the Asiatic shrub *Pimelea* has a roof of large plates that bear many tiny spines. Pollen of the mallow (*Malva*) is magnified 2,500 times (*second from*

disrupts the maturation of the pollen.

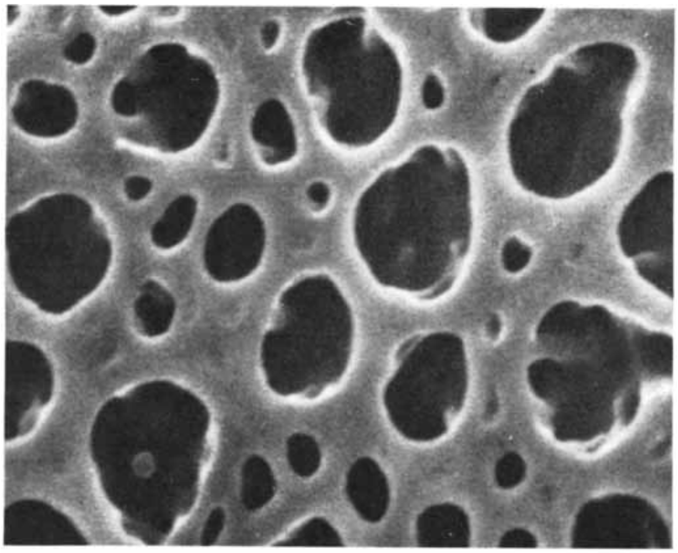
The second archesporial component is the primary sporogenous tissue. This tissue produces the many pollen mother cells from which the pollen grains later arise. Each mother cell divides by the process of meiosis, in which the usual diploid number of chromosomes in the cell nucleus is reduced by half. At the end of this process the original cell has been transformed into four microspores, each with a haploid number of chromosomes. The four microspores, collectively called a tetrad, then mature into four pollen grains within the anther cavity.

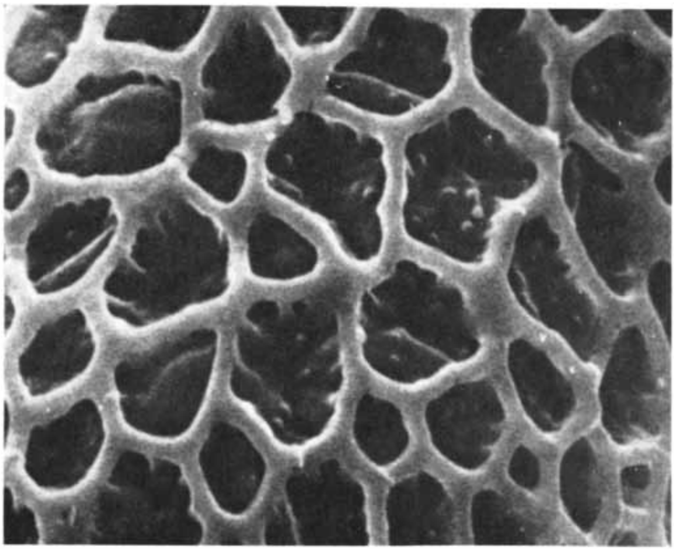
The tetrad stage is an important one in the development of the pollen grain. The surface features of the mature grain are definitely related to the original orientation of the microspore within the tetrad. One such feature is the single furrow that characterizes one of the two major classes of pollen grains; the furrow develops on the side of the grain that is not in contact with the other three grains during the tetrad stage. It is also during the tetrad stage that the outer layer of the grain wall develops the more complex configurations characteristic of each genus.

In our study of the development of pollen within the hellebore anther the earliest stage we have recognized so far comes after the differentiation of archesporial tissue into its parietal and sporogenous components. Transmission elec-



POLLEN-GRAIN DEVELOPMENT is shown in schematic cross sections. The first four stages (*left*) are not at the same scale as the next five. When the two kinds of tissue that comprise the anther interior can first be distinguished (*1*), cells within each kind are linked by bridges but no links exist between the two kinds. The inner, sporogenous tissue gives rise to pollen mother cells that share a common pool of protoplasm (*2*). Next the mother cells undergo meiotic division until each consists of a tetrad of microspores (*3*). Each tetrad is isolated by a layer of callose tissue. The tetrads then separate (*4*). Meanwhile aggregates that will become Ubisch



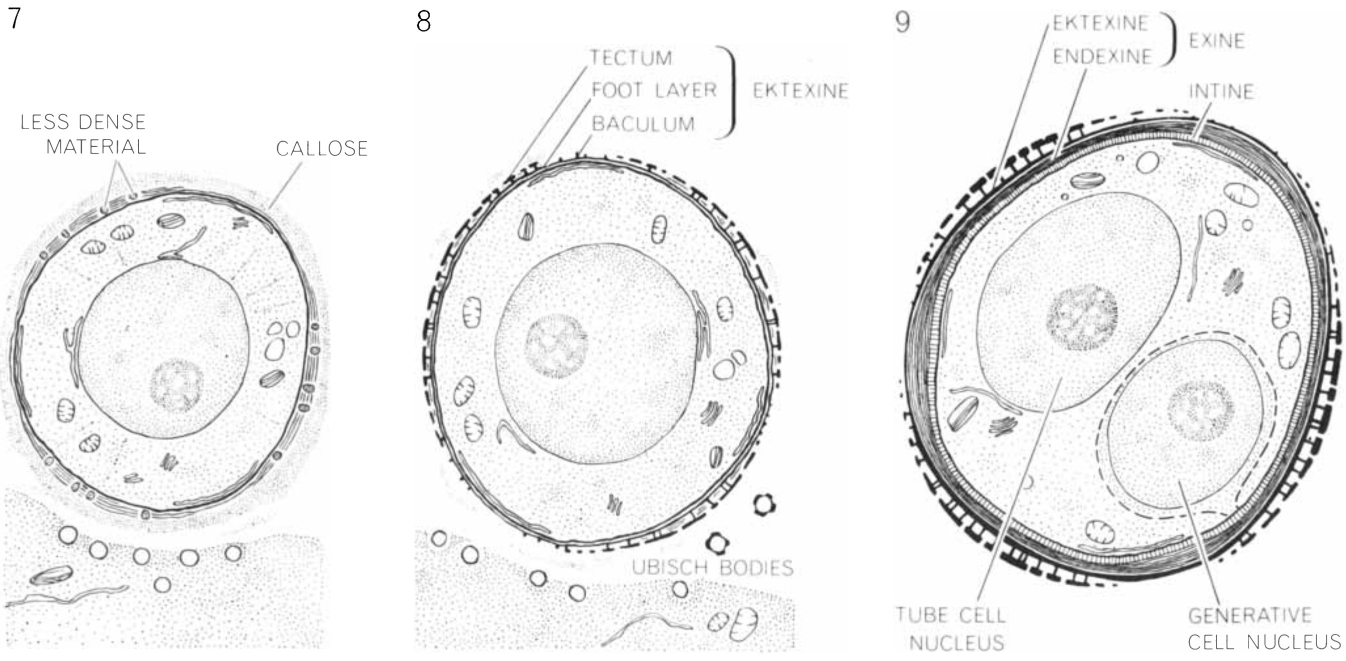


left); it is covered with spines. Pollen of the bluebell (*Endymion*) is magnified 16,000 times (*third from left*); it has many large and small roof openings. Pollen of the Australian shrub *Callistemon*, magnified 16,700 times (*right*), has only a lacelike trace of a roof.

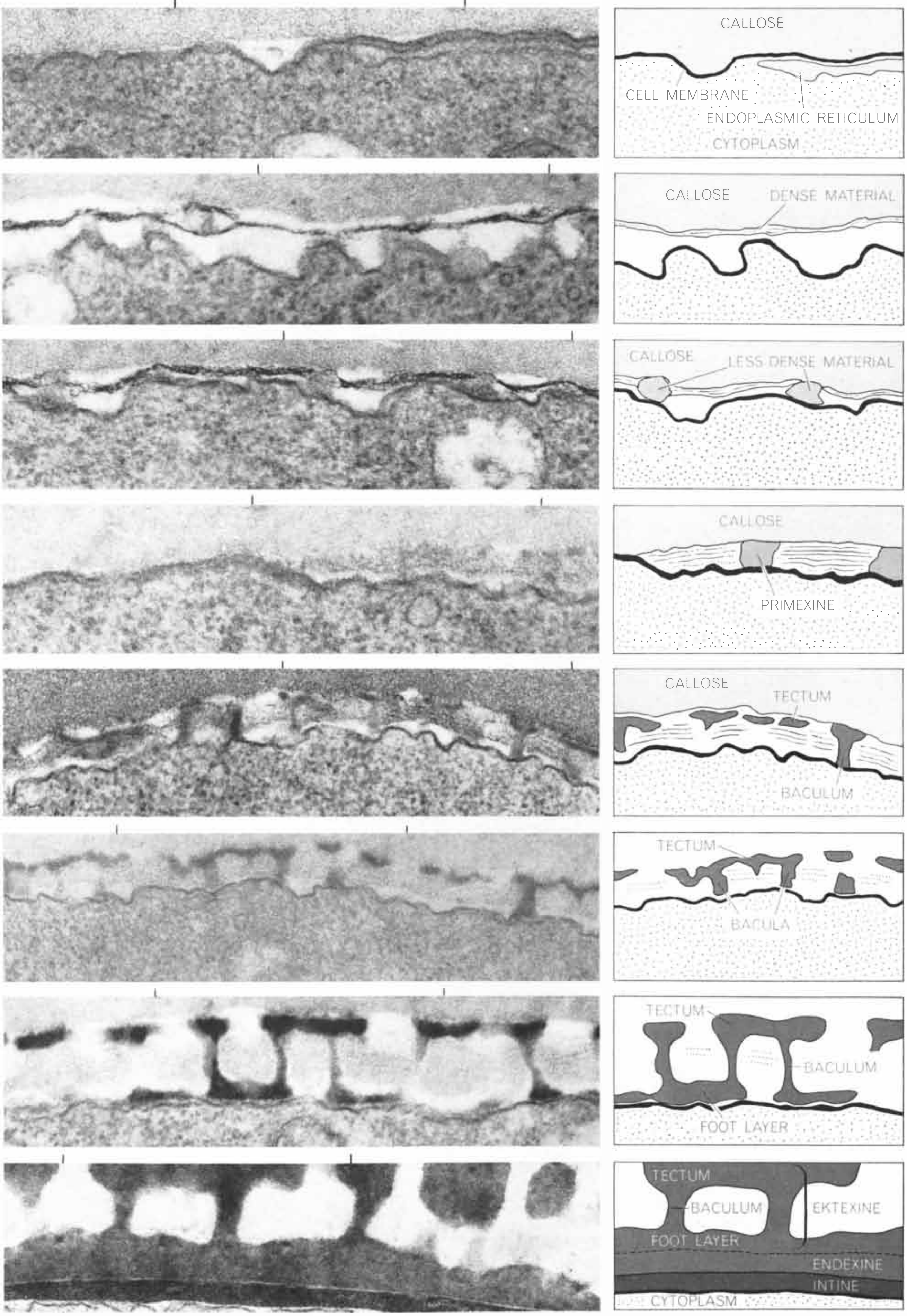
tron micrographs show sporogenous cells surrounded by tapetal cells. Bridges of protoplasm called plasmodesmata are visible between tapetal cells and between sporogenous cells but not between the two kinds of cell.

The next event we can recognize is the transformation of sporogenous cells into a mass of mother cells. This is the result of mitosis, the process of cell division in which the number of chromosomes is not reduced by half but remains the same. The pollen mother cells are interconnected by canals through which the cytoplasm passes freely. Accordingly the entire mass of pollen mother cells is a kind of large single cell that shares a common pool of cytoplasm.

Each pollen mother cell continues to grow in size and is progressively enveloped in a layer of callose, an amorphous cell-wall substance. Callose has been shown to be resistant to the diffusion of relatively small molecules; it seems clear that its function at this stage is to act as a barrier between mother cells. Thus far the sharing of cytoplasm has presumably presented no problems. With the microspores about to emerge, however, the requirements of genetic identity probably demand that each nucleus act within its own independent unit of cytoplasm. In any case it is not until each mother cell is successfully isolated from the others by a layer of callose that the mother cell undergoes meiosis and is



bodies have formed in the surrounding anther tissue, the tapetum. Networks of dense endoplasmic reticulum now begin to form in the cytoplasm within each microspore (*5, only one microspore shown*). In areas where these networks are absent the microspore cell membrane becomes coated with a dense fibrous material (*6*), containing gaps in which a less dense material now appears (*7*). Callose diminishes (*8*), the maturing grain's layer of ektexine develops and Ubisch bodies erupt from the tapetum. As the endexine and the intine appear (*9*) the pollen grain reaches the state of full maturity and its nucleus divides into a pollen tube cell and a generative cell.


CALLOSE
CELL MEMBRANE
ENDOPLASMIC RETICULUM
CYTOPLASM
CALLOSE
DENSE MATERIAL
CALLOSE
LESS DENSE MATERIAL
CALLOSE
PRIMEXINE
CALLOSE
TECTUM
BACULUM
TECTUM
BACULA
TECTUM
BACULUM
FOOT LAYER
TECTUM
BACULUM
EKTEXINE
FOOT LAYER
ENDEXINE
INTINE
CYTOPLASM

transformed into a tetrad of microspores. Each of the four microspores is similarly sheathed in callose and isolated from its siblings.

In the next stage the first precursor of the mature pollen grain's exine outer coat appears. The microspore is still enclosed within its wall of callose, but the cell membrane that forms a boundary between the callose and the microspore cytoplasm begins to increase in thickness. A network of denser substances in the microspore cytoplasm, consisting of elements in the endoplasmic reticulum, appears in some regions immediately below the cell membrane. We believe the region in which this endoplasmic reticulum develops corresponds to the area on the surface of the mature pollen grain where the furrow (or furrows) will eventually form.

In the regions not associated with endoplasmic reticulum the thickened cell membrane now has a convoluted appearance. A thin layer of fibrous material, which is dark in transmission electron micrographs, begins to appear along the top of the convolutions outside the cell membrane. When the fibrous material has reached a certain thickness, gaps appear in it, and material that has a somewhat lighter appearance in transmission electron micrographs is deposited in the gaps. The regions where the deposition of this lighter (and more uniform) material takes place correspond to the areas where the first elements of the precursor to exine, known as primexine, are subsequently deposited. This phase of maturation thus appears to be the one in which the surface pattern of the mature pollen grain is determined.

The progression from primexine to exine is not difficult to follow. Elements of the primexine give rise to precursors of the rodlike bacula of the mature exine. Hellebore pollen grains have a distinctive roofed appearance; our studies show how the roof develops in a series of steps. The first is the positioning of the bacula, which in cross section look like pillars. The upper end of each baculum now spreads sideways in all directions. When the spreading tips meet, they form a perforated roof on top of the pillars. While this is going on the lower ends of the bacula also spread sideways and coalesce to form a floor at the base of the pillars. Roof, pillars and floor together comprise the outermost, or ektexine, layer of the pollen-grain wall. As the ektexine structure is completed it is impregnated with sporopollenin. As this feat of construction and coating is being accomplished the layer of callose that surrounds the maturing pollen grain gradually becomes thinner. Finally the callose layer disappears, the tetrads break apart and the individual grains of pollen lie free within the anther.

DEVELOPMENT of the outer coating of a hellebore pollen grain is seen in a series of transmission micrographs magnified 50,000 times (*opposite page*). Marks above each photograph indicate area in the drawing at right, in which structures are identified.

During the microspores' growth into mature pollen grains structural changes also occur in the cells of the tapetum, the inner wall of the anther. At the same time that meiosis is transforming mother cells of the hellebore into tetrads, the tapetal cells of the anther enlarge and begin to form curious spherical bodies. These bodies, which in their eventual free state are called Ubisch bodies (after their discoverer, G. von Ubisch of the University of Heidelberg), are at first closely associated in the tapetal cells with rows of the cytoplasmic particles known as ribosomes. Later they are associated with the tapetal cells' network of endoplasmic reticulum.

The next change to occur in the tapetum coincides with the microspores' development of their first structural wall elements. Some of the spherical bodies within each tapetal cell now begin to migrate to the cell surface, where they break through into the anther cavity. As soon as a sphere breaks through it is encased in sporopollenin and can be considered a mature Ubisch body.

It must be more than coincidence that the Ubisch bodies receive their coat of sporopollenin at the same time the ektexine elements of the pollen-grain wall do. We believe that most tapetal cells and pollen-grain cells alike have the capacity to secrete sporopollenin but that only in developing pollen grains is the substance laid down in an elaborately organized manner.

During the period when the spherical precursors of the Ubisch bodies appear and begin to migrate the cells of the tapetum show increasing signs of dissolution. Their cellulose walls diminish in thickness, their cytoplasm becomes less dense and many of the subcellular bodies in it become unrecognizable. By the time the Ubisch bodies break free into the anther cavity, the tapetal-cell walls have disappeared and only a thin cytoplasmic membrane surrounds each tapetal cell. What function the Ubisch bodies serve is not known.

As the pollen grain's protective ektexine covering is forming, the second component of the outer coat—the endexine—is deposited below it. The process involves a number of thin white membranes that appear to arise from the cytoplasm and provide a locus around which sporopollenin is deposited. As the deposition proceeds the membranes grow into plates that finally merge to form the endexine zone. No sign of either the membranes or the plates can be seen in the mature pollen-grain wall.

Formation of the endexine zone signals that the pollen grain has almost reached maturity. All that remains now is for the last component of the grain wall—the intine—to form inside the endexine. This takes place quite rapidly. At about the same time the nucleus of the pollen grain also takes a last step toward maturity: the simple mitotic division that gives rise to the male sexual nucleus and the nucleus of the future pollen tube. Recently Roger Angold, working in our laboratory, has shown that in the development of the pollen grain of the bluebell (*Endymion*) the male generative, or sexual, nucleus becomes surrounded by a thin wall of cellulose. This wall forms in close association with the intine, then surrounds the generative nucleus and eventually pinches off and becomes completely separate from the intine. Our own studies have shown that a similar wall is formed at this stage in hellebore pollen.

As these climactic events occur in the pollen grain the tapetal cells of the anther wall also make their final contribution. Within each cell the spherical bodies that have not broken free to become Ubisch bodies gradually coalesce, and when the tapetal-cell membrane finally dissolves, the aggregates enter the anther cavity. It may be that these coalesced bodies give rise to the sticky material—an oleaginous substance called tryphine—that covers the mature pollen grains of most insect-pollinated plants.

Almost all we know about the details of pollen growth and development comes from the analysis of electron micrographs. Returning to the questions raised earlier—whether the surface patterns of pollen grains are created by nature or nurture, something within the pollen grain itself or some element in the microenvironment—it is interesting to note that the first responses to these questions were given long before electron microscopy was available as a research tool.

It is quite clear to us that, in hellebore at least, the patterning of the pollen grain's surface is a consequence of information inherited by the microspore when meiosis transforms each mother cell into four microspores. We have selected as the key point in time the moment when locations for the later deposition of primexine appear in the fibrous material between the microspore membrane and its covering of callose. Are there any factors within the microspore cytoplasm that determine these locations? As long ago as 1911 Rudolf Beer observed thin threads radiating from the nucleus of the pollen grain of the morning glory (*Ipomoea*). Beer hinted that in some mysterious way these threads determined the organization of the exine. With the aid of the electron microscope we have located in the cytoplasm of hellebore pollen grains that appear to be microtubules radiating from the nucleus in the manner of Beer's morning-glory threads. We believe the microtubules, together with other cytoplasmic organelles called dictyosomes, may be the factors that determine the pollen grain's exine pattern. This view, based at least in part on a duplication of Beer's finding of nearly 60 years ago, is not unchallenged. John Helsop-Harrison of the University of Wisconsin, together with John Skvarla and Donald A. Larson of the University of Texas, believe surface patterns in the pollen grains they have investigated are determined by the endoplasmic reticulum instead.

Can the microenvironment be dismissed as an insignificant factor in the patterning of pollen-grain surfaces? Again we can turn to an earlier answer. In 1935 Roger P. Wodehouse, then with the Arlington Chemical Company, produced convincing evidence that in many types of pollen the pattern of pores and furrows bore a close relation to the contact geometry of the microspores during their association in the tetrad. Our hellebore studies have produced evidence in general support of Wodehouse's conclusion: One of the three furrows that mark each hellebore pollen grain may well be initiated at the point of common contact within the tetrad.

It would thus appear that both heredity and environment play a part in determining the complex surface patterns of pollen grains. If one or the other factor must be declared the more significant, heredity far outweighs environment. Granting that some gross features such as furrowing may be attributed to tetrad contact geometry, all the rest—including the myriad variations in wall structure and patterning—is the product of inheritance alone.

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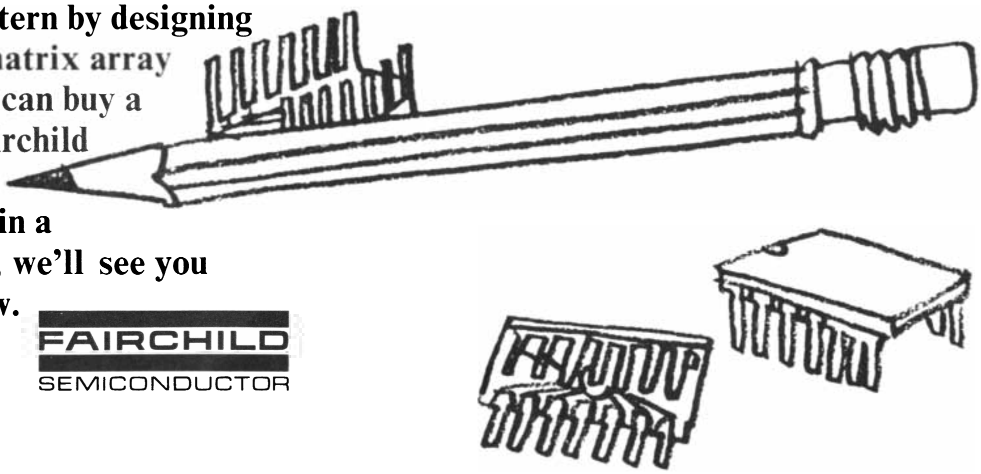

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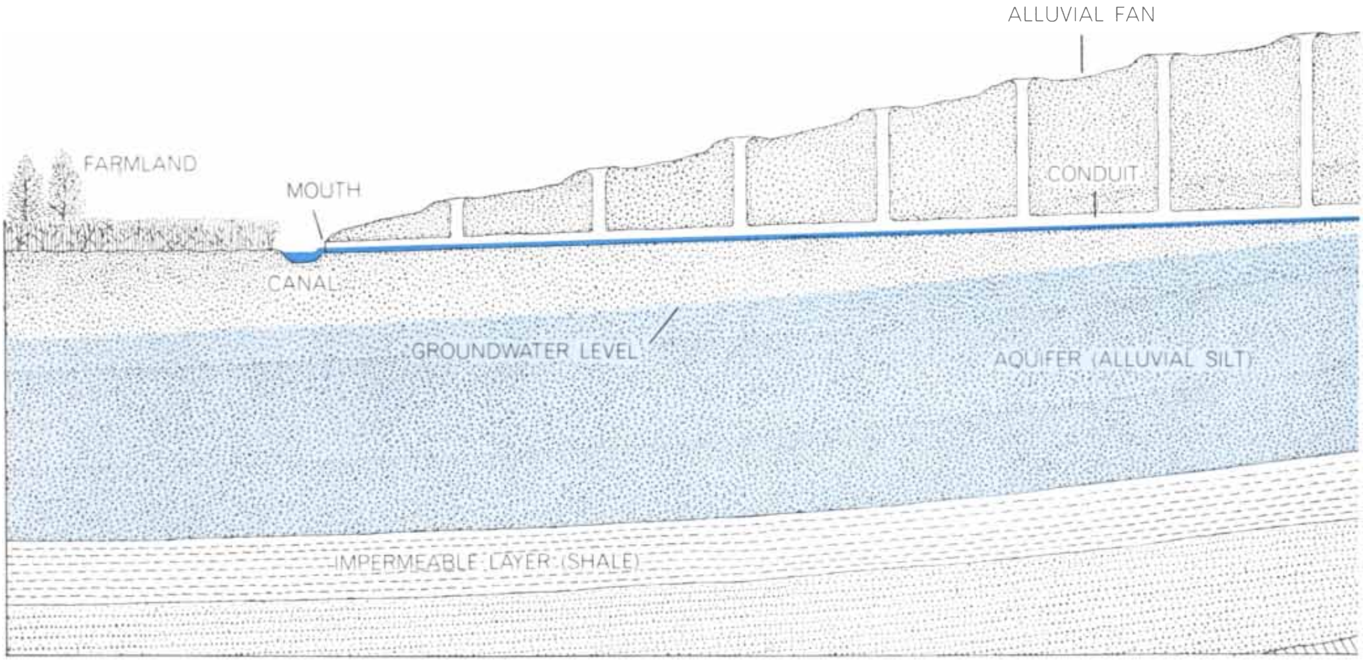
The Qanats of Iran

Some 3,000 years ago the Persians learned how to dig underground aqueducts that would bring mountain ground water to arid plains. Today the system provides 75 percent of the water used in Iran

by H. E. Wulff

A traveler flying over Iran can see plainly that the country has an arid climate. The Iranian plateau is largely desert. Most of Iran (excepting areas in the northwestern provinces and along the southern shores of the Caspian Sea) receives only six to 10 inches of rainfall a year. Other regions of the world with so little rainfall (for example the dry heart of Australia) are barren of attempts at agriculture. Yet Iran is a farming country that not only grows its own food but also manages to produce crops for export, such as cotton, dried fruits, oilseeds and so on. It has achieved this remarkable accomplishment by developing an ingenious system for tapping underground water. The system, called qanat (from a Semitic word meaning "to dig"), was invented in Iran thousands of years ago, and it is so simple and effective that it was adopted in many other arid regions of the Middle East and around the Mediterranean.

The qanat system consists of underground channels that convey water from aquifers in highlands to the surface at lower levels by gravity. The qanat works of Iran were built on a scale that rivaled the great aqueducts of the Roman Empire. Whereas the Roman aqueducts now are only a historical curiosity, the Iranian system is still in use after 3,000 years and has continually been expanded. There are some 22,000 qanat units in Iran, comprising more than 170,000 miles of underground channels. The system supplies 75 percent of all the water used in that country, providing water not only for irrigation but also for household consumption. Until recently (before the building of the Karaj Dam) the two



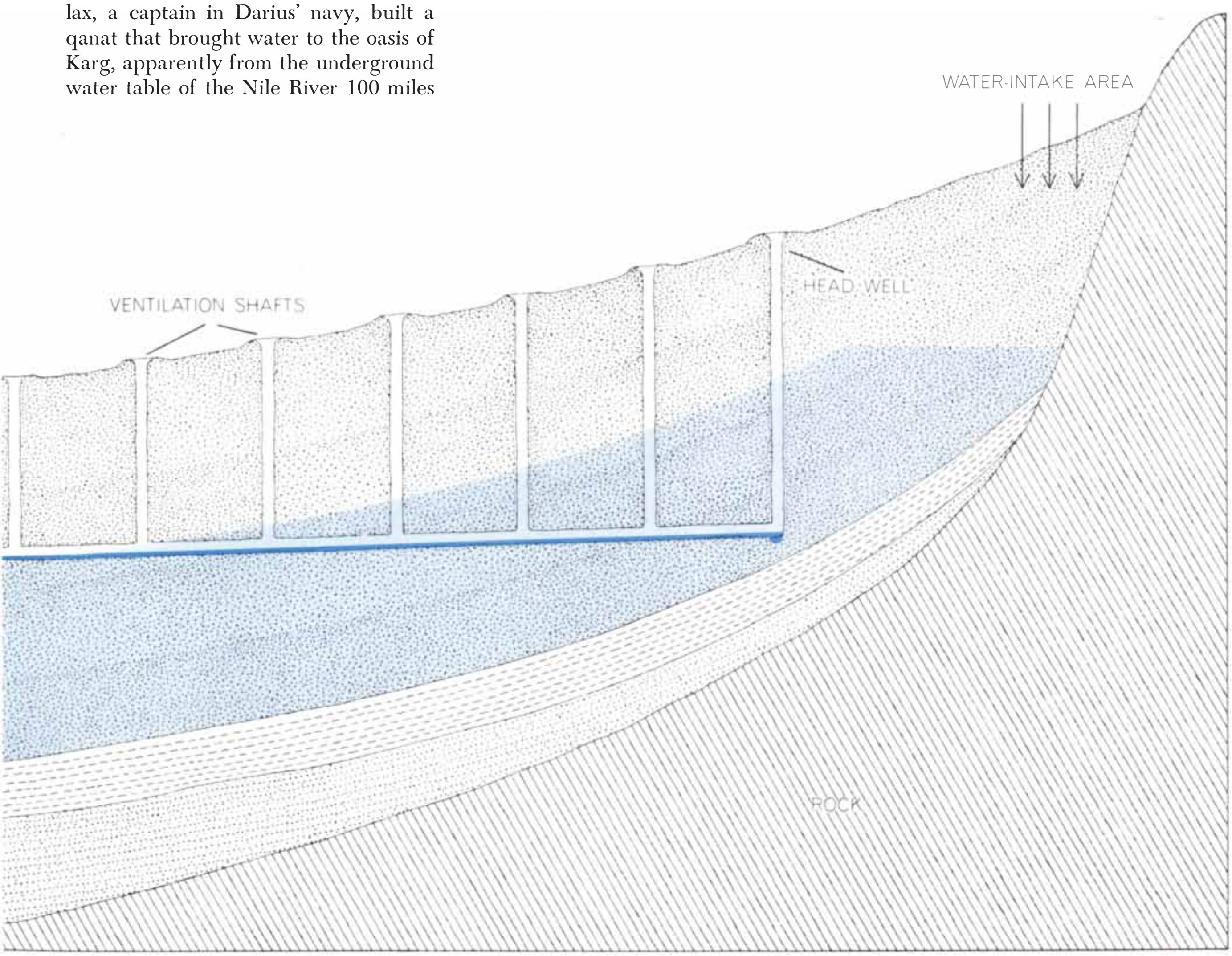
UNDERGROUND AQUEDUCT conveys water gently downhill from the highlands to distribution canals in the arid plain below. The water source is the head well (*right*), which reaches down to the water table. The other shafts provide ventilation and give access million inhabitants of the city of Tehran depended on a qanat system tapping the foothills of the Elburz Mountains for their entire water supply.

Discoveries of underground conduits in a number of ancient Roman sites led some modern archaeologists to suppose the Romans had invented the qanat system. Written records and recent excavations leave no doubt, however, that ancient Iran (Persia) was its actual birthplace. As early as the seventh century B.C. the Assyrian king Sargon II reported that during a campaign in Persia he had found an underground system for tapping water in operation near Lake Urmia. His son, King Sennacherib, applied the "secret" of using underground conduits in building an irrigation system around Nineveh, and he constructed a qanat on the Persian model to supply water for the city of Arbela. Egyptian inscriptions disclose that the Persians donated the idea to Egypt after Darius I conquered that country in 518 B.C. Scylax, a captain in Darius' navy, built a qanat that brought water to the oasis of Karg, apparently from the underground water table of the Nile River 100 miles away. Remnants of the qanat are still in operation. This contribution may well have been partly responsible for the Egyptians' friendliness to their conqueror and their bestowal of the title of Pharaoh on Darius.

References to qanat systems, known by various names, are fairly common in the literature of ancient and medieval times. The Greek historian Polybius in the second century B.C. described a qanat that had been built in an Iranian desert "during the Persian ascendancy." It had been constructed underground, he remarked, "at infinite toil and expense . . . through a large tract of country" and brought water to the desert from sources that were mysterious to "the people who use the water now."

Qanats have been found throughout the regions that came within the cultural sphere of ancient Persia: in Pakistan, in Chinese oasis settlements of Turkistan, in southern areas of the U.S.S.R., in Iraq, Syria, Arabia and Yemen. During the periods of Roman and then Arabian domination the system spread westward to North Africa, Spain and Sicily. In the Sahara region a number of oasis settlements are irrigated by the qanat method, and some of the peoples still call the underground conduits "Persian works." In the Middle East several particularly interesting qanats constructed by Arab rulers of early medieval times have been excavated. In A.D. 728 the caliph of Damascus built a small qanat to supply water for a palace in the country. A century later the caliph Mutawakkil in Iraq likewise constructed a qanat system, presumably with the aid of Persian engineers, that brought water to his residence at Samarra from the upper Tigris River 300 miles away.

Thanks to detailed descriptions by



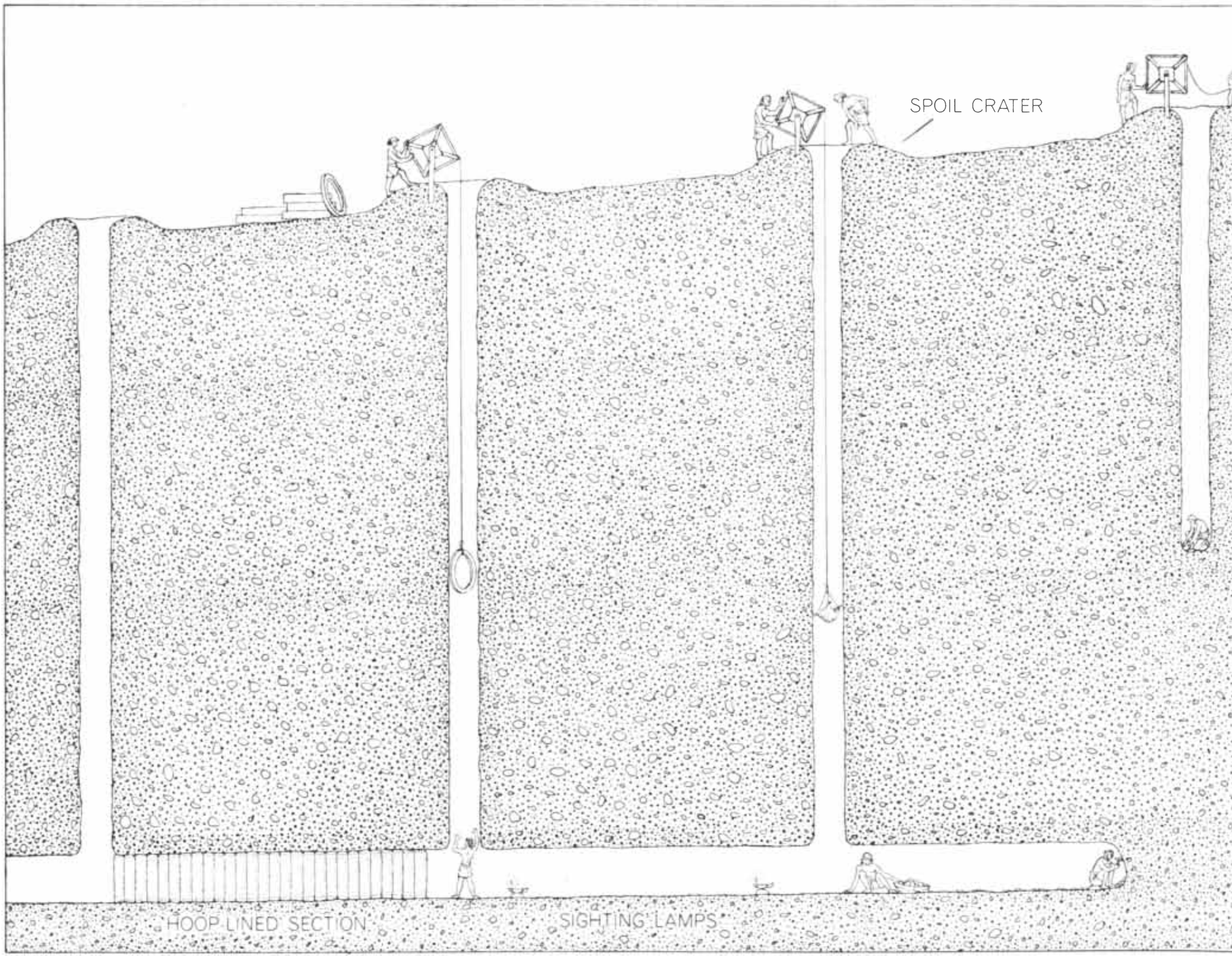
for cleaning and repair of the conduit tunnel below. Called qanats after the Semitic word meaning "to dig," the irrigation systems were invented in Persia during the first millennium B.C. The horizontal tunnel of the qanat is commonly from six to 10 miles long.

several early writers, we have a good idea of the techniques used by the original qanat builders. Vitruvius, the first systematic historian of technology, gave an account of the qanat system in technical detail in his historic work *De Architectura* (about 80 B.C.). In the ninth century A.D., at the request of a Persian provincial governor, Abdullah ibn-Tahir, a group of writers compiled a treatise on the subject titled *Kitab-e Quniy*. And about A.D. 1000 Hasan al-Hasib, an Arabian authority on engineering, wrote a technical work that fortunately is still available and gives surprisingly good details of the construction and maintenance of the ancient qanats.

The methods used in Iran today are not greatly different from the system devised thousands of years ago, and I shall describe the system as it can now be observed. The project begins with a careful survey of the terrain by an expert engaged by the prospective builders. A qanat system is usually dug in the slope of a mountain or hillside where material washed down the slope has been deposited in alluvial fans. The surveyor examines these fans closely, generally during the fall, looking for traces of seepage to the surface or slight variations in the vegetation that may suggest the presence of water sources buried in the hillside. On locating a promising spot, he arranges for the digging of a trial well.

Two diggers, called *muqannī*, take up this task. They set up a windlass at the surface to haul up the excavated material in leather buckets and proceed to dig a vertical shaft about three feet in diameter, one man working with a mattock and the other with a short-handled spade. As they load the spoil in the buckets, two workers at the surface pull it up with the windlass and pile it around the mouth of the shaft. If luck is with them, the diggers may strike an aquifer at a depth of 50 feet or less. Sometimes, however, they dig down 200 to 300 feet to reach water, and this necessitates installing a relay of windlasses at stages 100 feet apart on the way down.

When they arrive at a moist stratum—a potential aquifer—the diggers scoop out a cavity to its impermeable clay bottom, and for the next few days the leather buckets are dipped into the hole periodically to measure the rate of accumulation of water in it. If more than a trickle of water is flowing into the hole, the surveyor can conclude that he has tapped a genuine aquifer. He may then decide to sink more shafts into the stratum in

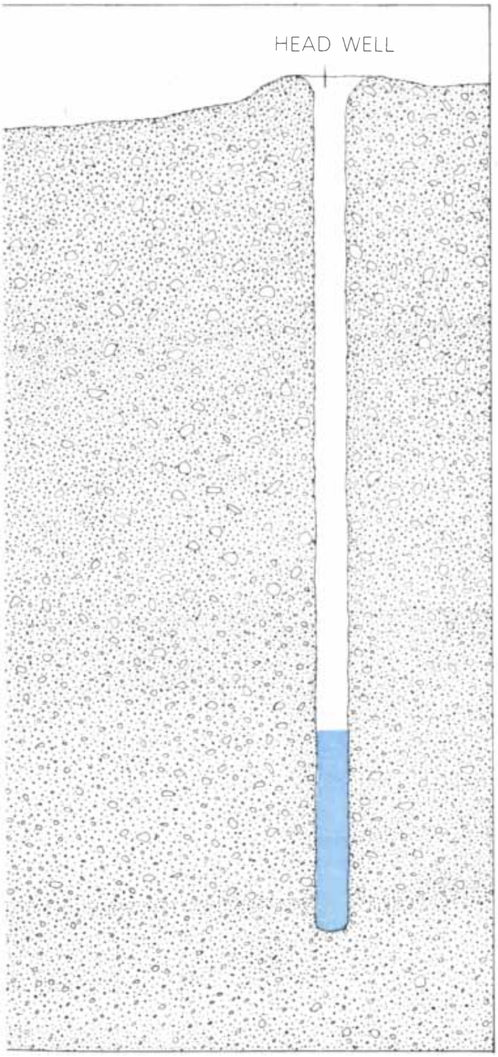


EXCAVATION OF A QANAT begins at the downhill end after a trial well (*right*) has successfully tapped the uphill water table. Where the gradually sloping tunnel passes through zones of loose earth (*left*) hoops of tile support the walls, but a tunnel generally lacks masonry except at the discharge point. Ventilation shafts are dug at intervals of 50 yards or so; earth and rock excavated from the tunnel face are winched to the surface through the shafts. Sightings over a pair of oil lamps help to keep the tunnel diggers'

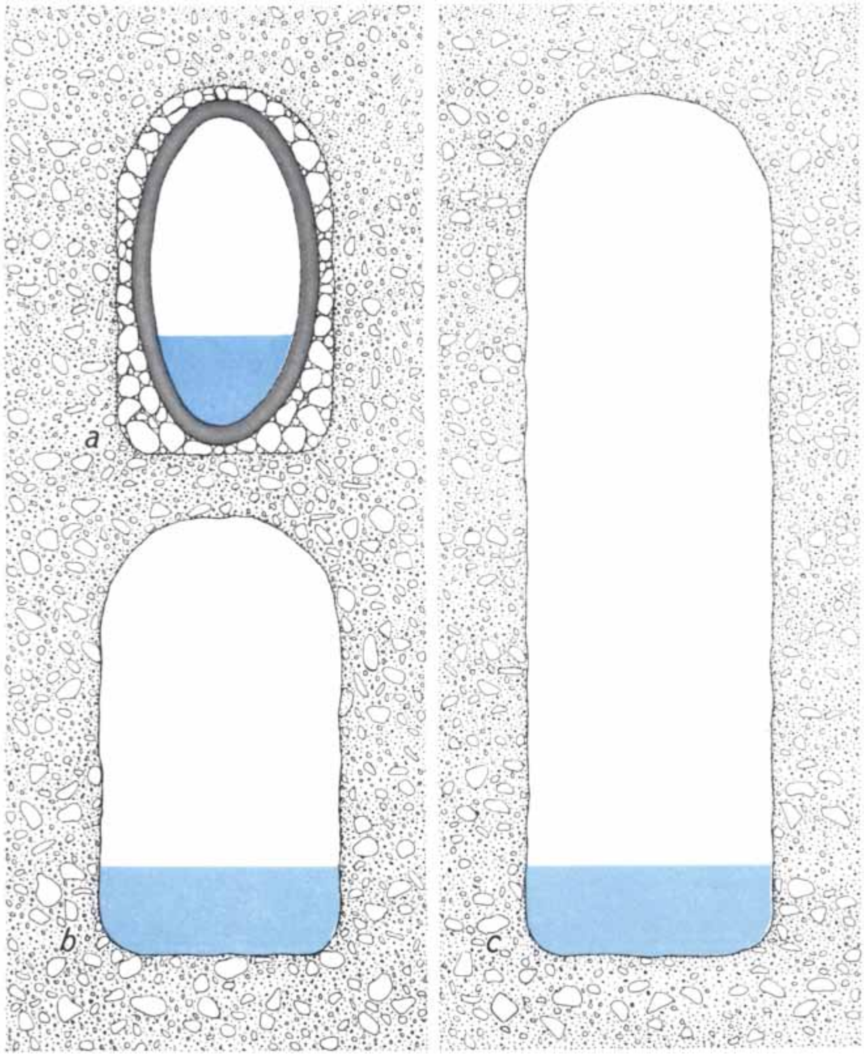
the immediate area to determine the extent of the aquifer and its yield.

The surveyor next proceeds to chart the prospective course of an underground conduit through which the water can flow from this head well or group of wells to the ground surface at some point farther down the slope. For the downward pitch of the conduit he selects a gradient somewhere between one foot in 500 and one in 1,500; the gradient must be slight so that the water will flow slowly and not wash material from the bottom of the conduit or otherwise damage it. For his measurements the surveyor uses simple instruments: a long rope and a level. (The ninth-century treatise *Kitab-e Quniy* described a tubular water level and a large triangular leveling device with a plumb that was then employed in this task.) The surveyor lets the rope down to the water level in the well and marks the rope at the surface to show the depth. This will be his guide for placing the mouth of the conduit; obviously the mouth must be at some point a little below the water level indicated by the rope. A series of vertical shafts for ventilation will have to be sunk from the surface to the conduit at certain measured intervals (perhaps 50 yards) along its path. Consequently the surveyor must determine the depth from the surface for each of these shafts. He uses a level to find the drop in the ground slope from each shaft site to the next and marks the length of this drop on the rope. This tells him how far down from the surface each shaft would have to be dug if the conduit ran a perfectly level course. He then calculates the additional depth to which each should be dug (in view of the prospective pitch of the conduit) by dividing the total drop of the conduit from the well's water level to the mouth by the number of proposed ventilation shafts.

As the *muqannī* proceed to dig the conduit itself, guide shafts are sunk to the indicated depths at intervals of about 300 yards to provide information regarding the route and pitch of the conduit for the diggers. They start the excavation of the conduit from the mouth end, digging into the alluvial fan. To protect the mouth from storm-water damage they often line the first 10 to 15 feet of the tunnel with reinforcing stone. The conduit is about three feet wide and five feet high. As the diggers advance they make sure they are following a straight course by sighting along a pair of burning oil lamps. They deposit the exca-



progress on a straight line. A lamp flame that burns badly also gives warning of bad air. Before the tunnelers break through to the head well, men at the surface bail it dry.



TUNNEL CROSS SECTIONS indicate some of the variations possible in qanat conduits. The tunnel walls may be strengthened with tile hoops (*a*) or where the tunnel passes through clay or well-compacted soil the walls may be left unlined (*b*). If the head well should go dry and therefore need to be dug deeper, the conduit would also need to be deepened (*c*).

vated material in buckets at the foot of the nearest ventilation shaft, and it is hauled up by their teammates above. The tunnel needs no reinforcement where it is dug through hard clay or a coarse conglomerate that is well packed. When the *muqannī* come to a boulder or other impassable obstacle, they tunnel around it and then must recover their bearing toward the next ventilation shaft. They show a good deal of skill in this, relying partly on their sense of direction and partly on listening for the sounds of the diggers working on the vertical shaft ahead. The greatest danger encountered by the *muqannī* is sandy, soft, friable or otherwise unstable soil, which may cause the roof of the tunnel to collapse on them. In such passages the diggers generally line the excavation with oval hoops of baked clay as they cut away the face of the work. Gases and air low in oxygen also are hazards; the diggers carefully watch their oil lamps for warning of the possibility of a suffocating atmosphere. As the *muqannī* approach the aquifer they must be alert to another danger: the possible flooding of the tunnel by a sudden inrush of water. This hazard is particularly great at the moment of breakthrough into the head well; the well must be emptied or tapped very cautiously if the men are not to be washed down the conduit by a deluge. Because of all these hazards *muqannī* call the qanat "the murderer." A *muqannī* always says a prayer before entering a qanat, and he will not go to work on a day he considers unlucky.

WINDLASS CREW, sheltered from the sun by an improvised tent, raises a load of accumulated silt in the process of cleaning a qanat conduit tunnel. Standing beside the tent is a child who is needed on this job because the ventilation shafts are smaller than usual.

Depending on the depth of the aquifer and the slope of the ground, qanats vary greatly in length; in some the conduit from the head well to the mouth is only a mile or two long, and at the other extreme one in southern Iran is more than 18 miles long. Commonly the length is between six and 10 miles. The water discharge obtainable from individual qanats also varies widely. For example, of some 200 qanats in the Varamin plain southeast of Tehran the largest yields 72 gallons per second and the smallest only a quarter of a gallon per second.

Not until the qanat has been completed and has operated for some time is it possible to determine whether it will be a continuous "runner" or a seasonal source that provides water only in the spring or after heavy rains. Because the initial investment in construction of a qanat is considerable, the owner and builders often resort to probing and laborious devices to enlarge its yield. For example, they may extend branches from the main conduit to reach additional aquifers or excavate the floor of the existing conduit in order to lower it and tap water at a deeper level [*see illustration at right on page* 97]. A great deal of care is also given to the maintenance of the qanat. The ventilation shafts are shielded at the top with crater-like walls of spoil and sometimes with hoods to prevent the inflow of damaging storm waters. *Muqannī* are continually kept employed cleaning out silt that is washed into the conduit from the aquifer, clearing up roof cave-ins and making other repairs.

As is to be expected of a system that has existed for thousands of years and is so important to the life of the nation, the building of qanats and the distribution of the water are ruled by laws and common understandings that are hallowed by tradition. The builders of a qanat must obtain the consent of the owners of the land it will cross, but permission cannot be refused arbitrarily. It must be granted if the new qanat will not interfere with the yield from an existing qanat, which usually means that the distance between the two must be several hundred yards, depending on the geological formations involved. When the parties cannot agree, the matter is decided by the courts, which normally appoint an independent expert to resolve the technical questions at issue.

Similarly, there are traditional systems

RUINS OF PERSEPOLIS, the ancient capital of Persia built by Darius in 520 B.C., are at the center of the aerial photograph on the opposite page. The rows of small holes resembling pockmarks reveal the presence of several qanat systems below the surface: each hole is the top of a ventilation shaft. Most of the qanats around the ruins of Persepolis were built only a few decades ago.

for the fair allocation of water from a qanat to the users. If the qanat is owned by a landowner who has tenant farmers, he usually appoints a water bailiff who supervises the allotment of water to each tenant in accordance with the size of the tenant's farm and the nature of the crop he is growing. When the peasants themselves own the qanat, as is increasingly the case under the new land reforms in Iran, they elect a trustworthy water bailiff who sees that each farmer receives his just share of the water at the proper time—and who receives a free share himself for this service. The bailiff is guided by an allocation system that has been fixed for hundreds of years. For instance, three hamlets in the region of Sehdeh in western Iran still receive the shares that were allotted to them in the 17th century by the civil engineer in the reign of Shah Abbas the Great. The hamlets of Dastgerd and Parvar are entitled to eight shares apiece and Karton

TILE HOOPS are piled up near one of the vertical shafts that lead to the conduit tunnel of a qanat under construction in rural Iran. Their presence indicates that the construction crew has encountered a zone of loose earth and must shore up the tunnel walls.

ROW OF CRATERS, each one marking the mouth of a qanat ventilation shaft, runs across an arid plain in western Iran. The walls of the craters protect the shafts and the tunnel below from erosional damage from the inflow of water during a heavy desert rainstorm.

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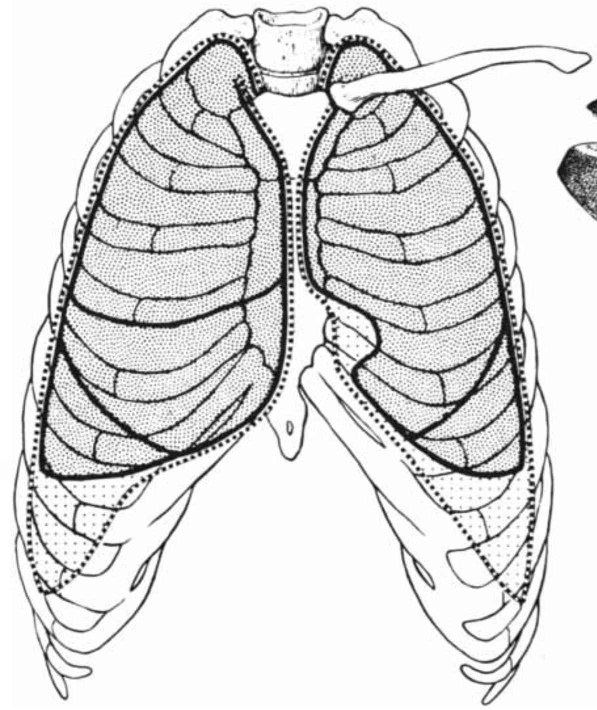

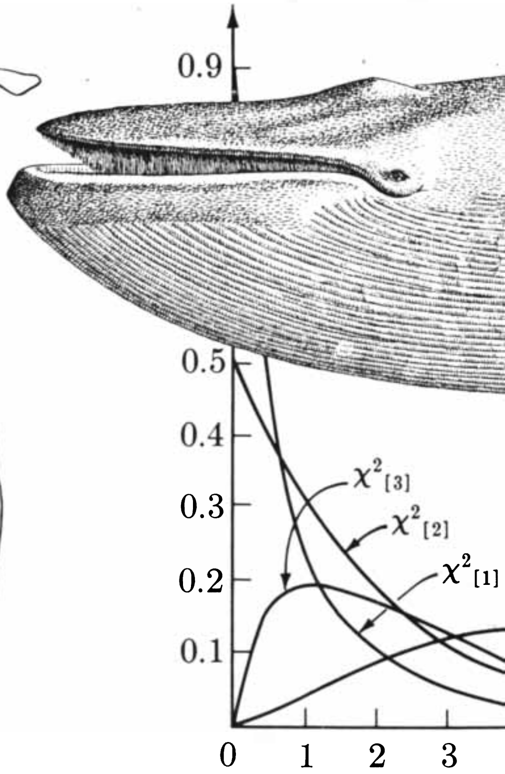

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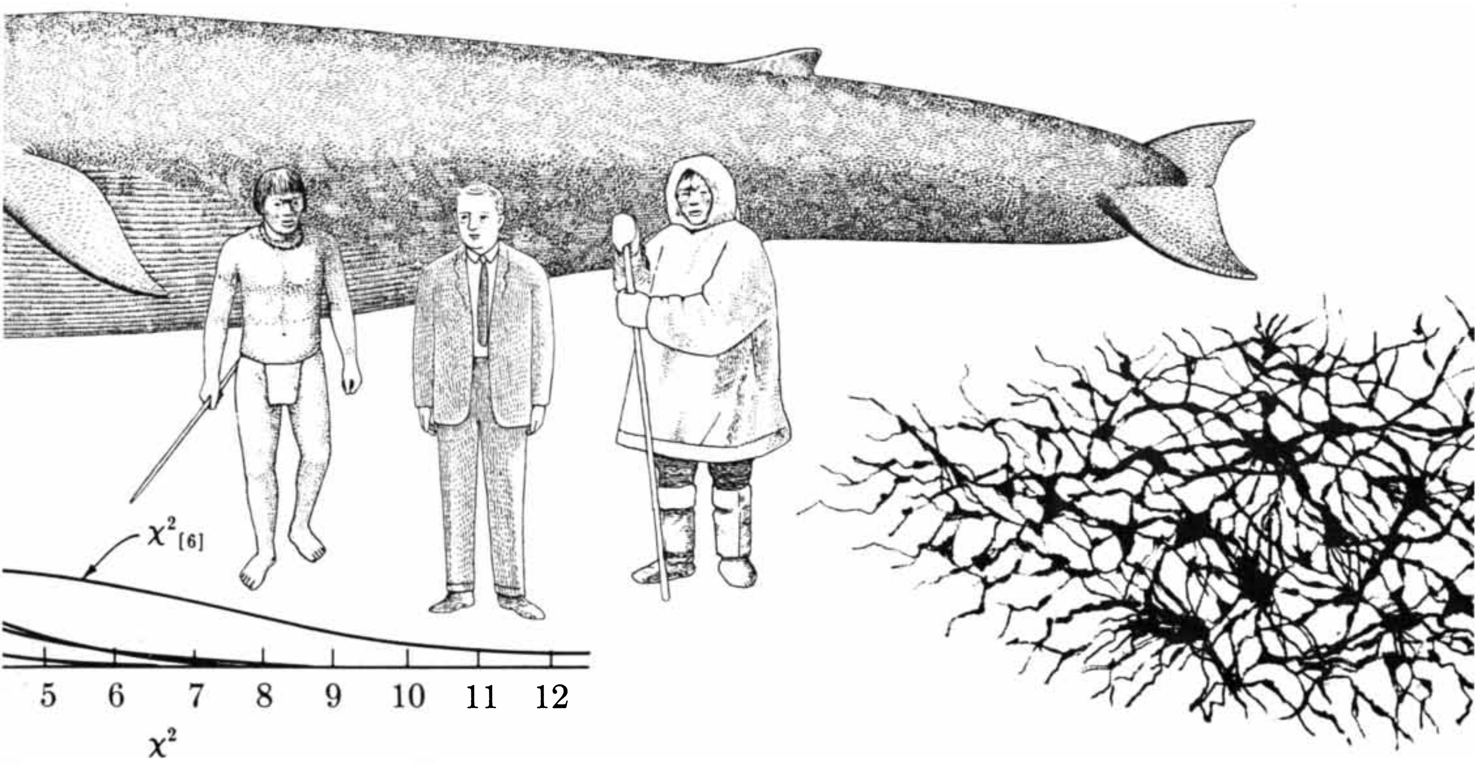

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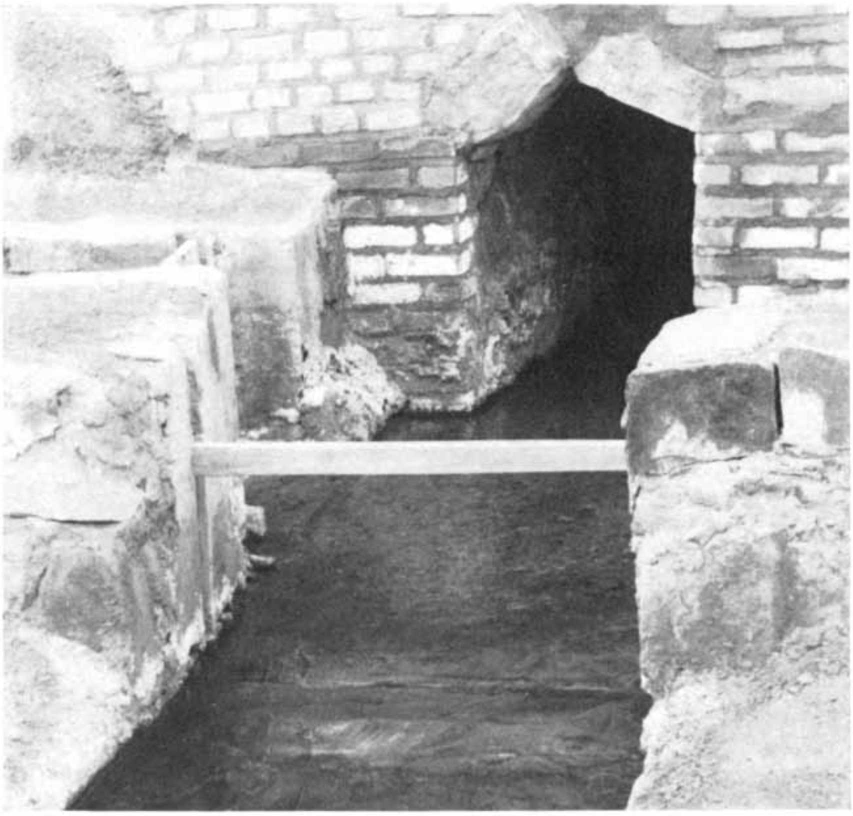
A SUBSIDIARY OF LING-TEMCO-VOUGHT, INC. DALLAS to nine shares, and these allocations are built into the outlets from the qanat distribution basin: the outlets at Dastgerd and Parvar are eight spans wide and the one at Karton is nine spans wide.

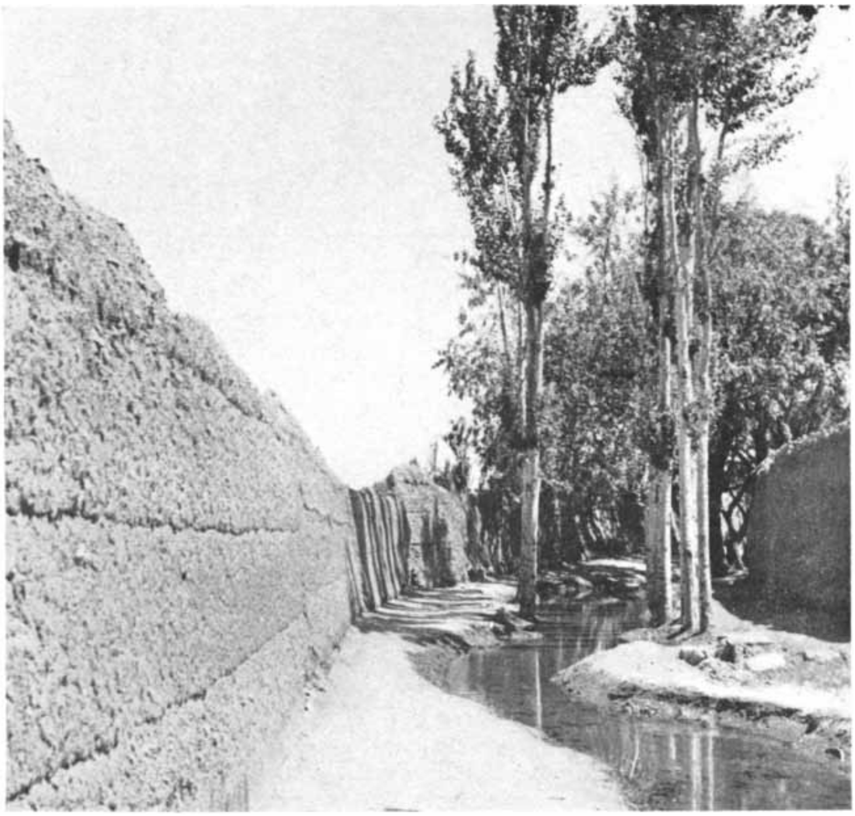
The agricultural production made possible by the qanats amply repays the investment in construction and maintenance. My own recent inquiries showed that the return on these investments in the value of crops and sale of water ranges from 10 to 25 percent, depending on the size of the qanat, the yield of water and the kind of crop for which it is used. A qanat about six miles long costs between $13,500 and $34,000 to build, the cost varying with the nature of the terrain. For a qanat 10 to 15 miles long the cost runs to about $90,000.

Construction costs have risen in recent years as the standard of living in Iran has improved and labor costs have increased. Moreover, the division of large landholdings into smaller ones under the new land-distribution policy, as well as the introduction of expensive modern farming machinery, has made it difficult for the individual landowners to afford the expense of constructing new qanats or maintaining old ones. Many of these farmers are now drilling wells and using diesel pumps, rather than building underground conduits, to bring the water to the surface. Consequently the construction of new qanats may cease, unless the peasants' newly formed village cooperatives find it profitable and can raise the necessary capital to build them.

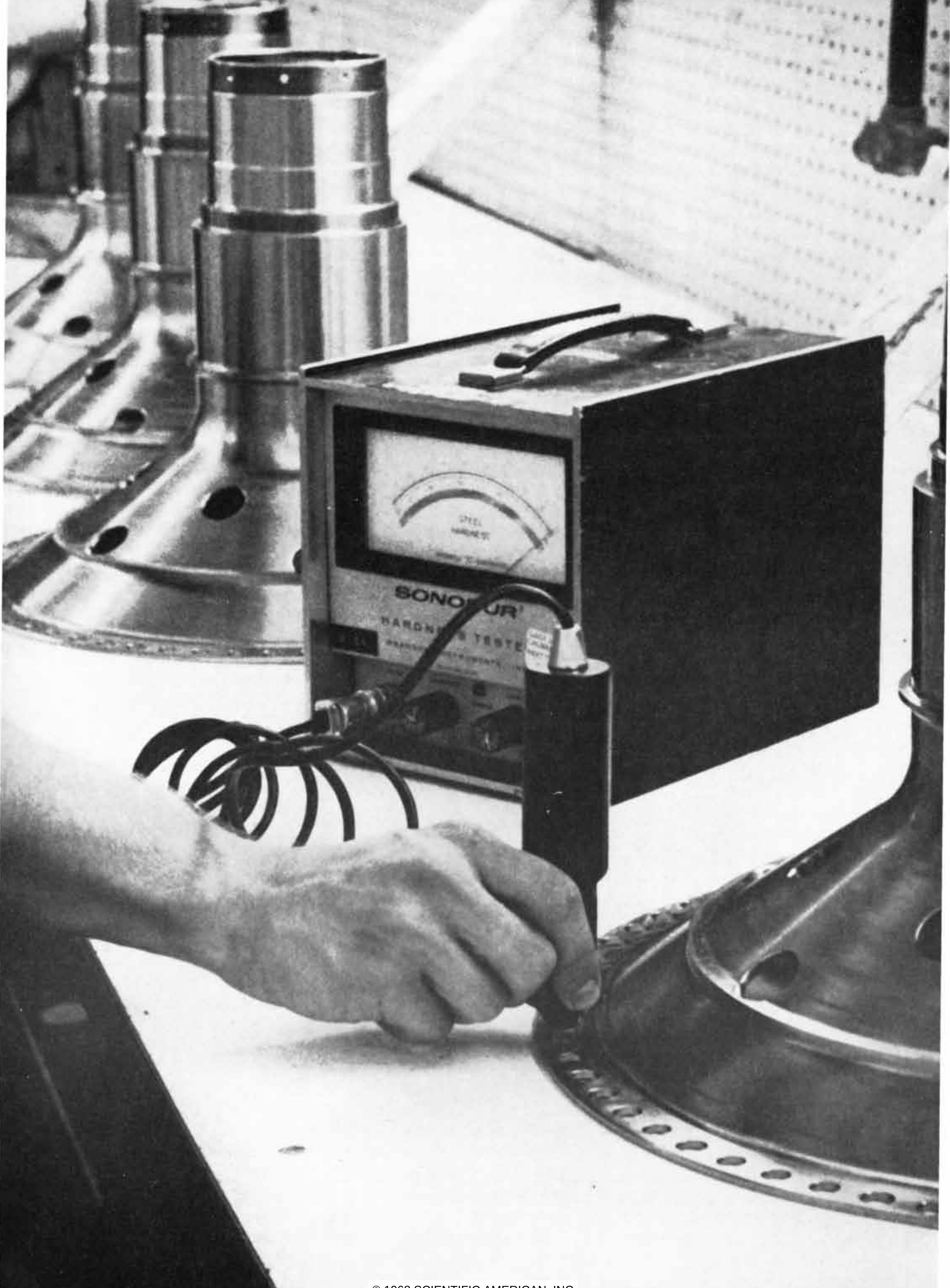
Whatever the future of Iran's qanat system may be, it stands out today as an impressive example of a determined and hardworking people's achievement. The 22,000 qanats in Iran, with their 170,000 miles of underground conduits all built by manual labor, deliver a total of 19,500 cubic feet of water per second—an amount equivalent to 75 percent of the discharge of the Euphrates River into the Mesopotamian plain. This volume of water production would be sufficient to irrigate three million acres of arid land for cultivation if it were used entirely for agriculture. It has made a garden of what would otherwise have become an uninhabitable desert. There are indications that in early times the country had a flourishing vegetation that gradually dried up, partly because of deforestation and the loss of fertile soil by erosion. The Persian people responded to potential disaster with an ingenious and farsighted solution that represents a classic tribute to human resourcefulness.

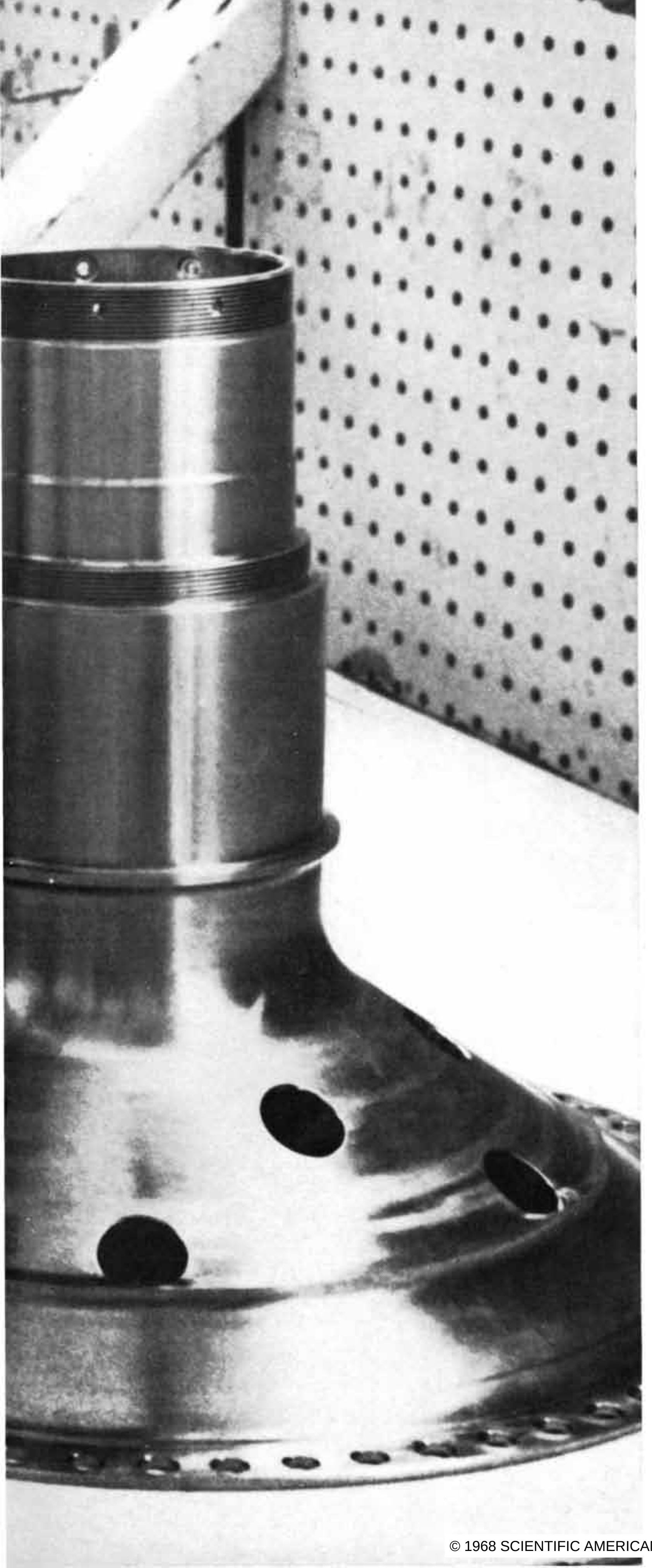


MASONRY MOUTH of an Iranian qanat is equipped with a pair of sluice gates that allow diversion of the water into separate canal systems. The amount of qanat water that may be allotted to village or individual is sometimes determined by decisions made centuries ago.



STREAM OF QANAT WATER flows past a wall-enclosed garden in an Iranian town. The stream first flows through the town and then is diverted into farm irrigation channels.





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The Sexual Life of a Mosquito

Modern methods of insect control call for detailed knowledge of an insect's physiology and behavior. Reproduction in Aedes aegypti, *the yellow-fever mosquito, is surprisingly elaborate*

by Jack Colvard Jones

The spectacular success achieved in recent years in eradicating the screwworm fly by blocking its reproduction has encouraged hopes that a similar strategy might be effective against a much more serious insect pest —the mosquito. Mosquitoes, transmitting malaria, yellow fever, encephalitis and other grave diseases, have probably caused more human deaths than any other group of insects. The control or elimination of the mosquito, like the control or elimination of any insect pest, may call for an entire arsenal of judiciously chosen methods, and new methods are constantly being sought. Among the most attractive methods are biological ones: they are aimed at a specific pest and do not involve the use of chemicals that may be hazardous to other organisms. Biological methods of control, however, require an intimate knowledge of the target species' way of life.

The surest method of eradicating a species is to destroy its ability to reproduce. In the case of the screwworm fly this was accomplished by sterilizing males and releasing them into the wild population in saturating numbers. This tactic is now being studied with various species of mosquito, and it has proved highly effective in the laboratory. Unfortunately it has not met with much success under natural conditions. Clearly there is a need for more information about the sexual life and reproductive mechanisms of mosquitoes. The relatively small amount of information already available has suggested a number of approaches to preventing the reproduction of the insect and bringing about the autocide of disease-carrying species.

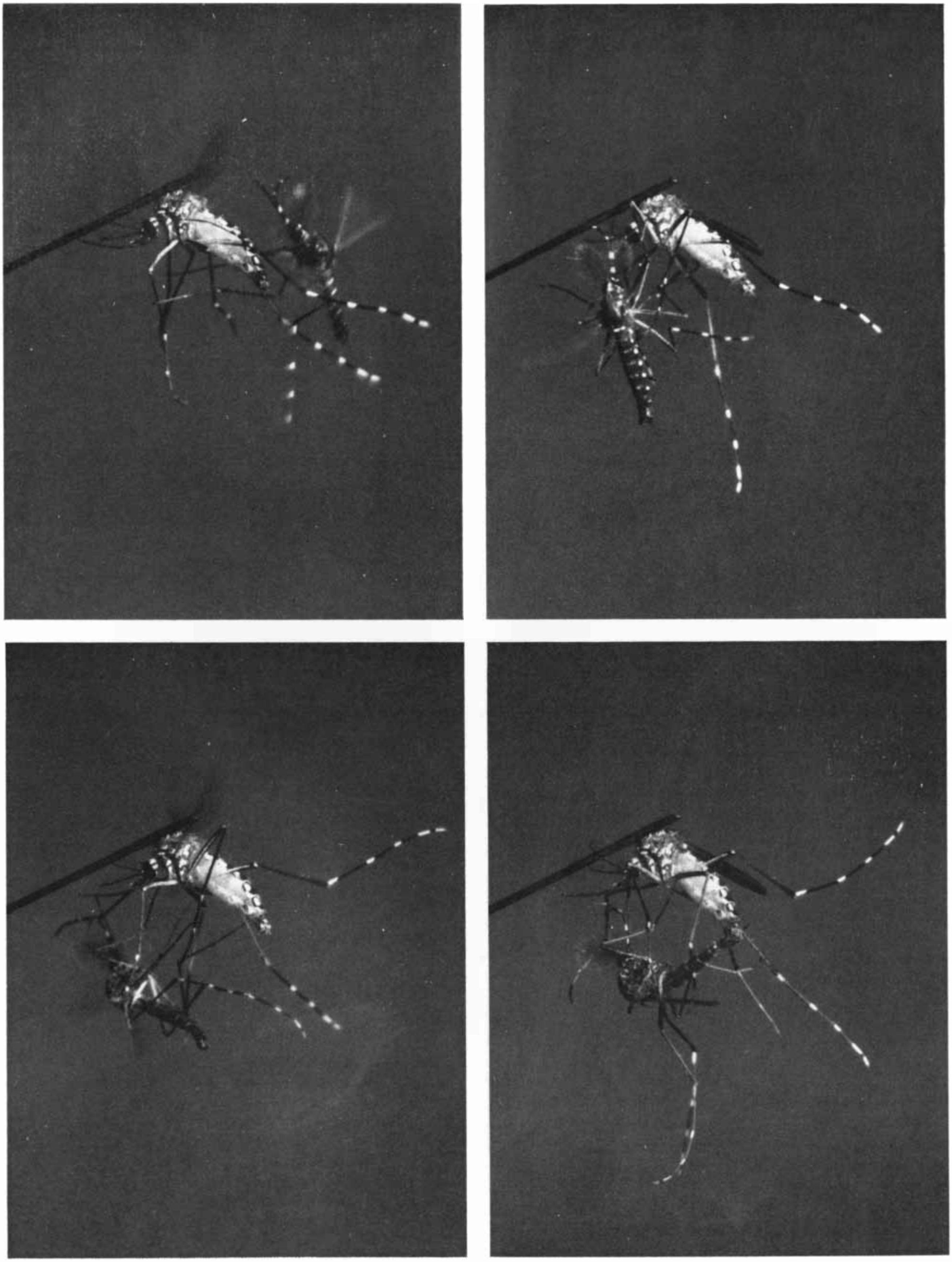
The sexual behavior of mosquitoes varies remarkably from species to species. The species for which the most detailed information has been gathered is the yellow-fever mosquito *Aedes aegypti,* which has probably caused as much human illness and as many human deaths as any other man-biting mosquito. Here I shall describe what has been learned about the sexual life of this species by many investigators, including my colleagues and myself at the University of Maryland.

Every mosquito begins its life with the fertilization of the egg. Within the protective shell of the egg the embryo develops rapidly. When eggs containing fully developed embryos are placed in water that is poor in oxygen, they give rise to larvae. In about a week the larvae are mature. All mosquito larvae go through four distinct stages of growth, shedding their old skin before each new stage. Microscopic examination of the insect in its last larval stage shows that it has already formed the rudiments of the antennae, eyes, legs and wings of an adult mosquito. The antennae are enclosed within two small sacs in the larva's head. These sacs disclose the individual's sex: if they are large and well developed, the larva will give rise to a male; if they are small and poorly developed, the adult will emerge as a female.

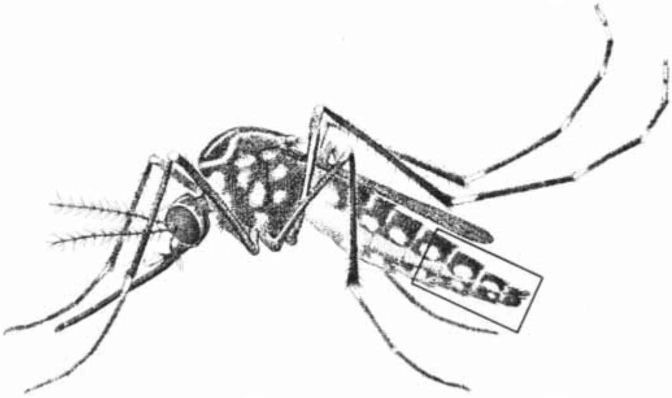
After the transformation from the larval to the pupal state, the pupa (which to the unaided eye looks something like a comma) completes the development of the anatomical structures that will characterize the adult. In this development the alimentary tract is completely remodeled, the female forms its internal reproductive organs, the male develops mature sperm in its testes and many other changes hidden from surface view take place. The decaying larval tissues provide food for the synthesis of the adult tissues. In about two days the púpa sheds its skin and the insect emerges as an adult mosquito. The female then differs from the male not only anatomically but also in behavior. For example, whereas the *Aedes aegypti* male feeds only on plant nectar and water, the female has a thirst, in addition, for animal blood—a thirst the male mosquito does not share because its proboscis lacks the necessary cutting tools.

The male is relatively small and is distinguished by large, hairy antennae. Shortly after the male's emergence into the winged state its rear end undergoes a remarkable rotation. The last two segments of the abdomen, pivoting on the membrane between the seventh and the eighth segment, begin to rotate (either clockwise or counterclockwise). In the first three hours this end portion turns 90 degrees, and by the 20th hour it has made a full turn of 180 degrees, so that the male's rear end is upside down from its original position. The change is permanent. Were it not for the 180-degree reversal of the abdominal tip, the male would be unable to copulate with the female—whose abdomen always retains its original position.

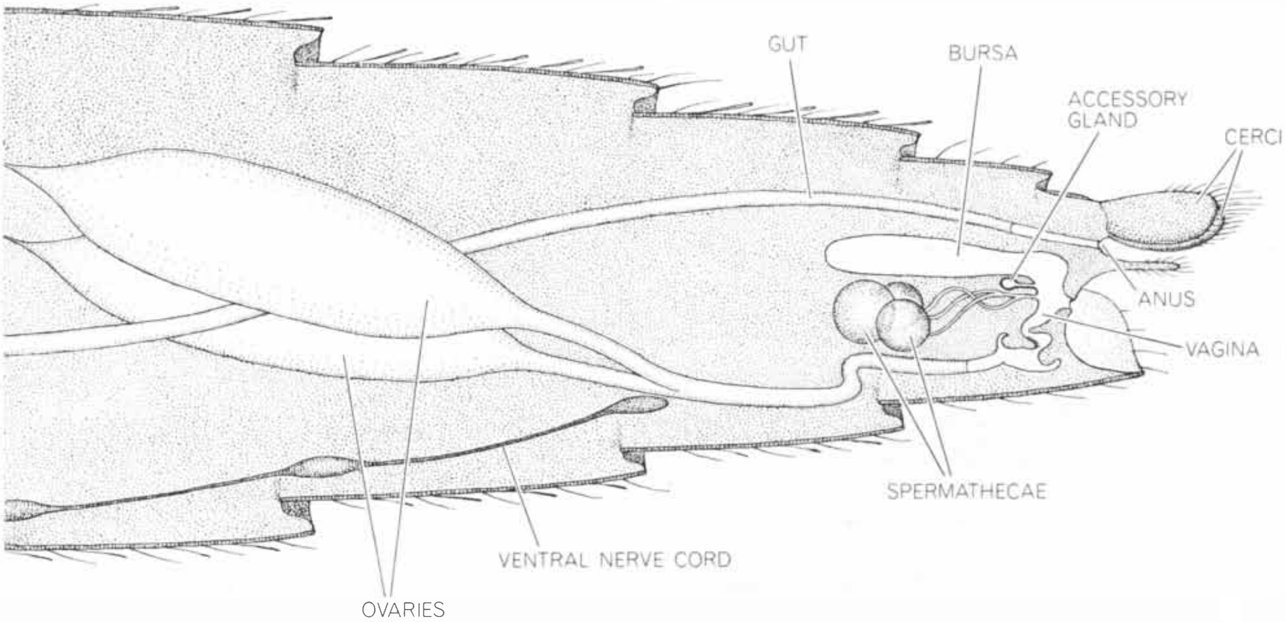
Similar rotations of the male abdomen are characteristic of all Diptera (two-winged insects). What kind of mechanism is responsible for this curious twist? The process is not fully understood. There is no indication that the muscles of the body wall cause the rotation. It appears that the twisting force may be applied by powerful rotational contractions of the hindgut, operating rather like a screwdriver. It has also been suggested that the membrane on which the end segments pivot may originally be plastic and then slowly harden during the rotation, thus fixing the rear end in the new position. The membrane itself shows no external

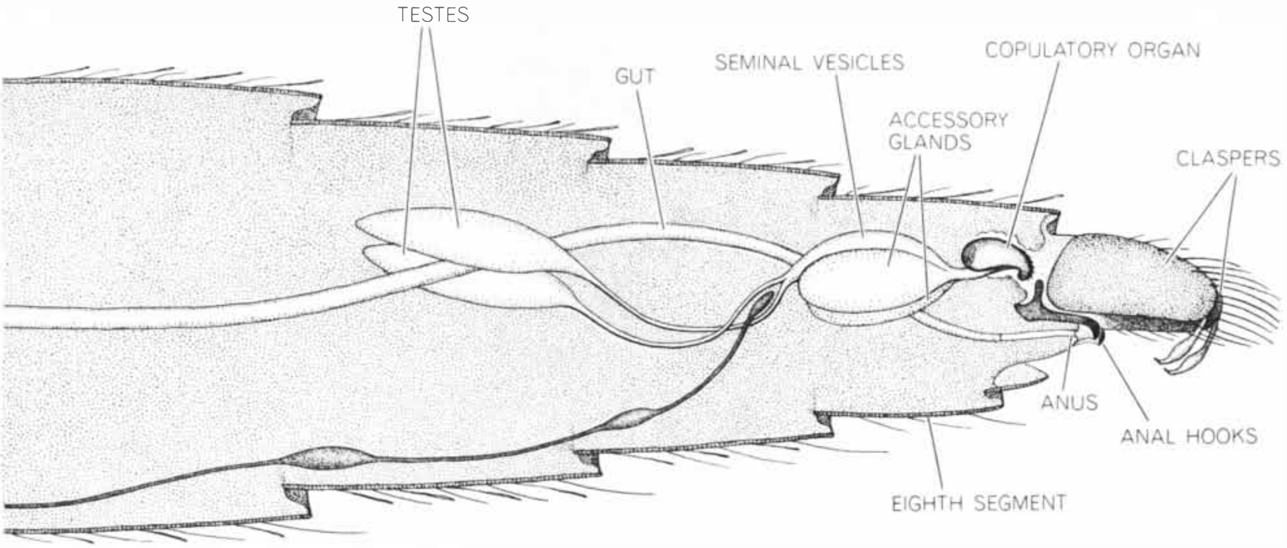


COPULATING MOSQUITOES belong to the yellow-fever species *Aedes aegypti*. The male mosquito is attracted to the female (tethered to a fine steel wire by rubber cement) by the sound of her moving wings (*top left*). With tiny hooks on his leg tips he grasps the female while swinging around to hang below her (*top right*). In this position he brings his genital organs into contact with those of the female (*bottom left and right*). These photographs and the others in this article were made by Thomas Eisner of Cornell University.



MALE AND FEMALE YELLOW-FEVER MOSQUITOES are shown 10 times actual size. The adult female (*left*) is larger than the adult male (*right*), and her antennae are less elaborate. The two rectangles outline the parts depicted in the cross sections below.





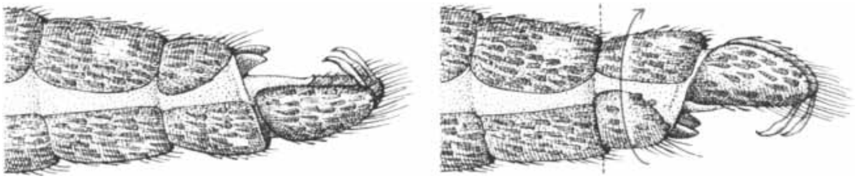
REPRODUCTIVE ORGANS of the female mosquito (*top*) and the male (*bottom*) appear in longitudinal section. The external structure of the male's genital apparatus is more complex than that of the female; her internal structure is more complex than the male's.

sign of having been twisted, but if the insect is dissected, the twist is clearly visible in internal organs such as the tracheae (air tubes), the nerve cord and the sperm ducts.

During the rotation of the male's rear end, spermatozoa from its two testes pass down thin-walled sperm ducts to fill two seminal vesicles at the end of the abdomen. The sperm, consisting of needle-like heads and long tails, all become precisely aligned inside the vesicles with the heads pointing toward the abdominal tip. On both sides of the seminal vesicles are large, pear-shaped accessory glands that secrete a major component of the seminal fluid. A small ejaculatory duct opens into the male's copulatory organ.

The genital apparatus is extremely complex [*see bottom illustration on opposite page*]. The copulatory organ itself, deeply retracted in a fleshy pocket, is composed of a hinged pair of tiny, curved plates; these are intricately attached to a pair of large claspers positioned externally on the abdominal tip. A large anal cone between the two claspers obscures the copulatory organ. On both sides of the cone are hooks that serve as grasping accessories. The external genital structures of male mosquitoes are so intricate and distinctive that taxonomists use them to identify many mosquito species.

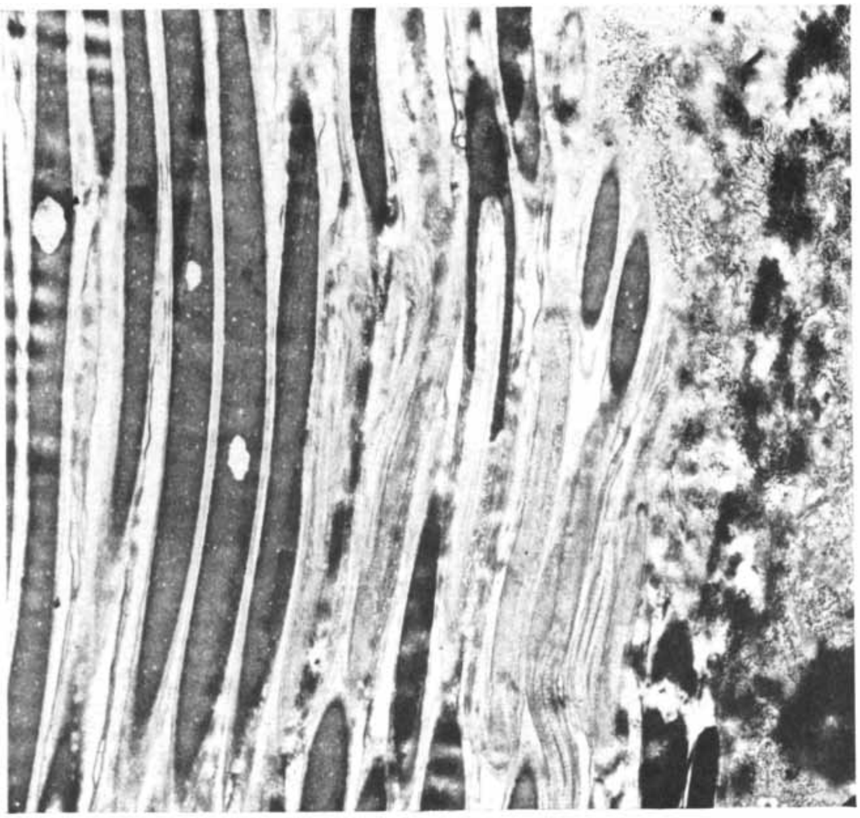
Whereas the male mosquito's reproductive system is complex on the outside and relatively simple on the inside, the female's is relatively simple on the outside and complex on the inside. Externally it consists of two paddle-like plates (called cerci) with long sensory hairs above the anus and a long tonguelike structure next to the retracted vagina below the anus. The vagina is S-shaped and contains three interlocking valves of different shapes, one of them with teeth along its tip. Four distinct internal structures open into the vagina: a sac called the bursa, which first receives sperm from the male; a tiny, globular accessory gland; three spherical organs called spermathecae to which the sperm migrate by way of a tiny funnel and long, twisted ducts, and a long oviduct through which the eggs pass from the ovaries.



ROTATION of the tip of the male mosquito's abdomen takes place early in adult life. Before the 180-degree turn (which may be clockwise or counterclockwise) the clasper claw points up (*left*); it points down when the turn is completed about 20 hours later (*right*). With the tip reversed, copulation can occur (*see illustrations at bottom of next two pages*).

In general female mosquitoes must feed on blood to develop eggs. Some species can develop the first batch of eggs without having had a blood meal, but even these require blood in order to lay subsequent batches. Some species must have more than one blood meal before their eggs can mature. The blood meal initiates a chain of essential physiological events in the female. It is believed that her stomach, greatly distended by the drink of blood, presses on the nerve cord and causes it to send electrical signals to the brain. Within an hour the message excites certain cells in the upper part of the brain to secrete a hormone into the insect's circulating body fluid, and this in turn results within a few hours in the secretion of a secondary hormone from a pair of small glands in the female's neck. The latter hormone triggers a spectacular series of events in the ovaries. Submicroscopic pits (as many as 300,000 of them) appear on the surface of the egg. The eggs then begin to imbibe protein from the fluid in the ovary that collects in the surface pits; droplets of yolk form rapidly and soon fill the egg. The egg cell enlarges enormously and the egg nucleus, originally large, shrinks to a tiny mass of genetic material. A thin shell forms over the egg within the ovary.

A female mosquito that has fed on blood will produce and lay eggs even if she has not been fertilized. Fertilization, however, strikingly increases her egg production. Immediately after her blood meal the female is not very attractive to males, but at any other time she attracts them instantly merely by flying about. The males are drawn by the buzzing sound of the wings. The attractive

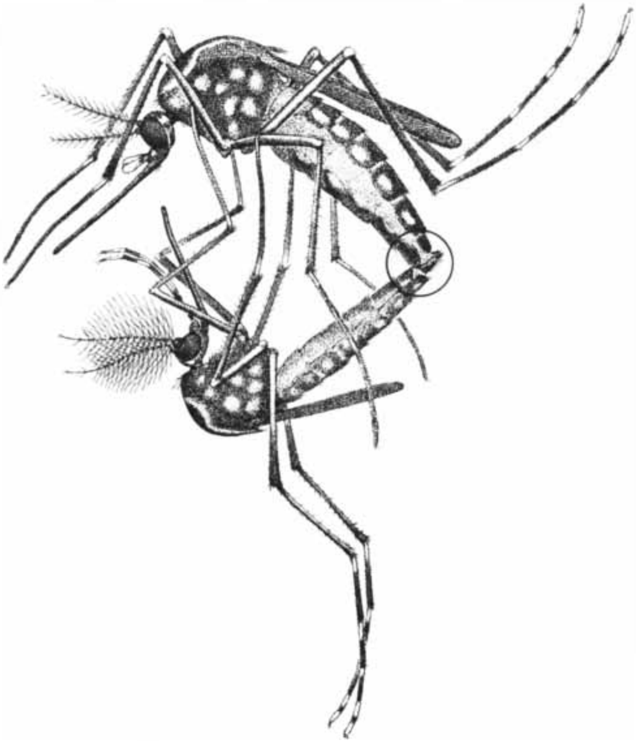


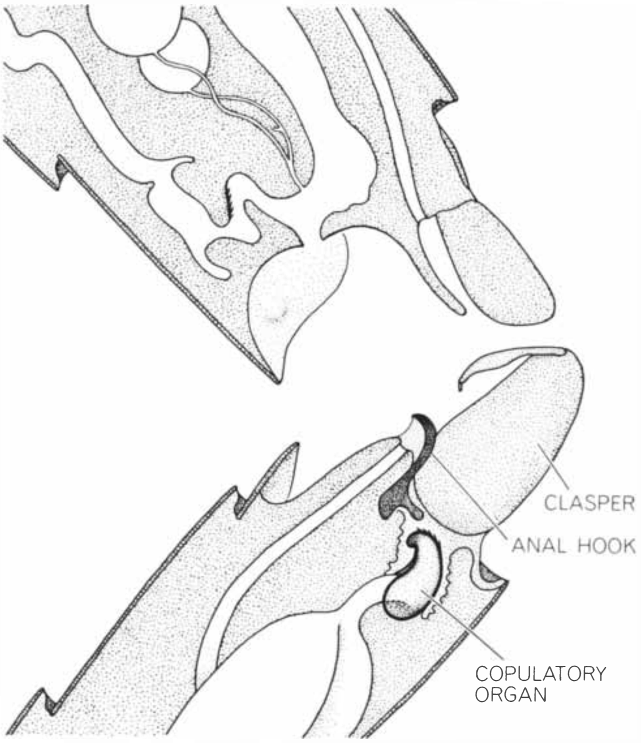
SPERM inside the seminal vesicle, the male's storage sac, are precisely aligned. The headpieces (*dark cigar-shaped areas*) all point in the same direction. The tails are wormlike. At right is the wall of the vesicle (*mottled area*). Magnification in this electron micrograph, made by Victor H. Zeve of the National Institutes of Health, is about 15,000 diameters.

FEEDING on human blood from an index finger, a female yellow-fever mosquito appears at left. The needle-like part of the proboscis is piercing the skin. At right the mosquito is seen with abdomen swollen from the blood meal. Only the female insect drinks blood.

sounds are in the range between 300 and 800 vibrations per second. Experiments conducted by Louis M. Roth, then at the U.S. Army Quartermaster Research and Development Center, show that a male mosquito will pursue a sound in this range regardless of the source—whether it is male or female, of its own or another mosquito species or even simply a tuning fork. (Mature females and males just emerged from the pupal state beat their wings at about the same rate and are pursued by older males; young, newly emerged females have a different beat and therefore are not pursued.) According to Roth, the male's hearing range is only about a foot. Roth has also demonstrated that the male is deaf to the flying female if his antennae are removed or prevented from vibrating.

The stimulating sound causes the male not only to pursue the source but also to seize it with his claspers. He will clasp the cloth walls of a cage if a tuning fork





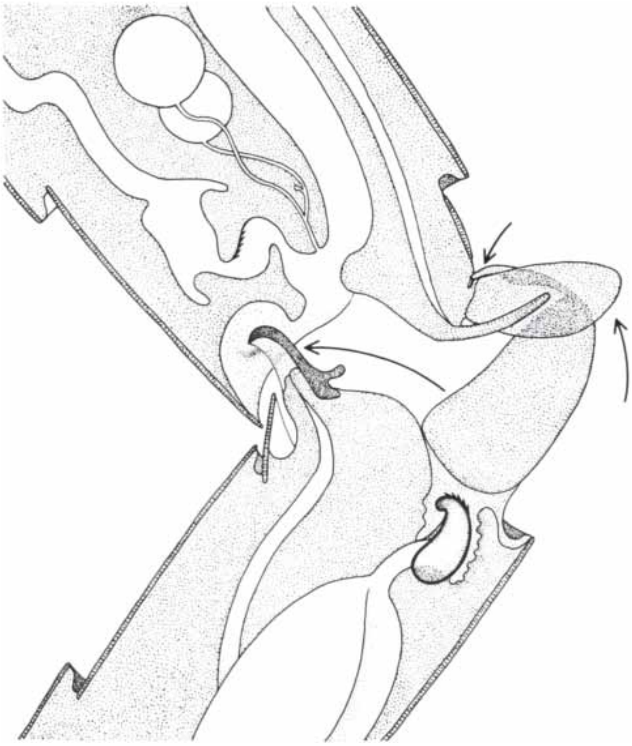
COPULATORY POSITION, bringing the male yellow-fever mosquito below the female, is shown at left. In the schematic diagram at right of the anatomy of the male and female insects, the organs are drawn as they appear before coital contact. The male's copulatory organ (here retracted), the anal hook and the clasper are rigid elements; in coitus they stretch and distort the female's more flexible tissues.

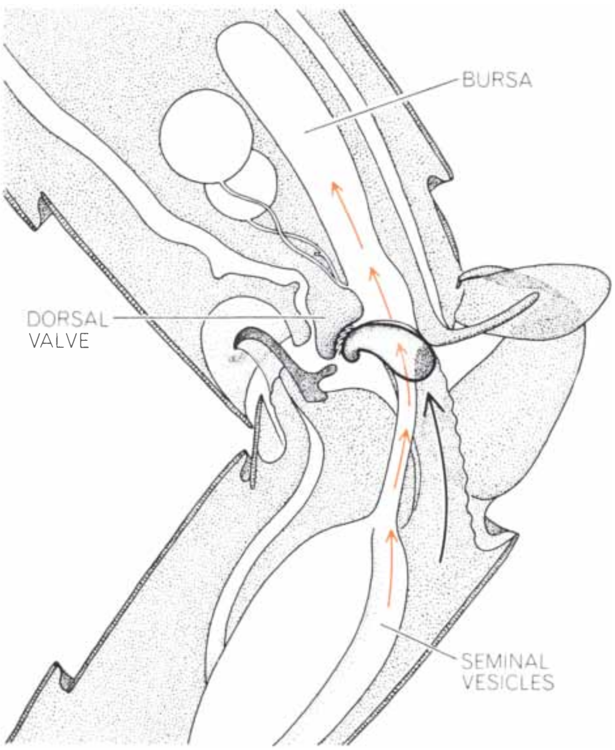
is sounded outside the walls, and indeed will seize anything that comes within his reach in the direction of a suitable vibrating source, including a male mosquito.

The process of copulation with a female is rapid but complex. On reaching the flying female the male first seizes her back with his legs, the tips of which are equipped with little grappling hooks. Then, with remarkable agility, he swiftly swings around until he is hanging face-to-face below his partner. The female, exhibiting no obvious response, may continue her flight, or the pair may fall to the floor of the cage. In either case the male quickly proceeds to bring his genitalia into contact with those of the female [*see illustrations at bottom of opposite page and below*]. His claspers grasp her cerci; this causes the tongue-like plate under her anus to move upward and expose the edges of the vagina. The male then uses his anal hooks to pull the female's genitalia toward him. He rapidly extends his previously retracted copulatory organ so that teeth at its tip mesh with the teeth on the dorsal valve in the vagina. The forceful entry everts the valve, and the hinged plates of the male's organ then spread out and widen the vagina, enlarging the opening into the bursa. At that instant the male organ discharges a large quantity of seminal fluid, containing about 2,000 sperm, into the bursa. The pair then quickly separate, frequently with a parting kick against the male by the female's hind legs. The entire copulatory act takes from 14 to 20 seconds under natural circumstances, and about 30 seconds when a nonflying pair of mosquitoes are artificially induced to mate in the laboratory under a microscope.

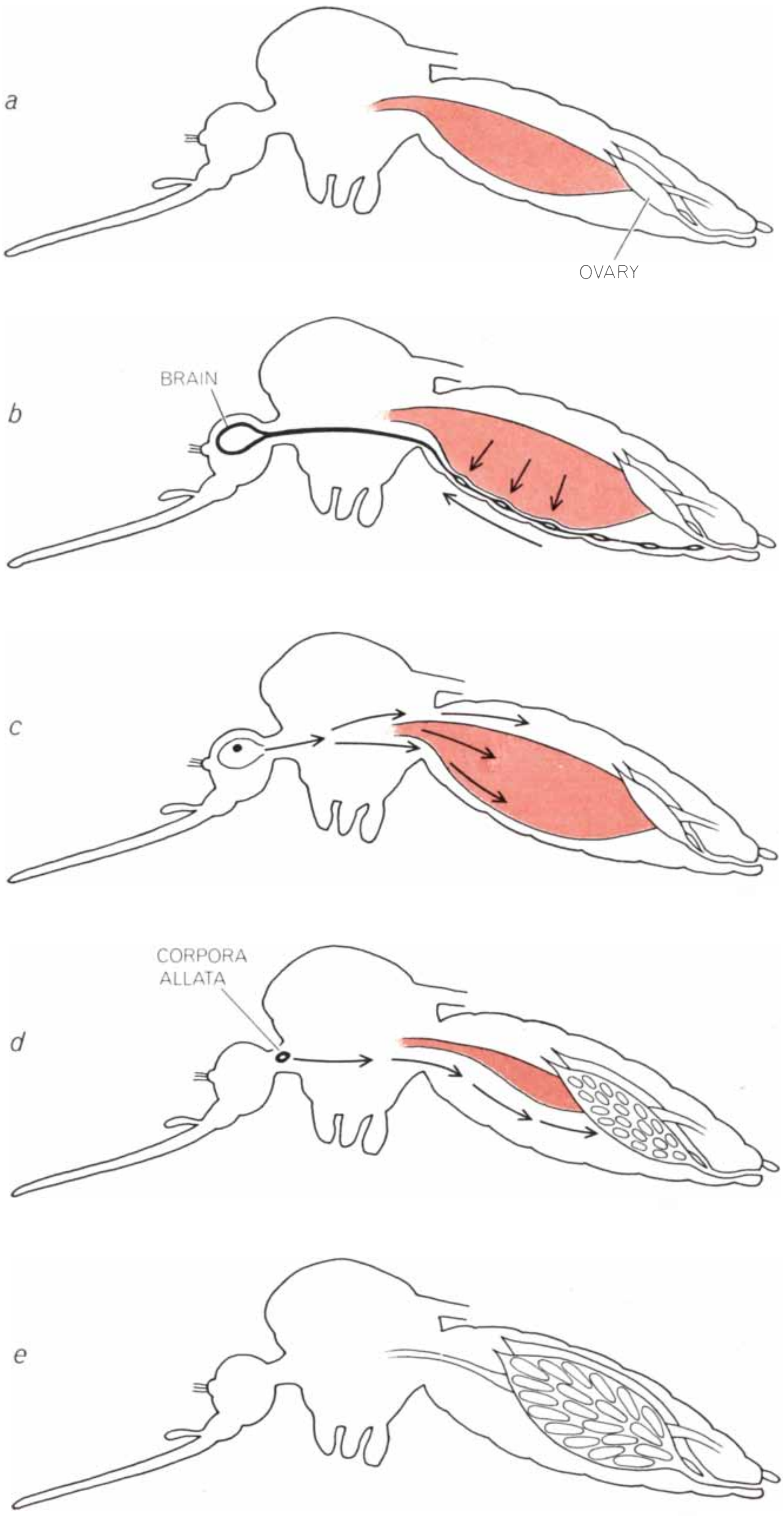
Experiments in our laboratory have established that an *Aedes aegypti* male can be induced to mate mechanically if its rear end is placed in contact with the genitalia of an unfertilized female. The technique is quite simple. A male and a female are lightly anesthetized, a drop of glue is put on the head of a pin and the glue is applied to the abdomen of each insect. The mosquitoes are then rubbed together while being observed under the microscope. The technique makes possible a number of experiments that otherwise could not be done. With it we have demonstrated that the rear end of the male alone, immediately after being severed from the rest of the body, is capable of copulating with and inseminating a female. A noteworthy and perhaps critically important finding is the fact that in such experiments only the rear end of an unfertilized female will cause the male to extend his copulatory organ and ejaculate. When a fertilized female is offered mechanically to a male under the microscope, he somehow recognizes instantly that she has been mated and he makes no attempt to copulate with her; indeed, he frequently draws away. A flying female, however, may induce the male to copulate even if she has been fertilized. Andrew Spielman and his colleagues at the Harvard School of Public Health have recently found that if these females are reinseminated, the mass of semen is rapidly ejected. Presumably the enticement of the female's buzzing overrides the male's recognition of her fertilized condition.

A male mosquito can inseminate five or six females in rapid succession. He may copulate with many more—as many as 30 within 30 minutes—but his supply of seminal fluid and sperm is exhausted after five or six matings. It takes about two days for the male to refill the seminal vesicles with a fresh supply of sperm and





COPULATION begins as the male grasps the female with clasper and anal hook, thereby pulling her genitalia closer and enlarging the vagina entrance (*left*). The copulatory organ then thrusts forward, engages the teeth of the dorsal valve and spreads to widen the entrance into the bursa (*right*). In this position the male ejaculates into the bursa sperm from the seminal vesicles (*colored arrows*).



DEVELOPMENT OF EGGS begins after the female mosquito imbibes blood (*color*) and her gut distends (*a*). The gut then presses on the ventral nerve cord and signals are sent to the brain (*b*). In response certain brain cells secrete a hormone into the insect's circulating fluid (*c*), giving rise to the secretion of a second hormone by the corpora allata (glands in the neck). With the arrival of this hormone at the ovary (*d*), protein from the blood enters the ovary fluid and is taken up by the eggs. Yolk droplets form and eggs enlarge (*e*).

regenerate the accessory-gland material.

Let us turn our attention now to the female. After her bursa has been filled with semen from the male the long, threadlike sperm swim toward the opening of the bursa and line up in dense bundles with their tails undulating rapidly. They remain there for 30 to 40 seconds. Then groups of the sperm abruptly make a sharp U-turn, swim to the funnel leading to the spermathecae and make their way up long, twisted ducts to those receiving organs. Generally they reach only two of the three spermathecae. Within less than five minutes the migrating sperm (perhaps 1,000 of them, probably together with seminal fluid) have filled the two reservoirs, and there the sperm swim rapidly in circles and remain active as long as the female lives. In short, once the female has been mated, she is fertilized for the rest of her lifetime.

The behavior of the sperm in the female's reproductive tract presents several puzzles. Why do the highly active sperm wait in the bursa for 30 to 40 seconds before starting their journey to the spermathecae? How do they make their way there without error, although neither the bursa nor the ducts provide contractions that might give them direction? Why do no sperm or so few sperm enter the third spermatheca? Curiously, our experiments have failed to develop any definite proof that the sperm can actually travel to the spermathecae without assistance. In fact, our efforts to fertilize females by artificially inseminating their bursae with highly active sperm and accessory gland material have generally been unsuccessful. We deduce from these facts that in some unknown way the female exercises a control of her own over fertilization.

At all events, the consequences of her fertilization are quite clear. The sperm that reach her spermathecae enable her to produce fertile eggs. And a fertilized female lays a great many more eggs than an unfertilized one, as a result of the slow absorption into her body of the seminal material (sperm and granular material from the male's accessory glands) that remains behind in her bursa after the migration of sperm to the spermathecae stops. It is not clear how the spermatozoa get out of the spermathecae to reach the egg. The sperm cell does, however, enter the egg through a specialized tiny opening at its front end just as it is laid.

The female lays her eggs one at a time. After finding a suitable water site for depositing them, she first lifts her

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hind legs and fans them up and down. Then she wipes the tip of her abdomen with them and vigorously scrubs them together. The tip of the abdomen almost touches the water surface. Her cerci and the tonguelike plate below the anus are pressed close together and point down. As an egg descends from the ovary through the oviduct there is considerable contraction and twitching of the genital structures, particularly the edges of the vagina. In emerging from the vagina the large white egg pushes the cerci and subanal plate upward, everts the vaginal opening and then drops into the water. One egg follows another until the female has delivered her batch. Some species of mosquito array the eggs in rafts on the water. Some species lay their eggs while hovering over the water, the eggs dropping like little bombs. Others eject their eggs into water that has collected in the hollow of a tree. There is even a mosquito that lays her eggs on her hind legs and then dips her legs into the water to set the eggs free.

The female mosquito has a remarkable capacity for retaining eggs in her ovaries after the eggs have fully ripened. The majority of mosquitoes will not lay eggs unless they have located an appropriate site for them. We have been able to force such females to deposit their eggs under the microscope, however, by a shock treatment such as crushing the head or thorax or cutting off the head or abdomen. Within less than a minute after the injury eggs begin to emerge from the vaginal opening, and occasionally a considerable number will be laid.

We have also investigated the action of portions of the egg-delivering system. If the ovary itself is cut away from the body when it is greatly distended with ripe eggs and placed in a drop of saline solution on a glass slide, eggs will slide out through the open end. It appears, however, that in normal circumstances the main force for drawing eggs out of the ovary under natural conditions comes from vigorous rhythmic contractions of the internal oviducts (the exit ducts of the ovaries). Ordinarily the lateral oviducts are constricted, and this constriction may be responsible for the ovary's retention of ripe eggs until the female has found a suitable site in which to lay them.

The female mosquito invariably lays her eggs in daylight, principally in midafternoon between 2:00 and 3:00 P.M. It has been demonstrated by A. J. Haddow and J. D. Gillett of the East African Virus Research Institute in Uganda that light controls the egg-laying rhythm (perhaps by activating some hormone); these workers showed that the mosquito will lay her eggs in the nighttime hours and refrain in the daytime hours if the light cycle in her cage is reversed.

A female that is ready to lay eggs explores possible sites primarily with her feet. She flies about and alights on various water surfaces, setting all six legs down on the water. The hairs on her legs evidently possess a chemical sensitivity, particularly to salinity. It has been shown by Robert C. Wallis, who was then at the Johns Hopkins School of Medicine, that they can distinguish between distilled water and weak saline solutions. Most species of mosquito prefer fresh water for laying their eggs, but some favor brackish waters. On finding a favorable site the female walks to the edge of the water and lays her eggs there.

Soon after they are laid the white eggs swell and turn black. Normally the egg hatches into a larva in two days. If the conditions are not suitable, the larva, even though they are fully developed within the shell of the egg, can remain alive for a considerable time. Charles L. Judson of the University of California at Davis has shown that when such eggs are placed in water with a low oxygen content, the pharynx of the larvae suddenly becomes active. It makes rapid swallowing motions, apparently without actually imbibing fluid, and proceeds to break out of the shell. A small spine on top of its head presses against the shell along a preformed line and the top of the shell neatly snaps off.

The larva wriggles out quickly, air suddenly enters its breathing tubes, which take on the appearance of silvery capillaries, and its heart begins to beat. The insect at once starts to feed, and so a new cycle of mosquito life gets under way.

There are definite periods in the life cycle of mosquitoes in which reproduction can be profoundly affected by some specific treatment. William R. Horsfall and J. R. Anderson of the University of Illinois have demonstrated, for example, that the sex of larvae in certain strains of mosquito can be completely reversed by subjecting the larvae to a certain temperature at a certain period. Many other entomologists are examining similar phenomena in the sexual life of mosquitoes in the hope of finding some way of eliminating the insect when it is not wanted.

Principles of Geology

JAMES GILLULY, University of California, Santa Cruz, formerly of the U. S. Geological Survey,
AARON C. WATERS, University of California, Santa Cruz, and A. O. WOODFORD, Pomona College

Publication date: April 1968

In this, one of the most influential and widely used textbooks in geology, the authors give the student an understanding of geologic concepts, processes, and principles instead of a catalogue of technical terms. Avoiding an authoritarian approach, they provide him with some insight into the nature—and intrinsic uncertainties —of geologic evidence.

ABOUT THE THIRD EDITION: The authors have completely rewritten from new outlines more than half of the book and have revised and updated every chapter to take account of new developments since 1958. Much new quantitative information has been incorporated, and interesting and controversial subjects—both new and old— are reevaluated. Among the topics given increased attention are sea-floor spreading, magnetic reversals, submarine volcanism, continental drift, and the origin of life. From this analysis of thought-provoking topics emerged the need for an entirely new chapter entitled "Speculations about the Origin of the Earth and of Life," the final chapter in the third edition. Appendix V, "Fossils," is also new. Many new illustrations have been added, and color is used in most line drawings for added clarity.

Teachers are invited to write for examination copies on their departmental letterheads.

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MATHEMATICAL GAMES

Puzzles and tricks with a dollar bill

by Martin Gardner

A remarkable variety of small man-made objects lend themselves to tricks and puzzles that are sometimes mathematical in character. This month we take a not so serious look at some puzzling aspects of dollar bills.

A curious folding stunt involving symmetry operations on the rectangular shape of a bill is well known to magicians. The performer holds the bill at each end, with the picture of Washington upright [*see illustration on opposite page*]. He folds the bill in half lengthwise, then in half to the left and once again in half to the left. Then he unfolds the bill, apparently by reversing the three previous steps, but now Washington is upside down! When others try to do the same thing, the bill stubbornly refuses to invert.

The secret lies in the second fold. Note that it is made by carrying the right half of the bill *behind* the left half. The third fold is made the opposite way. When those two folds are undone, they are both opened to the front. This has the effect of rotating the bill 180 degrees around a vertical axis, as you will see by comparing the bill at step 2 with the bill at step 6. Even so, the final inversion comes as a surprise. One must practice until the three folds can be made smoothly and quickly. The unfolding should be slow and deliberate while you assert (magicians have the privilege of fibbing) that you are carefully repeating the same three steps in reverse time sequence.

Origami experts have devoted much time to devising ways of folding dollar bills into such things as a finger ring, bow tie, peacock, rabbit in hat; indeed, two treatises on this have been published by the Ireland Magic Company of Chicago: *The Folding Money Book* by Adolfo Cerceda (1963) and *The Folding Money Book Number Two* by Samuel and Jean Randlett (1968). The folds described in those books are rather complicated, but here is a simple and amusing one that readers are invited to discover for themselves before the solution is given next month. How can a dollar bill be given two creases in such a way that it makes the best possible picture of a mushroom?

All bills have identifying eight-digit serial numbers, and of course those numbers can figure in many different kinds of mathematical diversion. Has the reader ever played dollar-bill poker? Each of two players takes a bill from his pocket and the two then alternate claims of a pair or better, using the digits of the serial number as if they were cards. No straights or full houses are allowed, but sets of like digits may go higher than four of a kind. At each turn a player must raise his claim or call. Bluffing is permitted. After a call both numbers are inspected and the player who made the last claim is allowed to use the serial numbers on *both* bills to satisfy his claim. For example, if he had claimed six 3's and there are two 3's in his serial number and four or more in his opponent's, he wins his opponent's dollar. Otherwise he loses his dollar.

A trick that was a favorite of Royal V. Heath, a New York stockbroker and amateur magician who in 1933 wrote a book called *Mathemagic,* begins by someone's being asked to take a dollar bill from his pocket and look at the serial number. He calls out the sum of the first and second digits and then the sum of the second and third digits, the third and fourth, and so on to the end. For an eighth and final sum he adds the last and *second* digits. The performer jots down these eight sums as they are called. Without making any written calculations he immediately writes out the bill's serial number.

The problem is one of solving quickly a set of eight simultaneous equations. The solution goes back to Diophantus, a third-century algebraist who lived in Alexandria; the earliest presentation of it as a trick that I have found is in *The Magician's Own Book* (Dick and Fitzgerald, 1857). The anonymous author explains a simple procedure for calculating the original number: Add the second, fourth, sixth and eighth sums; subtract the sum of the third, fifth and seventh sums; halve the result. This can be done easily in the head as the sums are called out. Starting with the second sum, the numbers are alternately subtracted and added as shown schematically on page 120. Halving the final result gives the second digit of the serial number. Instead of calling it out, however, the performer subtracts it from the first sum so that he can write and call out the serial number's first digit. It is a simple matter to give the remaining digits in order. The second is already known. Subtracting it from the second sum gives the third digit of the serial number. The third digit subtracted from the third sum gives the fourth digit, and so on to the end.

The trick is not limited to the digits of eight-digit numbers. It applies to any series of real numbers, positive or negative, rational or irrational. If there is an even number of numbers in the series, the procedure just explained is used. If there is an odd number of numbers, you ask that the final sum be that of the last and *first* numbers. Instead of ignoring the first sum, start with the first sum and alternately subtract and add. Halving the final result then gives the first (not the second) number in the original series. Suppose, for instance, the series is 100, −27, 2/3, −1, 2,456. The five sums will be 73, −26⅓, −1/3, 2,455 and 2,556. When these are alternately subtracted and added, the result is 200. Half of 200 is 100, the first number of the original series.

Many tricks with serial numbers are based on what magicians call the "nine principle," which in turn derives from the fact that our number system is based on 10. For example, ask someone to take a bill from his pocket while you stand with your back turned. Have him jot down its serial number. Tell him to scramble the eight digits—that is, to write them down in any order—to make a second eight-digit number and then to subtract the smaller number from the larger. With your back still turned, ask him to cross out any digit (except zero) in the answer and then call out to you, in any order, the remaining digits. You immediately name the digit that he crossed out.

The secret lies in the fact that if any number is scrambled and the smaller number is taken from the larger, the difference has a digital root of 9. An example will make this clear. Suppose the serial number is 06281377 and that this is scrambled to 87310267. The difference is 81028890. The digital root of this number is obtained by adding the digits in any order, casting out nines as you go along. Eight plus 1 plus 2 is 11, but in your mind you add the digits of 11 and remember only 2, which is the same as taking 9 from 11. Continue in this way, adding the digits whenever a partial sum has more than one digit. The single digit at the finish is the digital root. Since the number obtained by subtraction is certain to have a digital root of 9, it is easy to determine the missing digit. Merely add the digits as they are called, casting out nines as you go along. If the final digit is 9, your subject must have crossed out 9. Otherwise take the final digit from 9 to get the crossed-out digit.

Many other procedures also result in numbers with digital roots of 9. For instance, your subject can add the digits of the serial number and then subtract the sum from the serial number. Or he can add the digits, multiply by 8 and add the product to the original number. Instead of naming a number crossed out in the final result, you can calculate a person's age by asking him to add his age to the final result and call off, in any order, the digits in the sum. What you do is obtain the digital root of the numbers called out and then keep adding nines to it mentally until you reach what you estimate to be his age. Suppose a woman follows any of the above procedures that produce a number with a digital root of 9. She adds her age and gives you, in scrambled order, the digits in the sum. Assume that they have a digital root of 4. In your mind you simply tick off: 4–13–22–31–40–49 and so on, picking the number that seems most likely to be her age. (When in doubt, pick the lower!)

For another trick based on the nine principle, obtain a bill with a serial number that has a digital root of 9 and carry it with you. You ask someone to jot down eight random digits but, before he starts, you appear to have an afterthought. Take out your bill and tell him to use the digits of its serial number; it is a handy way, you explain, to obtain random digits. While your back is turned he can scramble the number and *add* the two eight-digit numbers, and you can proceed with any of the tricks described above. Indeed, he can form as many scrambled eight-digit numbers as he wishes; their sum will always have a digital root of 9. He can scramble and multi-

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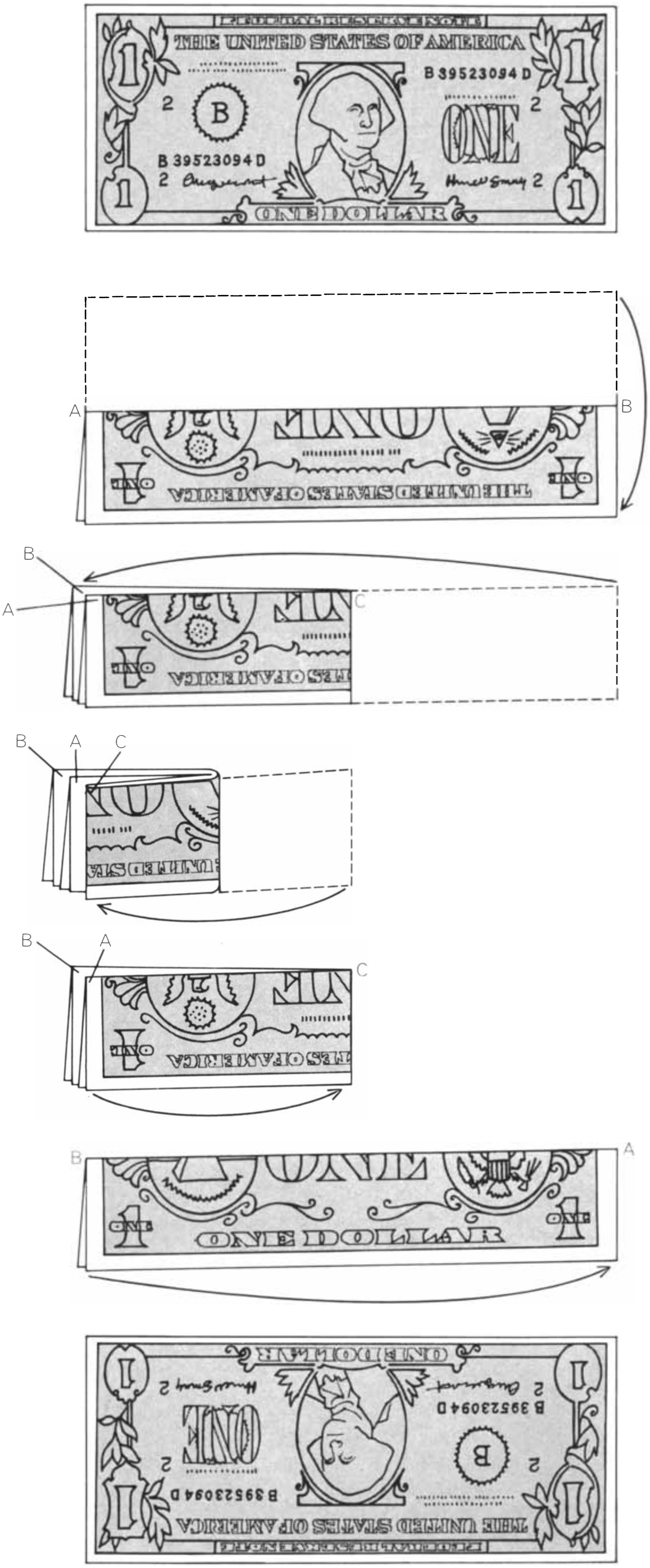
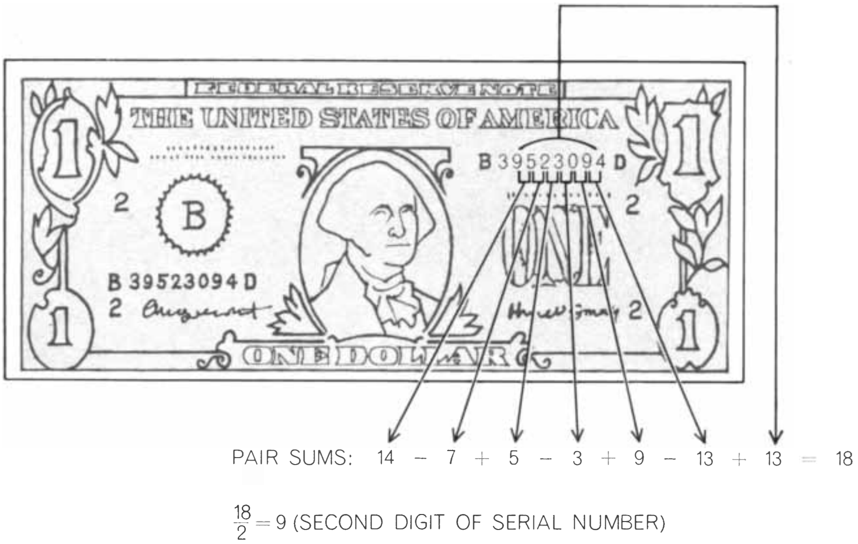


Inverting a dollar bill



An ancient formula solves a dollar-bill trick

ply by any number; the product will have a digital root of 9. If he suspects that your bill is a special one and insists on using one of his own, shift to one of the previously described procedures.

A bit harder to puzzle out is the following serial-number stunt that appeared recently in a magic periodical with the unlikely name *The Pallbearers Review*. The subject writes down the serial number of his own bill, reverses it and adds the two numbers. He crosses out any digit and reads the result aloud, substituting x for the missing digit. Suppose the serial number is 30956714. The subject begins by adding this to its reversal, 41765903. He crosses out 6 in the sum and reads aloud: 72722x17. How can you figure the missing digit? The nine principle is not involved here; I leave it as a second problem to be answered next month.

Serial numbers serve, of course, to forestall various kinds of criminal activity, but there is at least one swindle in which a bill's serial number plays an essential role. The fraud pops up from time to time in American bars. A man at one end of the bar starts doing magic tricks for the bartender and customers seated nearby. After a few tricks he announces that he will perform the most sensational trick he knows. It requires a $10 bill. He asks the bartender to lend him such a bill and, to make sure that the identical bill is returned, asks him to copy down the bill's serial number. The magician folds this bill and apparently seals it in an envelope. Actually it is passed through a slot in the back of the envelope and palmed. The empty envelope is burned in an ashtray, seemingly destroying the bill. While the envelope burns, the magician secretly passes the bill to a confederate as he walks by on his way to the other end of the bar. The confederate uses the bill to pay another bartender for a drink. After the envelope is burned the magician tells the bartender to look in his cash register, where he will find the original bill. The bill is found, its serial number is checked, everyone is flabbergasted, and the two swindlers leave with a profit of about $9 in change.

Does the reader know how to use a dollar bill as a ruler? The distance from the right side of the shield below the eagle to the right margin of the bill is one inch. The width of "United States" at the top of the green side is two inches. The rectangle containing the words "Federal Reserve Note" at the top of the bill's face is three inches wide. The bill itself is three-sixteenths of an inch longer than six inches. Eliminate one margin and you come very close to six inches.

I conclude with a series of puzzles, all concerning a $1 bill unless otherwise specified:

1. The numeral 1 appears in 10 places on a dollar bill, not counting those numbers that vary from bill to bill but including the 1 in 1963 and the Roman numeral I below the pyramid. How many times does a *word* for 1 appear?
2. How many times does the word "ten" appear on a $10 bill?
3. Find the date 1776 on a dollar bill.
4. Find a picture of a door key.
5. Find a word that is an anagram of "poetics."
6. Find a word that is an anagram of "a night snow."
7. Find these four four-letter words: "sofa," "dose," "shin," "oral."
8. Find "Esau" and "Iva."
9. Find the phrase "at sea."
10. Find a Spanish word printed upside down.
11. Find a word with "O" as one of its letters, but an "O" pronounced like a "W."
12. What is the meaning of the eye above the pyramid and who suggested that it be put there?
13. On a $5 bill find "New Jersey" and the number 172.

Last month's first problem was to find a rule, given a perfect number's Euclidean formula, for writing that number in binary form. The formula: $2^{n-1}(2^n - 1)$. The rule: Put down n ones followed by $n - 1$ zeros. Example: Perfect number $2^{5-1}(2^5 - 1) = 496$ has the binary form 111110000.

The rule is easily understood. In binary form 2^n is always 1 followed by n zeros. The expression on the left side of Euclid's formula, 2^{n-1}, therefore has the binary form of 1 followed by $n - 1$ zeros. The parenthetical expression $(2^n - 1)$, or one less than the nth power of 2, has the binary form of n ones. The product of these two binary numbers obviously will be n ones followed by $n - 1$ zeros.

Readers will find it amusing to test a theorem given last month, that the sum of the reciprocals of the divisors of any perfect number (including the number itself as a divisor) is 2, by writing the reciprocals in binary form and then adding.

There are several ways to state rules for determining the final digit of a perfect number by inspecting its Euclidean formula, but the following rule seems the simplest. It applies to all perfect numbers except 6. Halve the first exponent and note whether the result is even or odd. (If the exponent has more than two digits, only the last two must be halved to obtain this result.) If even, the perfect number ends in 6; if odd, it ends in 8. Example: The 23rd perfect has the formula $2^{11,212}(2^{11,213} - 1)$. Half of 12 is 6, an even number, and so the 23rd perfect ends in 6.

It is interesting to study the endings of perfect numbers in systems other than the binary and the decimal system. If the base is a multiple of 3, all perfects except 6 have terminal digits of 1. If the base is a multiple of 6, as in the duodecimal (base 12) system, all perfects except 6 end in 4.

January's column on square numbers

Some computers baffle even the most experienced scientist. Others are a snap.

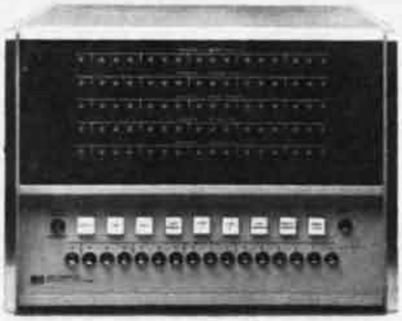
No computer is going to help a scientist much if he's scared to go near it. Or if it's so complicated he spends more time learning to use it than his problem is worth. But one that's designed for simple, direct, conversational operation is a joy. It may open whole new avenues of thought. That's what Hewlett-Packard had in mind.

First, you have your choice of FORTRAN, ALGOL or Conversational BASIC. Whichever best fits your problem. In Conversational BASIC you work back and forth, on-line with the computer. Yet you can learn to use BASIC in less than four hours.

This software gives the HP family of computers exceptional power for their size. But the real advantage is convenience. HP is also an instrument maker—we *understand* the scientist who may want to hook up a gas chromatograph, or a digital voltmeter, to a computer for direct data acquisition, and we make it easy.

Our Input/Output interfaces put the computer right next to the instrument. Easily, with standard plug-in cards. And software drivers that automatically program the data flow into the computer. We've simplified the system so that you can easily control the instruments through the computer. Without being baffled.

For more information about HP computers and their straightforward software, call your local HP field engineer. Or write Hewlett-Packard, Palo Alto, California 94304; Europe: 54 Route des Acacias, Geneva.



HEWLETT hp PACKARD

DIGITAL COMPUTERS

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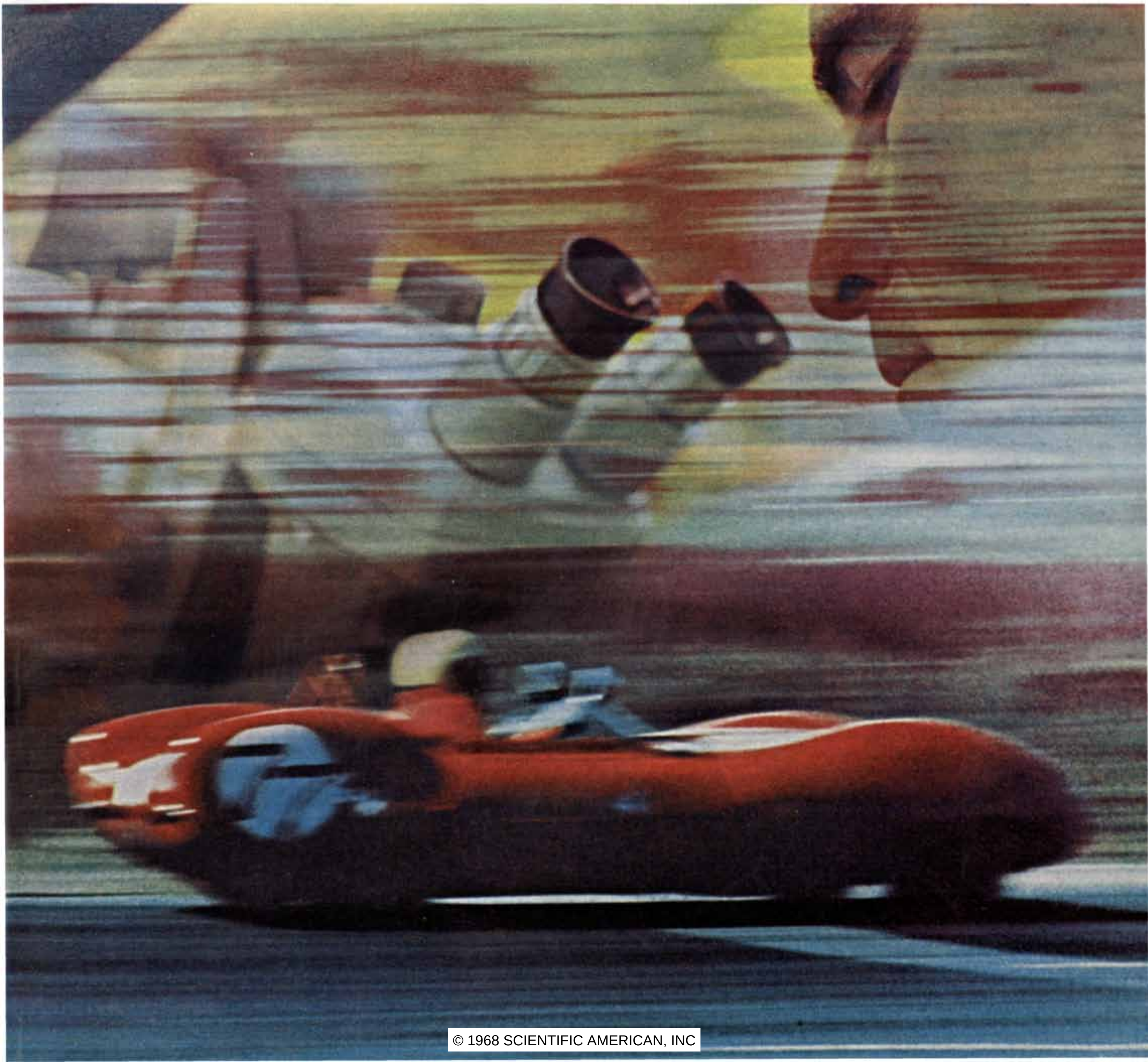
brought many letters from readers who found an easy way to expand the base-10 automorph that ends in 5. Just square it and take the digit next to the automorphic tail. For example: $90{,}625^2 = 8{,}212{,}890{,}625$. The next digit is 8 and therefore the six-digit automorph is 890,625. This makes possible a simple computer program.

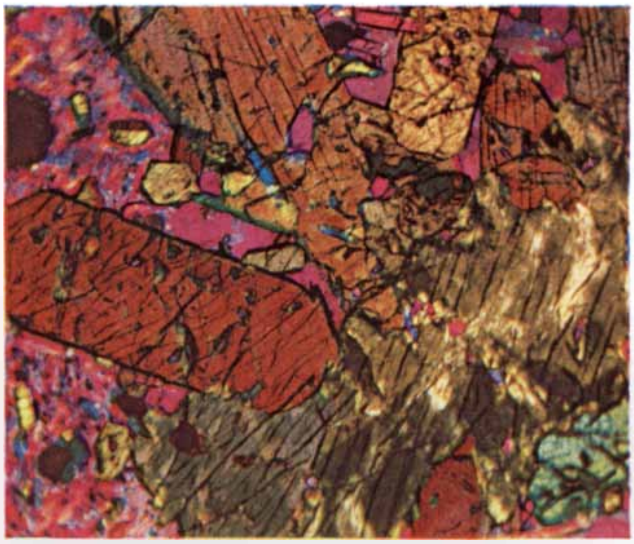
So many readers sent in printouts of giant automorphs that I must be content with mentioning only Martin Ross, of the Information Control Systems in Detroit, who supplied printouts of the two base-10 automorphs to 5,000 digits and of the two base-6 automorphs to 500 digits, and Jerry M. Feinberg and Terry Moore, two sophomores at the California Institute of Technology, who sent a printout of 22,300 digits for the base-10 automorph that ends in 5.

The number of different automorphs for any number system is 2^p, where p is the number of different prime factors in the base. Thus if the base is $2 \times 3 \times 5 = 30$, there are $2^3 = 8$ different automorphs. This includes the trivial cases of 0 and 1, which are automorphic in all number systems. Edwin M. McMillan, the University of California physicist who won the Nobel prize in chemistry in 1951 and who enjoys number theory as a hobby, was the first to inform me of this. McMillan proved the theorem before he found out that it had been done earlier, and he also discovered a variety of other fascinating theorems about automorphs.

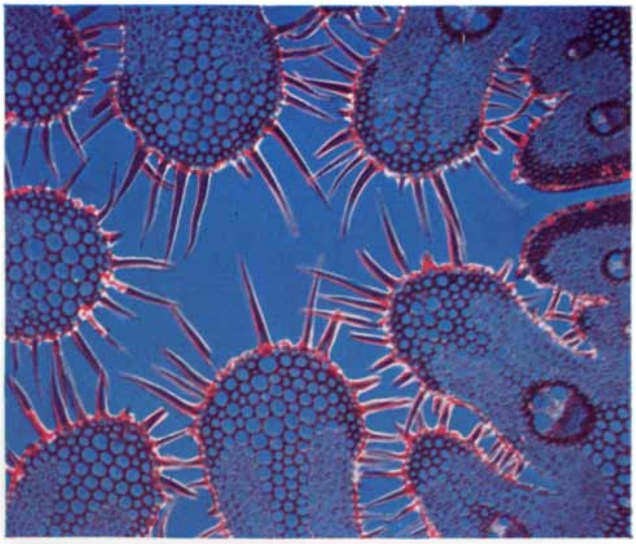
Joseph S. Madachy pointed out that Father Victor Feser, in *Recreational Mathematics Magazine* for August, 1962, page 39, anticipated the work I reported on "par numbers" (squares with curious reversal properties) in February's answer section.

R. L. Brackney of Whittier, Calif., and Victor Meally of Mount Merrion in Ireland caught Dr. Matrix in an error. The numerologist had contended (in the January issue) that he had proved that if two integers are unequal and one is a reversal of the other, their product is square if and only if the two numbers are themselves square. Dr. Matrix probably came on this theorem in *Excursions in Number Theory*, by C. Stanley Ogilvy and John T. Anderson, pages 88–89, where it is given as a conjecture only. Either Dr. Matrix pretended he had proved it or his proof was faulty, since there is an infinity of counterexamples: for instance, $288 \times 882 = 504^2$. The series 2,178, 21,978, 219,978 and so on (inserting 9's in the middle) is one of several infinite series of counterexamples.



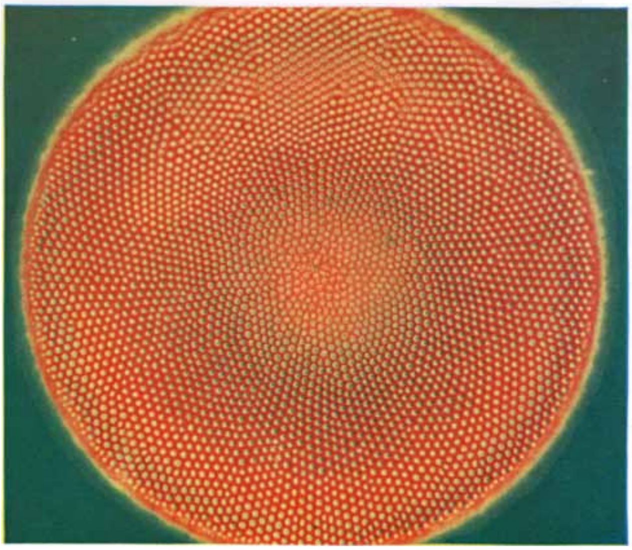


Polarized-light photomicrograph made by Mortimer Abramowitz

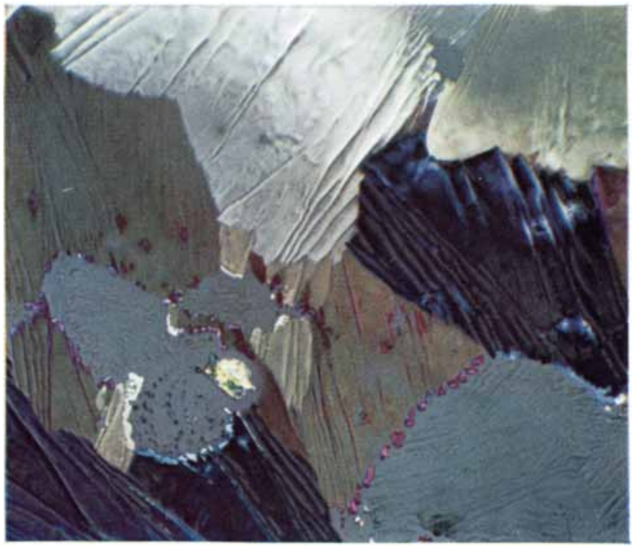


Beach grass in Rheinberg illumination

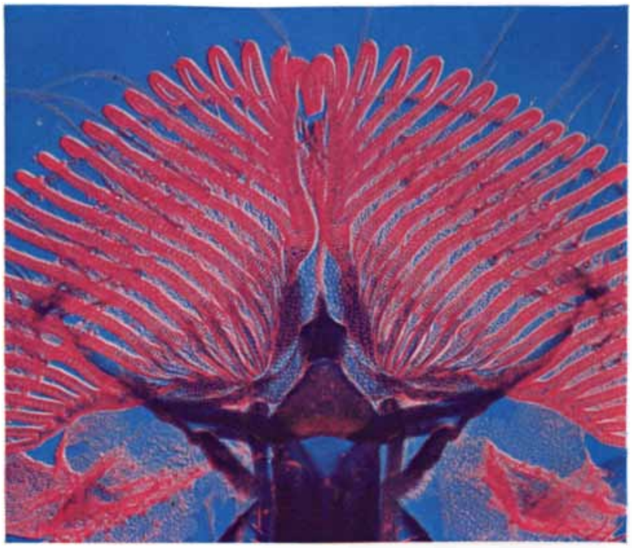
Crystals of salol in polarized light



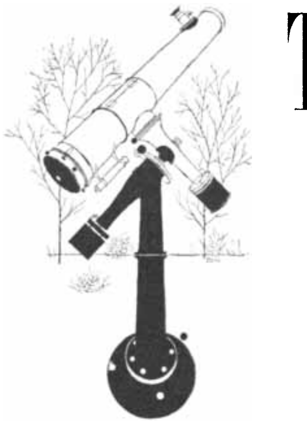
A diatom in Rheinberg illumination



Crystals of oxalic acid in polarized light



Mouthparts of a blowfly in Rheinberg illumination



THE AMATEUR SCIENTIST

Two methods of microscope lighting that produce color

Conducted by C. L. Stong

Most objects examined under the microscope have colorless features that are difficult to see in white light. The microscopist often detects the presence of such structures by creating images that are colored synthetically. Plant and animal tissues, for example, can be dyed by chemicals that color individual features selectively. The microscopist observes the image of the dye and from it draws conclusions about the nature of the specimen. The technique is limited in application because some substances reject dyes or are damaged by them.

Synthetic images of many objects can be made by manipulating the light so that rays transmitted by the specimen emerge altered in intensity, direction or color or some combination of the three. The principal scene of these operations is the substage of the microscope, which includes the condensing lenses and the iris diaphragm associated with them, a filter, a mirror and a lamp assembly. Control of the image is largely lost after the rays emerge from the specimen. The body-tube assembly of the instrument, which includes the objective lens and the eyepiece, merely magnifies the image to a size that is convenient for viewing. The performance of this part of the microscope is fixed by the instrument maker. The substage components provide opportunities for innovation in creating images; the opportunities have sustained the interest of amateurs in microscopy for more than a century. Some techniques of lighting that yield colored images of remarkable detail are discussed by Mortimer Abramowitz, assistant superintendent for instruction in the public schools of Great Neck, N.Y. He writes:

"I have been experimenting with two systems of lighting. One was first suggested by the British microscopist Julius Rheinberg. The second makes use of polarized light. Both systems add color to images that would otherwise appear in black and white.

"I am primarily interested in making color photomicrographs. For this reason I begin experiments by adjusting the substage components of the microscope for a type of lighting that was developed specifically for photomicrography by the German microscopist August Köhler. Köhler illumination is then modified for either Rheinberg illumination or polarized light. In Rheinberg illumination color is introduced by inserting filters of selected hues into one or more regions of the light that floods the specimen. Alternatively, color effects can be developed in Köhler illumination by inserting polarizing filters of two kinds at appropriate points in the optical path of the instrument.

"The kind of specimen used for demonstrating Rheinberg illumination should be one with prominent features. Examples include the appendages of a small insect, a thin section of wood and living protozoa. Magnification of about 100 diameters, such as is provided by a 10X objective lens in combination with a 10X eyepiece, is adequate. Open the iris diaphragm of the condenser fully. Turn on the lamp and adjust the mirror to direct some light through the instrument.

"Köhler illumination is established by a series of simple adjustments. Move the body tube up or down until the specimen appears in sharp focus. Partly close the diaphragm of the lamp and move the substage condenser up or down until a sharp image of the diaphragm appears in the plane of the specimen, as viewed through the eyepiece. Center the light by moving the lamp or mirror.

"Enlarge the diameter of the disk of light by opening the lamp diaphragm until its edge just disappears from view. Remove the eyepiece, observe the spot of light that appears in the rear lens of the objective and close the iris diaphragm of the substage condenser until the diameter of the spot appears to be about three-quarters of the diameter of the rear lens. Replace the eyepiece and examine the specimen. It will appear against a bright background. Most details will seem darker than the background, but (depending on the nature of the specimen) some may seem brighter. In general the brightness of the background will be uniform.

"The microscope has now been adjusted for 'bright field' work. The term refers to a form of lighting that is useful for making photomicrographs of stained specimens in black and white or color. The tenuous structures of some specimens, however, are difficult to see against the bright background. Many of the structures can be brought into view by a simple modification of Köhler illumination. The effect of the change is to reverse the character of the scene: the image appears bright against a dark background.

"This effect can be achieved by blocking the solid cone of rays that normally enters the objective lens and illuminating the specimen with the surrounding hollow cone of rays that remains. The solid cone is blocked by putting an opaque disk of appropriate diameter in the center of the substage iris diaphragm, which is just below the condensing lenses. The opaque disk can be cut from black paper. It is cemented to a disk of clear glass that fits into the filter holder of the instrument's substage.

"The unobstructed circular space that remains between the edge of the opaque disk and the edge of the filter holder transmits a hollow cone of light through the condenser. The light illuminates the specimen with oblique rays that miss the objective lens. None of the rays reach the eye directly. The field appears dark. Features of the specimen, however, diffract, or scatter, light from the hollow cone. Some of the rays enter the objective lens. They are brought to focus at the eye in the form of a bright image that appears against the dark background. Minute details that are easily overlooked in a bright field stand out clearly against the dark field in an image of high visibility.

"To prepare an opaque disk of the

right size for dark-field work, adjust the instrument for Köhler illumination. Remove the eyepiece and replace it with a pinhole aperture. The pinhole, which should be about a millimeter in diameter, can be made in a thin sheet of black cardboard or metal that is painted flat black. The hole must be centered on the axis of the body tube. It can be supported in this position by an opaque bottle cap that fits snugly into the body tube. A larger hole is cut in the center of the cap to expose the pinhole [*see bottom illustration on opposite page*].

"With the pinhole in place and Köhler illumination established, look through the pinhole and close the iris of the condenser until the edge of the iris barely cuts into the field of view. Open the iris until its edge just disappears. Measure the diameter of the opening of the substage iris diaphragm at this adjustment. An opaque disk about 5 percent larger in diameter will, when it is placed in the substage filter holder, block all direct rays to the objective lens and result in dark-field illumination.

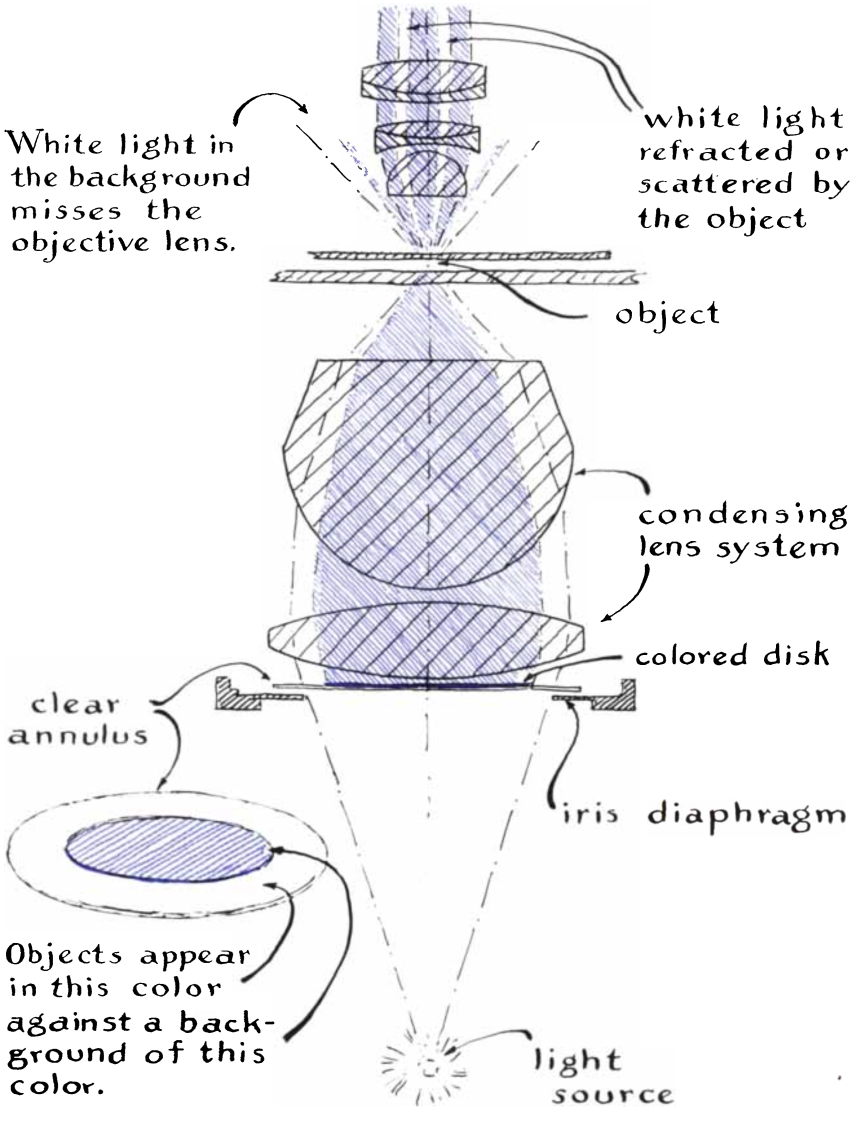
"Although dark-field illumination reveals many features of specimens that cannot be seen clearly against a bright field, visibility can be increased still more by introducing color into the image. The background can be made to appear in color by substituting a transparent colored disk for the opaque disk. Specimens then scatter white light into the objective and appear bright against a background of the selected color [*see illustration below*].

"What I have described is a simple version of Rheinberg illumination. Full Rheinberg illumination is established by installing a colored filter in the form of a ring in the clear space between the colored stop and the edge of the filter holder. When complementary hues are selected for the colored stop and the surrounding annulus, the specimen appears in one color against a background of contrasting color. Effective combinations are red against green and blue against yellow. A third color can be introduced by dividing the annulus into four equal parts and installing contrasting colors in adjacent sectors—red, say, in one pair of opposite quadrants and green in the other pair. The colored stop, which might be dark blue, provides the third color [*see illustration on page 128*].

"The colored field is lighted by the solid cone of direct rays from the colored stop, whereas the image is formed by annular rays of lesser intensity that are scattered into the objective by diffraction. If the two Rheinberg filters are equal in density, the rather dim image of the specimen may be lost in the brilliant background. The relative intensity can be adjusted in several ways. The density of the colored stop can be increased by means of multiple layers of colored plastic. Alternatively, a neutral-density filter can be combined with the colored plastic. I cut such filters from a piece of developed negative film that has been exposed in a camera to a sheet of white paper. The density of the negative is controlled by the exposure.

"The brightness of the background color can be made continuously variable by the use of two Polaroid filters. The filters transmit waves of light that vibrate in a single plane but absorb waves that vibrate in other planes. A filter consists of a plastic sheet in which needle-like crystals of iodoquinine are embedded. They all point in a single direction, like the pickets of a fence. Light waves that vibrate in a plane parallel to the crystals are transmitted by the Polaroid. Waves that vibrate in other directions are increasingly absorbed by the filter as the plane of vibration departs from the direction in which the crystals point.

"Light that makes its way through one sheet of Polaroid will be transmitted by a second sheet turned so that the crystals of both sheets are parallel. Conversely, the second sheet will largely absorb light transmitted by the first if its crystals make a right angle with respect to those in the first sheet. By placing one Polaroid filter in the central stop of the Rheinberg filter and a second one in or on the eyepiece of the microscope, the brilliance of the background can be controlled by rotating the upper Polaroid filter. Polaroid filters, sheets of plastic in assorted colors (for making Rheinberg filters), clear disks of glass, Canada bal-



How Rheinberg illumination is achieved sam and related supplies for the microscope are available from the Edmund Scientific Co., Barrington, N.J. 08007.

"Three-color Rheinberg illumination is particularly effective for examining specimens that display recurring features. These specimens include textiles and the fossils of marine plants such as diatoms. When a specimen of fine silk is examined under three-color Rheinberg illumination, the warp appears in one color and the woof in another; both appear against the background of the third color. The colors can be blended and interchanged by rotating the specimen.

"Color filters for Rheinberg illumination can be made by cutting the central disks and the surrounding rings from thin sheets of colored plastic and cementing them with Canada balsam to disks of clear glass that fit into the filter holder of the instrument. For best results the edges of adjacent colors should be covered by an opaque border about three millimeters wide. The border can consist of a ring of black paper cemented directly to the filters. The accompanying photomicrographs [*at right on page 124*] illustrate some effects of combining two and three colors. Most of my photomicrographs are made with a Nikon S-Ke microscope and a Nikon EFM Microflex camera.

"Images so colored do not correspond perfectly to the actual appearance of the object under examination. The same situation is more or less true of all microscope images. Complete correspondence between the object and its image can be approached but not attained because light from a point comes to a focus as a small disk of finite size. Disks resulting from closely spaced points merge into a fuzzy spot. Moreover, all the light from a point would be required for the formation of a perfect image of the point, whereas only a small portion of the emitted light ever reaches the image. Most of the light is scattered in other directions. For such reasons the microscopist must judge the true nature of the object by examining the image while taking account of the techniques that were used to create it. Color, when employed in this sense, becomes a powerful aid for isolating individual details in specimens.

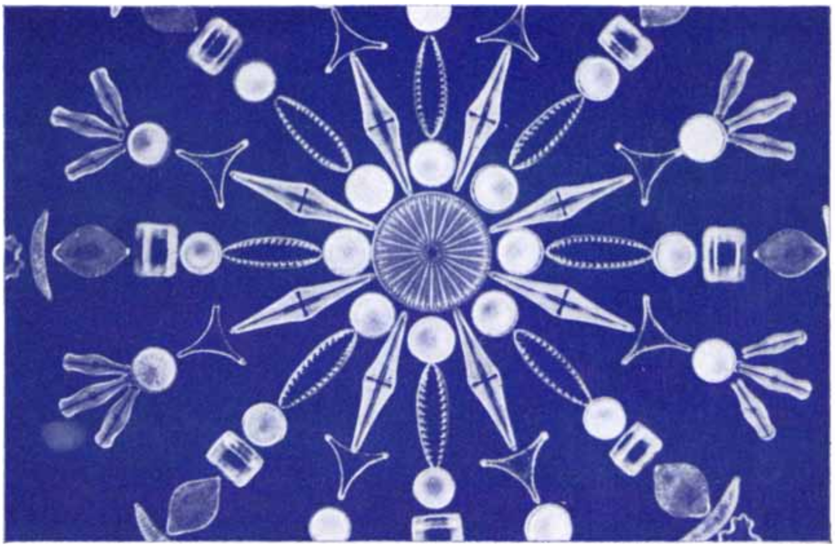
"Although Rheinberg illumination increases the visibility of specimens that have physically distinct parts, it is of less use for examining the fine, transparent features of rocks, crystals and plant fibers and of no use for detecting patterns of stress in glass and other amorphous substances. Many of these materials, however, have an optical property of great value to the microscopist. They rotate the plane in which light waves vibrate. This property can be used for creating color in many features of otherwise clear and transparent materials.

"The technique requires only two accessories: a pair of Polaroid filters and a retardation step wedge, which consists of a series of progressively shorter strips of Scotch tape applied to a microscope slide [*see top illustration on page 130*]. The material to be examined is placed on the slide of the microscope, lighted by the Köhler technique and focused. A Polaroid filter is placed in the filter holder below the substage condenser. The second Polaroid filter, which is called the analyzer, can be placed on top of the eyepiece and supported in that position by a holder made from an opaque bottle cap. The analyzer can also be put in a holder attached to the front end of the eyepiece. When the analyzer is rotated, the brightness of the background will vary from a maximum to a minimum twice during each revolution. The brightness of details in the specimen will vary similarly and some may appear in color.

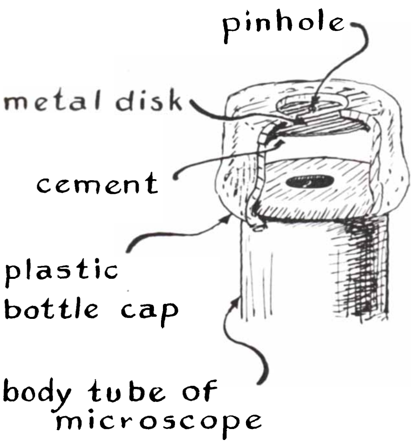
"If the retardation step wedge is now inserted under the specimen in a position that admits light through two thicknesses of Scotch tape, the image will be seen as a spectacular pattern of hues that span the spectrum. The various colors can be made to blend, to shift from one detail of the specimen to another and to change in saturation by rotating the wedge with respect to the optical axis of the microscope. Rotate only the wedge, not the specimen slide. The insertion of the wedge will move the specimen and throw the image out of focus. The instrument should be refocused each time the position of the wedge is changed. The saturation of the colors can be decreased from vivid hues to pale pastels by advancing the wedge so that the light passes through several additional layers of Scotch tape.

"More pleasing colors and images of improved resolution can be produced by substituting thin sheets of mica for Scotch tape. The sheets can be split from a block of mica by thrusting the point of a sewing needle into the edge of the block. The optimum thickness of the sheets must be determined experimentally but will be about .003 inch. Split off a sheet about the thickness of tissue paper and try it on the stage of the microscope. If the colors are brighter than those that appear when Scotch tape is used, cut the sheet into strips and make the wedge. If the colors are not brighter, try thinner or thicker sheets.

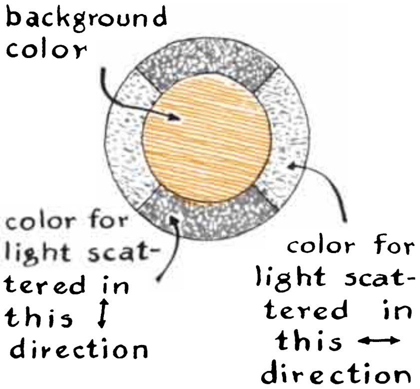
"Some transparent materials fail to show color when they are examined by



Symmetrically arranged group of diatoms in Rheinberg illumination



Pinhole for an eyepiece



Three-color Rheinberg filter

this technique. Indeed, nonopaque solids can be divided into two groups according to how they appear when they are examined between a pair of Polaroid filters that are rotated to the 'crossed' position at which they transmit minimum light. One of the two groups consists of substances that do not rotate the plane in which light vibrates. Such substances, which are described as being optically isotropic, remain dark when viewed between the filters; an example is ordinary table salt. The second group consists of substances that do rotate the plane of polarization. Called anisotropic substances, they include such readily available chemicals as potassium chlorate, oxalic acid, calcium carbonate, boric acid, salol and DDT. Many plant fibers, most transparent plastics, thin sections of rock and also glass that has been heated until it is soft and cooled without annealing are anisotropic.

"Specimen slides of these materials, particularly the chemicals, are easy to prepare. Place one or two drops of distilled water in the center of a clean slide and sprinkle a few crystals of the chemical into the water. Granulated sugar is an excellent specimen, as is vitamin C. Do not add more of the substance than will dissolve in the water at room temperature. Place the slide in a dustproof box until the water evaporates. Examine the resulting deposit of crystals with polarized light. (Some chemicals that do not dissolve in water can be melted by heat and cooled on a slide, where they recrystallize.)

"Most of the accompanying photomicrographs were made with a 35-millimeter camera equipped with a self-contained exposure meter and a telescopic eyepiece through which the image can be viewed until the moment of exposure. Pictures of comparable quality can also be made with an improvised lightproof box for supporting the film [see "The Amateur Scientist," February, 1961]. In either case the illumination of the image is fairly low because much of the light is absorbed by the polarizing filters. The experimenter can compensate for part of the absorption by increasing the brightness of the lamp. The filters are sensitive to heat, however, and may be damaged by temperatures above 60 degrees centigrade. They can be protected by the insertion of a heat filter between the lamp and the lower Polaroid. Heat filters of this type are used in 35-millimeter slide projectors and are available from dealers in photographic supplies.

"Exposures can be made with flashbulbs if care is taken to put the bulb in the position normally occupied by the microscope lamp. If the flash results in overexposure, the intensity can be reduced by inserting a neutral-density filter between the flashbulb and the mirror of the microscope. The neutral-density filter must be of good optical quality to prevent the introduction of spurious color.

"A light meter sensitive to .5 footcandle and capable of indicating exposure intervals of 20 seconds or more is helpful for determining exposures. I usually 'bracket' the meter reading by making exposures one stop higher and one stop lower than the ones indicated by the meter. With practice one learns to judge the brightness of the image by eye and to make the exposure accordingly. Color film is sensitive to the length of the exposure as well as to the intensity of the light.

"Some films take on false color during exposures of more than 1/10 second. This error can be corrected by the use of a special filter. For example, when exposing Kodachrome IIA for intervals between 1/10 second and 10 seconds, insert a CC 10R filter between the lamp and the microscope; for exposures between 10 and 20 seconds use a CC 20R filter. Incidentally, optical imperfections in filters degrade the quality of the image least when they are placed between the light source and the instrument; the degradation is somewhat greater when they are placed between the objective lens and the camera. Filters should never be used between the specimen and the objective lens.

"The hues of color photographs are determined in part by the temperature of the light source. Kodachrome IIA is designed for a temperature of 3,400 degrees Kelvin. When this film is exposed by a lamp that is rated at 3,200 degrees K., for example, a correction filter must be used, in this case an 82A Wratten filter.

"Full information on the characteris-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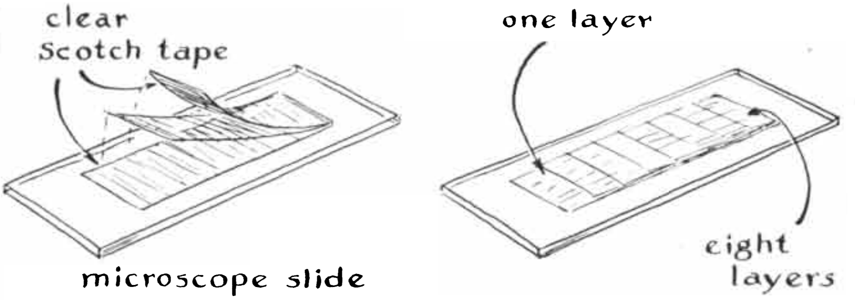
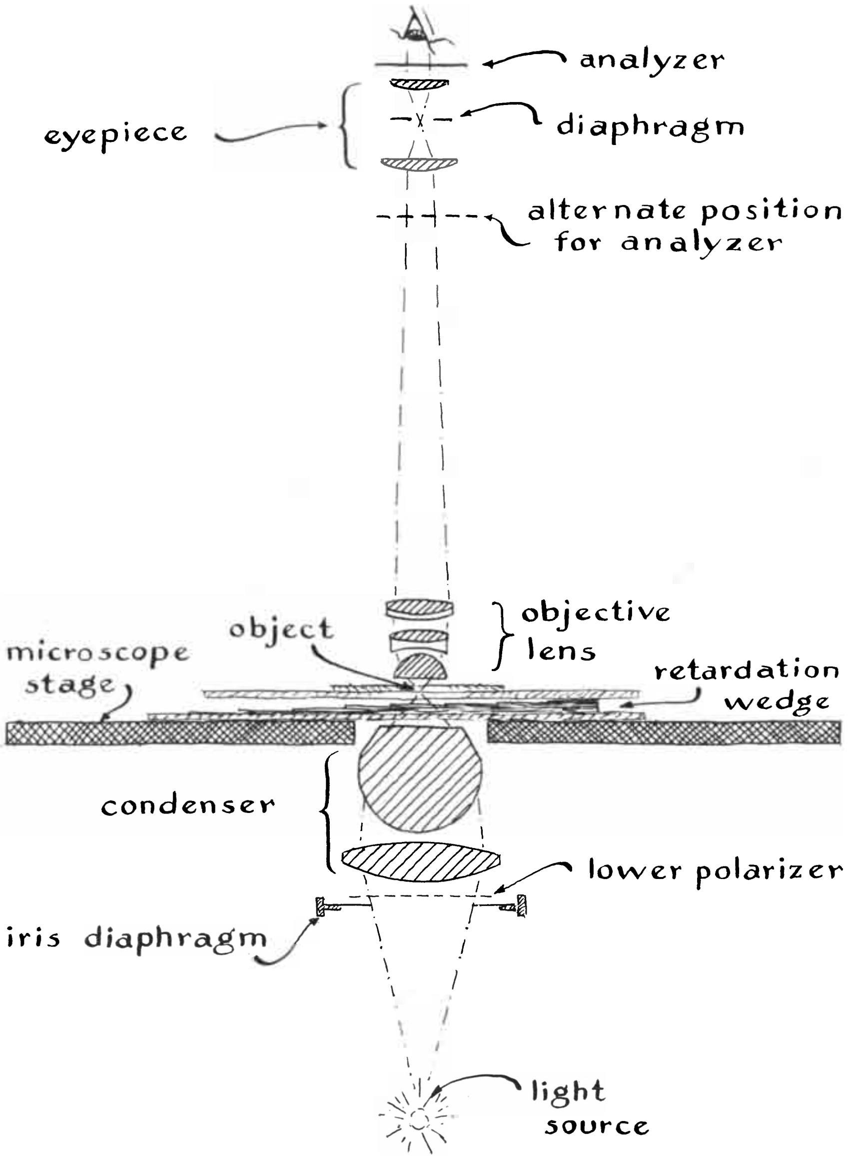
FLORIDA

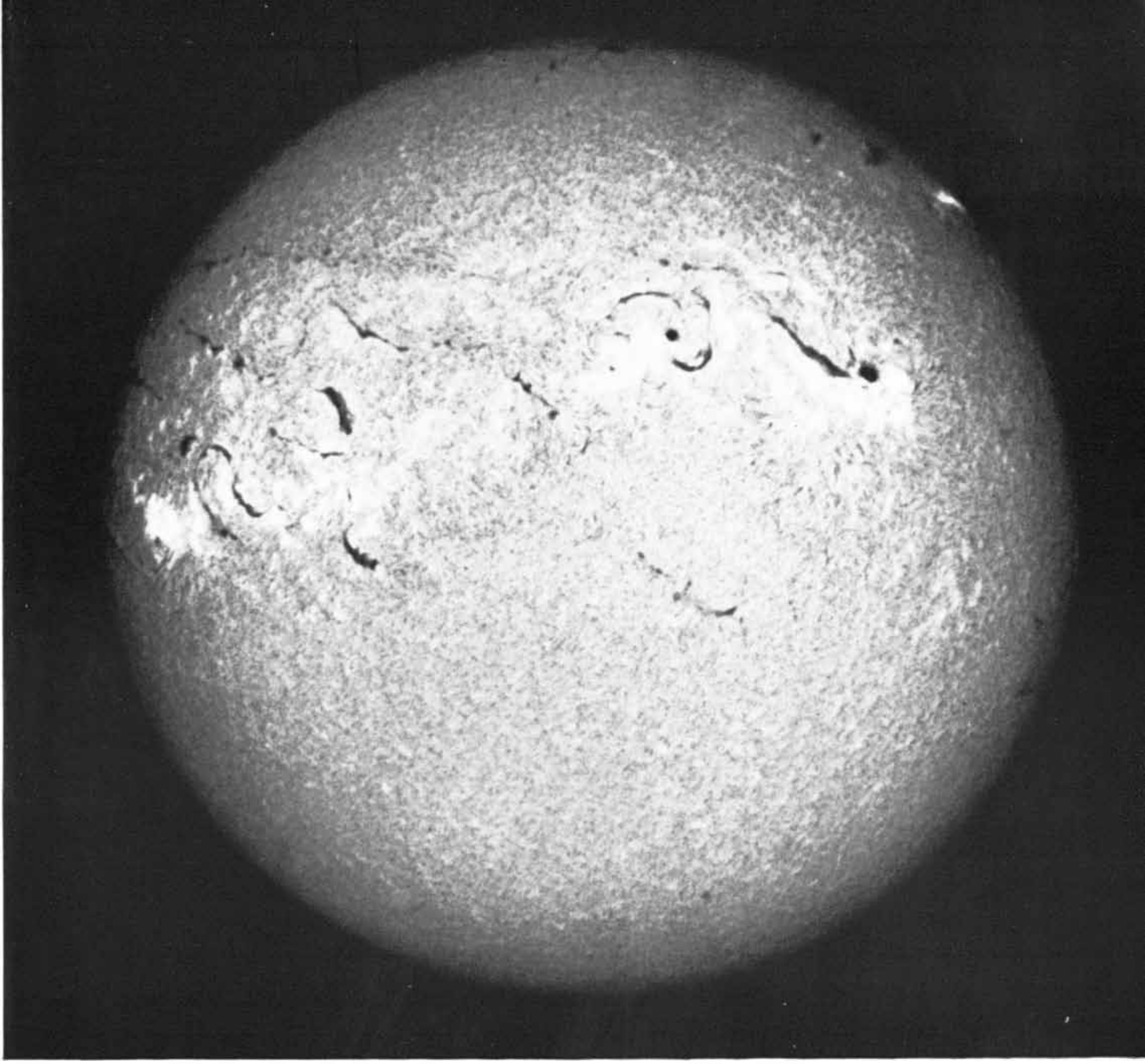


Details of a retardation step wedge

tics of the various films and the conditions under which compensating filters must be used can be found in data books or in the leaflets that accompany the films. I have had excellent results with Polacolor film. I use the four-by-five-inch film sheets in a film holder that is attached to the eyepiece fixture of the camera. When using this material, I find that exposures are somewhat more difficult to estimate. The fidelity of the prints is not quite up to that of positive transparencies, but the overall results have been gratifying."



Optical path of the polarizing microscope



The sun in the light of the red hydrogen line at 6,563 Å, 0.25 Å bandwidth, photographed through a Zeiss H-alpha Monochromator (Lyot filter).

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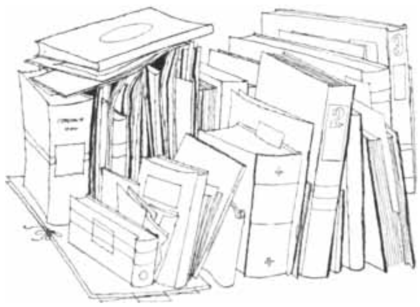


BOOKS

Colin Clark and the benefits of an increase in population

by Kingsley Davis

POPULATION GROWTH AND LAND USE, by Colin Clark. St. Martin's Press ($14).

Colin Clark is famous as the author of *The Conditions of Economic Progress*, originally published in 1940 and now in its third edition, which profoundly influenced all subsequent study of economic development. He is also known for his skill in quantitative analysis and for the unusually wide range of his interests and knowledge. Familiar with the economic statistics of nearly every country in the world, he has written widely on cities, agriculture, income, industry and population with respect to nations as diverse as China and Australia, France and the U.S. Never one to shirk a major issue, he wrote (in 1939) *A Critique of Russian Statistics* and (in 1942) *The Economics of 1960*. On the less scholarly side, Clark is known for critical sharpness and strength of opinion, traits that do not always endear him to colleagues, and he is one of the few distinguished social scientists in the English-speaking world who are at the same time spokesmen for the views of the Roman Catholic church.

In the present book, 20 years in the writing, all these traits are manifested in a new and puzzling amalgam. The old interest in long-run trends, the old flair for empirical data and skill in their analysis, the dazzling breadth of knowledge, the critical sharpness, the subtle defense of an unspoken religious ideology—all are there. Knowing the toil that goes into such a work, I wish I could call the result brilliant, whether or not I agreed with it, but somehow, in spite of the excellence of particular sections, an overall integration is missing. The old ingredients are overplayed this time, and they are mutually discordant. The general theme—clearly a major issue of today's world—gets lost from view or inadvertently contradicted in long stretches of irrelevant writing. The separate chapters, usually beginning or ending abruptly in picayune points, have little structure. The tools of scholarship are casually handled, with frequent omissions of authors, dates or titles, occasional misspellings, ambiguous labeling of charts and tables, use of derived ratios without absolute figures, and unexplained inconsistencies. These faults, condoned by a man who knows better, not only impede an evaluation of his work but also, when combined with disregard of contrary arguments and evidence, erode one's trust in it.

The overall position is not new to Clark. He took it in 1942 in *The Economics of 1960* and has maintained it since then, on television, in learned papers and in an article in *Fortune* in 1960. "Population growth," he says in the preface to the present volume, "brings economic hardship to communities living by traditional methods of agriculture; but it is the only force powerful enough to make such communities change their methods, and in the long run transforms them into much more advanced and productive societies." In industrial communities "the principal problems created by population growth are not those of poverty" but of excessive concentration and "the unmanageable spread" of cities. The thesis appears self-contradictory, but let us examine its logic and his evidence.

Clark's theory of population economics is eclectic. He cites Sir William Petty's idea that a dense population brings economies of scale, Everett Hagan's view that investment errors prove less costly when population is growing than they do when it is not growing, Albert O. Hirschman's thought that a growing population offers the possibility of windfall profits and expanding markets and therefore stimulates investment, and Alfred Sauvy's contention that the per capita overhead costs of government and public services are less when population is growing than they are when it is not growing. Clark adds that a slowly growing population, with its large proportion of old people, will tend to consume capital rather than to save it, because the old save less than the young. He also suggests that the parents of large families make more effort to save, and that in such families younger sons expect less of an inheritance and therefore make great effort to accumulate for themselves.

From Clark's silence on contrary views the unwary reader might conclude that the last economist to lament population growth was Thomas Malthus. The writings of such modern economists as Joseph J. Spengler, Ansley J. Coale, James E. Meade, Edgar M. Hoover and Ragnar Nurkse, to mention only a few who have dealt with the theory of the adverse effects of population growth, are ignored. Since Clark has not provided his readers with a basis for critical judgment, I shall try to do so.

The economic benefits of rapid population growth in Clark's theory are all on the basis of other things being equal. The benefits will be gained if population growth influences no variables in the system other than the ones it is supposed to influence favorably. The ground for expecting adverse economic effects, however, is precisely that as population growth proceeds it tends to damp various crucial factors. For instance, a rapid increase in population *would* provide economies of scale *if* the purchasing power, or productivity, of the added people remained satisfactory. But the very nature of rapid population growth is that it gives rise to a high proportion of child dependents. Since the productivity of human beings depends overwhelmingly on their skills, the fact that a disproportionately large stream of children is flowing into the society places a heavy burden on parents, who have less time per child for the transmission of skills, and on the schools. The schools themselves require highly trained labor that is frequently in short supply and are therefore peculiarly susceptible to deterioration with added strain. If the skills of the population are not improving, economic development will not take place. In that case population growth will not provide an expanded market, will not stimulate investment and will not reduce the overhead costs of government. Clark's view that large families will make more of an effort to save than small ones is again an other-things-being-equal theory. The capacity to save is not only a function of effort but also one of income, which is in turn dependent on the circumstances of the society. Moreover, saving is now more a matter of corporate and government policy than of individual volition.

Clark does not rest his case on economic benefits alone. These, he says, "are only one part of much wider changes in the nature of society, in its cultural and political as well as its economic aspects, which population growth evokes." A dense population, he believes, is advantageous for art and science and for freedom, particularly freedom from state regulation. His theory of how population exercises such effects is even less specific than his theory of how it brings economic advantages, but he seems to think that population growth is valuable because it offers hardship, thus challenging people to improve their lot. This argument holds only if it is assumed that there are no hardships other than population growth. Even so, it is a sterile tautology. All hardships can be (and many have been) justified on the ground that they encourage human achievement. This is the theological basis for explaining evil. It is of course impossible to refute, because for every improvement in human life there is necessarily a corresponding prior evil—the absence of that improvement. Furthermore, Clark admits that some societies fail to rise to the challenge of population growth. If this is the case, there must be an intervening variable. This variable, whatever it is, might be sufficient in itself to generate progress.

Theory is clearly not Clark's forte. Casual theorizing weakens his ambitious effort to achieve universal generality. The only instrument that would allow analysis of cause-and-effect relations between population and society on a world basis would be a complex theoretical model. So let us shift to the evidence, remembering that without theory we may have abundant statistics but little understanding.

Consider Clark's proclaimed association between population growth and social progress. Even if he had had statistical evidence to prove that population grew swiftly with the rise of "Greece about the sixth century B.C., Holland in the sixteenth century A.D., Britain in the latter part of the eighteenth century, Japan at the end of the nineteenth and the beginning of the present century," or that Roman population declined as Roman civilization did, what reason would he have to assume that the demographic change *caused* the social change? Without a theory of the mechanisms of interaction, capable of being independently tested, mere correlation has little use. As far as classical civilizations are concerned, there is no statistical evidence that would enable us even to correlate population growth and social progress. From what we can piece together about mortality it would be foolish to think that any major civilization achieved growth rates remotely approximating those of the past 150 years. In other words, to the modern mind the surprising thing about the Greek population in classical times would be how *slowly* it grew. (Clark's vagueness about his independent variable is exasperating; it is usually impossible to tell whether it is population density, a high rate of population growth or any growth at all that has the beneficial effects he alleges.)

Turning to modern history, from which we have some reliable evidence, one certainly finds through the 19th century an association between population growth and prosperity. It is, however, a loose association, admitting of much variation, it reverses itself in the 20th century and, above all, when it exists, it is due to causation that runs from economic improvement to population growth, not vice versa. The long-run effect of the escalating economic gains associated with the Industrial Revolution was to lower death rates drastically, and to lower them more rapidly than birth rates were lowered. The result was an unprecedented rate of population increase. In northwestern Europe, where people were already numerous, this growth would probably have damped the pace of economic development if it had not been mitigated by two factors: first, a great outward migration (which had the further effect of bringing vast new overseas resources to the service of Europe), and, second, a decline of fertility that, in its later stages, was faster than the drop in mortality. These depressants reduced Europe's population growth to a slow pace in the 20th century, yet the rates of economic improvement did not decline but in most cases rose to their highest levels.

Since World War I the correlation between population and prosperity has disappeared everywhere—not only in the advanced countries but also in the world as a whole. Clark's own data show this. In his chapter "The History of Population Growth" he gives estimates for world regions, from which I find that the population increase between 1920 and 1962 was 58 percent for the underdeveloped countries and 47 percent for the developed. This result emerges in spite of the author's apparent effort to conceal it. Not only does he omit estimates for certain backward but fast-reproducing Asian countries but also he gives China 572 million people in 1920 (nearly 100 million more than the United Nations gives the whole of East Asia at that time and 12 million more than John D. Durand in his recent world estimates gives China 30 years later!). Having credited China with 572 million in 1920, he "finds" that it had a zero growth rate between 1920 and 1950, and since it weighs so heavily in the total population of the underdeveloped world, he thus minimizes the association of population growth with poverty that characterizes the 20th century. If China is omitted, then according to Clark's table the underdeveloped regions grew by 97 percent between 1920 and 1962, compared with 47 percent for the developed regions. Of course, he could maintain that the underdeveloped regions, although still poor, are moving ahead faster than the developed ones, and that it is for this reason their populations are growing faster. But he knows that the underdeveloped countries are falling farther behind in the economic race, a trend interpreted by most experts as showing that rapid population growth is hindering, not helping, progress.

By avoiding a comparison of population increase in developed and underdeveloped countries Clark escapes the necessity of explaining why the increase is so much higher in the poorer nations. An explanation would bring out the fact that since World War I the control of death rates has become increasingly independent of domestic economic conditions, first because public health techniques, once they have emerged, are relatively inexpensive to apply, and second because the supplies, personnel and organization can be furnished largely from the outside. In his chapter on mortality Clark devotes 18 pages to a speculative history of mortality from the Bronze Age to the 19th century and half a page to a bare mention of the accelerating drop in mortality since the 1930's (without separating the developed countries from the underdeveloped ones). He thus ignores the basic fact that death rates in today's underdeveloped countries have dropped far faster than they did in the early history of the industrializing countries, and that the reason is that mortality control is now much more independent of domestic economic improvement than it once was. Some of the more progressive underdeveloped countries—Taiwan, Chile, South Korea, certain nations in eastern Europe—are developing socioeconomic conditions that move fertility downward to an industrial level. In the more backward and more numerous of the underdeveloped nations fertility is either rising or holding steady, giving them an extremely high rate of population increase that is a function not of their economic development but rather of their lack of it.

Instead of admitting the ominous divergence between population growth and economic improvement in the 20th century Clark shifts his ground. He forgets about the actual direction of the two trends and tries to prove his theory of why they *should* be associated. Beginning with economies of scale and confining himself to manufacturing, he finds that in 18 industrialized nations, "all other things being equal, productivity tends to rise by a factor of the one-sixth power of the increase" in the scale of manufacturing. But "scale of manufacture" is defined as the total value of manufacturing production for each nation, which is governed by the size of the market and the productivity of the workers, not by the size of the population. I calculated the population growth of each of his 18 countries during the period covered (1910 to 1960) and found no correlation between it and the rise either in value of manufactures or in productivity of labor in manufacture, as he gives them.

Clark further tries to show statistically that the rate of savings is favorably influenced by population growth. In 31 countries, including underdeveloped as well as developed ones, he finds that a 20 percent growth in population per decade raises the proportion of national income saved by 2 percent. Since he does not give the data, his procedure cannot be tested by other approaches without spending weeks to regather the information. He does, however, give the rates of saving for the 31 countries. When I related these rates to the population growth of the countries for the period 1955–1961, I did find a correlation, but it was a negative one. Actually Clark's 31 countries are a mixed lot, with quite different circumstances. By grouping them one can show that the basic difference is between European and non-European countries. For the period 1955–1961 the 16 European countries in the group had a higher savings rate (16.4 percent on the average) than the 15 non-European countries did (12.3

percent), but the European nations had a far slower rate of population growth (4.5 percent in six years) than the non-European countries did (15.1 percent). The data suggest that populations with a high proportion of aged persons in them tend to save more than those with younger populations.

Not content with proving to his own satisfaction that population growth promotes economic development, Clark, in his chapter "Population and Food," protects his flank by refuting the predictions of those who see calamity ahead. Here he has an easier time, not only because he is an expert in agricultural economics but also because the proponents of population control have been slipshod in their reasoning. Setting out to show that the earth could support a huge population, he uses on the demand side two standards of food consumption, one a "subsistence unit," the equivalent of a quarter-ton of grain per person per year, and the other the American level. On the production side he uses a "standard land" measure in which "the sort of farmland to which we are accustomed in the humid temperate countries" has a value of 1, with other lands being a fraction or multiple of that according to their potential. On this basis he finds that the world could support, on the American standard of consumption, 47 billion people, or about 14 times the present world population. At the subsistence standard—for practical purposes taken to be the Japanese level of food consumption and the Asian standard of timber requirements—the world could support 157 billion people. If we were to acquire methods of improving the efficiency of photosynthesis, Clark adds, we could support even more people.

Clark thus takes advantage of the naïveté of those opponents of population growth who state the problem in terms of food. Like other organisms, human beings cannot live long without eating; consequently the population cannot "exceed" the food supply for more than a few days. There are doubtless millions who have less to eat than they would like, or less of the right kind of foods than they need for good health, but this has little to do with the "support" of population, because these same millions are obviously reproducing and rapidly growing in numbers. Clark rightly berates the Food and Agriculture Organization and other agencies for their false propaganda about a "hungry world." He cites other critics to the effect that the FAO's criteria for minimum calorie requirements are absurdly high. "FAO," he says, "like many similar organizations, appears to waste enormous sums of money, and devotes much of its energies to political manoeuvres to secure its own perpetuation and aggrandizement." If it "were disbanded and a fraction of its revenue devoted to the universities and private institutes..., the world would be better off."

By presenting the population problem as one of feeding the world's people, the advocates of population control must argue their case primarily by reference to the future. Although the human population is not starving today, it will, if it keeps growing rapidly, starve in the future. This view enables Clark, and those who share his position, also to argue in terms of the future. They correctly point out that if all resources were rationally utilized to augment the food supply, the number of people who could be fed would be many times the present number. It makes no difference that the proposition is hypothetical; so is the proposition about future starvation. Clark would have a more difficult time if his opponents stopped thinking biologically and started thinking sociologically. Since human beings do not live by bread alone, the crux of the problem lies in the variety of losses they suffer from population growth, not simply tomorrow but yesterday and today. As far as the future is concerned, since it appears that starvation has in the past seldom been the main cause of death, it is unlikely that the world's prospective population growth, if it is stopped, will be stopped by starvation. If it is stopped by mortality, the causes will more likely be warfare and disease. If it is stopped by fertility control, the motive for such control is not likely to be fear of starvation but fear of a loss of numerous values other than nourishment.

Clark himself shows more recognition of the social disadvantages of population growth than many of the antipopulationists. After seven chapters of intermittent praise for population expansion, he gives the reader welcome but surprising relief: he opposes big cities. He feels so strongly about them that he is willing to sacrifice one of his cherished values—economic freedom through the unrestricted marketplace—in order to get rid of all cities of more than a million inhabitants, a feat he would accomplish by taxing employment in cities and subsidizing employment in small towns and rural areas.

The interesting thing about this distaste for big cities is not that it is widely shared or that it comes naturally to a man who spent many years in Queensland, Australia, and then 15 years in

Oxford, England (population 109,000 in 1967). It is rather that Clark's attitude toward cities seemingly conflicts with his attitude toward population growth. Let us see if the conflict is real.

His objection to large cities is not on economic grounds. The real problems of population growth in industrial countries, he says, are not those of impoverishment. "Such growth . . . enriches us economically. . . . What it does do is to create acute problems of requirements of land, for our homes, our recreation, for driving and parking our cars, for industry, and for many other uses." He accounts for these disadvantages in terms of what the economist calls "externalities"—the indirect consequences of economic transactions for individuals not in a position to be directly a party to those transactions. "One of the most important examples of an 'externality' in the modern world," he says, "is the congestion of traffic." When a man buys a car to drive to work instead of using a train or a bus, he is accepting the extra costs for himself, but inadvertently he "imposes upon other road users further costs arising from the slowing down of traffic, additional use of fuel, and additional probability of accidents." The other users "have no opportunity of entering the market as competing buyers or sellers, and thereby affecting the decision of the customer in question as to whether or not to buy the car." Similar externalities arise, according to Clark, regarding the availability of land for recreation, agreeable residential sites and other needs.

His argument is convincing. But is it not applicable to family size and population growth as well? If city expansion has deleterious noneconomic effects, does not general population expansion also have such effects? Cannot the concept of negative externalities be applied to reproduction as cogently as to car-buying? A particular father may enjoy having nine children and be willing to bear the extra costs directly chargeable to him, but he thereby increases the burden on his fellow citizens, who must support the schools and must endure extra noise, congestion and competition for goods, and yet who have no chance to be a party to his reproductive decisions. The externalities of reproductive behavior extend even to the next generation, which obviously has no control in the matter.

Clark's justification for general population growth should apply equally to cities. Historically urbanization is more strongly correlated with economic development than population growth is.

There has never been economic modernization without a corresponding urbanization. If, therefore, the justification of population expansion is to be found in its alleged economic effects, why is this not also the justification for city expansion? If it is sensible to stop city growth, why is it not sensible to stop population growth?

Even more indicative of Clark's inconsistency is the fact that general population growth and city growth are close to being the same thing. Cities are no longer growing overwhelmingly by migration, as they did in the 19th century and early in the 20th, but by their own excess of births over deaths. In the U.S. in 1960, for instance, there were 22 metropolitan areas with more than a million inhabitants. These areas, with 36 percent of the nation's total population, had added nearly six million people by 1966. This seems like a frightening addition to our big cities in six years—and so it is—but the *rate* of increase was exactly the same as that for the nation as a whole. During the six years, of course, other metropolitan areas (six in all) entered the million-plus class. If we include them, the proportion of the nation's people living in metropolitan areas of more than a million rose from 36 to 39 percent in six years. If the Government were to have implemented Clark's recommendation that a million be the maximum size of city allowable, it would have had to "disperse" 64 million Americans in 1960. Six years later it would have had to disperse 76 million. In the year 2010, if our cities grow no faster than the rate predicted for our total population, approximately 165 million people will have to be dispersed.

It is hard to avoid the conclusion that Clark's views are contradictory. If they are, he shows himself to be at one with his church. The ambivalence between an urge for population increase and a distrust of cities runs deep in Catholic ideology. The heart of the church still belongs to the Middle Ages. Medieval society had, in the church's eyes, an idyllic combination of rustic virtues and numerous births. It also had, however, virtually a fixed population, which helped the society to retain its rural simplicity. Modern death control has unintentionally destroyed the idyll and has faced the church with the painful choice of giving up either its preference for large families or its penchant for rurality. Having turned to Clark as one of its distinguished lay social scientists, making him a member of the Pope's expert commission on population and family limitation, the church receives no consistent answer; it gets back only a reflection of its own indecision.

In emphasizing Clark's general thesis, I have not done his book justice, because that thesis is not its best feature. Most parts of the book are tangential or irrelevant to his major argument, and some of them are the most interesting. The best chapters are those that deal with topics on which he himself has done research, namely the two chapters on cities and the location of people and industries and the chapter on population and food (which contains his main discussion of agriculture). His chapters on central topics in demography—fertility, mortality and population growth—are, in spite of their wide and esoteric coverage of the research literature, somewhat old-fashioned. I have emphasized his main theme because it bears on a major issue and should therefore not be allowed to stand by default. Clark's reputation and his skill with words and numbers give his argument a halo of credibility that may mislead the unpracticed eye.

Short Reviews

CANCER EPIDEMIOLOGY: METHODS OF STUDY, by Abraham M. Lilienfeld, Einar Pedersen and John E. Dowd. The Johns Hopkins Press ($6.50). The statistics of disease found their classic entry as a tool of the physician with the London cholera epidemic of 1854. John Snow went from house to house south of the Thames, in a district where two private companies competed to supply water. Twelve hundred patrons of the Southwark & Vauxhall Company were dead of that scourge; only a hundred of their neighbors, who were customers of the Lambeth Company, which served about half as many people, had died. The inference was plain: cholera was waterborne, and the Southwark water was the more polluted. No one yet knew of the vibrio that causes cholera. Snow did not need that argument; it was yet to come. His case was made.

In our days cancer, by no means contagious in the normal sense, has become a kind of contagion through exposure to all sorts of agents—particularly old age. This brief and clear book is an introduction to the methods of the epidemiologist: the comparisons, the corrections for age and improved diagnosis, the controls, the studies to follow up a hunch, and the careful double-blind studies to test a subtle theory. It is written for readers interested in cancer but untrained in these methods. Half of the book is a practical guide to the statistical methods used, and it also contains a World Health Organization classification of neoplasms. The first draft of the work was made by an expert committee in one week. Like another famous committee product—the King James Version—the book is a success, although not, to be sure, on quite so exalted a level.

This is detective work with a real mission. The data shown are fascinating, and they present still-open cases, such as the rising mortality from the leukemias seen nearly worldwide. Is it merely better diagnoses or is it the use of X rays? Or what is it?

There are two eloquent graphs. One, made by the pioneers on the statistics of lung cancer, Richard Doll and A. B. Hill of London, was published in 1964. By that time there had been plenty of British physicians each year convinced by earlier data to give up smoking cigarettes. The plot shows the death rate from lung cancer, standardized for age and amount smoked, as a function of the years elapsed since these doctors had stopped smoking. The curve falls steadily and smoothly by a factor of five in 15 years, when it reaches a plateau. Genetics, occupation, air pollution and work habits, one can assume, remained unchanged; the smoking of cigarettes stopped and the lung cancer deaths went down. Another bar graph speaks volumes. A small black line barely shows the number of dead per man-year from bronchogenic carcinoma, adjusted for age, among men who never smoked. A tall bar running to the top of the page—60 times higher!—shows the same statistic for the foolhardy smokers of more than two packs a day.

CAPE GELIDONYA: A BRONZE AGE SHIPWRECK, by George F. Bass, with the collaboration of Peter Throckmorton, Joan du Plat Taylor, J. B. Hennessy, Alan R. Shulman and Hans Günter Buchholz. The American Philosophical Society ($5). The fishermen of the Aegean drag up amphoras by the thousands as they pull their weighted nets across the bottom. In 1953 one Turkish trawler off the southern coast of Turkey caught a bronze bust of Demeter. A couple of years later hard-helmet divers had seen some bronze bars at 16 fathoms among the great boulders and the playing dolphins off the cape mentioned by Pliny as "dangerous to mariners," and where a lighthouse is maintained by the Turks today.

The bronze was Cypriot ingots and scrap dating from about 1200 B.C., the cargo of a Phoenician ship wrecked with a captain who sailed as a merchant smith with all the tools of his trade. Among

Western Electric gets a fast fix on magnetics.

Anyone planning to use a magnetic material for anything more subtle than picking things up had better know its hysteresis curve. That's the curve that shows how much magnetic flux is induced in a material by applied magnetizing forces of either polarity. Western Electric uses many kinds of magnetic materials in the communications equipment we build for the Bell System. And for very subtle purposes indeed.

So we draw a lot of hysteresis curves. And, by old test methods it could take up to two hours to draw even one.

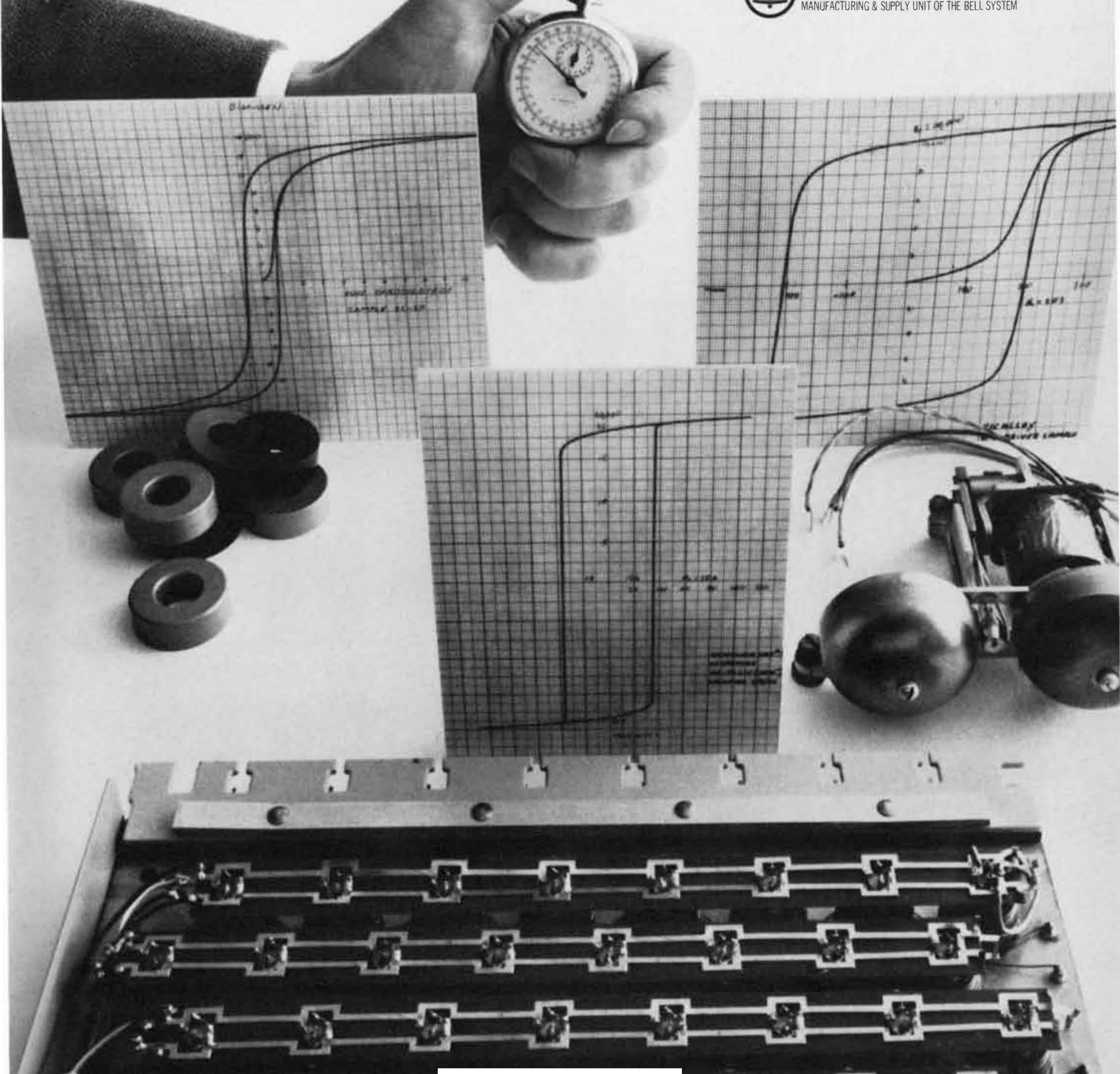
Since flux changes in many of the materials we use produce very weak forces, people have been trying for years to work out a hysteresigraph that will get these forces to move a recording pen. Until recently, the closest anybody had come was one of our engineers.

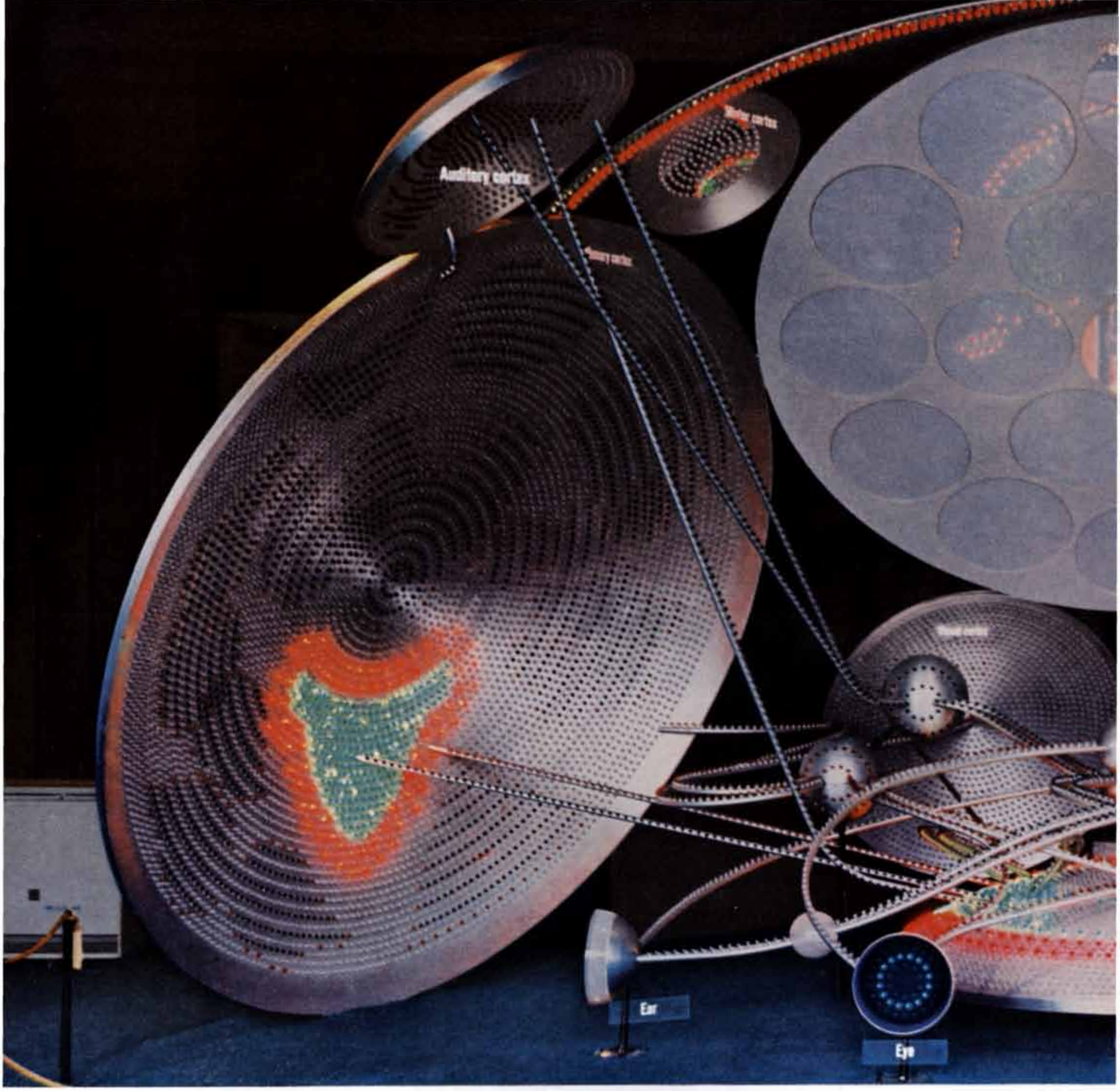
His device employed a galvanometer, a mirror, a pair of photocells, a servo amplifier and motor, and an elaborate set of balancing and positioning controls. It drew nice curves, but the slightest vibration threw it off, and getting it set to go again took time, skill, and infinite patience.

The same engineer who devised *that* hysteresigraph recognized the possibilities of a newly developed device called an electronic operational amplifier. He designed a new, all-electronic hysteresigraph around it that draws accurate curves in about five minutes, needs hardly any adjusting, and is completely indifferent to vibration.

This is the kind of continuing inventiveness Western Electric brings to its job as manufacturing and supply unit of the Bell System.

Western Electric
MANUFACTURING & SUPPLY UNIT OF THE BELL SYSTEM

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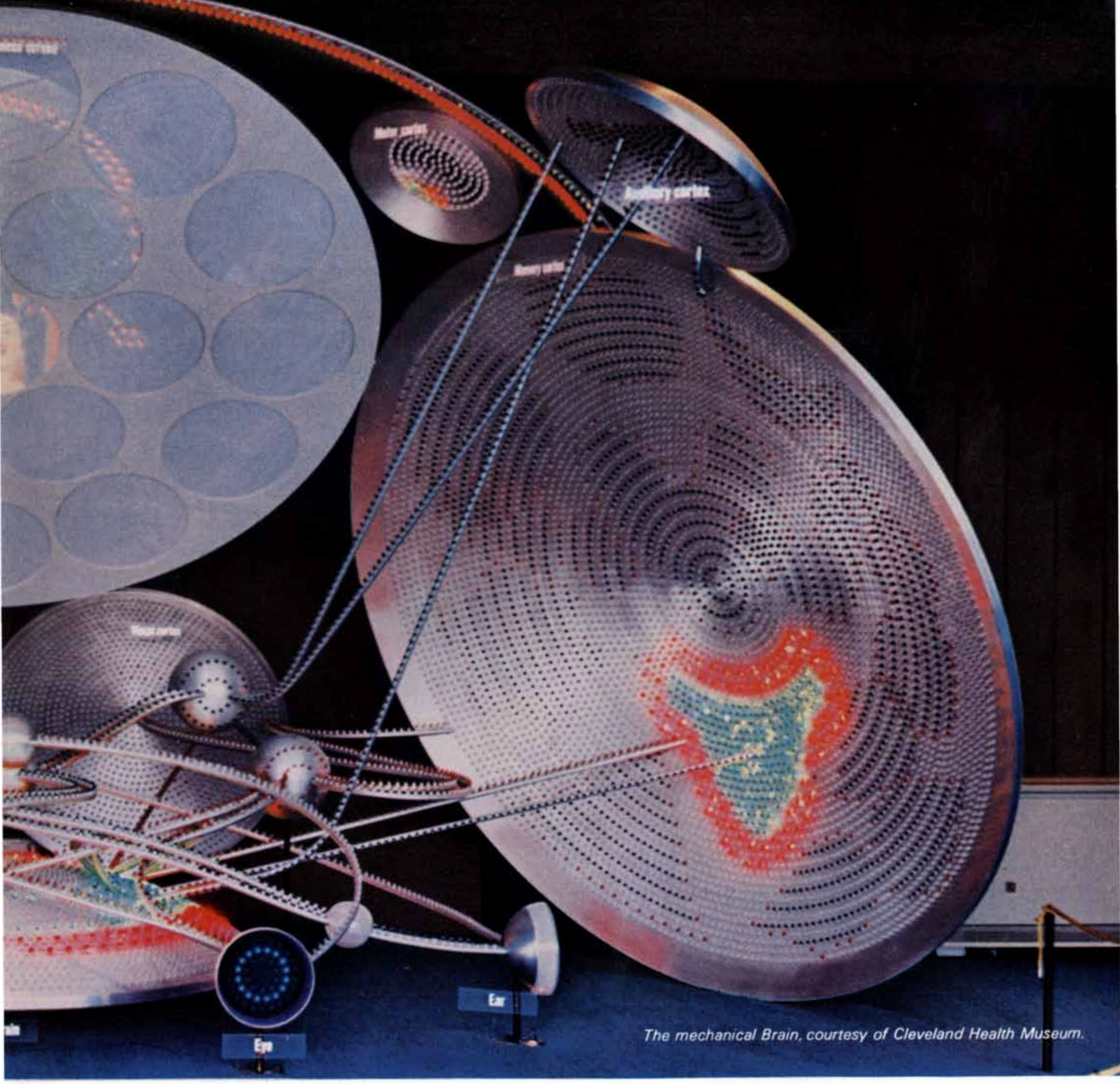

The mechanical Brain, courtesy of Cleveland Health Museum.

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...helping people communicate

What's an ad for softwood plywood doing in a magazine full of information on far-out space age materials?

Maybe it's to remind you of a lot of useful properties you've either forgotten about or never even knew.

Like its ancestor, good old wood, plywood has certain desirable qualities that many plastics and metals lack. Such as: predictable strength under stress. Resistance to chemicals. Natural insulation. Easy fastening. And absolute refusal to rust or corrode.

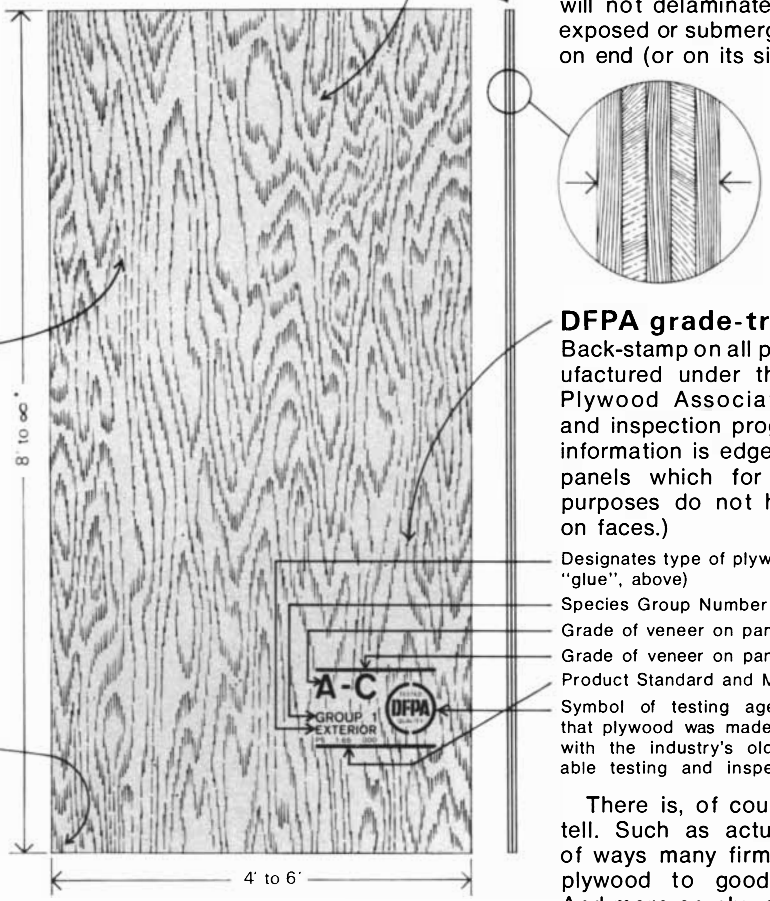
But in plywood, man and technology have improved on nature, to give this surprisingly versatile material its own set of unique advantages. You know the splendid job plywood does in construction. But have you seriously considered its suitability for hundreds of demanding applications in the industrial sector? From acid tanks to mock-ups of the SST, it's worth considering. So, in 345 words, here's plywood:

Strength: Astonishing. Pound for pound, actually stronger than steel. Thanks largely to its cross-laminated construction, plywood excels in impact resistance, stiffness, compression and flexural strength. E.g.: ultimate load on a 3/4″ panel, supported on 16″ centers, and through a typical forklift wheel, is 5,200 pounds. For more on plywood's strength and test descriptions, see Product Designer's Guide, offered below.

Corners: Square. Everything about plywood is square and true. It's designed by engineers for engineers.

Standard panel size: Big. Width, 48″. Length, 96″. Thickness, from 1/4″ to 1-1/8″. Oversized panels to 72″ by 144″ available. Theoretically, a scarfed panel may be made a mile long — if you can figure out how to carry it away.*

Surface: Your choice, among some 50 textures, patterns, or special coatings impervious to natural and unnatural hazards. Including: Sanded. Unsanded. Preprimed. Prepainted. Hardboard faced. Medium Density Overlaid (smooth, flat, paintable). High Density Overlaid (hard-surfaced, abrasion-resistant, especially resistant to acids). Aluminum-faced. Vinyl coated. Fiberglassed. Epoxy coated. Polyvinyl fluoride overlaid. And many, many more.



Species: Used to be mostly Douglas fir. Now, improved knowledge of wood properties and how to combine and balance them permits use of some 30 species, grouped according to stiffness. (Group number appears on every panel.)

Glue: Exterior or Interior. Interior type plywood, made with highly moisture resistant glue, is used where the product won't encounter prolonged dampness or exposure. Exterior type is made with 100% waterproof glue and with a higher grade of inner plys. It simply will not delaminate even if left exposed or submerged for years on end (or on its side).

1/4″ to 1-1/8″
(3 ply to 7 ply)

DFPA grade-trademark: Back-stamp on all plywood manufactured under the American Plywood Association testing and inspection program. (Same information is edge-branded on panels which for appearance purposes do not have stamps on faces.)

- Designates type of plywood (see "glue", above)
- Species Group Number
- Grade of veneer on panel face
- Grade of veneer on panel back
- Product Standard and Mill number
- Symbol of testing agency indicating that plywood was made in accordance with the industry's oldest, most reliable testing and inspection program.

There is, of course, more to tell. Such as actual examples of ways many firms have used plywood to good advantage. And more on plywood itself: Its gas permeability (low), hygroscopic and thermal changes (minimal), dielectric properties (when dry), chemical resistance (superb). But you'll find it all in these publications: "Guide to Plywood for Product Designers" and "U. S. Product Standard PS 1-66 for Softwood Plywood." Yours by writing us at Tacoma, Washington 98401, Dept. SC.

AMERICAN PLYWOOD ASSOCIATION

Plywood quality-tested by the Division For Product Approval them were standard weights for markets in eight lands and his personal cylinder seal, an heirloom then centuries old. This small merchantman, in size and shape rather like the 10-meter fishing vessel that found it, was "excavated" in the summer of 1960 by an expedition wholly professional in its central purpose but cheerfully amateur in the equipment and attitudes of the pioneer. Its aim was to dig up the wreck, not in the treasure-salvage style of the divers who at the turn of the century brought up what they saw of a precious cargo off the Greek island of Antikythera but in the meticulous and observant style of the archaeologist. The archaeologists themselves had to work the depths. That meant aqualungs, improvisation and, above all, slow labor. It was not possible to supervise crews of divers in the work; only a couple of divers went down each day, to draw, photograph, measure and dislodge, after careful discussion and photographic planning of the day's effort. Helmeted divers did the heaviest work, often with an aqualung diver present to "guide their leaden feet through the wreck with his hands." They raised the big coralline lumps to the surface with air-filled plastic balloons; they learned to work in light so much changed by the sea that "blood from minor cuts... was green."

Here in word and drawing and photograph is the ship, its contents and their meaning after 30 centuries. The sailors had a single oil lamp and ate olives freely with meals, as Aegean sailors do today. The polished weights they used were mainly of hematite, made to an accuracy of one part in 1,000. These weights, all used by one man at one period, are far more uniform than contemporary finds on land, where samples of different age and use are hard to avoid. The wreck is what the experts call a "closed deposit."

The scrap tools are lovingly identified; the ingots are all measured and analyzed; the pottery is carefully typed. The tin, found as a powdery oxide, is the earliest industrial sample of this metal known; the absence of traces of germanium and cobalt argues that it did not come from the famous tin workings of Cornwall. The lead too is isotopically not British in origin but Levantine—iron is absent. Carbon-14 dating was done on brushwood that lined the vanished hull as a cushion for its heavy cargo, a practice followed to this day on the same sea route. The carbon date is 1200 B.C. Pottery, scarabs, the shape of the ingots as represented in Egyptian frescoes, the style of the tools all concur.

The single find seems to demonstrate that the Phoenicians plied the sea as traders centuries before the era of their great colonial expansion; Homer was not anachronistic in his picture of these people at the time of Troy. The scale and the diving methods of this small success under the sea are already outdated, but its lesson, like its finds, will remain. There is a great reward for the archaeologist who remains in control, in the coral ooze as in the desert dust.

THE FIRST MERCHANT VENTURERS: THE ANCIENT LEVANT IN HISTORY AND COMMERCE, by William Culican. McGraw-Hill Book Company ($5.50). A compact and elegant account of the second millennium B.C.: the fortunes and fate of its seafarers, their tools, their art and their alphabets. The very ingots fished up off Cape Gelidonya are here in color photographs. The Phoenicians planted the pomegranate throughout the Mediterranean. The author compares this symbol to that culture itself: "...ripe but enduring, and if not the most palatable, at least the most shapely fruit."

COMPUTATIONAL ANALYSIS OF PRESENT-DAY AMERICAN ENGLISH, by Henry Kučera and W. Nelson Francis. Brown University Press ($15). Here are some 300 pages of computer output, with a handsome and learned surround of explication and analysis. The topic is the 1,600 feet of magnetic tape on which the authors and their colleagues recorded just over a million words of text, all published in the U.S. in 1961. The Corpus, as they call it, was a carefully stratified random sample. It includes 500 texts, each 2,000 words long, drawn from 15 types of writing—everything from "the sports page... to the scientific journal... and from popular romantic fiction to... philosophical discussion." Newspapers furnished about a sixth of the sample, learned writing a little less, fiction of all kinds nearly a fourth. Once the categories were chosen and weighted by the authors the texts were selected randomly from the big library holdings in Providence, with a few other sources such as "one of the largest secondhand magazine stores in New York...."

In the book the 50,000 distinct words, formulas, abbreviations and whatnot that form the sample are arranged in two great lists: by frequency and then alphabetically. A statistical treatment of the data by John B. Carroll makes clear how closely the frequencies follow the well-known log normal distribution. From his two-parameter fit (which is really excellent) he can derive from the theory the expected finite number of words in the entire population sample, which comes to about 350,000. Such a distribution has rather strange properties. Nearly half of the word forms listed occur only once in a million times, whereas the 80 most frequent words—down to *man*—comprise more than half of the total sample. The 92nd place is held by mathematical formulas as a whole—any set of symbols including signs for operations. Our common printed language is about one part in 1,000 mathematics. After *Washington,* which must include the city, the most-mentioned person is *Kennedy* (in 1961 America). *Viet Nam* in all its forms and cognates appears 30 times; *Hanoi* is missing. The Anglo-Saxon four-letter words are not fit to print: they occur fewer than 10 times in all. *Iron* and *oxygen* are the most-mentioned elements, tied at 43. *One, two, three* appear in that order a total of 5,000 times. *Zero* occurs a couple of dozen times, *infantry* only twice.

The tape itself—plus a manual for using it, raw material for a dazzling number of curiosities and linguistic researches—is available to all who wish to order a copy. The heroine of the enterprise is Loretta Felice, who punched the entire megaword.

RADAR ORNITHOLOGY, by Eric Eastwood. Methuen & Co Ltd ($12). Radarmen during World War II came to realize that the occasional small dots randomly scattered over the face of the picture tube they viewed were caused by birds. Their aphorism was that "all birds are angels"; "angels" was the generic word for mysterious signals that were definitely not aircraft. By the 1950's the high-power search radar sets using centimeter waves showed not a few dots but whole nebulas—shifting signals, mostly around an altitude of 3,000 feet or less, moving both with and against the winds at 40 miles per hour. Sometimes the angels spread over 100 miles. Were all of them birds? By a decade ago it was well established that bird "angels" were indeed commonplace. A high-powered research radar, such as the one at Bushy Hill in Essex around which much of this British book is centered, can detect a few birds at many scores of miles, and every single bird up to some 10 miles away. The North Sea, the waters off Cape Cod and the plains of Illinois have been searched by day and night to take a census of the birds, their migrant patterns, their numbers, directions, speeds and altitudes. The Distant Early Warning Line has made a coordinated study of the migration of birds into the Canadian Arctic, a use far more hopeful than the grimmer task for which it was designed. Eastwood, a physicist who has himself done much pioneer work on bird signals, gives an account of all these matters in a book aimed at the nonelectronic reader. The radar photographs are remarkably clear and interesting.

The most startling result so far is the identification of ring angels. These rings, beautifully circular, form around many points in England at dawn—around Canterbury, around Trafalgar Square. They spread out in concentric fashion like the ripples from a stone thrown into a pond, moving at 40 miles per hour. Observers who were watching from the central spot finally confirmed the remarkable truth: these angels are rings of starlings, which fly out in great spreading circles from their roosts at dawn. Half a dozen such concentric starling rings can be seen at once, spaced a few minutes apart. Sometimes flights can be seen converging at sunset, but not in clear rings. A well-marked ring contains some 100,000 birds; there were three million starlings within the range of Bushy Hill.

Radar will increasingly help to make known the way of a bird in the air; work on signals from single birds, on the identification of species, on studies using widespread groups of radar stations lies in the future of this powerful form of bird-watching.

THE MIND OF THE DOLPHIN: A NONHUMAN INTELLIGENCE, by John Cunningham Lilly. Doubleday & Company, Inc. ($5.95). After six wet and thoughtful years we have a second book by our envoy among the dolphins. Most of the new book is a sober, possibly somewhat shallow but everywhere honest effort by Lilly to search out the nature of the human mind as an indispensable preface to the ultimate arrival at a meeting of minds with our distant cousin. He does not fail to discuss mental health, religion or cultural restrictions. There is a chapter considering "the spiritual side." He contrasts the freely breathing but gravity-bound clothed human with the dolphin: the dolphins are under the enormous discipline of a lifelong conscious necessity to seek the pool of the air, but they are immune from gravity, effortlessly acrobatic, they rid themselves of waste without need for disposal, they are always thermally comfortable, they sense by sound, smell and touch, little by sight. So it is to some degree with a human being suspended in a warm, silent, salty pool in the dark, breathing by mask, in sensory near-isolation. Lilly writes here out of experience; his essay is a moving evocation of another world of the mind.

In the laboratory matters move slowly. The most explicit report is of an experiment in joint living. The dolphin was met halfway. Margaret Howe and Peter, a young dolphin, for 10 weeks shared a couple of rooms flooded knee-deep with seawater. Miss Howe's journal is fascinating to read; she and her inseparable friend grew to exchange a profound trust. Peter seems to have fallen in love with his teacher, a situation she was required to handle with courage, candor and tact. The game they played with counting colors and languages, however, remained uncertain, enigmatic and obscure. If the large brain of *Tursiops* houses a great mind, we have not yet made contact with it. Lilly has faith in what the future holds. The book ends with the heartening news that the Russian government made dolphin-catching illegal in 1966, and with a plea for shallow flooded parks where dolphin and man might make extensive voluntary contact. Perhaps we ought not to expect too much in so few years; after all, dolphins have been watching men for a long time. It was an Athenian who wrote: "Oh, my good, kind dolphins, beware the savagery of men!"

THE COSMOS OF ARTHUR HOLLY COMPTON, edited by Marjorie Johnston, with an introduction by Vannevar Bush. Alfred A. Knopf ($10). It was Nobel laureate Compton, director of the laboratory, who telephoned Cambridge when the first nuclear chain reaction had been achieved to report that "the Italian navigator has just landed in the New World." In this volume are collected Compton's informal autobiography and 44 papers addressed to the general public on a wide variety of topics, both in science and outside it. The story of the sunny Ohio boyhood of this faculty child at a small denominational college, his graduate work in the Ivy League and his year of research abroad is, as he writes, "more or less representative" of the scientists of our country in the years before World War II. His account will remain an important and touching document. After the war that innocence was gone, and his papers are filled with accounts of the decision to use the bomb in combat, of the McCarthy attack on intellectuals, of the struggle against atomic testing and above all of his pride in his Mennonite heritage, his Christian belief and an American "spirit of enterprise combined with a certain altruism ... more than ordinarily present among our people." He thought the atomic attacks on Japan were justified in that they ended the war; indeed, he had written an intimate memorandum arguing for "a military demonstration with minimum human damage." He stoutly defended J. Robert Oppenheimer and others before their accusers. He favored a ban on large nuclear tests, which more or less became the form of the present treaty. He was never a severe critic of any American institution, and he never voiced those black dilemmas that have been the vision of so many of his reflective contemporaries. Altogether he played the role that he personally fitted so well: the moderate, reasonable, right-minded man, with an inherent—almost complacent—sweetness.

THE WORLD FROM ABOVE, edited by Hanns Reich. Hill and Wang, Inc. ($7.50). Aerial photographs presented frankly as objects of beauty—abstract, metaphorical and revealing. A hundred in black and white and a handful in color, these photographs, with a few pages of critical text, set out to dazzle the eye and the mind. They succeed all too easily. Here are four trees: one, a silhouette in flames, is the delta of the Colorado River; another, a feathery leafless form, the tracks of automobiles in the snow; the third, dark roots searching, the tide ebbing from the sands of a North Sea canal; the fourth, a gnarled and bent fruit tree in winter, the delta of the Rajang River in Borneo. The book is all artifice of choice and viewpoint, beautifully contrived.

TREASURES OF PREHISTORIC ART, by André Leroi-Gourhan. Harry N. Abrams, Inc. ($40). The logical and statistical arguments of Professor Leroi-Gourhan, which make plain the intellectual depth of Paleolithic art, are by now familiar to SCIENTIFIC AMERICAN readers. Here is the rich and ponderous volume, in a clear English translation by Norbert Guterman, that documents his point of view. It is a worthy successor to the fine large volumes by Abbé Breuil and Paolo Graziosi that in the past decade have presented this art to American readers. The color plates are still larger and handsomer, and the whole book is still more sumptuous than we have seen before. Five hundred careful black-and-white photographs and small index drawings describe the major works with clarity and precision. The coverage of minor objects is perhaps less complete than Graziosi's, but the photographs by Jean Vertut show us the art with better vision and with new understanding.

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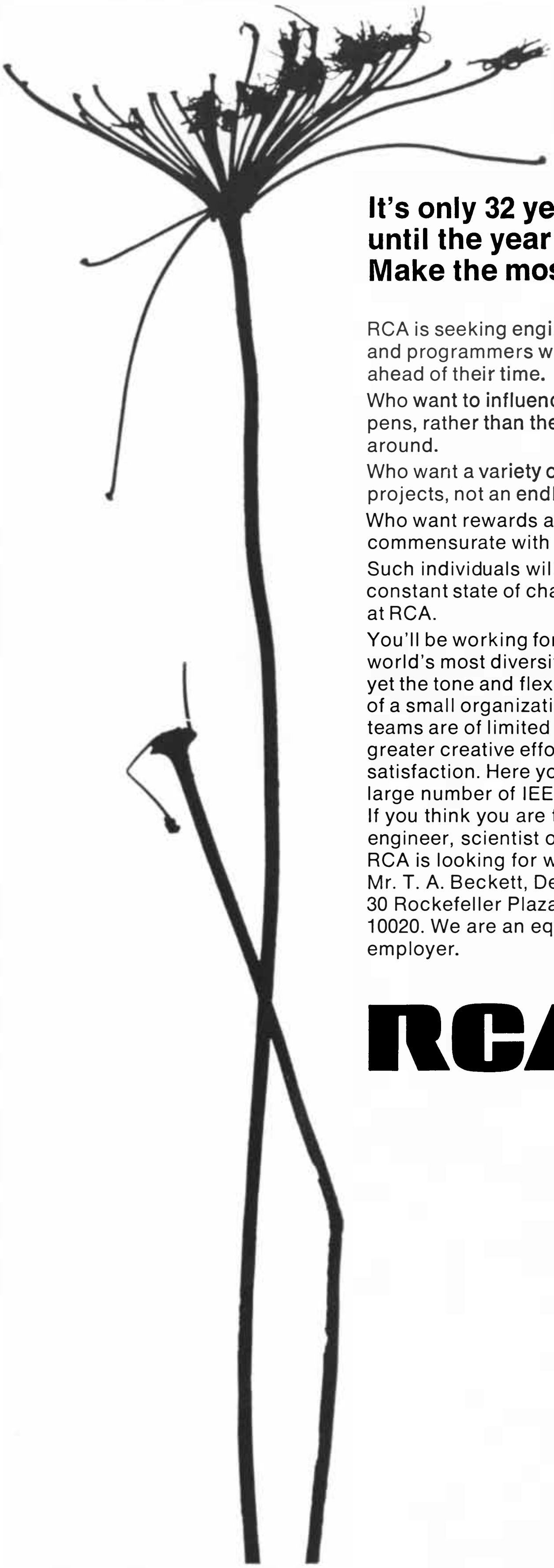

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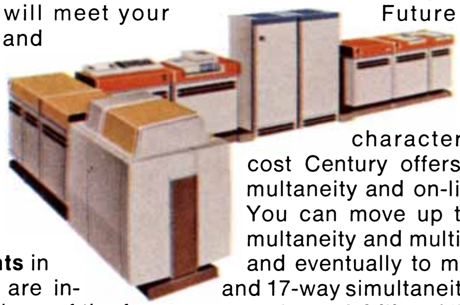

Great advancements in computer technology are incorporated in all members of the family. Their internal memories utilize thin film, short rods. Offering speed in the 800 nanosecond range. Yet automated manufacturing techniques have made this ultra-fast memory lower cost than slower core memory.

Monolithic integrated logic circuitry is used throughout the Century components. This new generation of super circuits has the power of conventional or hybrid types used in the past and at a fraction of the size. A universal type is arranged in only six different patterns to make up 80% of all logic circuitry in the Century. This standardization achieves a high degree of operating reliability at greatly reduced cost.

Dual spindle disc unit is an important common feature of all Century computers. For small Century systems it provides magnetic file processing. For larger Century systems the disc unit serves as a storage device for operating software.

Wide range of CPU memories, from 16,384 to 524,288 eight-bit characters. Future Century computers will offer memories up to one million characters. The lowest cost Century offers three-way simultaneity and on-line processing. You can move up to nine-way simultaneity and multi-programming, and eventually to multi-processing and 17-way simultaneity.

Expandability! All Century computers have it. You can add more disc units with 108 or 180 kc transfer rates and eight-million character capacities. Card Random Access Memory (CRAM) units each with a capacity of 125 million characters. Magnetic tape units with transfer rates up to 240 kc. 3000 LPM printers. MICR sorter/readers. OCR readers. Punched card and tape equipment. Remote on-line devices.

Sophisticated software! No other computer in the same price range as any Century computer can offer as much. Compilers, operating systems, applied programs and utility routines. All written, tested and ready-to-go for all members of the family. Programming languages: COBOL, FORTRAN and NCR's own NEAT/3. You'll appreciate the completeness of the Century operating system. The monitor section, for example, can completely schedule a Century computer's operation. Programs are loaded and automatically executed in the desired sequence based on priority, date or special conditions.

NEAT/3, a language with built-in simplicity, incorporates simple English instructions with powerful tools that enable the computer to generate its own program. Complicated logic and coding are eliminated because flexible procedural instructions and pre-programmed major computer functions are combined in one language.

Get the complete story of the Century. There's much more to tell about the Century Series that gives unequalled per-dollar performance. Call your NCR representative today for more information or write to The National Cash Register Company, Dayton, Ohio 45409.

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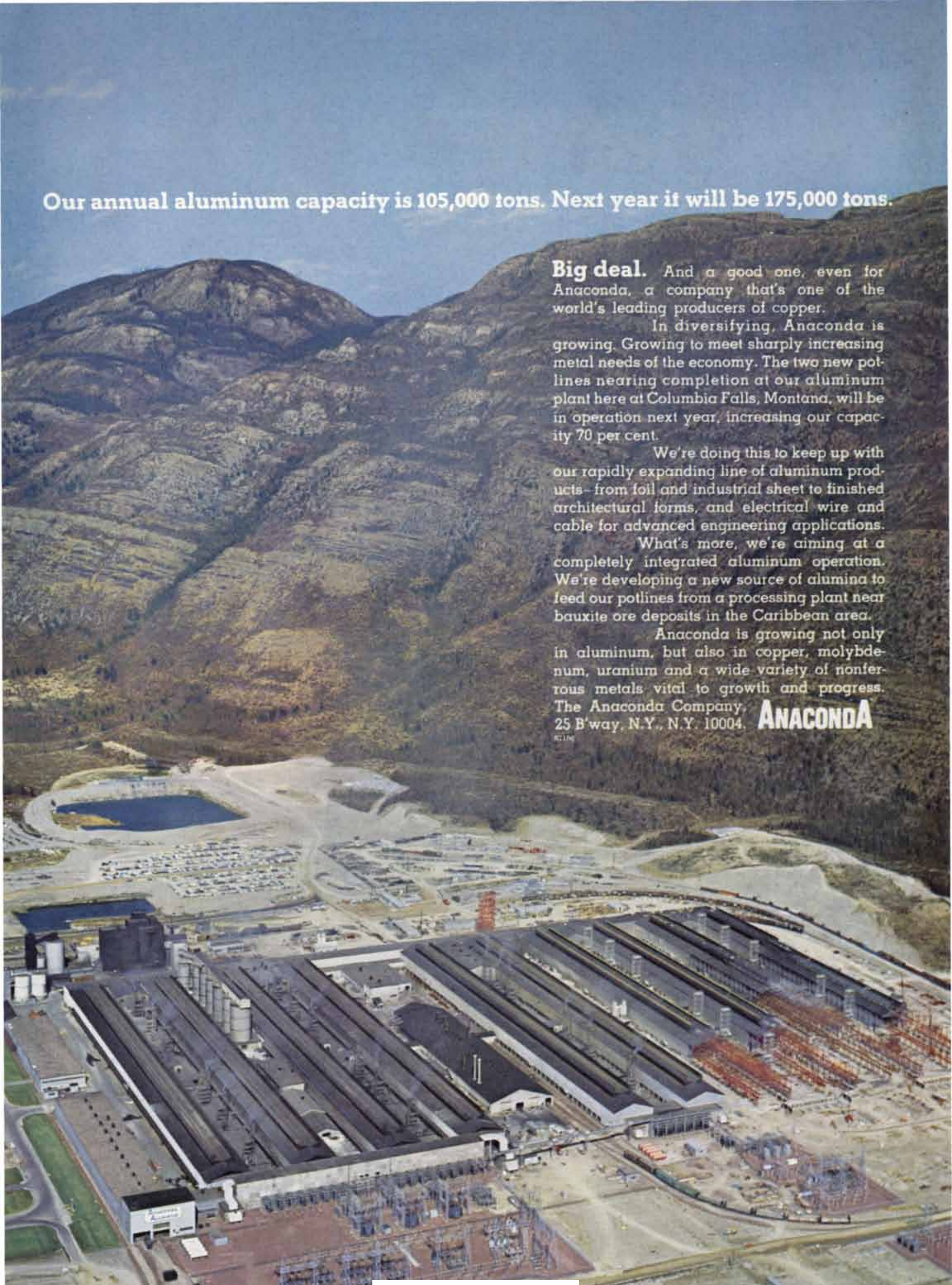
Our annual aluminum capacity is 105,000 tons. Next year it will be 175,000 tons.
Big deal. And a good one, even for Anaconda, a company that's one of the world's leading producers of copper.
In diversifying, Anaconda is growing. Growing to meet sharply increasing metal needs of the economy. The two new potlines nearing completion at our aluminum plant here at Columbia Falls, Montana, will be in operation next year, increasing our capacity 70 per cent.
We're doing this to keep up with our rapidly expanding line of aluminum products—from foil and industrial sheet to finished architectural forms, and electrical wire and cable for advanced engineering applications.
What's more, we're aiming at a completely integrated aluminum operation. We're developing a new source of alumina to feed our potlines from a processing plant near bauxite ore deposits in the Caribbean area.
Anaconda is growing not only in aluminum, but also in copper, molybdenum, uranium and a wide variety of nonferrous metals vital to growth and progress.
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