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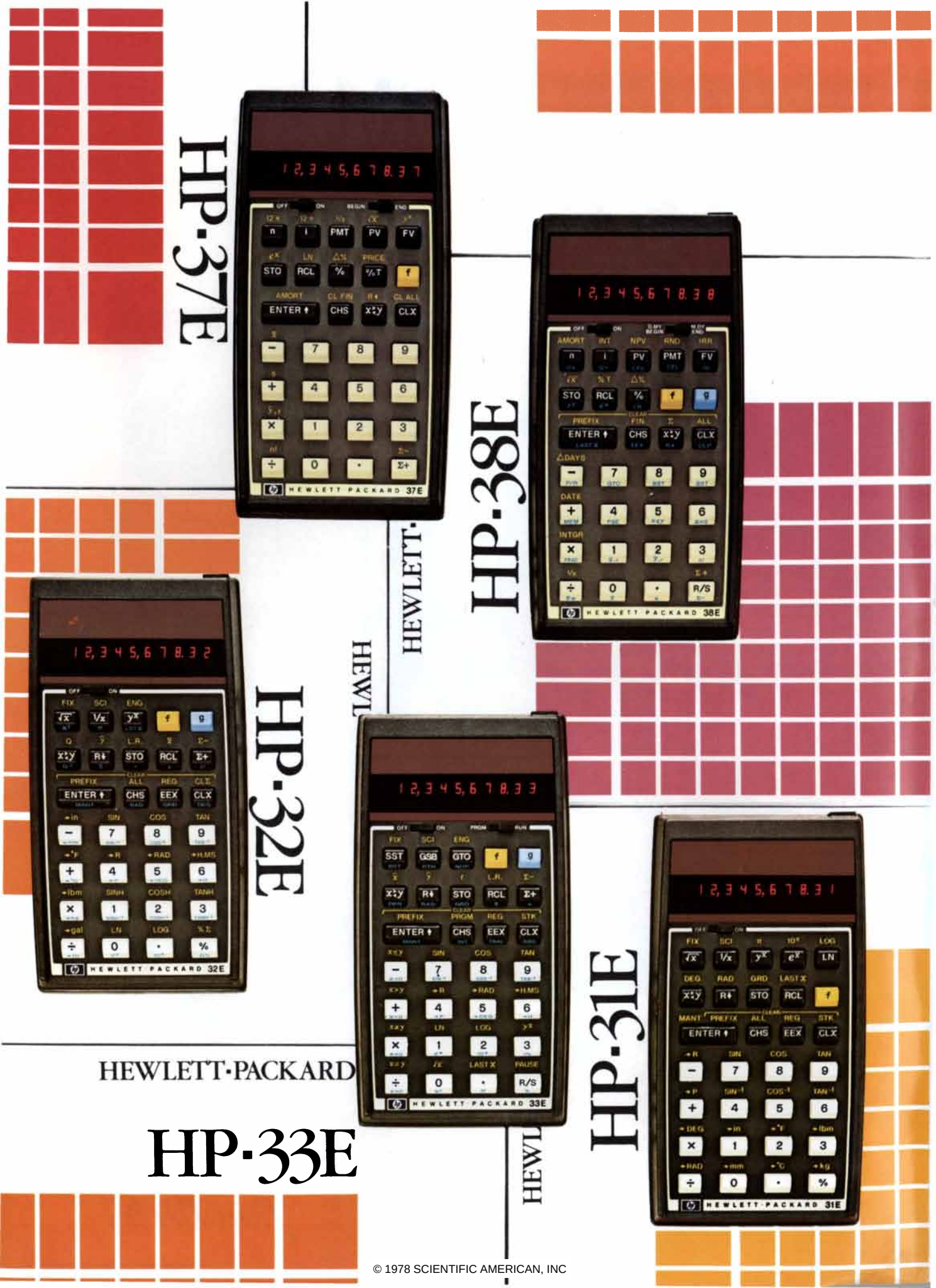
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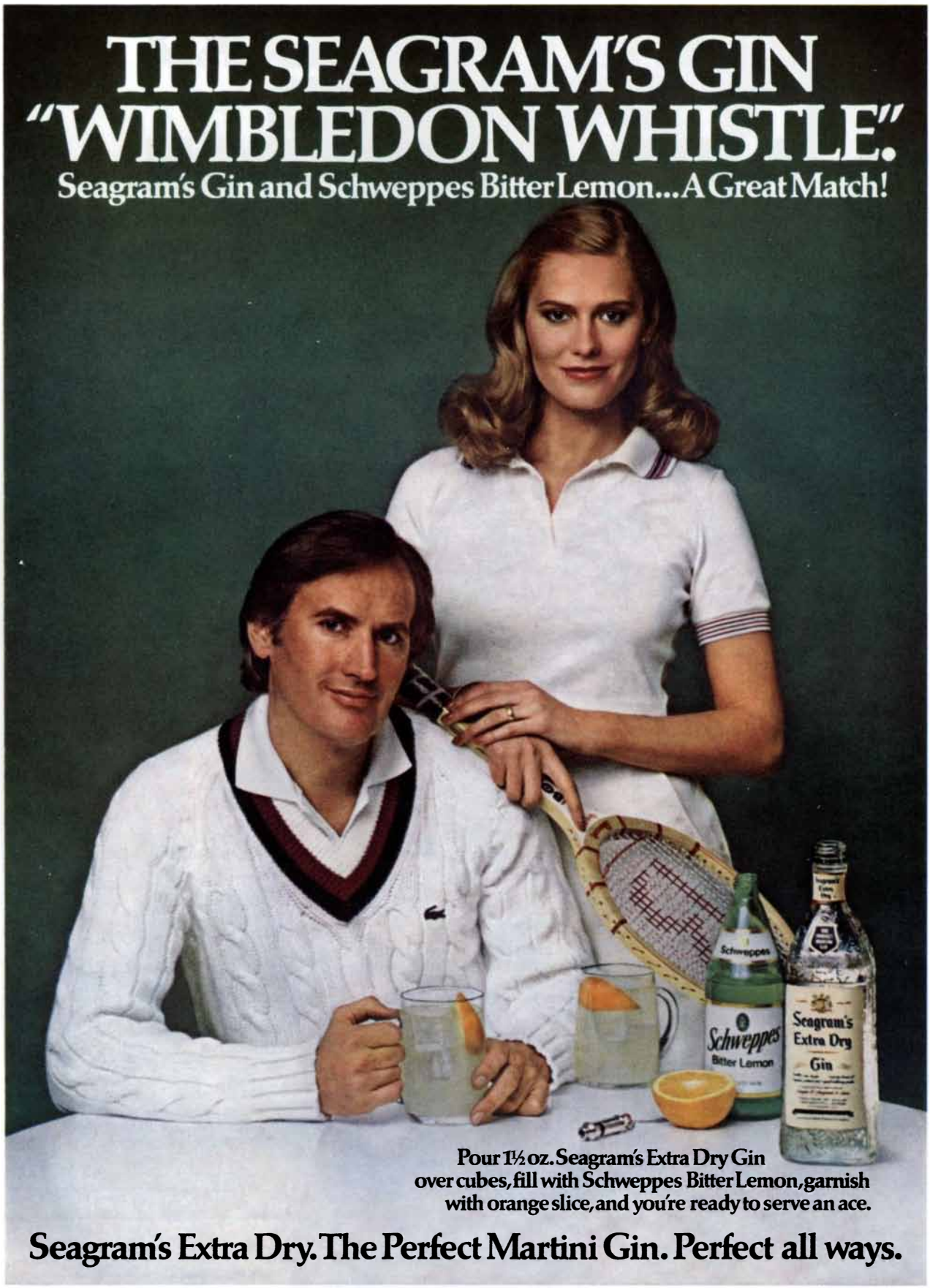

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the report that briefs you on what to watch

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Volume XIV, Number 8 • May, 1978 • Pickfair Bldg., Rancho Santa Fe, Calif. 92067 • Area 714:756-2600

Albert Szent Gyorgyi, M.D., Ph.D.:

HOW NEW UNDERSTANDINGS ABOUT THE BIOLOGICAL FUNCTION OF ASCORBIC ACID MAY PROFOUNDLY AFFECT OUR LIVES

One of the world's most honored scientists, winner of the 1937 Nobel Prize for Physiology and Medicine, outlines what has happened and why this is so vital to our good health and chance for a long life!

PUBLISHER'S NOTE: It was August 7th, 1973 at Stanford University's Symposium on Ascorbic Acid (Vitamin C) that I first met Albert Szent-Gyorgyi, then the new member of our Editorial Board. I would like to give you part of the intriguing news story about him that appeared the next day:

"STANFORD, CALIF. (AP) Forty years ago a Hungarian physician named Albert Szent-Gyorgyi discovered that a mysterious chemical in certain fruits seemed to protect them against infection and discoloration when they were bruised.

"He wondered if the chemical had anything to do with human disease, so he crystallized the substance to study it.

"First he called it *ignose* (because he was so ignorant about it), and then he called it *God-knows* (because neither he nor anyone else could really tell what it was good for).

"Finally he had to settle for calling it ascorbic acid — which has since become more and more famous as Vitamin C.

"Szent-Gyorgyi tried to extract enough to study from the adrenal glands of slaughtered cattle. He managed to collect barely 15 grams in a year of work in Minnesota.

"Then he went home to Hungary, and while he was visiting the University of Szeged, located in the center of Hungary's paprika-growing region, his wife doused a dinner dish with some of the local sweet peppers.

"Yesterday, at Stanford University, Szent-Gyorgyi recalled that momentous dinner.

"I didn't like the paprika," he related, "so I told my wife, I'll take it to the lab.

"By midnight that night I knew I had found a treasure trove."

"The paprika peppers, he discovered, were a bountiful source of ascorbic acid, and within a month he had prepared more than three pounds of it to ship to scientific colleagues all over the world.

"In 1937 Szent-Gyorgyi won the Nobel Prize for his discovery of Vitamin C. Now nearly 80, he is still

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THE COVER

The photograph on the cover shows deteriorating marble on the exterior of the church of Santa Maria dei Miracoli (Saint Mary of the Miracles) in Venice (see "The Preservation of Stone," by K. Lal Gauri, page 126). Eight flat pieces of marble serving as exterior facing come together at an intersection that is covered by a decorative rectangular stone of porphyry. The lower pieces of marble in particular show the effects of reactions with atmospheric gases that are dissolved in water, both rainwater and the periodic Venetian floodwater to which the church is subjected. Marble consists mainly of the mineral calcite, which is highly vulnerable to the action of carbon dioxide in solution. The calcite reacts with the solution by forming products that go into solution themselves, so that the marble is leached. Sulfur dioxide, another compound in the air, transforms calcite into gypsum, which is soluble and therefore tends to be washed away by rain, thus eroding the stone and exposing fresh surfaces to weathering.

THE ILLUSTRATIONS

Cover photograph by David Lees

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LETTERS

Sirs:

The article "Deinstitutionalization and Mental Health Services," by Ellen L. Bassuk and Samuel Gerson [SCIENTIFIC AMERICAN, February], has been carefully studied and discussed by the membership of the National Council of Community Mental Health Centers (NCCMHC).

The authors obviously researched their article extensively, and it generally reflects a good understanding of the multiple factors involved in providing community-based care to a large number of recently deinstitutionalized individuals throughout the country.

We do, however, strongly disagree with the authors' conclusion that the failure to deal adequately with this segment of our population is a failure of the community mental health center system alone.

The guilt for this "failure" to deal effectively with a special segment of the population is a *corporate* guilt, shared by many institutions and agencies within our society. It is naïve and shortsighted to imply that a very new, still growing and relatively small system of care, the community mental health center system, can singlehandedly correct 200 years of community neglect toward America's chronically mentally ill patients.

We do not argue with most of the article's information; it makes a concise and strong argument for improved coordination and funding of programs for deinstitutionalized persons. In various places throughout the article the authors list the following institutions, agencies and events as having impact on the problem of deinstitutionalization: state legislatures, Federal legislation, insufficient funding, ineffective therapy, housing, vocational rehabilitation, sheltered workshops, transportation and recreation. Yet the basic conclusion remains that community mental health centers are responsible for the entire deinstitutionalization process.

Our concern, and our disappointment, with the article lies in this biased and simplistic conclusion—that the community mental health system is a failure because it has not been successful in coping with the multiple factors involved in deinstitutionalization.

The community mental health center system is a success in areas that serve approximately 44 percent of the nation's population. Surely *Scientific American* and the article's authors can be objective enough to realize that community mental health centers are making a viable and valuable contribution to America's health-care system.

Please do not judge a single system, community mental health centers, with the success, or lack of success, of the many agencies and institutions working together trying to bring about a viable program of deinstitutionalization. Everyone shares in the responsibility of what has happened to the chronically mentally ill, and only by the collective efforts of everyone will the necessary changes occur.

JOHN C. WOLFE, PH.D.

Executive Director
The National Council of Community
Mental Health Centers, Inc.
Washington

Sirs:

Dr. Wolfe's concerned response to our article reminds us that the provision of optimal care and treatment of chronically ill mental patients represents a challenge to the entire network of public-health services. His argument that "it is naïve and shortsighted to imply that... the community mental health center system can singlehandedly correct 200 years of community neglect" corresponds quite closely to our own view. Such an expectation was, however, an integral component of the "blind faith" that pervaded the initial stages of the community mental health move-

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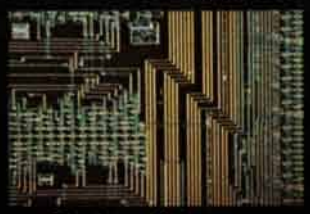

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ment. It was an expectation that was unrealistically propagated and resulted in a generally rapid and uncoordinated massive exodus of chronic mental patients from state institutions into communities ill-prepared to meet their needs.

In articulating the view that the community mental health centers as a whole have not been, and are yet to be, capable of dealing effectively with the needs of chronically disabled patients the article did not conclude that this represented a failure of the community mental-health-care system alone. Rather we argued that the ideological rationale behind deinstitutionalization generally has not been translated into an adequate number of researched, funded and staffed treatment programs because of constraints on the necessary resources. Furthermore, we pointed out that services for deinstitutionalized patients represent only one aspect of the community mental health movement and that these centers have greatly contributed to the increased number of available services for many formerly neglected populations. We concluded that it has been a failure in the process of implementation of the goals of the community mental health movement, particularly the development of an adequate number and range of comprehensive community alternatives, and not of the goals themselves.

We agree wholeheartedly with Dr. Wolfe's assertion that the responsibility for alleviating the plight of the chronic mental patient is a "corporate" one that demands the collective efforts of all. The multiple and unique needs of chronic patients of all ages for medical and psychiatric care, adequate living arrangements, rehabilitation and employment require a coordinated approach free from the ideological constraints that have marked the past 20 years.

ELLEN L. BASSUK, M.D.

Harvard Medical School
Boston

SAMUEL GERSON

Cambridge Hospital
Cambridge, Mass.

Sirs:

The two articles on polarized light by Jearl Walker ["The Amateur Scientist," SCIENTIFIC AMERICAN, December, 1977, and January] prompt me to describe some striking phenomena, which although discovered long ago seem to be generally forgotten. They concern the circular polarization of the light reflected from the surface of certain beetles. Like many other beetles, flies and other insects, the rose chafer or goldsmith beetle, *Cetonia aurata,* a common European species, is of a green metallic color, which is generally assumed to be due to reflection and interference by the structures of the beetle's cuticle. If one looks at such beetles—alive or dead—through a polarizing filter, some faint specular reflections are dimmed in certain filter orientations, and the entire picture appears to be slightly darkened, but the green metallic sheen is not otherwise affected, whatever the filter orientation.

If one then puts a quarter-wave plate between the beetle and the polarized filter, so as, according to the screw-shape convention, to produce a left-circular polarizer, the green sheen will completely disappear and the beetle will appear a dull black. Joint rotation of the filter and the plate does not affect this appearance.

The circular nature of the polarization by the beetle's cuticle can be most convincingly demonstrated by the use of a mirror. If one looks simultaneously at the beetle and its reflection in the mirror, the beetle will be black and the mirror image will be green. If one rotates the quarter-wave plate by 90 degrees in its own plane, thus producing a right-circular polarizer, the beetle will appear green and the mirror image will appear black. By mounting two quarter-wave plates rotated by 90 degrees against each other onto a polarizing screen both effects can be observed in quick succession.

As far as I know light reflected from the surface of natural objects is only rarely circularly polarized. One may ask whether this property of the cuticle has some selective value for the beetles and whether they can themselves perceive the polarization, their cornea perhaps serving as a quarter-wave plate. (The ability of arthropods' eyes to "analyze" plane-polarized light was established some time ago by Karl von Frisch). Another problem is to find out the exact arrangement and dimensions of the cuticular structures, which produce the circular polarization.

To avoid disappointment it should be stated that the cuticles of most green metallic beetles and other insects do not exhibit circular polarization. In Europe the property seems confined to the green species of *Cetonia*. The green and orange surface of a beetle from New Guinea, *Ischiopha jamesi* var. ignipennis, also can be "blackened" by viewing it through a quarter-wave plate. It would be interesting to find out whether the nearest American relatives of *Cetonia,* of the genus *Cotinis,* are affected.

H. KALMUS

Galton Laboratory
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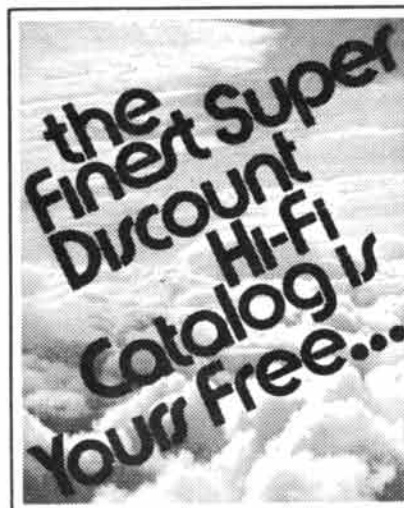

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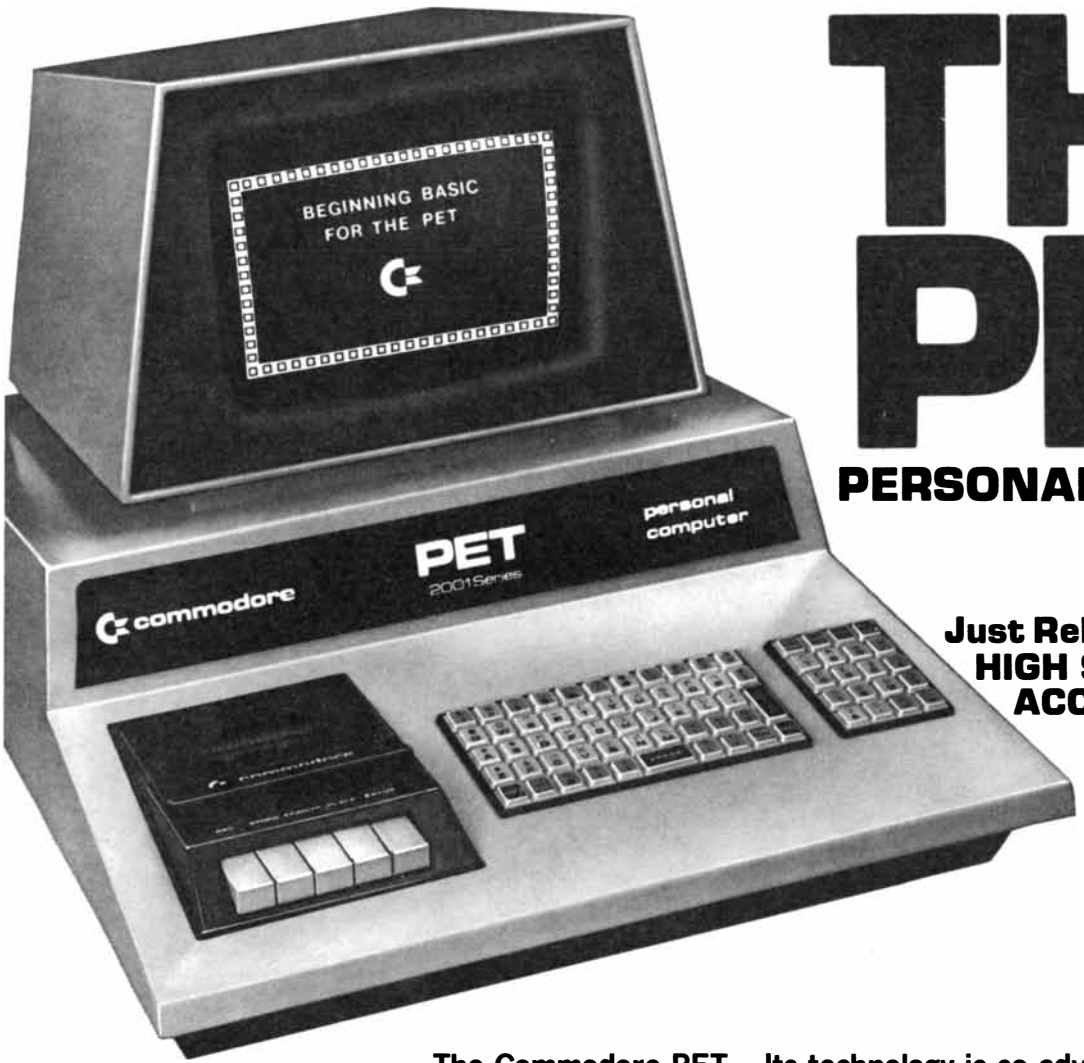

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THE PET has become the standard for the emerging personal computer industry. Computer magazines, trade journals, consumer and business publications have lauded its discovery. POPULAR SCIENCE put THE PET on its October, 1977 cover, in full color, and devoted a feature news story to the coming revolution in personal and office computing. PLAYBOY, February, 1978, gave full color coverage to the "mind-boggling" PET.

IN A LEAGUE WITH IBM, HP AND WANG MINICOMPUTERS

THE PET should not be confused with game products that hook up to household T.V.'s. It is a minicomputer. What sets THE PET light years apart from other computers is its price. While the others cost from $11,000 to $20,000 and more, THE PET, with similar capabilities and power, costs only $795.00.

One extremely important capability shared with HP's minicomputer, and full size computers, is its IEEE-488 Bus. This standard data/control channel means your PET can be directly connected to a variety of peripherals and laboratory measuring equipment. Over 120 pieces of compatible equipment such as counters, timers, spectrum analyzers, digital voltmeters and printer plotters from manufacturers such as HP, Phillips, Fluke, and Textronix are currently available.

ROM Magazine, January 1978, writes, "THE PET comes out of the box, plugs into the wall, and is ready to use." It is equipped with a CRT video display with reverse and blink features, an alpha-numeric keyboard with complete graphics and a built-in standard cassette tape deck.

THE PET is an exceptionally powerful think tank with 8K bytes of RAM (User Memory). Optional equipment, permits expansion to 32K. The system contains 14K bytes of ROM (Program Memory).

THE PET COMMUNICATES IN THE EASIEST COMPUTER LANGUAGE

Computers talk in many languages. The easiest is BASIC or English-like words. If THE PET wants you to press a key, it will flash, "Press such and such", right on the display. You speak back to THE PET through its full size 73-key keyboard.

EXTENSIVE CHARACTER ORIENTED GRAPHICS

The unit features a 9-inch, high resolution, 1000 character CRT. Characters are arranged 40 columns by 25 lines on an 8 x 8 matrix for superb graphics.

WHAT IS THE PET REALLY FOR?

It is the single most important teaching device for any computer related subject. It can help a youngster learn number facts, or help a med student do tissue analyses. It will entertain the most sophisticated data application, or the simplest inquiry-response assignment.

IN THE LAB it handles instrumentation, process monitoring, computer aided instructions, and more. A number of Fortune 500 companies have already made PETS an integral part of their lab and general office system.

As a **BUSINESS TOOL** it will; Maintain ledgers. Illustrate cash flow charts. Keep payroll records. Create P & L's. Control inventory. Store and analyze sales data. Draw bar graphs. Issue invoices. Do statistical work. Hook up to on-line computer system.

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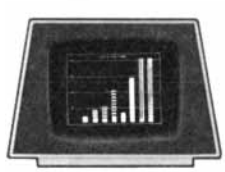
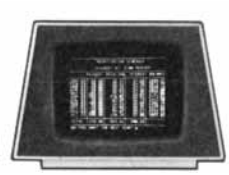
THE PET is the only totally integrated, self-contained, personal computing system. It measures a compact 16½" wide; 18½" deep; 14" high, and weighs just 44 pounds.


Bar Graphs


Amortization Chart


Blackjack


Teaching Trigonometry

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Engineers, scientists, doctors, educators, students of computer science, attorneys, stock brokers, realtors, insurance people, list brokers, home economists, churches, grocery store owners, automobile dealers, sales people, organizations.

JUST FOR FUN

There is hardly a game, from Blackjack to Master Chess, that cannot be programmed into the unit. A variety of game programs is currently available.

ANNOUNCING THE PET PRINTER

This powerful word processing accessory lets you print hardcopies, invoices, and computer correspondence. Faster than an IBM Selectric, THE PET Printer delivers 60 characters per second at a sustained rate -- or 3,600 characters every minute -- with upper and lower case capability. Characters are 1/8" tall and printed in a 7 x 8 dot matrix. The printer uses a standard 8½" wide paper roll. And, most unbelievable -- it is only $599.95.

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This optional component expands storage and increases flexibility. Only $99.95.

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Contemporary Marketing is a major source for advanced electronic products. Our commitment to this exciting industry is the reason why Contemporary was selected to bring THE PET to you. In comparison with other full-fledged computers, it is an incredible value. Nevertheless, we recognize that it is a substantial investment for any company or individual. Please be assured that we are pledged to protect your investment. As a Contemporary PET owner, we will see to it that you are kept abreast of all new peripherals and software, as they are developed. We want you to use THE PET with complete confidence. If, for any reason, you are not satisfied with your PET, simply return it within 30 days for a prompt and courteous refund.

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50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

JUNE, 1928: "Between the hours of 12 and one o'clock the morning of March 13th the St. Francis Dam of the Los Angeles aqueduct system gave way, releasing 12,000,000,000 gallons of water that swept a wide path of death and destruction from the mountains to the Pacific Ocean. In some places there must have been an 80-foot wall of rolling water. The roaring of the flood, reverberating back and forth against the sides of the canyon, was the first warning to residents. It was a sound like thunder, survivors said. The St. Francis Dam was completed two years ago by the Los Angeles Bureau of Water and Power. The dimensions of the dam were as follows: height above the foundation, 205 feet; height above the stream bed, 175 feet; crest length, 668 feet; thickness at the base, 175 feet; thickness at the top, 16 feet with a traversing roadway, and radius of slope curve, 492 feet. The dam was constructed on the San Francisquito fault, a geological feature known for a number of years and the subject of publication. Harry R. Johnson, consulting geologist of Los Angeles, said he believed the dam to have been a 'competent structure,' but the fact that it went out was a lesson pointing to the advisability of consulting geologists regarding the selection of dam sites rather than leaving such selection to engineers."

"Winging their way westward through storm and fog the three aviators Koehl, von Huenefeld and Fitzmaurice, aboard the Junkers airplane *Bremen,* have made the first successful heavier-than-air east-to-west trans-Atlantic flight in history. To traverse the ocean in the eastward direction is a remarkable feat, but the crossing from Europe westward is fraught with far greater risk, as this German-Irish crew of the *Bremen* knew full well when they attempted it. In the Temperate Zone the weather moves from west to east, rarely from east to west. Steamers make a slower passage when heading westward, and airplanes must negotiate about 600 added air miles in the westward crossing of the Atlantic."

"Captain Geoffrey de Havilland, the famous British designer, recently gave a wonderful demonstration of the foolproof qualities it is possible to obtain in the modern airplane. When the wing of an airplane meets the air at a big angle, the ordinary ailerons become almost inoperative. But if ahead of the ailerons, at the leading edge of the wing, there is placed the famous Handley Page slot, the ailerons are entirely satisfactory even in the 'stalling' attitude of the craft. De Havilland, flying his *Moth* light plane, with this automatic slot installed, found that even the most violent backward movement of the stick (intended to stall the plane) would not give rise to a spin. The most striking test was that of a stalled glide from a height of 200 feet. The machine was made to glide down, steeply but slowly, with the nose of the craft well above the horizon. Such a descent is particularly useful when negotiating a small emergency field."

SCIENTIFIC AMERICAN

JUNE, 1878: "There are bodies in the sky which did not attract much attention in former days, mainly because telescopes were not so large, but which are now catalogued by thousands. These are the nebulae. The name denotes their cloudy appearance. They are small bodies among the stars, sometimes appearing to have stars in them, or to be connected with stars, and sometimes not. They have the strangest and most capricious shapes imaginable. If a nebula is contracting its parts together so as to form a world, its rotation in the course of condensation will become so rapid that it may form suns and planets and earths. On this supposition there is no difficulty in making a complete solar system out of such a mass as that of the nebula in Orion."

"The death of Professor Joseph Henry, which occurred on May 13, has not been unexpected, for he had attained the ripe age of 80 years, and the signs of failing health for some time past have been indicated in the near termination of a life fruitful in great works. It would require a volume to explain all of Professor Henry's investigations and discoveries in detail. Among them are the first application of electro-magnetism as a power to produce continued motion in a machine, an exposition of the method by which electro-magnetism might be employed in transmitting power to a distance, a demonstration of the practicability of an electro-magnetic telegraph and the discovery of the induction of an electrical current in a long wire upon itself. In relation to the electro-magnetic telegraph it has been clearly shown that Professor Henry was the originator of the only practicable method of sending telegraphic signals through long distances, and that he was the first to put into actual operation a telegraph of this kind. The inventions of Henry are all embodied in the Morse instrument. The honor of originating the telegraph undoubtedly belonged to Professor Henry, and had Congress granted him a patent for his inventions, at the time of his death he would have enjoyed a monopoly of all the telegraphs, railway signals, fire alarms and electro-magnetic machines of every kind now in the United States, for he was the father of them all."

"Ever since the discovery of America by Columbus, the question of the infectious nature of yellow fever has agitated the medical mind, and much diversity of opinion has obtained regarding it, many names of authority being ranged on the side of infection, while as many and as authoritative are found on that of its non-infectious nature. Whatsoever the cause or whatsoever the germ that originates yellow fever, there is every reason to believe that it is essentially the cause or the germ of yellow fever, differing totally from that which produces remittent fever or dysentery. Yellow fever, which finds its birth in the delta of the Mississippi, invariably engenders yellow fever. As Professor Tyndall has said: 'As surely as a thistle grows from a thistle seed, as surely as a fig comes from the fig, the grape from the grape, the thorn from the thorn, so surely does the typhoid-fever virus increase and multiply into typhoid fever, the scarlatina virus into scarlet fever, the smallpox virus into smallpox.' And so with yellow and remittent fever, each distinct in itself, each having a germ *sui generis,* a germ endowed with like and constant properties, indicated in its effects by special symptoms during life, and specific pathological lesions revealed by examination after death."

"A recent English visitor remarks that the Russo-Turkish War ought to have shown the American manufacturers that they have little reason to fear the English. So far as he had been able to learn not a single cartridge had been made in Birmingham for either Russia or Turkey; but when he was in Bridgeport, the cartridge factories had been running day and night for months, and he saw a Russian and a Turkish commissioner in the same works. The fact was the Americans had made the rifles as well as the cartridges for both combatants. As further evidence of the threatened supremacy of American manufacturers he noted the fact that Lowell was sending cotton cloths to Manchester, and that in our retail stores cotton goods were marked at a lower price than that at which goods of the same quality could be sold at Liverpool or London. 'It is the same,' he said, 'with the other manufacturing industries of America. The manufacturers of hardware are beating us in market after market from Hamburg to Melbourne.'"

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SOMEHOW, SCOTCH BOTTLED ELSEWHERE ISN'T QUITE THE SAME.

Contrary to popular belief, many more brands of Scotch are bottled in America than in Scotland. They are bulk-shipped and bottled here, often using municipal water.

The makers of Cutty Sark, however, remain adamant on the subject of Scottish Scotch.

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To recognise genuine Scots Whisky, you need look no further than the very top of the label on a bottle of Cutty Sark.

It spells out exactly what you're getting right there in black and yellow.

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THE AUTHORS

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JOSEPH CERNY and ARTHUR M. POSKANZER ("Exotic Light Nuclei") are nuclear chemists with a shared interest in unstable nuclei. Cerny is professor of chemistry and chairman of the department of chemistry at the University of California at Berkeley and also faculty senior scientist at the Lawrence Berkeley Laboratory of the University of California. He did his undergraduate work in chemical engineering at the University of Mississippi and spent a year as a Fulbright scholar at the University of Manchester. He then completed his graduate work in chemistry at Berkeley, receiving his Ph.D. in 1961. In 1974 Cerny received the Atomic Energy Commission's Ernest Orlando Lawrence Memorial Award for his research. Poskanzer is staff senior scientist at the Lawrence Berkeley Laboratory and scientific director of the Bevalac, "the world's only relativistic heavy-ion accelerator." He did his undergraduate work in chemistry and physics at Harvard College, obtained his master's degree at Columbia University, and received his Ph.D. in chemistry from the Massachusetts Institute of Technology in 1957. After nine years at the Brookhaven National Laboratory he joined the Lawrence Berkeley Laboratory.

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RICHARD GORDON and ANTONE G. JACOBSON ("The Shaping of Tissues in Embryos") have collaborated on studies of embryonic development since 1969, when they met during a summer embryology course at the Marine Biological Laboratory in Woods Hole, Mass. Gordon is professor of pathology and radiology at the University of Manitoba and director of the Computer Department for Health Sciences there. He obtained his bachelor's degree in mathematics from the University of Chicago and his Ph.D. in chemical physics from the University of Oregon in 1967. After working at the University of Colorado, Columbia University and the Center for Theoretical Biology at the State University of New York at Buffalo, Gordon joined the Mathematical Research Branch of the National Institutes of Health in 1972. He moved to Manitoba this year. In addition to devising models of embryonic development he does research on the theory of computerized axial tomography, a subject on which he coauthored the article "Image Reconstruction from Projections" in the October, 1975, issue of *Scientific American*. He hopes eventually to combine his fields of interest by applying tomography to following the movements of cells inside living embryos. Jacobson is professor of zoology at the University of Texas at Austin. He did his undergraduate work at Harvard College and his graduate work in experimental embryology at Stanford University under Victor C. Twitty, obtaining his Ph.D. in 1955. Since then he has worked in the areas of embryonic induction and morphogenesis.

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K. LAL GAURI ("The Preservation of Stone") is professor of geology at the University of Louisville. A native of India, he obtained his bachelor's and master's degrees from Punjab University and his Ph.D. in geology from the University of Bonn in 1964. He then spent a postdoctoral year at the California Institute of Technology, where he became interested in paleontology, specifically "the evolution and structure of mineralized tissue of a group of fossil brachiopods." These studies included the electron microscopic examination of the fine structure of living shells, for which it was necessary to chemically strengthen the shell and the embedded soft tissue. On the suggestion of a friend in the art-history department at Cal Tech, Gauri began to develop similar techniques to strengthen weathered stone as an aid to the preservation of stone statuary. He has been at the University of Louisville since 1966.

JACK COLVARD JONES ("The Feeding Behavior of Mosquitoes") is professor of entomology at the University of Maryland. He obtained his bachelor's and master's degrees from Auburn University in Alabama and his Ph.D. from Iowa State University in 1950. For the next eight years he worked at the National Institutes of Health investigating the anatomy and physiology of the southeastern malaria mosquito. He has been at the University of Maryland since 1958. Of his present work, he writes: "Aside from teaching insect morphology and physiology I am currently devoting most of my time to writing my second book on the anatomy of the grasshopper."

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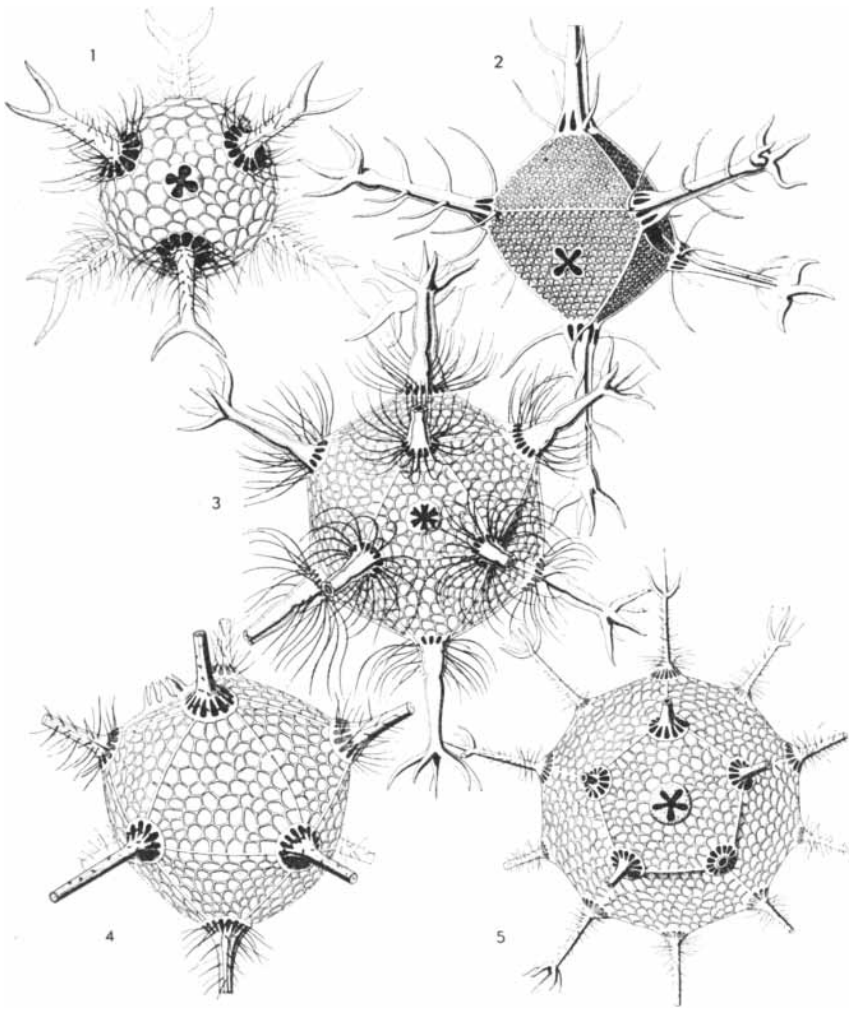
MATHEMATICAL GAMES

A mathematical zoo of astounding critters, imaginary and otherwise

by Martin Gardner

There has never been a zoo designed to display animals with features of special interest to recreational mathematicians, yet such a zoo could be both entertaining and instructive. It would be divided, as I visualize it, into two main wings, one for live animals, the other for pictures, replicas and animated cartoons of imaginary creatures. Patrons of the "mathzoo" would be kept informed of new acquisitions by a newsletter called ZOONOOZ (with the permission of the Zoological Society of San Diego, which issues a periodical of that name), a title that is both palindromic and the same upside down.



***Radiolaria skeletons in Ernst Haeckel's* Monograph of the Challenger Radiolaria**

A room of the live-animal wing would contain microscopes through which one could observe organisms too tiny to be seen otherwise. Consider the astonishing geometrical symmetries of radiolaria, the one-celled organisms that flourish in the sea. Their intricate silica skeletons are the nearest counterparts in the biological world to the patterns of snow crystals. In his *Monograph of the Challenger Radiolaria,* the German biologist Ernst Haeckel described thousands of radiolaria species that he discovered on the *Challenger* expedition of 1872–76. The book contains 140 plates of drawings that have never been excelled in displaying the geometric details of these intricate, beautiful forms.

The illustration on this page, from Haeckel's book, is of special interest to mathematicians. The first radiolarian is basically spherical, but its six clawlike extensions mark the corners of a regular octahedron. The second skeleton has the same solid at its center. The third is a regular icosahedron of 20 faces. The fifth is the 12-sided dodecahedron. Other plates in Haeckel's book show radiolaria that approximate cubical and tetrahedral forms.

It is well known that there are just five Platonic solids, three of which have faces that are equilateral triangles. Not so widely known is that there are an infinite number of semiregular solids also with sides that are equilateral triangles. They are called "deltahedra" because their faces resemble the Greek letter delta. Only eight deltahedra are convex: those with four, six, eight, 10, 12, 14, 16 and 20 faces. The missing 18-sided convex deltahedron is mysterious. One can almost prove it should exist, and it is not so easy to show why it cannot. It is hard to believe, but the proof that there are only eight convex deltahedra was not known until B. L. van der Waerden and Hans Freudenthal published it in 1947.

The four-faced deltahedron is the regular tetrahedron, the simplest of the Platonic solids. The six-faced deltahedron consists of two tetrahedra sharing one face. Note the fourth radiolarian in Haeckel's picture. It is a 10-faced deltahedron, or rather one that is inflated slightly toward a sphere. It may surprise you to learn that there are two topologically distinct eight-sided deltahedra. One is the familiar regular octahedron. Can you construct a model of the other one (it is not convex) before it is revealed here next month?

Surfaces of radiolaria are often covered with what seems to be a network of regular hexagons. The regularity is particularly striking in *Aulonia hexagona,* shown in the illustration on page 20. Such networks are called "regular maps" if each cell has the same number

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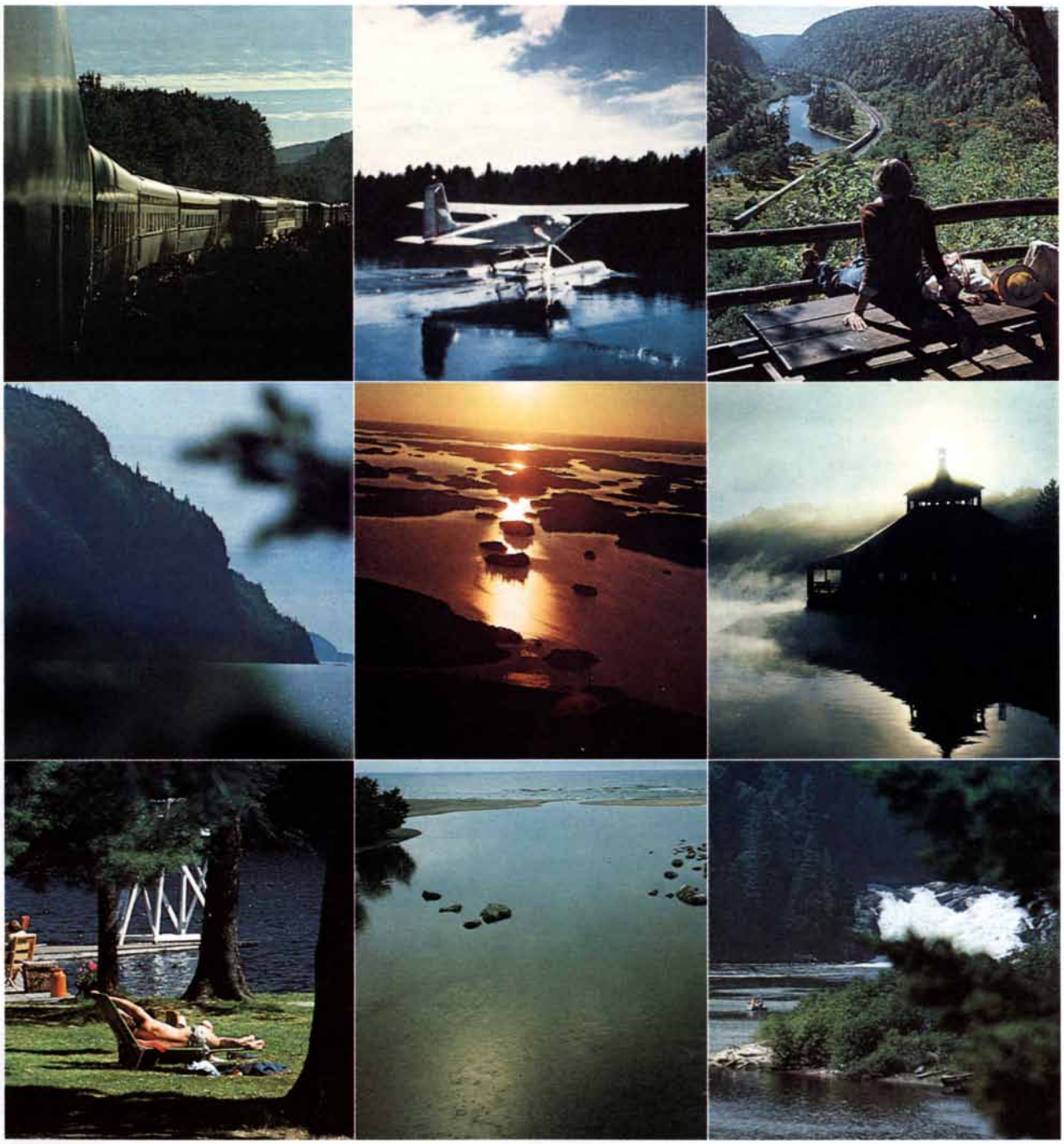

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of edges and each vertex has the same number of edges joined to it. Imagine a regular tetrahedron, octahedron or icosahedron inflated like a balloon but preserving its edges as lines on the resulting sphere. The tetrahedron will form a regular map of triangles with three edges at each vertex, the octahedron a map of triangles with four edges at each vertex, and the icosahedron a map of triangles with five edges at each vertex. Inflating a cube produces a regular map of four-sided cells with three edges at each vertex. Inflating a dodecahedron produces a regular map of pentagons with three edges at each vertex.

Aulonia hexagona raises an interesting question. Is it possible to cover a sphere with a regular map of hexagons, three edges at each vertex? Only the topological properties of the map concern us. The hexagons need not be regular or even convex. They may have any size or shape, and their edges may twist and curve any way you like provided they do not intersect themselves or one another and provided three of them meet at each vertex.

The answer is no, and it is not hard to prove impossibility with a famous formula that Leonhard Euler discovered for the skeletons of all simply connected (no "holes") polyhedra. The formula is $F + C - E = 2$, where the letters stand for faces, corners and edges. Since all such polyhedra can be inflated to spheres, the formula applies also to maps on the sphere. In Chapter 13 of *Enjoyment of Mathematics,* by Hans Rademacher and Otto Toeplitz, you will find it explained how Euler's formula can be used in proving that no more than five regular maps can be drawn on a sphere and that therefore no more than five regular convex solids can exist. As a second problem to be answered next month, can you use Euler's formula to show that a regular map of hexagons is impossible on a sphere?

D'Arcy Wentworth Thompson, whose classic work *On Growth and Form* contains an excellent section on radiolaria, liked to tell about a biologist who claimed to have seen a spherical radiolarian covered with a perfect map of hexagons. But, said Thompson, Euler had proved this impossible. "That," replied the biologist, "proves the superiority of God over mathematics."

"Euler's proof happened to be correct," writes Warren S. McCulloch in an essay where I found this anecdote, "and the observations inaccurate. Had both been right, far from proving God's superiority to logic, they would have impugned his wit by catching him in a contradiction." If you look carefully at the picture of *Aulonia hexagona* you will see cells with more or fewer than six sides.

Under electron microscopes in our zoo's micro room would be the many viruses that recently have been found to crystallize into macromolecules shaped like regular icosahedra: the measles virus, the herpes, the triola iridescent and many others (see "The Structure of Viruses," by R. W. Horne; *Scientific American,* January, 1963). Viruses may also have dodecahedral shapes, but as far as I know this remains unsettled. Another recent discovery is that some viruses, such as the one that causes mumps, are helical. It had formerly been thought that helical structures were restricted to plants and to parts of animals: hair, the umbilical cord, the cochlea of the human ear, the DNA molecule and so on. A section of our zoo would feature such spectacular helical structures as molluscan seashells, the twisted horns of certain sheep, goats, antelopes and other mammals, and such curiosities as "devil's corkscrews"—the huge fossil burrows of extinct beavers (see Chapter 1, "The Helix," of my *Sixth Book of Mathematical Games from Scientific American*).

In the macro world of fishes, reptiles, birds, insects, mammals and human beings the most striking geometrical aspect of the body is its overall bilateral symmetry. It is easy to understand why this symmetry evolved. On the earth surface gravity creates a marked difference between up and down, and locomotion creates a marked difference between front and back. But for any moving, upright creature the left and right sides of its surroundings—in the sea, on the land or in the air—are fundamentally the same. Because an animal needs to see, hear, smell and manipulate the world equally well on both sides, there is an obvious survival value in having nearly identical left and right sides.

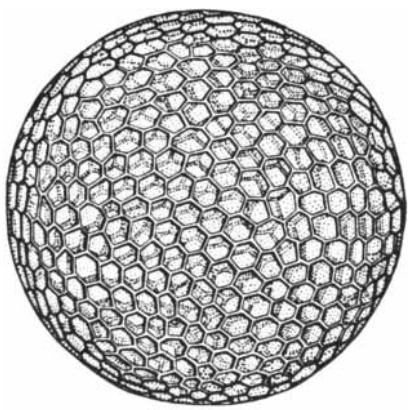
Animals with bilateral symmetry are of no interest for our mathzoo—you can see them at any zoo—but it would be amusing to assemble an exhibit of the most outrageous violations of bilateral symmetry. For example, an aviary would feature the crossbill, a small red bird in the finch family that has its upper and lower beaks crossed in either of the two mirror-image ways. The bird uses its crossed bill for prying open evergreen cones in the same way a cook uses a plierlike device to pry off the lid of a jar or can. A medieval legend has it that the bill became twisted as the bird was trying vainly to pull the nails from the cross when Jesus was crucified; in the effort the bird's plumage became stained with blood. In the same aviary would be some wry-billed plovers from New Zealand. The entire bill of this funny bird is twisted to the right. The bill is used for turning over stones to find food. As you would expect, foraging wry-billed plovers search mainly on the right.

An aquarium in our mathzoo would exhibit similar instances of preposterous asymmetry among marine life: the male fiddler crab, for example, with its enormous left (or right) claw. Flatfish are even more grotesque examples. The young are bilaterally symmetric, but as they grow older one eye slowly migrates over the top of the head to the other side. The poor fish, looking like a face by Picasso, sinks to the bottom, where it lies in the ooze on its eyeless side. The eyes on top turn independently so that they can look in different directions at the same time.

Another tank would contain specimens of the hagfish. This absurd fish looks like an eel, has four hearts, teeth on its tongue and reproduces by a technique that is still a mystery. When its single nostril is clogged, it sneezes. The hagfish is in our zoo because of its amazing ability to tie itself into an overhand knot of either handedness. By sliding the knot from tail to head it scrapes slime from its body. The knot trick is also used for getting leverage when the hagfish tears food from a large dead fish and also for escaping a predator's grasp (see "The Hagfish," by David Jensen; *Scientific American,* February, 1966).

Knots are, of course, studied by mathematicians as a branch of topology. Another exhibit in our aquarium would be beakers filled with *Leucothrix mucor,* a marine bacterium shaped like a long filament. A magnifying glass in front of each beaker would help visitors see the flimsy filaments. They reproduce by tying themselves into knots—overhands, figure-eights, even more complicated knots—that get tighter and tighter until they pinch the filament into two or more parts (see "Knots in *Leucothrix Mucor,*" by Thomas D. Brock; *Science,* Vol. 144, pages 870–871; May 15, 1964). Do higher animals ever tie parts of themselves into knots? Fold your arms and think about it.

The most popular of our aquarium exhibits would probably be a tank containing specimens of *Anableps,* a small (eight-inch) Central American carp sometimes called the stargazer. It looks



The radiolarian **Aulonia hexagona**

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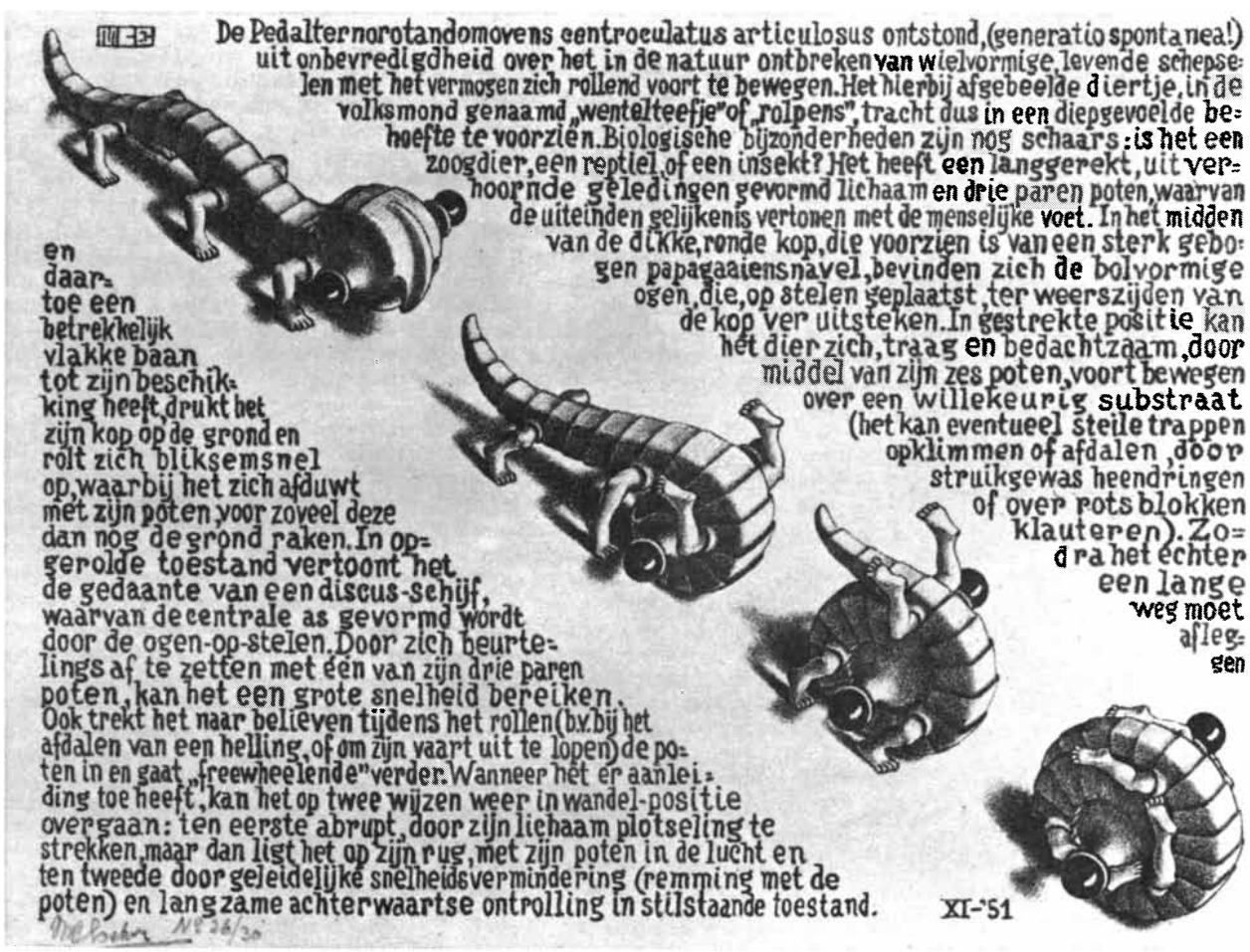
as if it had four eyes. Each of its two bulging eyes is divided into upper and lower parts by an opaque band. There is one lens but separate corneas and irises. This little BEM (bug-eyed monster) swims with the band at water level. The two upper "eyes" see above water while the two lower ones see below. The *Anableps* is in our zoo because of its asymmetric sex life. The young are born alive, which means that the male must fertilize the eggs inside the female. The female opening is on either the left side or the right. The male organ also is either on the left or the right. This makes it impossible for two fish of the same handedness to mate. Fortunately both males and females are equally left- or right-sexed, and so the species is in no danger of extinction.

In a larger tank one would hope to see some narwhals, although until now they have not survived in captivity. This small whale, from north-polar seas, has been called the sea unicorn because the male has a single "horn" that projects straight forward from its upper jaw and is about half the whale's body length. Both sexes are born with two small side-by-side teeth. The teeth stay small on the female, but the male's left tooth grows into an ivory tusk, straight as a javelin and seven to 10 feet long. This ridiculous tooth, the longest in the world, has a helical groove that spirals around it like a stripe on a barber pole. Nobody knows what function the tusk serves. It is not used for stabbing enemies or punching holes in ice, but during the mating season narwhals have been seen fencing with each other, so that its main purpose may be a role in sexual ritual (see "The Horn of the Unicorn," by John Tyler Bonner; *Scientific American,* March, 1951). Incidentally, the narwhal is also unusual in having a name starting with the letter *n*. It is easy to think of mammalian names beginning with any letter of the alphabet except *n*.

Among snakes, species that sidewind across the desert sands are mathematically interesting because of their highly asymmetric tracks: sets of parallel line segments that slant either right or left at angles of about 60 degrees from the line of travel. Many species of snakes are capable of sidewinding, notably the sidewinder itself, a small rattlesnake of Mexico and the U.S. Southwest, and the African desert viper. Exactly how sidewinding works is rather complicated, but you will find it clearly explained in Carl Gans's article, "How Snakes Move," in *Scientific American* for June, 1970.

The insect room of our mathzoo would certainly display the nests of bees and social wasps. They exhibit a hexagonal tessellation even more regular than the surfaces of radiolaria. A large literature, going back to ancient Greece and still growing, attempts to explain the factors that play a role in producing this pattern. D'Arcy Thompson, in his book cited above, has a good summary of this literature. In times before Darwin bees were usually regarded as being endowed by the Creator with the ability to design nests so that the cells use the least amount of wax to hold a maximum amount of honey. Even Darwin marveled at the bee's ability to construct a honeycomb, calling that ability "the most wonderful of known instincts," and "absolutely perfect in economizing labor and wax."

Actual honeycombs are not as perfect as early writers implied, and there are ways of tessellating space with polyhedral cells that allow an even greater



The curl-up, an animal imagined by M. C. Escher, can roll like a wheel when it wants to

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economy of wax. Moreover, it seems likely that the honeycomb pattern is less the result of evolution finding a way to conserve wax than an accidental product of how bees use their bodies and the way they form dense clusters when they work. Surface tension in the semiliquid wax may also play a role. The matter is still far from settled. The best recent discussion I know is a paper by the Hungarian mathematician L. Fejes Tóth, "What the Bees Know and What They Do Not Know," in *Bulletin of the American Mathematical Society,* Vol. 70, pages 468–481; July, 1964.

No actual animal propels itself across the ground by rolling like a disk or a sphere, but our insect room would be incomplete without an exhibit of a remarkable insect that transports its food by rolling near-perfect spheres. I refer to the dung beetle, the sacred scarab of ancient Egypt. These sometimes beautiful insects (in the Tropics they have bright metallic colors) use their flat, sharp-edged heads as shovels to dig a supply of fresh ordure that their legs then fashion into spheres. By pushing with its hind legs and walking backward the dung beetle will roll the little ball to its burrow where it will be consumed as food. No one has described the process with more literary skill and humor than the French entomologist, Jean Henri Fabre, in his essay on "The Sacred Beetle."

Our zoo's imaginary wing would lack the excitement of living creatures but would make up for it in wild fantasy. In Flaubert's *Temptation of St. Anthony,* for example, there is a beast called the Nasnas that is half of an animal bisected by its plane of symmetry. Jorge Luis Borges, in his delightful *Book of Imaginary Beings,* refers to an earlier invention of such a creature by the Arabs. L. Frank Baum's fantasy, *Dot and Tot of Merryland,* tells of a valley inhabited by wind-up animals. The toys are kept wound by a Mr. Split, whose left half is bright red and right half white. He can unhook his two sides, each of which hops about on one leg so that he gets twice as much winding done. Conversing with a half of Mr. Split is difficult because Mr. Left Split speaks only the left halves of words and Mr. Right Split only the right halves.

A variety of mythical "palindromic" beasts violate front and back symmetry by having identical ends. Borges writes of the fabled *amphisbaena* (from the Greek for "go both ways"), a snake with a head at each end. Dante puts the snake in the seventh circle of Hell, and in Milton's *Paradise Lost* some of Satan's devils are turned into *amphisbaenas.* Alexander Pope writes in his *Dunciad:*

> Thus Amphisbaena (I have read)
> At either end assails;
> None knows which leads,
> or which is led,
> For both Heads are but Tails.

The fable is not without foundation. There are actual snakes called amphisbaenas that crawl both ways and have such tiny eyes that it is hard to distinguish one end from the other. If a flatworm's head is cut off, another grows at the base of the severed head, so palindromic animals actually can exist. In Baum's *John Dough and the Cherub* one meets Duo, a dog with a head and forelegs at both ends. The animal anticipates the Pushmi-Pullyu (it has a two-horned head at each end) that flourishes in the African jungle of Hugh Lofting's Dr. Dolittle books.

Rectangular parallelepipeds are never the parts of real animals, but in Baum's *Patchwork Girl of Oz* there is a block-headed, thick-skinned, dark blue creature called the Woozy. The animal's head, body, legs and tail are shaped like blocks. It is friendly as long as no one says "Krizzle-kroo." This makes the Woozy so angry that its eyes dart fire. Nobody, least of all the Woozy, knows what Krizzle-kroo means, and that is what makes it so furious. Borges reminds us of the Gillygoo, a bird in the Paul Bunyan mythology, that nests on steep slopes and lays cubical eggs that will not roll down and break. Minnesota lumberjacks hard-boil them and use them for dice. In Stanley G. Weinbaum's story, "A Martian Odyssey," a species of nondescript animals on Mars excrete silica bricks that they use for building pyramidal dwellings.

Baum also imagined spherical creatures. The Roly-Rogues, in *Queen Zixi of Ix,* are round like a ball and attack enemies by rolling at them. In *John Dough and the Cherub* one of the main characters is Para Bruin, a large rubber bear that likes to roll into a rubber ball and bounce around.

Borges, writing about animals in the form of spheres, tells us that Plato, in the *Laws,* conjectures that the earth, planets and stars are alive. The notion that the earth is a living, breathing organism was later defended by such mystics as Giordano Bruno, Kepler, the German psychologist Gustav Theodor Fechner and Rudolf Steiner (who broke away from theosophy to found his rival cult of anthroposophy). The same notion is basic to the plot of one of Conan Doyle's stories about Professor George Edward Challenger of *Lost World* fame. When Professor Challenger drills a deep hole through the earth's epidermis, in a story called "When the Earth Screamed," the planet howls with pain.

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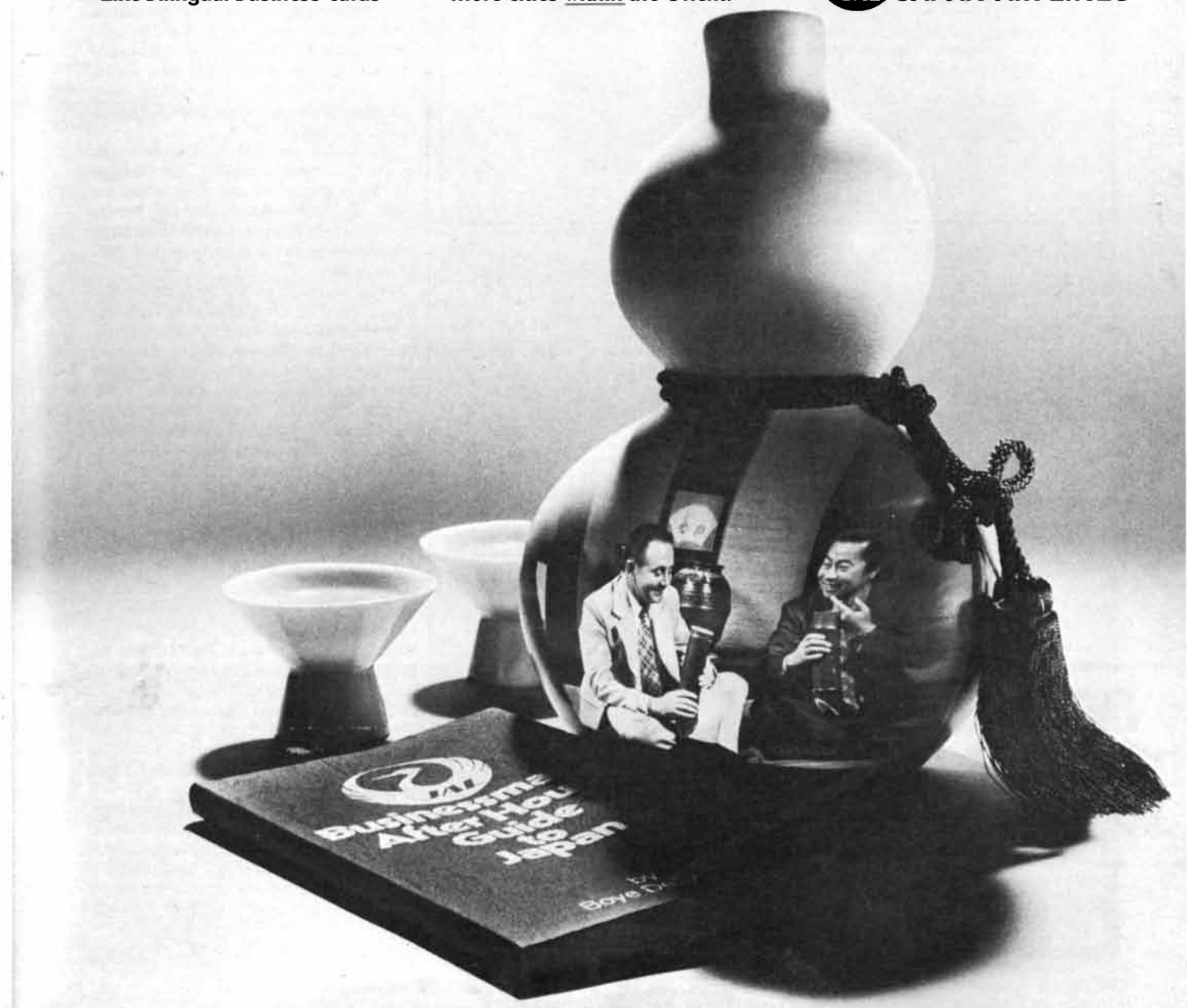

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had been unable to exploit rotational devices for propulsion. A few years ago biologists were amazed to discover that the flagella of bacteria actually spin like propellers (see "How Bacteria Swim," by Howard C. Berg; *Scientific American,* August, 1975).

The imaginary wing of our zoo would display two of Baum's creatures that use the wheel for propulsion. In *Ozma of Oz* Dorothy has an unpleasant encounter with the Wheelers, a race of fierce, four-legged humanoids that have wheels instead of feet. In *The Patchwork Girl of Oz* we read about the Ork, a huge bird with a propeller at the tip of its tail. The propeller can spin both ways, enabling the bird to fly backward as well as forward.

I know of only two imaginary beasts that bend themselves into wheels and roll across the ground. From time to time, in most parts of the world, people have claimed to have seen "hoop snakes" that bite their tails to form a hoop and then go rolling across the terrain. Some snakes, such as the American milk snake, travel by gathering their body into large vertical loops and pushing forward so rapidly that they create an optical illusion of a rolling ring. These animals may be the origin of hoop-snake fables.

The Dutch artist M. C. Escher made several pictures featuring his curl-up, the beast shown in the illustration on page 23. This unlikely animal moves slowly on six humanlike feet, but when it wants to go faster it curls up and rolls like a wheel.

Most animals, particularly the earthworm, may be thought of as being basically toroidal—a shape topologically equivalent to a doughnut. There must be many science-fiction animals shaped like toruses, but I can recall only the undulating silver ringfish, floating on the canals of Ray Bradbury's *Martian Chronicles,* that closes like an eye's iris around food particles.

Topologists know that any torus can be turned inside out through a hole in its surface. There is no parallel in earth zoology, but there is a spherical organism called volvox that actually does turn inside out through a hole. It is a strange freshwater-pond colony of hundreds of flagellated cells bound together in a spherical jellylike mass that rotates as it moves through the water. Volvox is one of those twilight things that can be called a green plant (because it obtains food by photosynthesis) or an animal (because it moves freely about). One is equally hard put to decide whether it is a colony or a single organism.

Young volvox colonies grow inside the mother sphere, but the cells have their flagella ends pointing inward. At the spot where each infant sphere is attached to the inside of the mother, there is a small hole in the infant sphere.

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When the infant reaches a certain size, it breaks away from the mother and turns inside out through the hole! Flagella quickly sprout at the ends of the cells that now point outward, and the newborn colony goes spinning about inside the mother. The mother eventually dies by splitting open and allowing her offspring to escape, one of the earliest examples on the evolutionary tree of nonaccidental death (see "Volvox: A Colony of Cells," by John Tyler Bonner; *Scientific American,* May, 1950).

We could have considered volvox earlier, but I kept it for now to introduce the ta-ta, a mythical but much higher form of animal capable of turning inside out. It was invented by Sidney H. Sime, the British artist who so wondrously illustrated Lord Dunsany's fantasies. Sime drew and described the ta-ta in his only book, *Bogey Beasts,* a rare collection of original verses set to music:

The Ta-Ta

There is a cosy Kitchen
Inside his roomy head
Also a tiny bedroom
In which he goes to bed.

So when his walk is ended
And he no more would roam
Inside out he turns himself
To find himself at Home.

He cleared away his brain stuff
Got pots and pans galore!
Sofas, chairs, and tables,
And carpets for the floor.

He found his brains were useless;
As many others would
If they but tried to use them
A great unlikelihood.

He pays no rent, no taxes
No use has he for pelf
Infested not with servants
He plays with work himself.

And when his chores are ended
And he would walk about,
Outside in he turns himself
To get himself turned out.

Readers were asked last month to count the ways of connecting six labeled spots by drawing lines according to specified rules. Isolated spots are subsets of one element each, a pair of joined spots is a subset of two elements, three joined spots a subset of three elements, and so on. Each pattern corresponds, therefore, to a way of partitioning a set of elements into disjoint subsets. Since these ways are counted by Bell numbers, the number of patterns for six spots is the sixth Bell number, 203. In general, the number of patterns for n spots is the nth Bell.

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BOOKS

The early evolution of the telescope; the fishing Indians of the Northwest

by Philip Morrison

THE INVENTION OF THE TELESCOPE: TRANSACTIONS OF THE AMERICAN PHILOSOPHICAL SOCIETY, by Albert Van Helden. The American Philosophical Society, 1977 ($6). Galileo was not one quick to rush into print. Eighteen years a professor in Padua, he had published only two books, one an instruction manual for a geometrical instrument he had invented and sold out of his own private workshop, the other a witty polemic against a Padovan student who had sought to rip off that very instruction book! But from the time Galileo first heard of the spyglass of "a certain Fleming" until his book *The Starry Messenger* opened the Copernican universe to our extended senses, just 10 months elapsed. He was onto a good thing, and he published it first, in March of 1610.

There were probably three men who had telescopes by early in October of 1608. At the autumn fair in Frankfurt that year a Dutchman was offering one for a high price. And it was not a novel idea to look through such an instrument at the stars. The first printed account from the Hague mentions that the glass showed new stars in the Pleiades, months before any telescope came to Paris, Milan, Venice or Naples. But Galileo worked hard and well, he had the help of a master craftsman in his own shop, he had access to selected lots of the best Venice glass, he ground scores of lenses and chose the best of them, he grasped the importance of a steady mount and he invented an aperture stop to correct the faults of his high-powered lenses. There is no doubt that his was a magnificent and purposeful development, even though it was not an invention; he described the new cosmos, beating out Thomas Harriot, Simon Marius, Christoph Scheiner and the wonderful Paris amateur Nicolas de Peiresc, all of whom were gazing at the sky through telescopes at about the same time.

Professor Van Helden's fascinating and learned little monograph includes Galileo; it focuses, however, not on him but on the "certain Fleming," whoever he was. We see the main evidence in this long detective story: 30-odd key passages from books, letters, journals and official documents, in the original Latin, English, Italian, French and Dutch, all with clear translations. The documents begin with Roger Bacon, who wrote in about 1250 of "Glasses so cast, that... starres shine in what place you please." They end with a long passage of 1655 from a book seeking "the true inventor of the telescope" and finding him in an artisan of Middelburg in Zeeland.

One reads the 1609 letter of Giovanbaptista della Porta himself, who says of the new Dutch wonder: "I have seen it, and it is a hoax, and it is taken from the ninth book of my *De refractione*." Nevertheless, the noble Girolamo Sirtori pursued the glass over all Europe, seeking experts who could grind usable lenses. He examined and measured Galileo's own tube and lenses at that famous dinner of the Academy of Lynxes in Rome where the word "telescope" was coined in the spring of 1611, yet he was not able to duplicate the success of the Tuscan artist.

There is a famous journal entry that cites a statement (against self-interest) made by the son of Sacharias Janssen, the strongest candidate for the designation of inventor, suggesting that the father (an unsavory character, a convicted counterfeiter) "made the first telescope in this country in the year 1604, after one belonging to an Italian which bore the date *anno* 190." (Stillman Drake thinks the error was for 1590; since the text clearly intends a date, 1590 is hard to fault.) Another claimant is a Florentine, Raffael Gualterotti, who wrote Galileo in April, 1610, asserting that he, and no Dutchman, was the inventor: "It is now twelve years since I made an instrument... for the benefit of a cavalry soldier.... A feeble thing."

How can all this be true? How can the telescope have become the cynosure of Europe in a year or two after 1608 and yet have remained unknown for a decade or more before that? Professor Van Helden, a historian at Rice University, offers a persuasive explanation. The erect-image two-lens instrument was indeed not very new. It had been found quite naturally during the 1590's by combining the then common lenses of the spectacle makers. It was of some help to myopics, but its lower power and poor lenses made it a thing of no great virtue. The early optical experimenters, on the other hand, were hoping for wonders like the glass of Roger Bacon's dreams. There was no excitement in "a feeble thing" with magnification well under two diameters. But the concave lenses for the myopic grew better, their focal lengths shorter, the glass clearer; and one of those clever Middelburg artisans, or more than one, saw a new potential. The magnification, close to threefold, was striking.

We can see now, however, that in a way "'telescopes' existed before anyone, *including the men who made them,* were aware of them." The key point was the development of effective higher magnification. That began near Middelburg when the utility came clear. The rich, the curious and the military seized on the device. Galileo speedily developed the concept, pushed the workable power up to near 30 in a few months and put it to work penetratingly. Once the news got around more than one man realized he had already long possessed the same device, but with low magnification and used in a very different way. Quantity is the hero of this story, as it is of much science in the post-Galilean years.

Old Gualterotti put it well: "'Astonishing' will never seem to me what I shall [have to] say about the accomplishments of the Florentines."

INDIAN FISHING: EARLY METHODS ON THE NORTHWEST COAST, by Hilary Stewart. The University of Washington Press ($17.95). AQUACULTURE IN SOUTHEAST ASIA: A HISTORICAL OVERVIEW, by Shao-Wen Ling. Edited by Laura Mumaw. The University of Washington Press ($7.50). "I was curious to see this hook in action.... I made one, complete with deer bone barb, spruce root lashing, inner cedar bark leader and line, and a perforated stone sinker. For luck I carved a river otter on one arm of the hook." Halibut are big flatfish. Specimens up to 200 pounds were taken on hook and line by all the coastal peoples of the Northwest: a clumsy hook, often two pieces lashed together into a flat *V,* with an inpointing barb at one end. Was the design functional? There is one way to find the answer. Try it on a hungry halibut in plain sight, a captive in a tank. The species does not bite at its food but draws it in with a strong sucking action and then forcefully expels what it would like to reject. The baited hook is ejected with great force, but when the barb pierces the cheek from the inside, the fish is cunningly hooked. Any forward motion is stopped at the apex of the *V,* and with-

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drawal simply sets the barb more deeply. And thus was "Great-One-Coming-Up-Against-the-Current" commonly taken. Not long afterward the thin-sliced white meat of the great fish, hanging on the drying racks like so much laundry, was smoked to a golden tan; the people could face the winter nights without fear of hunger.

Hilary Stewart is no mere external observer of the old ways. She finds her way close to the center of the old life, and she takes the reader along. The experiment with the halibut hook was only one of many trials; she takes little for granted. Half a dozen long pages of this attractive book display loving and clear drawings of halibut hooks. Here is a photograph of Chief Charles Jones of the Pachenaht Band, a round 100 years old, who bends *U* hooks by steaming sticks of fir on the coals overnight inside hollow tubes of kelp. "Gotta be just *limber,*" he says. Not any old wood will work, but only the hard, dense wood of fir knots, so that the hook will hang downward in the water. The carved designs are equally part of a fine halibut hook. A dozen are carefully drawn here: raven, shaman, octopus tentacles and much more. The Kwagiutl prayed to fish and hook alike. To the hook: "Now Younger Brother your dress has been put on. You will go to the village of Scenting Woman.... Do not let go of Old Woman when she takes hold of you, Good Younger Brother." And the first-catch ritual meal would follow, after which all the scraps were carefully collected in a new mat and thrown back into the sea.

Not halibut hooks alone but also the craft, technology, art and spirituality of the eight peoples nourished by the rich upwelling seas that stretch from the Columbia to Alaska are treated in this gift of a book, half analysis and half celebration. Gaffs, lures and lines, nets and clubs, traps and sinkers—all are described, drawn with care, examined incisively, often by remaking them in the old way. "Fish were holy." The cultures fused a sea-unity of the knowing experience, clever tools, deep myth and dignified prayer. The pages are aromatic with the scent of reality; this is how it works and, a little, how it was. No technical ethnography, the book cuts deeper than most ethnography, documented as it is from primary literature and, even better, founded on the stuff itself.

EULACHON FISH ARE HUNG OUT TO DRY by Pacific Northwest Indians in 1884. Photograph appears in *Indian Fishing: Early Methods on the Northwest Coast,* by Hilary Stewart.

The small, silvery eulachon (the candlefish) filled the nets in tons each spring, to be processed to render up a strong, nutritious oil. It still comes to a Haida table, innocently enough, as if it might be a jar of honey, but "I am without hope that I ever" will get to like it, the author admits. A hundred years ago the great sturgeon was the spring prey of the Coast Salish. Down the wide Fraser the fishermen drifted, perhaps 30 canoes abreast, carrying jointed poles up to 60 feet long with a spear point on a strong line at the end, feeling along the river bottom. Once a sleepy monster was found and struck, the slate-and-antler barbs held fast, and the happy hunters would be carried downstream "at any pace" by a 600-pound fish in an exact freshwater analogue of the salty Nantucket sleigh ride.

Most fish are still hunted, although all but universally landlubbers have passed from the hunt to the life of the farmer and herdsman. Yet from India and Ceylon all the way around to Korea, Shao-Wen Ling reminds us in *Aquaculture in Southeast Asia,* the people win about a fourth of all the fish they eat from aquaculture, tending ponds for fishy crops in a high tradition of husbandry. It is nothing new. Here is old Fan Lee's essay, written down in the fifth century B.C.: "There are five ways of making a living, the foremost of which is in aquatic husbandry, by which I mean fish culture." Put 20 gravid carp in your well-made pond in March and take out 240,000 three-pounders a couple of years later.

The antique method was monoculture of the tasty, hardy, easily cultured common carp. But in the Tang era polyculture began, the foundation of the present success of tropical aquaculture. Dr. Ling cites some careful studies of ponds in Taiwan. A heaviiy fertilized pond produces more than seven tons of fish per hectare in a year. The silver carp yields almost half the total; it is a very efficient feeder on phytoplankton. Next comes the gray mullet, which is adapted to consume mostly tiny crustaceans, the zooplankton. Three carp species graze the life of the bottom ooze and the higher plants: "The grass carp eats macrophytes as efficiently as a cow eats grass." The carnivorous perch can provide

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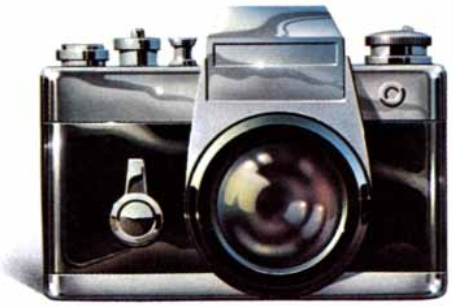

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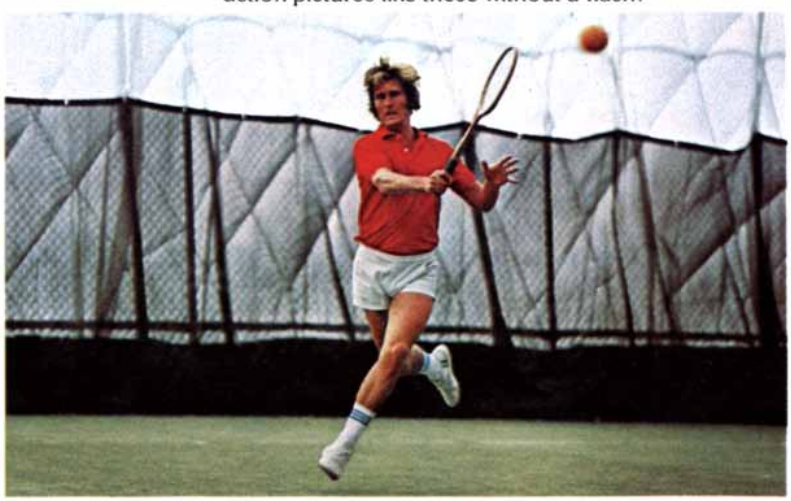

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some more yield by feeding on insect larvae and other freely moving animals, but they cannot be put in the pond until the other fishes are big enough to escape their predation.

Under intensive care a fertilized pond yields 10 times as much as an unfertilized, stocked but little tended farm reservoir. Nearly all the extra biomass is in the phytoplankton; the higher underwater plants do better in a less rich pond because the green swarms of plankton cut out their sunlight. Almost half of the yield arises from the direct ingestion of the fertilizer by the fish. Manures and night soil are the usual fertilizers in Southeast Asia. Inorganic chemicals alone do not work so well: the combination is excellent, but the inorganics are too costly for the fish farmers there. The night soil is thoroughly disinfected before being applied, but the problem of parasitic disease remains, particularly if fish is not well cooked; the flukes of blood and liver are the most serious infestations.

Not until the 1960's did this remarkably adaptive aquaculture become true domestication. Husbandry was advanced; the old masters had even worked out how to sort fry, inducing their stratification by species by skimming off the larvae as they came to the surface during a careful succession of disturbances. (The method depends on the differential oxygen needs of the different larvae.) For most species, however, the fry still had to be taken from the river and brought to the pond. Now, for some 15 years, the main species have been induced to spawn under controlled conditions by pituitary injections. The gland is often taken by a special core drill, so that the fish is not spoiled for the table. A closely related species can be chosen: the common carp is known as a "universal donor." A suspension of the ground gland is injected into the female. Within the day the fish is ready; it is carefully stripped of its eggs by gentle hands, and the eggs are fertilized. In the mild climate a simple hatchery will do; in a couple of weeks, the fingerlings are sent to the farmer's growing ponds. For short distances the fry are transported in shallow bamboo baskets lined with paper to hold water and hung on the ends of a carrying pole on a man's shoulders; the natural motion aerates the water adequately. Once they made the long voyage from the interior through Hong Kong by boat in large wood tubs, each tub churned day and night by an attendant. Now plastic bags filled with oxygen have ended that laborious task.

Dr. Ling writes engagingly and draws the sleek fish of his story elegantly. It was he who some years ago first worked out a way to rear Malaysian freshwater prawns, thereby domesticating a valuable new species. The first-stage larvae would not survive in spite of every variation of *p*H, of temperature, of "everything I could think of." He was obsessed and would not give up. Desperate he struck out at random, adding juices, milk, coffee, tea and so on. "Lo and behold," the larvae in water with soy sauce added survived. "I had been so foolish!" The larval stages need dilute salt water; although the gravid prawns were collected in fresh water 100 miles from the sea, in nature the larvae drift slowly downstream unnoticed, and mature near the river mouth.

The art of fish culture is slowly becoming a domestication under full control; chase will give way to crop, and the wider world will share the bounty of the Fraser and the Columbia of long ago.

ULTRASHORT LIGHT PULSES: PICOSECOND TECHNIQUES AND APPLICATIONS, edited by S. L. Shapiro. Springer-Verlag ($42.70). From Galileo's pulse onward the physicist has sought means of measuring short time intervals. The Los Alamos editor of this expert's review volume on the state of the flashy art traces its history with a delightful summary graph in the first chapter. J. A. von Segner of Göttingen measured in 1740 the comet tail he saw by viewing an ember glowing at the edge of a rotating disk. The ear's nimbler response was exploited by the familiar siren disk, whose holes, rotating past an orifice, provided a speed measurement by their varying tone. Then came the spark light source, together with the image made by a moving mirror. The extension of man's perceptions had gone to microseconds by the 1820's, once the laboratory had become electrical. By 1870 we had snapshots of sound pulses.

The nanosecond regime was entered at the turn of this century, when the Kerr cell was so applied. In this device the shutter action follows from a voltage-induced rotation of the plane of polarization with the speed of the reorientation of the molecular dipoles, in a refractive substance placed in the optical path. All that the rise of electronics could do, with its photomultipliers and oscilloscope tubes, was to replace the moving mirrors and the whizzing disks. High-frequency techniques brought the interval down only by a factor of a few, although of course its utility was much widened. The plateau remained at a nanosecond (light moves a foot in that time) until about 1965. With a bang the art improved 1,000-fold in one decade. The bang was the laser. Amid a wide range of methods and results one page of this review shows a light pulse, caught in passage through water made a little turbid with milk. The pulse was defined to a millimeter or better in work that is already classical: it is seven years old.

The picosecond era is the theme of

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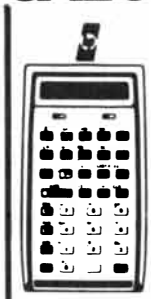

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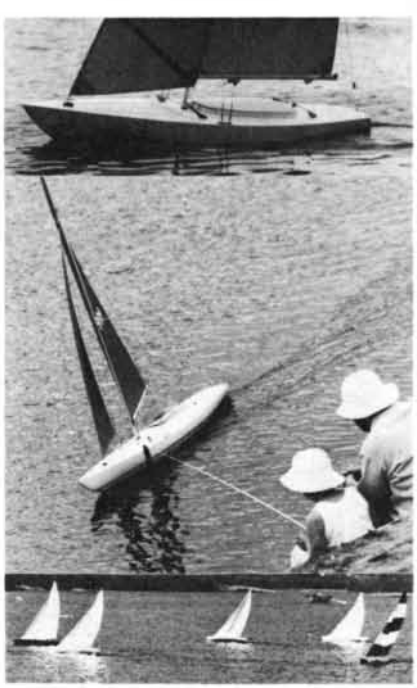
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this volume. There are chapters on pulse generation and measurement and on the four main applications (putting aside the large-scale use of picosecond pulses in fusion): nonlinear optics, the physics of solids and liquids, chemistry and biochemistry. No swift bullets or bird wings are shown here, of course. The picosecond domain is molecular: on this time scale "a speeding bullet moves like a dead ant." The discussion is highly technical; although it is not very mathematical, it does require some familiarity with the idea of the reciprocal time and frequency domains and some interest in the molecular world.

How can one measure picosecond pulses? The quantum limits set in the visible-light region by the photoeffect response time is at least 100 times shorter; no trouble there yet. But oscilloscopes are too big and hence too slow; they respond only in about 100 picoseconds. The first studies were based on various indirect correlation tricks, and were more than once misleading. Nowadays picosecond streak cameras are in wide use both in the U.S.S.R., where the idea emerged, and outside it. Modern image-intensifier techniques provide brightness and final screen-writing speed for the job, with good image detail and hence good time resolution—to better than one picosecond. The trick is to avoid the time jitter inherent in the initial motion of the photoelectrons that bring the signal, some of them slow and some fast. The essence of the scheme is high voltages and fields throughout, to swamp the ruinous initial energy spread in the freshly ejected photoelectrons. The devices are reliable and their time resolution is dependably linear.

The source of pulses is even subtler. Laser output usually shows an intrinsic spikiness in the picosecond domain, more like noise than like a pulse train on this time scale. One has to get the laser to exhibit its high coherent gain not just in any of the ways it can do so but in a very few of the many modes of the optical resonator that controls the laser. In the time language the laser must be made to concentrate gain in a sharply defined number of crosswise and to-and-fro reflections in the light path, with the other passes canceling by interference. Such mode-locking has been achieved for glass-rod and dye-laser media. The details are rather subtle, but the fundamental idea is that of using a thin layer of a strongly absorbing dyestuff to limit laser gain to a narrow band of frequency, but in such a way that the buildup is soon saturated by nonlinear effects in the dye. Then, it turns out, the noisy, fluctuating laser output that follows the long exciting light pulse (in the simplest case) soon steadies and amplifies only a few nearby modes; the others are negligible because they are not much amplified during the nonlinear phase of the absorber's action.

A mode-locked laser of the glass-rod type requires careful control, to avoid thermal distortions and spurious reflections, as well as correct design. Not every train of pulses will be successful; chance plays a role. But when the laser works, the modest energy fed into it is released somewhere in a picosecond or two. There the power is high indeed: each pulse matches in power the world's total electric power (how briefly!). High-order, multiple-photon, modulation and harmonic effects abound. Beam breakup, optical damage, self-induced transparency, rectification and much more puzzle the theorist and challenge the physicist looking for applications.

The latter half of the volume is a review of applications of fast pulses as probes for studying the behavior of matter, primarily the nature of the spread of energy. In solids and liquids energy is taken away by lattice vibrations, by electrons and by complexes of electrons and holes. In solutions and gases the pulse enables the chemist to watch bonds, charge and even orientation relax through the molecular system. If the change can be induced by light, there is an opportunity to follow its relaxation either by direct streak-camera observation or more indirectly. The last chapter carries the method to the big molecules of biology, where hemoglobin, the visual pigments, photosynthetic centers and the DNA tape are obvious materials in which to study the entry of energy and its migration, a test for all types of processes of transfer and repair.

THE DISTRIBUTION AND DIVERSITY OF SOIL FAUNA, by John A. Wallwork. Academic Press ($27.25). In the crevices and dark, tiny tunnels belowground dwells a bizarre fauna, humble and mainly hidden. Any small volume of soil is as rich in species as a coral reef, but these groups are ubiquitous, found in peat bogs and sand dunes, the tundra and the blazing Mojave, the soft grasslands and the towering rain forest. This beautifully organized treatment by a London ecologist who has worked and photographed from the desert in Baja California to the clumpy mosses of South Georgia in the South Atlantic, is a critical effort to understand not only the players but also the stage set and the play. Each principal chapter is organized around a particular environment. The author treats half a dozen at some length, setting out, against the background of climate and soil types, the muster of soil fauna that thrive within it. Readable enough for the general reader concerned with the living world, the book is also comprehensive enough for a first text and will surely be a pleasure of summation and reflection for the re-

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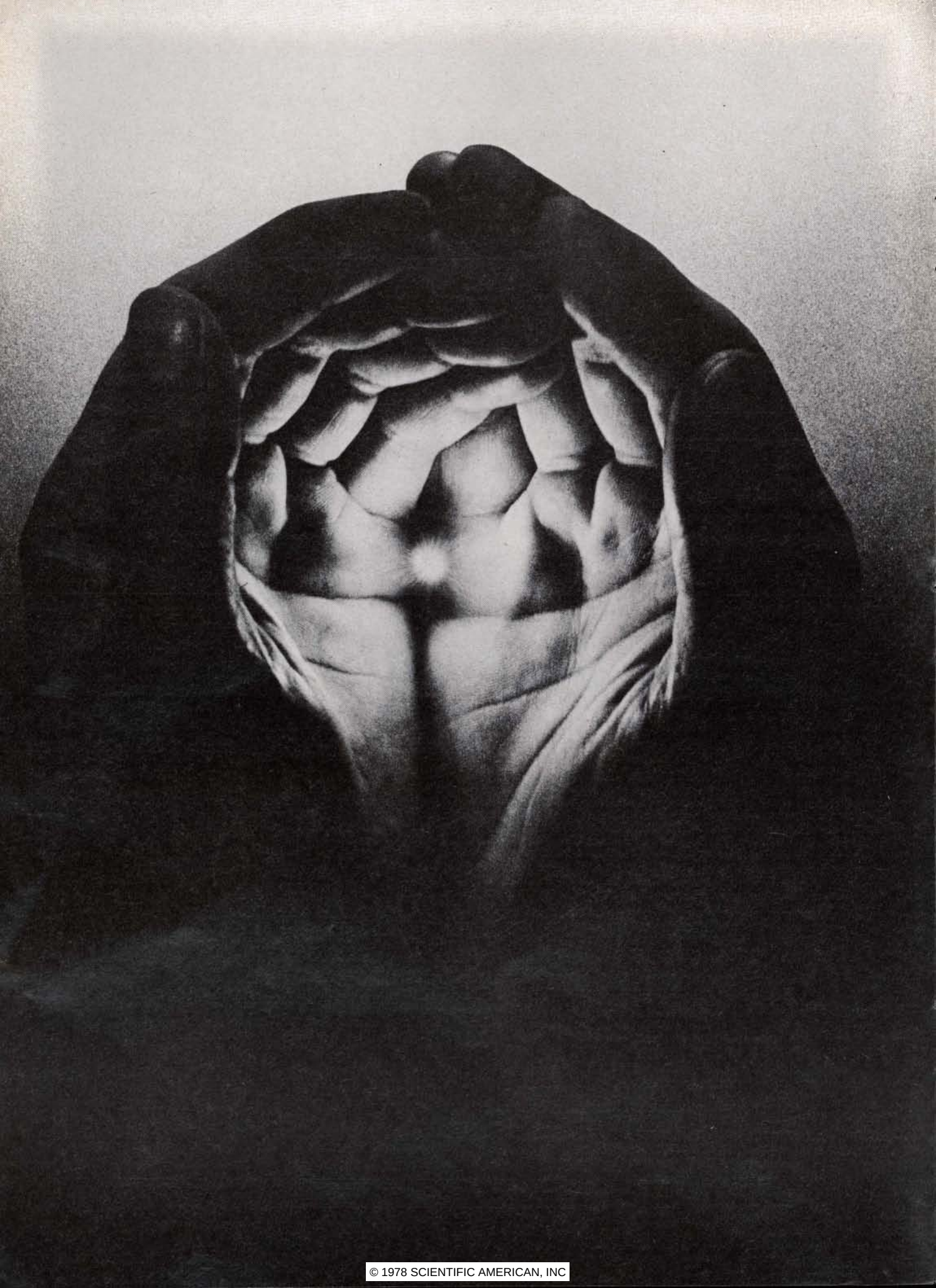

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search ecologist. Plenty of tables and photographs enrich the pages. The mathematics in one chapter is perhaps touched too gingerly for most readers to follow; those indexes and entropies do not seem to help much yet, anyhow.

Every major phylum of animal save the marine phyla is found somewhere or other in the soil. The animals are tiny, invisible until they are somehow sieved from the substrate, a millionfold in a typical square meter, to be studied only by sampling. (In one photograph you can see a few happy ecologists sitting on the Yorkshire grass taking their ease with the cores.) Of course, there are special associations. The protozoa, those with tiny hard tests as well as oozing amoebas, are found by the tens of millions in the water films of soggy peat bogs. The nematodes are not less abundant in the grasslands, where the familiar earthworms flourish as well. The mites are everywhere, the springtails only somewhat less cosmopolitan; the millipedes and false scorpions are in the temperate and tropical woodlands.

Samples must suffice here too. Grassland fauna differ sharply in Temperate and Tropical zones. It is not so much temperature but rainfall that makes the difference. Tropical climates generally have seasons that are either soaking wet or bone dry. Tropical earthworms must burrow deep; they are fewer in number but more active when the rains come. In tropical grasslands the termites and the ants replace the tinier insects and play a role in working the soil not unlike that of the worms. The chemical environment too can be decisive. Where calcium is high, as on limestone, snails, isopods (wood lice) and millipedes abound; all of them harden themselves more or less with calcite crystals rather than by the organic tanning process of the hard-shelled beetles, say. Of course, the world is not so simple: a peat bog has a complex structure, from bare mud-cracked peat to mossy hummocks a few feet higher. (Mites abound in the acid bog world; here is a photograph of a good-sized crane fly with a cluster of mite passengers on its thorax.) The detail is elaborate; people have worked on those variations yard by yard.

The forest is perhaps the most complex. It offers new possibilities because there is a vertical dimension. Solar energy flows in at the top and the flow is downward with gravity as the leaves fall. Leaf litter covers the ground in the Temperate Zone forest; in the Tropical one the microhabitats shift upward toward the canopy with the epiphytic plants. (In a grassland grazing is the biggest secondary flow: energy goes upward from the solar input at the grass blade level. Here the special habitat is the dung pat.)

In the forest the leaves fall, and even

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logs and branches form special habitats. One experimenter put out artificial logs: oak boxes filled with oak sawdust, with four variants of packing and nutrient quality. In a year or so he could report what had come to live within, "an astonishing variety of animal life." The experiment is timed from the fall of the wood. There is a regular succession of forms: chewing beetles, softening fungi, then forms that prefer softer food or feed on the fungi. Finally the log merges with the litter and the soil. An oak log harbors a much richer fauna than a pine one because it decomposes more slowly and offers diversity of structure for a long time. In the end it all belongs to the soil. Why the animals are so attracted to logs is not sure; there is not much protein there, except secondarily. The artificial logs consisting of oak boxes and oak sawdust had about 900 individuals of 41 species, with some two dozen species as the basic fauna for all seasons and in all logs.

Then follows the fascination of the deserts, hot Mojave and cool Gobi, where the caravans can pack drinking ice in the camel bags. The soil harbors a specialized life indeed, relatively simple, with such large and showy forms as scorpions. The soil here is mineral, with little organic matter. It forms more a shelter than a subsistence zone. The occasional layer of litter and the root systems of plants harbor a reduced population of mites. "The poverty of life in the Antarctic region is surprising"; latitude for latitude the Arctic is more shrubby and varied. It may be that the adaptive processes have not had enough time to work in the isolated Antarctic, where postglacial recolonization by plants and animals is sure to be slow. The springtails and mites tell the story. Some of them belong to an old-settler world, relics of ancient preglacial life; but there is also an immigrant element, South American in origin and newcomers to the region.

The entire picture is merely sketched in. It is far from clear to what extent we should regard the clusters of species we see as communities that are somehow necessary and to what extent as simply what has happened. Only in the extreme cases of salt marshes or deserts is it plain that there is a restricted community, found there more or less exclusively. In most places the idea of community is only one approximation; the idea of continuum is no less real. Time, structure and chemistry define the hypervolume of habitat diversity in a multitude of ways. Each species dwells in some small region of that vast and little-known space. Perhaps the origin of the complexity of the soil fauna lies here, in the world of grains and crannies where so many distinct evolutionary niches abound.

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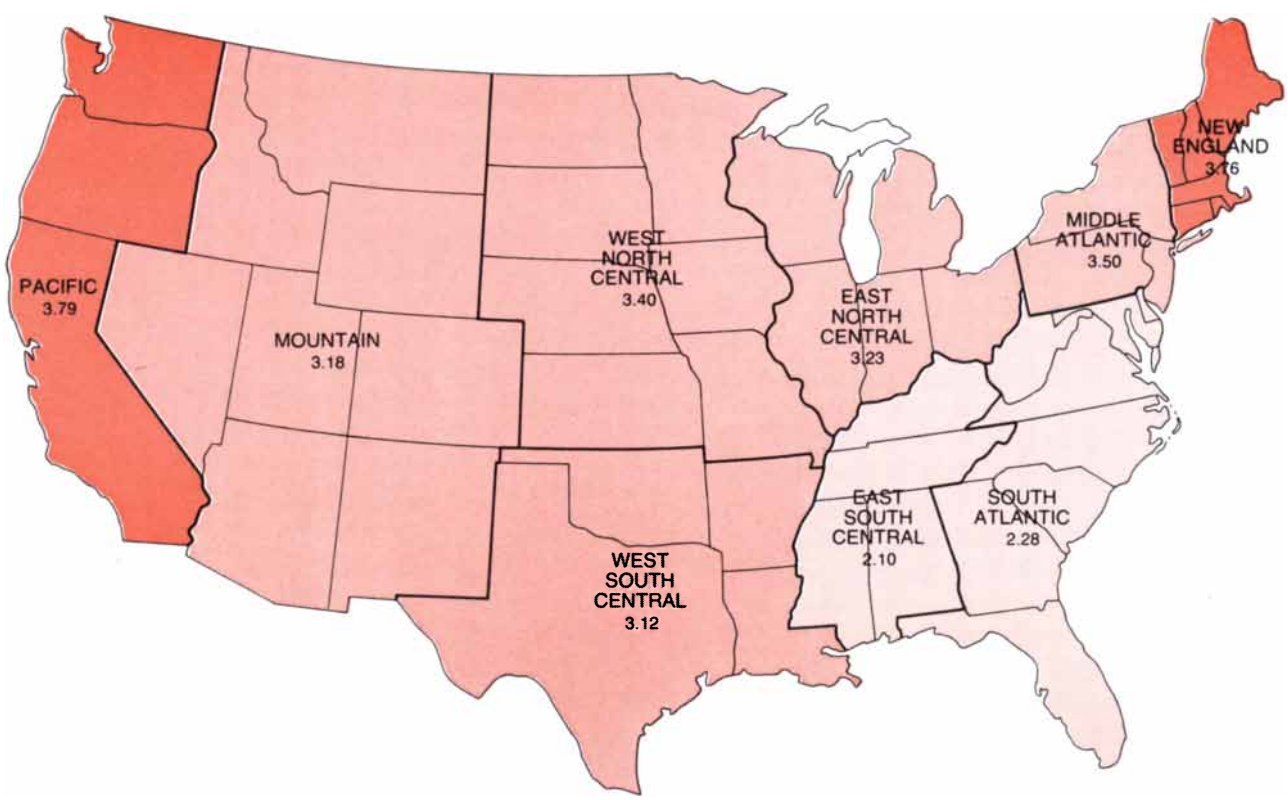
Attitudes toward Racial Integration

The fourth in a series of reports on racial attitudes shows that U.S. whites have increased their support of integration at a steady pace, with a striking period of more rapid change between 1970 and 1972

by D. Garth Taylor, Paul B. Sheatsley and Andrew M. Greeley

The 1970's are generally characterized as being years of disgruntled reaction to the rapid social, economic and political changes of the 1960's. In some areas of American life that may well be a correct assessment, but it does not seem to have been the case in race relations. The continuing monitoring of racial attitudes conducted by the National Opinion Research Center (NORC) makes it clear that since 1970 white Americans have moved steadily toward approval of racial integration. The most striking fact to emerge from our analysis of the surveys is that the years between 1970 and 1972 were an extraordinary interlude in U.S. history: just when the "white backlash" was thought to be taking effect there was instead a leap forward in racial tolerance—or, to be more specific, in the verbalized attitudes of white Americans with regard to the integration of blacks into U.S. society. The early 1970's were marked also by an increased rate of change in several other measures of support for civil or personal liberties, equality between the sexes and tolerance (some call it permissiveness) in general. The years since 1972 have seen not a reversal of the liberal trend in racial and other matters but rather a return to the slower, but nevertheless steady, rate



GEOGRAPHIC DISTRIBUTION of white Americans' 1976 scores on a scale of attitudes toward integration is displayed for the U.S. Census regions. The average scale score was highest in the Pacific Coast region and in New England and lowest in the Southern states.

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of change that has been recorded by NORC surveys for the past 35 years.

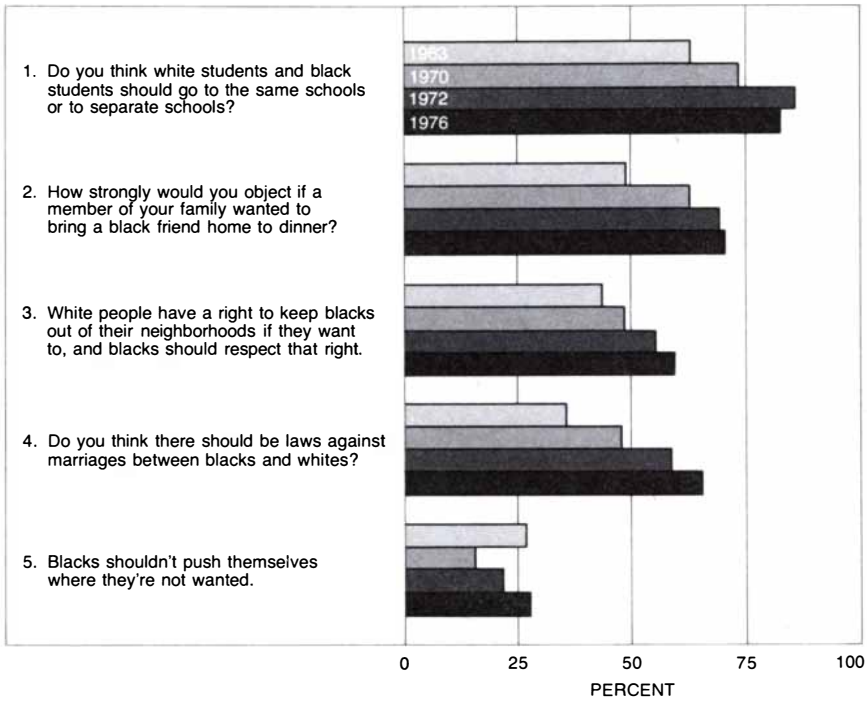
The changing racial climate revealed by the response of white Americans in those surveys has been described in these pages in a series of articles [see "Attitudes toward Desegregation," by Herbert H. Hyman and Paul B. Sheatsley; SCIENTIFIC AMERICAN, December, 1956, and July, 1964, and "Attitudes toward Racial Integration," by Andrew M. Greeley and Paul B. Sheatsley; SCIENTIFIC AMERICAN, December, 1971]. Since 1963 the surveys have been based on a particular scale of racial tolerance and in 1976 the scale was again included in NORC's General Social Survey. (The survey is conducted by interviewing a nationwide sample of about 1,500 people; the questions constituting the scale were put to the approximately 1,350 whites in the sample.)

The purpose of this article is to report the results of that study, to highlight the continuities and the striking discontinuity in the rate of improvement and to examine some of the causes of the trends we observe. We find that some of the movement can be accounted for by the entry into the population of younger people and by the rising level of educational attainment, but that a good deal of the trend represents actual modification of attitudes on the part of older people. Moreover, our analysis indicates that the change in attitude on racial matters is part of the broader movement toward what can be considered a more liberal position on a range of other social issues.

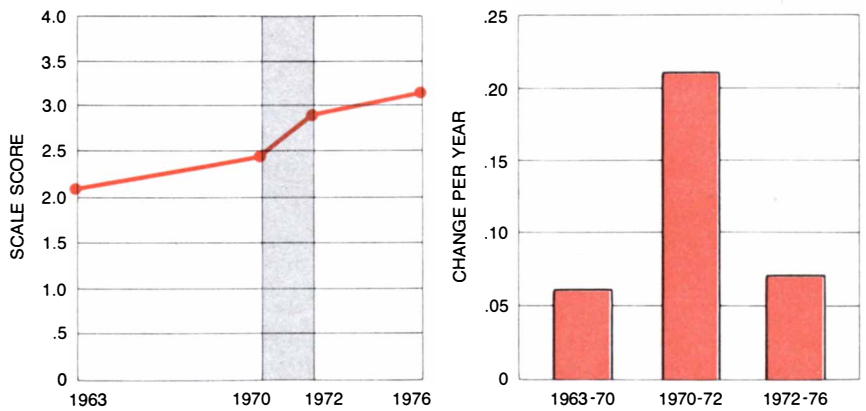
The five items of the scale, which was devised by Donald J. Treiman, are selected and arranged in order of what might be called increasing stringency, that is, people are more likely to give the "liberal," or prointegration, response to the first item than to the second one, to the second item than to the third one, and so on [*see upper illustration at right*]. For each question the percentage of the white population giving the prointegration response is recorded. In addition, each respondent is assigned a score ranging from 0 to 5 depending on the number of his prointegration responses. Mean scores can then be computed for the total white population and for various subgroups of the population. Almost every item shows a substantial change in the integrationist percentage from 1963 to 1970, 1972 and 1976. As for the mean score for all white Americans, it was 2.09 in 1963, indicating that the average white American then gave the prointegration response to just over two of the five integrationist questions. By 1976 the score had increased to 3.17.

Two observations should be made with regard to the scale questions. One is that the first item is coming to elicit such broad agreement that it will soon not be useful in discriminating racial opinion. Three of the items in the original eight-question Treiman scale had to be "retired" for just that reason. They had to do with the integration of public facilities, an issue that was problematic not so many years ago but then became so settled in the public mind that it was difficult to find whites who would not endorse the principle. If the racial climate continues to improve, other questions in the scale will presumably become less effective and will have to be dropped as new items, reflecting current issues such as busing for school integration, are added to the bottom of the scale.

The second observation is that not all the items show the same pattern of change. The last question, about blacks pushing themselves "where they're not wanted," elicited a more negative response in 1972 than in 1970, and its integrationist percent is about the same now as it was in 1963, whereas the other items show unambiguous trends in the prointegration direction. We believe the last question may not measure the same dimension of racial attitude as it measured when the scale was first administered, but rather other dimensions or values such as politeness and conventional social behavior. For example, a person might decide that whites do not have the right to exclude blacks from a neighborhood without necessarily deciding that blacks should "push" into the neighborhood. (Indeed, an otherwise



TREIMAN SCALE of questions on racial attitudes was administered to a nationwide sample of about 1,350 whites in 1963, 1970, 1972 and 1976. The bars show for each year the percentage of respondents giving what is considered to be a prointegration response to each question.



SCORE ON TREIMAN SCALE is the number of questions to which a respondent gives an integrationist response. The curve (*left*) shows how the mean scale score of the U.S. white population increased in successive surveys, with a sharper rise between 1970 and 1972. The bars (*right*) show the amount of change per year during the intervals between nationwide surveys.

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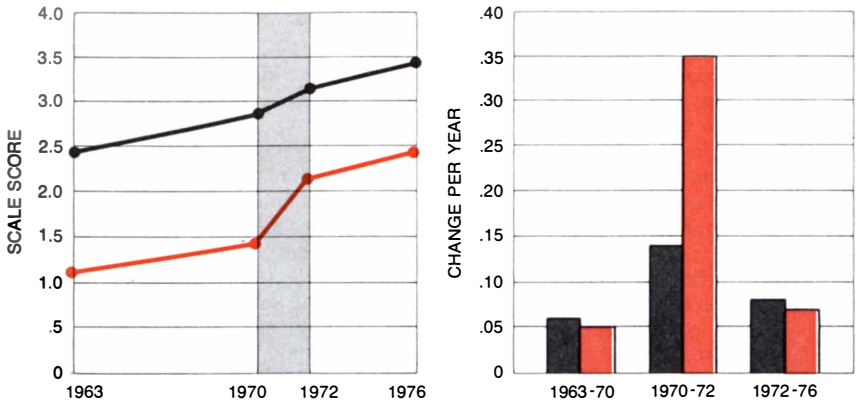

RATE OF CHANGE in scale score has been about the same in the North (*gray*) and the South (*color*) except during the 1970–72 period, when the mean score in the South rose more rapidly.

quite liberal person might believe that no one, including a sociologist, should push in where he is "not wanted.")

The different periods of change in white racial attitudes since 1963 are revealed if one compares the annual rates of change in the scale score during the several intervals between surveys. Between 1963 and 1970 the score moved in the liberal direction at the rate of six-hundredths of a question, or .06 point, a year. Between 1970 and 1972 the rate of change was .21 point a year, more than three times as high. For 1972–76 it declined to just about the pre-1970 level. A number of studies of U.S. attitudes on other issues show a similar pattern: slow but steady change through the 1960's, a quick spurt in the early 1970's and then a return to a stable, slower pattern of change. For example, analyses by James A. Davis and his colleagues at NORC show this pattern of change in the population's support for legalizing abortion under certain circumstances, for expansion of various rights of women and for some other measures of liberalism. In the last part of this article we shall attempt to interrelate some of these patterns of change in an effort to understand the reasons for the modification of white American racial attitudes.

Comparing the changes in scale scores for various subgroups of the population provides a fuller description of the trends we have noted and also some clues to factors that may account for the different periods of change. The causes of the steady long-term trend could include demographic changes, such as the succession of new age groups and the increasing educational level, or other persistent kinds of forces, such as the expansion in scope of civil-rights legislation. The accelerated movement of the early 1970's, however, will have to be explained in terms of more rapid introduction and acceptance of new values within the population or within regional or other subpopulations.

Regional differences persist, and there is little evidence to suggest that they will disappear in the near future. The most liberal regions are the Pacific Coast states and New England. The Middle Atlantic region, the Middle West and the Mountain and West South Central regions are grouped at a level fairly close to the national average. In the Deep South the verbally expressed level of toleration of interracial contact remains substantially below the level in other regions. The gap between the South as a whole (the three southern regions) and the rest of the country (the North) did close substantially during the period between 1970 and 1972; in those years the rate of change in the South increased by a factor of seven while the rate in the North about doubled: otherwise the rates of change have been about the same in the North and the South. Whatever forces caused the increased liberalization of the early 1970's apparently hit with particular force in the South.

Why did that happen? And as a matter of fact has the apparently similar long-term pattern of steady change actually been the same in the North as in the South? To answer these questions we turn to a more detailed breakdown of the trends in regional differences [*see illustrations on opposite page*]. Before 1970, in both the South and the North, the youngest age group became liberal faster than other age groups; the older age groups changed a little faster in the North than in the South; there were no appreciable differences among educational groups in rate of change. In other words, there was some increase in North-South polarization and there was rapid polarization by age within each region.

Between 1970 and 1972 the rate-of-change pattern is quite different. In the North the three older age groups became substantially more liberal, whereas the youngest group (which by 1970 had become quite distinctive in outlook) changed hardly at all; as a result, by 1972 age differences were smaller in the North than they had been in 1970. As for education, it was those who had finished high school or finished college and those who had not entered high school (those, in other words, who had been able to achieve what they had striven for in education) whose scale scores rose most sharply. Those who had started high school or started college but had not finished also moved in the integrationist direction, but at slower pre-1970 rates.

In the South between 1970 and 1972 the age gap widened instead of narrowing. In general, the younger a person was the faster he changed; the two youngest groups changed at the rate of .43 point a year and the oldest group changed at the rate of .12 point a year, about the same rate as the older groups in the North. This age-group pattern was reflected in, and partly responsible for, the educational-level differences in the South during this period: the rates of change increase with education. The pattern of age and educational differences in the South during those two years was what one might expect of a region undergoing modernization and increasing acceptance of the dominant values of a society. This modernization pattern is observed only in the South, and there only between 1970 and 1972.

For many years the history of racial prejudice in the U.S. has been influenced by religious and ethnic considerations and the movements of religious and ethnic subgroups. Since World War II the distribution of such groups in the population has changed very little, and so shifts in ethnic composition cannot account for changes in racial attitudes of the kind we have described. Examining patterns of change within various groups, we find that in each of the four survey years the three major religious groups differed in their average scale score. The differences have been narrowing, however. In the period between 1963 and 1970 almost all the country's increase in racial liberalism was accounted for by the Protestant population, the least integrationist of the three religious groups. (The rate of change was .07 point per year for Protestants, .02 for Catholics and .03 for Jews; the figure for the U.S. population as a whole was .06.) During the period of rapid liberalization in the early 1970's the Protestant and the Catholic mean scores rose sharply at about the same rate, and they both continued to increase at lower rates between 1972 and 1976. Jews, historically the most liberal of the religious groups in verbal expression of racial tolerance, have had the lowest rate of liberalization over the entire period since 1963; indeed, their mean score actually decreased from 1970 to 1972. The reason for the slow rate of long-term change among Jews may be that their prointegration level has been so high

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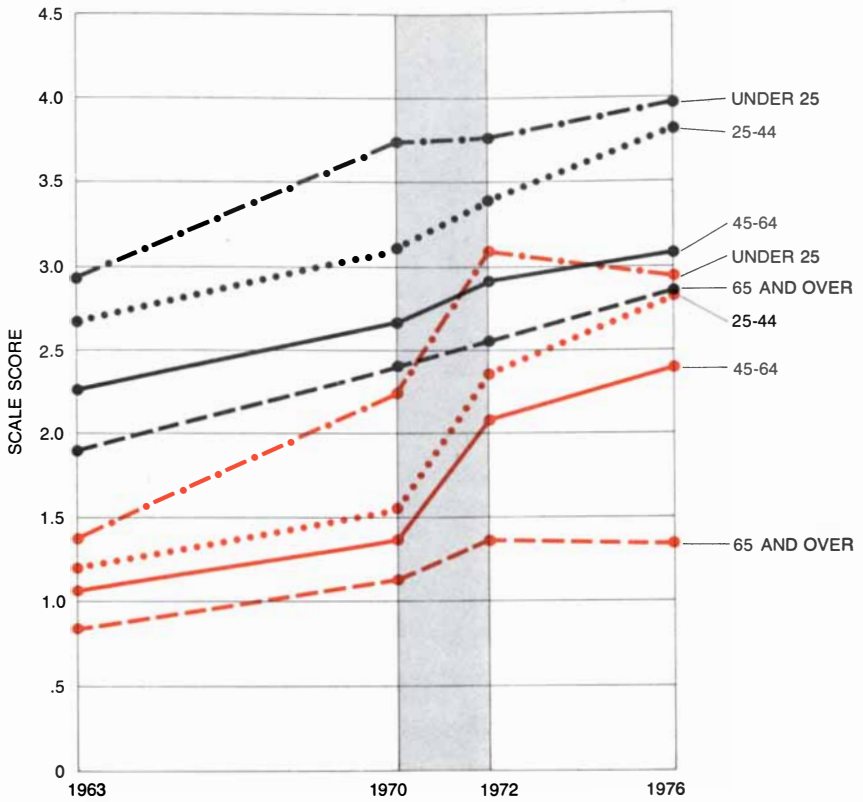
that further change has become difficult to discern. Such an explanation would not, however, account for the apparent retrogression in the early 1970's. (The small size of the Jewish subgroup in our sample somewhat reduces our confidence in our ability to measure trends in the group.)

Differences among various ethnic groups within the northern Protestant and Catholic populations can be identified for the period since 1970. (It is only in the past decade or so that social researchers have "rediscovered" ethnicity as a factor in public opinion, and ethnic-identity questions were not included before that.) The highest rates of change between 1970 and 1972 were experienced by Anglo-Saxon Protestants and by Irish, Italian and Slavic Catholics (even though Catholics from eastern and southern Europe are popularly considered to be most resistant to racial change). The most resistant group appears to have been the German Protestants, who had the smallest increase over the six-year period.

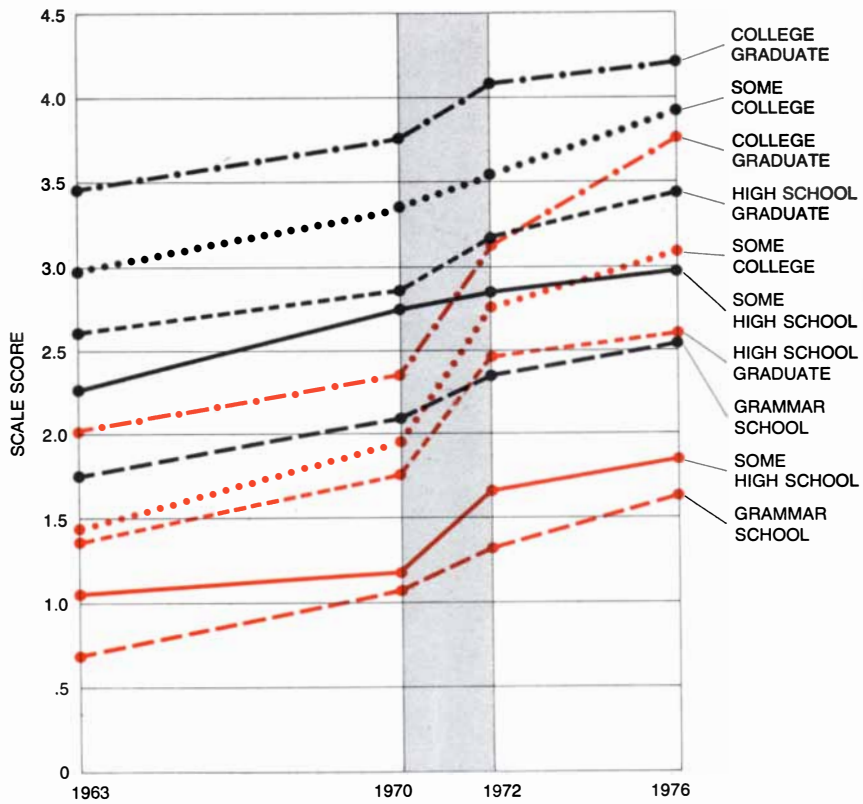
The differences in the 1976 scores of various income and occupational groups are about what one might expect on the basis of educational and ethnic differences: the higher the income and the higher the occupational prestige are, the more favorable a white person is to the integration of his neighborhood and social relationships [*see illustration on page 47*]. There is a distinct gap between the white-collar and blue-collar occupational groups, and the gap is larger than can be accounted for by the income and educational differences between those groups. There is no significant sex difference on the racial tolerance scale.

The data we have cited can be summarized very briefly. The facts do not support the common assumption that the pace of liberalization in racial matters has been slowed by a white backlash. Instead the rate of change toward a more integrationist attitude has been rather constant since 1963, with a short period of faster change in the early 1970's. In the remainder of this article we shall attempt to "decompose," or account for, the changes in the Treiman scale, parceling out the total change into component changes brought about by various demographic factors and what can be termed a cultural factor: the general movement toward a liberal position on several measures of personal and civil liberties.

Our problem was to find an index of that general change in liberal values, such as responses given by Americans to some question that measures liberalization and that was posed, in the same form, at the right times to be incorporated in a statistical model explaining the racial data. We found one such question: "If your party nominated a woman for president, would you vote for her if



BREAKDOWN OF SCORES BY AGE GROUP shows that in the North (*gray*) and the South (*color*) younger groups had higher scores and scores increased more rapidly. During 1970–72 younger groups in the South changed particularly rapidly, tending to close North-South gap.



BREAKDOWN OF SCORES BY EDUCATION highlights the fact that the 1970–72 rate of change in the South (*color*) increased linearly with education. Together with the age-group variation, this pattern is a characteristic of a region that has been undergoing rapid modernization.

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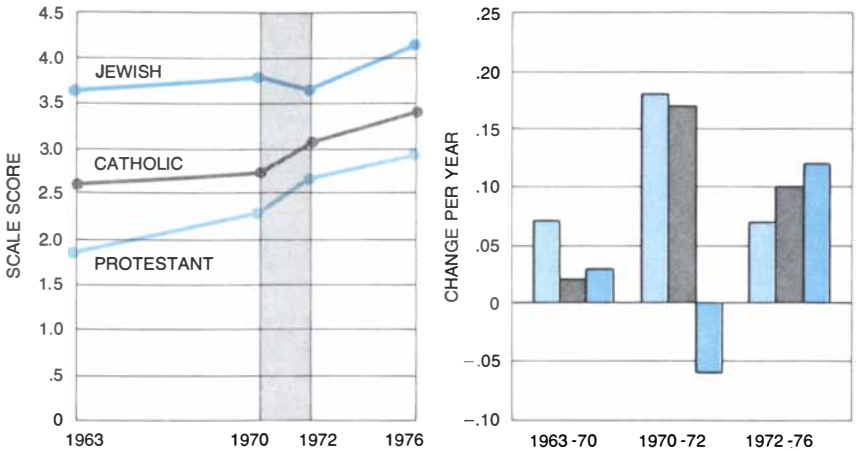
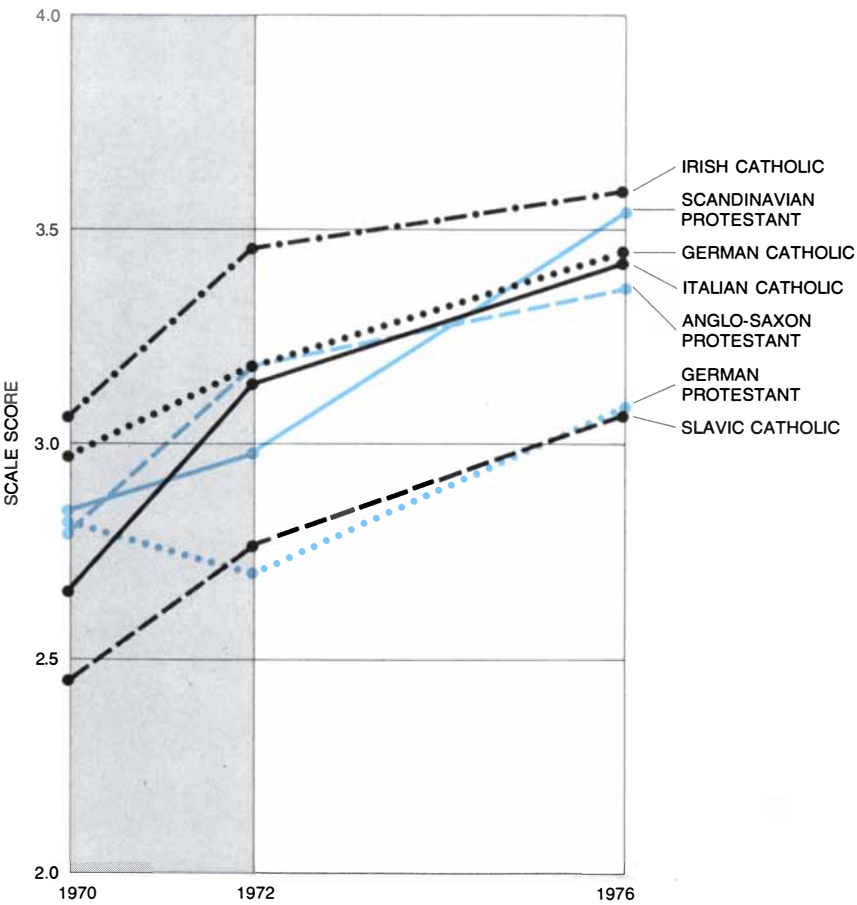


BREAKDOWN BY RELIGION shows gaps between the scores of Protestants, Catholics and Jews are narrowing. Protestants and Catholics changed at about same rate, Jews more slowly.

she were qualified for the job?" It was included in Gallup surveys in almost exactly the same years as our earlier racial surveys, and it appeared in our General Social Survey along with the Treiman scale in 1972 and 1976. The level of support for a woman as president rose with the same dynamic as the racial-liberalism scale. A "yes" answer was given by 54 percent of the population in 1963 and then by an estimated 59 percent in 1970. Between 1970 and 1972 there was a dramatic increase to 69 percent. The trend continued after 1972, but at a slower pace, with 78 percent giving the positive response in 1976.

We adopted this variable as an index of a general shift in the society toward support for the expansion of civil and personal liberties. It is far from being a perfect indicator, to be sure, since attitudes on a woman as president must have been affected by the changing climate with regard specifically to women's rights and roles. Moreover, it would have been better to have several indicators rather than one. Because we had only the one indicator whatever role we ultimately assign to the general cultural movement toward liberalism must necessarily represent a lower limit for the role of that cultural factor.

A somewhat similar analysis, also aimed at allocating responsibility for change in liberal values to various determinants of change, was performed in 1975 by Davis and his colleagues. The sociologist Samuel A. Stouffer had predicted in 1955 that support for liberal values would increase with increases in education and with the succession of new cohorts, or age groups, whose members were more educated and more open-minded. Davis found that by 1975 the level of support for measures of liberalism Stouffer had devised had indeed increased, by an average of 28 percent, and that the dynamics of cohort succession and increasing educational attainment alone accounted for more than half of that change. We could not expect demographic changes to account for that much of the change we sought to analyze in racial attitudes because our time span was only 13 years rather than 20. On the other hand, the explanatory power of the model we devised should be increased by our inclusion of another explanatory variable: support for a woman as president.



ETHNIC SUBGROUPS among Northern Protestants and Catholics have been separately recorded since 1970. The most rapid change was in mean score of Italian Catholics between 1970 and 1972. Irish and Slavic Catholics increased score rapidly, as did Anglo-Saxon Protestants.

The logical basis of our analysis is an assumption that changes in the Treiman scale result from changes in a number of "predictor variables" related to racial liberalism, which themselves change over time. The predictor variables are cohort succession, rising educational level and the general liberalization of values. (There are other variables that tend to predict racial attitude but that are ineffective for explaining changes because they themselves do not change much over time. Region of residence is a good example.) We defined four cohorts—"old" (born before 1907), "middle" (born from 1907 through 1923), "young" (1924–39) and "new" (1940–58)—and tracked them through the population with data from a number of NORC surveys. Three educational groups (those with at least some college, high school graduates and nongraduates) could be established within each cohort on the basis of another question on each racial-attitude survey. And support for a woman as president, of course, was our measure of general liberalization.

Having specified the important predictor variables, we arrange them on what is called a linear flow graph that indicates their presumed causal relation

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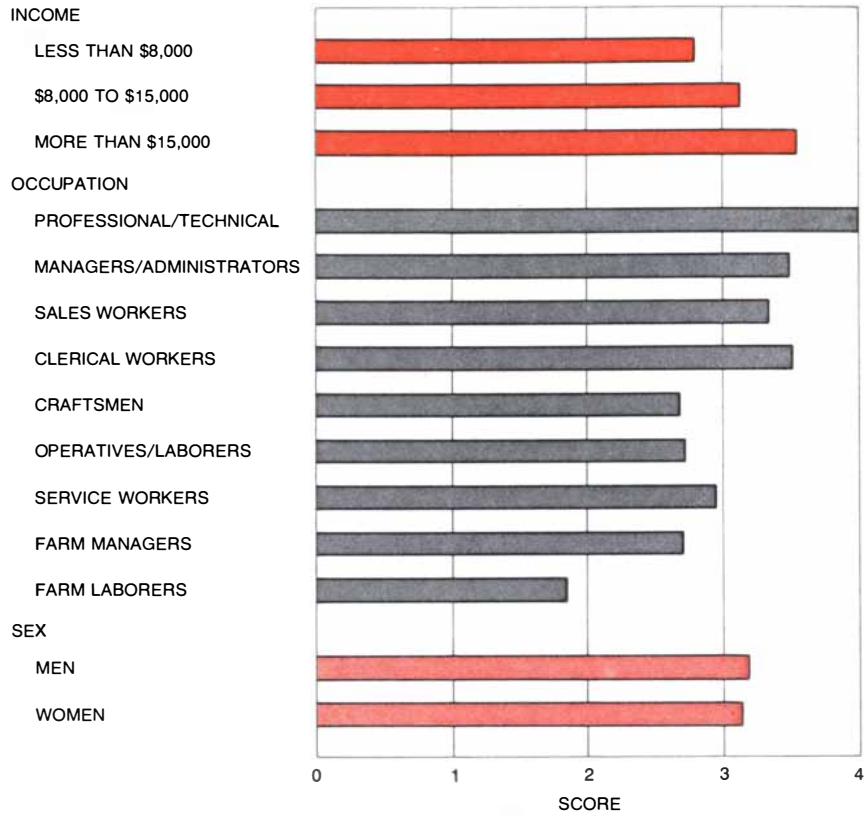
[*see top illustration on page 49*]. The next step is to determine the quantitative relation between each predictor variable and the dependent variable: a person's score on the racial-liberalism scale. This is a problem in multiple regression analysis. The numbers (the path coefficients) on arrows near the right side of the flow graph show the extent to which each characteristic of a respondent tends to raise or lower his racial-liberalism score—after controlling for the other characteristics. For example, young people are more liberal on racial matters in part because they are better educated, and so we need to control for educational differences before making statements about "pure" cohort effects. The path coefficient (.56) on the arrow from "new cohort" to "racial liberalism" is the difference in score between the new cohort and a base group (the middle cohort), after adjustment for the differences between those cohorts in educational attainment and support for a woman as president. In other words, controlling for differences in education and in support for a woman as president, people in the new cohort score, on the average, .56 point higher on the Treiman scale than do people in the middle cohort. The young cohort scores .23 point higher than the middle cohort, the old cohort .30 point lower than the middle cohort.

Again, within any cohort and whatever the opinion on a woman as president, a person who has finished high school scores .49 point higher on the Treiman scale than someone who has not finished high school; a person with at least some college scores 1.01 points higher than someone who has not finished high school. And people who would vote for a woman as president score .68 point higher, no matter what their age or educational level, than those who would not vote for a woman. The other paths in the flow graph show how the variables that predict the racial liberalism score are themselves interrelated. They show how age cohorts differ in attaining a particular educational level and in supporting a woman as president.



1976 SCALE SCORES are shown here for various income and occupational groups and by sex. The occupational groups are listed here in the order of decreasing perceived "prestige," as determined by a public-opinion survey conducted by National Opinion Research Center.

The flow graph, then, shows the structure of the relations between the variables. In order to determine how much of the total change in the score (the dependent variable) is explained by changes in each of the prior variables, we first need to determine the amount of change over time—the delta (Δ)—for each of the prior variables. The new cohort, for example, came to constitute a much larger proportion of the population over the years and the old cohort accounted for a much smaller percentage. The young cohort's percentage did not change significantly. Specifically, the percent of the population in the new cohort increased by 12.85 percent between 1963 and 1970, by 11.95 percent between 1970 and 1972 and by 9.99 percent between 1972 and 1976.

These numbers provide change coefficients for the new cohort, or delta 1, for the three periods [*see illustration on next page*]. The deltas measure the amount of change in each variable that is not accounted for by a change in a prior variable. Deltas 2 and 3 are the change coefficients for the young and the old cohorts. Deltas 4 and 5 are zero because we find that just about all of the increase in educational level is a by-product of the succession of better educated cohorts; there is no significant net change, or increase in educational level within cohorts (by a back-to-school trend, for example). As for support for a woman as president, again some of the change is attributable to the succession of younger and better educated cohorts, but a significant amount of change is still not accounted for. This delta 6, the net change in our liberalism indicator, was small before 1970 and large thereafter—particularly large, in terms of change per year, between 1970 and 1972.

The final step is to multiply the changes in prior variables, the deltas, by the path coefficients linking the prior variables to the dependent variable, which we want to explain. The change in racial attitude that is attributable to the direct effect of the increase in the new cohort during a particular period, for example, is found by multiplying the change for that period (delta 1) by the direct path linking the new cohort to the racial-liberalism scale. For the period from 1963 to 1970 that means multiplying .1285 by .56. The product, .0719, is the fraction of a point by which the mean U.S. Treiman-scale score increased between 1963 and 1970 because of the direct effect of the succession of the new cohort; it comes to 18 percent of the gross change (.40 point) in the scale score for that period [*see bottom illustration on page 49*]. There are other, indirect effects of new-cohort succession, as the flow graph arrows make clear. One of them is the effect of the new cohort's increased probability of being a high school graduate, graduates in turn tending to have higher Treiman scores. That effect is calculated by multiplying .1285 by .26 by .49. In the same way the change attributable to the independent effects of the liberalization measured by support for a woman as president can be seen to be .0207 multiplied by .68, or .0141.

What can an examination of these numbers reveal about the process of change in racial attitudes? For one thing, the results illuminate the two kinds of effect of cohort succession. One is indirect. Younger cohorts are better educated and more supportive of other liberal values in addition to racial inte-

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gration. As these cohorts loom larger, the population as a whole becomes better educated and more attached to liberal values, and those changes in turn have implications for racial liberalism. There is also a direct effect of cohort succession. Quite apart from their higher level of education and their increasingly liberal stance in general, younger white people have been exposed to different values in race relations. They are more likely to go to school with blacks, serve with them in the Army and work with them. The impact of recent advances in race relations has been age-specific in many respects. If a segment of a population is changed by certain events, then that change is preserved as a cohort effect. As the proportion of the population exposed to these change-generating events becomes larger, U.S. society will move in the liberal direction.

For the entire period from 1963 to 1976 the increase of the new cohort accounted directly for 18 percent of the total amount of change in the white racial-attitude score. Another 19 percent of the change was an indirect effect of the same increase: the new cohort was better educated and more liberal—and therefore more prointegration. In other words, the succession of the cohort of whites born between 1940 and 1958 has been tremendously important; it accounted, directly or indirectly, for 37 percent of the total change in racial liberalism from 1963 to 1976. (The result is similar to Davis' finding that the direct and indirect effects of cohort succession accounted for 32 percent of the increased support he found for unpopular political and religious minorities.) The impact of the new cohort is particularly impressive for the period 1970–72. It accounted for an increase in the Treiman score of almost .07 point per year, thus explaining at least part of the sharp increase in integrationist support during that period. The decline of the oldest cohort had much the same effect as the increase of the new one, both directly and indirectly, but it accounts for much less of the change (particularly after 1972, by which time most of its members had died). Nevertheless, its effect was far from trivial.

We come finally to the question of how much of the change in racial liberalism can be explained by a broad shift in the society's evaluation of personal and civil rights and liberties. We believe that some of the contribution of that factor is measured by the direct effect of the change in the percentage of the population who would vote for a woman as president (only a lower limit of what might be explained by the broad liberalization factor, as we pointed out above, because we have only the one indicator). For the period as a whole, increased support for liberal values, as measured by the woman-as-president indicator, accounted for 10 percent of the increase in the racial-attitude score. What is most interesting is the variation of this factor over time, which helps to explain the difference between the 1970–72 period and the other periods. Before 1970 the woman-as-president issue accounted for only 4 percent of the change in the Treiman-scale score. Between 1970 and 1972 the influence of this factor was much greater; it accounted for 12 percent of the total change. In absolute terms, the liberalization factor contributed .025 point per year in those two years. Meanwhile, as we pointed out above, the effects of cohort succession also increased sharply. The result was a rapid change in the two-year period, much of it accounted for by these two factors. After 1972 the amount of change attributable to broad liberalization declined along with that attributable to the other variables, but the relative importance of this variable increased.

When all the changes explained by these variables in the flow graph are added up, the sum is less than the gross change in the Treiman-scale score. That means there are other sources of change that are not accounted for by our model. The model does account for between 53 and 65 percent of the change in each time period, which suggests that we are doing a respectable, but by no means complete, job of accounting for the trend in racial attitudes.

Our data do not allow us to do more than speculate about the meaning of the liberal leap of the early 1970's, one that has been hitherto invisible to observers of U.S. politics and society. We note that most of the change must have been generated during the time of the Kent State and other disturbances arising from the invasion of Cambodia. We also know it was during the two years just before this period that the majority of the American public turned against the war in Vietnam, as was shown in a study by John E. Mueller of the University of Rochester in 1973. Is it possible that the process of deciding that the leadership of the country had been wrong about the war—and had deceived the people about the war—was a radicalizing experience for a substantial segment of Americans, an experience that made people reexamine their beliefs on a variety of related subjects? Is it possible that even though they disapproved of student radicals and vigorously rejected Senator George McGovern as a presidential candidate a substantial number of Americans were willing to accept some of the ideology of the McGovern wing of the Democratic party? May the antiwar Democrats have been more successful than they thought, precisely when they thought they had begun to fail?

To be even more speculative, could a more adroit liberal leadership have taken advantage of this unperceived trend in the early 1970's to build new coalitions with the people they had unknowingly influenced? Were those who talked about such coalitions in the early 1970's right about the possibility and wrong about the strategy? May they not have offended their most likely recruits by adopting strategies designed to please those who were already in their camp?

The fact that our evidence even raises such questions suggests that both conventional public-opinion polls and the traditional "feel" of politicians and political activists for shifts in public attitudes are imperfect instruments for shaping political strategies. To the sociologist our results may suggest that more carefully designed and more elaborate time-series measurements of public attitudes are needed if we are to document and understand social change in America and challenge the myths that become history because there are no data to refute them.

Δ	VARIABLE	1963 – 1970	1970 – 1972	1972 – 1976
1	NEW COHORT	.1285	.1195	.0999
2	YOUNG COHORT	0	0	0
3	OLD COHORT	–.0948	–.0562	–.0078
4	HIGH SCHOOL	0	0	0
5	COLLEGE	0	0	0
6	WOMAN AS PRESIDENT	.0207	.0718	.0727

CHANGE COEFFICIENTS, or deltas, give the change in the course of each period for "predictor variables" (*see top illustration on opposite page*). Deltas 1, 2 and 3 give the increase in age cohorts as a percent of the total population; the young cohort did not change significantly. Deltas 4 and 5 are zero because the effect of increasing education is fully measured by the succession of new cohorts. Delta 6 is the net change, after controlling for cohort succession, in the support of a woman as president. Deltas are multiplied by "path coefficients" in the final step.

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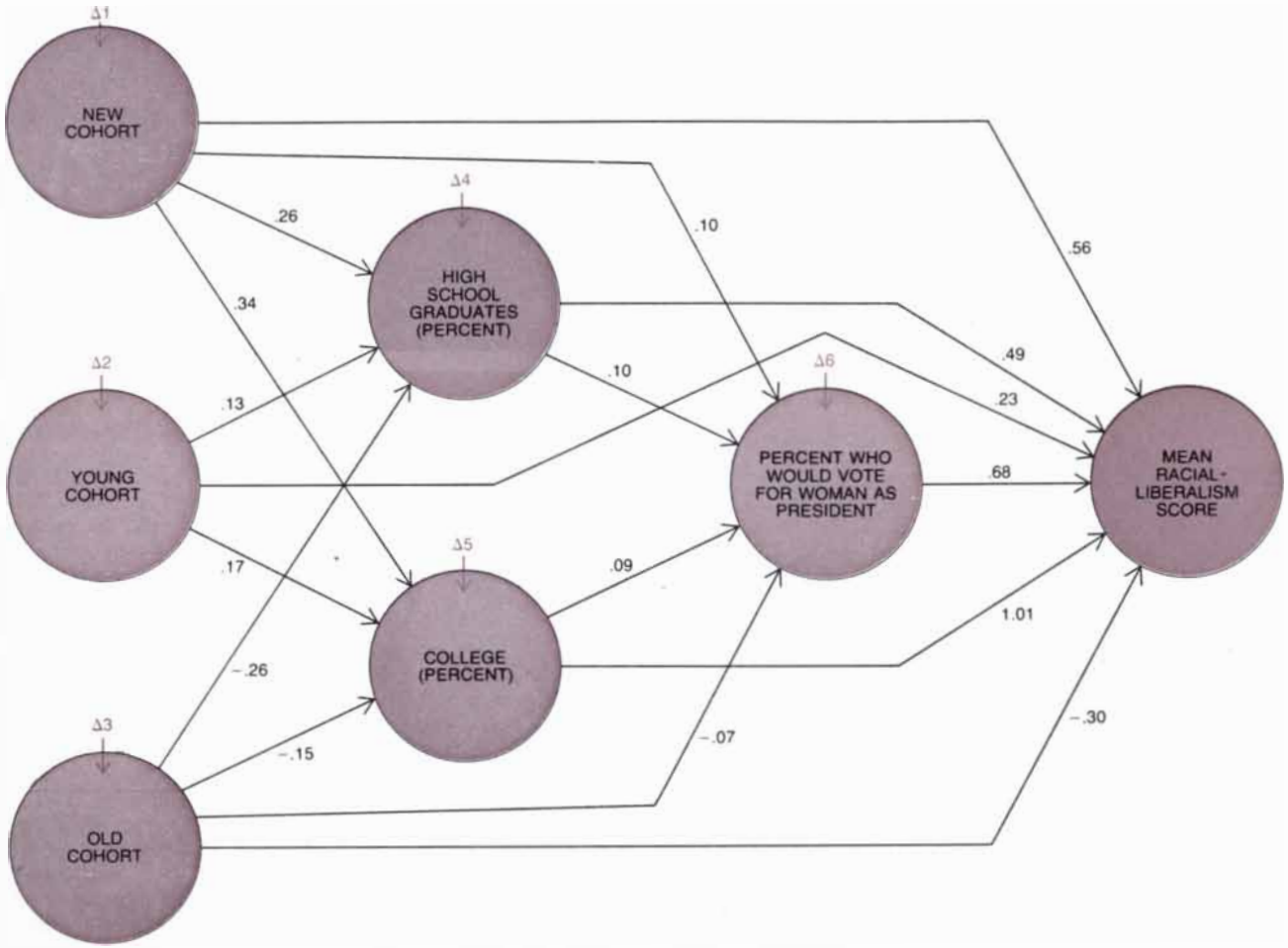

LINEAR FLOW GRAPH shows the relations between predictor variables (*light color*) and the dependent variable (*dark color*), which is the racial-liberalism score. The numbers (path coefficients) on the paths from the predictor variables to the score state the extent (in fractions of a point) to which a given variable raises the score of a respondent above that of a member of the appropriate base group (the middle cohort, those with less than a high school education or those who would not vote for a woman as president), controlling for other variables; other paths, at the left and center, show the interrelations of the predictor variables. For example, a member of the old cohort is 15 percent less likely to have gone to college than a member of the middle cohort, and people who have gone to college tend to score 1.01 points higher than those who have not graduated from high school. The short arrows labeled delta (Δ) refer to the change coefficients.

	1963 – 1970		1970 – 1972		1972 – 1976		TOTAL, 1963 – 1976	
GROSS CHANGE IN SCALE	.40		.42		.26		1.08	
	AMOUNT	PERCENT	AMOUNT	PERCENT	AMOUNT	PERCENT	AMOUNT	PERCENT
COHORT SUCCESSION, DIRECT:								
INCREASE OF NEW COHORT	.0719	18	.0668	16	.0559	22	.1946	18
DECLINE OF OLD COHORT	.0284	7	.0168	4	.0023	1	.0475	4
COHORT SUCCESSION, INDIRECT:								
INCREASE OF NEW COHORT	.0742	19	.0690	16	.0577	22	.2009	19
DECLINE OF OLD COHORT	.0330	8	.0195	5	.0028	1	.0553	5
VALUE CHANGE:								
NET CHANGE ON WOMAN AS PRESIDENT	.0141	4	.0489	12	.0495	19	.1125	10
TOTAL CHANGE ACCOUNTED FOR	.2216	55	.2210	53	.1682	65	.6108	57

CHANGES IN SCALE SCORES are "decomposed," or parceled out, to show the contribution of each of the predictor variables. The gross change in score for each interval is shown at the top. Then the amount of change contributed by each variable (the product of the appropriate path coefficient and delta) is listed, along with the percent of the gross change that it accounts for. At the bottom the various contributions are summed to show how much of the gross change in mean score can be accounted for by demographic and cultural variables.

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The Earliest Precursor of Writing

Long before the Sumerians invented writing, accounts in western Asia were kept with clay tokens of various distinctive shapes. It appears that the tokens gave rise to the Sumerian ideographs

by Denise Schmandt-Besserat

What led to writing? The art itself is a good example of what students of the past call independent invention, since systems of writing have evolved in isolation at different times in different parts of the world. For example, one system—the Chinese ideogram—can be traced to its origin in archaic signs engraved on the scapular bones of sheep or the shells of turtles in the second millennium B.C. as a means of asking questions of heaven. Roughly 1,000 years later an entirely independent system of writing arose halfway around the world in Mesoamerica. It combined a simple system of numerical notation with complex hieroglyphs and was principally used to indicate the dates of various events according to an elaborate calendrical system.

Both Chinese and Maya writing were relatively late inventions. Some one system of writing must have been the earliest, and it is from such an initial point that we may begin the search for the antecedents of the art. The credit for being the first to write texts is usually given to the Sumerians of Mesopotamia. By the last century of the fourth millennium B.C. the officials of such Sumerian city-states as Uruk had developed a system of recording numerals, pictographs and ideographs on specially prepared clay surfaces. (A pictograph is a more or less realistic portrayal of the object it is supposed to represent; an ideograph is an abstract sign.)

At Uruk a team of German archaeologists directed by Julius Jordan turned up many examples of these archaic records in 1929 and 1930. The texts, about 1,000 of them, were first analyzed by Adam Falkenstein and his students. Today additional discoveries have increased the total number of Uruk and Uruk-style texts to about 4,000, and Falkenstein's pioneer efforts are being continued mainly by Hans J. Nissen of the Free University of Berlin and his associate Margaret W. Green.

Although the clay blanks used by the Uruk scribes are universally referred to as tablets, a word with the connotation of flatness, they are actually convex. Individual characters were inscribed in the clay by means of a stylus made of wood, bone or ivory, with one end blunt and the other pointed. The characters were basically of two kinds. Numerical signs were impressed into the clay; all other signs, pictographs and ideographs alike, were incised with the pointed end of the stylus. The repertory of characters used by the Uruk scribes was large; it is estimated at no fewer than 1,500 separate signs.

Hypotheses about the origin of writing generally postulate an evolution from the concrete to the abstract: an initial pictographic stage that in the course of time and perhaps because of the carelessness of scribes becomes increasingly schematic. The Uruk tablets contradict this line of thought. Most of the 1,500 signs (Falkenstein compiled 950 of them) are totally abstract ideographs; the few pictographs represent such wild animals as the wolf and the fox or items of advanced technology such as the chariot and the sledge. Indeed, the Uruk texts remain largely undeciphered and an enigma to epigraphers. The few ideographic signs that have been identified are those that can be traced back stage by stage from a known cuneiform character of later times to an archaic Sumerian prototype. From the fragmentary textual contents that such identities allow it appears that the scribes of Uruk mainly recorded such matters as business transactions and land sales. Some of the terms that appear most frequently are those for bread, beer, sheep, cattle and clothing.

After Jordan's discovery at Uruk other archaeologists found similar texts elsewhere in Mesopotamia. More were found in Iran: at Susa, at Chogha Mish and as far off as Godin Tepe, some 350 kilometers north of Uruk. In recent years tablets in the Uruk style have been unearthed in Syria at Habuba Kabira and Jebel Aruda, nearly 800 kilometers to the northwest. At Uruk the tablets had been found in a temple complex; most of the others came to light in the ruins of private houses, where the presence of seals and the seal-marked clay stoppers for jars indicate some kind of mercantile activity.

The fact that the Uruk texts contradict the hypothesis that the earliest form of writing would be pictographic has inclined many epigraphers to the view that the tablets, even though they bear the earliest-known writing, must represent a stage in the evolution of the art that is already advanced. The pictographic hypothesis has been revived anew. The fact that no writing of this kind has yet appeared at sites of the fourth millennium B.C. and even earlier is explained away by postulating that the writing of earlier millenniums was recorded exclusively on perishable mediums that vanished long ago, such as parchment, papyrus or wood.

I have an alternative proposal. Research into the first uses of clay in the Near East over the past several years suggests that several characteristics of the Uruk material provide important clues to what kinds of visible symbols actually preceded the archaic Sumerian texts. These clues include the choice of clay as a material for documents, the convex profile of the Uruk tablets and the appearance of the characters recorded on them.

Nuzi, a city site of the second mil-

CLAY TOKENS FROM SUSA, a city site in Iran, are seen in the composite photograph on the opposite page. The tokens, in the collection of the Musée du Louvre, are about 5,000 years old. The five tokens in the top row represent some of the commonest shapes: a sphere, a half-sphere, a disk, a cone and a tetrahedron. The more elaborate tokens in the next row have been marked with incisions or impressions. Unperforated and perforated versions of similar tokens appear in the third and fourth rows. Tokens in the bottom two rows vary in shape and marking; some can be equated with early Sumerian ideographs (*see illustration on pages 56 and 57*)**.**

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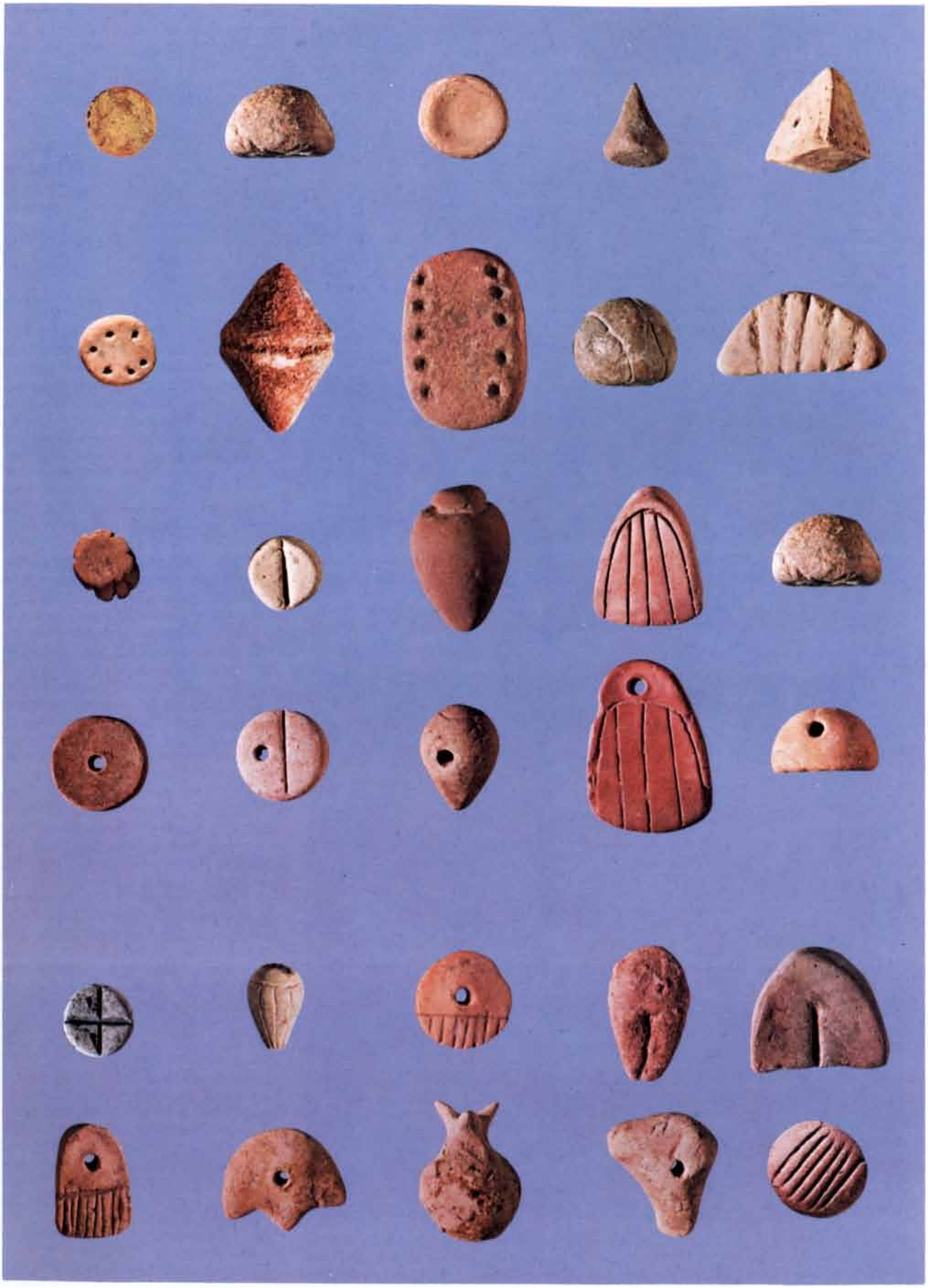

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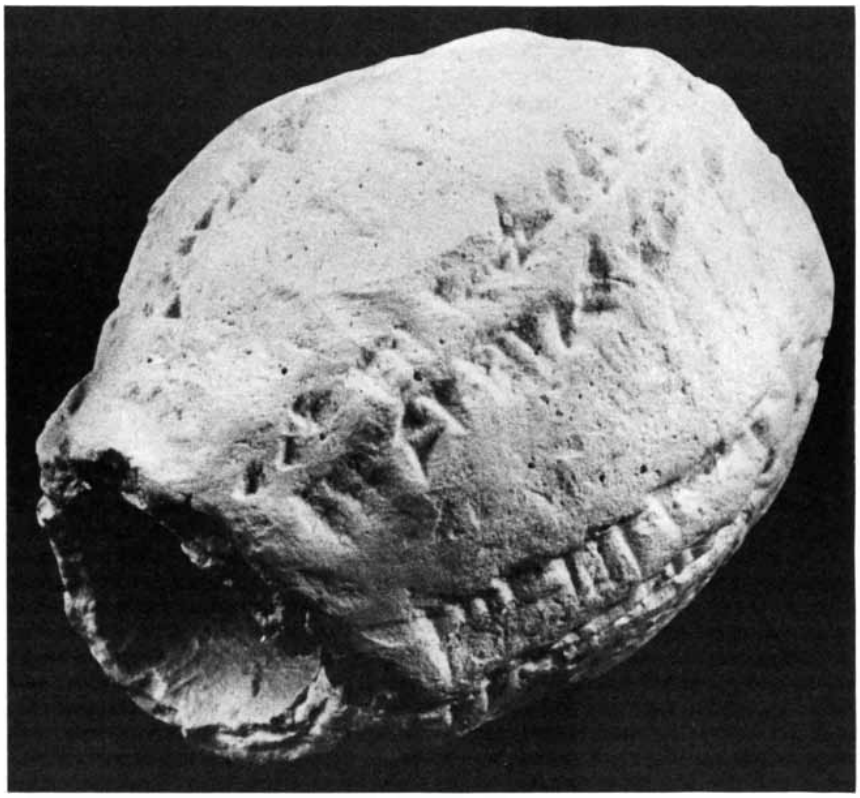
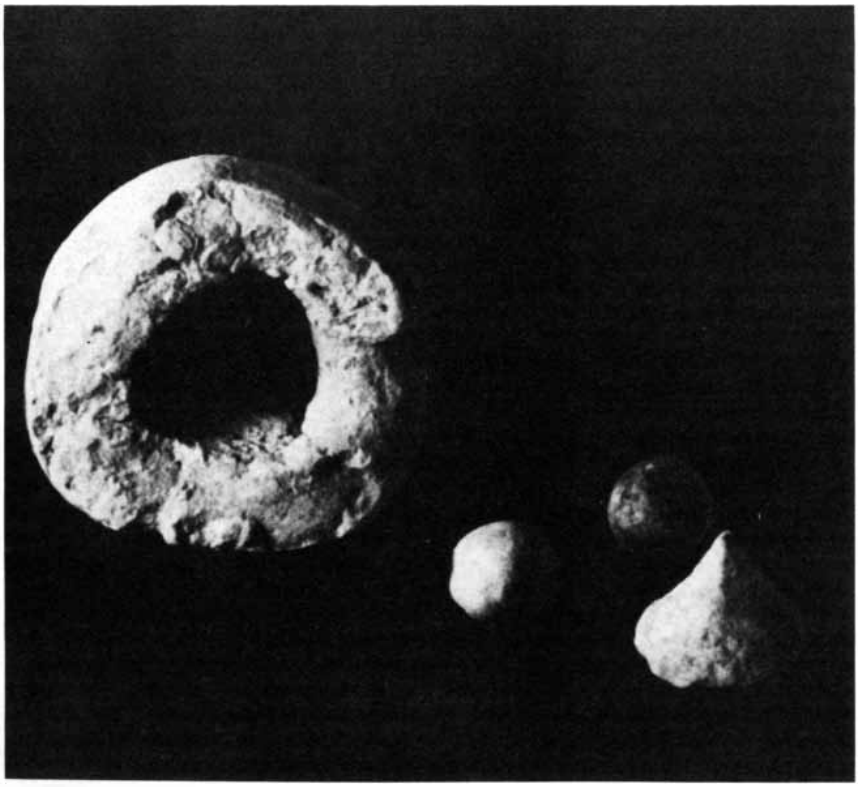


EGG-SHAPED HOLLOW TABLET was found in the palace ruins at Nuzi, a Mesopotamian city site of the second millennium B.C. The cuneiform inscription on its surface lists 48 animals. On being opened the tablet was found to contain 48 counters. The counters were lost before an accurate description had been prepared, but Nuzi texts suggest their use for reckoning.



SPHERICAL BULLA, an envelope of clay with tokens enclosed, was excavated from levels of the third millennium B.C. at Tepe Yahya, a site in south-central Iran halfway between the Indus Valley and lower Mesopotamia. Three tokens (*right*) were enclosed: a cone and two spheres.

lennium B.C. in Iraq, was excavated by the American School of Oriental Research in Baghdad between 1927 and 1931. Nearly 30 years later, reviewing an analysis of the Nuzi palace archives, A. Leo Oppenheim of the Oriental Institute of the University of Chicago reported the existence of a recording system that made use of "counters," or tokens. According to the Nuzi texts, such tokens were used for accounting purposes; they were spoken of as being "deposited," "transferred" and "removed."

Oppenheim visualized a kind of dual bookkeeping system in the Nuzi texts; in addition to the scribes' elaborate cuneiform records the palace administration had parallel tangible accounts. For example, one token of a particular kind might represent each of the animals in the palace herds. When new animals were born in the spring, the appropriate number of new tokens would be added; when animals were slaughtered, the appropriate number of tokens would be withdrawn. The tokens were probably also moved from one shelf to another when animals were moved from one herder or pasture to another, when sheep were shorn and so forth.

The discovery of a hollow egg-shaped tablet in the palace ruins supported Oppenheim's hypothesis. The inscription on the face of the tablet turned out to be a list of 48 animals. The hollow tablet rattled, and when one end of it was carefully opened, 48 tokens were found inside. Presumably the combination of a written list and countable tokens represented a transfer of animals from one palace service to another. Unfortunately we have no accurate description of the tokens; they were subsequently lost.

The Nuzi archives are dated to about 1500 B.C. The great Elamite site, Susa, has levels that are more than 1,500 years older. The digging at Susa, undertaken by French investigators, began in the 1880's and continues to this day. Six years after Oppenheim's 1958 report Pierre Amiet of the Musée du Louvre was able to confirm the existence of a similar accounting system at Susa. The token containers at Susa, unlike the container from Nuzi, were hollow clay spheres. Amiet called them "bullae"; so far about 70 of them have been found. The tokens they contain are clay modeled in a variety of geometric forms, including spheres, disks, cylinders, cones and tetrahedrons.

Amiet's finding was one of great significance; not only did it demonstrate that bullae and tokens were in existence at least a millennium and a half before they appeared at Nuzi but also it showed that they were as old or older than the earliest written records at Uruk. Indeed, it later became clear that the tokens, at least, were very much older.

In 1969 I began a research project

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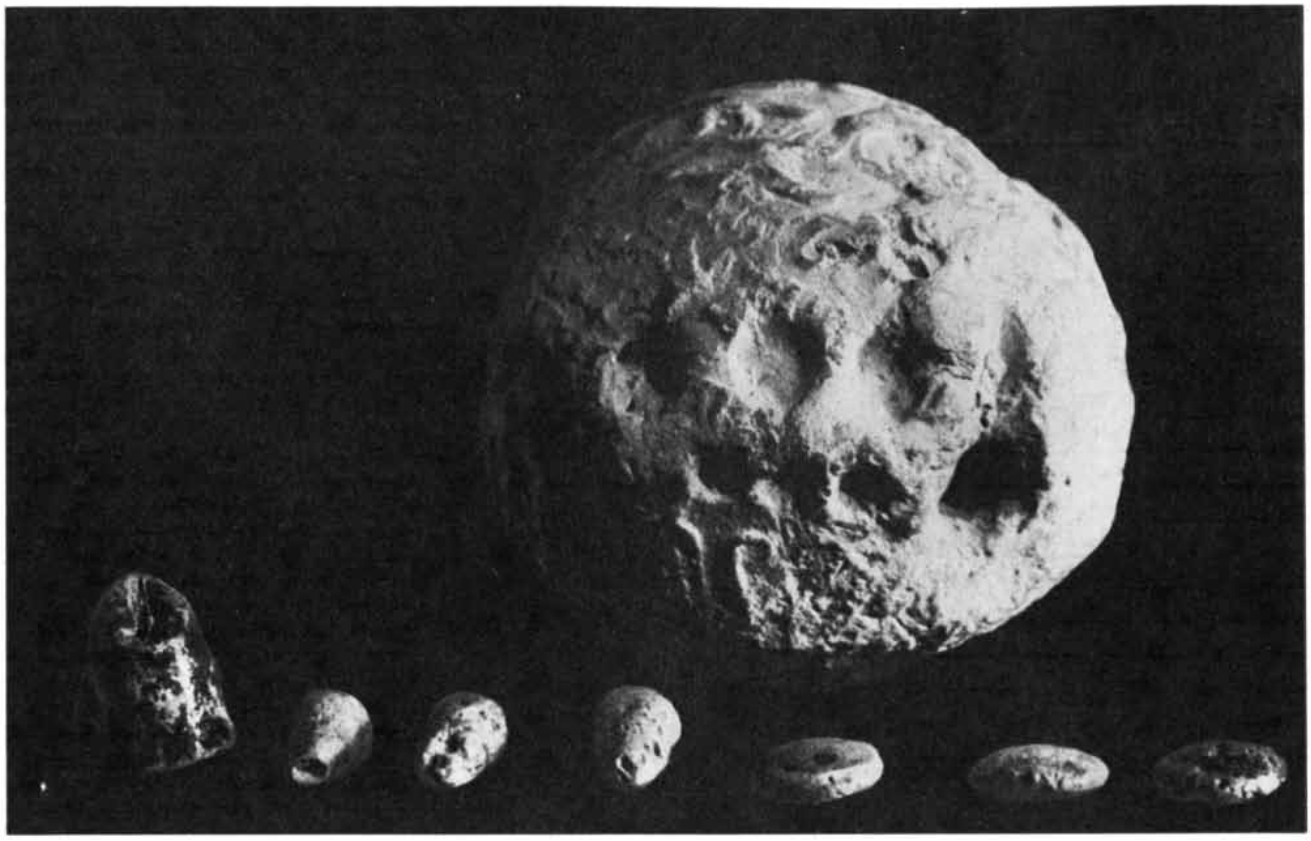

BULLA FROM SUSA shows two rows of surface impressions that match in number and shape the tokens it contained (*foreground*): one large cone, three small cones (*bottom row*) and three disks (*top row*). Tablets with incised representations of tokens probably evolved next.

with the objective of discovering when and in what ways clay first came to be used in the Near East. The making of pottery is of course the most familiar use of clay, but before the appearance of pottery man was making clay beads, modeling clay figurines, molding bricks out of clay and using clay for mortar. As a start on my project I visited museums in the U.S., in Europe and in various Near Eastern cities that had collections of clay artifacts dating back to the seventh, eighth and ninth millenniums B.C. This interval of time, beginning around 11,000 years ago and ending a little more than 8,000 years ago, saw the firm establishment of the first farming settlements in western Asia.

In the museum collections, along with the beads, bricks and figurines I had expected to find, I encountered what was to me an unforeseen category of objects: small clay artifacts of various forms. As I later came to realize, the forms were like those Amiet had found inside his Susa bullae: spheres, disks, cones, tetrahedrons, ovoids, triangles (or crescents), biconoids (double cones joined at the base), rectangles and other odd shapes difficult to describe. Could these artifacts, some of them 5,000 years older than the tokens from Susa, also have served as tokens?

I began to compile my own master catalogue of these oddities, listing each token that was known to have come from a specific site. In summary, I found that whereas all of them were small, measuring on the average from one centimeter to two centimeters in their greatest dimension, many were of two distinct sizes. For example, there were small cones about a centimeter high and large cones three to four centimeters high. There were also thin disks, only three millimeters thick, and thick ones, as much as two centimeters thick. Other variations were evident. For example, in addition to whole spheres I found quarter-, half- and three-quarter spheres. Some of the tokens had additional features. Many were incised with deep lines; some had small clay pellets or coils on them and others bore shallow circular punch marks.

The tokens had all been modeled by hand. Either a small lump of clay had been rolled between the palms of the hands or the lump had been pinched between the fingertips. The clay was of a fine texture but showed no sign of special preparation (such as the addition of tempering substances, a practice in pottery making that enhances hardness after firing). All the tokens had, however, been fired to ensure their durability. Most of them varied in color from buff to red, but some had become gray and even blackish.

I found that the tokens were present in virtually all museum collections of artifacts from the Neolithic period in western Asia. An extreme example of abundance is provided by the early village site of Jarmo in Iraq, first occupied some 8,500 years ago. Jarmo has yielded a total of 1,153 spheres, 206 disks and 106 cones. Reports generally indicate that the excavators found the tokens scattered over the floors of houses located in various parts of a site. If the tokens had once been kept in containers, such as baskets or pouches, these had disintegrated long ago. Nevertheless, there is evidence suggesting that the tokens were segregated from other artifacts and even implying what their function was. The reports indicate that many were found in clusters numbering 15 or more and that the clusters were located in storage areas within the houses.

As I reviewed the museum collections and the related site reports I became increasingly puzzled by the apparent omnipresence of the tokens. They had been found in sites from as far west as Beldibi in what is now southwestern Turkey to as far east as Chanhu Daro in what is now Pakistan. Tokens had even been unearthed at an eighth-millennium-B.C. site on the Nile near Khartoum.

At the same time I found that some site reports failed to take note of the tokens that had been collected, or men-

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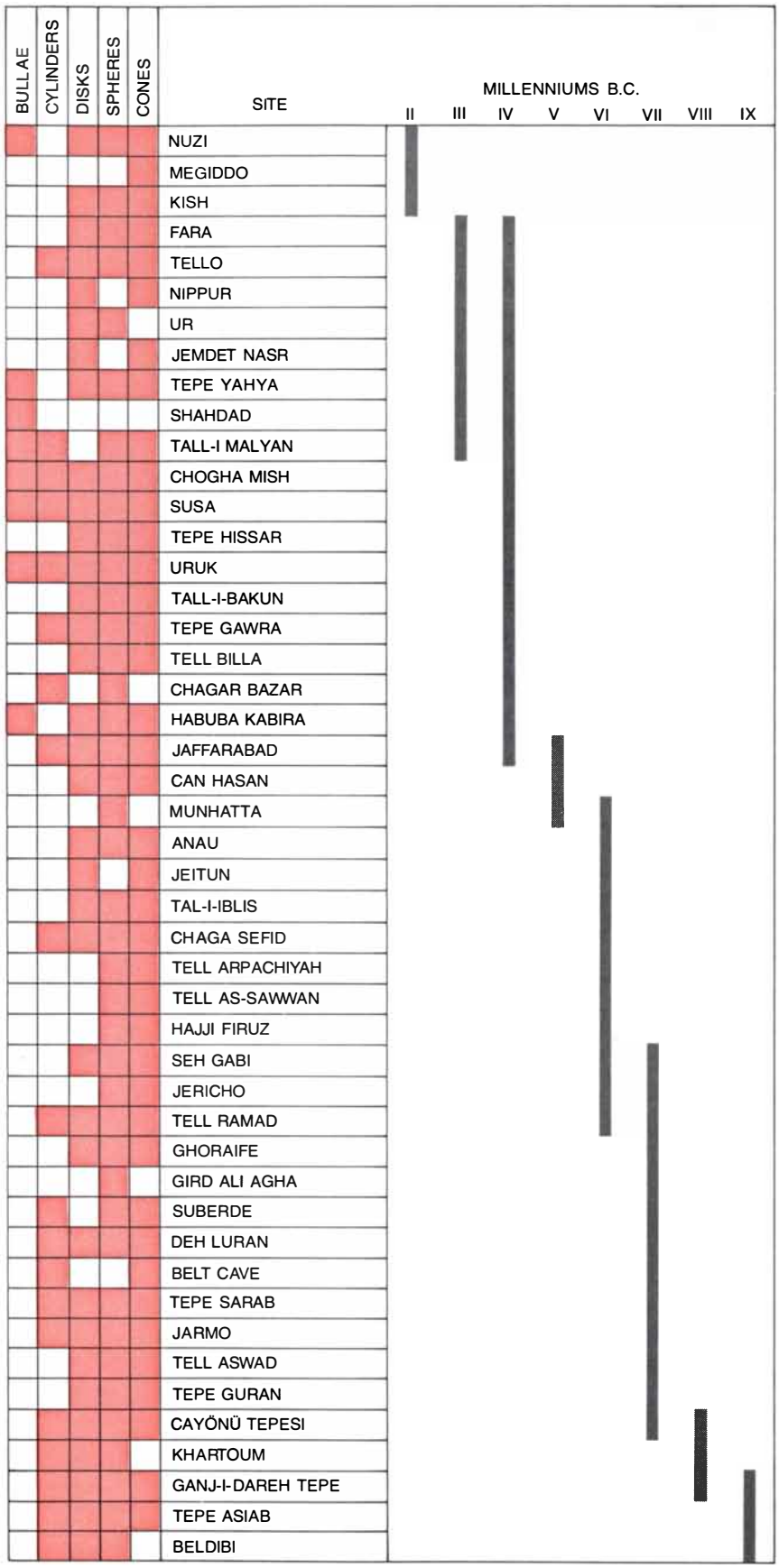

SITES WHERE TOKENS APPEAR represent a span of time from the ninth millennium B.C. to the second. As many as 20 variations on four basic token shapes are present at the earliest sites. Clay envelopes as containers for tokens do not appear before the fourth millennium B.C.

tioned them only casually. When the tokens were noted, the heading might read "objects of uncertain purpose," "children's playthings," "game pieces" or "amulets." As an example, the tokens from Tello in Iraq were interpreted by their discoverer, Henri de Genouillac, as amulets that expressed the residents' desire for "personal identification." Another example appears in Carleton S. Coon's report on Belt Cave in Iran: "From levels 11 and 12 come five mysterious . . . clay objects, looking like nothing in the world but suppositories. What they were used for is anyone's guess."

The realization that the tokens were all artifacts of the same kind was also hampered because, when they were listed at all in the site reports, they usually appeared under not one heading but several headings depending on their shape. For example, cones have been described as schematic female figurines, as phallic symbols, as gaming pieces and as nails, and spheres were mostly interpreted as marbles or as sling missiles.

Having studied at the École du Louvre, I was familiar with the work of Amiet. Nevertheless, I had compiled a catalogue of hundreds of tokens before I at last realized how much like Amiet's tokens from Susa these far earlier clay artifacts were. At first it seemed impossible that the two groups could be related; a minimum of 5,000 years separated the tokens of Neolithic times from those of Bronze Age Susa. As I extended my investigations to include later clay artifacts, dating from the seventh millennium B.C. to the fourth millennium and later, I found to my surprise that similar clay tokens had been found in substantial numbers at sites representative of the entire time span. Evidently a system of accounting that made use of tokens was widely used not only at Nuzi and Susa but throughout western Asia from as long ago as the ninth millennium B.C. to as recently as the second millennium.

The system appears to have been much the same as many other early, and even not so early, methods of account keeping. Classical scholars are familiar with the Roman system of making "calculations" with pebbles (*calculi* in Latin). Up to the end of the 18th century the British treasury still worked with counters to calculate taxes. For that matter, the shepherds of Iraq to this day use pebbles to account for the animals in their flocks, and the abacus is still the standard calculator in the markets of Asia. The archaic token system of western Asia was if anything only somewhat more complex than its later counterparts.

Considered overall, the system had some 15 major classes of tokens, further divided into some 200 subclasses on the basis of size, marking or fractional vari-

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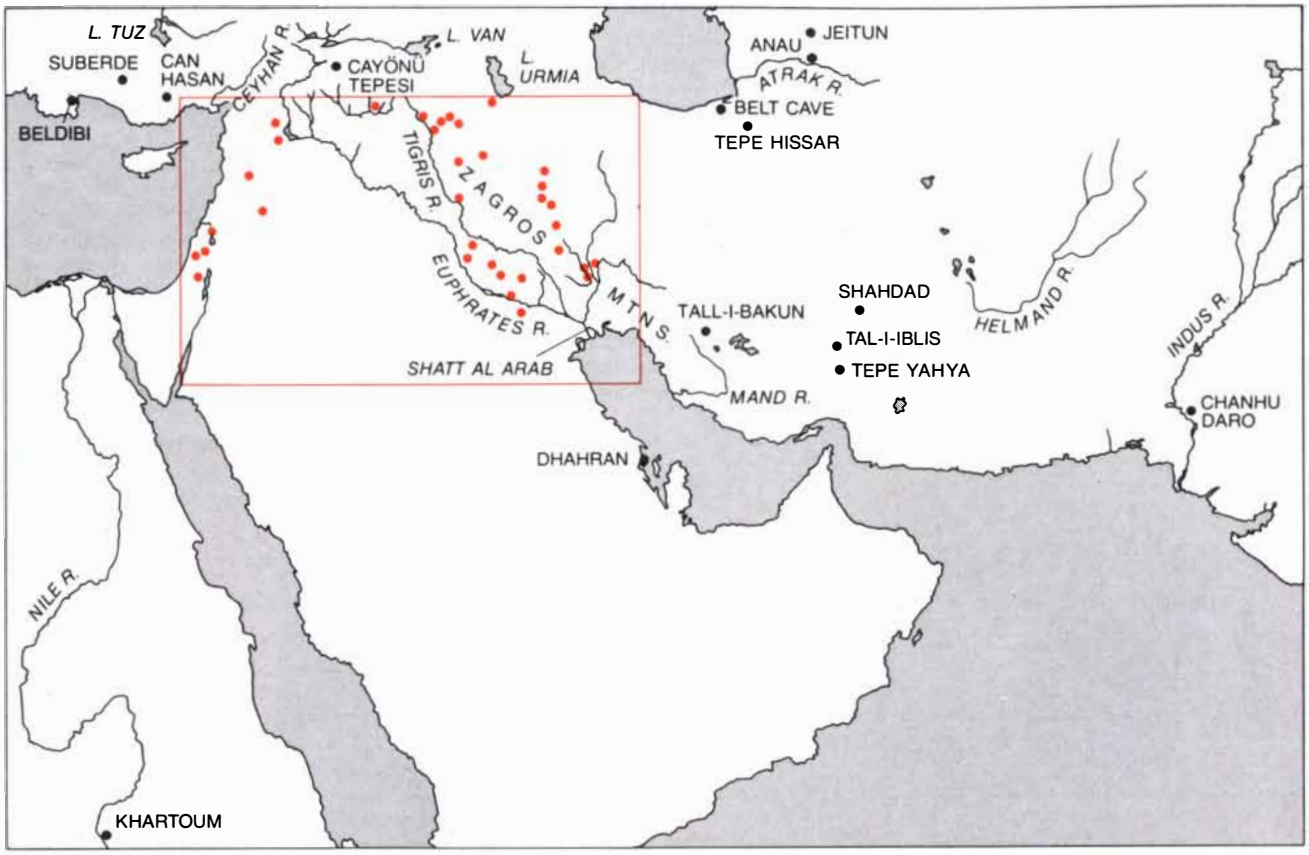
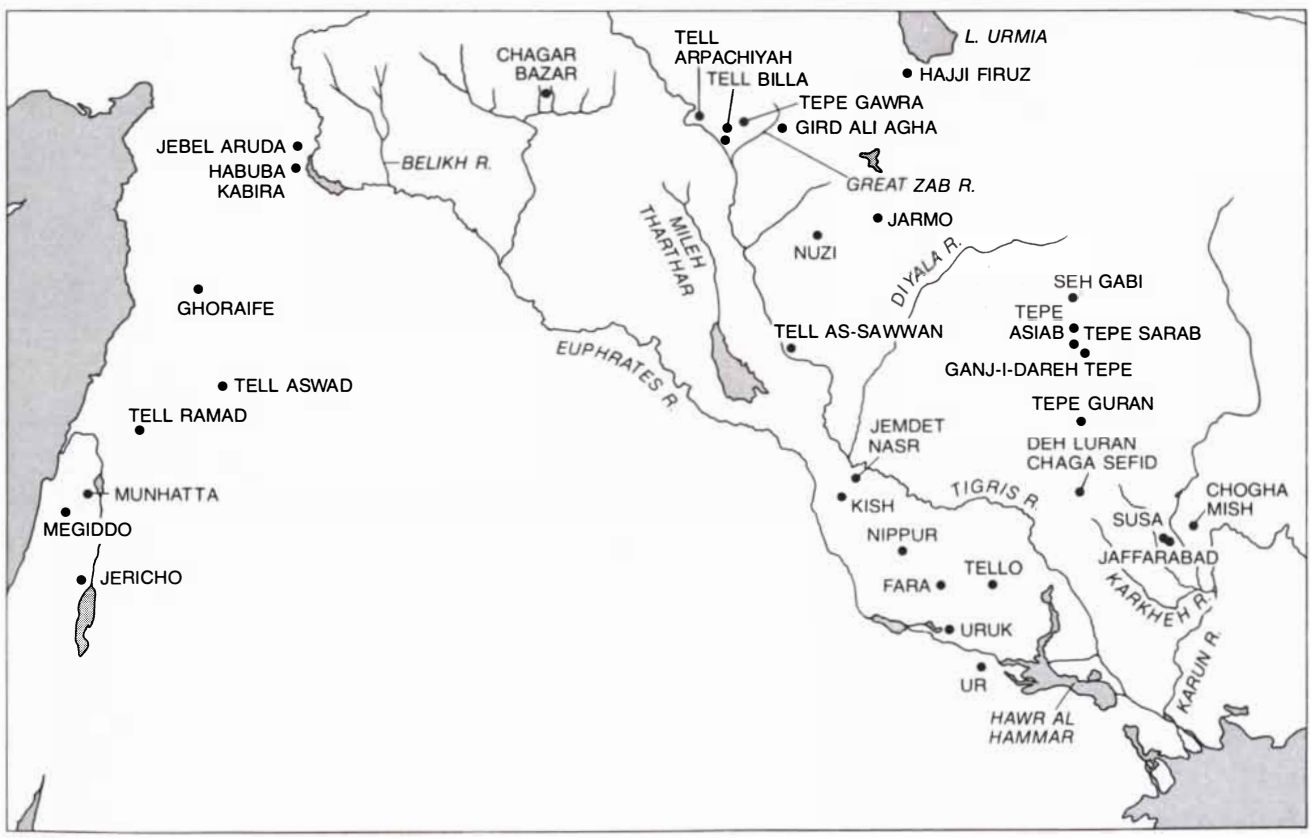


GEOGRAPHICAL DISTRIBUTION of tokens extends from as far north as the Caspian border of Iran to as far south as Khartoum and from Asia Minor eastward to the Indus Valley. Sites identified only by dots (*color*) within a rectangle here are named in the map below.



CLUSTERING OF SITES in the drainage of the upper and lower Tigris and the lower Euphrates and in the Zagros region of Iran is more a reflection of the availability of study collections than a measure of the actual extent and frequency of token use in the area.

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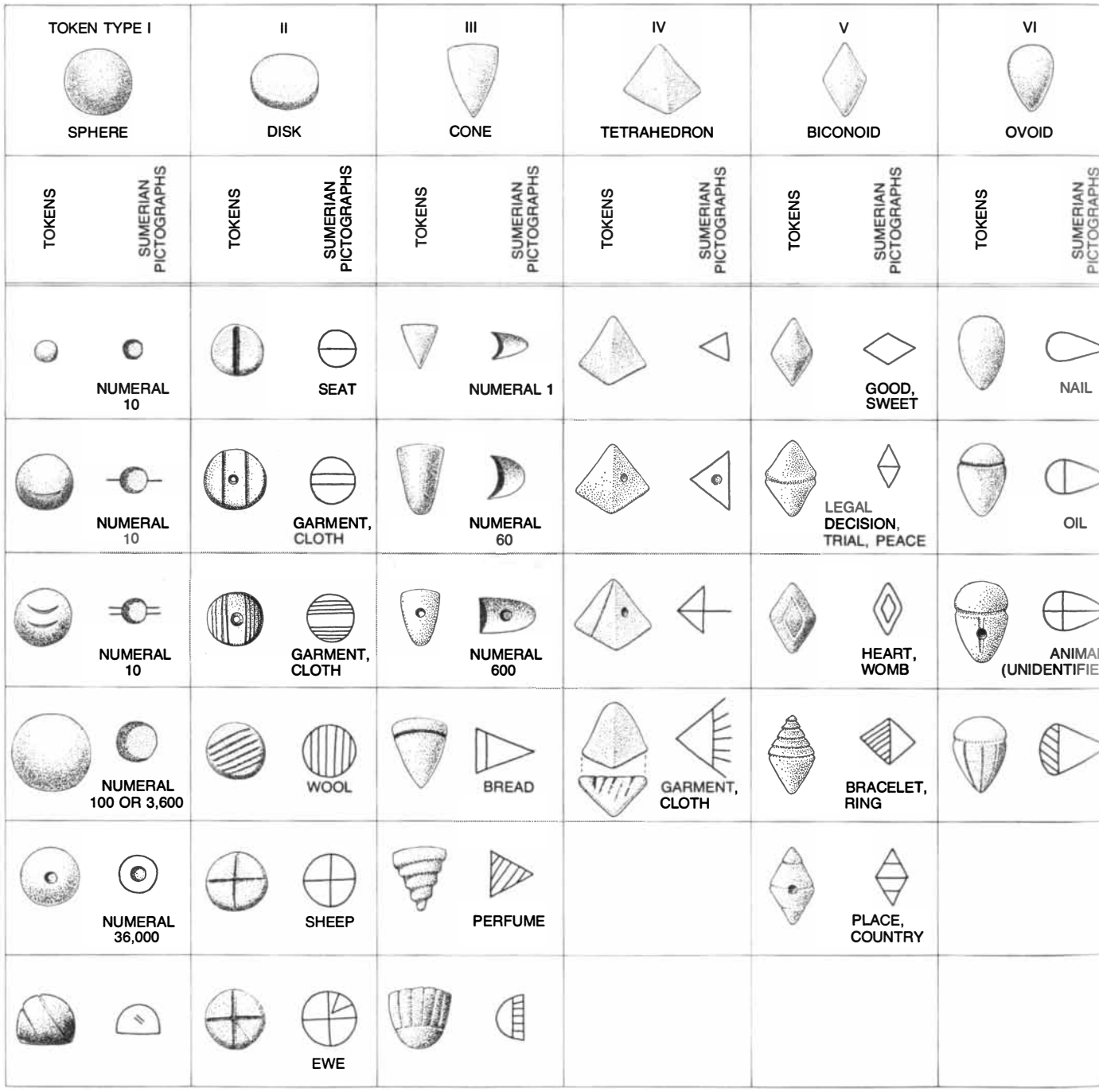
ation, as in the case of the quarter-, half- and three-quarter spheres. Evidently each particular shape had a meaning of its own; a few appear to represent numerical values and others specific objects, commodities in particular.

It is not necessary to theorize about some of these meanings; a number of ideographs on the Uruk tablets almost exactly reproduce in two dimensions many of the tokens. For example, Uruk arbitrary signs for numerals, such as a small cone-shaped impression for the number one, a circular impression for the number 10 and a larger cone-shaped impression for the number 60 are matched by tokens: small cones, spheres and large cones. Further examples of ideographs that match tokens include, under the general heading of commodities, the Uruk symbol for sheep (a circle enclosing a cross), matched by disk-shaped tokens incised with a cross, and the Uruk symbol for a garment (a circle enclosing four parallel lines), matched by disk-shaped tokens incised with four parallel lines. Still other examples are ideographs for metal and oil and more clearly pictographic symbols for cattle, dogs and what are evidently vessels; each tablet sign can be matched with a similarly shaped and marked token. In addition, the forms of many still unread Sumerian ideographs appear to match other tokens.

Why did such a repertory of three-dimensional symbols come into existence? It cannot simply be a coincidence that the first tokens appear early in the Neolithic period, a time of profound change in human society. It was then that an earlier subsistence pattern, based on hunting and gathering, was transformed by the impact of plant and animal domestication and the development of a farming way of life. The new agricultural economy, although it un-



FIFTY-TWO TOKENS, representative of 12 major categories of token types, have been matched here with incised characters that appear in the earliest Sumerian inscriptions. Most of the inscriptions cannot be read. Here, if the meaning of the symbol is known, the

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doubtedly increased the production of food, would have been accompanied by new problems.

Perhaps the most crucial would have been food storage. Some portion of each annual yield had to be allocated for the farm family's own subsistence and some portion had to be set aside as seed for the next year's crop. Still another portion could have been reserved for barter with those who were ready to provide exotic products and raw materials in exchange for foodstuffs. It seems possible that the need to keep track of such allocations and transactions was enough to stimulate development of a recording system.

The earliest tokens now known are those from two sites in the Zagros region of Iran: Tepe Asiab and Ganj-i-Dareh Tepe. The people of both communities seem to have tended flocks and were possibly experimenting with crops around 8500 B.C., although at the same time they continued to hunt game and gather wild plants. The clay tokens they made were quite sophisticated in form. There were four basic types of token: spheres, disks, cones and cylinders. In addition there were tetrahedrons, ovoids, triangles, rectangles, bent coils and schematic animal forms. Subtypes included half-spheres and cones, spheres and disks with incisions and with punch marks. The set totaled 20 individual symbols.

The Neolithic period and the succeeding Chalcolithic period, or Copper Age, in western Asia lasted about 5,000 years. Over this substantial span one finds surprisingly few changes in the tokens, a fact that may indicate how well suited to the needs of an early agricultural economy this recording system was. In about 6500 B.C., 2,000 years after the rise of the first Zagros farming communities, another Iranian village, Tepe Sarab, began to flourish. The token inventory from excavations at Tepe

equivalent word in English appears. The Sumerian numerical symbols equated with the various spherical and conical tokens are actual impressions in the surface of the tablet. In two instances (*sphere*) incised lines are added; in a third (*cone*) a circular punch mark is added.

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Sarab shows no increase in the number of main types and an increase in subtypes from 20 only to 28, among them a four-sided pyramid and a stylized ox skull that is probably representative of cattle.

Perhaps it was during the Chalcolithic period that the agricultural surpluses of individual community members came to be pooled by means of taxes in kind, with the supervision of the surplus put into the hands of public officials such as temple attendants. If that is the case, the need to keep track of individual contributions evidently failed to bring any significant modification in the recording system. The tokens unearthed at four sites that flourished between 5500 and 4500 B.C.—Tell Arpachiyah and Tell as-Sawwan in Iraq and Chaga Sefid and Jaffarabad in Iran—reflect no more than minor developments. A new type of token, the biconoid, appears, and among some of the subtypes painted black lines and dots have taken the place of incisions and punch marks.

Early in the Bronze Age, between 3500 and 3100 B.C., there were significant changes in the recording system. This period saw an economic advance quite as remarkable in its own way as the rise of the farming economy that laid the foundation for it. The new development was the emergence of cities. Surveys of ancient sites in western Asia indicate a drastic increase in the population of Iraq and Iran; urban centers with many inhabitants begin to appear close to the earlier village settlements.

Craft specialization and the beginnings of mass production appear at this time. The bronze smithies and their products gave the age its name, but craftsmen other than smiths also arose, concentrated in various areas. The invention of the potter's wheel allowed the development of a pottery industry, and the output of various mass-production kilns came to be distributed over great distances. A similar trend is apparent in the manufacture of stone vessels, and the development of an expanded trade network is indicated by the appearance in Iraq of such exotic materials as lapis lazuli.

The development of an urban economy, rooted in trade, must have multiplied the demands on the traditional recording system. Not only production but also inventories, shipments and wage payments had to be noted, and merchants needed to preserve records of their transactions. By the last century of the fourth millennium B.C. the pressure of complex business accountancy on the token system becomes apparent both in the symbols and in how the tokens were used.

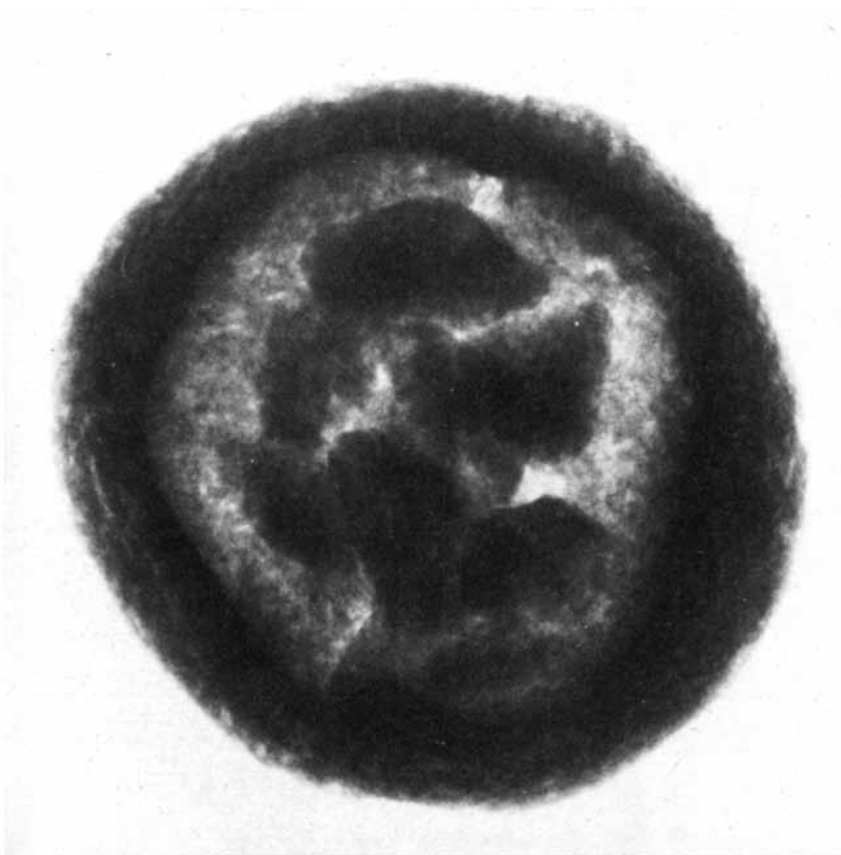
To consider the symbols first, six sites of the late fourth millennium B.C. in Iraq (Uruk, Tello and Fara), in Iran (Susa and Chogha Mish) and in Syria (Habuba Kabira) have yielded tokens representative of the full range of early shapes. In addition, some new shapes appear, among them parabolas, rhomboids and replicas of vessels. Even more significant than the appearance of new shapes, however, is the great proliferation of subtypes indicated by a variety of incised markings on the tokens. It is also now that a few of the tokens begin to have appliqué markings: added pellets or coils of clay.

The six sites have yielded a total of 660 tokens dating to about 3100 B.C. Of this number 363, or 55 percent, are marked with incisions. Most of the incisions are deep grooves made with the pointed end of a stylus; the grooves are placed conspicuously and with a clear concern for symmetry. On rounded tokens such as spheres, cones, ovoids and cylinders the incisions usually run around the equator and are thus visible from any aspect. On flat tokens such as disks, triangles and rectangles the incisions appear only on one face.

Most of the incisions present a pattern of parallel lines, although incised crosses and crisscross patterns are also found. The number of parallel lines would not seem to be random: there can be as many as 10 incisions, and the frequency of one-stroke, two-stroke, three-stroke and five-stroke patterns is conspicuous. It is noteworthy that with the exception of two-stroke patterns odd-numbered patterns are the most frequent.

Although incised patterns are by far the most abundant, 26 of the tokens (some 4 percent of the total) show circular impressions apparently made by punching the clay with the blunt end of a stylus. Some of the punched tokens bear a single impression. Others show a cluster of six punches, arranged either in a single row or in two rows with three impressions each.

As for changes in how the tokens were used, it is significant that 198 of them, or 30 percent of the total, are perforated. The perforated tokens run the gamut of types and include subtypes of the unmarked, incised and punched variety. In effect this means that tokens of any type or subtype were available in both unperforated and perforated forms. The perforations are so small that only a thin string could have passed through them. Of the explanations that come to mind one is that all 15 types of tokens and their 250 subtypes are nothing more than individual amulets that the early Bronze Age urban folk of western Asia wore on strings around their neck or wrist. I reject this explanation on two grounds. First, none of the perforated tokens that I have examined shows any evidence of being used as an amulet, such as wear polish or erosion around



X RAY OF UNOPENED BULLA reveals tokens, some apparently cones and others ovoids. Age of the bulla is unknown; it was an isolated surface find near Dhahran in Saudi Arabia.

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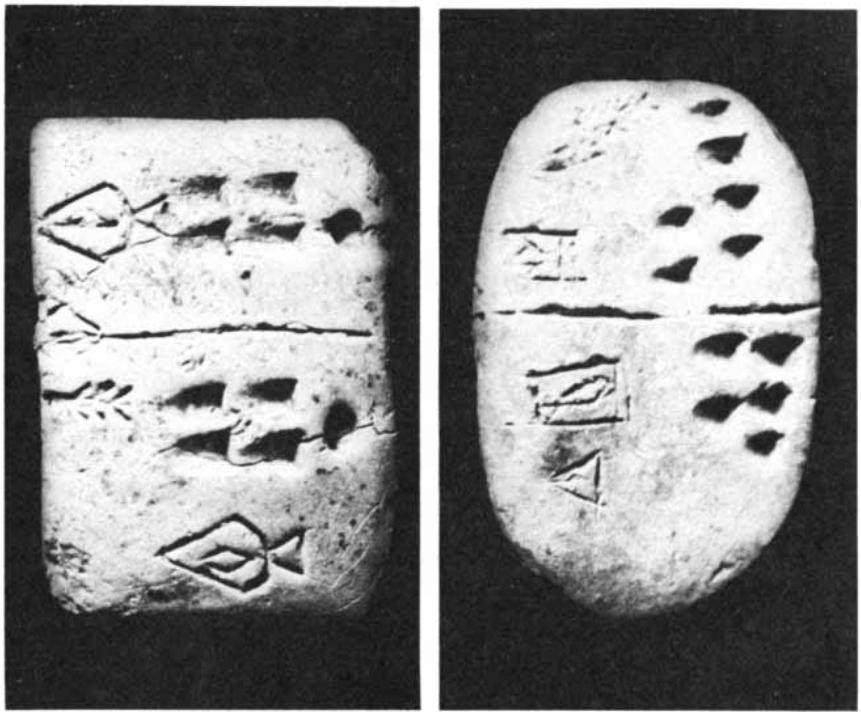
the string hole. Second, it seems preposterous that such a complex repertory of forms, so widespread in geographical distribution and manufactured with such remarkable uniformity, should have served as personal adornment in 30 percent of the cases and for some other purpose in the remaining 70 percent.

I prefer the hypothesis that some tokens representative of a specific transaction were strung together as a record. It seems at least plausible that the complexity of record keeping in an urban economy might have given rise to duplicate tokens suitable for stringing.

The stringing of tokens, if that is what the perforated tokens imply, would be only one change in how these symbolic bits of clay were used at the end of the fourth millennium B.C. A much more significant change is the first appearance at this time of clay bullae, or envelopes, such as those Amiet found as containers of tokens at Susa. The existence of a bulla is clear-cut direct evidence of the user's desire to segregate the tokens representing one or another transaction. The envelope could easily be made by pressing the fingers into a lump of clay about the size of a tennis ball, creating a cavity large enough to hold several tokens; the envelope could then be sealed with a patch of clay.

There is no doubt in my mind that such bullae were invented to provide the parties to a transaction with the kind of smooth clay surface that according to Sumerian custom could be marked by the personal seals of the individuals concerned as a validation of the event. The fact that most of the 350 bullae so far discovered bear the impressions of two different seals lends support to my conviction. Amiet has suggested that the Susa bullae may have served as bills of lading. In this view a rural producer of, say, textiles would consign a shipment of goods to an urban middleman, sending along with the shipment a bulla that contained a number of tokens descriptive of the kind and quantity of merchandise shipped. By breaking the bulla the recipient of the shipment could verify the makeup of the shipment; moreover, the need to deliver an intact bulla would inhibit the carrier from tampering with the merchandise in transit. This sealed transfer of tokens between trade partners represents an entirely new way of using the ancient recording system.

The innovation had one serious drawback. The seals impressed on the smooth exterior of the bulla served to validate each transmission, but if the seal impressions were to be preserved, the bulla had to remain intact. How, then, could one determine what tokens were enclosed and how many? A solution to the problem was soon found. The surface of the bulla was marked so that in addition to the validating seal impressions, it bore images of all the enclosed tokens.



TABLETS FROM URUK show the convex shape that may reflect their evolution from hollow bullae. Impressions represent numerals. Tablets are in the Pergamon Museum in Berlin.

The most striking example of this stratagem is a bulla that proved to contain six grooved ovoid tokens. Each of the six tokens had been pressed into the surface of the bulla before being stored inside it; they fit the surface imprints exactly. This means of recording the contents of a bulla on its exterior was not, however, universally practiced. On most bullae the impression was made with a thumb or a stylus; a circular impression stood for a sphere or a disk, a semicircular or triangular impression stood for a cone, and so forth.

The bulla markings were clearly not invented to take the place of the token system of record keeping. Nevertheless, that is what happened. One can visualize the process. At first the innovation flourished because of its convenience; anyone could "read" what tokens a bulla contained and how many without destroying the envelope and its seal impressions. What then happened was virtually inevitable, and the substitution of two-dimensional portrayals of the tokens for the tokens themselves would seem to have been the crucial link between the archaic recording system and writing. The hollow bullae with their enclosed tokens would have been replaced by inscribed solid clay objects: tablets. The strings, baskets and shelf loads of tokens in the archives would have given way to representative signs inscribed on tablets, that is, to written records.

The convex profile of the early Uruk tablets may well be a morphological feature inherited from the spherical bullae. Much the same may be true of the selection as a writing surface of a material as unsuitable as clay, a soft and easily smeared medium that must be dried or baked if it is to be preserved. There can be little doubt about the relation between the shapes and markings of the tokens and the supposed arbitrary forms of many Uruk ideographs. No fewer than 33 clear-cut identities exist between the ideographs and two-dimensional representations of tokens and more than twice that many are possible.

To summarize, the earliest examples of writing in Mesopotamia may not, as many have assumed, be the result of pure invention. Instead they appear to be a novel application late in the fourth millennium B.C. of a recording system that was indigenous to western Asia from early Neolithic times onward. In this view the appearance of writing in Mesopotamia represents a logical step in the evolution of a system of record keeping that originated some 11,000 years ago.

On this hypothesis the fact that the system was used without significant modification until late in the fourth millennium B.C. seems attributable to the comparatively simple record-keeping requirements of the preceding 5,000 years. With the rise of cities and the development of large-scale trade the system was pushed onto a new track. Images of the tokens soon supplanted the tokens themselves, and the evolution of symbolic objects into ideographs led to the rapid adoption of writing all across western Asia.

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Exotic Light Nuclei

Among the light elements nuclei with unequal numbers of protons and neutrons are highly unstable. Some survive just long enough to be detected and exhibit unusual regimes of radioactive decay

by Joseph Cerny and Arthur M. Poskanzer

In principle, protons and neutrons can be brought together in a great many combinations to form atomic nuclei. The nuclei representing the majority of these combinations, however, do not exist; even if they could be created they would decay too quickly to be observed directly. Altogether some 8,000 nuclei are thought to be capable of surviving long enough that they can be said to exist. Of these about 300 are stable indefinitely, and they are therefore by far the commonest nuclei in nature. Another 1,600 nuclei are known that are not stable but decay by the various processes grouped under the term radioactivity. That leaves some 6,000 nuclei that should exist but that have not yet been discovered.

The nuclei that have been investigated most completely are those of the lightest elements, the first 20 or so in the periodic table. Stable nuclei in this region have roughly equal numbers of protons and neutrons, and as a rule the further a nucleus departs from this ratio of equality the shorter its lifetime becomes. Those that are very far from stability have been called exotic light nuclei.

Such exotic nuclei are not observed among the natural elements on the earth today; their lifetimes are in many cases less than a second and some are much less. The exotic nuclei must be created in the laboratory by bombarding stable nuclei with accelerated protons or with heavier projectiles. Even then the short lifetimes hamper the experimental investigation, since all the information that can be obtained about an exotic nucleus must be gathered in the few moments that elapse between its creation and its disintegration.

Among the 20 lightest elements (up to calcium in the periodic table) some 200 nuclear species have been identified, of which perhaps 40 percent could be considered exotic. Theoretical calculations suggest that there should be about 110 other isotopes of elements in this region that are even further from stability. Extreme ratios of protons to neutrons are most easily achieved in light nuclei, simply because a given ratio requires a smaller numerical excess. For this reason the light elements provide an excellent opportunity for exploring the properties of exotic nuclei, many of which should have unusual sizes, shapes and spectra of energy levels. Many of them also exhibit unusual modes of radioactive decay, and the investigation of those decays is under way.

In order to identify a nucleus it is necessary to specify both the number of protons and the number of neutrons. By convention that is usually done by stating the number of protons (the atomic number) and also giving the sum of the proton and neutron numbers, a quantity called the mass number. When these numbers are written with the symbol for a chemical element the mass number appears as a superscript and the proton number as a subscript. (The proton number is often omitted since each element corresponds to a unique proton number.) Thus a nucleus of boron with five protons and five neutrons is denoted by the symbol $^{10}_{5}B$.

The proton and the neutron differ principally in their electrical properties: the proton carries a positive electric charge of one unit and the neutron is electrically neutral. The two kinds of particle are collectively called nucleons. Because the proton number determines the electric charge of the nucleus it also controls the configuration of the electron cloud surrounding the nucleus and hence the chemical properties of the atom. The proton number alone therefore determines the identity of the elements. A nucleus with five protons is a boron nucleus no matter how many neutrons it includes. Nuclei with the same number of protons but different numbers of neutrons (and hence different mass numbers) are isotopes. The search for exotic light nuclei is essentially a search for the lightest and the heaviest isotopes of those elements that have proton numbers ranging from one to about 20.

Nuclei can exist only because a tightly bound aggregate of several nucleons can have a lower mass than the total mass of the same nucleons when they are all considered in isolation. The small "missing" mass, or mass defect, is the binding energy with which the nucleons are held together. Like the electrons in an atom, the nucleons in a nucleus can be regarded as occupying discrete and well-defined energy levels. The lowest level can accommodate two nucleons, and as additional particles are added they must be allotted to levels of progressively higher energy. An important feature of this energy structure is that the levels for protons and those for neutrons can be considered independently. Thus in the helium-4 nucleus ($^{4}_{2}He$) the two protons can occupy their lowest-energy level, and so can the two neutrons. If all four were protons, then two would have to occupy a higher energy level, resulting in a nucleus with a larger mass. Thus, among the light nuclei those with equal numbers of protons and neutrons tend to be the most stable.

If the balance of proton and neutron numbers were the only influence on

CHART OF THE NUCLIDES lying on its side on the opposite page arranges nuclei according to their composition; each square represents a unique combination of protons and neutrons. The color of the upper left half of the square indicates by what method a nuclide was shown to exist; the color of the lower right half indicates by what method its decay was observed. Among the light elements (the first 22 are shown here) the stablest nuclei tend to have roughly equal numbers of protons and neutrons. The exotic nuclei are those that depart substantially from that ratio. They include both neutron-rich species, along the right-hand edge of the sequence, and neutron-deficient ones, along the left-hand edge. Nuclides with labels inside their square have been discovered since 1961, when one of the comprehensive charts of nuclides was made.

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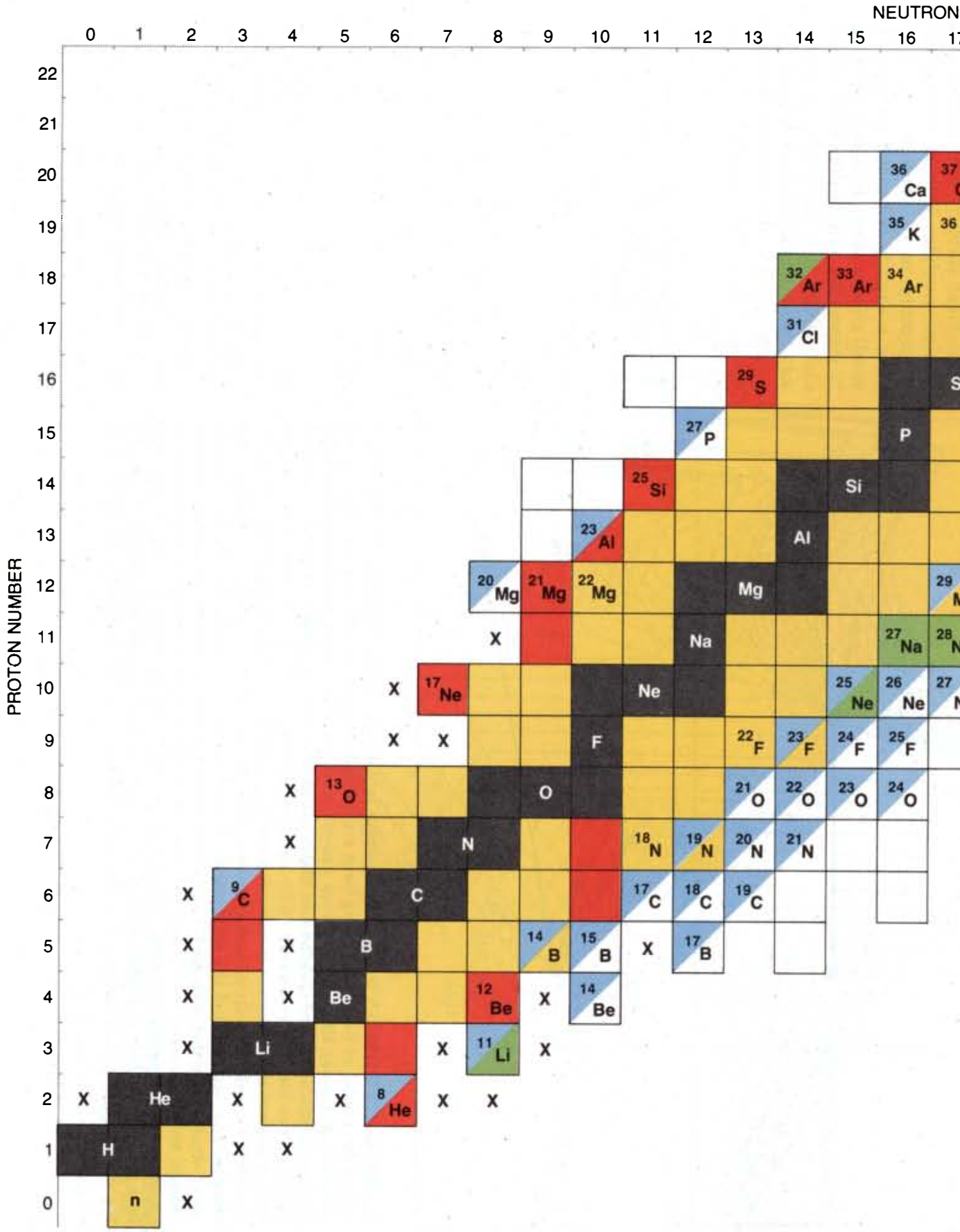

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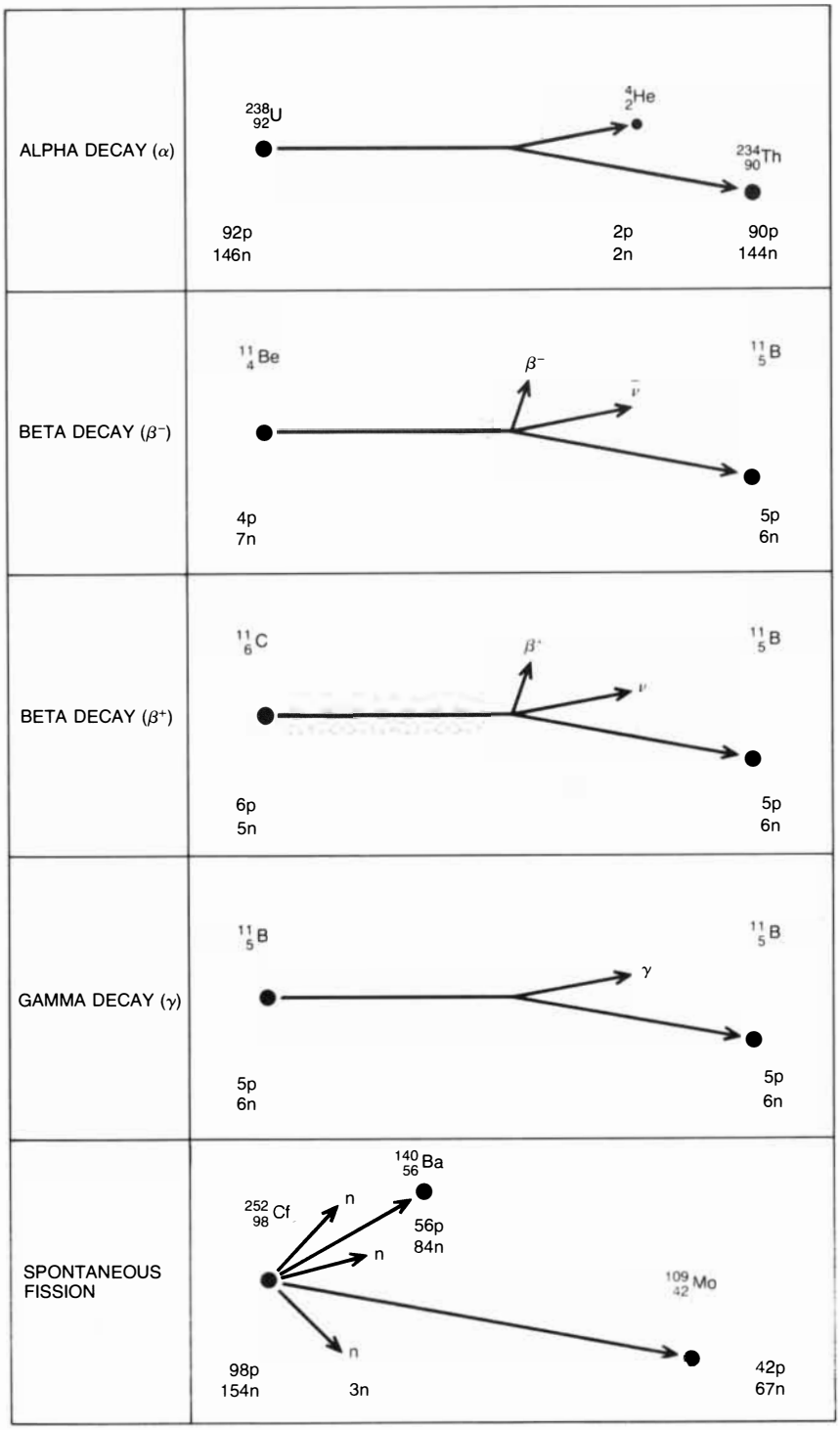

RADIOACTIVE DECAY transforms a nucleus into a more stable configuration of lower energy. Four modes of decay have long been recognized: alpha, beta and gamma emission and spontaneous fission; all of these except gamma emission convert one chemical element into another. Alpha decay and spontaneous fission are predominantly found in the heavy elements. There are two kinds of beta decay. In β^- emission an electron and an antineutrino are emitted when a neutron in the nucleus is converted into a proton; in β^+ decay the emitted particles are a positron (a positive electron) and a neutrino when a proton in the nucleus is converted into a neutron. The neutrino and the antineutrino are massless neutral particles with an extraordinarily weak interaction with nuclei. In gamma decay the composition of the nucleus does not change; only the energy level is affected. The emitted gamma ray is a high-energy photon, or quantum of electromagnetic energy. Some exotic nuclei have modes of decay more complicated than those shown here. A feature of all decays is that the total mass of the products is less than the mass of the parent nucleus; it is this reduction in mass that makes the decay possible.

nuclear stability, then all stable nuclei would have roughly equal numbers of protons and neutrons. In fact there is another factor, which becomes more important as the proton number increases: the growing electrostatic repulsion between protons also diminishes the binding energy of the nucleus. As a result, very heavy nuclei tend to be most stable when they have an excess of neutrons; the longest-lived isotope of uranium, for example, $^{238}_{92}U$, has about 1.6 times as many neutrons as protons.

The relative stability of the nuclides can readily be perceived in a graph that presents the mass defect per nucleon for each of the nuclides. Those nuclei with the largest mass defect, and hence those with the greatest binding energy, form a "valley of stability." Among the light elements the valley runs through those nuclides with roughly equal numbers of protons and neutrons; then among the heavier ones it bends toward nuclear species that are progressively richer in neutrons. On each side of the valley the less stable nuclei have a smaller mass defect and form steep slopes. The exotic nuclei occupy the upper slopes on both the neutron-rich and the neutron-deficient sides of the valley.

The ratio of protons to neutrons and the absolute number of protons determine the major features of the valley of stability, but there is one other influence on nuclear stability that cannot be neglected: nuclides with an even number of protons or of neutrons or of both have a slightly enhanced stability. The small enhancement becomes particularly important among the exotic light nuclei, where it is sometimes possible to add two nucleons to a nucleus to create a new species, although the intermediate nuclide with one extra nucleon does not exist.

It should also be pointed out that all the nucleons do not always occupy the lowest possible energy levels. When a nucleon or several nucleons have been promoted to a higher energy level, the nucleus is said to be in an excited state. The excited state must of course have the same complement of protons and neutrons as the corresponding ground state, but it may differ in size and shape. The excited state can also differ in angular momentum: each nucleon has an intrinsic spin, equal to 1/2 when measured in natural units, and in the nucleus the nucleons can also have orbital angular momentum, reflecting their state of motion, which must always assume integer values (again in natural units). These quantities must be added or subtracted, depending on the orientation of the momenta, to find the total angular momentum of the nucleus.

Any nuclide that has a small mass defect, or a small binding energy, tends to

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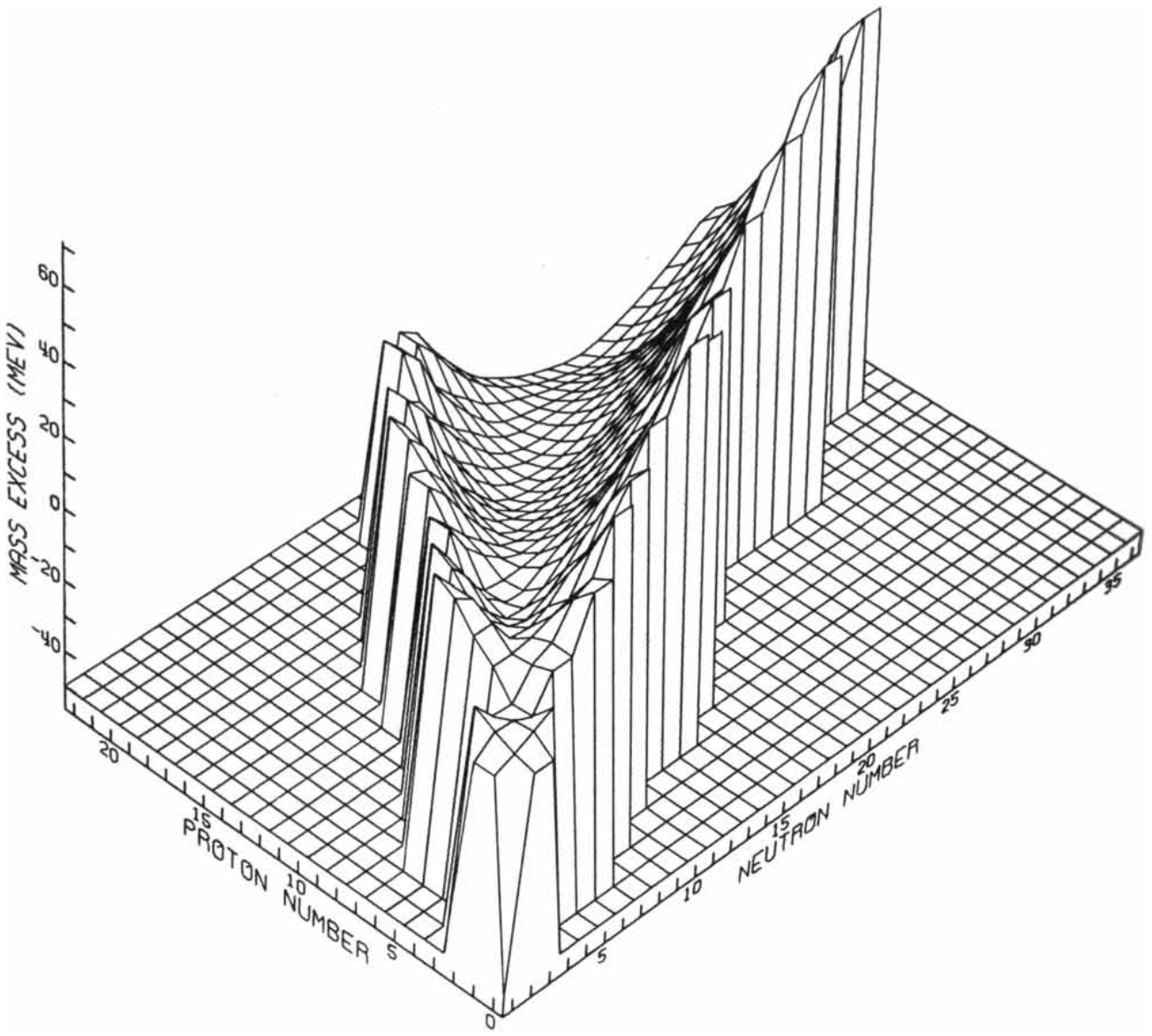
decay to nuclei further down the slope toward stability. Three modes of radioactive decay that transmute one element into another have long been recognized: alpha and beta decay and spontaneous fission. Several additional modes of decay have been observed among the exotic nuclei, and a few more decay schemes have been predicted.

Alpha decay is the emission of a helium nucleus ($^4_2$He). When uranium 238 ejects an alpha particle, the $^{238}_{92}$U is converted to the thorium isotope $^{234}_{90}$Th. The difference between the mass of $^{238}_{92}$U and the combined mass of $^{234}_{90}$Th and $^4_2$He is equivalent to an energy of about four million electron volts (MeV), which appears mainly as the kinetic energy of the alpha particle.

Among the light nuclei the commonest mode of radioactive decay is beta decay, which takes two forms. In β^- decay a neutron in the nucleus is converted to a proton and two particles are emitted: an electron and an antineutrino. In β^+ decay a proton in the nucleus is converted into a neutron and the emitted particles are a positron and a neutrino. In neither case does the total number of nucleons change but the balance of protons and neutrons and the chemical identity of the nuclide are altered. For example, the neutron-deficient carbon isotope $^{11}_6$C decays by β^+ emission; one proton is changed into a neutron, yielding the stable daughter nuclide $^{11}_5$B. In a similar manner $^{11}_4$Be, a neutron-rich beryllium isotope, decays by β^- emission, also yielding $^{11}_5$B.

Spontaneous fission is possible whenever a nucleus can be split into two daughter nuclides that have a smaller total mass than the parent nuclide. Californium 252 can decay by spontaneous fission to yield, for example, a nucleus of molybdenum and a nucleus of barium, usually accompanied by a few free neutrons. The fission products are them-



VALLEY OF STABILITY is occupied by nuclides that have minimal mass and are stable. The valley is mapped by graphing the "mass excess" for each nuclide. The mass excess is related to the negative of the binding energy, with a mass excess of zero assigned to a reference nuclide: the carbon isotope with mass number 12 ($^{12}_6$C). Nuclei on the slopes above the valley can reduce their mass excess by decaying into a more stable nuclide. The exotic nuclei, which occupy the upper slopes on both sides of the valley, have the largest mass excess, and they generally decay the fastest. The graph was constructed with the aid of a computer by Jef Poskanzer, the son of one of the authors.

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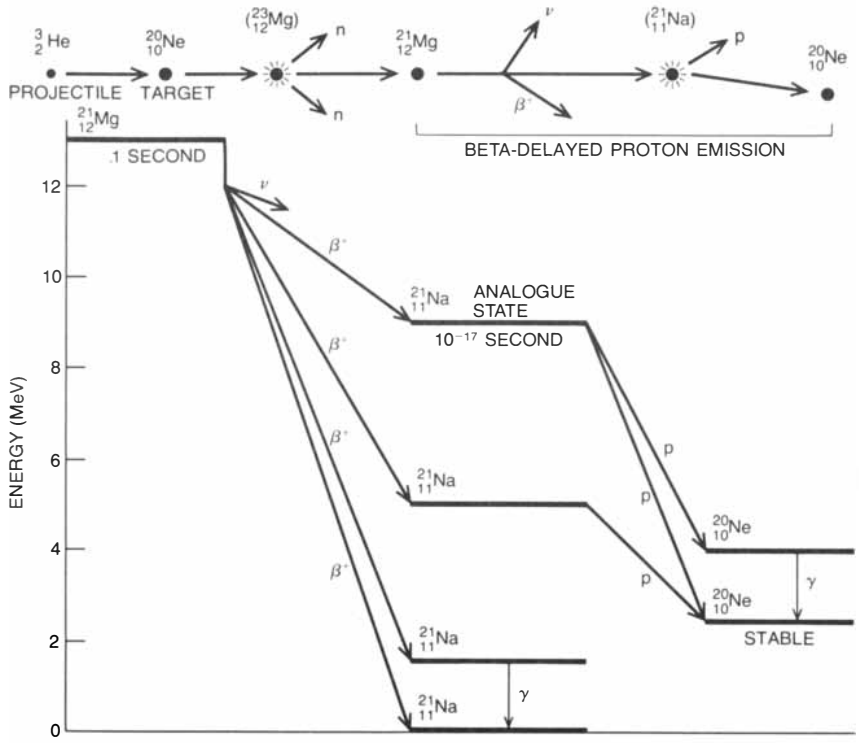
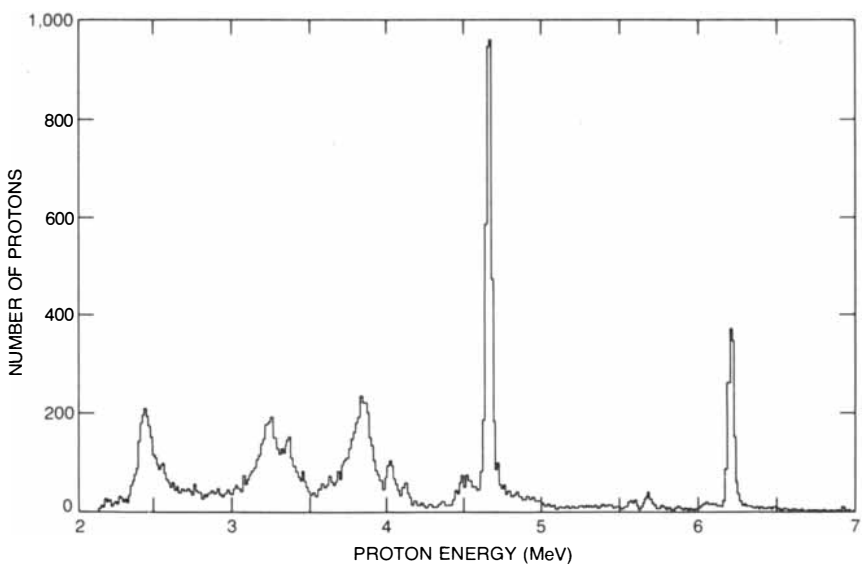


NEUTRON-DEFICIENT ISOTOPE of magnesium, $^{21}_{12}$Mg, sometimes decays by the unusual process of beta-delayed proton emission. The isotope is prepared by bombarding neon atoms with accelerated ions of helium 3. The nucleus formed is highly excited and decays by emitting two neutrons to yield $^{21}_{12}$Mg. That nucleus in turn decays by β^+ emission; the product is a sodium isotope, $^{21}_{11}$Na. The sodium isotope is often created in the ground state or in a low-lying excited state that can decay by gamma emission to the ground state. When a higher excited state is formed, however, it quickly expels a proton, yielding the stable neon isotope $^{20}_{10}$Ne. Because the excited $^{21}_{11}$Na nucleus decays almost instantaneously, the entire process must be regarded as the two-stage decay of $^{21}_{12}$Mg. A highly favored beta decay occurs between $^{21}_{12}$Mg and a state in $^{21}_{11}$Na called the analogue state; in the analogue state all the nucleons have same relative motions as nucleons in the parent state, except that one proton has become a neutron.



ENERGY SPECTRUM of the protons emitted by decaying $^{21}_{12}$Mg nuclei includes a number of broad peaks and two narrow peaks. The narrow peaks are at the energies of 4.7 and 6.2 million electron volts (MeV) and arise from a highly favored beta decay between the $^{21}_{12}$Mg parent state and its analogue in the $^{21}_{11}$Na daughter state. There are two groups because in the decay of the analogue state both the ground state and the first excited state of the $^{20}_{10}$Ne nucleus are populated. The proton groups are sharply defined because the protons emitted in the decay process have a definite energy. For this reason the protons provide more information about the nucleus than do the positrons of the initial beta decay. Positrons have a continuous energy spectrum because energy of beta decay can be shared in any way by the positron and the neutrino.

selves unstable and are subject to further decays, but in all cases the sum of their masses is less than the mass of the parent $^{252}_{98}$Cf nucleus. (The energy released in this way appears as the kinetic energy of the fission fragments.)

There is one other common form of radioactive decay in which the chemical identity of a nucleus is not changed; indeed, neither the number of protons nor the number of neutrons is altered. This is gamma emission, and it affects only the energy state of the nucleus. The gamma ray is a high-energy photon, or quantum of electromagnetic radiation. The energy of the gamma ray is equal to the difference in mass between the parent state and the daughter state. Many of the products of radioactive decays are formed in excited states, so that alpha or beta decay is often followed promptly by gamma emission.

The rate of a radioactive decay is usually expressed in terms of a half-life: the time required for half the atoms of a particular species to decay. The observed time scale of beta decay ranges from about 10^{-3} second to more than 10^5 years; even the minimum lifetime is comparatively long in the realm of subatomic events. The delay is caused mainly by the weakness of the fundamental process that converts one kind of nucleon into the other kind in the nucleus. Certain other nuclear events, which do not involve such a transformation, can take place much faster. One that is of particular importance in the study of exotic nuclei is the spontaneous emission of a nucleon.

A nuclide is susceptible to decaying by emitting a proton or a neutron whenever the mass of the parent is greater than the total mass of the daughter nuclide and the emitted nucleon. The minimum time required for this decay is readily calculated: it is simply the time required for a nucleon moving at a typical speed of 10^9 centimeters per second to cross the nucleus, which has a typical diameter of 10^{-13} to 10^{-12} centimeter. The time is some 10^{-21} to 10^{-22} second. The existence of various inhibiting barriers can increase the time substantially, but only in exceptional cases should it be greater than about 10^{-16} second.

The enormous gap between the typical lifetime for beta decay (10^{-3} second or more) and that for prompt nucleon emission (10^{-16} second or less) provides a convenient experimental boundary separating those nuclides that can be considered to exist from those that cannot. It is possible to calculate theoretically which nuclides are bound against prompt nucleon emission and should exist by this criterion and which should not. One such set of predictions was made by Gerald T. Garvey and I. Kelson, who were then of Yale University. Their method was to calculate the mass

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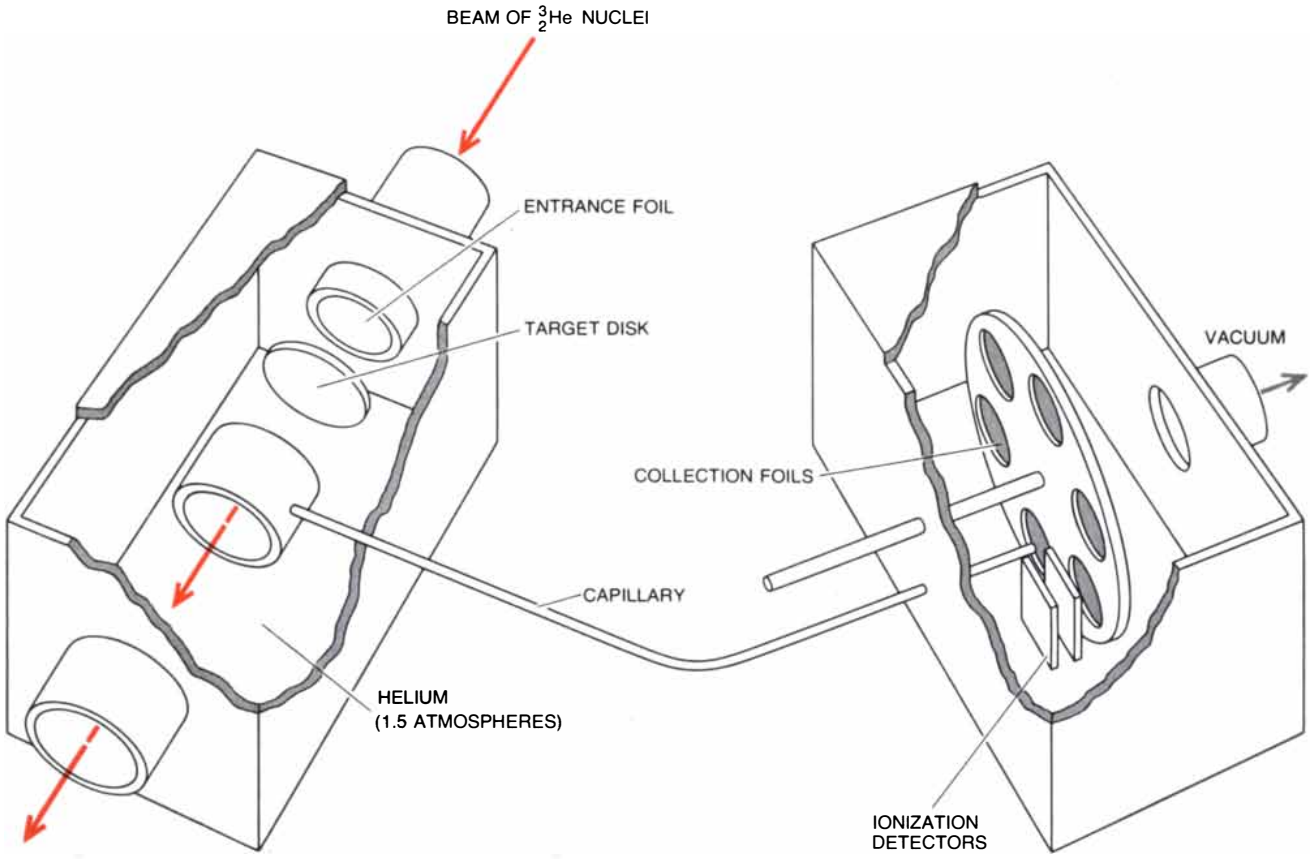

HELIUM JET is employed to transport beta-delayed proton-emitting nuclei from an accelerator target to a detector in the few hundred milliseconds available before most of the nuclei have decayed. The target is enclosed in a vessel that contains helium at about 1.5 times atmospheric pressure. The nuclei produced in reactions with the accelerated $^{3}_{2}$He beam recoil from the target; they are then entrained by the helium jet and are carried with it through a capillary tube into another vessel, which is continuously evacuated. In the particular case of $^{21}_{12}$Mg production the solid target was removed and $^{20}_{10}$Ne gas was mixed with the helium. In the second vessel the nuclei are deposited on a series of foils, which are rapidly stepped past a pair of detectors that are sensitive to electrically charged particles. The detectors measure the energy of the protons and can thus distinguish them from the electrons and the positrons, which are also emitted copiously.

of an unobserved nuclide by extrapolating from the masses of known nuclides in the context of an independent-particle model of nuclear structure.

The theoretical limits of stability against prompt nucleon emission and the present experimental limits can be illustrated by the isotopes of boron, an element that has two stable isotopes, $^{10}_{5}$B and $^{11}_{5}$B. Among lighter boron isotopes, $^{9}_{5}$B is known to be unstable to very rapid proton emission and therefore does not exist. The isotope with still one less neutron, however, $^{8}_{5}$B, does exist; it decays by β^+ emission with a half-life of .8 second. On the other side of the valley of stability five neutron-rich boron isotopes have been observed, the heaviest being $^{17}_{5}$B, which is expected to decay by β^- emission, although its half-life has not been measured. The isotope $^{18}_{5}$B is not expected to exist, but $^{19}_{5}$B should be stable to neutron emission. It has not yet been detected.

A chart of the known and predicted nuclides reveals several general features of their distribution. The most conspicuous trend is that the number of isotopes increases dramatically with increasing atomic number. Hydrogen (atomic number 1) has only three isotopes; sodium (atomic number 11) has 16 known isotopes and two more predicted ones; calcium (atomic number 20) is expected to have 31.

Another general feature of the distribution of nuclides is that there are more neutron-rich isotopes of all the elements than there are neutron-deficient ones. This effect is another consequence of the proton's electric charge. Adding a proton to a nucleus that is already neutron-deficient not only exacerbates the imbalance of protons and neutrons but also increases the electrostatic repulsion between the protons. Adding a neutron to a neutron-rich species affects only the balance of nucleon types.

The region of greatest interest in the study of exotic light nuclei is that lying between the nuclei that decay by conventional beta emission and those that are unstable to prompt nucleon emission. Among the neutron-deficient examples of these nuclei several decay by the two-stage process called beta-delayed proton emission.

An example of such a nuclide is $^{21}_{12}$Mg, which has three neutrons fewer than the lightest stable isotope of magnesium, $^{24}_{12}$Mg. Because of its neutron deficiency $^{21}_{12}$Mg is highly unstable; it decays with a half-life of .12 second by β^+ emission, yielding the nucleus $^{21}_{11}$Na. In its ground state $^{21}_{11}$Na also decays by the conventional mode of β^+ emission, but the nuclei formed by the decay of the magnesium isotope are not only in the ground state but also in many excited states. The additional energy of excitation is enough to make the $^{21}_{11}$Na nucleus unstable to the prompt emission of a proton, yielding as a granddaughter nuclide the stable neon isotope $^{20}_{10}$Ne. To the experimenter this decay sequence appears as the essentially simultaneous emission of a positron and a proton. (The neutrino that is also emitted cannot be detected.)

In the analysis of these events the protons arising from the secondary decay carry more information than the primary positrons, because the protons emitted in decays to each energy level have a definite energy. In beta decay the energy available can be partitioned in any way between the positron and the

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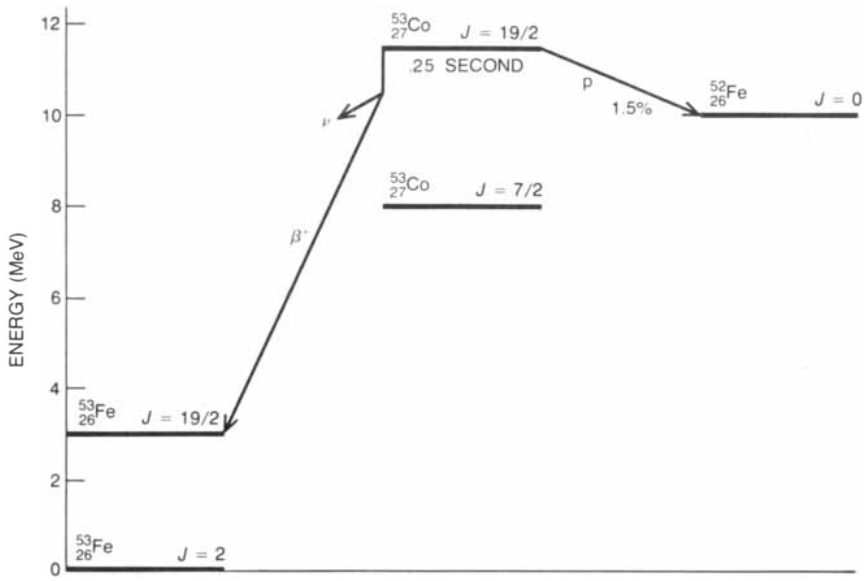

PROTON RADIOACTIVITY has been observed from a long-lived excited state of a neutron-deficient isotope of cobalt: $^{53}_{27}$Co. By far the commonest decay mode of this excited state is conventional beta emission to $^{53}_{26}$Fe; about 1.5 percent of the time, however, the cobalt nucleus simply expels a proton to yield the iron isotope $^{52}_{26}$Fe. What is remarkable is the lifetime of the nuclide. Most nuclei that decay by the direct emission of a proton or a neutron do so very quickly, in as little as 10^{-21} second. Cobalt 53, on the other hand, has a half-life of .25 second, and if proton radioactivity were its only mode of decay, it would survive some 17 seconds. The symbol *J* represents the intrinsic-angular momentum of nuclides, measured in fundamental units.

neutrino. From the proton spectrum it is possible to deduce which states of the $^{21}_{11}$Na nucleus have been populated. Not all the beta decays, however, leave the nucleus in a state that can decay by proton emission; the rest return to the ground state of $^{21}_{11}$Na by gamma emission. The gamma rays also have unique energies (equal to the energy difference between the excited state and the ground state), and they convey information about the states populated.

Beta-delayed proton emission was first observed in 1963 by V. A. Karnaukhov, G. M. Ter-Akopian and V. G. Subbotin of the Joint Institute for Nuclear Research at Dubna, near Moscow, and by Richard D. Barton, Ross McPherson, Robert E. Bell, William R. Frisken, William T. Link and Robert B. Moore of McGill University in Montreal. Many light nuclei that decay in this way have since been identified, largely through the work of three groups of investigators: one led by John C. Hardy of McGill, another that included one of us (Poskanzer), then at the Brookhaven National Laboratory, and most recently a third group that included the other one of us (Cerny) at the Lawrence Berkeley Laboratory of the University of California. The 10 lightest nuclei in which this decay sequence has been observed, beginning with the carbon isotope $^{9}_{6}$C and continuing through the titanium isotope $^{41}_{22}$Ti, have half-lives ranging from nine milliseconds to 470 milliseconds.

The nuclide $^{21}_{12}$Mg was produced by employing as an accelerator target a gas containing atoms of $^{20}_{10}$Ne. (Since this nuclide is also the end product of the decay sequence, the entire reaction is cyclical.) The gas was bombarded by nuclei of the neutron-deficient isotope $^{3}_{2}$He that had been accelerated to an energy of 30 MeV. In some of these interactions the two nuclei fuse, forming $^{23}_{12}$Mg in a highly excited state. A fraction of the excited nuclei promptly eject two neutrons to form $^{21}_{12}$Mg.

Because of the short half-life of this isotope (.12 second) and of other beta-delayed proton emitters, special means are required for transporting the nuclide from the target area of the accelerator to the apparatus employed to detect its decay. In early studies of man-made isotopes the means of transport was sometimes a runner, who carried the specimen by hand from one room to another. As interest shifted to nuclei with shorter lifetimes a pneumatic shuttle, or "rabbit," was often adopted. For studies of the beta-delayed proton emitters even that method is too slow. The $^{21}_{12}$Mg nuclei were carried to the detector by a helium jet. The neon target nuclei were mixed with a large volume of helium gas at 1.5 times atmospheric pressure. The product nuclei were entrained by the helium and swept through a capillary tube to another vessel that was continuously evacuated by a high-speed pump. There the magnesium nuclei (and others) were deposited on thin foils that were stepped several times per second past the detector.

Nuclei of $^{21}_{12}$Mg were not the only radioactive species formed in this reaction; indeed, they were a small minority. Most of the nuclides decayed by β^+ or β^- emission, and so the detector was required to recognize a small flux of protons in an intense background of electrons and positrons. In general particle detectors operate by sensing the ionization of atoms caused by the passage of a charged particle. Positrons, electrons and protons all bear an electric charge, but because the proton is much more massive it can be recognized. Protons lose energy more quickly as they pass through matter, and by arranging for the particles emitted to pass through two detectors in sequence the rate of energy loss can be measured.

The decay of a specimen of magnesium 21 yields a great many protons, which can be arranged in groups according to their energies. Each of the groups represents decay events to a specific energy level in the intermediate daughter nucleus, $^{21}_{11}$Na. A particularly interesting group of protons arises from a favored transition between the parent nucleus and an energy level in the daughter species that is called the analogue state of the parent. The concept of an analogue state is based on the theory of the charge independence of nuclear forces. This theory holds that if electromagnetic forces can be neglected, then the interaction between a proton and a proton, between a proton and a neutron and between a neutron and a neutron should all be the same. Hence if two nuclei have the same number of nucleons and those nucleons are in the same state of motion, then the two nuclei should be identical, even though their nucleons are apportioned differently between protons and neutrons. In this case both nuclei have 21 nucleons, and the theory of charge independence predicts that they have the same motion in the favored excited state of $^{21}_{11}$Na as they have in the ground state of $^{21}_{12}$Mg. Actually, of course, electromagnetic interactions cannot be neglected entirely, and small differences between the states of the nuclei should be observed. The extent of the differences can be determined by studying the proton spectrum. For $^{21}_{12}$Mg and for several other beta-delayed proton emitters the discrepancies have been found to be quite small; the analogue state and the parent nucleus resemble each other quite closely, typically to about 90 percent.

These experiments established the existence of $^{21}_{12}$Mg, along with its half-life and its decay modes, but they did not reveal its exact mass. The mass has been measured through another technique by one of us (Cerny) and his col-

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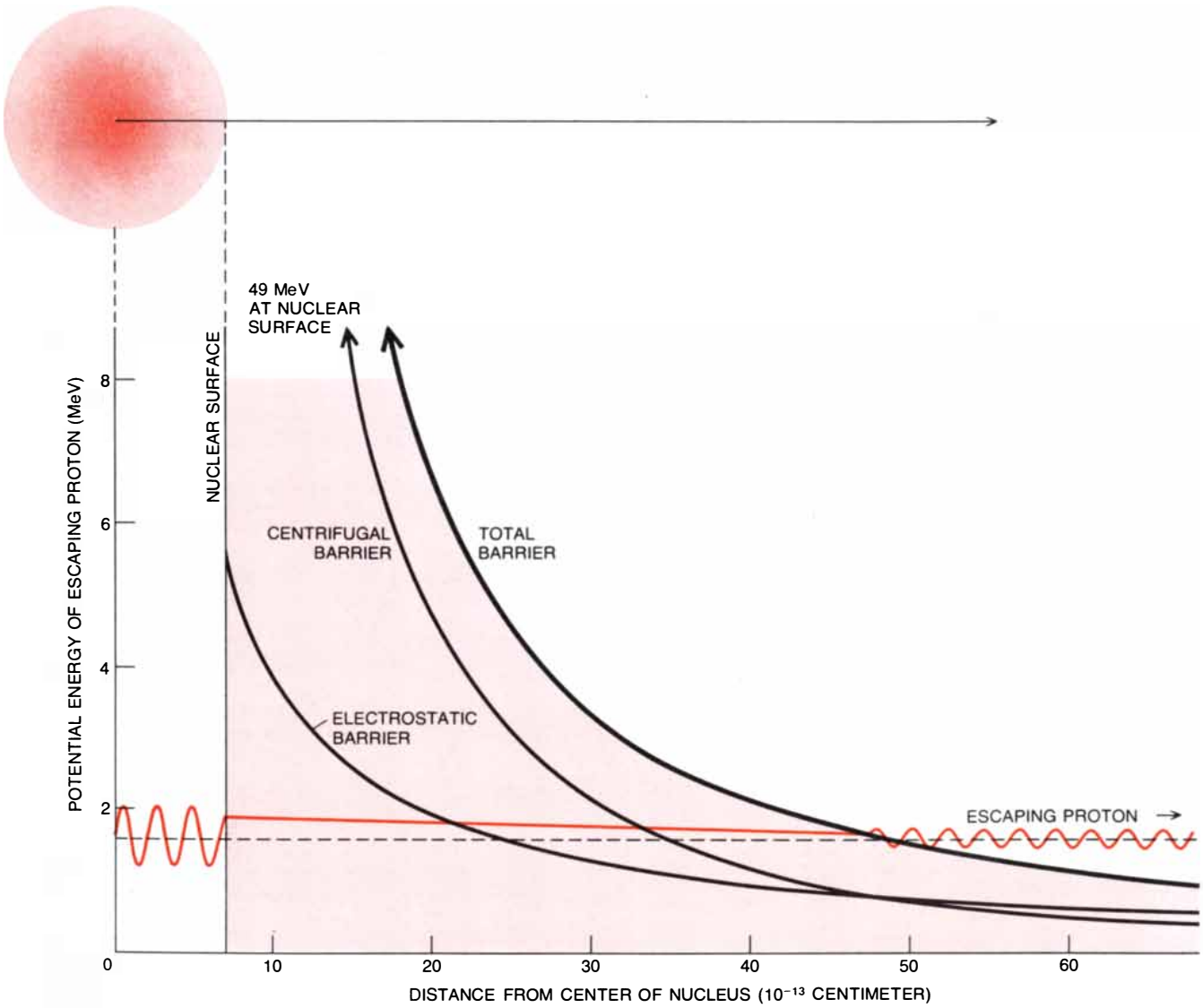
leagues and by Walter Benenson and Edwin Kashy and their colleagues at Michigan State University. Again the accelerated projectile was $^{3}_{2}$He, but the target employed was the stable isotope $^{24}_{12}$Mg. Collisions between these nuclides include very rare events in which the helium nucleus picks up three additional neutrons, creating the isotope $^{6}_{2}$He and leaving behind a nucleus of $^{21}_{12}$Mg. The $^{21}_{12}$Mg nucleus goes undetected, but the energy of the $^{6}_{2}$He nucleus is measured. Since the energies and the masses of three of the four nuclei involved in the reaction are known, the exact mass of the fourth one ($^{21}_{12}$Mg) can be deduced by applying the laws of conservation of energy and momentum.

Direct nucleon emission was discussed above as a decay mode so fast that it excludes certain nuclei from existence. A nuclide could decay by the emission of a proton or a neutron with a comparatively long lifetime, however, if the emission were strongly hindered by a large barrier. A nuclide of this kind was discovered in 1970: it is a long-lived excited state of the cobalt isotope $^{53}_{27}$Co, which decays by the direct emission of a proton with a half-life of .25 second. The proton radioactivity was discovered at the Harwell Atomic Energy Research Establishment in England by a group of investigators from the University of Oxford made up of one of us (Cerny) and K. P. Jackson, C. U. Cardinal, H. C. Evans and N. A. Jelley. The discovery was confirmed by additional experiments at the Lawrence Berkeley Laboratory by one of us (Cerny) and J. E. Esterl, R. A. Gough and R. G. Sextro.

In the latter experiments the cobalt



EXTENDED LIFETIME of the $^{53}_{27}$Co nucleus can be explained in terms of barriers that a proton must be able to penetrate in order to escape the nucleus. There are two such barriers for $^{53}_{27}$Co: an electrostatic one, generated by the electrical repulsion between protons, and a centrifugal one, arising from the requirement that the emerging proton carry off the large angular momentum of the parent nucleus. The total barrier is some 49 MeV high at the surface of the nucleus; since the protons emitted have an energy of only about 1.6 MeV, they clearly cannot surmount it. There is a small probability, however, that the protons can pass through the barrier by the quantum-mechanical process called tunneling. The proton can be regarded as a wave that strikes the barrier and appears again on the other side of it. The emergent wave has the same wavelength as the wave inside the nucleus, indicating that the proton has the same energy, but the amplitude of the wave is vastly reduced, reflecting the smaller probability of finding the proton outside the nucleus. The amplitude is reduced by a factor of about 10^{7}, which is much smaller than can be shown in the illustration. It is the very small probability of such tunneling, along with an improbable nuclear rearrangement that is also required, that accounts for the long lifetime of the cobalt isotope.

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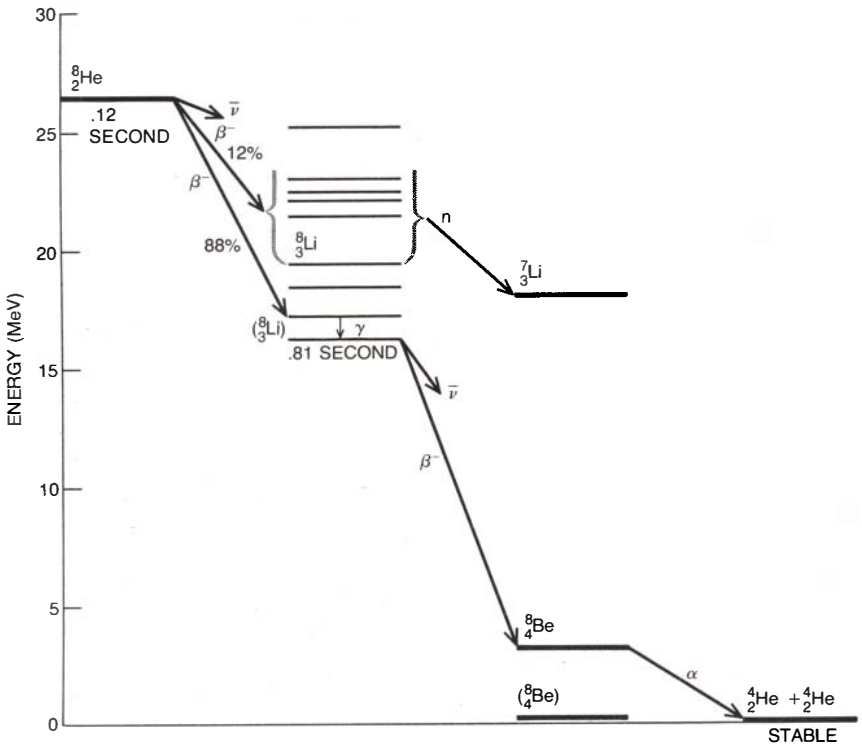
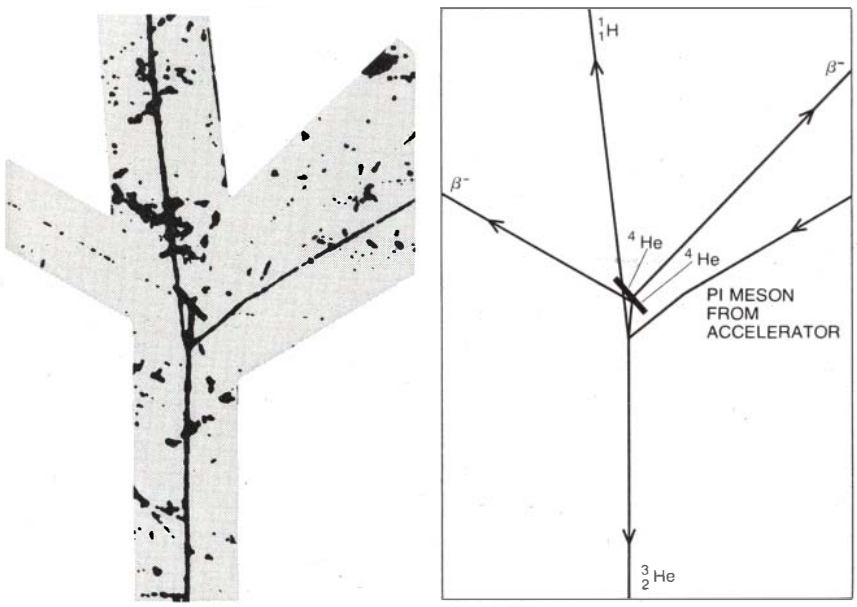


NEUTRON-RICH ISOTOPE of helium, $^{8}_{2}$He, can decay through either of two unusual pathways. In each case the initial event is a beta emission, forming the lithium isotope $^{8}_{3}$Li. If the $^{8}_{3}$Li is created in a highly excited state, it promptly emits a neutron, giving rise to the stable product $^{7}_{3}$Li. The overall process is beta-delayed neutron emission. If the $^{8}_{3}$Li is formed in its lower excited states, those states decay to the ground state by gamma radiation; the ground state then beta decays to yield an unstable excited state of $^{8}_{4}$Be. The beryllium nuclide in turn promptly emits an alpha particle, or in other words splits into two nuclei of $^{4}_{2}$He, the commonest isotope of helium. In the latter pathway decay of $^{8}_{3}$Li can be described as beta-delayed alpha emission.



DECAY OF A HELIUM-8 NUCLEUS is recorded in a photographic emulsion at the left; the same events are diagrammed at the right. The $^{8}_{2}$He nucleus was one of three fragments created when a low-energy pi meson was captured by a carbon nucleus in the emulsion. The other two fragments, a proton ($^{1}_{1}$H) and a helium-3 nucleus ($^{3}_{2}$He) are shown leaving the field of view. The $^{8}_{2}$He nucleus moved only a short distance before it came to rest, and then it underwent two successive beta decays to $^{8}_{4}$Be, which split into two $^{4}_{2}$He nuclei. Tracks of the two $^{4}_{2}$He nuclei go in opposite directions because $^{8}_{4}$Be nucleus was essentially at rest when it split up. The photograph was supplied by Yu. Batusov of the Joint Institute for Nuclear Research in the U.S.S.R.

nuclide was made by bombarding the iron isotope $^{54}_{26}$Fe with protons accelerated to an energy of 35 MeV. The unobserved intermediate product was the cobalt isotope $^{55}_{27}$Co, which immediately ejected two neutrons to yield an excited state of $^{53}_{27}$Co. Unlike most excited states this one is inhibited from returning to the ground state by gamma decay and for that reason is called a nuclear isomer. Most of the time it decays by β^+ emission, but in about 1.5 percent of the decays proton emission is observed. Unlike the protons emitted in beta-delayed decays, which come from several excited states and therefore have several characteristic energies, all the protons emitted by $^{53}_{27}$Co are clustered at the same energy, 1.59 MeV.

The β^+ decay of $^{53}_{27}$Co is a highly favored mode because it leads to the creation of a "mirror" nucleus, which has the composition $^{53}_{26}$Fe and which occupies the same excited state as the parent cobalt nucleus. Mirror nuclei are a special case of analogue states in nuclei; in mirror nuclei the only difference between the two nuclides is that the number of protons and neutrons is interchanged. In this case the parent cobalt isotope has 27 protons and 26 neutrons and the daughter iron isotope has 26 protons and 27 neutrons. Because transitions between such states are highly favored, the β^+ decay mode is the major influence on the lifetime of $^{53}_{27}$Co. In fact, if the β^+ decay could be turned off, and proton emission were the only decay mode available, the half-life of the nuclide would be some 17 seconds, roughly 20 orders of magnitude longer than the usual time scale of direct nucleon emission. It is this "partial" half-life that a theory of the slow proton emission must explain.

The explanation lies in the exceptionally large barrier to proton emission that must be overcome. Moreover, the explanation closely resembles theoretical accounts of alpha-particle emission by heavy nuclei, such as uranium 238. The major barrier to alpha emission arises from the electromagnetic interactions of protons, following Coulomb's law for the electric force. For an alpha particle to overcome the Coulomb barrier and escape from the nucleus requires an energy of about 25 MeV. According to the laws of classical physics only particles with that energy or more should be able to escape the nucleus, but in fact alpha particles are emitted by uranium with an energy of 4.2 MeV. These lower-energy particles are able to get out by the quantum-mechanical process of tunneling through the Coulomb barrier.

In quantum mechanics particles can be regarded as waves, and a wave has a small probability of penetrating a barri-

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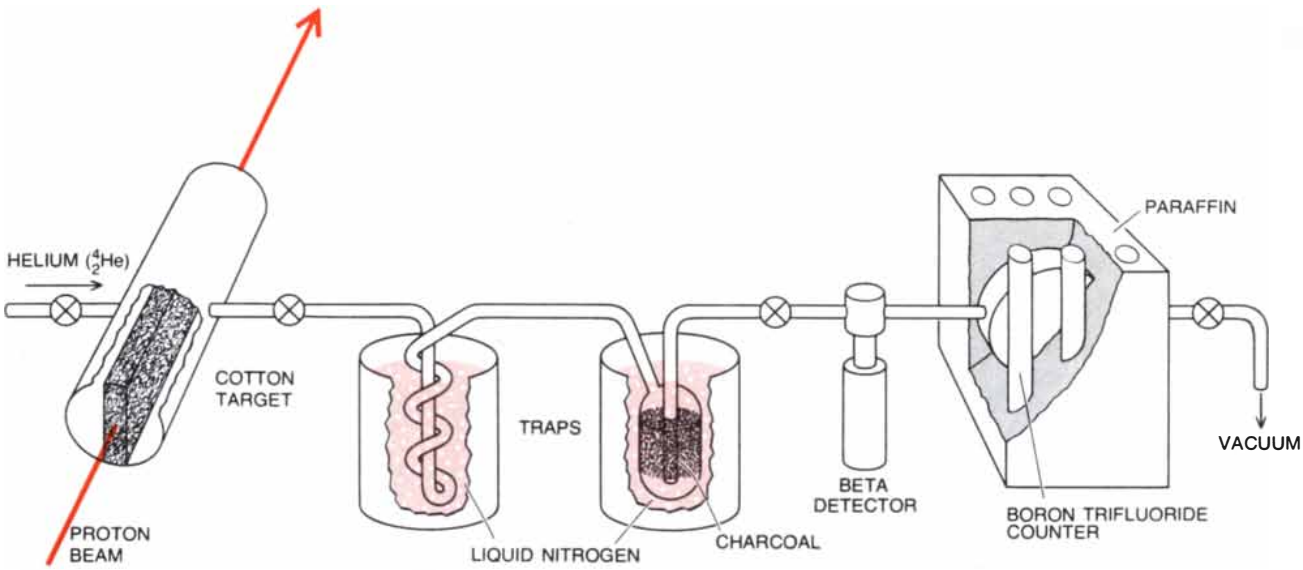
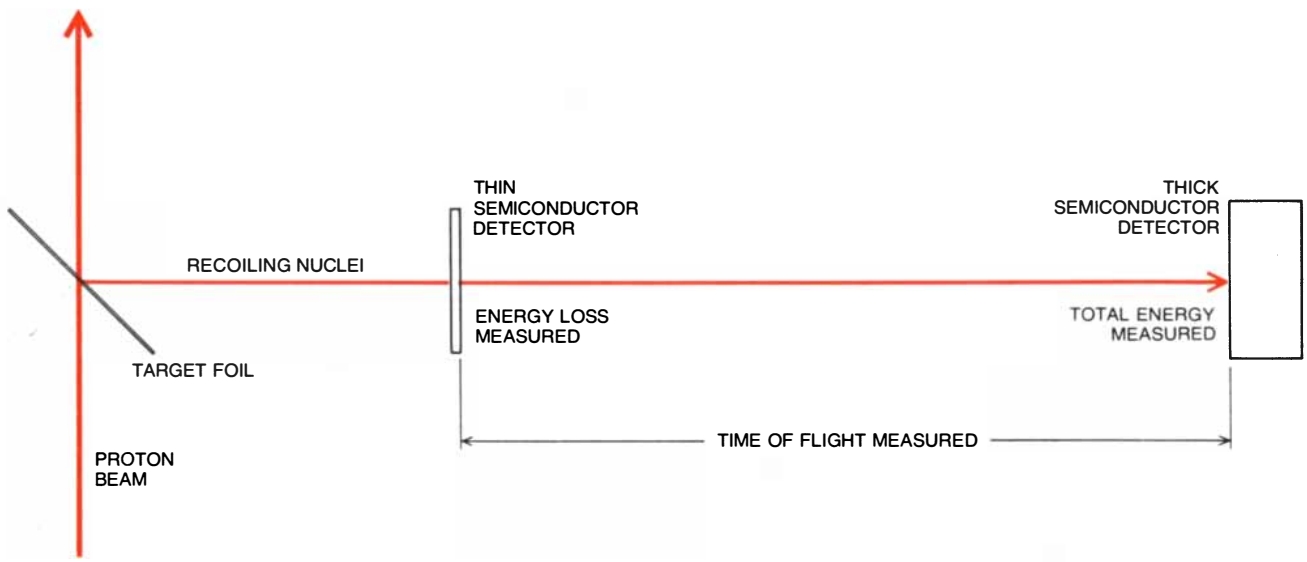
er. In the decay of the uranium nucleus the alpha particle has about one chance in 10^{38} of escaping on any given attempt. Although that is an extremely small likelihood, the alpha particle collides with the "walls" of the nucleus some 10^{21} times per second. It can therefore be expected to escape after some 10^{17} seconds, or three billion years. The measured half-life of uranium 238 is 4.5 billion years.

A similar Coulomb barrier inhibits proton emission in $^{53}_{27}$Co, but on calculating the probability that the proton will tunnel through the barrier the half-life turns out to be only 10^{-19} second, still many orders of magnitude short of the experimentally observed partial half-life. Part of the discrepancy can be attributed to an additional barrier, called a centrifugal barrier. The $^{53}_{27}$Co nucle-



DETECTION OF HELIUM 8 relies on the distinctive chemical and physical properties of helium to separate $^8_2$He from the numerous other nuclides created in collisions of accelerated particles with target nuclei. The target employed is cotton, which for the nuclear reactions of interest here can be regarded as being carbon. Nuclei of $^8_2$He diffuse out of the cotton fibers and are swept up by a stream of ordinary helium gas ($^4_2$He). Other elements are condensed out of the stream in two cryogenic traps, which helium is able to pass through because of its extremely low boiling point. The residual gas then flows by a beta-ray scintillation detector into a tank embedded in a large block of paraffin. The neutrons from $^8_2$He decay are slowed down in the paraffin so that they react with boron in the ionization detectors.



NUCLEAR TELESCOPE identifies nuclides recoiling from a metal target foil placed in the beam of an accelerator by measuring some of the nuclides' physical properties. The telescope consists of two semiconductor detectors lined up so that recoiling nuclei can pass through both of them in sequence. The amount of energy deposited by a nucleus in each detector can be determined from the number of ions created. The first detector is thin and measures the rate at which the nucleus loses energy in passing through matter; the second detector is thicker and stops the nucleus and measures its remaining energy. From these data a dimensionless quantity called the particle identification number can be determined; it is proportional to the product of the mass number and the square of the nuclear charge. In a refinement of the same technique the time of flight of the nucleus between the two detectors is also measured. This determines the velocity of the nucleus, which together with the nucleus' kinetic energy provides an independent and more accurate result for mass number of nucleus.

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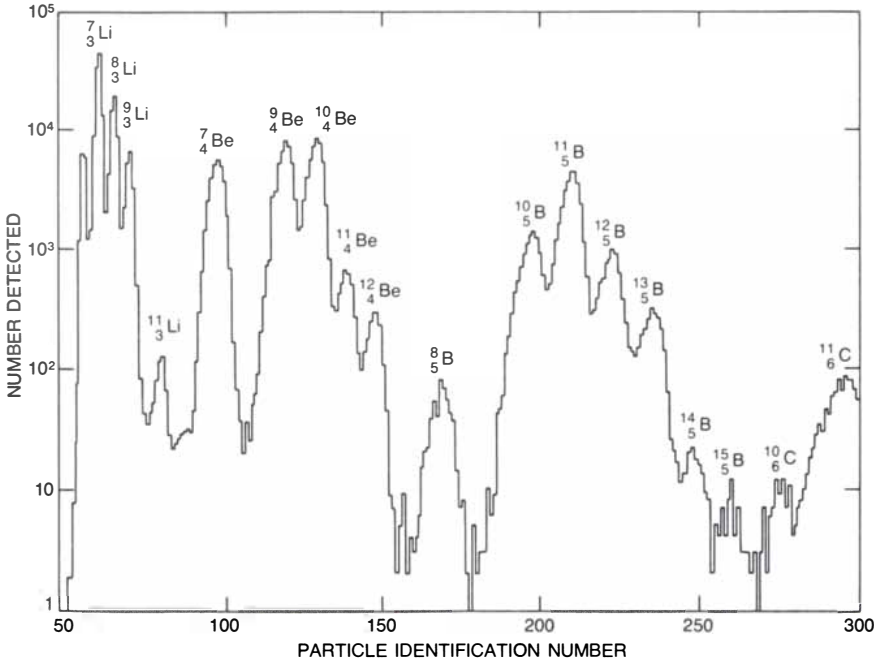
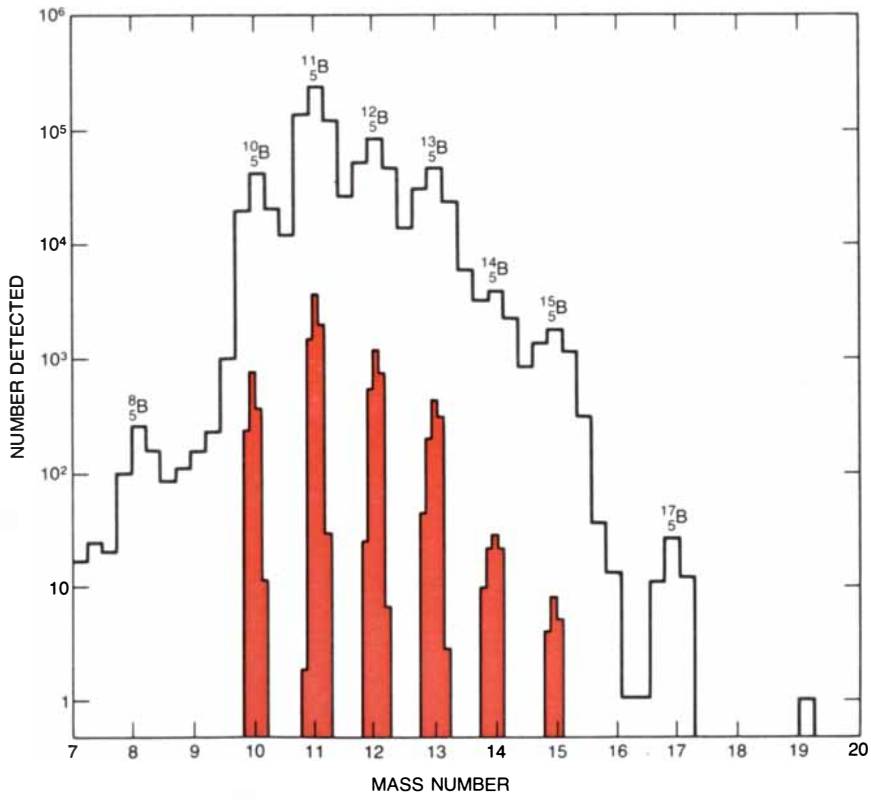


RECOILING NUCLEI from a heavy-element target irradiated by high-energy protons were identified entirely by measuring their kinetic energy and rate of energy loss, without measuring their velocity. The peaks represent the yields of the many isotopes produced in this reaction. The neutron-rich nuclides $^{11}_{3}$Li, $^{14}_{5}$B and $^{15}_{5}$B were first observed in such an experiment. On the other hand, the heaviest known boron isotope, $^{17}_{5}$B, cannot be observed because of interference from the more abundant carbon isotopes. The interference arises because the particle identification number is not unambiguous: product of mass number and square of nuclear charge is nearly the same for certain heavy isotopes of boron and certain light ones of carbon.



SPECTRUM OF BORON ISOTOPES is fully resolved in experiments where velocities of recoiling nuclei are also measured. Boron 17 was detected in such an experiment (*black*), in which time of flight was measured between first and second detectors. Even greater resolution is achieved (*color*) by measuring time of flight over a path between target and first detector.

us has an exceptionally high angular momentum of 19/2 units, whereas the daughter nucleus, $^{52}_{26}$Fe, is produced in its ground state and has zero angular momentum. The emitted proton must therefore carry off all 19/2 units of angular momentum. One-half unit is accounted for by the intrinsic spin of the proton; the other nine units must appear as orbital angular momentum in the system made up of the daughter nucleus and the emitted proton.

The half-life expected for a proton to tunnel through both the Coulomb barrier and the centrifugal barrier is about 6×10^{-8} second. The remaining factor of 3×10^{8} can be accounted for by the exceptionally complicated and improbable rearrangement of the nuclear material that is required for the excited state of $^{53}_{27}$Co to decay into the ground state of $^{52}_{26}$Fe. Hence two separate probabilities must be satisfied before the decay can take place, the first for the emerging proton to tunnel through both barriers, and the second for the residual nucleus to have a structure that resembles $^{52}_{26}$Fe.

Another mode of decay might be available to some nuclei that are extremely deficient in neutrons. This mode, first suggested by V. I. Goldanskii of the Institute of Chemical Physics in Moscow, is the simultaneous emission of two protons. It might arise in an even-even nucleus where the decay to the next lighter (and therefore odd-even) nucleus was energetically impossible; in such a nucleus the enhanced stability of even-even nuclei might favor double proton emission.

On the neutron-rich side of the valley of stability the characteristic phenomenon of proton emission is not available. Beta-delayed neutron emission does take place, and indeed it has been known much longer, since 1939. The first light element that decays by delayed neutron emission was discovered in 1948 by Ernest O. Lawrence and was identified as $^{17}_{7}$N by Luis W. Alvarez. Because neutrons are electrically neutral they are not as readily detected as protons and different experimental techniques are required.

Where the nuclide of interest is an isotope of a gaseous element it is still possible to transport it from an accelerator target to a detector. Such a technique was employed by Alvarez for $^{17}_{7}$N and later by one of us (Poskanzer) in the study of helium 8, the heaviest isotope of helium and the only nuclide that has three times as many neutrons as protons. The $^{8}_{2}$He nuclei were created by irradiating the carbon nuclei in cotton with high-energy protons, which occasionally broke up the carbon nuclei. The helium atoms diffused out of the thin cotton fibers and were then swept by a stream of ordinary helium through

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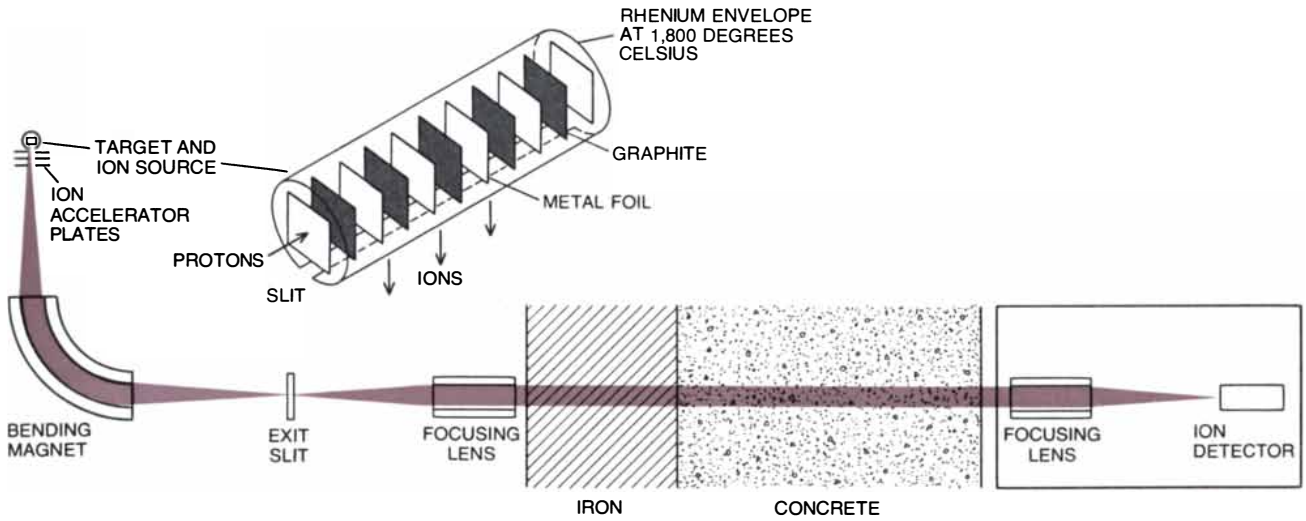

MASS SPECTROMETER linked directly to a particle accelerator separates short-lived nuclei according to their mass. The device in the detail drawing at the top is both the target of the accelerator and the ion source for the mass spectrometer. Nuclei created by collisions in the metal foils are stopped in the graphite, where they acquire electrons and become electrically neutral atoms. The atoms of the alkali metals diffuse out of the graphite and are ionized by contact with the hot rhenium envelope; they are then accelerated into the magnet of the spectrometer by an electrostatic potential of 10,000 volts. In the magnetic field the ions are deflected through various angles according to their mass. A particular mass is selected for study by an exit slit, and ions with that mass pass through an iron-and-concrete shield to a detector. The on-line mass spectrometer was developed at the Laboratory for Nuclear and Mass Spectroscopy at Orsay in France.

a series of cryogenic traps, which condensed all elements other than helium, and then on to the detection equipment. There beta and gamma emissions were monitored with scintillation detectors and neutrons were slowed by paraffin and counted with a boron trifluoride detector. The latter relies on the fact that a nucleus of $^{10}_{5}B$, after absorbing a slow neutron, sometimes decays by alpha emission; the ionization caused by the alpha particles can be detected. The detector only counts the neutrons, however; it cannot measure their energy.

These studies revealed an unusual decay sequence for $^{8}_{2}He$. About 12 percent of the time the nucleus decays by β^- emission to a highly excited state of the lithium isotope $^{8}_{3}Li$; that state then promptly decays by neutron emission to $^{7}_{3}Li$. In other words, the decay is an example of beta-delayed neutron emission. In the remainder of the decays the initial β^- emission leads to a lower excited state of $^{8}_{3}Li$, which is not capable of neutron emission but instead decays to the ground state by gamma radiation. The ground state of $^{8}_{3}Li$ is not stable either, however, but undergoes a β^- decay to $^{8}_{4}Be$, which promptly breaks up into two nuclei of $^{4}_{2}He$. (The last decay can be regarded as an example of beta-delayed alpha emission.) The overall reaction can therefore be described as one atom of helium ($^{8}_{2}He$) breaking up into two atoms of helium ($^{4}_{2}He$) plus two electrons and two antineutrinos.

An efficient method of creating many neutron-rich species is by bombarding a heavy element, such as uranium, with high-energy protons capable of breaking off small fragments of the nucleus. In the uranium nucleus the ratio of 1.6 neutrons for each proton provides optimum stability, but when the same ratio is conferred on a light fragment it represents an extreme excess. Such a procedure has the one disadvantage that an enormous variety of nuclides are created at once, and they must somehow be distinguished from one another. In spite of this difficulty most of the extremely neutron-rich nuclides have been discovered by some variant of this method.

One way of identifying the various nuclides created makes use of the kinetic energy with which they are knocked out of the target. The identification can be accomplished by a simple "telescope" made up of two ionization detectors that the recoiling nuclei strike in sequence. The first detector is thin and the nuclei pass through it, depositing only a part of their energy; the second detector is thick enough to stop the nuclei and to measure the total remaining energy. The product of those energies is known to be proportional to the product of the mass number and the square of the nuclear charge of the fragment. Although there are a few nuclei that cannot be distinguished from one another in this way most leave a unique signature.

By this method the extremely neutron-rich nuclide $^{11}_{3}Li$ was discovered by us and Earl K. Hyde and S. W. Cosper at the Lawrence Berkeley Laboratory. The nuclide appeared as a small bump in a curve recording the production of many commoner nuclei. The bump revealed nothing more than that the nucleus lived long enough to reach the two detectors, about 10^{-8} second. That in itself was a surprise, however, because theoretical calculations had indicated that $^{11}_{3}Li$ should be a prompt neutron emitter. Other prompt neutron emitters were not represented by bumps in the curve.

In a refinement of this technique developed by Gilbert W. Butler, James D. Bowman and one of us (Poskanzer) the differential energy loss in the thin detector is employed only to determine the nuclear charge. The mass number is given by the total kinetic energy and the velocity of the particle, the velocity being determined by measuring the time of flight between the two detectors. Because the velocities are roughly 5 percent of the speed of light and the path over which they are measured is only about 25 centimeters, the timing must have a precision of about 10^{-10} second. In return for making that precise measurement the nuclides are identified unambiguously by both proton number and mass number. By this method a new isotope of boron was discovered, $^{17}_{5}B$. It had been obscured by various carbon isotopes in the earlier experiment.

A further refinement of the technique was possible in an experiment conducted at the Los Alamos Meson Physics Facility by Butler, Dennis G. Perry, Louis P. Remsberg, Joseph B. Natowitz, Franz Plasil and one of us (Poskanzer). The high-intensity proton beam produced there is divided into bursts that are only about 10^{-9} second long. By measuring the time of flight of a fragment between the two detectors, both of which are far from the target, it is possible to determine which beam burst produced the fragment. Knowing this, one

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can then measure the time of flight over the path of about five meters from the target to the first detector. The much higher mass resolution achieved in this way has led to the identification of five new neutron-rich nuclides in the region from neon to phosphorus.

Many neutron-rich nuclides have also been identified by V. V. Volkov and his colleagues at the Joint Institute for Nuclear Research at Dubna. They also employed a heavy-element target, which was bombarded by beams made up of particles such as helium nuclei. The recoiling nuclei were identified by measuring their kinetic energy with an ionization detector and their momentum with a magnetic field. In spite of the success of these techniques a great many neutron-rich nuclei remain to be detected.

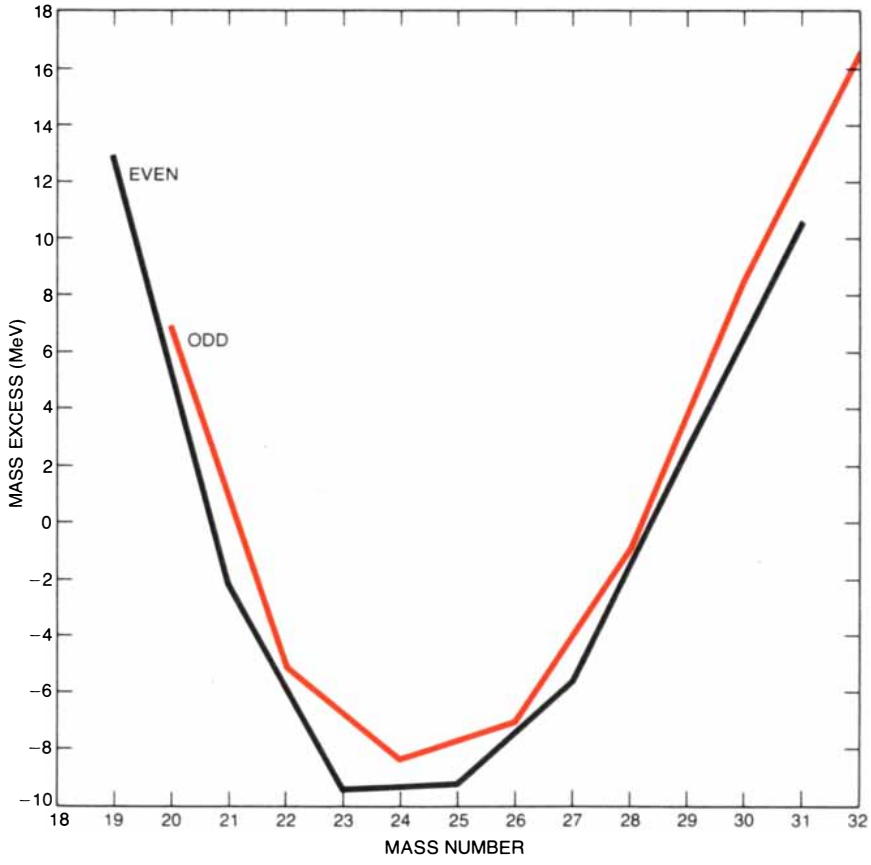
At best, the experimental techniques outlined above can reveal only the existence of a nuclide; to determine its mass, lifetime or decay modes more elaborate methods are required. D. R. Goosman and David E. Alburger of the Brookhaven National Laboratory have studied many exotic nuclei by producing them selectively, employing unusual beams and isotopically pure targets. When it is necessary to irradiate heavy-element targets, however, there is such a variety of products that the nuclide of interest must be physically separated from the target and from the other product nuclei.

A powerful method for accomplishing the separation with the necessary speed has been developed by R. Klapisch and C. Thibault of the Orsay laboratories in France. In their method the product nuclei are recovered from the target in the form of ionized atoms and injected directly into a mass spectrometer. In the spectrometer the ions are accelerated to a fixed velocity, then passed through a magnetic field. The extent to which their paths are bent by the field is determined by their momentum, and hence by their mass. An exit slit allows only those nuclides of a particular selected mass to reach an ion detector. Similar apparatus is employed in another machine, called ISOLDE, at the European Organization for Nuclear Research (CERN) near Geneva. It has recently detected the most neutron-deficient isotope of argon that is predicted to exist, $^{32}_{18}$Ar.

The device built at Orsay is particularly well suited to the study of the alkali metals, and largely as a result of work with that machine more neutron-rich isotopes are known of sodium and potassium than of any other light elements. What is more, the masses, lifetimes and decay modes of most of those isotopes have been determined.

The Orsay group was able to measure the lifetime of $^{11}_{3}$Li by monitoring the rate at which the activity declined after each burst of particles irradiated the target. They found it has a half-life of 8.5 milliseconds. In order to measure other properties of the nuclides the ion detector at the exit slit is replaced by a metal foil on which the ions are deposited. Beta, gamma and neutron emissions can then be monitored with standard detectors, but without the complication of background events from other nuclides. In this way $^{11}_{3}$Li and all the sodium isotopes between $^{29}_{11}$Na and $^{32}_{11}$Na were found to be emitters of beta-delayed neutrons.

Finally, the mass of $^{11}_{3}$Li was measured by the Orsay collaboration and one of us (Poskanzer). The mass spectrometer has an intrinsic resolution of about one part in 500, which is ample for discriminating between isotopes but inadequate for a precise mass measurement. In order to determine the binding energy of the nuclide the mass must be known to an accuracy of about .1 MeV; since the total mass of $^{11}_{3}$Li is almost 11,000 MeV, that requires a resolution of roughly one part in 100,000. The necessary precision was obtained by measuring the mass of tens of thousands of $^{11}_{3}$Li nuclei and averaging the results. It was found that lithium 11 is bound against the prompt emission of a neutron by only .17 MeV (±.08 MeV).



MASSES OF SODIUM ISOTOPES were determined out to the high-neutron-excess region with the on-line mass spectrometer in experiments at the European Organization for Nuclear Research (CERN). The graph is a cross section of the valley of stability at the line where the proton number is 11. Again the quantity represented is mass excess. Masses of those isotopes in which the number of neutrons is odd (*color*) are graphed separately from those in which it is even (*black*); the two groups form separate series because nuclei in which particles form pairs have enhanced stability. Masses of two more sodium isotopes (mass numbers 33 and 34) are being determined by experimenters, and the isotope with mass number 35 has been observed.

The study of exotic nuclei continues to generate unexpected results. Although on the neutron-deficient side of the valley of stability all nuclei predicted to exist up to $^{20}_{12}$Mg are known, only for hydrogen, helium, lithium and beryllium have the frontiers been pushed to the edge of existence on both sides of stability. For the other light elements much remains to be learned. New methods of production and ingenious methods of detection will be required. It is of interest to explore nuclei in all their exotic forms and not to be confined simply to the region near the narrow bottom of the valley of stability. Perhaps other modes of radioactive decay will be discovered. Certainly new knowledge of the structure of nuclei will emerge.

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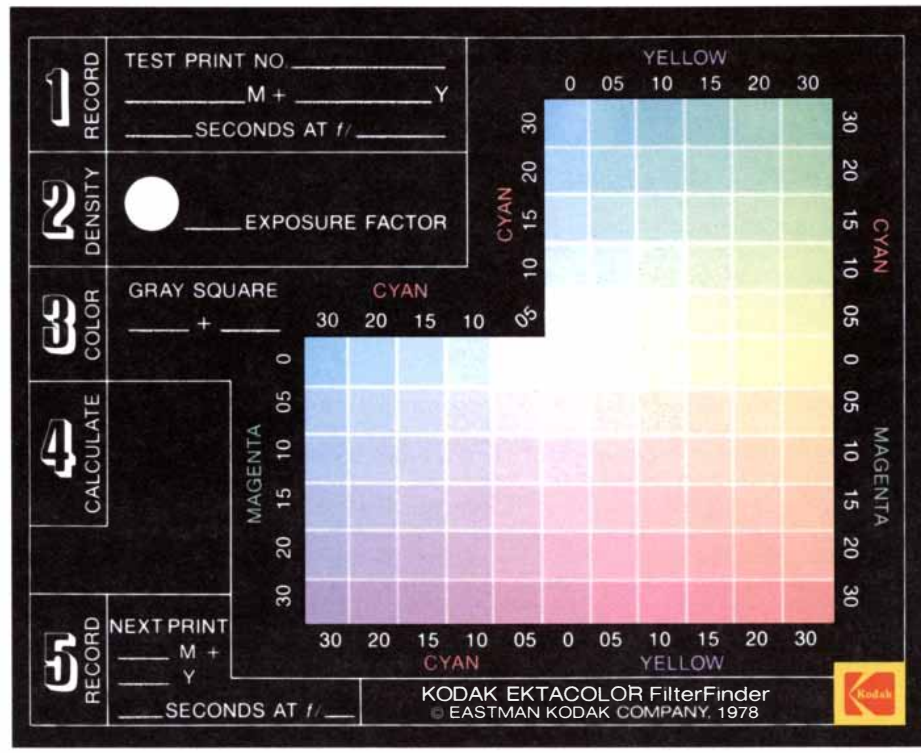
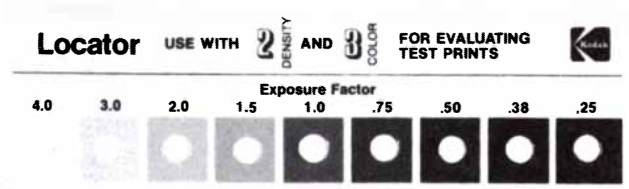
The leap from black-and-white to big, superb color prints made in your own darkroom is now easier but still justifies considerable pride of accomplishment

To have fun with this device next winter start now to catch summer's color on negatives



It's a black mask of film—the KODAK EKTACOLOR FilterFinder—bearing one clear hole and 96 precise tints of color. It works with a gray card that you include in a test shot made at the scene on the same roll of film. When you begin your printing, you place the FilterFinder on the enlarging easel over the image of the gray card to make a test print. From the image of the clear hole on the processed test print, with the use of this Locator ▼



you read off an exposure correction factor from your best test print. You also mark off which one of the 96 little squares has come out closest to gray on the test print. The two coordinates of that tint tell you what changes are needed in the combination of color filters you used in the enlarger for the test print. You jot down all the data right on the test print in the spaces provided on the FilterFinder image.

Then, with the corrections applied to the exposure and filter combination, you use the enlarger with an empty negative carrier as the light source for contact-printing your whole roll of negatives to a sheet of Ektacolor paper on the easel. That gives you proof prints for selecting the negatives best worth enlarging. Knowing they will require the same filters and exposure, you cut down frustration and waste.

The KODAK EKTACOLOR FilterFinder Kit, comprising the gray card you'll be including in the summer's test negatives, the FilterFinder, the Locator, a calculator dial, a "Color Space Map" for guidance in cases where none of the 96 squares comes out neutral on the first test print, and detailed instructions, is available from dealers in professional photo supplies. They also sell *Basic Developing, Printing, Enlarging in Color* (Kodak Publication No. AE-13) and the more advanced *Printing Color Negatives* (No. E-66). Might even be a good idea to check out those books first.

A little sidelight

We proudly announce that this way of appreciating color photographs as much in the doing as in the seeing came in through the company suggestion system. John T. Phelps, the young man who devised it and who will be appropriately rewarded, was joined by a retired Kodaker, Robert P. Speck, in applying those 96 tints to Kodalith film by means of the venerable Kodak Dye Transfer Process. Even today with the presently available color-sensitized papers, that process is still the one to use when quality matters above all in color prints. Speck is one of the two men who worked it out before joining Kodak. Some day you may graduate to it.

Kodak

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SCIENCE AND THE CITIZEN

Long March

China has set out on "a new Long March" to catch up with the most highly developed countries in science and technology. The objectives and proposed methods are set forth in a draft "Outline National Plan for the Development of Science and Technology 1978–1985," which was proclaimed and strongly endorsed by the country's political leadership at an unprecedented National Science Conference held in Peking in the spring. The conference marked a major turning point in Chinese policy. It identified the mastery of modern science and technology as the crux of the "four modernizations" (in agriculture, industry, defense and science and technology). Its principal speakers extolled the key role of scientists and other intellectual workers, called for a policy of "letting a hundred schools of thought contend," endorsed international scientific and academic exchanges and the value of learning from other countries and implied that research and technological innovation should be guided more by scientific considerations and somewhat less by ideological dogma. They charged that the "gang of four," the group that is said to have made an unsuccessful bid for power after the death of Mao Tse-tung, "had intense hatred for science" and "persecuted and tormented intellectuals," thus setting back Chinese science and the country's modernization.

The new eight-year program was put before the 6,000 delegates to the science conference by Vice-Premier Fang Yi, minister in charge of the State Scientific and Technological Commission. "Our revolution needs science," he said. "So does production, and the people need it too. If we are eager for socialism, we should also be eager for science and technology. No one who is against science can possibly be a revolutionary." Fang said China now lags 15 to 20 years behind the most highly developed countries in many areas "and more still in some others." By 1985 the country should narrow the gap to 10 years or so, he said, and it can catch up with or surpass developed-world levels by the year 2000. The plan lists 108 "key projects" in 27 areas. Fang gave top priority to eight broad fields.

1. Agriculture. A survey of all resources is to be accomplished within three to five years. Scientific farming should bring about a large increase in output. Traditional intensive-farming techniques should be accommodated to mechanization. Low-yield farmland accounting for a third of the country's acreage can be upgraded by improving alkaline, lateritic and clay soils, preventing erosion and combating sandstorms and drought. Projects are to be developed for diverting water from the south to the north. Other objectives include biological nitrogen fixation, improved seed strains and crop varieties, effective insecticides that are harmless to the environment and basic research in agricultural biology.

2. Energy. Oil and gas exploration is to be extended; about 10 new large oil fields should be developed. Major coal mines should be mechanized. Coal gasification and liquefaction should be studied. Research should be pressed in hydroelectric power, including "huge dams and giant power-generating units." Atomic power plants should be built; research should be conducted in solar, geothermal, wind-power, tidal and controlled-fusion energy processes. "People in all professions and trades should... lower energy consumption."

3. Materials. Steel is "the key link in industry." Methods of beneficiating hematite ore are required. China should become "one of the biggest producers of titanium and vanadium in the world." New lightweight building materials incorporating industrial waste materials should be designed. New synthetic materials based on petroleum, natural gas and coal should be developed. Special "compound materials" are required for national defense.

4. Computers. Within three years the industrial production of large-scale integrated circuits should be under way and China should make "a breakthrough in the technology of ultralarge-scale integrated circuits." A line of computers should be in production; by 1985 there should be "a fair-sized modern computer industry." Microcomputers will be "popularized." Some industrial production will be computer-controlled.

5. Lasers. China will build "experimental lines of optical communications," study laser-induced nuclear fusion and apply laser technology "in all departments of the national economy and national defense."

6. Space. Emphasis is laid on communications and scientific satellites and on research in remote sensing. China will "actively carry out research in the launching of skylabs and space probes."

7. High-energy physics. "We expect to build... a proton accelerator" with a capacity of 30 to 50 GeV within five years and a larger one by 1988, by which time there should be "a modern high-energy physics experimental base." This is "a key project on the nation's list of research centers."

8. Genetic engineering. "Our country has only a rather weak foundation in this respect." After three years of basic studies and laboratory construction, the new techniques should be combined with studies in molecular biology, molecular genetics and cell biology. Genetic engineering (recombinant-DNA techniques) should be applied "to treat certain difficult and baffling diseases and evolve new high-yield crop varieties capable of fixing nitrogen."

Fang went on to describe broad objectives in the organization and administration of education and research. "It is imperative to remove from leading bodies those persons who are politically bad and make political 'earthquakes,' persons who belong to the 'weathervane school' and the 'slippery school.'" He warned that "it is not at all a proletarian policy to disregard priorities and forbid people to become top-notch." Leading workers should be given time for advanced study at home and abroad. "Technical titles should be restored, the system of individual responsibility established." People who make important contributions to knowledge should be rewarded. "Moral encouragement should be the main form, but there should also be proper material rewards.... Free contention among different schools should be encouraged and fostered in science. Imposing one particular school and banning another by administrative fiat can only hamper the development of science. Truth develops through contention."

Twelve Percent

At the beginning of this year the U.S. had 68 operable nuclear power plants in 26 states. Two more plants have reached the operating stage so far this year. The plants in operation last year accounted for about 12 percent of the country's electric-power generation; their total output was nearly 250 billion kilowatt-hours, a rise of 31 percent over the amount of power generated by nuclear plants in 1976.

The data have been assembled by the Atomic Industrial Forum, which also issued a map showing the locations of the plants that were operable at the beginning of 1978 and of other plants that were under construction or have been proposed (*see illustration on page 78*). According to Carl Walske, president of the Forum, it would have taken 120 million tons of coal, 425 million barrels of oil or 2.6 trillion cubic feet of natural gas to duplicate the contribution that nuclear plants made to the country's power supply in 1977. Walske also cited

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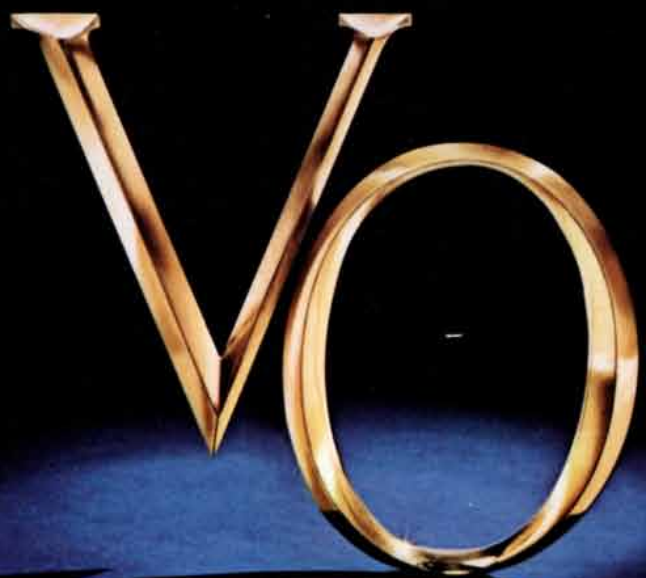

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To assemble the *Coins of All Nations* collection, The Franklin Mint is making special arrangements with the central banks or monetary authorities of more than 150 coin-issuing nations—and with the postal authority of each of those nations as well. Every nation that regularly mints and issues coins will be represented in this collection, except where government regulations prohibit. The result will be a comprehensive collection of uncirculated mint-fresh coins that otherwise could only be assembled if one were to actually travel to every coin-issuing country in the world.

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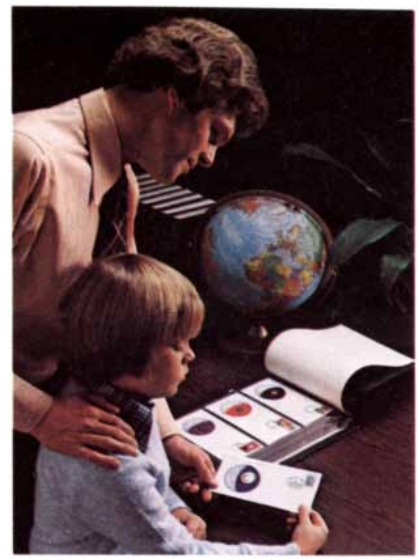
Fascinating coins from distant lands

Each coin will be both attractive and



interesting in itself. The *50 Centavos piece of Mexico*, bearing the portrait of the heroic Cuauhtemoc, last of the Aztec rulers. The *5 Paisa coin of Pakistan*, an unusual four-sided coin with the star and crescent of the Moslem faith. The *Papua New Guinea 1 Kina coin*, depicting the rare sea crocodiles native only to this lush Pacific land. The *2 Dollar coin of Hong Kong*, featuring the famous coinage portrait of Queen Elizabeth II by Arnold Machin. The *50 Ore coin of Sweden*, designed around the crowned monogram of King Gustaf VI Adolf. And the *5 Drachmai coin of Greece*, bearing the image of the Greek philosopher Aristotle. More than 150 coins in all, each one telling a fascinating story.

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production costs (per kilowatt-hour) of 1.5 cents for nuclear power, two cents for coal and 3.9 cents for oil. He noted that nuclear plants now generate more power than hydroelectric plants, and he predicted that within five years nuclear fuel will be second only to coal as a source of energy in the U.S.

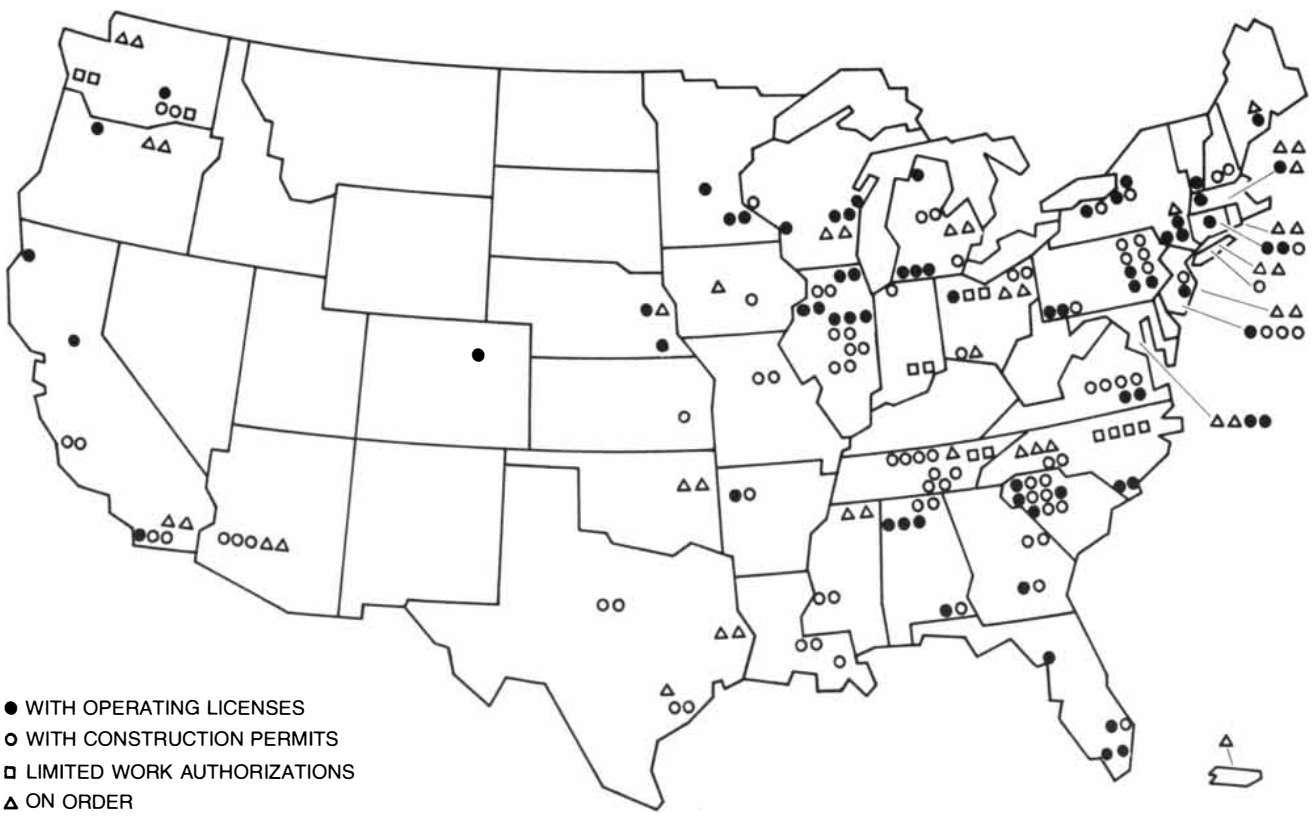
The Presidents' Report

The bond of mutual dependency that has existed since World War II between the Federal Government and the nation's major research universities (the 100 or so doctoral-degree-granting institutions where most of the science is done in the U.S.) has been severely strained in the past decade, but there are signs that it may be due for a renewed commitment on both sides. Beginning in 1968, when the extraordinary postwar growth of the Government's role in the funding of scientific research reached a peak, Federal expenditures for basic research, measured in constant dollars, have fallen substantially, dropping by almost 15 percent between 1968 and 1976. Since the universities rely on the Federal Government for approximately 70 percent of the money they spend on scientific research, university research programs have felt the brunt of that reduction.

The drop in Federal support for university science was accompanied by an uneven redistribution of the available funds. The falloff from previous maximum funding levels amounted to 20 percent in chemistry, 30 percent in physics and engineering, and more than 40 percent in astronomy. The life sciences fared somewhat better, declining by only 7 percent. (The compensating gain here was mainly in the area of medical research, financed through the National Institutes of Health.) The only significant increase during this period was in support for environmental sciences, which rose by about 13 percent.

The general decline in Federal support for basic research seems finally to have halted, and in the fiscal year 1978 the level of Federal support for university-based research is expected to rise by approximately 12 percent in current dollars. Inflation will cut that increase to perhaps 6 percent in constant dollars, however, so that by the end of this fiscal year the increase will still have made up less than half of the decline in constant dollars from the peak that was achieved a decade ago.

The problems presented to university administrators as a result of this erratic funding history have been compounded by a number of other factors. For example, the decline in Federal support has been particularly severe in funds provided for equipment and facilities, causing a deterioration that many scientists feel is beginning to affect the quality of their work. University investigators also complain of being hampered by the unpredictability of Federal funding, by the growing emphasis on the "targeting" of Federal research grants in the expectation of obtaining quick results, by increasingly complicated regulations, by accumulating administrative burdens and by attacks on the established peer-review system of awarding Federal grants purely on the basis of scientific merit. The stringent financial pressures felt by the universities and the anticipation of a decline in the college-age population owing to long-term demographic trends have combined to limit the possibilities for the promotion of younger scientists, thus driving many of them into less creative research environments. Meanwhile the Federal Government, acting mainly through the Office of Management and Budget, has in the view of many university administrators and scientists consistently misapplied the concepts of the commercial marketplace to the university campus. Thus, for example, the OMB has adopted a general policy of opposition to Federal grants for the support of graduate students (apparently on the grounds that the benefits are primarily private, not social), and the number of doctoral fellowships funded by such grants, which totaled 50,000 per year a decade ago,



Nuclear power plants operable, under construction or proposed at the beginning of 1978

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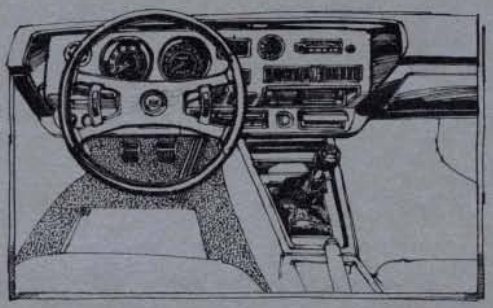
Motor Trend Magazine's Import Car of the Year. The Toyota Celica. A car which meets or exceeds all 1980 Federal fuel economy and safety standards. And the car which best met Motor Trend's criteria for Import Car of the Year. A car with comfort, style, efficiency and durability. The 1978 Celica GT and ST Sport Coupes and GT Liftback (not pictured).



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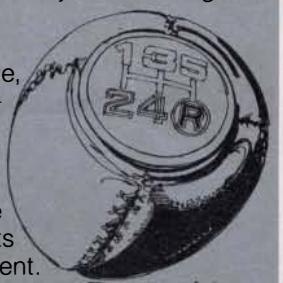

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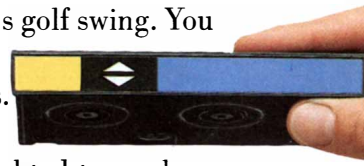

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3. In seconds, your instant movie appears on the screen. (That simple-looking cassette has actually recorded in breathtaking detail the images you saw through the viewfinder.) The picture is sharp, the colors rich and clear. There's no projector or movie screen to set up, no threading or winding. To start the player, you just drop in a cassette. Children can entertain themselves indefinitely replaying the cassettes. Treat your family to a Polavision system. Enjoy the new experience of making instant movies, and start building a living diary of the memorable moments of your life.

SIMULATED PICTURE

POLAVISION FROM POLAROID

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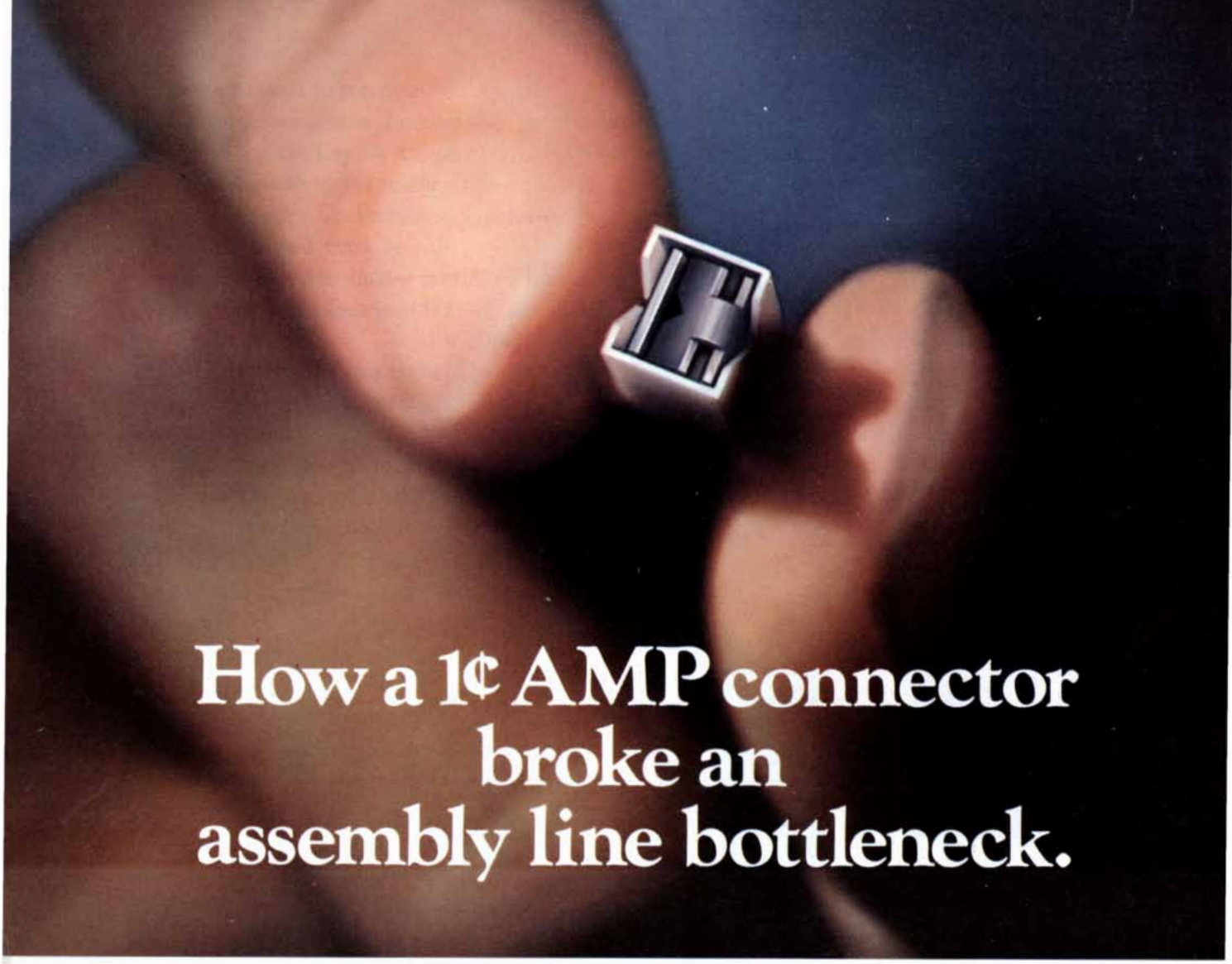

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has fallen to less than 15,000 annually.

Vexed by these and other widely perceived flaws in the relations between the universities and the Federal Government, the presidents of 15 major universities held a series of meetings last year to discuss the matter. A report based on their deliberations has since been published by the Ford Foundation, one of several private foundations that sponsored the group's working sessions. In the preface to that report the university presidents call for "a renewed and stronger partnership between the government and the major research universities," adding that "because of the inescapable financial realities of the situation, we believe a modest increase in Federal funds must be a part of that renewal."

The report, titled "Research Universities and the National Interest," makes a number of specific recommendations. In the area of "human-resources support" the university presidents recommend "a substantial increase in the number of merit-based National Science Foundation Fellowships, from 500 new starts each year to 2,000." In the event that the proposed increase in these three-year fellowships is delayed, they urge "the immediate annual provision of 1,500 new one-year fellowships, to cover students in their first year of graduate work." In addition, the report proposes that "a selected group of unusually promising younger scientists be designated as 'national scientists' and be awarded a high degree of support." It is further recommended that "these scientists be permitted to choose the institutions in which they wish to work, and, with the agreement of the institutions, be offered regular faculty appointments." In a related proposal the report recommends the establishment of a new system of merit-based awards to distinguished senior scientists.

To encourage "longer-term planning" and to promote "the greatest possible degree of stability, flexibility and effectiveness" in Federally aided research projects, the university presidents go on to recommend that a number of specific new funding mechanisms be incorporated into Federal grant procedures. They also propose that all agencies supporting research in universities "follow the practice of the National Institutes of Health in providing overhead payments out of funds . . . designated for the direct support of research projects."

On the issue of project awards for equipment the group proposes that "Congress provide additional funding of $100 million a year for the next three years to be allocated to academic departments or research centers for the purchase of equipment." Furthermore, the Federal Government is urged to increase the percentage of project awards devoted to equipment "from the present 5 percent level to the 10–15 percent range of a few years ago." The allocation of another $150 million a year is requested for the renovation of existing university research facilities.

Other recommendations pertaining to basic research in the university presidents' report are aimed at strengthening "pluralism" in the funding of university research by various Federal agencies, at developing improved methods for long-range planning in the support of university research and at providing "new opportunities for dialogue" between representatives of the universities and the Federal funding agencies.

In a separate section of the report devoted to graduate education the university presidents list a corollary set of recommendations calling for increased Federal aid in the form of fellowships, research assistantships, traineeships, loan programs and special programs for increased participation in scientific research by minority groups and women. The report also contains sections on ways to strengthen the major research libraries of the country and to help the research universities achieve competence in international studies and research.

What is essential in all of this, the report concludes in an overview of the current state of relations between the major research universities and the Federal Government, "is to turn away from mistrust and back to the concept of partnership, away from misplaced short-run standards and back to the idea of excellence, away from profit-and-loss accounting and back to the rousing conviction that there can be no good and free society, still less a great one, where the university's not-for-profit science and scholarship do not flourish."

The 15 signers of the university presidents' report are Derek C. Bok, Harvard University; William G. Bowen, Princeton University; Kingman Brewster, Yale University; Robert Christy, California Institute of Technology; John E. Corbally, University of Illinois; Dale R. Corson, Cornell University; Robben W. Fleming, University of Michigan; William C. Friday, University of North Carolina; Richard W. Lyman, Stanford University; C. Peter Magrath, University of Minnesota; William J. McGill, Columbia University; David Saxon, University of California; John C. Weaver, University of Wisconsin; Jerome B. Wiesner, Massachusetts Institute of Technology, and John T. Wilson, University of Chicago.

Test-tube Potatoes

The potato differs from other major food crops in that the edible portion of the plant is a tuber, the swollen fleshy

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Above: *Footed Bowl.* The exact purpose of this five-thousand-year-old Egyptian "walking bowl" remains somewhat of a mystery, but perhaps it is significant that many centuries later, a bowl with feet was used as the hieroglyph "to bring." The Museum's copy, like the original, is unglazed terracotta burnished by hand. Diameter 5". Price $15.00, shipping $2.00. Add state and local taxes for delivery within N.Y. State.

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portion of an underground stem. Each tuber bears spirally arranged buds ("eyes") that can develop into new individuals identical to the plant that bore the tuber. This vegetative, or asexual, form of propagation is exploited commercially to achieve mass production of the identical offspring of a single superior plant.

Now James Shepard and Roger Totten of Kansas State University have developed a new means of propagating the potato: they induce single "naked" cells from the leaves of mature potato plants to grow in tissue culture and give rise to whole plants. The naked cells, or protoplasts, are released from the leaf tissue by means of enzymes that digest the cell-wall material that holds the cells together. When the protoplasts are placed in the appropriate medium, they begin to form new cell walls and to divide, yielding a tiny callus of undifferentiated tissue. A shoot then emerges from the callus and eventually develops into a mature plant. Several thousand potato plants have already been generated by this method. Although tobacco and carrot plants have previously been grown from single somatic (nongerm) cells, this is the first time that the "cloning" technique has been applied to a major crop plant.

Mendelian genetics would predict that since cloning is a form of asexual reproduction, the leaf protoplasts of the potato plant will develop into new individuals with characteristics identical to those of the parental type. Unexpectedly although many of the clones closely resemble the parental strain, about 25 percent of them have a physical appearance that is quite different. Some have two pistils (the female flower part), some have narrower leaves or reduced lengths of stem between the leaves and others look more like climbing ivy than potato plants. It is not yet understood how the clones can give rise to properties that are not expressed by the parental plant, but the process may involve regulatory genes, cytoplasmic factors or a loss of chromosomes in the course of the cloning process.

Shepard and Totten have done most of their experiments on the "Idaho" potato (*Solanum tuberosum* L. cv. Russet Burbank), which is the most prized of the North American varieties because of its large size, pulpy interior, high protein content and russeted (textured) skin. Selected from plants developed by Luther Burbank nearly a century ago, it is the variety preferred by families for baking and by processors for preparing French fries and potato chips. As a result the Russet Burbank occupies more acreage than any other type of potato in the U.S. The variety is a tetraploid, that is, it has four sets of chromosomes. For this reason it has been virtually

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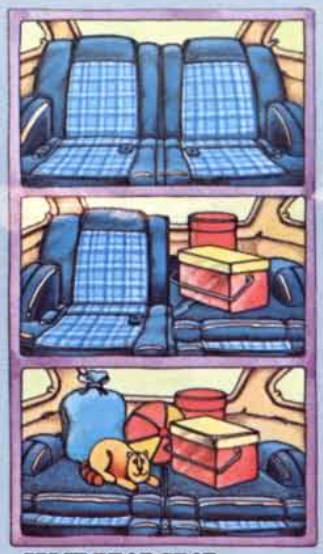

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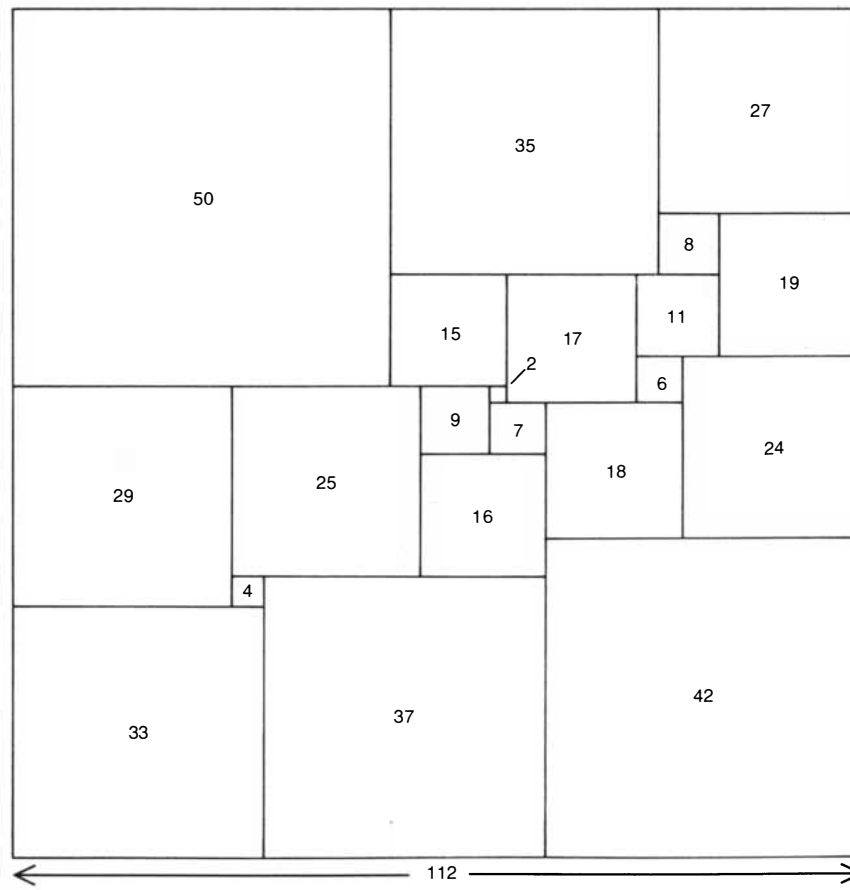
impossible to improve the Russet Burbank by traditional plant-breeding techniques without losing some of its desirable characteristics. Moreover, the variety is extremely susceptible to several important plant diseases, including late blight (which decimated the Irish potato crop in the late 1840's), early blight and a variety of other disorders caused by fungi, bacteria, viruses and nematodes.

Ulrich Matern and Gary A. Strobel of Montana State University, in collaboration with Shepard, have isolated two toxins from the early-blight fungus (*Alternaria solani*) that together elicit all of the symptoms of the disease. When they applied the toxins to the leaves of some 500 protoplast-derived clones of a Russet Burbank plant, they noted a wide variation in the resistance of the clones, ranging from the death of the leaves to total resistance. The trait for early-blight resistance could be passed on from generation to generation by vegetative reproduction, indicating that the resistance characteristic, once obtained, was not lost during asexual reproduction. Strobel and Shepard believe that by generating mutant clones of the Russet Burbank it should be possible to improve the plant "not only with respect to disease resistance but also in terms of the number of tubers, plant size and shape, and tuber quality."

Pluperfect Square

A perfect, or squared, square is one that is completely made up of smaller squares, no two of which are the same size. The first perfect square was discovered in 1938 by a group of four mathematicians at the University of Cambridge. The square was divided into 69 smaller squares, and so it was said to be a perfect square of order 69. Many other perfect squares have been discovered since, but now, 40 years after the discovery of the first perfect square, perhaps the most interesting perfect square of all has been discovered. A. J. W. Duijvestijn of Twente University of Technology in the Netherlands has found the perfect square of the lowest possible order.

Duijvestijn employed a highly sophisticated computer program to obtain a perfect square of order 21: a square 112 units on a side, divided into 21 different smaller squares (*see illustration below*). For some time it has been known that there are no perfect squares of order 20 or less, but until now no perfect square had been found of an order less than 24. The discovery of the new per-



The lowest-order perfect square, discovered by A. J. W. Duijvestijn

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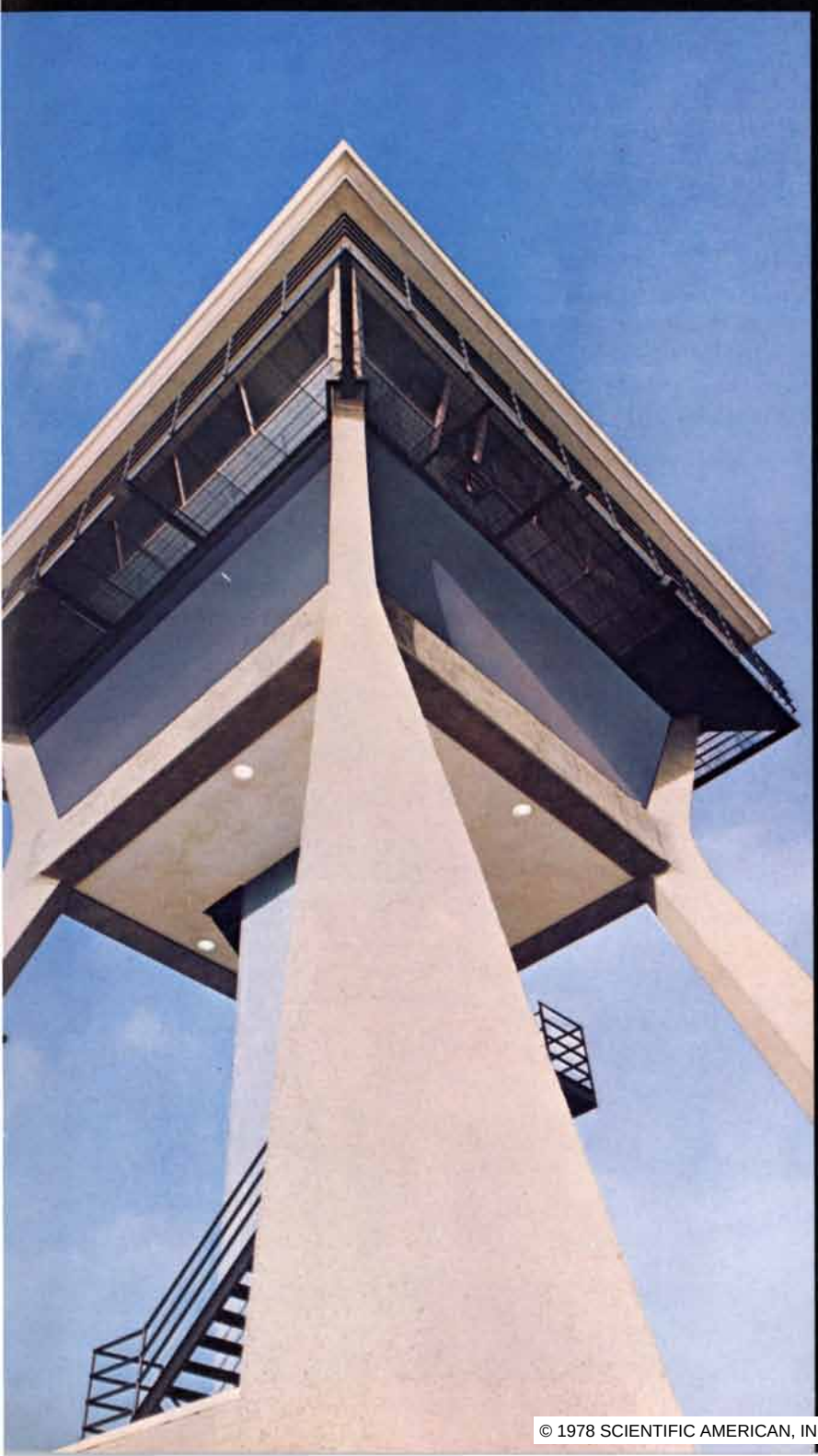

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fect square indicates that the lowest possible order of a perfect square is 21. Duijvestijn was also able to show that his order-21 square is unique. Thus his square is the one perfect square with the lowest possible order, that is, no square will ever be found that is made up of as few different squares or fewer.

Déja Vu

In a period when even the American Association for the Advancement of Science has provided a forum for the discussion of paranormal "phenomena," it is instructive to learn about a not dissimilar vogue for the paranormal a century ago in Russia. Arguing during the 1870's in favor of the reality of the paranormal were a number of respectable Russian men of science, and the main opponent of their view was none other than Dmitri Ivanovich Mendeleev, creator of the periodic table of the chemical elements. Writing in *Proceedings of the American Philosophical Society,* Don C. Rawson of Iowa State University summarizes the debate.

"Scientific" spiritualism, phenomenologically rooted in the physical evidence of levitation, automatic writing, phantom music, table rapping and the materialization of ectoplasm under the supervision of certain influential "mediums," had its main beginnings in the U.S. of the 1840's. The movement caught on in England within a few years, where it resulted in the formation of the Society for Psychical Research in London. It then spread to the Continent, including Russia. Rawson notes that one of the earliest Russian converts was another famous chemist; like Mendeleev, he taught at the University of St. Petersburg, and he was second only to Mendeleev in international reputation. This was Aleksandr Butlerov, whose opinion in favor of the physical reality of the spiritual world had been influenced by the enthusiastic espousal of this point of view by such famous British scientists as the physicist and chemist Sir William Crookes and Alfred Russel Wallace, who with Charles Darwin pioneered the doctrine of organic evolution.

Among other Russian proponents of spiritualism was Aleksandr Aksakov, a student of the 18th-century scientist-theologian Emanuel Swedenborg, and Nikolai Vagner, a professor of zoology at the university. Vagner in particular joined Butlerov in pressing for the scientific investigation of spiritualist phenomena.

Mendeleev, a skeptic, pressed in the same direction. He persuaded the physical society at the university to set up a 12-member investigatory commission in May, 1875. Over a period of months the members of the commission attended séances in St. Petersburg that were conducted by British mediums imported by Aksakov for the occasion. In 1876 Mendeleev was able to embark on a lengthy lecture circuit with the findings of the commission as his subject matter.

Several hypotheses had been framed by the commission. First, it was hypothesized that the raps or clicks produced by the mediums might be made by their joints or internal organs, possibly in some unintentional manner. As for levitation, it was hypothesized that table lifting, at least, might result from involuntary muscular actions of the mediums or the spectators. Two other hypotheses were that all the spiritualist phenomena resulted either from the actions of spirits or from fraud. The commission, as Mendeleev firmly declared to his audiences, dismissed all the hypotheses except fraud. "Superstition," Mendeleev told his listeners, "is but assurance based on unfounded knowledge. Science struggles against superstition, as does light against darkness."

Butlerov and his sympathizers continued to push for a further hearing, but by 1878 support for their views had begun to wane. Vagner eventually founded and became the first president of a Society for Experimental Psychology at the university, but the other members of the society resisted his plans to pursue psychic research. It was Aksakov who wrote the epitaph for the movement. "Russia," he declared, "is barren soil for spiritualism."

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If you have an older car that still needs an annual tune-up, what should it include? There are some basic things to be checked: spark plugs, points, condensers, idling speed, and drive belts. It can't hurt to check the air cleaner and fuel filter, tire pressure, and brake fluid, either. And when you do take your car in for a tune-up, don't be shy. Find out exactly what you need and what you're getting for your money.

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Cosmic Masers

Intense radiation at microwave frequencies is emitted by certain nebular regions and stellar atmospheres. It is generated by maser action, which does for microwaves what laser action does for light

by Dale F. Dickinson

The development of the maser 24 years ago as a time-keeping device of unprecedented accuracy and as a means for amplifying faint microwave signals was a technological achievement of the first magnitude. Conceived by Charles H. Townes, the maser exploited the deep understanding of the quantum-mechanical behavior of matter that had been won in the preceding half-century. It is interesting to speculate what radio astronomers would have made of a peculiar signal detected in 1965 from a cloud of hydroxyl molecules (OH) in the Great Nebula in Orion if the maser had not yet been invented. Actually the question is academic, because by then masers were already installed as amplifiers in radio telescopes. Nevertheless, the signal was so completely unexpected in strength that until the puzzle was solved radio astronomers, only partly in jest, referred to the unknown emitting gas as "mysterium." It was finally recognized that gas clouds in the vicinity of nebulas containing bright young stars can function as giant cosmic masers. A few years later masers were also discovered in the dusty atmospheres of aging red stars.

A maser operates by raising a large number of atoms or molecules in a gas to a particular energy (or quantum) state and then stimulating them to tumble simultaneously to some lower energy state. The energy, and hence the frequency, of each photon emitted in the process corresponds exactly to the energy surrendered by one atom or molecule in dropping from the higher state to the lower. The word maser stands for a capsule description of the process: microwave amplification by stimulated emission of radiation. (If the radiation emitted is in the optical region of the spectrum, "light" is substituted for "microwave," whence the word laser.)

Within the past dozen years much has been learned about interstellar and stellar masers. Roughly 300 sources with hydroxyl masers have now been discovered. In addition water masers have been found in association with more than 80 stars. About 80 percent of the stars with water masers that have been searched for hydroxyl emission turn out to have hydroxyl masers as well, which is hardly surprising since the molecules H_2O and OH are chemically so much alike. More recently silicon monoxide (SiO) masers have been identified in the envelopes of variable stars, many of which also harbor water masers and hydroxyl masers.

For a maser to function, some source of energy must "pump" the molecules to a quasistable level, from which they can be stimulated to fall to a lower level. Various pumping processes were originally proposed, including molecular collisions, shock waves and chemical reactions. It now seems certain that in the masers detected in the envelopes of variable stars, and perhaps in other cosmic maser systems as well, the pumping agency is infrared radiation.

The First Hydroxyl Maser

In 1963, two years before the discovery of the baffling signal from the Orion nebula, hydroxyl had been the first molecule ever detected in interstellar space. The hydroxyl molecules in a cloud of cool gas revealed themselves by absorbing some of the radio-frequency energy emitted by Cassiopeia A, the remnant of a supernova explosion. They caused a telltale dip, or absorption line, in the radio spectrum at a frequency of 1,667 megahertz, which corresponds to a wavelength of 18 centimeters. The discovery stimulated a wide search for hydroxyl absorption lines in other regions of space known to be illuminated from behind by strong radio sources. It also seemed possible that hydroxyl molecules might be discovered emitting faintly at 1,667 megahertz if they were present in sufficient density, perhaps in clouds known to be rich in atomic hydrogen (H). No hydroxyl emission was detected, however, from the sites that had originally been thought to be the most promising.

The initial discovery of emission lines from hydroxyl molecules in space was made by radio astronomers from the University of California at Berkeley, who had actually expected to find hydroxyl absorption lines while observing the Orion nebula, a large region of ionized hydrogen some 1,500 light-years away. The reason for their initial perplexity was that the observed emission line not only was far stronger than what anyone had expected to find but also had the unexpected frequency of 1,665 megahertz. Although this line is one of four emission lines that characterize the ground state, or state of lowest energy, of the hydroxyl molecule, it is normally only about half as strong as the 1,667-megahertz line. In the radio spectrum of the Orion nebula the line at 1,667 megahertz was strangely absent. The other two ground-state lines of the hydroxyl molecule lie at 1,612 and 1,720 megahertz, and since both normally have only a ninth the strength of the 1,667-megahertz line in the laboratory, one would not have expected them to be detectable. Reasoning that hydroxyl molecules could not generate a 1,665-megahertz line without generating a much stronger line at 1,667 megahertz, the Berkeley workers resorted to their mysterium hypothesis.

After further study of the Orion nebula emission line and the observation of similar lines in spectra from other nebulas the Berkeley astronomers were forced to the bizarre conclusion that they had found the first natural maser. Any remaining doubt was dispelled when astronomers were able to calculate the apparent temperature of the "masing" regions, that is, the temperature to which a collection of hydroxyl molecules in thermal equilibrium would have to be raised in order for them to emit the quantity of energy observed in the emission lines. Some estimates of the temperature ran as high as 10^{13} degrees Kelvin (degrees Celsius above absolute zero). Since molecules would be destroyed at far lower temperatures, the computed figure clearly indicated that the ordinary rules of thermodynamics did not apply: the emission lines of the

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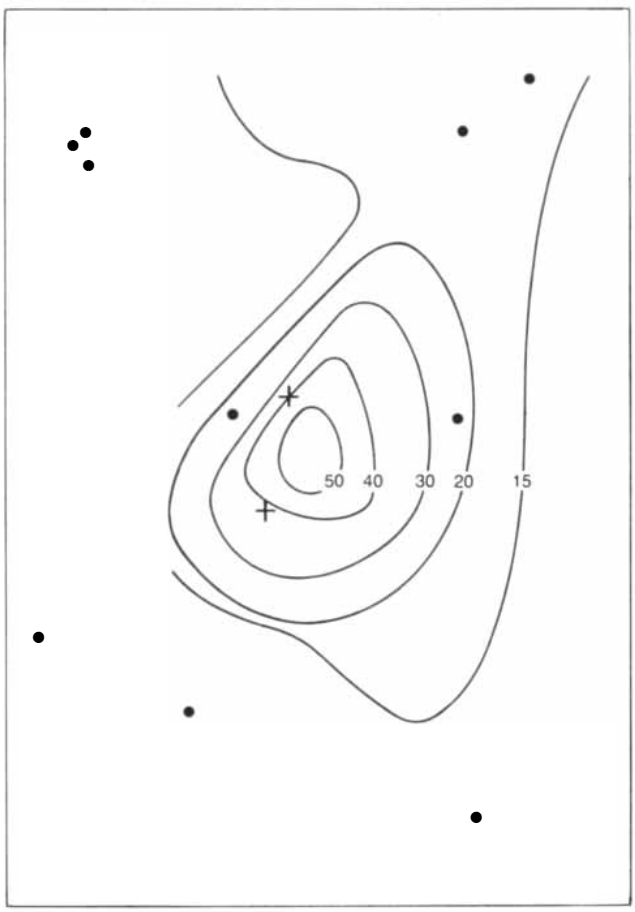
Orion nebula had to be the result of a nonequilibrium process. The only reasonable explanation was a maser.

The Quantum Mechanics of Masers

Let us look somewhat more closely at the quantum phenomena that underlie the maser, man-made or cosmic. Atoms and molecules possess energy that manifests itself in various ways. In the traditional picture of the atom electrons move around the nucleus in simple orbits. In the case of molecules it is somewhat more accurate to visualize the electrons as forming clouds. Since the "nuclei" of molecules consist of two or more atoms, the motions of the atoms themselves can contribute to the total energy of the molecule. The atoms can vibrate with respect to each other; they can rotate, tumbling end over end like tiny dumbbells, and they can also exhibit other weak electromagnetic interactions—all contributing to the molecule's energy. The total amount of energy will vary, depending on the molecule's momentary state of excitation, but quantum mechanics teaches that the energy cannot vary continuously; only discrete energy levels, or steps, are available. When an atom or molecule is excited (gains energy), for example by a collision with another atom or molecule or by encountering a photon of light, it must make an exact quantum jump to a new step in the energy staircase. Conversely, when the atom or molecule is de-excited, it drops back one full step or more and the energy difference is either radiated away as a quantum of electromagnetic energy or transferred directly, through a collision, to another atom or molecule.

The most energetic transitions are those involving the energy levels of electrons, which usually give rise to photons of ultraviolet or visible radiation. Such transitions, which take place in stars and hot gaseous nebulas, are studied by optical astronomers. The least energetic transitions involve the rotations of molecules whose quanta usually fall in the radio region of the spectrum. Such low-energy emissions, which are the province of radio astronomers, emanate from the cooler cosmic regions, such as interstellar clouds or, in the case of some masers, the extended atmospheres of certain types of cool stars.

Masers selectively amplify certain transitions by altering the equilibrium distribution of atoms or molecules in a particular energy level. Ordinarily at a given temperature the molecules in a given sample of gas are in thermal equilibrium, exhibiting a smooth distribution of energies with a peak value characteristic of the temperature. If the temperature is lowered, the average kinetic motion of the particles in the sample decreases, the mean state of excitation falls and the peak of emission drops to a lower energy. If the temperature is increased, the mean state of excitation rises and the peak shifts to a higher value. In thermal equilibrium the overall distribution of the atomic or molecular



INTERSTELLAR WATER MASERS in Messier 17 (the Horseshoe Nebula or the Omega Nebula) in the constellation Sagittarius, are marked by the two crosses. The region appears to be a site of active star formation. The contour lines show the relative intensity of microwave radiation from carbon monoxide molecules. An infrared object, not visible in the photograph, lies near the center of the innermost contour. The object may represent a star in the process of formation. The masers, discovered in 1973 by K. J. Johnston, R. M. Sloanaker and J. M. Bologna of the Naval Research Laboratory radiate strongly at a frequency of 22,235 megahertz (a wavelength of 1.35 centimeters). Several dozen interstellar water masers have now been found. In addition more than 80 water masers have been located in the atmospheres of giant and supergiant red variable stars. In many instances hydroxyl (OH) masers are present in the vicinity of the water masers.

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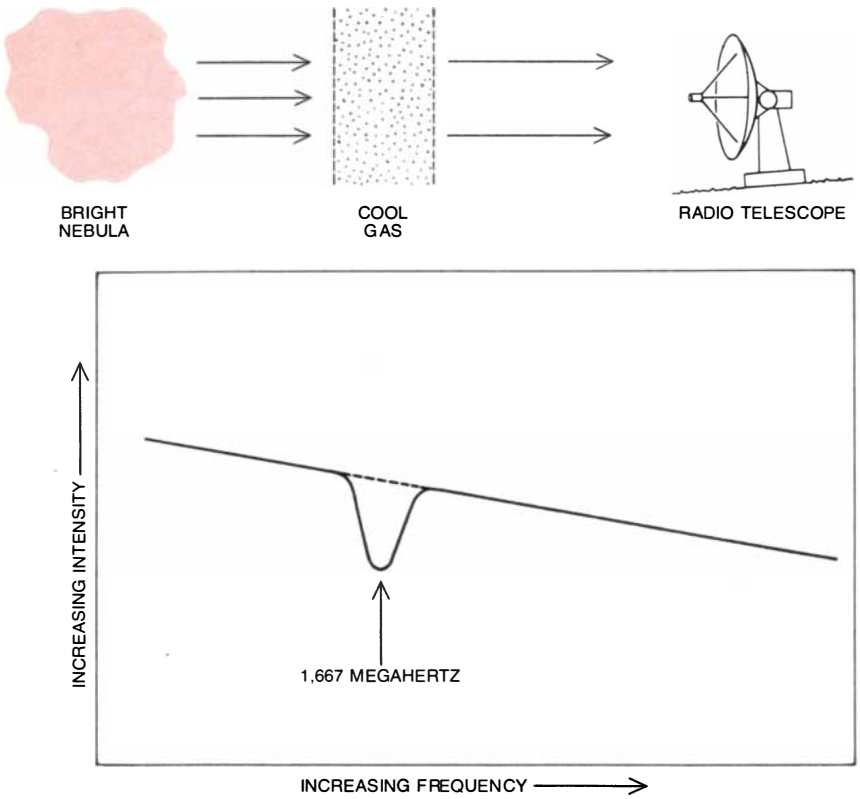
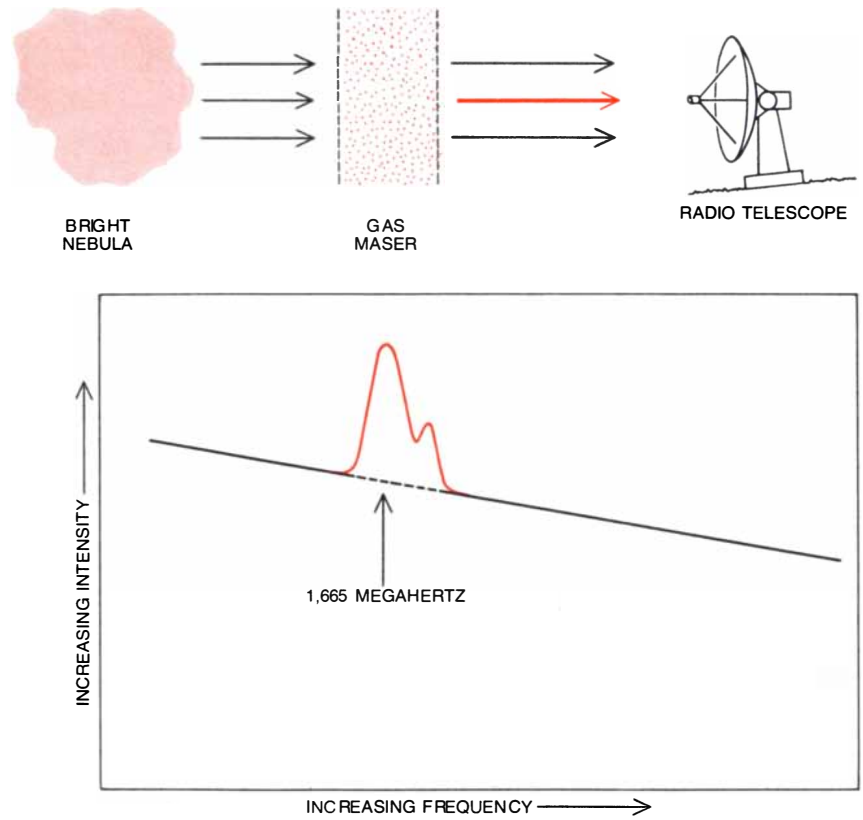


ABSORPTION LINES are formed when a cloud of cool gas absorbs some of the radiation from a bright nebula or similar source. The radiation is absorbed at a frequency characteristic of molecules in the gas, in this case hydroxyl molecules, with an absorption line at 1,667 megahertz. Width of absorption feature is a measure of velocity dispersion of molecules in the gas.



STRONG EMISSION LINE is observed if a cloud of gas contains a maser system. In this case radiation from the nebula excites a hydroxyl maser to emit a beam of radiation at a frequency of 1,665 megahertz rather than at the normally stronger frequency of 1,667 megahertz.

energy levels is determined by the kinetic temperature of the sample.

Maser emission can occur if the equilibrium situation is violated in such a way as to overpopulate a particular energy level so that it contains many more molecules than would be expected from the kinetic temperature of the gas. The creation of an overpopulated state is referred to as an inversion of that energy level. Such inversions can come about in low-density interstellar clouds, which typically contain only 10^3 to 10^7 molecules per cubic centimeter (as compared with about 10^{19} in the air we breathe). Because collisions between molecules are infrequent they do not always dominate the excitation of the gas as they do for a gas in thermal equilibrium. Departures from equilibrium populations can arise, "inverting," or distorting, some energy levels.

Such inverted populations can be created in two ways: by collisions or by the influx of radiation. In either case the gas can be made to absorb energy in a highly selective way. To be most effective the input energy itself must fall within a narrow range, consisting, in idealized cases, of photons predominantly of a single frequency or, for a collisional process, a beam of electrons nearly all of the same energy.

It is now believed that most cosmic masers are pumped by radiative processes. A typical example of such a pumping process is found in the "three level" maser. A molecule in level 3, the highest of the three levels, exhibits a high probability of spontaneously losing energy and decaying, often by cascading downward through many intermediate levels to level 2. On reaching level 2, however, the molecule has only a relatively small chance of spontaneously decaying to level 1. The gas can be pumped to level 3 if radiation corresponding in frequency to the transition from level 1 to level 3 is fed into it. Many molecules will absorb the energy, jump to level 3 and quickly radiate away some of the newly acquired energy as they cascade back to level 2. In this way level 2 is inverted, or overpopulated, making it ripe for maser action.

A molecule in level 2 has an affinity for a quantum whose energy is equal to the energy difference between levels 1 and 2. Like a boulder balanced at the top of a cliff, it needs only a small push to cause it to tumble to level 1 and radiate away a quantum of energy equal to the quantum that triggered its emission. If that happens, the two quanta traveling through the cloud can now induce two other molecules in level 2 to radiate. The two quanta beget four, the four eight and so on; the original quantum is amplified millions of times as the wave of radiation propagates through the gas cloud, feeding on the ready supply of molecules in level 2. Thus the maser process concentrates much of the

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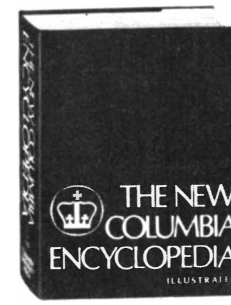

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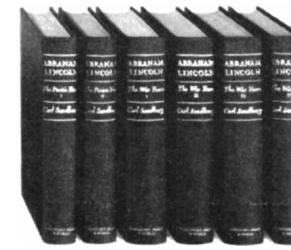

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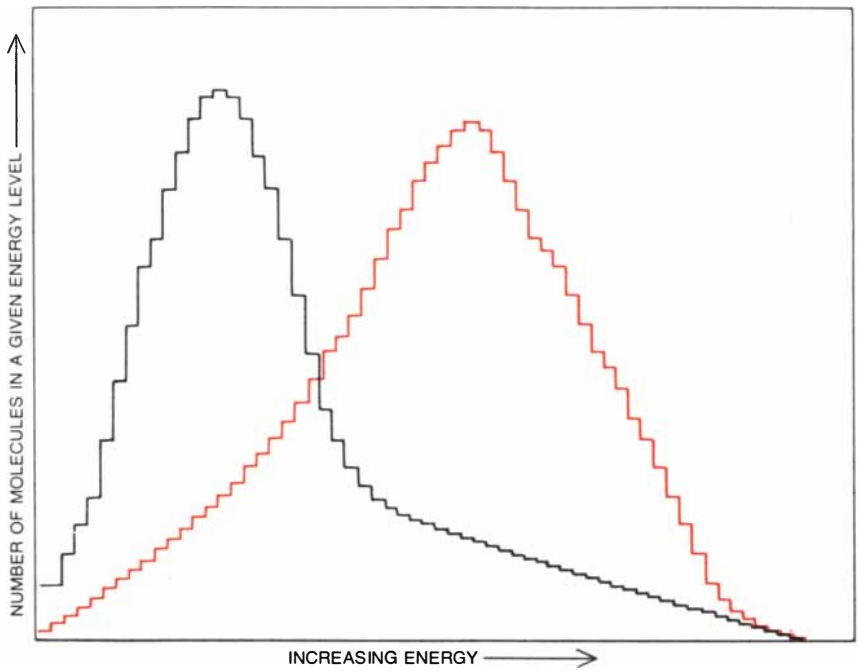
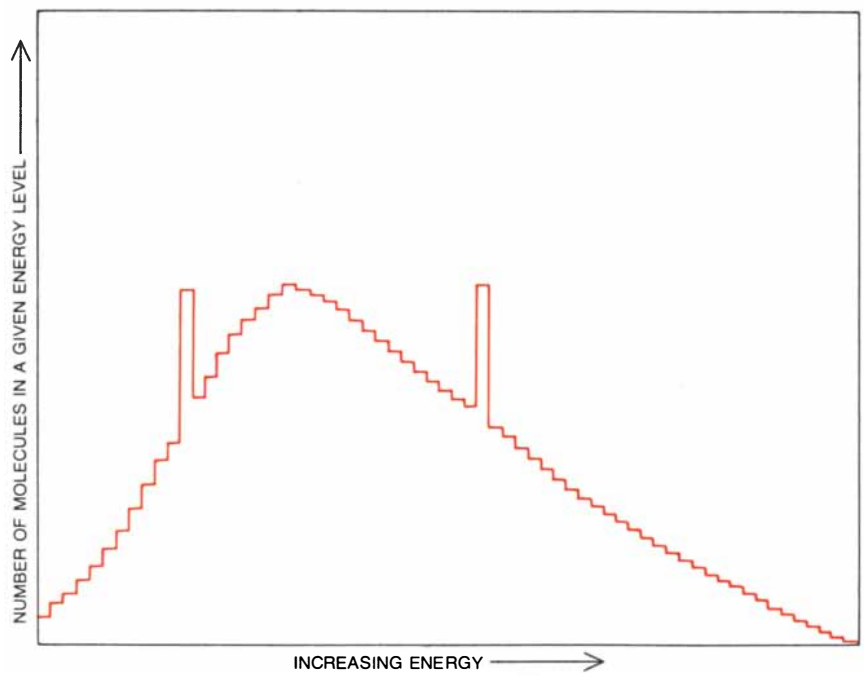
cloud's energy in a beam that is intense, highly directional and at a single frequency.

Molecular-Maser Stars

Since cosmic masers are such a recently discovered phenomenon, there is still much to learn about them. So far the masers that are best understood are those associated with a special class of old, dying stars known as red variables. The first stellar maser was detected in 1968, when William J. Wilson and Alan H. Barrett of the Massachusetts Institute of Technology observed strong hydroxyl emission from several red variable stars. These are stars that have consumed most of their hydrogen fuel and have left the "main sequence" of stable stars. With the depletion of their hydrogen the stars start losing the internal pressure needed to counterbalance the gravitational attraction of their own mass. Periodic shock waves eject matter into the surrounding interstellar medium as the stars themselves grow alternately brighter and dimmer.



THERMAL EQUILIBRIUM in a hypothetical population of gas molecules is represented by a smooth distribution of energy states around some mean value. At low temperatures most of the molecules are concentrated in low energy levels (*black curve*). As temperature goes up distribution moves toward higher levels (*color*). Such populations are said to radiate thermally.



NONTHERMAL EQUILIBRIUM is brought about when certain energy states (here two states) have gained an unusually large population of molecules at the expense of the others. Such "inverted" states are source of nonthermal radiation by masers, man-made or natural.

Such stars fall roughly into two classes. The Mira Ceti variables (named for the prototype of the class, whose variability was first described in 1597) are "giant," long-period variable stars whose cycles are quite predictable, typically 200 to 500 days. The second class consists of the larger, more luminous "supergiants," with less regular periods ranging from 500 to 1,000 days.

With the exception of novas and supernovas, the red variables lead the most cataclysmic lives of all stars. Every pulsation belches gas and dust into an extended circumstellar atmosphere, an atmosphere whose dimensions are comparable to those of the solar system. (The radius of the parent star could also well exceed the distance from the sun to the earth.) It is here in the circumstellar cloud that the maser emission originates.

A key property of those variable stars with maser emission is their color. The sun, whose surface temperature is about 6,000 K., radiates most intensely at a wavelength of about .5 micron, in the yellow-green region of the visible spectrum. The long-period red variable stars are much cooler, around 2,000 K., and most of their radiation is shifted into the invisible infrared region of the spectrum, with a peak intensity near 1.5 microns. Recently developed infrared techniques have enabled astronomers to probe this previously inaccessible spectral region. A major finding is that all the variable red giants and supergiants are characterized by a strong "infrared excess," that is, they radiate more infrared radiation than would be predicted from their visible spectra. The source of the infrared excess is the surrounding atmosphere of dust and gas that is expelled by the star and is therefore much cooler than the star itself. With a typical temperature of several hundred degrees K., scarcely above the boiling point of water, the shell of gas and dust radiates strongly at wavelengths in the region of 10 to 20 microns.

As we have seen, the hydroxyl molecule in its ground state normally emits radiation most strongly at 1,667 megahertz, about half as strongly at 1,665 megahertz and very weakly at 1,612 and 1,720 megahertz. In the large majority of stellar hydroxyl masers the most intense emission is at 1,612 megahertz, completely dominating the lines at 1,667 and 1,665 megahertz, which in-

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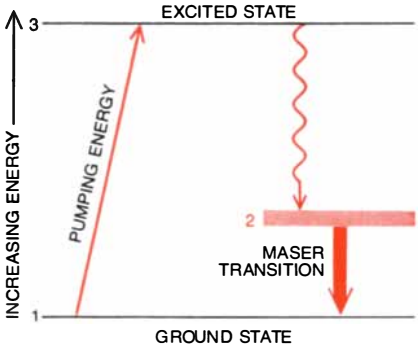

"THREE LEVEL" MASER illustrates the maser principle. A molecule in the ground state (*1*) absorbs energy by collision or radiation and is "pumped" to a much higher level (*3*). The molecule spontaneously loses some of its new energy and cascades perhaps through several intermediate levels before arriving at a quasistable state (*2*). Energy level 2 is thereby inverted. If the molecule is now struck by a photon whose energy exactly matches the energy between level 2 and level 1, the molecule will drop to level 1, releasing an identical photon of its own in the process of doing so. In this way one photon becomes two, two become four and so on, to yield exponentially growing number of monoenergetic photons.

deed are often absent. The line at 1,720 megahertz is never seen at all.

The second molecular species to be discovered in a maser associated with a star was water, which was found to be emitting at 22,235 megahertz, corresponding to a wavelength of 1.35 centimeters. In 1969 a strong water maser was observed in the star designated *VY* in the constellation Canis Major in the southern sky. Since then more than 80 stars with water masers have been discovered.

The third kind of molecular maser observed in variable stars exhibits emission lines of silicon monoxide (SiO), principally at 43,122 megahertz (6.95 millimeters) and 86,243 megahertz (3.47 millimeters). The discovery of strong emission at these frequencies was startling, because silicon monoxide is one of the least abundant molecules yet detected in space. Indeed, the discovery was the result of luck and shrewd detective work on the part of Lewis E. Snyder of the University of Illinois and David Buhl of the National Aeronautics and Space Administration. One of the silicon monoxide lines appeared in the frequency "window" of their instrument as they were searching for another molecule in the Orion nebula. A quick frequency check revealed that the signal was in the instrument's lower side band, a frequency range to which their receiver was sensitive but that was totally outside the range of interest.

Careful mapping of the celestial region revealed that the source of the emission was pointlike, as would be expected for a maser. The silicon monoxide line had multiple features that precluded an easy estimate of the emission frequency. A difficult and detailed comparison with the Orion nebula water maser, however, yielded clues that eventually led to a frequency that agreed with a known rotational transition of the silicon monoxide molecule. Surprisingly it was not a ground-state transition but a rotational transition found when the molecule is in a highly excited vibrational mode, requiring temperatures greater than 1,000 degrees K. for a significant molecular population.

The combination of a rare molecular species and an odd, highly excited state made for considerable skepticism. One astrophysicist ventured the guess that the source might be a maser but that it could not be silicon monoxide. Another averred that it was probably silicon monoxide but that it could not possibly be a maser! Vindication came when John H. Davis and Patrick Thaddeus, working at the University of Texas Millimeter-Wave Observatory, detected two adjacent rotational lines of silicon monoxide at 43,122 and 129,363 megahertz, confirming beyond any doubt that the original identification by Snyder and Buhl was right.

Doppler-shifted Masers

The molecular-maser stars have now been monitored for some years, and one of their most striking characteristics is the variation of their visible, infrared and hydroxyl-maser emissions. The variation in the visible emission of the star is periodic, rising and falling smoothly every several hundred days. Monitoring of the infrared flux has shown that it closely follows the variations in the visible emission. The intensity of emission from the OH masers has now been followed for a number of stars, and it too varies in phase with the visible emission. The situation with regard to emission from water masers is less well defined. Only a few stars have been closely monitored. Two show variations well synchronized with the visible emissions. One star shows an ambiguous relation, and in a fourth star the water and visible emissions are if anything anticorrelated.

The various spectral lines associated with the maser stars are commonly shifted upward or downward in frequency according to the velocity of the emitting source, thus providing important information about the structure of the star and its surrounding atmosphere. If the maser cloud is moving toward us, the frequency is shifted upward; if the cloud is moving away, the frequency is shifted downward. Astronomers are always alert for such Doppler shifts in frequency. Here the total spread in velocity may be as little as a few kilometers per second or as much as a few tens of kilometers per second.

The hydroxyl emission lines nearly always fall into two groups of differing velocity. The clear inference is that two masers are involved, one in the front of the circumstellar atmosphere as it is blown away from the star and the other in the back. Although masers are undoubtedly distributed spherically in the stellar atmosphere, maser beams are highly directional. Stellar masers evidently produce a "forward" beam and a "backward" beam displaced by 180 degrees. The orientation of the beam axis seems to be dictated by the flow of stimulating radiation from the central star. Thus only masers lying approximately in the line of sight to the star are observable; those elsewhere in the stellar envelope project their beams radially in other directions. Where water and silicon monoxide masers coexist with hydroxyl masers, their Doppler velocities always fall within the extremes of the hydroxyl-emission groups, sometimes exhibiting a double-peaked structure themselves.

In reconstructing the entire ensemble of emitting atoms and molecules in the star one must also take account of the star's more familiar emission and absorption lines as they are recorded by standard optical techniques. The optical lines exhibit certain distinctive features. For example, the emission lines always show a greater velocity shift in our direction than the absorption lines do, indicating that the emissions originate in matter that surrounds the star in an expanding shell.

I have said that the hydroxyl-maser lines usually exhibit two velocity peaks. If one plots the magnitude of the velocity separation against the pulsation period of the central star one finds them to be correlated in a surprisingly simple way: the longer the period, the greater the velocity separation. The hydroxyl masers associated with the short-period Mira Ceti variables have velocity separations on the order of five to 15 kilometers per second; the hydroxyl masers associated with the long-period supergiants have velocity separations as much as 40 kilometers per second. This remarkable regularity between two seemingly unrelated quantities suggests a degree of order that should eventually contribute to the model-making process. Let us now take what we have learned about the maser stars and see if we can fit the pieces into a coherent picture.

Maser Pumps

We shall separate the effort into two parts. First, what is the energy source that pumps the maser? Second, given a source, can we develop a picture of the stellar system that is host to the maser?

The two most likely pumping mechanisms are collisions and radiation. The hydroxyl-maser intensity changes in step with the light from the star. The

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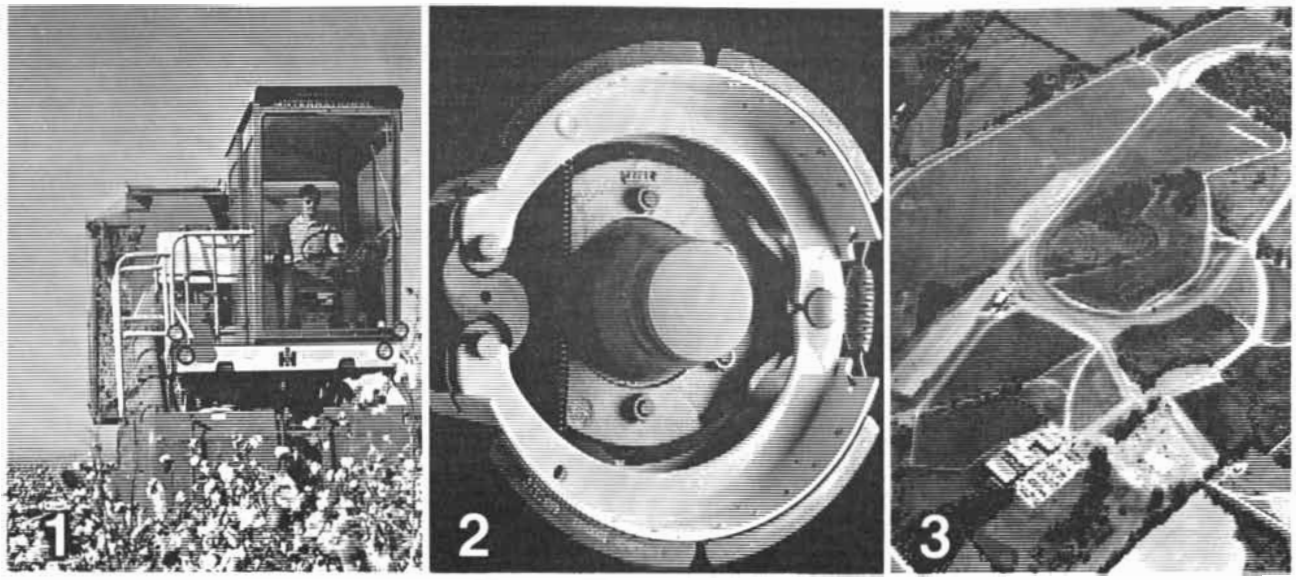

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maser cycle lags behind the light cycle by at most 30 days. This strongly implies that the maser is pumped by radiation, simply because collisions could not propagate quickly enough through the circumstellar cloud to bring about the intensity change in the time observed. For example, the velocities associated with the star and its circumstellar gas are of the order of 10 kilometers per second or less. Even if the radius of the circumstellar atmosphere were as small as 10^9 kilometers (somewhat greater than the distance from the sun to the orbit of Jupiter), the time for a collisional process to work its way through the atmosphere would be about 10^8 seconds, or three years. We must therefore conclude that the stellar maser is pumped by radiation.

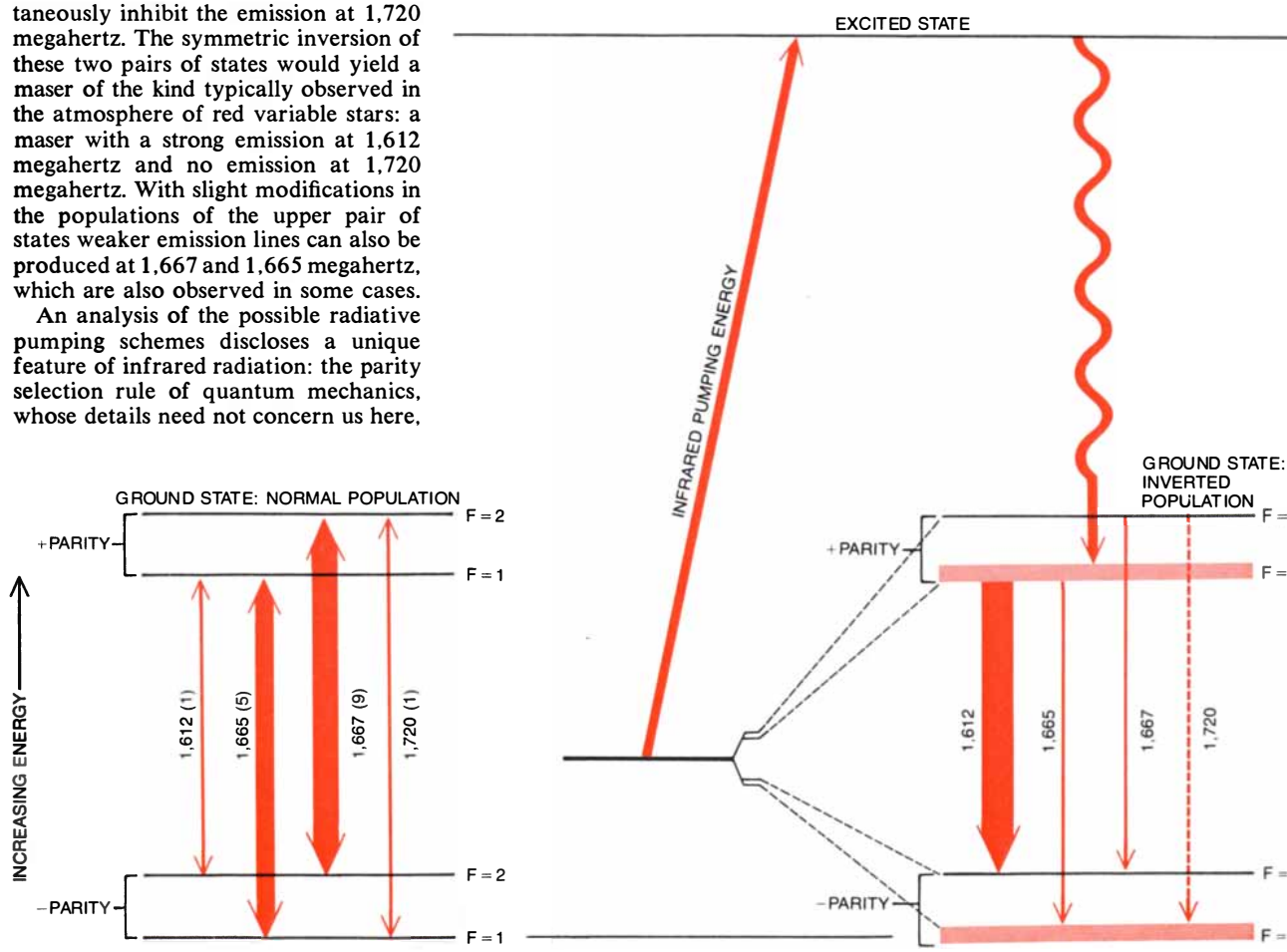
The next question is: What type of radiation is it? Is it visible, ultraviolet, infrared or microwave radiation? An important clue can be found in the character of the hydroxyl emission. In order to make the transition at 1,612 megahertz a strong maser line it is necessary to invert the populations of the two lower states in each half of the ground-state doublet. Such an inversion would simultaneously inhibit the emission at 1,720 megahertz. The symmetric inversion of these two pairs of states would yield a maser of the kind typically observed in the atmosphere of red variable stars: a maser with a strong emission at 1,612 megahertz and no emission at 1,720 megahertz. With slight modifications in the populations of the upper pair of states weaker emission lines can also be produced at 1,667 and 1,665 megahertz, which are also observed in some cases.

An analysis of the possible radiative pumping schemes discloses a unique feature of infrared radiation: the parity selection rule of quantum mechanics, whose details need not concern us here, tells us that when infrared pumping scrambles the populations of the four ground-state levels of the hydroxyl molecule, the inversion of the upper and lower pairs of levels must take place symmetrically in just the way needed to create the observed emission lines. Other radiation pumps are not so constrained, making it virtually certain that the stellar-maser pump is infrared radiation. Although maser mechanisms for water and silicon monoxide have not been studied as thoroughly as the hydroxyl mechanism, those molecules also have infrared transitions to states that could create inverted populations of the kind needed to yield the observed emission lines of water and silicon monoxide. When such analyses are combined with the observed infrared excess in red variable stars, the argument for infrared pumping is compelling.

The Velocity of Maser Stars

The physical setting for the maser is the shell of atmosphere surrounding the variable star. In order to make sense of the velocities of the maser emission lines, as they are measured from the earth, we must pin down the velocity of the parent star in the same frame of reference. This key point has been debated for half a century. The difficulty is that the optical emission lines recorded from the photosphere, or nominal "surface," of the star do not give the true velocity of the star because the photosphere is actually a thick envelope made up of gases moving outward at varying velocities. Terrestrial observers of course see only that part of the photosphere that lies between the star and the earth. If one could somehow see the photosphere on the opposite side of the star and measure its velocity, the average of the two velocities would yield the velocity of the star itself.

This trick has now been accomplished by measuring the Doppler velocity of the ordinary thermal (nonmaser) microwave radiation emitted from the circumstellar atmosphere of gas in several red variable stars. The silicon monoxide molecules in the atmospheric shell are transparent to their own radiation, so



COSMIC HYDROXYL MASERS involve the ground state of the hydroxyl molecule, four closely spaced energy levels (a lambda doublet). When the energy levels are normally populated (*left*), the molecule radiates at four frequencies: 1,612, 1,665, 1,667 and 1,720 megahertz. The relative line strengths are given by the numbers in parentheses. In stellar hydroxyl masers (*right*) a source of pumping energy, in many cases evidently infrared radiation, inverts ground-state population so that strongest emission is typically at 1,612 megahertz instead of at 1,667 megahertz. Although weak lines at 1,667 and 1,665 megahertz are sometimes seen, 1,720-megahertz line is always absent.

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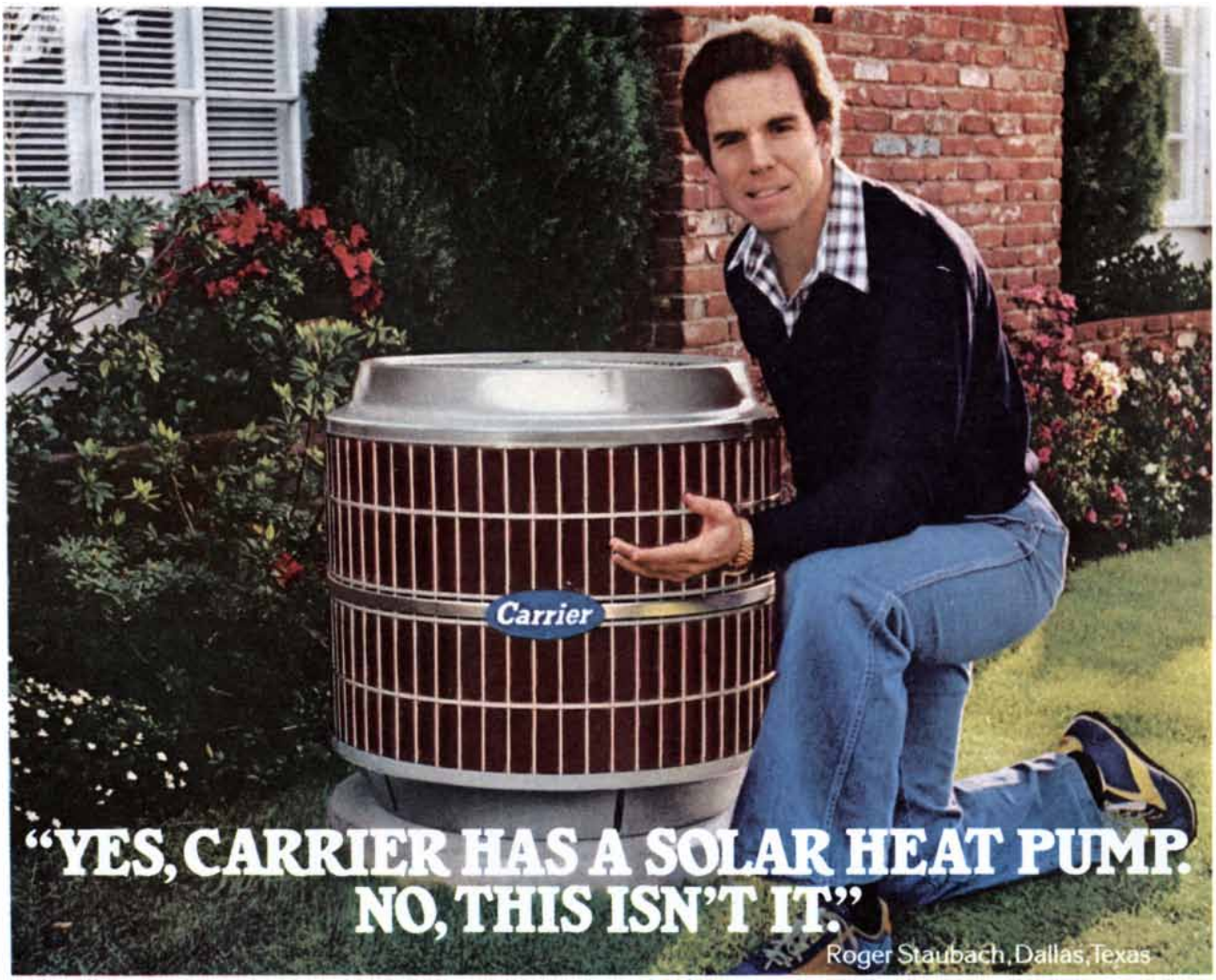

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that the silicon monoxide emission lines from all regions of the expanding shell, near side and far side, can be recorded. Since the shell is ejected more or less symmetrically, the average Doppler velocity must represent the stellar velocity. When Mark J. Reid and I recently measured the thermal silicon monoxide lines in 10 maser stars we found that in every case the lines' average velocity (and hence the stellar velocity) fell near the midpoint of the two hydroxyl-maser peaks. This result at once confirms that the hydroxyl peaks come from the front and rear regions of the circumstellar shell and offers an easy way of estimating the velocity of a star whenever the telltale double-peaked hydroxyl emission is detected.

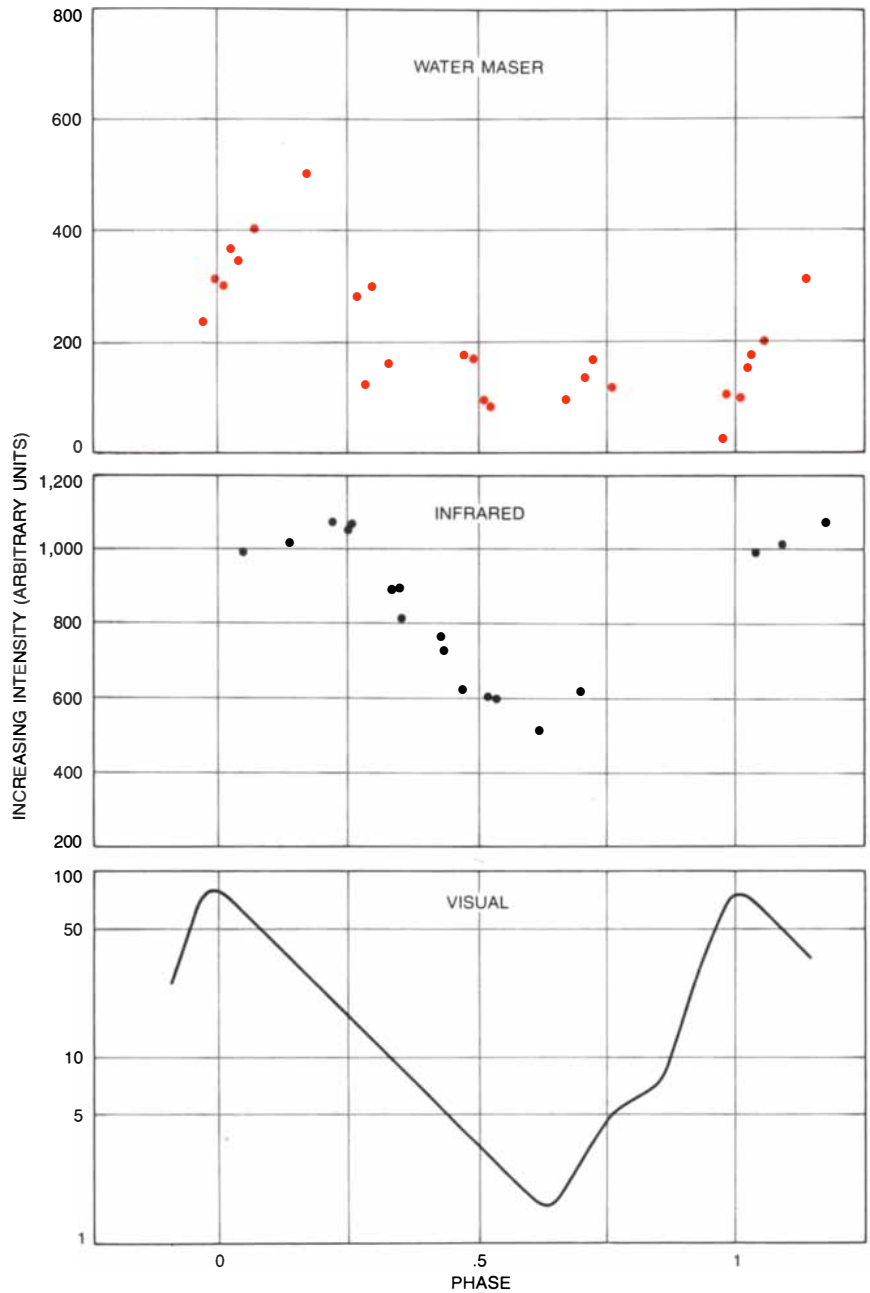
Our observations suggested that it might also be possible to detect the thermal emission from water molecules surrounding red variable stars, but a recent search by Ann St. Clair Dinger of Wellesley College and her co-workers has proved negative. Nevertheless, for variables that exhibit water and silicon monoxide maser emission lines recent observations by Susan G. Kleinmann of the Massachusetts Institute of Technology have shown that the emission peaks are often symmetric in velocity with the stellar velocity determined from the silicon monoxide thermal emission. It is also found that the velocities of the various molecules tend to nest and overlap. Thus the velocity spread for water lines is less than the spread for hydroxyl lines, and the spread for silicon monoxide lines is usually less than the spread for water lines.

A Picture of a Maser Star

Let us now try to develop a picture of a typical red-variable maser star. The diameter of the central star is several hundred times the diameter of the sun. The surrounding atmosphere has a radius somewhere between 10^{10} and 10^{11} kilometers, or as much as 15 times the radius of the solar system. The pressure of radiation from the star accelerates gas and dust outward, slowly at first, then much more rapidly in a transition zone and finally slowly again. In the transition zone the temperature is low enough for gas to begin condensing into dust. The large dust grains tend to sweep the gas rapidly outward, producing a high acceleration, until at some distance from the star the radiation pressure has dropped substantially and the material in the shell encounters interstellar gas and other dissipative forces that bring the acceleration to a halt.

If the atmosphere is to harbor a silicon monoxide maser, it must appear in a shell where the temperature of the gas is still substantial, possibly 1,000 degrees K. The temperatures suitable for a water maser are only slightly lower, and in fact the shells containing the two types of maser often overlap. The hydroxyl masers will be found in the coolest part of the circumstellar atmosphere: in the fastest-moving regions lying beyond 10^{10} kilometers. Within the transition zone, closer to the star, the rapid changes in velocity evidently inhibit maser action.

The model I have described gives a clue to the peculiar correlation between the velocity spread in the hydroxyl emission peaks and the pulsation period of the star. To oversimplify somewhat, we know that the more luminous stars have longer periods. Because radiation pressure is a function of luminosity one would expect the brighter, longer-period stars to have atmospheres with the fastest-moving outer shells, where the hydroxyl masers are located. The faster-



VARIATIONS IN INTENSITY OF WATER MASERS (*top*) in the atmosphere of the red-giant star U Herculis closely parallel the changes in the infrared emission at a wavelength of 2.2 microns (*middle*) and in the output of visible light (*bottom*). The light intensity, plotted here on a logarithmic scale, varies by a factor of more than 40, or slightly more than four magnitudes, during each half cycle. The parallel changes in the infrared radiation and in the water-maser output, both of which are plotted on linear scales, are much smaller. Synchronous behavior of three kinds of emission from U Herculis and similar stars is strong evidence that stellar masers are pumped by radiation (probably infrared) rather than by molecular collisions. Microwave spectra were obtained by Philip R. Schwartz of Naval Research Laboratory, Paul M. Harvey of University of Arizona and Alan H. Barrett of Massachusetts Institute of Technology.

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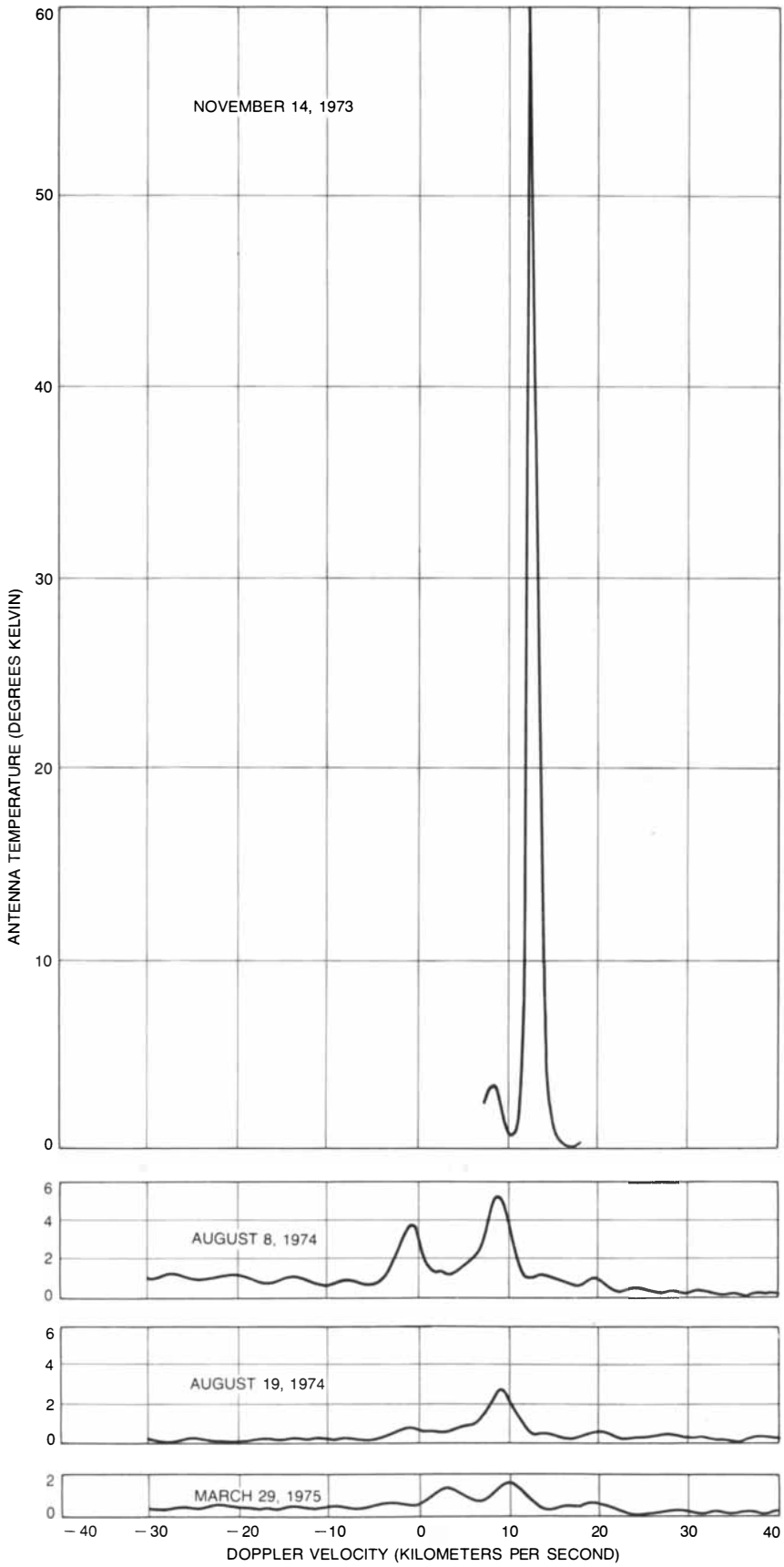

INTENSITY OF WATER MASER in the bright nebula Messier 17 altered dramatically during a 16-month period. In one case large changes took place in a matter of only 11 days. The individual peaks and the general spreading indicate a dispersion of velocities in the clouds containing the maser system. The maser itself emits at a single frequency: 22,235 megahertz (1.35 centimeters). Spectra were obtained by C. J. Lada, C. A. Gottlieb, E. L. Wright and the author.

moving the outer shells are, the greater is the velocity separation between a hydroxyl maser located on the side of the star closer to us and one located on the side farther away from us. The densities and temperatures of the gas within the shells are still not well established, and real stars are seldom as well behaved as the model I have been describing. Nevertheless, observations of stellar masers have provided major clues to the overall nature of the variable red giants and supergiants.

Interstellar Masers

In addition to the natural masers observed in the atmosphere of old variable stars, masers are also found in molecular clouds associated with newly formed or forming stars. In fact, as massive interstellar clouds begin collapsing under the influence of gravity, masers are a milepost on the evolutionary road, appearing as the first bright young stars begin to shine through their cocoon of gas and dust. One well-studied region is in the bright nebula known as Messier 17 in the constellation Sagittarius, where two intense water masers have been found near an infrared object, probably a protostar not yet bright enough to be observed at visible wavelengths. The adjacent maser regions may themselves be sites of undetected new stars. The masers are embedded in a molecular cloud whose dimensions are readily mapped from the emission of carbon monoxide molecules.

Such masers fall neither in the bright nebula region, where intense ultraviolet radiation would dissociate water molecules, nor in the coolest regions of the dark molecular cloud. They seem, rather, to lie within the shelter of the molecular region but always near a source of infrared radiation, which may indeed provide the pumping energy for the maser. In Messier 17 one maser region coincides with a region where the contour lines of carbon monoxide radiation are bunched, possibly indicating the passage of a shock wave produced by stellar ultraviolet radiation. The region of enhanced gas density in the wake of the shock wave may be initiating the condensation of new stars [see "The Birth of Massive Stars," by Michael Zeilik; SCIENTIFIC AMERICAN, April]. Such a speculation may rest on nothing more than coincidence, but several other interstellar water masers have been observed in similar settings.

All in all, less is known about interstellar masers than about the masers in the atmospheres of stars. Although both hydroxyl and water masers are found in interstellar regions, their association is less common than it is in stellar atmospheres. Moreover, when the two types of maser do appear as neighbors in interstellar regions, there is no simple pattern in their relative velocities. The sili-

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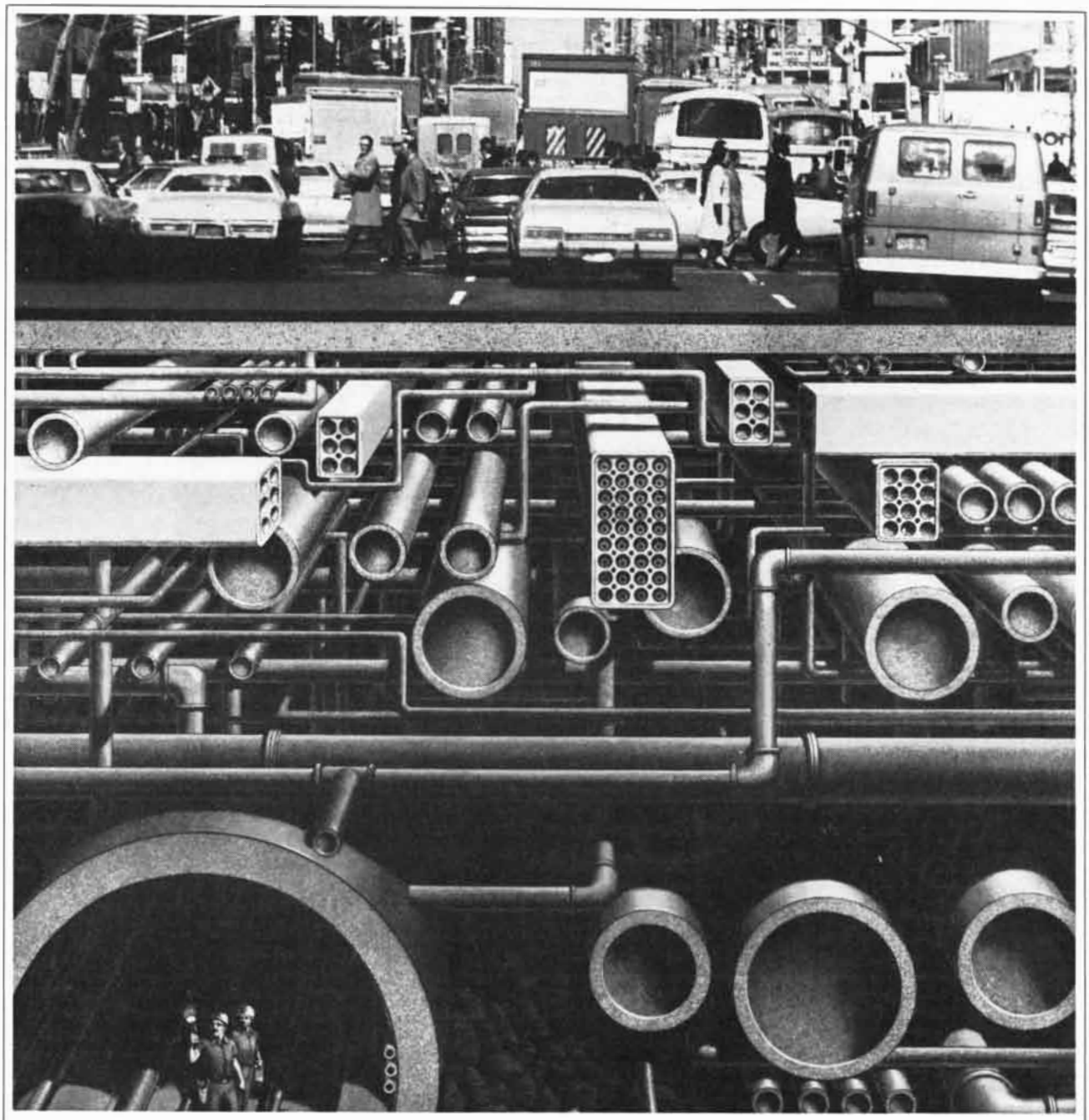

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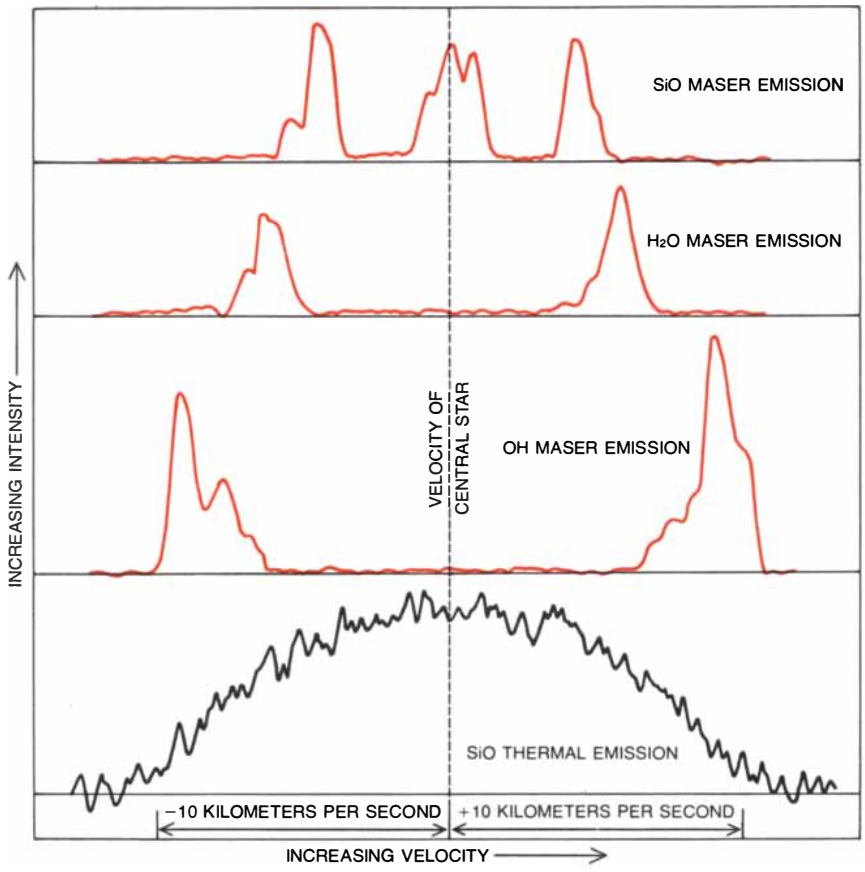
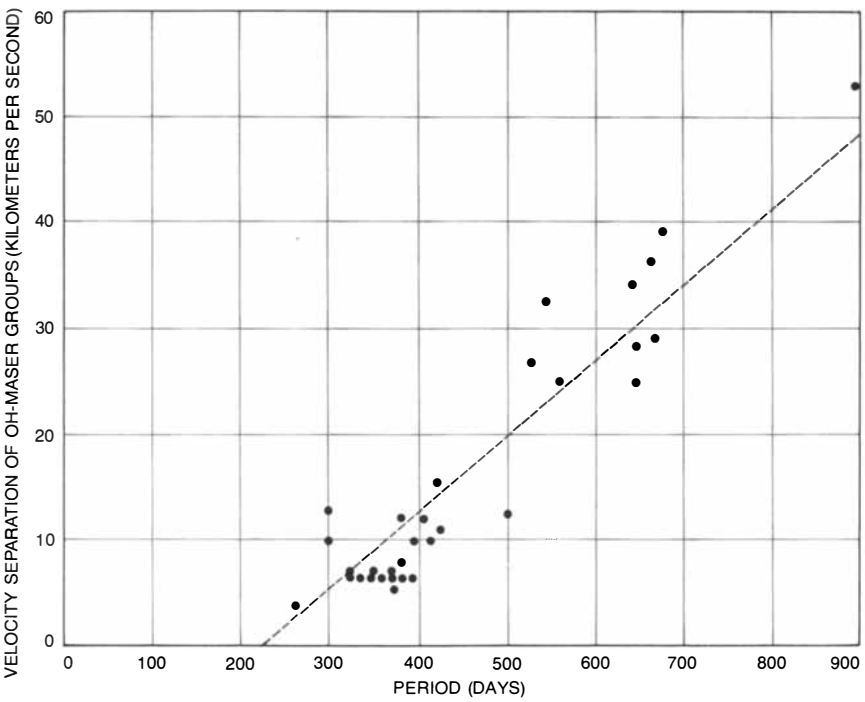


IDEALIZED SPECTRUM OF MASER EMISSION from a long-period red variable star shows emission peaks (*color*) from three types of maser spaced symmetrically on either side of a mean velocity, presumably the velocity of the central star, which cannot be established directly. Recently, however, the thermal (nonmaser) emission from silicon monoxide (SiO) in the gas surrounding 10 maser stars has been observed. Mean velocity of thermal silicon monoxide source, indicative of star's velocity, falls midway between hydroxyl-maser peaks (*black*).



PERIOD OF STARS with hydroxyl masers in their atmosphere correlates well with the separation in velocity between the hydroxyl emission peaks. The longer the period, the higher is the velocity of separation. Separation rate is roughly twice expansion velocity of the atmosphere.

con monoxide molecule is a known constituent of molecular clouds, but it has never been observed as an interstellar maser.

Although the emissions from interstellar masers vary in strength on time scales ranging from many months down to a few days, the variations exhibit no apparent periodicity. In one instance sharp changes were recorded within a 24-hour period. This is in contrast to the intensity of the typical stellar hydroxyl maser, whose level of activity rather closely follows the changes in the light flux of the central star.

Interstellar-maser Pumps

The pumping mechanism in interstellar masers is also not well established. In analogy with the stellar model one might expect the pumping energy to be the infrared radiation emitted from heated grains of dust or perhaps from a protostellar object. Although this is a distinct possibility, the infrared radiation does not seem to yield the symmetrical inversion of population levels that one observes in the stellar hydroxyl masers. In interstellar hydroxyl masers the emission at 1,612 megahertz is present but not necessarily dominant. In some instances the strongest emissions are at 1,665 and 1,667 megahertz, the lines characteristic of normal populations in the molecules. Often the high-frequency line at 1,720 megahertz, which is never seen in stellar masers, is also observed. All one can say with confidence is that hydroxyl and water masers are observed where nature sets the stage for star formation. The maser pump could be infrared radiation, which is abundantly present, but it could also be the ultraviolet radiation from bright, newly formed stars.

Judging from the evidence, with all its current limitations, my personal view—prejudice, if you will—inclines toward the ubiquitous infrared radiation as the pumping mechanism. A simple infrared-photon pump does not, however, give answers as satisfactory as those it gives for stellar masers. A complete picture will probably have to carefully consider the heating of the dust grains in the cloud and will have to account for the unusual differences observed, such as why silicon monoxide never appears as an interstellar maser.

Our overall picture of how stars form is now rather convincing, at least in a qualitative sense. The interstellar maser is present in regions where new stars have formed; it appears to be a harbinger of stellar birth. And in the case of the long-period variable the maser is witness to the final convulsions of a dying star. A better understanding of both types of maser will educate us not only about the physics of cosmic masers but also about the physics of stars and stellar evolution.

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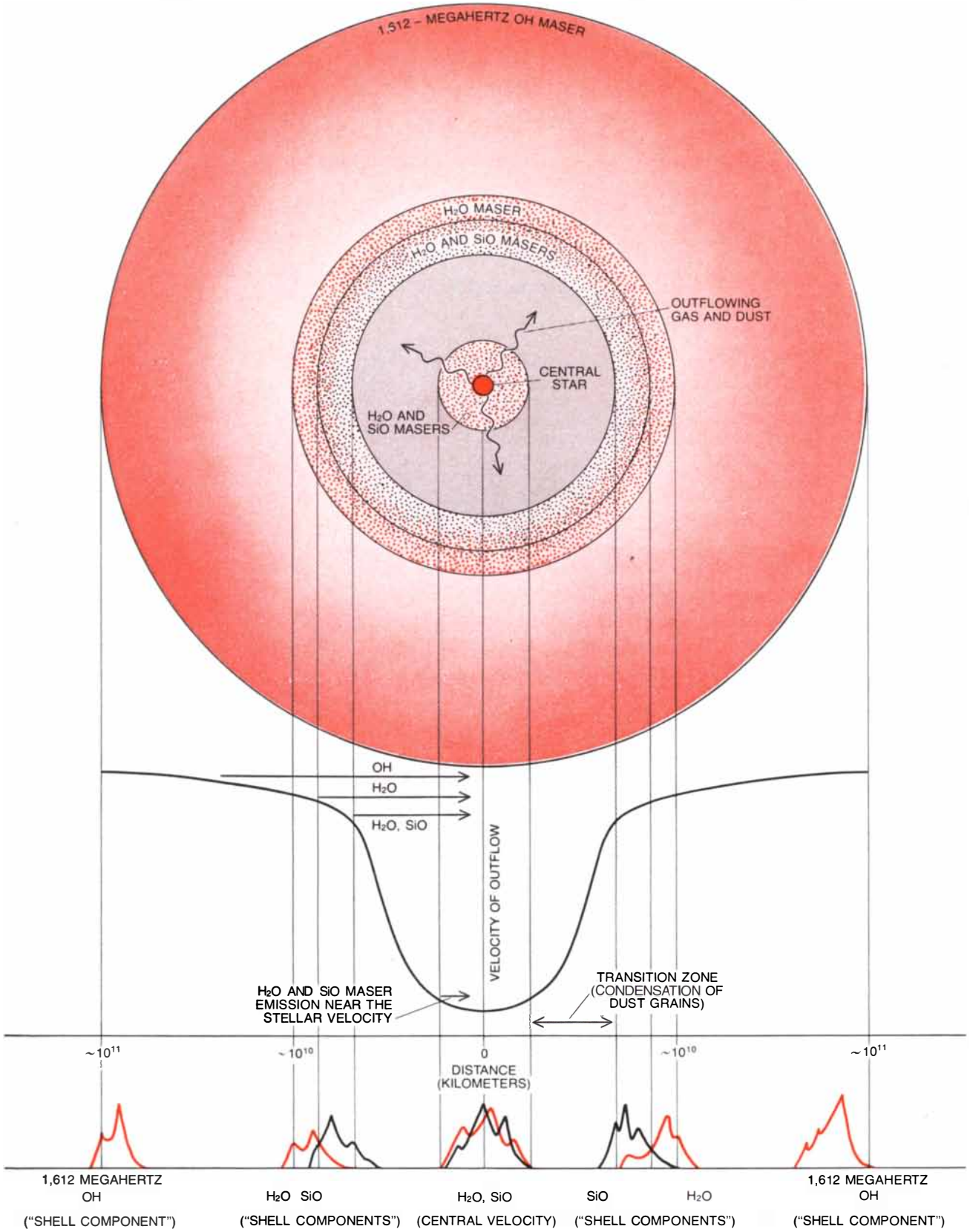

SCHEMATIC PICTURE OF RED VARIABLE STAR shows the apparent distribution of water, hydroxyl and silicon monoxide masers in shells of the atmosphere. Gas and dust ejected from the star are accelerated outward by radiation pressure. The *U*-shaped curve is a "velocity of outflow" profile. Masers are found in regions where the gas is accelerating smoothly and not too rapidly. In the transition zone of rapid acceleration conditions may be too unstable for masers to form. The maser emission profiles are depicted at the radial distance from the star where they are formed. Their relative velocities can be read off the velocity-of-outflow curve. As is explained in the text, the maser emissions that can be observed are confined to "caps" directly in front of and behind the star as it is viewed from the solar system.

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The Shaping of Tissues in Embryos

Computer simulations of development make it possible to perform experiments that cannot be done in the biological laboratory. They help to reveal some of the basic forces that sculpture the embryo

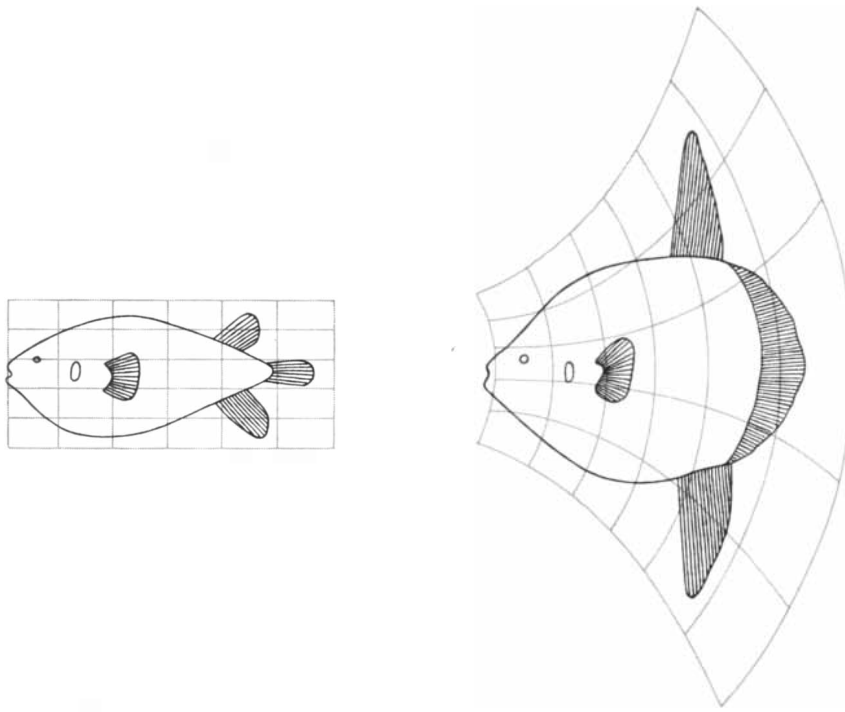
by Richard Gordon and Antone G. Jacobson

After the egg of a higher organism is fertilized it divides into many thousands of cells that arrange themselves into the tissue layers of the embryo. Understanding this elaborate process of embryonic development is one of the outstanding and most difficult problems challenging biologists today. The problem is so complex that it must be broken down into smaller problems before investigation can yield instructive solutions. Therefore in our own work we set out to address the general question of how tissues are shaped in the embryo by analyzing the formation of a single embryonic tissue: the neural plate, the earliest precursor of the central nervous system. The organism we chose for this purpose is the California newt, *Taricha torosa,* which is indigenous to the ponds and streams around San Francisco Bay.

In the first stages of development the successive divisions of the fertilized newt egg give rise to the hollow, single-layered ball of cells called the blastula. Half of the tissue then tucks itself through a slit in the blastula, forming in the spherical embryo two layers: the endoderm and mesoderm. The embryo is now called the gastrula. It is one hemisphere of the outer layer of the gastrula that is destined to become the neural plate. In the course of about 30 hours this hemisphere flattens into a disk and then assumes the shape of a keyhole. The wide part of the keyhole eventually gives rise to the brain and the narrow part to the spinal cord.

In the course of the neural plate's transformation from the disk stage to the keyhole stage its constituent cells move in a complex spatial and temporal pattern. In undertaking to analyze this pattern we made use of a computer simulation to test the adequacy of different modes of cell behavior to explain the observed changes in the shape of the tissue. Writing the simulation program required that we express the behavior of the cells quantitatively and that we make all our assumptions explicit. These requirements led in turn to more precise observations of the living embryo. Through such a process of simulation alternating with observation we began to discern the forces involved in the shaping of the neural plate (and by analogy in the shaping of many other embryonic tissues as well).

The newt embryo was chosen for a number of reasons. It is hardy and tolerant of experimental surgery, and its neural plate is one cell thick, making observation and analysis relatively easy. The embryonic newt cells are large enough to be examined with a low-magnification dissecting microscope, and they contain varying amounts of dark pigment, so that individual cells can be identified and followed during development without the need for stains or other markers. Moreover, each embryonic cell contains its own supply of stored food (yolk), so that it is possible to culture groups of embryonic cells or even single cells in simple salt solutions.



GRID-TRANSFORMATION METHOD was devised by the Scottish biologist D'Arcy Wentworth Thompson, who showed how related organisms could be represented as relatively simple distortions of each other. This illustration, based on one in Thompson's 1917 work *On Growth and Form,* shows the geometrical relations between the porcupine fish *Diodon* (*left*) and the sunfish *Orthagoriscus mola* (*right*). Thompson's grid-transformation method has proved useful in understanding the forces that shape sheets of cells into the tissue layers of the embryo.

The mathematical foundations of our computer simulation go back to the work of D'Arcy Wentworth Thompson of the University of St. Andrews at the turn of the century. In 1917 Thompson published his classic work *On Growth and Form,* in which he proposed that the evolutionary transformation of one species into another is a process involving the entire organism rather than successive minor alterations in the body parts. Thompson represented the transforma-

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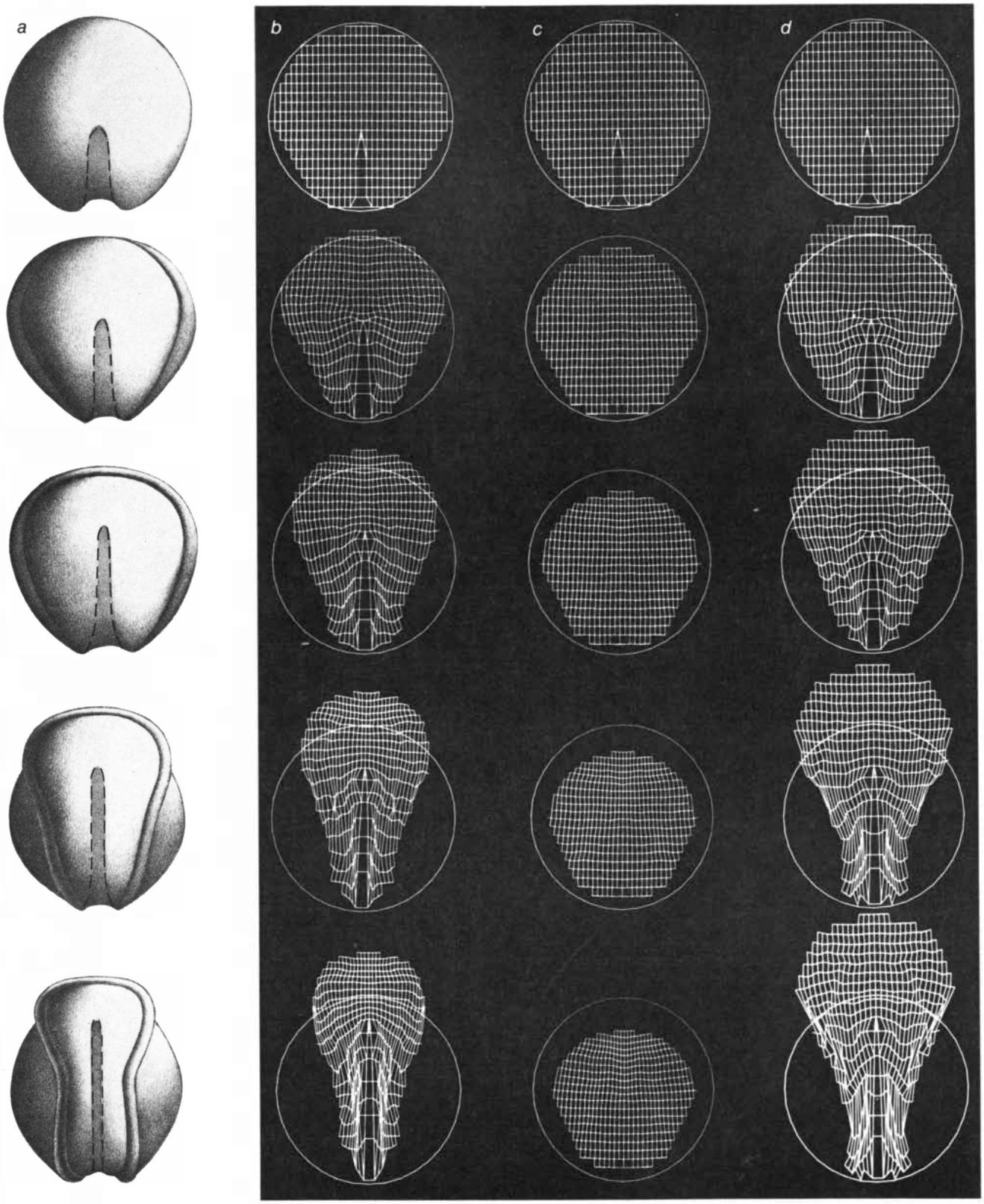

COMPUTER SIMULATIONS shown here were developed by the authors to model the formation in the embryo of the neural plate, the earliest precursor of the central nervous system. The shaping of the tissue is represented as the distortion of a geometric grid placed over the embryo. Column *a* shows a sequence of schematic diagrams of the developing neural plate, derived from a time-lapse motion picture. Column *b* shows a computer simulation that incorporates two forces: nonuniform shrinkage of the neural-plate cells and elongation of the supranotochordal region along the midline of the neural plate. The resulting shape of the transformed grid is virtually identical with that seen in the embryo. In column *c* supranotochordal elongation has been turned off so that the only force is provided by cell shrinkage; the resulting grid is reduced in size but does not attain the keyhole shape. In column *d* cell shrinkage has been turned off so that the only driving force is provided by supranotochordal elongation; this experiment could not be done with the living embryo. Although the grid does attain the keyhole shape, the top end is overlarge. Thus both cell shrinkage and cell movement appear to shape the neural plate.

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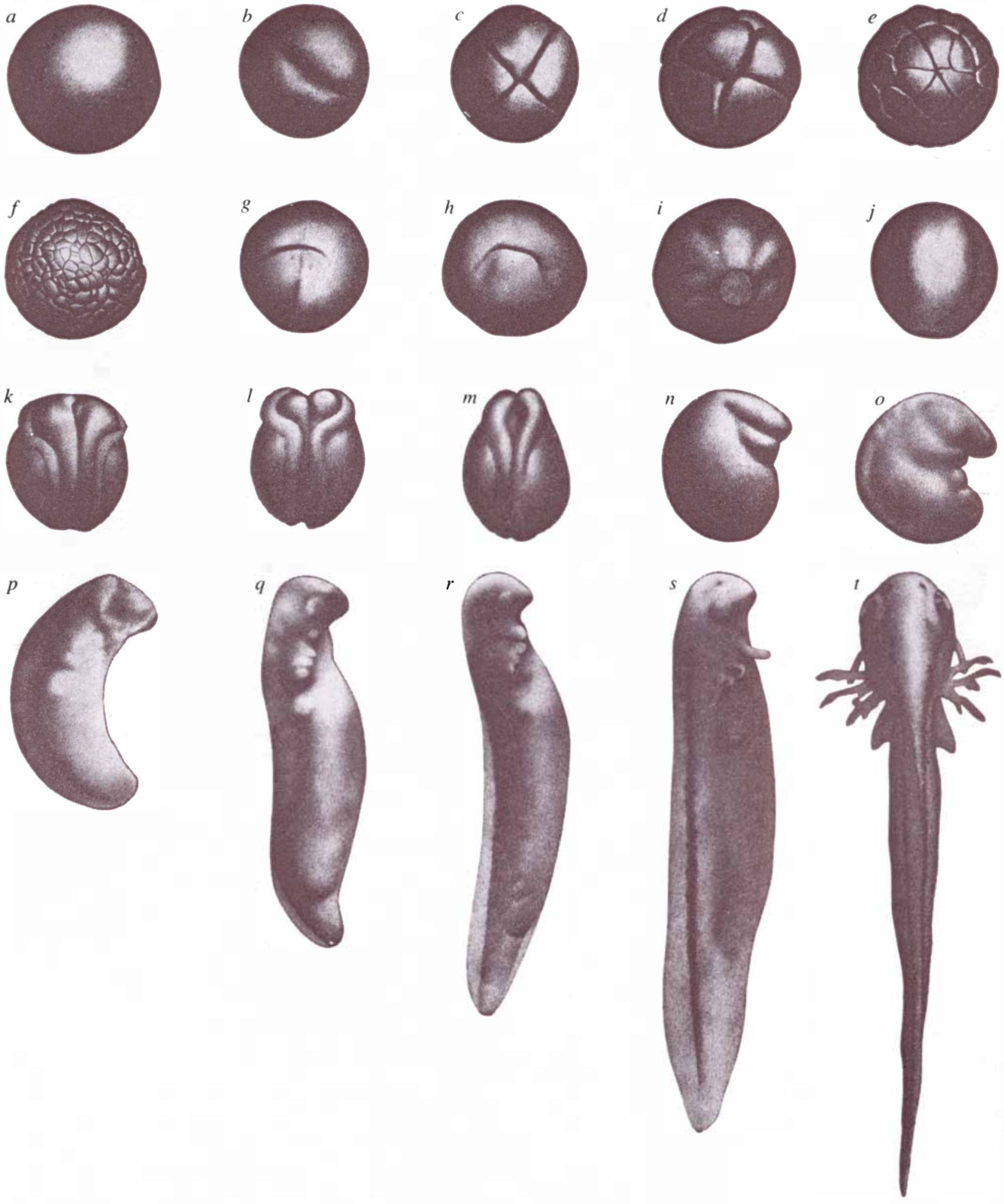

DEVELOPMENTAL STAGES of the California newt *Taricha torosa* are shown in this abbreviated version of a sequence prepared by Victor C. Twitty and Dietrich Bodenstein at Stanford University. First the fertilized egg divides many times over (*a–f*), giving rise to a hollow sphere of cells, or blastula. Then a groove appears below the equator of the embryo (*g*) and gradually deepens to form a spacious internal cavity as more and more surface tissue moves into the interior (*h, i*). This process, termed gastrulation, gives rise to two internal tissue layers: the endoderm and the mesoderm. The mesoderm later forms the main body musculature and the notochord (a rod beneath the embryonic nervous system). One hemisphere of the outer layer of the embryo then flattens into a disk (*j*) and forms itself into the keyhole-shaped neural plate (*k*). At the same time the supranotochordal region of the neural plate and the underlying notochord undergo a considerable elongation and narrowing along the midline. In the succeeding stages the neural plate rolls up to form the neural tube (*l–n*), the eyes develop and the embryo elongates into the larval form (*o–t*). Views *a–f* show the top of the embryo, *g–i* show the bottom, *j–m* and *t* show the back and *n–s* show one side. The newt embryo is particularly amenable to analysis because it is hardy and its cells are quite large.

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tion as the geometric distortion of a grid placed over the organism, resulting in extensive changes in spatial relations. As a consequence two organisms having a common ancestor will have shapes that are related by an often simple transformation. Thompson's method of geometrical transformation has proved to be extremely useful in mathematically analyzing the shaping of embryonic tissues.

In 1968 Mary Beth Burnside, who was then working at the University of Texas at Austin, analyzed the movement of individual pigmented cells in developing newt embryos by following the cells at the intersections of a superposed D'Arcy Thompson grid. By means of time-lapse motion pictures she determined how the geometry of the grid was distorted during the forming of the neural plate. The transformation was remarkably consistent from one embryo to the next: when she superposed the transformed D'Arcy Thompson grids of three different embryos, they overlapped almost exactly. She also observed that the distortion of the neural plate was correlated with shrinkage of the exposed surface areas of the cells, and that the extent of the shrinkage varied over the surface of the plate. As the plate shrank, the surface area of each cell remained inversely proportional to its height (its dimension perpendicular to the sheet). Moreover, the increase in height occurred without growth, with the volume of the neural plate remaining constant during the transformation.

The mechanism by which the neural-plate cells lengthen, or increase in height, and thereby reduce their exposed surface area is understood to some extent. With the aid of the electron microscope Burnside observed contractile microfilaments arranged like a purse string around the top end of each cell. Contraction of the microfilaments appears to be responsible for the shrinkage of the exposed cell surface. Larger fibers known as microtubules are oriented along the cell's length and are essential for its lengthening.

On the basis of Burnside's observations we undertook to devise a mathematical model of the neural plate as a sheet of cells, each cell of which lengthened perpendicular to the sheet while maintaining a constant volume. In formulating a quantitative model of the behavior of a neural-plate cell we had to know whether or not height increase was influenced by the behavior of neighboring cells. We transplanted small groups of neural-plate cells from one area of the neural plate to another, where they lengthened in accordance with their original positions. In 1946 Johannes Holtfreter, working at McGill University, isolated single neural-plate cells and observed that they continued to lengthen when they were cultured in laboratory glassware. His observation has been confirmed by Burnside. Therefore lengthening is an intrinsic property of each cell: the cell will increase its height by a characteristic amount wherever it is. Each neural-plate cell can be viewed as an autonomous entity whose "height program," or prospective course of lengthening, has been determined in advance.

NEWT EMBRYO is magnified 40 times in this photomicrograph (the embryo is 2.4 millimeters in diameter). The keyhole-shaped structure in the center of the embryo is the neural plate. The wide part of the keyhole is destined to become the brain and the narrow part the spinal cord. Because the newt neural plate consists of a single layer of cells, it provides a simple but representative system for examining how tissues are formed in the embryo. Moreover, the amount of brown pigment varies from cell to cell, so that it is possible to follow the movements of individual groups of cells at low magnification without the need for stains or other markers.

We obtained the height programs of different cells in the following manner. We first measured the heights of the cells in the disk stage in sectioned embryos and then used time-lapse motion pictures to see where the corresponding cells were relocated in the keyhole stage. (Some cells moved as much as .9 millimeter across the 2.4-millimeter embryo!) We then sectioned a keyhole-shaped neural plate and measured the new heights of the relocated cells.

Our mathematical description of a neural-plate cell consisted of five quantities: two spatial coordinates for the cell's location, the cell's initial height, its volume and its height program (which was placed in one of nine classes according to the cell's rate of elongation). The shrinkage pattern of the plate could thus be represented as the pattern of different height programs distributed over the disk-shaped plate [*see bottom illustration on next page*]. The pattern turned out to be quite complex.

At first we thought that the shrinkage pattern alone might be sufficient to explain the shaping of the neural plate. We tested this hypothesis by experiment, by mathematical modeling and by com-

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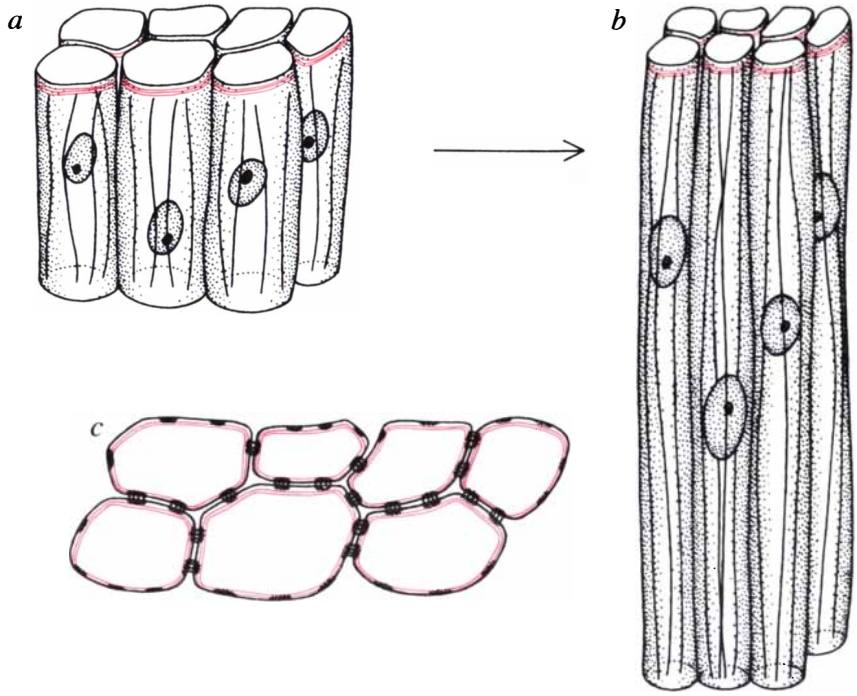
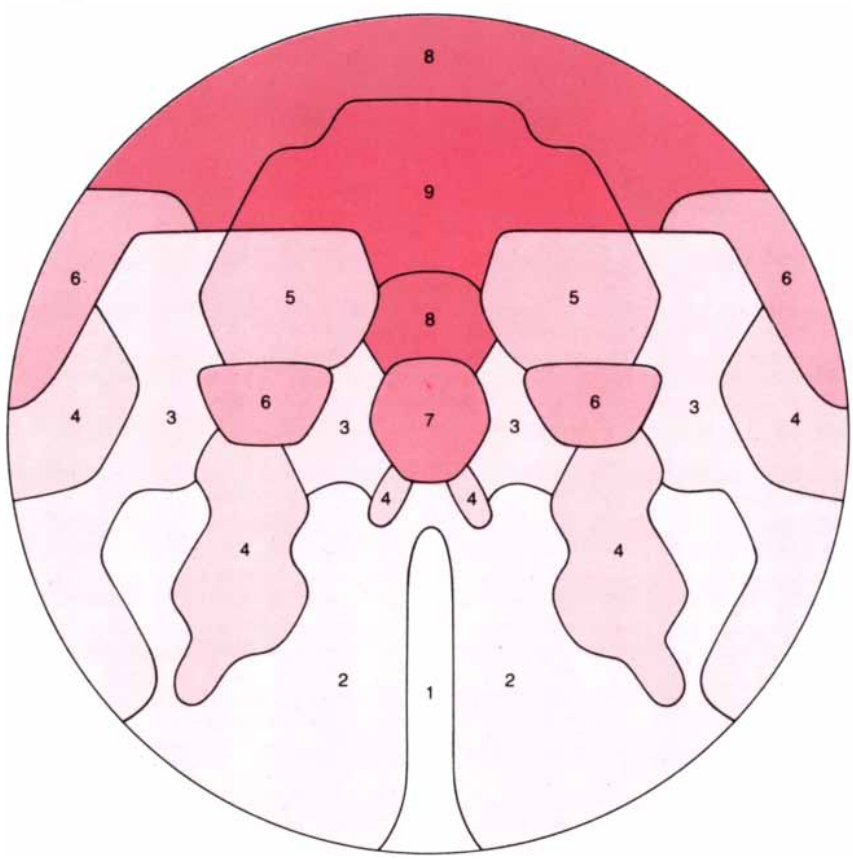


LENGTHENING AND SHRINKAGE of the neural-plate cells generate forces that help to shape the tissue. Here the same neural-plate cells are shown immediately after gastrulation (*a*) and after the closure of the neural tube (*b*). Each roughly cylindrical cell lengthens perpendicular to the sheet while maintaining a constant cell volume; as a result its exposed surface area decreases. Because the microfilament bundles (*color*) in each cell are coupled to those of the adjacent cells, the shrinkage of one cell pulls the other cells toward it, thereby reshaping the sheet (*c*).



PATTERN OF CELL LENGTHENING in the neural plate is quite complex, as is suggested by this map. The precise amount by which each cell lengthens (its "height program") varies considerably with the location of the cell in the neural plate. Here the height programs have been placed in nine classes according to the cell's rate of lengthening. The fastest class is *9*.

puter simulation. In our experiments we surgically removed the disk-shaped neural plate from the embryo and grew it in tissue culture. The surface of the isolated neural plate shrank, but the resulting shape was only slightly narrowed at the rear end and looked very little like the expected keyhole shape. We then reasoned that if each cell pulls isotropically (that is, equally in all directions) as it shrinks, the angle between two intersecting lines drawn on the sheet of cells should not change. In mathematical terms such a transformation is called conformal. Yet we knew that large changes of angle did occur in some regions of the D'Arcy Thompson grid during the transformation of the neural plate, indicating that the shape change was nonconformal.

Our computer simulation led us to the same conclusion. We modeled the neural plate as being made up of approximately 300 "shrinkage units," each unit being a cylinder representing a group of approximately 30 cells. When we ran the computer program allowing the shrinkage pattern to deform the D'Arcy Thompson grid, the simulated neural plate did not attain the keyhole shape but merely became smaller, much as had happened with the isolated neural plate grown in tissue culture [*see column c in illustration on page 107*]. It therefore seemed clear that no shrinkage pattern in itself could give rise to the keyhole shape, and we began to look for a second force.

The changes of angle in the D'Arcy Thompson grid of the transformed neural plate implied the existence of a shearing force that was moving some of the cells with respect to one another. In search of what might generate such a force we took a close look at the notochord, which is part of the mesodermal tissue underlying the neural plate. In older embryos the notochord is a rod running most of the length of the embryo under the spinal cord and brain. In the neural-plate stages the notochord is a flat sheet of cells that is in the process of shaping itself into a rod. Carl-Olof Jacobson and Jan Löfberg of the University of Uppsala had shown that although the mesodermal cells followed paths similar to those of the overlying neural-plate cells during the formation of the plate, only the cells in the notochord exactly followed the paths of the overlying cells. Moreover, we found that the cells of the notochord adhere tightly to the overlying neural-plate cells, whereas the rest of the mesoderm does not. This mechanical attachment was evident when we tried to separate the two tissue layers. We have termed the part of the neural plate that lies over the notochord the supranotochordal region.

If we removed the neural plate from the embryo along with the notochord

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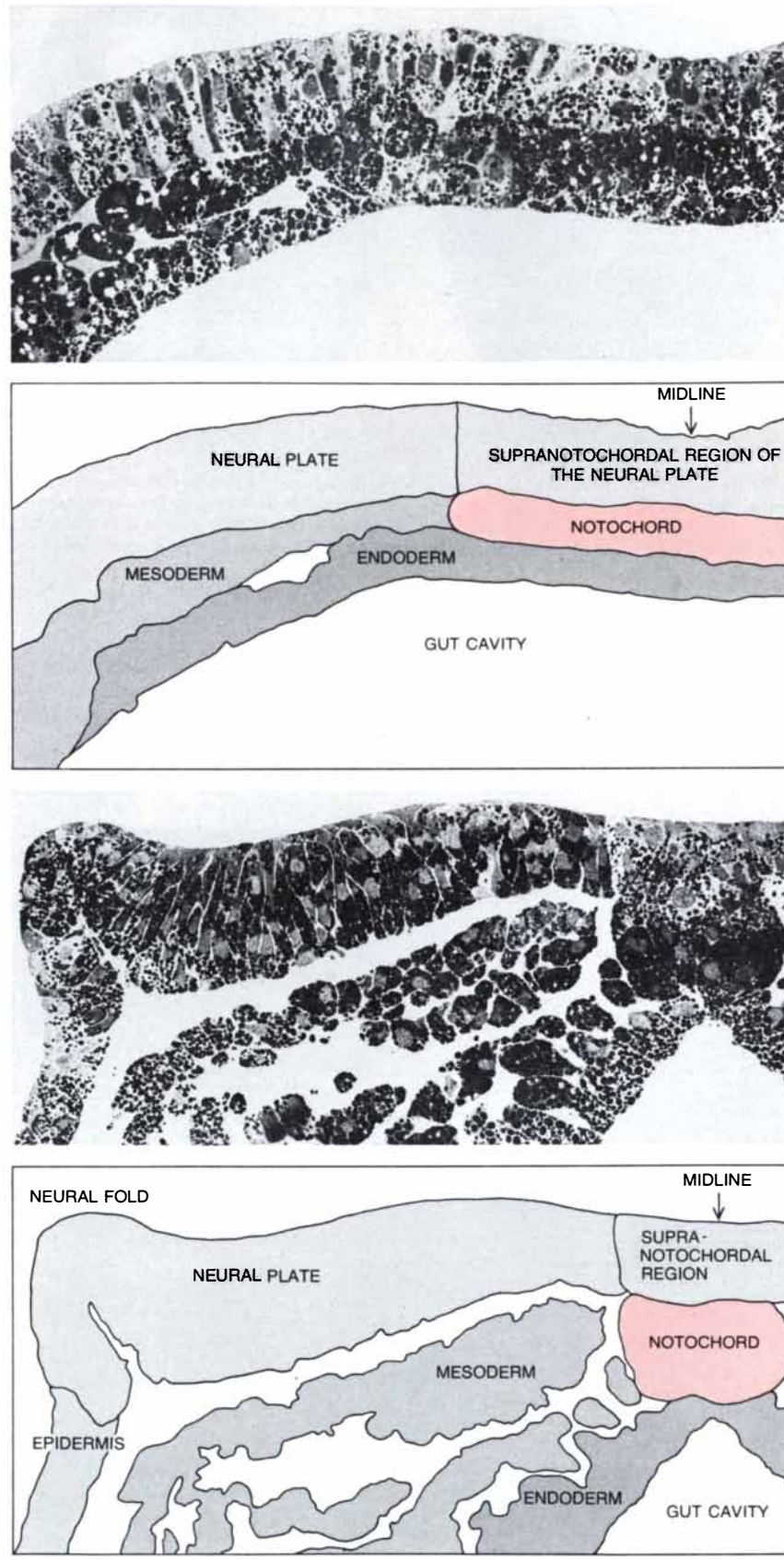
and grew it in isolation, a normal keyhole shape resulted. If, on the other hand, we left the neural plate attached to the embryo and removed the notochord by cutting it away from below, the keyhole shape did not arise. Similarly, if the notochord itself was isolated from the neural plate and grown in culture, the cells did not rearrange themselves into a rod. We concluded that the cells of the notochord and the supranotochordal region of the neural plate move synchronously, but that neither set of cells will execute these movements in isolation. Therefore our next step was to incorporate the elongation of the supranotochordal region into our computer simulation.

In programming the simulation we had to find a means of holding the shrinkage units together to represent a continuous sheet of cells. The neighboring units were connected by "bonds" that were modeled as if they were rubber bands. Problems soon arose with this approach. As the shrinkage units diminished in size and the supranotochordal region elongated, some of the bonds were stretched to lengths that could not normally be attained by cells in the embryo. Such stretching seemed to point to the possibility of unrelaxed tensions in the neural plate. We looked for signs of these tensions in the embryo by cutting small slits in the neural plate. As we had anticipated, the tensions in the plate during the disk stage caused the slits to gape open. In the keyhole stage, however, when slits were cut, they did not gape, indicating that the tensions in the neural plate had relaxed. Thus the neural plate does not behave simply like an elastic material; it also has a viscous character. Such mixed behavior in a material or a fluid is called viscoelasticity.

In order to model the viscous component of the neural plate we allowed the bonds between the shrinkage units to snap when they got too long; the length at which they snapped was derived from an empirical measurement of the maximum observed stretching of cells in the embryo. The separated shrinkage units were then allowed to join up with new neighboring units. This change of neighbors among the units allows for the viscous component of the flow and accounts for the observed shear.

We found that by combining the shrinkage pattern and the movements of the supranotochordal region in our simulation we could obtain a transformed D'Arcy Thompson grid that was virtually identical with the keyhole shape observed in the embryo. We wondered, however, if the second force alone might be sufficient to effect the transformation. Unfortunately we could not test this hypothesis by experiment because we knew of no way to prevent the shrinkage of the neural-plate cells without affecting the movement of the su-



CROSS SECTIONS through the newt embryo at two stages of its development illustrate the relations between the neural plate and the underlying tissue layers. The micrograph at the top shows the tissues of an embryo that has just completed gastrulation; the neural plate, the mesoderm and the endoderm are visible. The micrograph at the bottom is of an embryo with a keyhole-shaped neural plate. Note that between the two stages the cells of neural plate have lengthened, whereas those of notochord and supranotochordal region have converged along midline.

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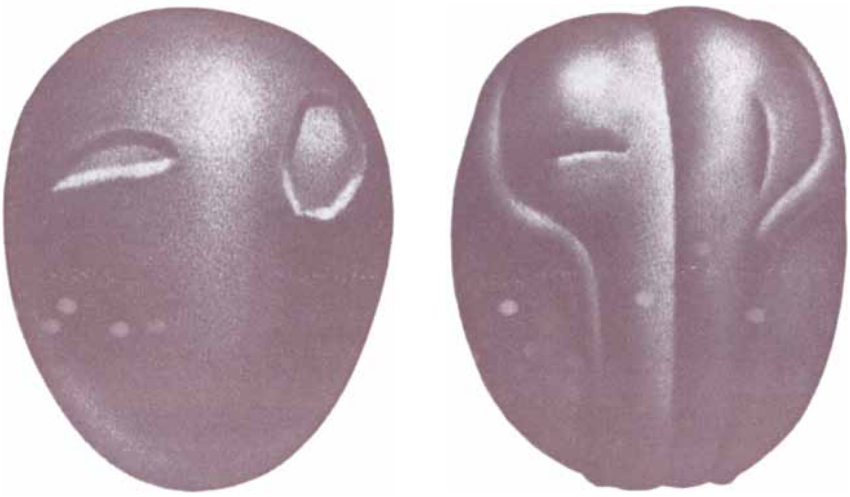
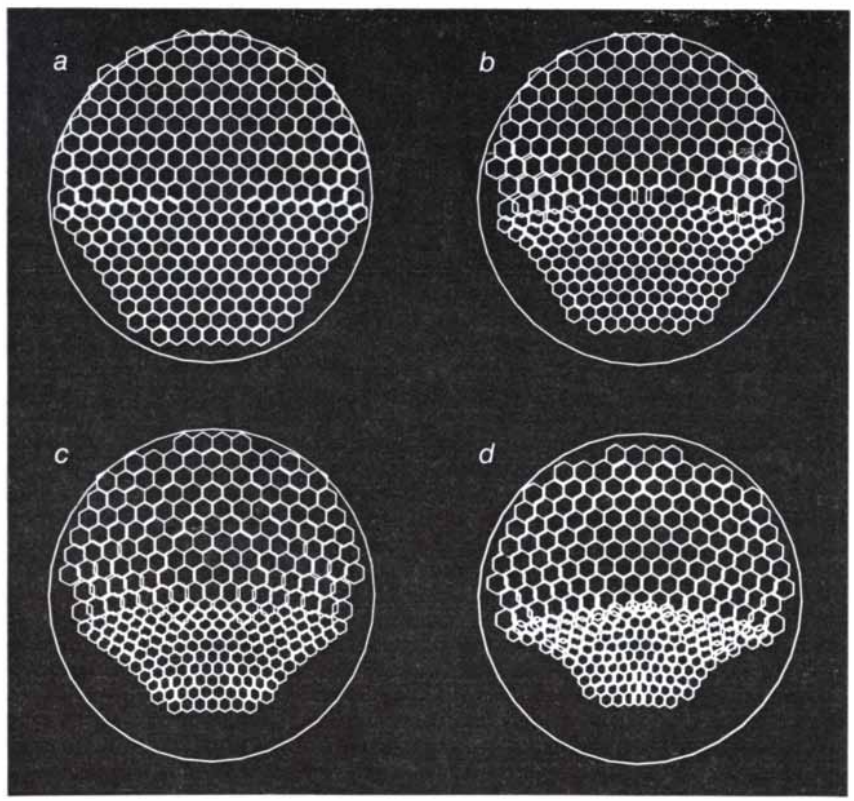


GAPING OF WOUNDS when the neural plate is slit reveals the presence of internal tensions in the disk-shaped stage of the embryo (*left*). The tensions have relaxed by the keyhole-shaped stage (*right*). The presence of these tensions indicates that the neural plate is both elastic and viscous, a property shared by nonbiological materials that flow, such as metals under pressure.

pranotochordal region. It was a simple matter, however, to modify the computer simulation so as to turn off the shrinkage as the supranotochordal region elongated. Although the resulting transformed D'Arcy Thompson grid had a keyhole shape, its front end was oversized [*see column d in illustration on page 107*]. We therefore concluded that both the shrinkage pattern and the elongation of the supranotochordal region are necessary and sufficient to account for the shaping of the neural plate.

In vertebrate animals the main role of the notochord is apparently to participate in the formation of the embryonic nervous system. Once the backbone has appeared the notochord has no further function and largely disintegrates.

Three lines of evidence led us to the conclusion that shear occurs in the neural plate: the nonconformality of the transformation of the D'Arcy Thompson grid, the need to introduce viscoelasticity into our computer model and direct observations of groups of cells changing neighbors. There are at least two regions of the neural plate where shear may be found: in the supranotochordal region and at the boundary between the neural plate and the epidermis (the rest of the outer layer of the embryo). In the latter region the neural-plate cells, which are shrinking at a rapid rate, are juxtaposed with epidermal cells that are actually flattening and increasing their exposed surface area. As a result an abrupt boundary is formed along which shear can develop [*see bottom illustration on this page*]. The massive amount of shear among the neural-plate cells in the supranotochordal region may play a major role in subdividing the neural plate into two bilaterally symmetric halves.



LINES OF SHEAR in the embryo are generated at the interface between a sheet of cells whose surface area is shrinking and an adjacent sheet of cells whose surface area remains the same or actually increases. This computer simulation shows a simplified example of such an interface, with shear (the changing of cell neighbors) occurring at the downturned edges. Shear occurs along midline of the neural plate during the elongation of the supranotochordal region and at the border between neural plate and the epidermis (the rest of the outer layer of the embryo).

The question of why abrupt boundaries arise between cell domains is largely unsolved, but lines of shear between cells may be an important factor. Several investigators, including Edwin J. Furshpan and David D. Potter of the Harvard Medical School and Werner R. Loewenstein of the University of Miami School of Medicine, have found that most cells in the embryo communicate electrically and chemically by means of permeable adhesions between their outer membranes called gap junctions [see "Junctions between Living Cells," by L. Andrew Staehelin and Barbara E. Hull; SCIENTIFIC AMERICAN, May]. Ions and even fairly large molecules can pass freely among the coupled cells, and this cellular communication may play an important role in the formation of cell domains that exhibit coordinated behavior during embryonic development. The cells of the neural plate comprise one such domain; the cells of the epidermis comprise another. Shear may sever or alter the function of the gap junctions between cells at the boundary between the neural plate and the epidermis, leading to their functional separation. This separation could lead in turn to different subsequent development in each of the two isolated cell domains.

Once the flat neural plate is formed it rolls into a tube. The dominant effect may be the elongation of the supranotochordal region, which at this time increases its rate of elongation tenfold. If one stretches an elastic sheet, such as a thin sheet of rubber or plastic, along a line, it will buckle out of the plane and form a tube. We are now embarking on a new computer simulation to test whether or not this phenomenon will quantitatively explain the formation of the neural tube.

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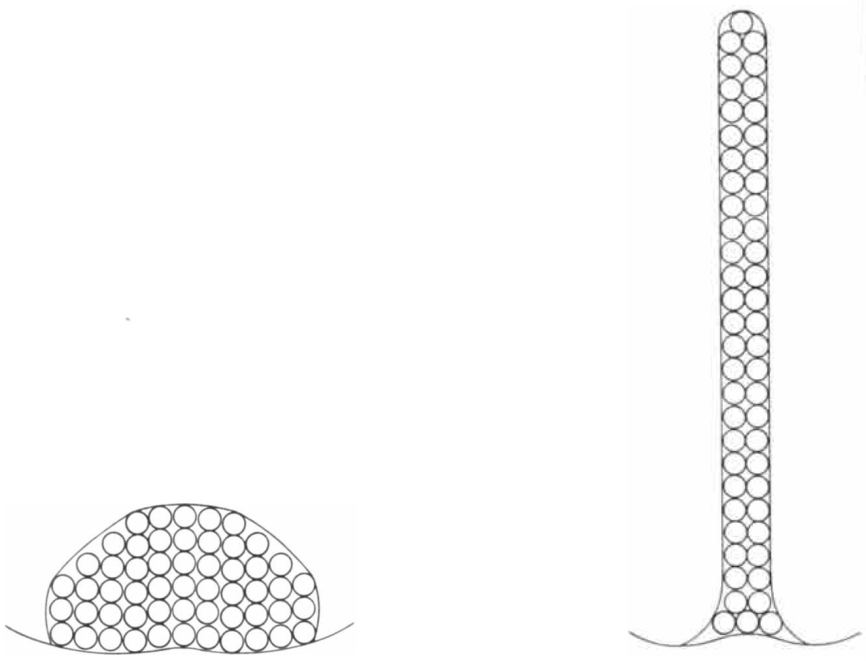
In devising our computer simulation of the neural plate we became aware of the analogy between its formation and the flow of nonbiological materials, such as metals. The branches of physics that deal with the flow of materials are hydrodynamics and the more general discipline of continuum mechanics. Yet there are two major differences between ordinary hydrodynamics and the flow of tissues during development (which we have proposed to name morphodynamics). First, ordinary fluids are passive, responding to the forces applied on them, whereas the forces that drive the flow of tissues are generated by the cells themselves. Second, most fluids are spatially uniform in their intrinsic properties, whereas the fluid properties of a tissue are highly nonuniform, as is evidenced by the complexity of the shrinkage pattern in the neural plate. The added complexity of morphodynamics makes it mathematically intractable and places it at the limits of the descriptive power of hydrodynamics, even with the availability of high-speed computers.

In our work on the neural plate we have shown how the morphogenesis of a sheet of tissue is a consequence of the behavior of its cells. One of these kinds of behavior, namely the carrying out of a height program by each cell, seems in turn to be a consequence of the behavior of the large structural molecules, such as microtubules and microfilaments, within each cell. As we have seen, the height program varies from cell to cell. This observation raises some fundamental questions. What is the mechanism by which the spatial pattern of height programs is established? The answer may well bear on pattern formation in general. Exactly what is it in each cell that varies from cell to cell to give the cells their different height programs? Perhaps the regulation mechanism is like a thermostat whose molecular control may be set differently in each cell. Finally, we need to learn how this control mechanism operates to carry out the height program. The molecular mechanisms seem within grasp for this tissue, so that we may have here an excellent opportunity to investigate these questions.

The formation of the supranotochordal region of the neural plate and the notochord itself remain an enigma. It is not understood how the cells in this part of each sheet can rearrange themselves drastically but in a coordinated fashion to give rise to elongated structures. The answer may lie in surface-tension interactions between the supranotochordal region and the rest of the neural plate that operate by way of the different strengths of adhesions between cells.

The development of an embryo is one of the most profoundly difficult and challenging phenomena to comprehend. After a number of years of study we have succeeded in obtaining a quantitative understanding of how the behavior of cells in a single tissue leads to its change in shape. Although this work has yielded a few important principles of embryogenesis, it has revealed or made explicit a number of other fundamental mechanisms that remain to be grasped.



SUPRANOTOCHORDAL REGION of the neural plate is shown diagrammatically at the disk stage of the neural plate (*left*) and at the keyhole stage (*right*). The circles represent equal numbers of cells. As the supranotochordal region elongates and narrows along the midline of the neural plate, cells from the interior of the flat region intercalate to take positions at the perimeter. The diagram illustrates immense amount of shear that is involved in the shape change.

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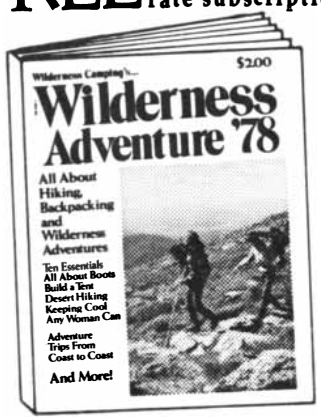

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Complexity Theory

Complex systems such as telephone exchanges and computers consist of large numbers of simple components. Complexity theory seeks to establish the number of components needed to perform a given task

by Nicholas Pippenger

Many complex systems such as those found in a computer or a telephone exchange are constructed by interconnecting a large number of simple components. The complexity of these systems arises from the number of components and the intricacy of their interconnections, rather than from any great complexity of the components themselves. The systems formed in this fashion are somehow much greater than the sum of their parts.

It is natural to assume that every component in a complex system is there for a reason, but although it may be true that the removal of any component would cause the system to malfunction, it is also possible that an overall reorganization would lead to a working system with many fewer components. For example, at the present time there is no convincing proof that the tasks performed by modern computers and telephone exchanges could not be performed just as well by systems with, say, half as many components. This possibility has given rise to a new mathematical discipline called complexity theory.

Complexity theory seeks to determine the minimum number of components needed for these systems. It pursues this goal in two ways: by finding new designs that call for fewer components and by showing that a certain number of components will be needed no matter what design is followed. Finding new designs for a system has an obvious practical significance: it can increase the efficiency of the system and reduce its cost. The second type of investigation, which sets limits beyond which further attempts at improvement are futile, is equally necessary for a complete understanding of a particular system and is often much harder to accomplish.

Of the two sources of complexity, the number of components and the intricacy of their interconnections, complexity theory is concerned almost exclusively with the first. This sometimes leads to confusion, because in common usage the word "complexity" refers more frequently to the second. The difference is important because systems that have fewer components are often obtained by interconnecting the components in a more intricate way. In complexity theory this is considered an advantageous transformation.

To illustrate some of the main themes of complexity theory I shall concentrate on one particular problem: designing an efficient telephone exchange. For many years, from the early 1900's to the 1950's, telephone exchanges were the most complex digital systems in existence. Much attention, both theoretical and practical, has been given to their design.

The purpose of a telephone exchange is to provide paths, or connections, for calls between subscribers. Since there may be many calls in progress at once, the exchange must be able to provide many paths simultaneously. A modern telephone exchange is connected not only to its own subscribers but also, through special lines called trunks, to other exchanges serving other subscribers. Such an exchange provides paths both between subscribers and between the subscribers and the trunks. (It may also provide paths between trunks, but this task is usually performed by special exchanges called toll exchanges.)

For the purposes of this article I shall consider only one of the many systems in a telephone exchange: a switching network with the sole task of providing paths for calls that arrive over trunks, destined for subscribers served by the exchange. The simplicity of the task makes it particularly well suited for a discussion of complexity theory.

The switching networks that perform this task in modern telephone exchanges can be regarded as interconnections of components of one basic type: the switch. A switch can be regarded as a very small switching network serving only one trunk and one subscriber; when the switch is closed, a path is established between the trunk and the subscriber, and when the switch is opened, the path is broken.

How many components (switches) are needed to build the system (the switching network)? My account of this problem will differ considerably from one that might be given by a telephone engineer, just as a physicist's account of the problem of designing an efficient power plant would differ from that of a mechanical engineer. I shall emphasize the possibilities and limitations inherent in the problem rather than those that are encountered in contemporary practice. For a power plant the inherent possibilities and limitations are expressed by the laws of thermodynamics; for a telephone exchange they are expressed by the findings of complexity theory.

To better understand the problem of designing an efficient switching network consider a telephone exchange at a typical moment in time. A certain number of calls are in progress, each involv-

COMPLEX SYSTEMS can be constructed by interconnecting a large number of simple components. The system shown in the illustration multiplies numbers in binary notation. In this instance the factors 0110, or 6, and 0111, or 7, are received at the inputs (*top*) and the product 00101010, or 42, is delivered at the outputs (*bottom*). The system is constructed of two types of components: those marked with a dot are "and" gates, which deliver a 1 when both of their inputs receive 1's; those marked with a plus sign are "exclusive-or" gates, which deliver a 1 when one but not both of their inputs receives a 1. Many large digital computers multiply numbers by using systems similar to this one but built on a larger scale. The number of components that would be needed to multiply two numbers with, say, 48 binary digits is not known, even to within a factor of two or three. Determining the minimum number of components needed in a system that multiplies numbers is one of the outstanding problems in complexity theory.

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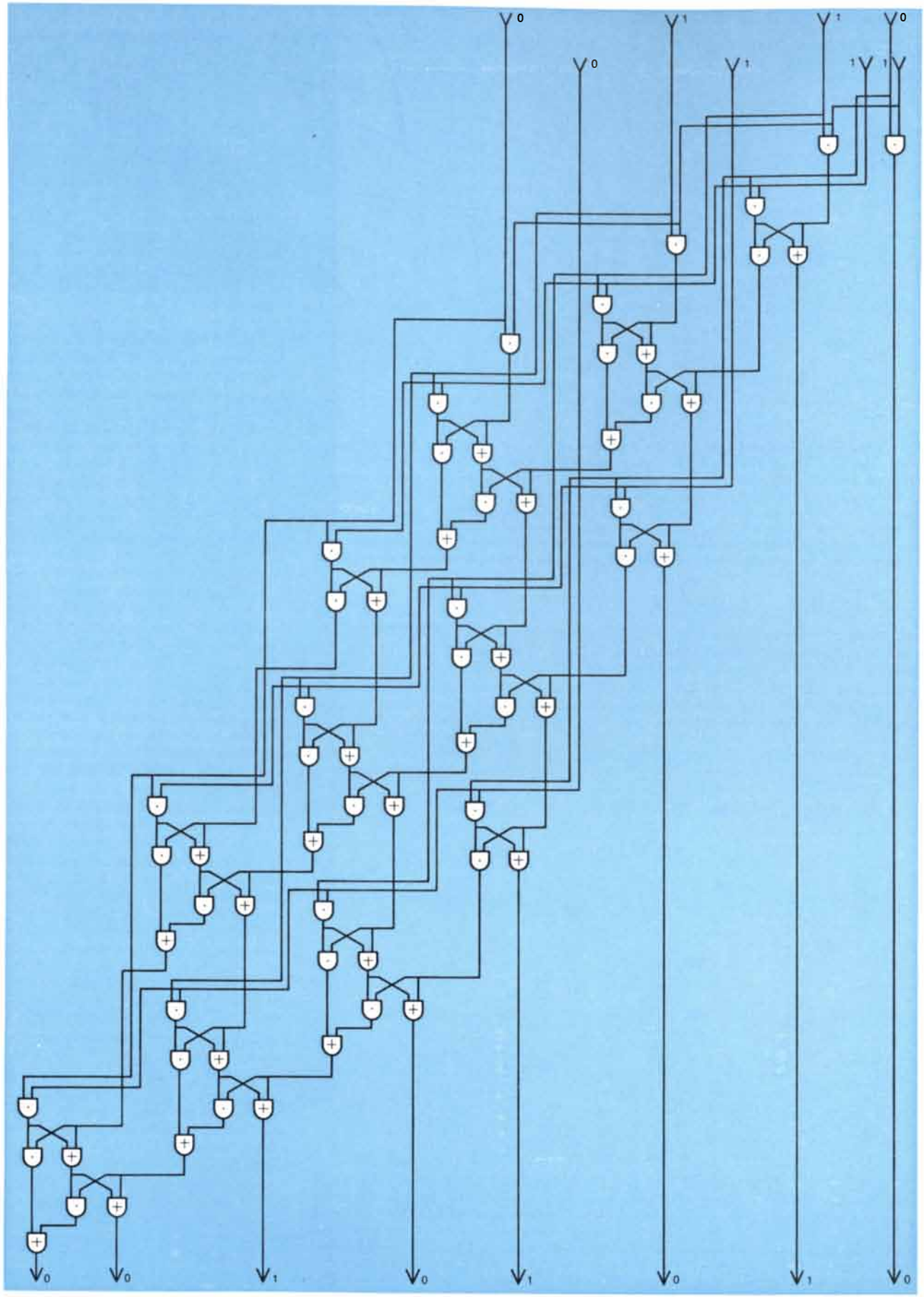

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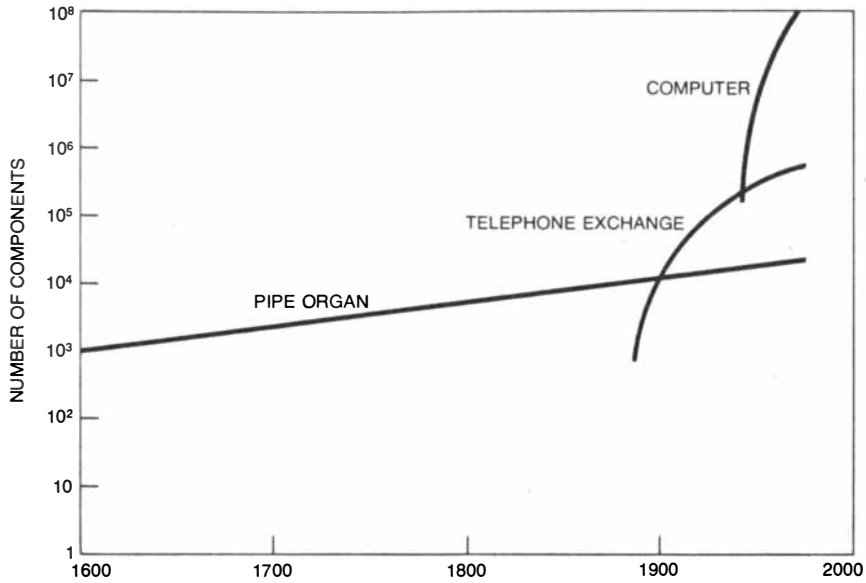
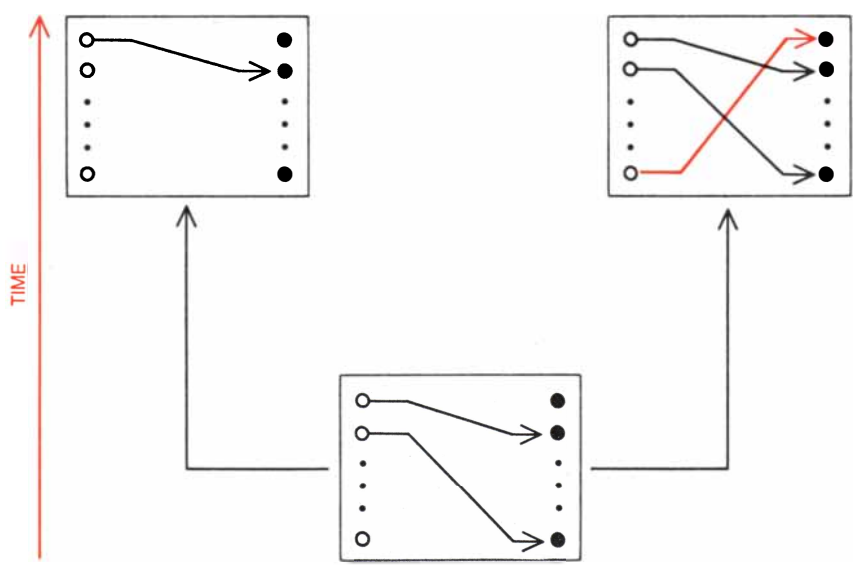


COMPARISONS OF COMPLEXITY among different types of physical systems are somewhat arbitrary, because there is no universally applicable method of measuring complexity. Over the past 400 years, however, the complex systems with the greatest number of components have been successively the pipe organ, the telephone exchange and the computer. The graph in this illustration shows the growth in the number of components in these three types of systems; each of them has grown substantially faster than its predecessor. When the components available for constructing a system and the task to be performed by the system can be precisely specified, complexity theory seeks to find minimum number of components required.

ing one trunk and one subscriber. The switching network provides a path for each of these calls, employing different switches for each path so that conversations being transmitted over the paths do not interfere. This situation can be transformed by two events. One of the parties participating in a call may hang up, terminating the call and freeing the switches that formed the path for the call. Or a new call may arrive over a trunk that is not engaged, destined for a subscriber who is also not engaged. In that case the network must provide a path for the new call without changing or otherwise disturbing any of the other calls in progress.



IN A TELEPHONE EXCHANGE calls arrive over trunk lines from different areas (*large open circles*) and must be connected to subscribers' lines (*large solid circles*). The connecting paths are provided by a switching network: a complex system consisting of a large number of interconnected switches. At any moment there are a certain number of calls in progress in the exchange (*bottom*). As time passes a call may terminate (*top left*), freeing the switches that formed the path for the call. Or a new call may arrive over a trunk that is not engaged, destined for a subscriber who is also not engaged (*top right*). In that case the network must provide a path for the new call (*color*) without interfering with any of the other calls in progress.

The most obvious way to construct a switching network is to provide a separate switch for each possible call. When a call arrives on a particular trunk, destined for a particular subscriber, the appropriate switch is closed; when the call is terminated, the switch is opened. A network designed in this way is called a crossbar because it is often implemented as a set of horizontal bars (corresponding to trunks) crossed with a set of vertical bars (corresponding to subscribers), with a switch located at each point of intersection.

To gauge the efficiency of this design consider a network capable of handling N calls, that is, one with N trunks and N subscribers. A total of $N \times N$, or N^2, different calls can be made through the network, and so there are N^2 switches in a crossbar. In other words, the number of switches in a crossbar is the square of the number of calls the crossbar can handle. Therefore as the number of calls increases, the number of switches increases much more rapidly. The number of switches required for a network that can handle, say, $2N$ calls is not twice the number required for a network that can handle N calls but 2^2, or four, times that number. This phenomenon of disproportionate growth can be called a diseconomy of scale.

Diseconomies of scale appear frequently in complexity theory. Another way to view this particular diseconomy of scale is to look at the number of switches required to build a network divided by the number of calls the network can handle, that is, the number of switches required per call. For the crossbar this number is N^2 divided by N, or N. If there were no diseconomy of scale, the number of switches per call would always be less than or equal to some fixed number rather than being an increasing function of the number of calls.

Of course, a real switching network is more complicated than the one I have been describing. For example, in a real network the number of trunks is not equal to the number of subscribers. (These numbers are nonetheless roughly proportional.) Moreover, it is an oversimplification to judge the cost of a network solely by the number of switches in it; other elements, such as the wires that connect the switches and the frames on which the switches are mounted, contribute to the cost. Even if these additional factors were taken into account, however, the crossbar would still display a diseconomy of scale. The diseconomy of scale is a real property of the design and not merely a consequence of the simplifying assumptions.

It might be expected that a design calling for N^2 switches in a network that

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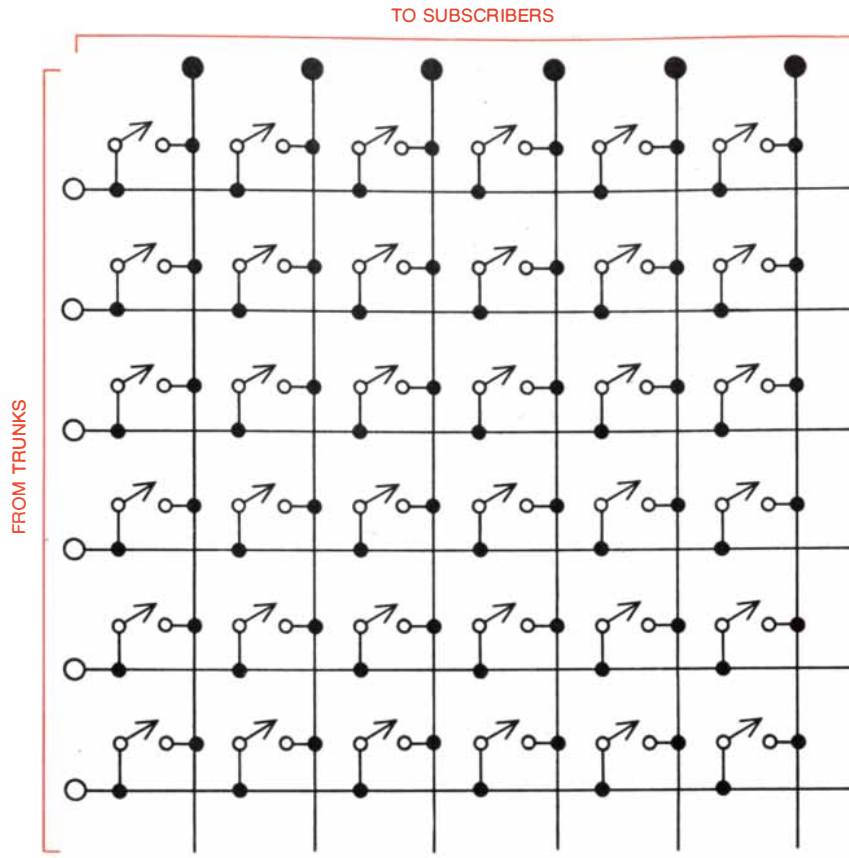
handles no more than N calls at a time is not the best. In fact, there is a better design, one that provides paths for the same number of calls with fewer switches. It was discovered in the 1950's by Charles Clos of Bell Laboratories.

Clos's design is based on the idea of building a large network out of smaller networks called subnetworks. These are arranged in three stages so that each call passes through three subnetworks. The subnetworks perform the same task as the large network (they provide paths between incoming and outgoing lines), but they do it on a smaller scale. Hence the subnetworks can be crossbars. Many of them are rectangular rather than square (that is, they have different numbers of incoming and outgoing lines), so that a sufficiently large number of alternate paths through the network are provided for each call.

In this design each call can follow any one of several different paths through the network, and it is possible for the alternate paths to share switches. In a crossbar, which has only one possible path for each call, there is no possibility of sharing. With Clos's design a network that can handle up to N calls at the same time can be constructed with about $6N^{1.5}$ switches. When N is 36 or greater, the number of switches is always less than N^2.

With some additional reproportioning of the network the number of switches can be further reduced: from $6N^{1.5}$ to $2^{2.5}N^{1.5}$, or $(5.656\ldots)N^{1.5}$. The reduction of the constant multiplier 6 in the expression for the number of switches is far less important, however, than the reduction of the exponent of N from 2 to 1.5. It is this exponent that determines the rate of growth of the number of switches as a function of N. Clos's design is effective because it reduces the exponent, thereby substantially slowing the rate of growth. Even if the multiplier were much larger than 6, the reduction of the exponent from 2 to 1.5 would ensure that for large values of N, Clos's design would require many fewer switches than a crossbar.

To emphasize the greater importance of the exponent, it is common to drop the multiplier and consider only the "order" O of the number of switches. For example, the crossbar requires $O(N^2)$, or order-of-N squared, switches. In other words, the number of switches in the crossbar is at most a constant multiple of N^2. Clos's method of construction requires $O(N^{1.5})$ switches.



A CROSSBAR SWITCHING NETWORK provides a separate switch for each possible call in a telephone exchange. When a call arrives on a trunk that is not engaged, destined for a subscriber who is also not engaged, the appropriate switch is closed; when the call terminates, the switch is opened. In a network capable of handling N calls (one with N trunks and N subscribers) a total of $N \times N$, or N^2, different calls can be made, so there are N^2 switches in a crossbar network. Hence as the number of calls handled by network increases, number of switches in the crossbar increases much more rapidly. This phenomenon of disproportionate growth is called diseconomy of scale. It is a feature of many systems studied in complexity theory.

The number of switches in a network can be reduced even further if Clos's method is applied repeatedly to the subnetworks of the network, that is, if the subnetworks are constructed not by making crossbars but by interconnecting even smaller subnetworks; the smaller subnetworks can in turn be constructed by Clos's method, and so on. Of course, with each application of this method the subnetworks become smaller, so that eventually a point is reached where it is more efficient to use crossbars than to continue nesting subnetworks, and the procedure terminates. The technique of constructing a network by nesting smaller and smaller subnetworks is called recursion. It is one of the most widely applied techniques in complexity theory.

This improved version of Clos's method was analyzed in the early 1970's by David G. Cantor of the University of California at Los Angeles. He found that it uses $O(N(\log N)^{2.269\ldots})$ switches. (The exponent $2.269\ldots$ is the solution of the equation $3^{1/(1-x)} + 2^{1/(1-x)} = 1$.) The logarithm of N, even with a large exponent, grows more slowly than N itself, or even N with a small exponent, and so the expression represents a slower rate of growth than $O(N^{1.5})$. (It is not necessary to specify the base of the logarithm here, since logarithms to different bases differ from one another by constant multipliers, which are suppressed by the order notation.)

Cantor also discovered an even better design. Like Clos's design, Cantor's is based on the interconnection of crossbar subnetworks, but the subnetworks are arranged in more than three stages and the pattern of interconnection is more intricate. It is not easy to describe the pattern of interconnection. In fact Cantor's design does not show its advantage until networks with 11 or more stages are considered. The resulting networks contain $O(N(\log N)^2)$ switches. This rate of growth is slower than $O(N(\log N)^{2.269\ldots})$. Once again the improvement is due to the reduction of the exponent, this time the exponent of the logarithm of N.

The Clos and Cantor designs are more efficient than the crossbar, but like the crossbar they exhibit diseconomies of scale. Is there any design that does not exhibit this property? Up to this point I have discussed only specific methods of constructing networks, but in order to answer this question it is necessary to consider methods of construction in general, that is, to employ an argument that applies to any method of construct-

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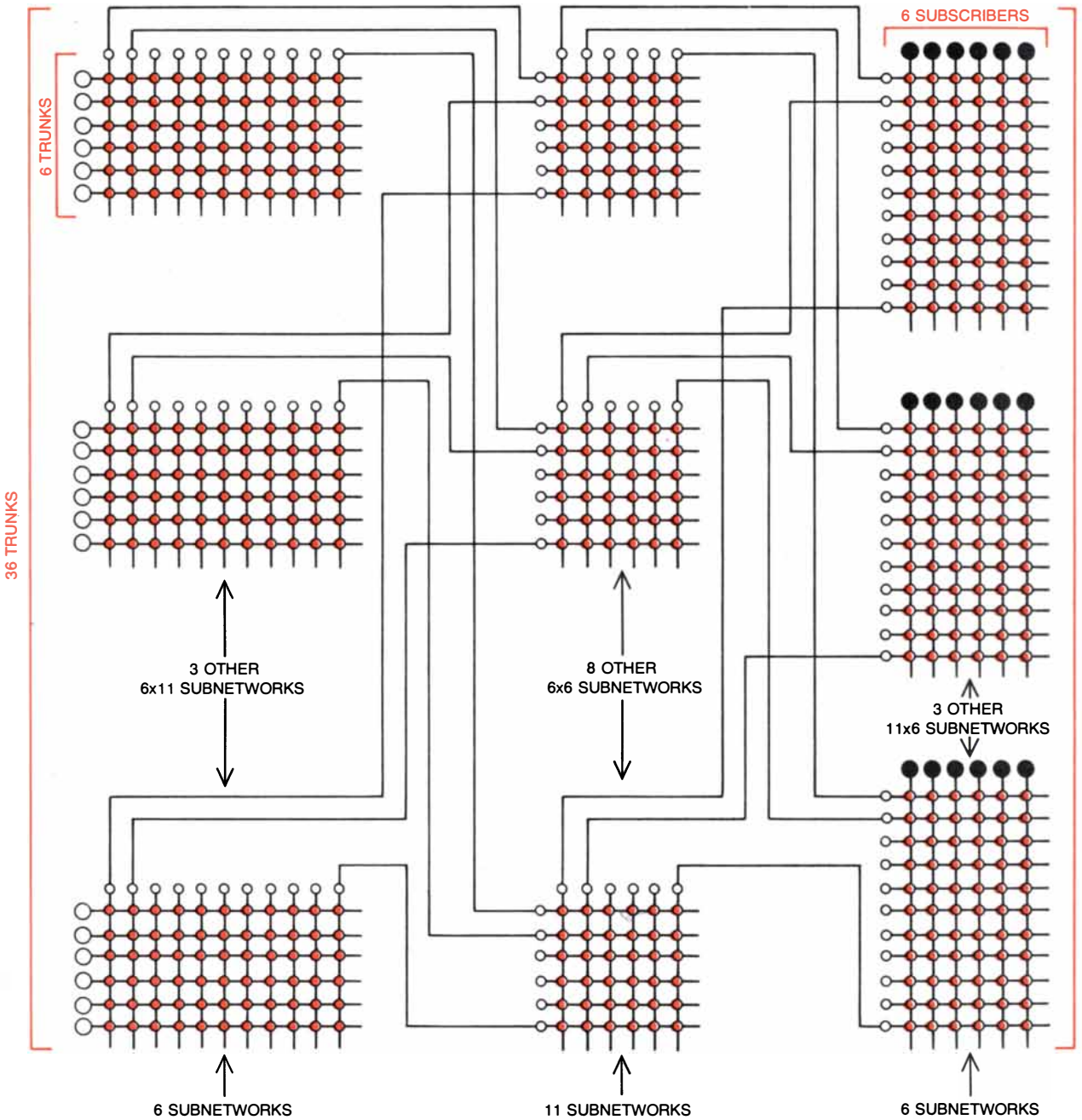
ing networks, no matter how complicated or ingenious. In 1950 Claude E. Shannon of Bell Laboratories devised such an argument to prove that no method of constructing switching networks can avoid a diseconomy of scale.

The key to Shannon's argument is the concept of the state of a network: the configuration of open and closed switches that exists in the network at a particular moment. The state of a network evolves as calls arrive and terminate, much as the state of a physical system evolves in response to external disturbances such as heating and compression. Shannon proved that a diseconomy of scale was unavoidable by determining upper and lower bounds on the number of different states a network can assume.

The first step of the proof is to show



A MORE EFFICIENT DESIGN for switching networks was discovered by Charles Clos of Bell Laboratories in the 1950's. A large switching network with fewer switches than a crossbar is formed by interconnecting small crossbar subnetworks. Many of these subnetworks are rectangular rather than square, that is, they have different numbers of incoming and outgoing lines. The subnetworks are arranged in three stages, or columns, and each subnetwork is connected to every subnetwork in the adjacent stage or stages. The illustration shows the construction for a switching network with 36 trunks and 36 subscribers; the switches in each subnetwork are indicated by color dots. (Many of the subnetworks and most of the interconnecting lines have been omitted for clarity.) The efficiency of this design is due to the fact that there are many alternate paths through the network for each call. Switches can be shared among these paths, and so the total number of switches in the network can be reduced without causing calls to be blocked (*see illustration on opposite page*). In a crossbar network there is only one path for each possible call and no possibility of sharing switches. In the construction shown in the illustration there are $6(6 \times 11) + 11(6 \times 6) + 6(11 \times 6)$, or 1,188, switches as compared to 36×36, or 1,296, switches in a crossbar for same network. In fact, for any switching network that handles 36 or more calls, Clos's design requires fewer switches than crossbar does.

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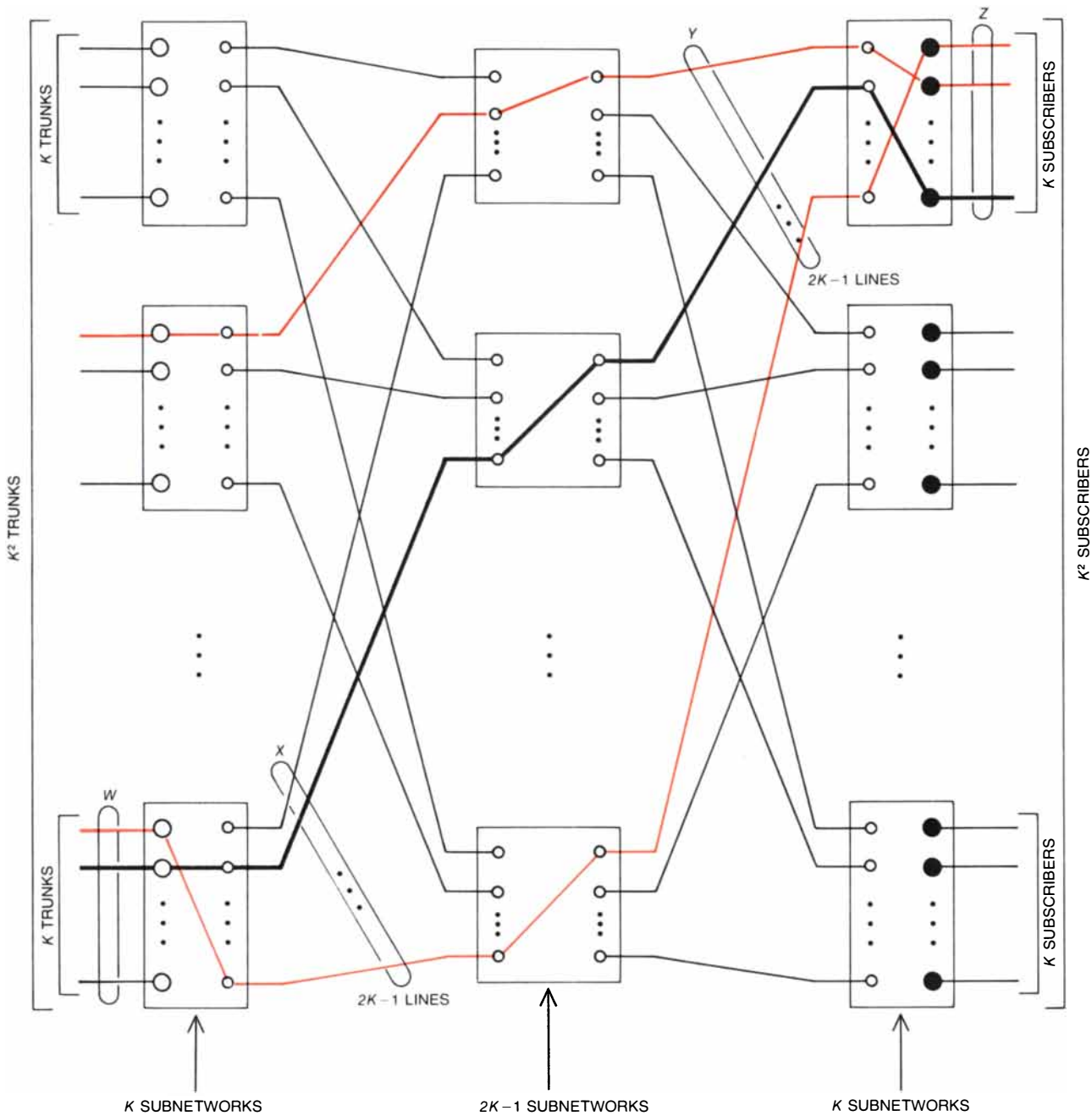
that a network capable of handling N calls must be able to assume at least $N!$, or $N \times (N-1) \times \ldots \times 1$, different states. Consider the network when there are no calls in progress. A call arriving on the first trunk can be connected to any of the N subscribers. If another call arrives on the second trunk before the first call has terminated, it can be connected to any of the $N-1$ remaining subscribers. Suppose the process continues until a call arrives on the last trunk and is connected to the last remaining subscriber. The number of possible sequences of destinations of the N calls is $N \times (N-1) \times \ldots \times 1$. For each of the sequences there will be a different set of calls in progress in the network, and so the network will assume a different state. Therefore there are $N!$ different states into which the network can be



CLOS'S DESIGN creates $2K-1$ different paths between each trunk and each subscriber to obtain a network capable of handling K^2 calls with about $6K^3$ switches. Clos's design for a three-stage network of arbitrary size is shown here. It consists of two outer stages each with K subnetworks and a middle stage with $2K-1$ subnetworks. If K is chosen to be about $N^{.5}$, the network can handle about N calls with about $6N^{1.5}$ switches. (For example, in the illustration on the opposite page K is equal to 6 and N is equal to K^2, or 36.) When N is 36 or more, the number of switches is always less than N^2, the number of switches in a crossbar handling the same number of calls. To verify that the reduction in the number of switches does not introduce the possibility of blocked calls suppose that a call arrives over one of the trunks in group W, destined for a subscriber in group Z. There are only $K-1$ other trunks in group W, and so no more than $K-1$ of the lines in group X can be engaged (*color*). Similarly no more than $K-1$ of the lines in group Y can be engaged (*color*). Hence the engaged lines in groups X and Y are connected to at most $K-1$ plus $K-1$, or $2K-2$, of the subnetworks in the middle stage. Since there are $2K-1$ subnetworks in the middle stage, there must be at least $2K-1$ minus $2K-2$, or 1, subnetwork in that stage for which neither the line in X nor the line in Y is engaged. Path through this subnetwork (*heavy line*) can be given to the new call and so the call will not be blocked.

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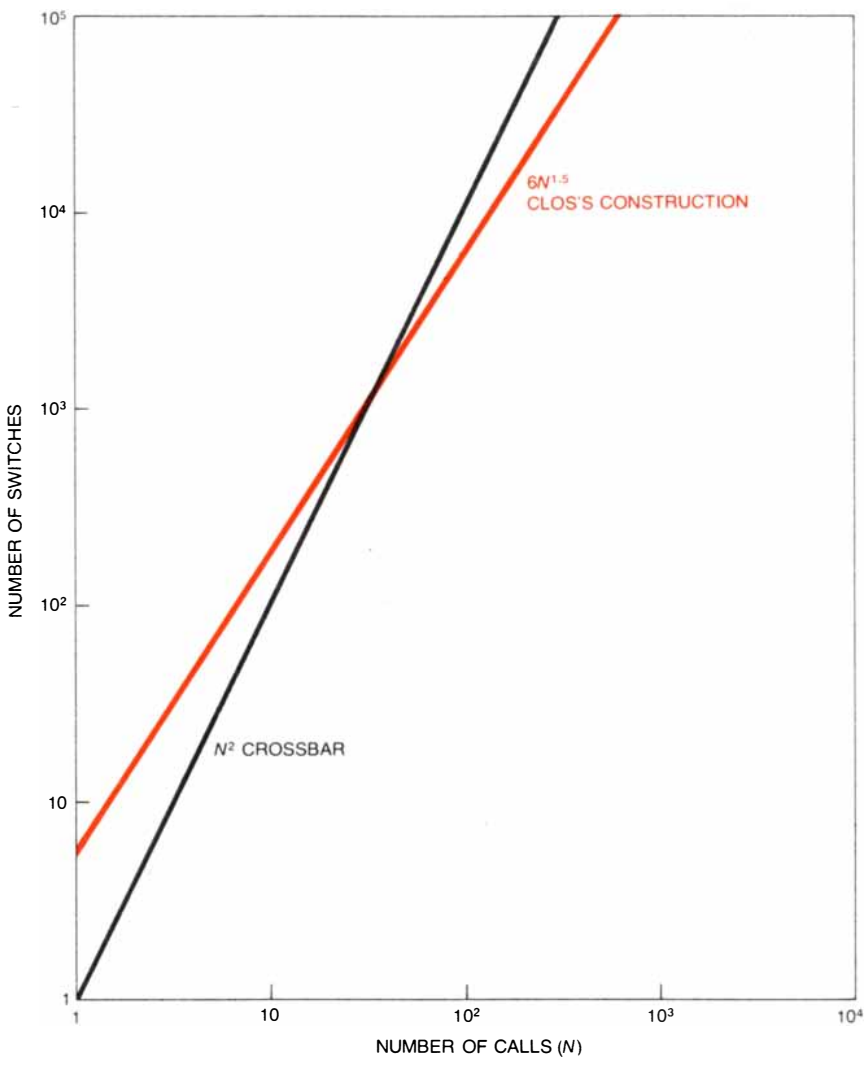
driven. (Actually only the states with exactly N calls in progress have been counted; the total number of states will be larger than $N!$.)

The second step of the proof is to show that a network with S switches can have no more than 2^S states. Since a single switch can be thought of as a subnetwork with just two states (open and closed), a network with S switches can have at most $2 \times 2 \times \ldots \times 2 = 2^S$ states. (In general, the network will have even fewer than 2^S states, because many combinations of open and closed switches will not make sense, that is, those combinations will not form a set of noninterfering paths.)

The conclusion is now at hand. If a network for N calls has S switches, it will have at least $N!$ states and at most 2^S states, and thus $2^S \geq N!$. Taking the logarithm to the base two of the quantities on each side of an inequality preserves the inequality, and so $2^S \geq N!$ implies that $S \geq \log_2 N!$.

In the early days of the calculus Abraham de Moivre and James Stirling studied the logarithm of $N!$. They found that $\log_2 N!$ is always close to $N \log_2 N$, and that this approximation becomes better and better as N increases. Therefore the number of switches in the network must be at least about $N \log_2 N$, and the number of switches per call must be at least about $N \log_2 N$ divided by N, or $\log_2 N$. In other words, the minimum number of switches per call required to construct any switching network is an increasing function of the number of calls the network can handle. This fact shows that diseconomy of scale is an intrinsic feature of switching networks; no method of construction, however ingenious, can avoid it.



DEPENDENCE OF THE NUMBER OF SWITCHES in a network on the number of calls it can handle is shown here for two methods of network construction. The scales for the number of calls the network can handle (N) and the number of switches are both logarithmic. Any function of the form cN^{α}, where c and α are constants, plots as a straight line on this type of graph; the multiplier c determines the point where the line intercepts the vertical axis and the exponent α determines the slope of the line. (In this instance the slope of the line is determined by the rate of growth of the number of switches.) For any two functions of this form there is a value of N beyond which the function with the smaller exponent assumes smaller values. Clos's design is superior to the crossbar because it reduces the exponent of N from 2 to 1.5.

The investigations I have described here follow a pattern typical of research in complexity theory: constructions are devised to reduce the number of components in a system and arguments are marshaled to establish bounds on the possible extent of that reduction. In the case of switching networks a gap remains between the constructions and the bounds. Cantor's method of construction requires $O(N(\log N)^2)$ switches. Shannon's argument shows that a diseconomy of scale cannot be avoided so that no method of construction can be found that requires $O(N)$ switches. Can a network be constructed with $O(N \log N)$ switches?

This question was answered recently by L. A. Bassalygo and M. S. Pinsker of the Institute for Problems of Information Transmission in Moscow. Their findings are remarkable in that they depart from the pattern of investigation I have been describing. Bassalygo and Pinsker proved that a network capable of handling N calls can indeed be built with $O(N \log N)$ switches, but they did so without providing an explicit design for such a network.

The networks Bassalygo and Pinsker described are constructed by interconnecting special subnetworks that I shall call sparse crossbars. A sparse crossbar is a crossbar from which many switches have been removed but that still fulfills the following requirement: every group consisting of a third of the horizontal bars is connected by switches to more than two-thirds of the vertical bars.

Of course, a regular crossbar (with every horizontal bar connected to every vertical bar) also fulfills this requirement, but a sparse crossbar does it with far fewer switches. Consider a K-by-K subnetwork, that is, one with K incoming and K outgoing lines. A crossbar of this size requires K^2 switches, but a K-by-K sparse crossbar can be built with only $12K$ switches. Once sparse crossbars are available they can be interconnected (in much the same way that crossbars were interconnected by Clos and Cantor) to construct networks capable of handling N calls with $O(N \log N)$ switches.

The striking part of Bassalygo and Pinsker's proof is the demonstration that K-by-K sparse crossbars can be built with $12K$ switches. Rather than dealing with a specific arrangement of switches in this part of the proof Bassalygo and Pinsker considered the class of all possible arrangements of $12K$ switches. Each arrangement in the class is either good (it forms a sparse crossbar) or bad (it does not). Routine combinatorial techniques can be applied to ob-

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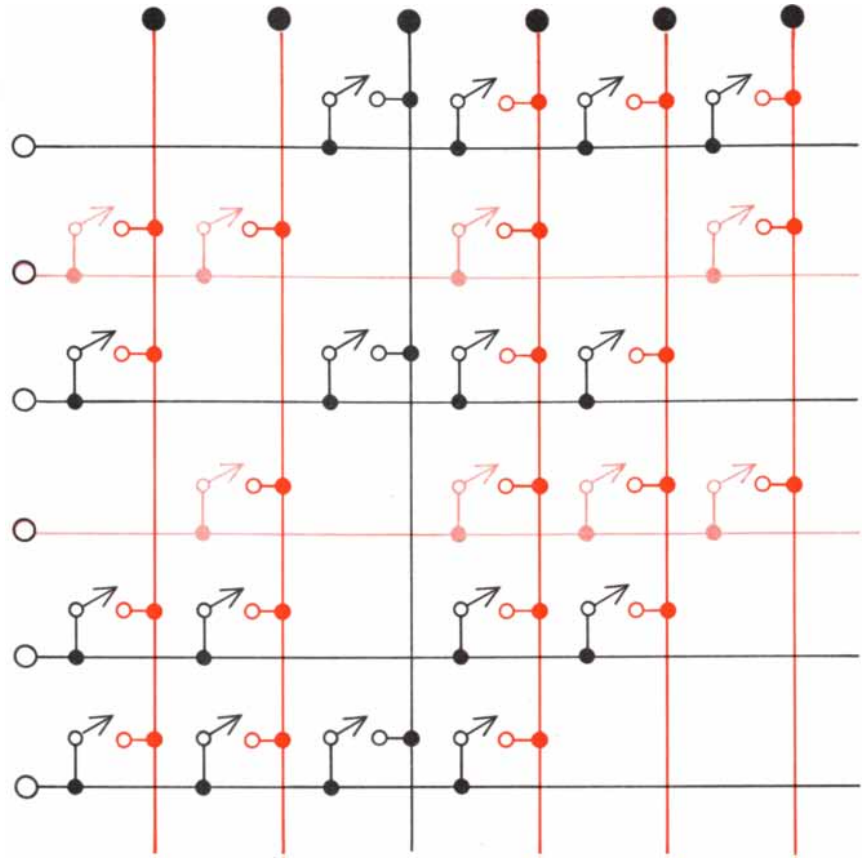
tain both a count of all the different arrangements and an upper bound for the number of bad arrangements.

The upper bound turns out to be smaller than the total number of arrangements. (In fact, only a small fraction of the arrangements are bad.) Hence there must be at least one good arrangement, that is, one that forms a sparse crossbar. (Actually the vast majority of arrangements must be good.) Thus it is possible to build a K-by-K sparse crossbar with $12K$ switches for every value of K. (And these sparse crossbars can be interconnected to form a network with $O(N\log N)$ switches.)

In what sense does this argument fail to provide an explicit design for constructing sparse crossbars? After all, there are only a finite number of ways $12K$ switches can be arranged on K horizontal and K vertical bars. Why not simply test each of the arrangements—check every group consisting of a third of the horizontal bars and see whether they are connected to more than two-thirds of the vertical bars—until a sparse crossbar is found? As soon as the number of possible arrangements of switches is calculated, however, it becomes obvious that this approach is not feasible.

If K is equal to 48, for example, there are more than 10^{514} different arrangements. Even if a million arrangements could be tested per second, it would take more than 10^{500} years to test all of them. Of course, since the vast majority of arrangements are good, testing one or two should suffice. There are so many conditions to be tested to show that an arrangement forms a sparse crossbar, however, that testing even one arrangement would be hopelessly time-consuming. For the 48-by-48 crossbar there are more than 10^{24} ways of choosing a third of the horizontal bars and two-thirds of the vertical bars. If a million of these choices could be tested per second, it would take more than 10^{10} years to test them all.



SPARSE CROSSBAR is a crossbar switching network from which many switches have been removed but that still fulfills the following requirement: every group consisting of a third of the horizontal bars is connected by switches to more than two-thirds of the vertical bars. For example, in the small sparse crossbar shown in this illustration, one group of two horizontal bars (*light color*) is connected to five vertical bars (*dark color*). L. A. Bassalygo and M. S. Pinsker of the Institute for Problems of Information Transmission in Moscow proved that by interconnecting sparse crossbars it is possible to construct switching networks with no more than $cN\log N$ switches, where c is a constant. Their proof differs from most work in complexity theory in that it establishes existence of a network without giving explicit design for the network.

The arguments of Shannon and of Bassalygo and Pinsker show that as the number of calls handled by a network grows, the number of switches per call must grow as fast as the logarithm of the number of calls and need grow no faster. No explicit design is known, however, for networks that achieve this minimum rate of growth. Moreover, the best available upper bound and lower bound on the number of switches per call required in a network have the same order, or rate of growth, but have multipliers that differ by a factor of 30. It is not yet known where in that range the correct figure lies.

These persistent problems can be avoided by asking a little less of switching networks. Up to this point I have discussed only nonblocking networks: networks that provide a path for any call that arrives on a free trunk, destined for a free subscriber. There are switching networks of a different kind that could be employed in a telephone exchange: seldom-blocking networks, which provide paths for most calls but not all. A nonblocking network is guaranteed to provide paths even for a sequence of calls chosen by an adversary to the network (an adversary being someone who undertakes to force the network to block a call). A seldom-blocking network is guaranteed only to provide paths for most calls in the benign environment of randomly arriving calls. (The processes that govern the placing of telephone calls are so complicated that it is more fruitful to view them probabilistically than to do so deterministically; from this point of view, although the ebb and flow of calling follow predictable cycles, the detailed arrival of individual calls can be regarded as being random.)

In a real telephone exchange it is not necessary to guarantee a path for every call in every possible state of the switching network. The subscribers of an exchange will probably not object if, say, one call in 1,000 is blocked, particularly if a substantial reduction in cost is obtained. It is by exploiting this fact that real telephone exchanges, which use fewer switches than any of the nonblocking networks I have described, provide satisfactory performance at low cost.

Seldom-blocking networks present additional problems for complexity theory. How should they be constructed? Do they too have an unavoidable diseconomy of scale? While I was a graduate student at the Massachusetts Institute of Technology I discovered that for any positive number ϵ (say, a thousandth) there is a network having the following property: If the network is in a randomly chosen state and a call arrives on a free trunk, destined for a free subscriber, then the probability that no path can be provided is at most ϵ.

Like the Bassalygo-Pinsker networks, these seldom-blocking networks contain $O(N\log N)$ switches. Moreover, for such

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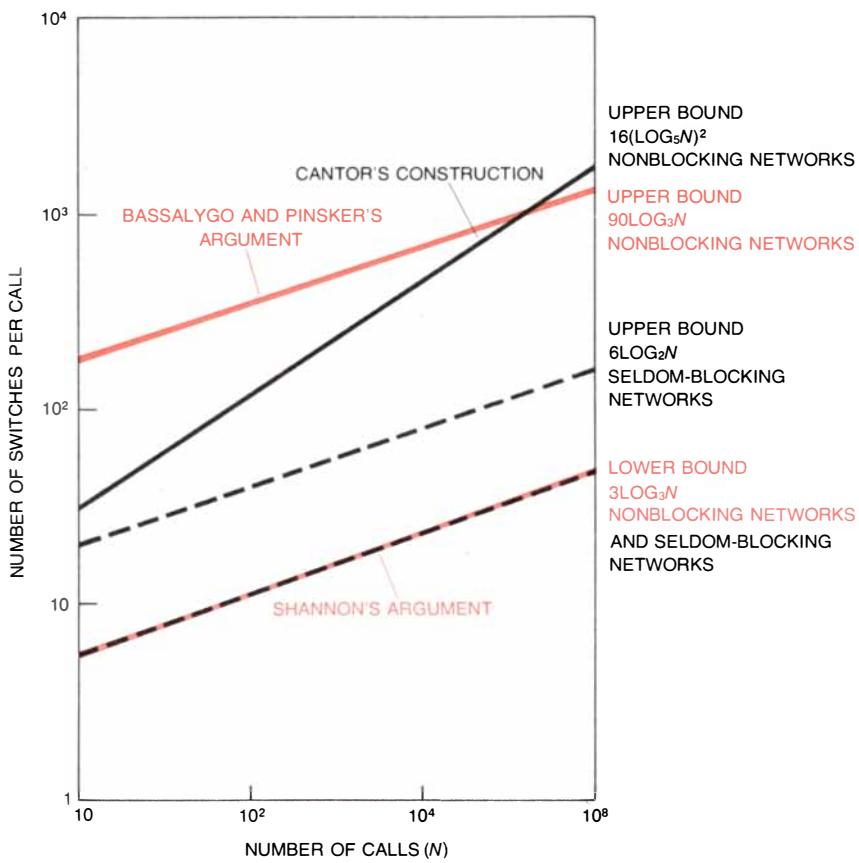
networks the multiplier suppressed by the order notation is smaller than the one given by Bassalygo and Pinsker by about a factor of 10 [*see illustration below*]. Finally, there is an explicit plan for these networks, so that the main problems of nonblocking networks have been avoided. One difficulty remains. The property describing the probability that a call will be blocked in a seldom-blocking network says nothing about the evolution of the state of the network in time, and it is not yet known whether or not a network in a randomly chosen state will be in another randomly chosen state after the arrival and termination of many calls. Thus there is still no complete understanding of why real telephone exchanges are as efficient as they are!

There are a number of ways of extending Shannon's argument regarding the diseconomy of scale of nonblocking networks to seldom-blocking networks. They all show that seldom-blocking networks have an unavoidable diseconomy of scale of the same type as nonblocking networks: the number of switches per call must grow as fast as the logarithm of the number of calls. Therefore allowing a fixed probability of blocking can affect no more than the constant multiplier in the expression for the number of switches in a network.

It appears that seldom-blocking networks are easier to build and cheaper than nonblocking ones, but it is still possible that a method of constructing nonblocking networks with as few switches as seldom-blocking ones will be discovered. Of course, if nonblocking and seldom-blocking networks can be had for the same cost (the same number of components), there is no reason to settle for the seldom-blocking kind, no matter how infrequently blockages are encountered. It is not known, however, whether the costs of these two kinds of network are indeed equal. For at least one problem, the transmission of information over a noisy channel, a premium in the form of a reduction in the rate of transmission must be paid for insisting on the kind of perfect performance analogous to nonblocking in networks.

There are two ways of showing whether or not the same is true for switching networks. If the lower bound on the cost of nonblocking networks were raised above the upper bound on the cost of seldom-blocking networks, that would prove that a premium must be paid for nonblocking performance. Or if the upper bound for nonblocking networks were reduced to the lower bound for seldom-blocking networks, that would prove that there is no premium for nonblocking performance. In either case a better understanding of nonblocking networks is needed.

What, then, is the status of the work on switching networks? For practical purposes the theory of seldom-blocking networks is quite satisfactory. Expanded versions of this theory—formulations that include the cost of components other than switches, fluctuations in calling traffic and so on—have been used in the design of real switching networks. The theory of nonblocking networks is also at an encouraging, if tantalizing, point in its development. It appears that further progress will require an essentially different kind of argument, based on a new perception of the problem.



UPPER AND LOWER BOUNDS on the number of switches per call required to construct a switching network (the number of switches in the network divided by the number of calls the network can handle) have been established by several different types of reasoning. When these bounds are plotted on a graph in which the scale for the number of switches per call is logarithmic and the scale for the number of calls is doubly logarithmic (moving one unit out along the scale corresponds to squaring rather than simply multiplying by 10), then the bounds are asymptotic to the straight lines shown here. (At present real telephone exchanges handle from 10^3 to 10^4 calls. The graph has been extended far beyond 10^4 calls to show the crossing of the upper bounds.) The upper bounds established by David G. Cantor of the University of California at Los Angeles and Bassalygo and Pinsker and the lower bound established by Claude E. Shannon at Bell Laboratories (*solid lines*) apply to nonblocking networks: networks guaranteed to provide a path for any call that arrives on a trunk that is not engaged, destined for a subscriber who is not engaged. The other bounds (*broken lines*) apply to seldom-blocking networks: networks guaranteed only to provide paths for most calls when calls arrive at random. The upper and lower bounds on the number of switches per call required in seldom-blocking networks fall below the upper and lower bounds for nonblocking networks. The difference between the lower bounds for nonblocking and seldom-blocking networks is negligible when the blocking probability (the fraction of the calls for which a seldom-blocking network cannot provide a path) is small. At present it appears that seldom-blocking networks are both easier and cheaper to construct than nonblocking ones. To determine whether or not that is true it will be necessary either to raise the lower bound for nonblocking networks above the upper bound for seldom-blocking networks or to lower the upper bound for nonblocking networks to the lower bound for seldom-blocking networks. It is not yet known which of the alternatives will prevail.

In this article I have examined a single problem in complexity theory, but the phenomena it brings to light appear frequently in other problems. Indeed, the most important lesson of complexity theory is the demonstration of the diversity of phenomena that can arise through the interaction of simple components. Today's computers and telephone exchanges present problems beyond our understanding, but these systems are dwarfed in complexity by even the humblest biological systems. While complexity theory struggles with the problems within its reach far greater problems lie beyond.

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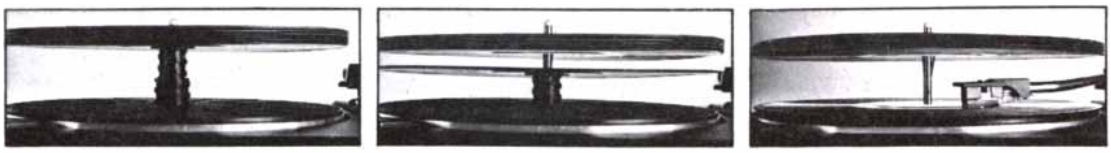

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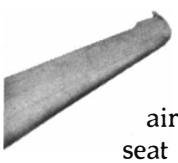

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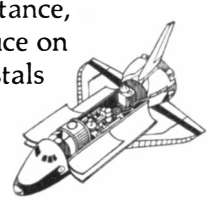

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The Preservation of Stone

The forces that erode stone in nature also erode it when it is used for buildings, and they are intensified by contaminants in the air of cities. The erosion can be retarded by novel chemical treatments

by K. Lal Gauri

Stone is traditionally the most durable of building materials, but of course its durability is not absolute. It depends on the type of stone and on its environment, particularly when the environment is an urban one rich in sulfur, nitrous oxides and carbon dioxide. Under such conditions stone decays, sometimes quite rapidly. Ironically the process has been accelerated in some instances by attempts made in the past to save deteriorating structures. Without suitable corrective action it is distinctly possible that such splendid buildings as the Parthenon, the Colosseum and the Taj Mahal, which are already in various stages of decay, will disintegrate.

Studies aimed at finding satisfactory methods of preserving stone are in progress in several laboratories around the world. One of them is the Stone Conservation Laboratory of the University of Louisville, where I as a geologist and workers from a number of other disciplines have joined forces to attack the problem. This article is based on our work.

The deterioration of stone is starkly manifested in dirty façades, behind which the stone is literally crumbling. The process at the very least makes the stone unattractive, and it may render the building structurally unsound. The purpose of preservation is to reverse the processes of deterioration so that the façade is clean and the stone is structually regenerated.

Another aspect of preservation involves restoring parts of a stone structure that have deteriorated beyond repair. Considerations of structural engineering may require the replacement of unstable portions of a historic building while the building's architectural integrity is maintained. Similar requirements arise in the earthquake zones of California, where architectural codes call for the removal of certain types of overhanging cornice in the interests of safety. The replacements are made of lighter artificial materials that maintain the structural and aesthetic qualities of the original.

The preservation of stone is therefore a subject with many aspects. It deals with the processes of weathering; with the cleaning, consolidation and restoration of weathered objects; with the fabrication of replacement structures and with the development of criteria that serve as standards for preservation work.

The common natural building stones are marble, limestone, sandstone, basalt and granite. Serpentine and verde antique, which have been erroneously called marble, are sometimes employed for ashlar (flat facing stones) and for supporting columns. The limestones and marbles consist primarily of the mineral calcite; other building stones consist of silicate minerals but may also include calcite. For example, the grains of quartz in a sandstone may be bonded together with calcite. Verde antique, which is essentially a silicate material, is always traversed by veins of calcite.

All these minerals are acted on (at various rates) by carbon dioxide dissolved in water. The ubiquitous calcite shows the maximum reactivity. An imposing example of this reactivity is Mammoth Cave in Kentucky, a huge system of holes leached in a Paleozoic limestone over millions of years.

The solution of carbon dioxide and water reacts with calcite to form soluble products that themselves go into solution. In a sandstone where the grains are cemented together by calcite such leaching reduces the stone's abrasive index (a measure of the degree to which the material resists abrasion) and eventually causes the grains to dissociate. Similarly in limestones and marbles dissolution at the grain boundaries of the rock erodes its surface.

The silicate minerals react at a lower rate, and their weathering products are different. The end results in terms of the decomposition of the stone, however, are precisely the same. A large-scale effect can be seen in the plateau basalts of India, which are composed of silicate minerals. Since their formation some 60 million years ago weathering has converted them into bauxite to a depth of several hundred feet.

In modern urban atmospheres oxides of sulfur and nitrogen are becoming more prominent as agents of stone decay. Sulfur dioxide is produced from the combustion of fossil fuels that contain sulfur-bearing compounds (an example being pyrite in coal). The nitrous oxides result from the oxidation of atmospheric nitrogen. The reactions of sulfur dioxide with building materials are well known, but information on the reactions of the nitrous oxides is meager.

Sulfur dioxide transforms calcite, which is fairly stable, into gypsum, which is much more soluble in water. Accordingly gypsum does not accumulate on stone surfaces in regions where driving rains are frequent. Instead it is washed off, and fresh stone is laid bare for further attack. (In the parts of buildings where the rain does not reach, such as under windowsills and on friezes, the gypsum is likely to remain.) In drier climates an appreciable thickness of gypsum accumulates on stone exteriors. For example, the sculptures in the Erechtheum on the Acropolis are reported to have accumulated gypsum to a depth of about a centimeter. The continued leaching of the mineral is slowly obliterating the surface relief while new gypsum is forming from the parent marble of the sculptures.

The weathering of stone involves more than the reactions of the material with solutions and atmospheric gases. Mechanical effects are important too. They include the wetting of the stone grains and the damage that is done when water penetrates the stone and freezes. Such processes are responsible for most of the structural damage to stone; the chemical reactions I have been describing are mainly confined to the surface. The net effects of weathering, then, are the formation of dirty crusts, the wearing away of stone surfaces, structural damage and, above all, the loss by the aging stone of its capacity to resist decay.

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The effort toward preservation begins with cleaning. The dirt on the surface of building stones is primarily street soot that coats the stone and even embeds itself in the outer layers. Calcite, after it has been dissolved, may recrystallize on the same façade or may be transformed into gypsum. Many of the dirty encrustations on stone are in fact combinations of calcite and gypsum that in the process of chemical transformation have incorporated silica, fly ash and carbonaceous material from polluted air.

Other common discolorations are produced by efflorescences, which are water-soluble salts that crystallize on the surface. Some of them, such as the gypsum in concrete, are present in the material initially and form efflorescences as a result of chemical weathering. Others, such as the sodium chloride in maritime regions, are deposited on the stone by sprays. Still others form by the reaction of substances in the material with substances deposited on it; an example is the reaction of gypsum with sodium chloride from ocean sprays, forming corrosive sodium sulfates. Moreover, the salts increase the concentration of ions in the stone and thereby make potential efflorescences even more soluble in water than they normally are.

On the surface of the stone the efflorescences are simply discolorations. They are capable, however, of being hydrated, that is, of incorporating water into their crystal structure. When efflorescences are hydrated behind the stone or within it, they literally shatter it. A related phenomenon is the oxidation of reinforcing iron bars and other metallic anchors employed to secure blocks of stone and concrete. The oxidation products from iron (limonite is one of them) are less dense than their reactants and therefore occupy a larger volume and damage the stone. (Limonite also migrates to the surface and results in a patchy, yellowish and brownish discoloration.) The oxidation of the iron bars installed in the buildings on the Acropolis to anchor marble blocks during a restoration of 1902 to 1909 is now the main disease of the marble in the buildings.

Stone surfaces can be cleaned by both mechanical and chemical means. It is best to try mechanical methods first, since the chemical ones have certain disadvantages. Every method, however, entails removing some of the stone along with the dirt. It is therefore necessary to choose the cleaning process on the basis of the chemistry of the stone so that the least possible quantity of stone is removed.

The mechanical methods of cleaning include brushing the stone and blasting it with air, water or grit. For example, most harmful efflorescences, which are complex sulfates of calcium and sodi-

CARYATID FIGURE, one of six serving as supports for the porch roof of the Erechtheum on the Acropolis, shows the effects of 2,300 years of weathering. The marble has been damaged by sulfur dioxide, which built a coat of gypsum on the surface. Adjacent areas of the building have also deteriorated from rusting of iron reinforcing bars installed between 1902 and 1909.

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um, are removed by brushing the surface. Steam and hot water, in which the solubility of these efflorescences is enhanced, are effective in removing them not only from the surface but also from deeper layers.

Although the degree to which dirt must be removed before a building can be called clean is largely a matter of judgment, the degree to which efflorescences must be removed can be specified quite precisely. Our experience with a variety of stones shows that sodium and sulfate ions should be reduced to .03 percent (by weight) of the stone. It is likely that the stone also contains other types of efflorescence. One determines their ionic composition (and thereby the degree to which they must be removed) by putting samples of the stone in deionized water. Ions from the stone mi-

WEATHERED PORTLAND LIMESTONE from St. Paul's Cathedral in London is shown in a scanning electron micrograph at an enlargement of 120 diameters. In the upper part of the micrograph one sees an area near the surface of the stone; the lower part is the interior, revealed by a right-angle cut at the surface. The darker material filling the pore space of the interior is recrystallized calcite formed from the solutions created by weathering at the surface. Calcite originally in the stone reacts with carbon dioxide dissolved in rainwater.

DEEPER SECTION of the limestone from St. Paul's Cathedral is enlarged 40 diameters in this scanning electron micrograph. The open pore spaces indicate that the lower part of the stone is less weathered. The weathering extends about 2.5 millimeters below the surface.

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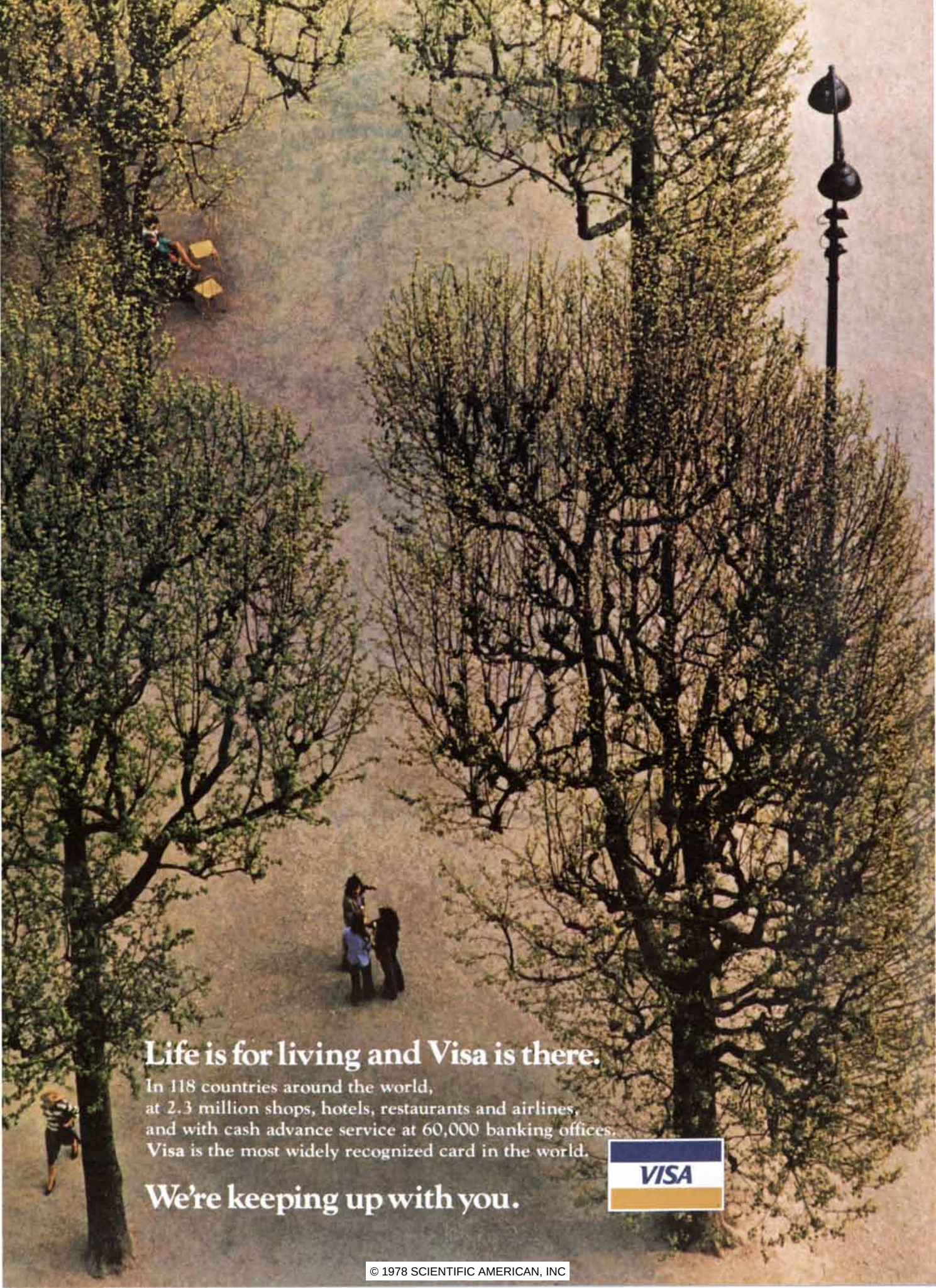

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grate into the water and can be identified and their quantity measured accurately and rapidly by atomic absorption spectrophotometry.

As for chemical methods, noncalcareous stones and unglazed masonry are routinely cleaned with fluoride-bearing chemicals such as hydrofluoric acid and ammonium bifluoride. Other chemicals (acidic, alkaline or chelating) serve in the cleaning of most other stones and masonry. As I have said, all the chemical cleaning agents have certain disadvantages. For example, the alkaline cleaners leave behind traces that form efflorescences. Moreover, all the chemical cleaning agents penetrate deeply and therefore tend to corrode and weaken the stone.

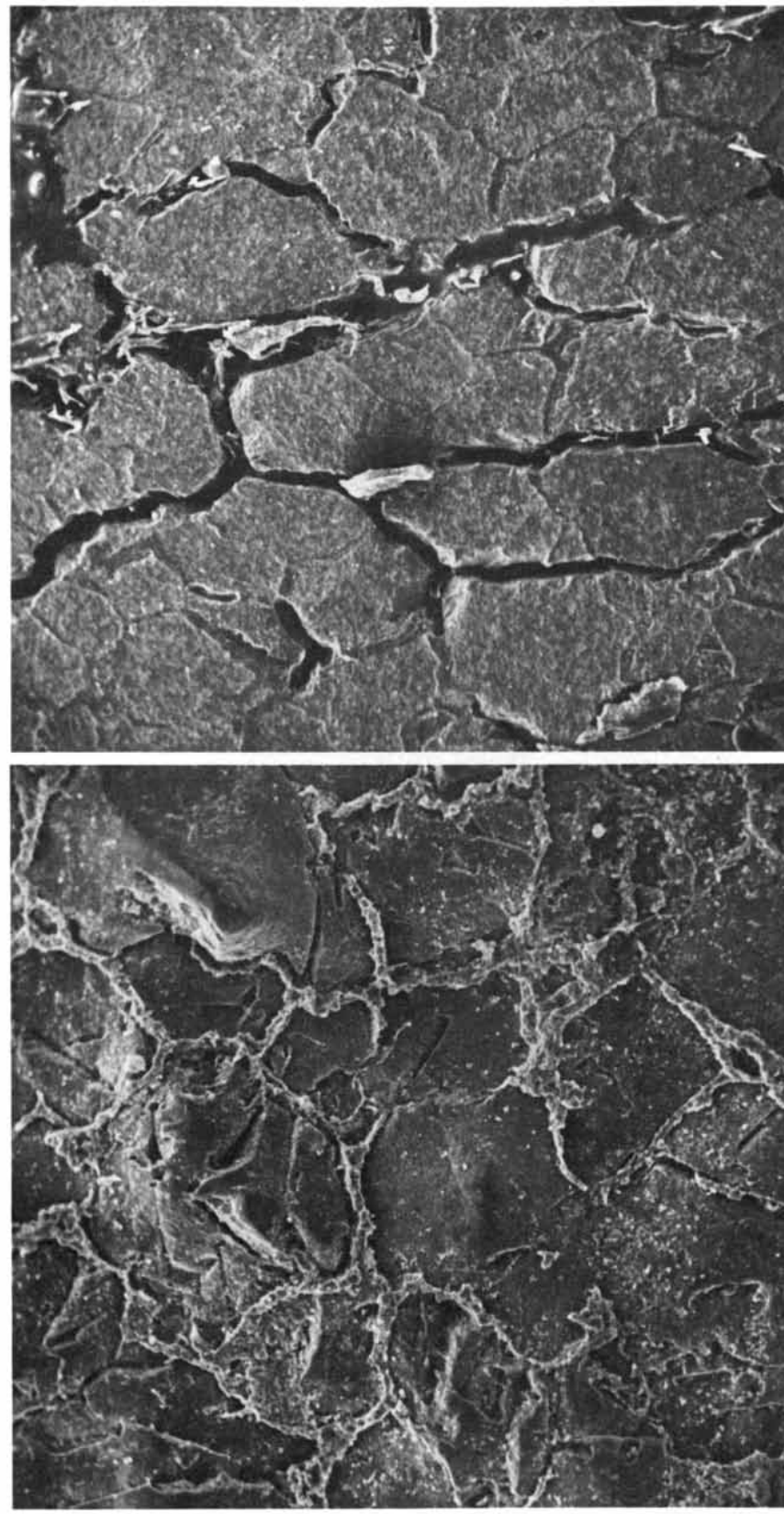
The cleaning of old buildings frequently exposes crumbling stone. This stone must be consolidated. Three methods of doing so are prevalent.

One is to replace the constituents of the stone that are prone to atmospheric attack. For example, barium hydroxide is introduced into the stone. Barium, on replacing the calcium of calcite or gypsum, forms less soluble barium carbonate or barium sulfate or else it forms a solid solution of calcium-barium carbonate and calcium-barium sulfate. Various versions of this procedure have been employed for a century. An inherent difficulty is in obtaining a true barium solution that will penetrate the stone easily. Moreover, the reaction rates that lead to the formation of the resistant barium products are quite low.

A second method is to bring about the precipitation of chemically resistant materials in the pore space of the stone. For example, silicon dioxide can be deposited in the pores from water-soluble organic silicates or from silicone esters. If the treatment is done correctly, the silicon dioxide bonds with the silica of the stone. It is therefore best to confine the treatment to sandstone and other stones that contain silicate minerals. One must also take care to be sure that the liquids introduced into the stone precipitate rapidly. If they do not, they tend to migrate toward the surface as the liquid evaporates. At the surface they form crusts that are harmful to the stone.

The third method of consolidating stone is to treat it with organic monomers and prepolymers. After such a substance has been introduced into the stone it is made to polymerize by means of a curing agent in the solution. On polymerization it recements the dislodged grains of the weathered stone. Our group's work on stone conservation has focused on the application of such synthetic polymers.

Some of the polymers not only possess cementing properties but also are water-repellent. Both properties are extremely useful for the preservation of



TREATED SPECIMENS of weathered Georgia marble appear at enlargements of 55 and 120 diameters in these scanning electron micrographs. The white material in the pore spaces of the stone is an impregnated polymer. In the upper micrograph the polymer does not entirely fill the pore spaces but does make them more tortuous, so that water penetrates the stone less readily. In the lower micrograph the polymer plugs the pore space. A polymer treatment that entirely fills the pore space is undesirable, since it reduces the ability of the stone to "breathe," that is, to allow the outward migration of water that enters the stone from elsewhere in the building.

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HP advances in computed measurement

For the first time, long-axis precision plotting *and matrix* printing *on a single machine.*

Systems designers who have had to choose between a plotter and a printer have inevitably compromised one function or the other. The alternative, installing both types of units, increases system cost and complexity. Victims of this quandry will welcome the HP 7245, a new, microprocessor-controlled plotter/printer that combines both functions in a single desktop unit.

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An unusually responsive plotter/printer, the 7245 can provide unattended graphics and printing in HP-IB (IEEE-488) systems. It responds to standard commands and control codes for both printers and plotters. A set of 46 programmable instructions—each a simple-to-use two-letter mnemonic—provides unit scaling, window plotting, graph rotation, and fast digitizing. A rare combination of design characteristics—bidirectional drive, high positioning accuracy, penless and inkless thermal printhead, and a 200-foot roll of paper—rounds out its capability to operate unattended.

Priced at $4600*, the HP 7245 is limited in application only by the imagination of the user.

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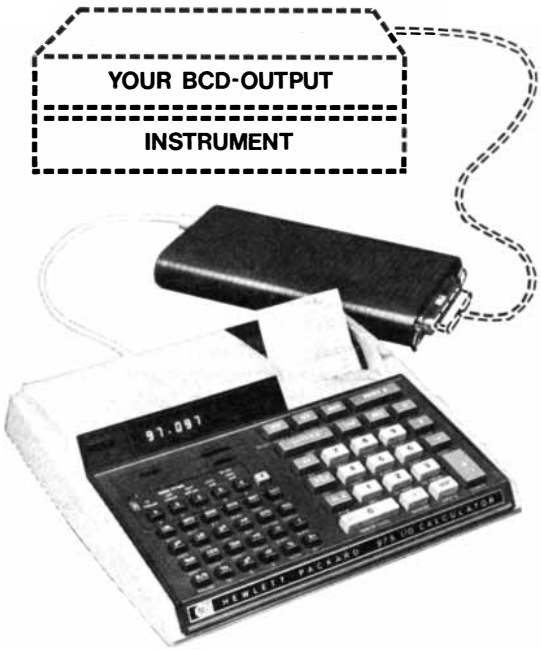

The HP-97S makes it economically and technically feasible to automate all kinds of instruments with BCD output, including electronic balances, photometers, thermal conductivity and pH meters, titrators, strain-gauge systems, and a score of other electronic devices.

With the HP-97S, automatic data acquisition and control is a matter of just two simple steps.

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You can do the next step—programming—either by keystroke or with prerecorded magnetic cards. Even beginners find keystroke programming easy. The *Owner's Handbook & Programming Guide* tells how to write and record your own programs, step by step.

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stone. Certain other properties of the polymers, however, can be detrimental to the stone. If the polymers absorb active gases, they can accelerate the rate of decay. If they absorb ultraviolet radiation, they may decay themselves, eventually leaving the stone unprotected. The selection of polymers for treating stone should therefore be based on determining in advance that the polymer does not enhance decay or react with substances in the environment.

In the early stages of our work we discovered that certain specimens of marble that had been treated with various epoxy resins actually deteriorated faster than untreated marble in an atmosphere of concentrated sulfur dioxide. We further determined that the epoxies bearing aliphatic radicals were the ones that produced this undesirable result. After further work we found that such epoxies copiously absorbed sulfur dioxide. Examining the sizes of the pores in the epoxy films, we found them to range from one to two nanometers. Since the size of the sulfur dioxide molecule is about .5 nanometer, it is evident that sulfur dioxide could be easily absorbed by the epoxy and passed on to the stone. Such a polymer is obviously unsuitable for the preservation of stone.

Polymers that break down under ultraviolet radiation presumably do so because the radiation breaks the bonds between the carbon atoms in the polymers. One therefore seeks polymers that do not absorb that part of the sun's ultraviolet radiation that penetrates the earth's atmosphere to ground level (with wavelengths of more than 290 nanometers). Fluorocarbon polymers prove to be particularly good in this respect.

The degradation of polymers by ambient ultraviolet radiation is slow. The epoxies that degrade fastest take about six months to show the first signs of degradation. In our experiments we have speeded up the process by exposing polymers to ultraviolet radiation of shorter wavelengths, taking care to maintain a plausible relation between the accelerated degradation and the degradation that would result from natural conditions of exposure.

One early symptom of degradation due to the absorption of ultraviolet light is discoloration of the polymer. The material begins to look yellow, and it also becomes chalky. Eventually it peels away from the stone. In the natural degradation process epoxies exposed in a middle-latitude environment showed a distinct yellowing in about six months. Fluorocarbon samples exposed for the past five years have yet to exhibit any discoloration. Our accelerated experiments have yielded similar results: epoxy films discolored in 10 hours and fluorocarbon films showed no change after 400 hours.

WEATHERED MADONNA stands in a cemetery in New York City. The weathering is the result of the reaction of the stone with oxides of carbon, sulfur and nitrogen dissolved in rainwater. In the open areas of the statue the reaction products have been washed off by rain in a natural cleaning process, but in the recessed and partly protected area of the face they have formed a crust that has begun to fall off in patches, aggravating the decay of the stonework.

We have also been concerned with developing efficient means of detecting the degradation of polymers. One of our methods is to determine by spectrophotometry the ultraviolet absorption of polymer films that have been subjected to a known amount of ultraviolet radiation. Another is to measure the angle of contact that a drop of liquid (usually water) makes with the surface of a polymer. The contact angle changes as the surface degrades.

This rigorous testing of a polymer that is being considered for application to stone as a preservative is most pertinent for composite materials that are prepared for patching purposes or for replacing structures such as cornices. The composites are customarily made by employing a polymer as the bonding medium for crushed and graded stone that has essentially the same mineral content and color as the stone that is to be patched. About half of the exposed surface of a composite is formed by the polymer. The degradation of the polymer therefore impairs both the appearance and the structural properties of the composite.

This consideration is not so important when the polymer is employed to consolidate stone, but other requirements must be met if the treatment is to be successful. It is particularly important that the polymer impregnate the stone deeply but that it do so without completely filling the pores. The penetration is needed to ensure that the zone of impregnation extends deeper than the zone affected by weathering. The pores are needed because the stone should retain its ability to "breathe." If the pores are plugged, water will be trapped behind the treated zone and will eventually cause the disintegration of the treated stone and part of the untreated stone as well. (A similar phenomenon is commonly observed in old buildings, where crusts formed on the surface of stone by weathering impede the outward migration of trapped water.)

Since most polymers are viscous, they do not easily penetrate stone. They do, however, readily form a solution with organic solvents, which therefore can be employed as carriers to get the polymer

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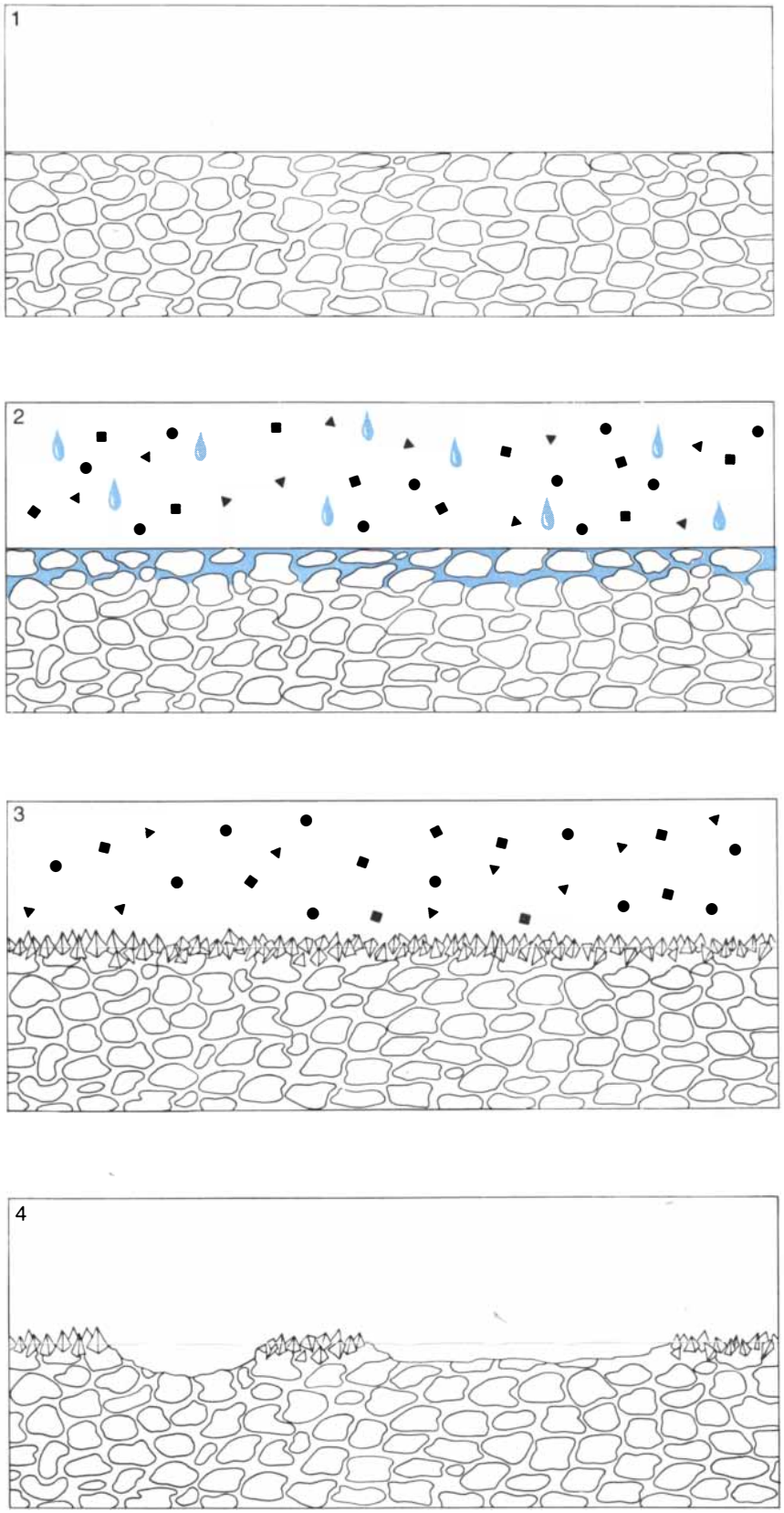
deeply into the stone. A method that I have developed begins by filling the pore spaces of the stone with a solvent that penetrates easily. The stone is then brought in contact with a series of polymer-solvent mixtures in which the concentration of polymer is progressively increased. Eventually the polymer has penetrated a suitable distance into the stone. The solvent migrates outward by diffusion.

The design of a consolidation treatment for a building is based on laboratory experiments with samples of stone from the building. The best design encompasses certain properties that a treated stone should acquire. They are (1) the rate of capillary movement of water in the stone, (2) the stone's permeability, (3) its compressive strength and (4) its chemical reactivity. Although quantitative values can be assigned to all these properties, no universally applicable values can be developed because there are so many different kinds of stone. Even when two building stones have been cut from the same parent stone, they can show different properties if they have weathered in different parts of a building. One must therefore compare treated and untreated specimens of stone in order to design a treatment.

One objective is to repel water at the surface of a stone while enabling water that is inside the stone (having come, say, from untreated regions of the building) to escape. Here again is a reason for carefully controlling the density of impregnation with polymer. High-density impregnation forms undesirable barriers to the movement of water; low-density impregnation, by lining the pores and increasing the tortuosity of porous passages, reduces but does not block the movement of liquids and gases. In our best treatments most stones have exhibited a reduction of up to a half in the absorption of water.

The term compressive strength normally describes the strength of a rock in compression but also refers to other mechanical properties of the rock. The improvement of compressive strength as a result of treatment is a measure of the improvement of specific gravity, abrasive index and tensile strength. Ordinarily one tests compressive strength by applying a force to a stone until it breaks. This approach is inappropriate for weathered stone, because weathering produces a graded zonation in which the properties nearest the surface are altered the most and those farthest from the surface resemble the properties of unweathered stone. Therefore one tests the compressive strength of the weathered zone layer by layer.

Developed standards are lacking for the chemical reactivity of stone. Our specifications for a contractor read that a treated stone is to experience no more



MECHANISM OF WEATHERING is depicted schematically. After an unweathered stone (*1*) has been exposed to the weather, it comes under attack by the oxides of carbon, sulfur and nitrogen that form a solution with rainwater (*2*). The solution penetrates some distance into the stone. By recrystallization at the surface and in depth and by the incorporation of environmental soot a crust is formed (*3*). If parts of the crust break off (*4*), they carry away with them constituents of the stone, which is thereby abraded and laid open to further chemical attack.

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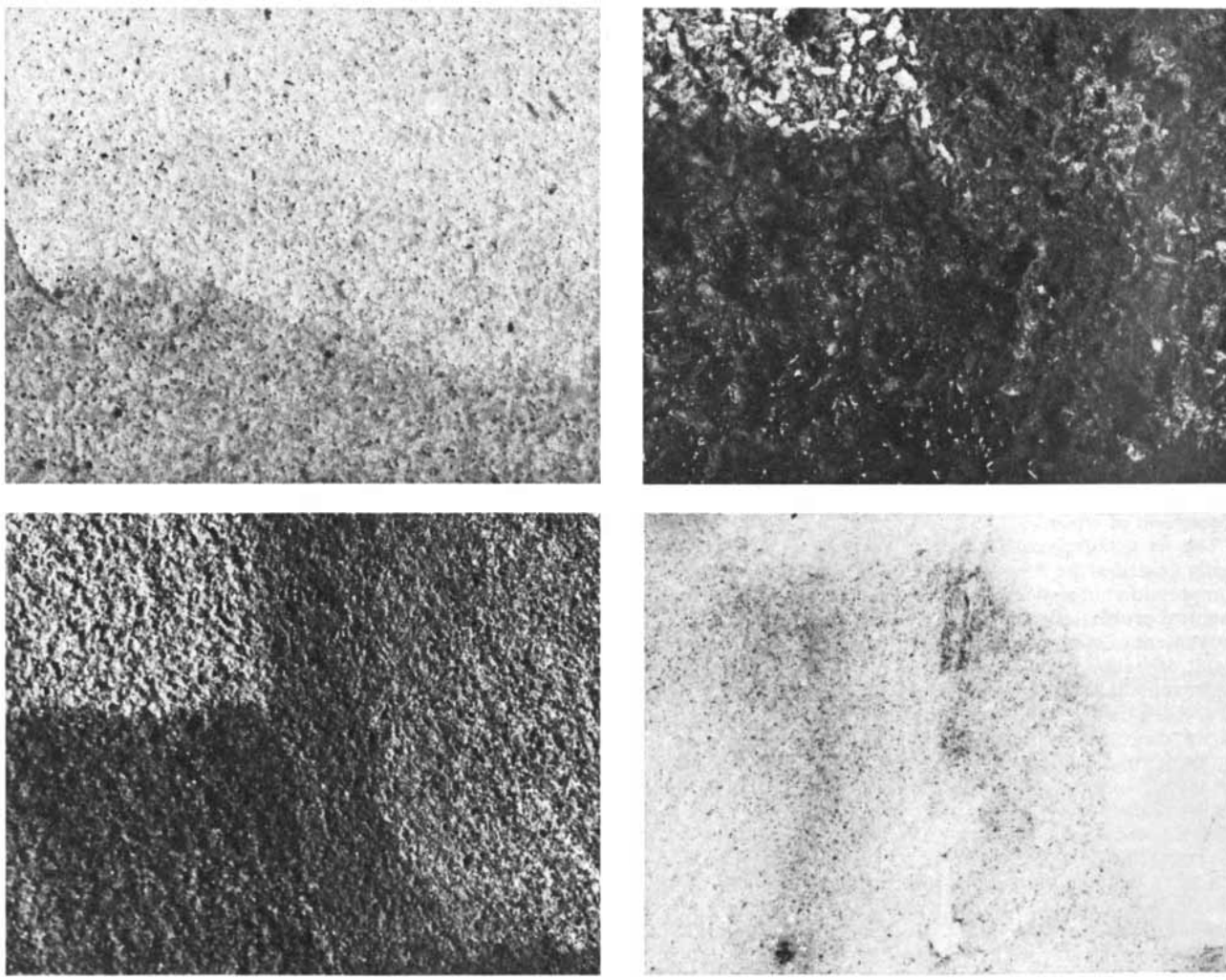
than half the reactivity of an untreated one during the first 24 hours of exposure to a given atmosphere of carbon dioxide and sulfur dioxide. (Our test atmospheres, which are slightly concentrated over normal ones, contain 2 percent carbon dioxide and 10 parts per million of sulfur dioxide.)

An overall estimate of the improvement of mechanical properties resulting from a preservative treatment can be obtained with the "soundness test" adopted by the American Society for Testing and Materials. In this test anhydrous sodium sulfate is deposited in the pore space of a stone from a solution brought to saturation at a temperature of 21 degrees Celsius. The stone is then dried. The anhydrous sodium sulfate absorbs water when the stone is placed again in the saturated solution. This treatment creates tensile stress within the stone. When this cyclic procedure is repeated a number of times, the eventual result is the fragmentation of the stone.

In our investigation specimens of Indiana limestone began to fragment in the second cycle of testing, whereas certain treated specimens of the stone lasted for more than 20 cycles. (The soundness of a treated stone, as determined by this method, reflects not only tensile strength but also the ability of the stone to absorb water.)

We modified the test by forcing the sodium sulfate solution into the specimen in a vacuum. This procedure removed the effect of water repellency arising from the polymer in the treated stone and thus rapidly accelerated the testing process. We applied the test to determine the soundness of specimens that had been subjected to both deep and shallow impregnations with a variety of polymers such as epoxies, fluorocarbon acrylics and silicone resins. The untreated controls began to decay in the second cycle. The mode of decay is best described as sanding, in which individual grains are shed from the stone. Certain treatments, particularly deep but low-density impregnations with epoxies, also gave rise to sanding. Certain other treatments, particularly the ones that involved putting silicone coatings on the surface of the stone, resulted in disintegration by peeling. In natural weathering Indiana limestone decays by sanding, but when dirty crusts develop on the surface, it gradually peels away. Treatment with fluorocarbons produced intermediate results.

It is now evident that a given treatment usually affects one property adversely while improving another. It thus appears that the best treatment will not necessarily produce ideal results for a particular property. Instead one should adopt a compromise formula that yields a treated stone with approximately the properties of a parent untreated stone that has not yet been subjected to the relentless effects of weathering.



BUILDING STONES show the effects of treatment with polymer. From left to right and top to bottom the stones are respectively Portland limestone from St. Paul's Cathedral in London, basalt from Borobudur temple in Indonesia, sandstone from Kenilworth Castle in Britain and Vermont marble. In each case the treated portion is at the right. Each specimen was put in shallow water for a few minutes with the bottom edge down. The water rose appreciably higher in the untreated portion of the stone than in the part treated with polymer.

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The Feeding Behavior of Mosquitoes

It is described for Aëdes aegypti, the female of which feeds on blood. The feeding apparatus is not some kind of hypodermic needle but an exquisitely made piece of biological machinery

by Jack Colvard Jones

There are some 3,000 species of mosquitoes. Most of them are not dangerous to man, even though their bite can be quite annoying and can drive people away from places they would like to be. There are at least 100 species, however, that are distinctly dangerous to man. Such diseases as malaria (caused by protozoans), filariasis (caused by filarial worms) and yellow fever (caused by a virus) are transmitted to man exclusively through the bite of specific kinds of mosquitoes. How do mosquitoes sense the presence of man and how do they draw blood? What makes their bite itch? How do some mosquitoes transmit disease? In seeking the answers to some of these questions and related ones my colleagues and I have been studying the feeding behavior of the most dangerous of all the species of mosquitoes: *Aëdes aegypti*. It is a beautiful creature, with patches of silvery scales interspersed among black ones, giving the insect the appearance of a tiny flying tiger. Although *Aëdes aegypti* is known as the yellow-fever mosquito, it can carry more different diseases than any other species.

Mosquitoes belong to the Diptera, the great order of flies. In this order there are many species of insects in which both the males and the females feed on blood. Among mosquitoes, however, only the females so feed. Not all species of mosquitoes will feed on human blood; there are numerous species that prefer the blood of birds or other animals. Mosquitoes have been observed to feed on numerous mammalian species, on a variety of reptilian species and even on other insect species.

Aëdes aegypti is one of the mosquito species in which the females prefer human blood. The males too are attracted to human beings and will often alight and walk on their skin. But even though a male mosquito may lightly touch the tip of its proboscis to the skin it will never make any attempt to pierce the skin and draw blood.

Only the adult female mosquito will seek human blood. A mosquito's life cycle has many stages, and its feeding behavior in each stage varies as much as its appearance. It begins life as a fertilized egg floating in a pool of water. The embryo mosquito forms rapidly inside the egg and begins to absorb yolky material within its newly formed stomach when it is about 24 hours old. When the mosquito larva is ready to hatch, its pharynx, the upper part of its digestive tract, begins to twitch rapidly; the twitching causes the larva's blood to distend its head in such a way that a sharp spine presses against the eggshell and snaps it off. As soon as the larva emerges from the egg it swims about and begins to feed by sweeping the water with two large fan-shaped bundles of chitinous bristles on the front of its head. The fans create currents in the water that direct food toward the larva's mouthparts and help stuff the food into its deeply concealed mouth.

The larva has a respiratory siphon at its rear end, which it must attach to the surface of the water in order to breathe, but frequently the larva will swim down through the water to feed on the bottom. The mosquito larva is omnivorous; it feeds on bacteria, pollen, microscopic plants and a wide variety of other things. The larva feeds almost continuously: it spends about 95 percent of the time filtering water for particles of food. The larva prefers polluted waters and will grow very fast in an almost pure culture of bacteria. In a few days it goes through the entire larval life cycle, which consists of four discrete stages, becoming larger and more complex with each stage.

Throughout its larval life the insect has been preparing to become an adult. The legs, wings and mouthparts of the adult mosquito slowly form, and in the last larval stage they can readily be seen under the larva's skin. Since the full transformation into an adult is such a radical change, however, the animal needs an intermediate pupal stage in which to complete the process.

To the unaided eye the pupa resembles a comma. Unlike the larva, it is attached to the surface of the water by little earlike respiratory trumpets on its thorax. If the pupa is not disturbed, it remains quietly floating just below the surface, but if a shadow falls on it, it will quickly dive toward the bottom. If shadows repeatedly fall on it, however, it quickly adapts and stops diving.

In the pupal stage the organism's mouth and anus are sealed off just before the pupa emerges from the larval skin; thus the pupa cannot take in food or eliminate solid or fluid waste. The old larval midgut falls into the center of the rapidly developing adult midgut, or stomach, where it is literally digested by the pupa and the young adult. Just before the adult begins to emerge from the pupal skin it begins to drink air from a bubble under its thorax. The air is swallowed and passes into the stomach and crop of the new adult; it causes the insect to swell and assists in lifting it out of its pupal case.

Immediately after the young adult emerges from the pupal case it makes no attempt to feed on anything. Even if flowers, sugar water or human beings are close at hand, the mosquito does not respond. Between 20 and 24 hours later, however, it becomes alert and begins to seek food. The males drink only sugary fluids such as flower nectar. Both in the wild and in the laboratory mosquitoes will visit certain flowers and will feed on fruit placed in their cage. Since they vigorously probe the flowers of some plants, and can distinguish between different types of sugars, they play a role in the pollination of certain plants.

The females will also drink sugary fluids, but when a hungry female is given a choice between sugar water and blood, it will always take blood. If a male is offered the same choice, it will always drink the sugar water. When ei-

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HUNGRY MOSQUITO, a female of the yellow-fever species *Aëdes aegypti,* is photographed as it inserts the feeding stylets of its proboscis into the skin of the hand of a human subject. The mosquito has all six of its legs planted on the skin, and the bottom part of its proboscis, known as the labium, is folded back in a hairpin curve as it prepares to draw blood. Note that its empty abdomen is still flattened and thin.

SATED MOSQUITO, photographed a few minutes later, has finished its blood meal and has just withdrawn the feeding stylets of its proboscis from the skin. The mosquito's midgut, or stomach, is swollen with blood. The shiny object out of focus in foreground is the fingernail of the human subject. Only the female mosquito feeds on blood. It will also drink sugary fluids, on which the male feeds exclusively.

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ther males or females feed on a sugar solution, the solution goes into the crop, a pouchlike enlargement of the esophagus. The solution is stored in the crop, and from time to time small amounts are regurgitated and pass into the midgut. When a female feeds on blood, however, the fluid bypasses the crop and goes directly into the midgut.

An average *Aëdes* female takes about 2.8 milligrams of blood. Normally the female drinks much less sugar water than blood. It is of some interest that shortly after feeding to repletion from a sugar solution most females will not seek a blood meal for about three hours. It is possible to bring a human hand directly in front of a sugar-fed female without inducing any reaction on the mosquito's part. In some unknown way the receptors that direct the mosquito to human beings and trigger its probing seem to be inactivated by a meal of sugar water.

The adult mosquito has good vision and will quickly track a moving human hand. It is clear that the primary factor that attracts the *Aëdes* mosquito to a human being from a distance, however, is odor, and that odors are picked up by tiny sense organs on the mosquito's antennae. One can prove this in a dramatic way. If both antennae are removed from a hungry female, it usually cannot be induced to feed even when it is placed directly on a human hand. Precisely what odors attract mosquitoes from a distance are unknown, and a great deal of work is still needed to find out what they are with any certainty. It is often maintained that lactic acid, sebum, amino acids and various hormones are attractive to mosquitoes, and that carbon dioxide, moisture, temperature and the movement of the host also play important roles. It has been shown by Rachel Galun in Israel and W. G. Friend in Canada that piercing behavior in mosquitoes can be induced by adenosine triphosphate (ATP). T. Hosoi in Japan suggests that gorging after piercing is promoted by adenosine-5-phosphate. Whatever the substances are that attract mosquitoes, their power can also be demonstrated in a dramatic way: if a human hand is pressed on a clean glass plate and the plate is then placed in a cage with hungry females, as many as 20 percent of them will go to the handprint and vigorously probe the area for as long as half an hour.

UNUSUAL FEMALE MOSQUITO not only has taken a large meal of sugar water but also has subsequently drawn blood from a human subject known to be highly attractive to mosquitoes. The sugar water, visible as the clear liquid containing a few bubbles, occupies the region at the front end of the mosquito's abdomen known as the crop; the blood occupies the midgut. Most mosquitoes that have been fed sugar water will not seek a blood meal for three hours.

COMATOSE MOSQUITO of the species *Anopheles quadrimaculatus,* a major vector of malaria, has taken too much blood and its abdomen has ruptured. Before the insect was allowed to feed its ventral nerve cord was cut. Normally a mosquito will imbibe about 2.8 milligrams of blood. A mosquito, such as this one, with its ventral nerve cord cut will drink up to four times that quantity of blood. Thus the ventral nerve conveys information that the abdomen is full.

A series of experiments can also be conducted using the two hands of the same individual to show how different properties of the individual have different effects on the insect. It can be shown that if a female mosquito is given a choice between a warm hand and a cold one, it will choose the warm one, but if the mosquito is presented only with the cold hand, it will feed on that. The mosquito prefers a normally warm hand to an abnormally hot one and a dry hand to a wet one.

In small cages containing free-flying mosquitoes it is difficult to test the relative attractiveness of different people to a mosquito, because a great deal depends on whether a mosquito is closer to one hand than to the other. If a female is exactly midway between the hands of two individuals, however, it can sometimes discriminate between them. When we compared one hand from each of 30 people against the hand of a control individual who remained constant throughout each test, we were able to grade the group into individuals who were more attractive, as attractive and less attractive than the control.

A clear demonstration of the preference of the yellow-fever mosquito for man can be seen if one holds a small, hot, bright yellow baby chick in one's hand and places it in a cage of hungry females. All the mosquitoes go to the human hand and none go to the chick.

Once the female mosquito has detected a human being from a distance, it will fly toward its target rather indirectly. In a one-cubic-foot cage containing starving female mosquitoes, it normally takes between five and 30 seconds

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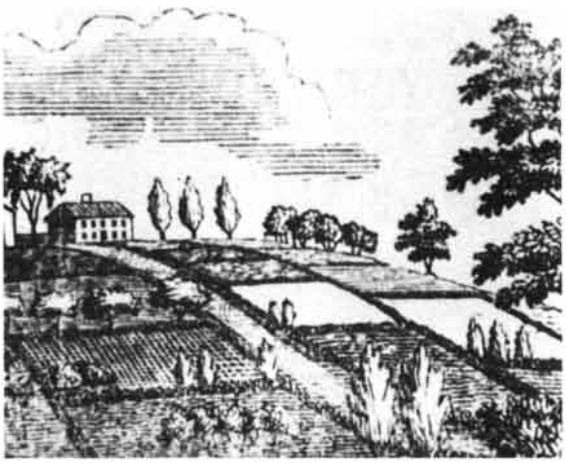

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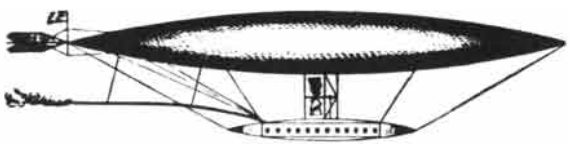

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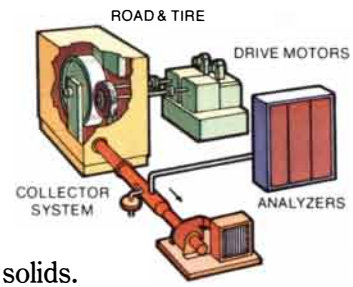
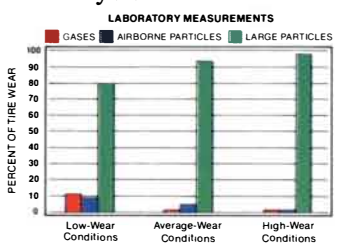
Tires: the great American disappearing act.

Every year, U.S. motorists wear off nearly a billion kilograms of tire tread. Where does it all go? Do the emissions contribute to air pollution?

Scientists here at the General Motors Research Laboratories were more than just curious. So, in 1972, they started a program to determine: The amount of tread that comes off as gas and as solid matter. What gases are involved. And what happens to the solids.



For this research, they had to design and build a special facility with an air-tight chamber. The facility allowed them to duplicate both front and rear tire wear under a wide range of driving conditions, and to collect all the wear products for analysis.



What did the study reveal? On the average, large (nonairborne) particles accounted for about 94% of total tread wear. Airborne particles, less than 5%. And gases, mostly hydrocarbon, a negligible 1%.

The particle results correlated with measurements of soil and air samplings taken along the San Gabriel River Freeway in Norwalk, California. (It was not feasible to measure gaseous hydrocarbons from tires at the road site.)

As for the disappearing act, outdoor measurements shed light on that too. The California study showed that the bulk of the tire debris lies within a five-meter strip next to the pavement edge.

All of which thus far suggests that tires play only a minor role in the air pollution picture.

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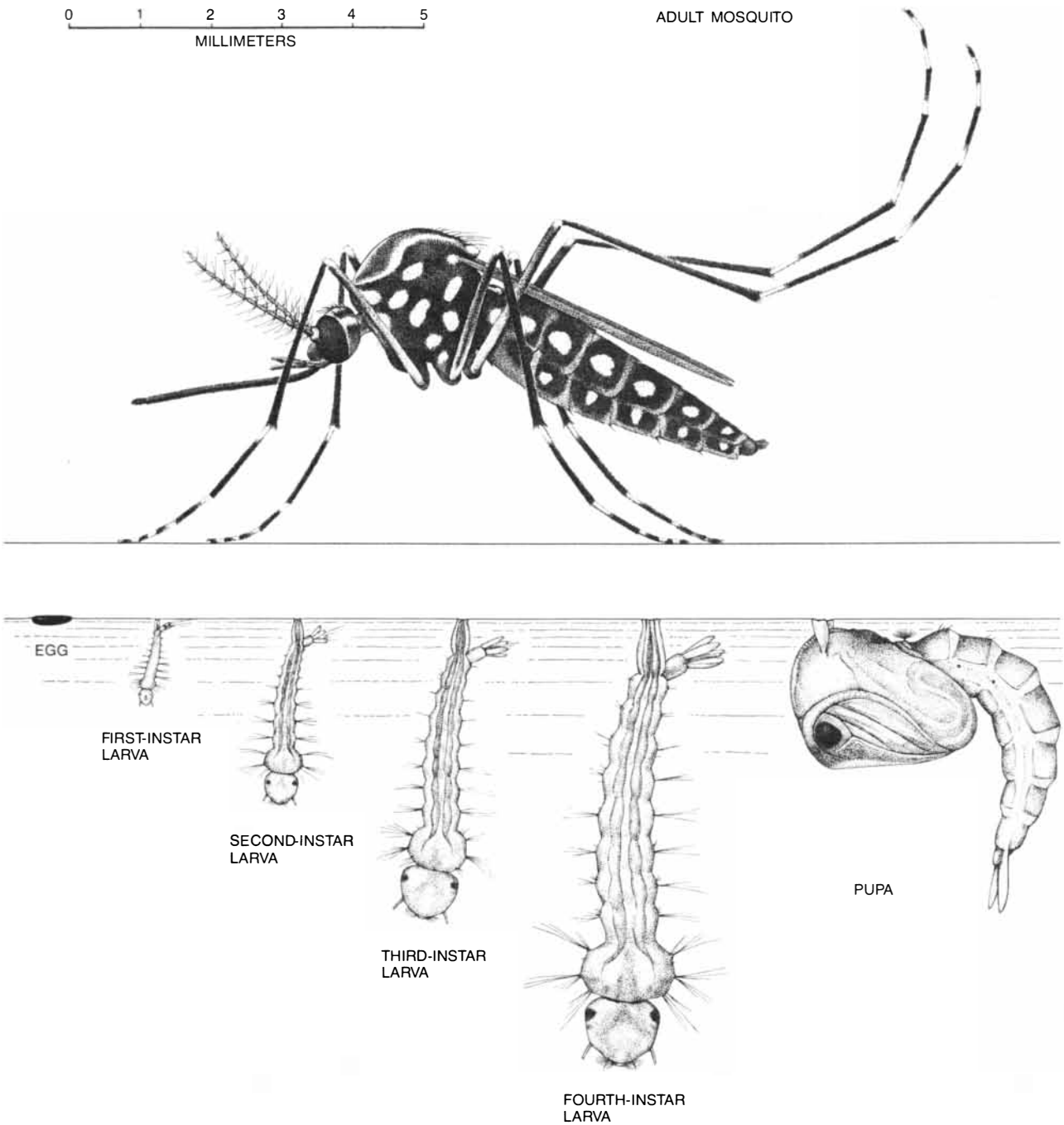
for one of the insects to land on a human hand. Once the mosquito has landed, it may either take a few strides before starting to pierce the skin or start to penetrate without any preliminary activity. One can always tell when the mosquito is about to pierce because it suddenly lifts the pair of sensory organs known as the maxillary palps, which are on either side of the proboscis, to an angle of about 75 degrees.

To appreciate the full complexity of what is involved in the act of blood feeding, it is necessary to have some knowledge of the anatomy of the mosquito's proboscis and alimentary canal [*see illustrations on next page*]. The proboscis projects directly in front of the insect. It consists of a large, scaly outer lower lip called the labium, which terminates at the tip in two hairy lobes



LIFE CYCLE OF THE MOSQUITO has several stages, and the insect's feeding behavior differs in each stage. The mosquito begins life as a fertilized egg floating in water (*bottom left*). Inside the eggshell the embryo forms rapidly, and within 24 hours after fertilization it begins to absorb yolky material within its newly formed stomach. The egg hatches some 48 hours after being laid. After the mosquito larva emerges, it soon begins to feed on pollen, fine microscopic plants and bacteria. The larva eats almost continuously and grows very fast; in several days it completes its larval life, molting three times and going through four distinct stages, in each stage becoming larger and more complex (*bottom four middle illustrations*). Before becoming an adult the insect goes through a pupal stage (*bottom right*). The mouth and anus of the pupa are sealed off; the pupa neither takes in food nor eliminates fluid or solid waste. (It does, however, eliminate waste gases.) During the insect's pupal stage the old larval midgut is destroyed and partially digested, and the new adult midgut is formed. After two days the pupal case ruptures, allowing the adult mosquito to emerge (*top*). All the stages shown in the illustration are enlarged 12 times.

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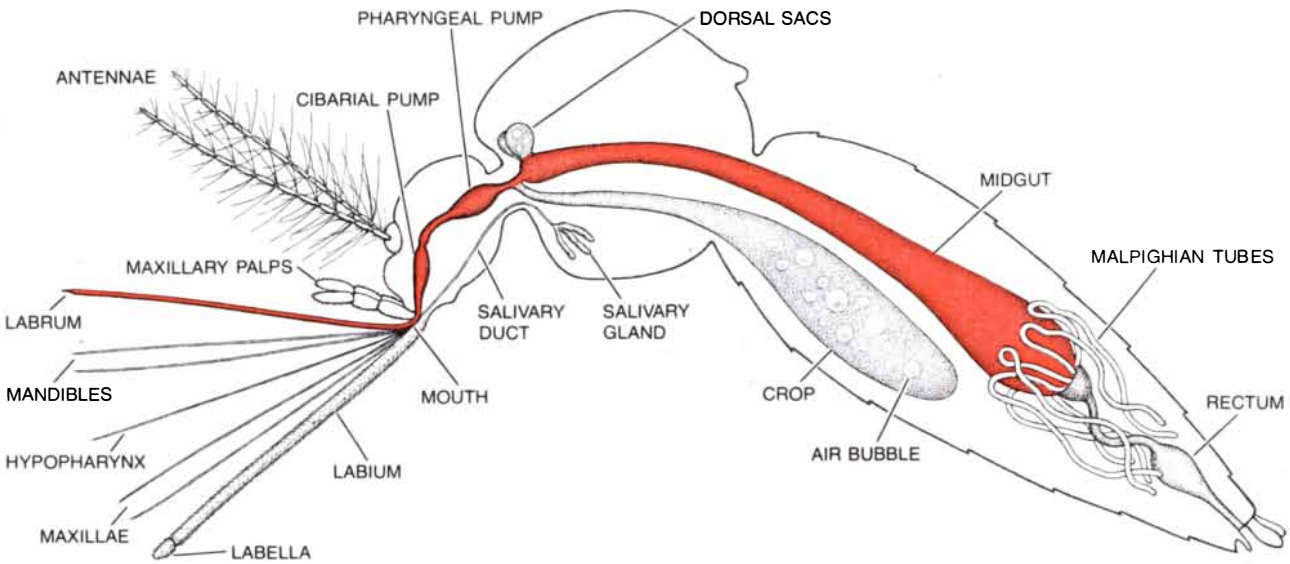
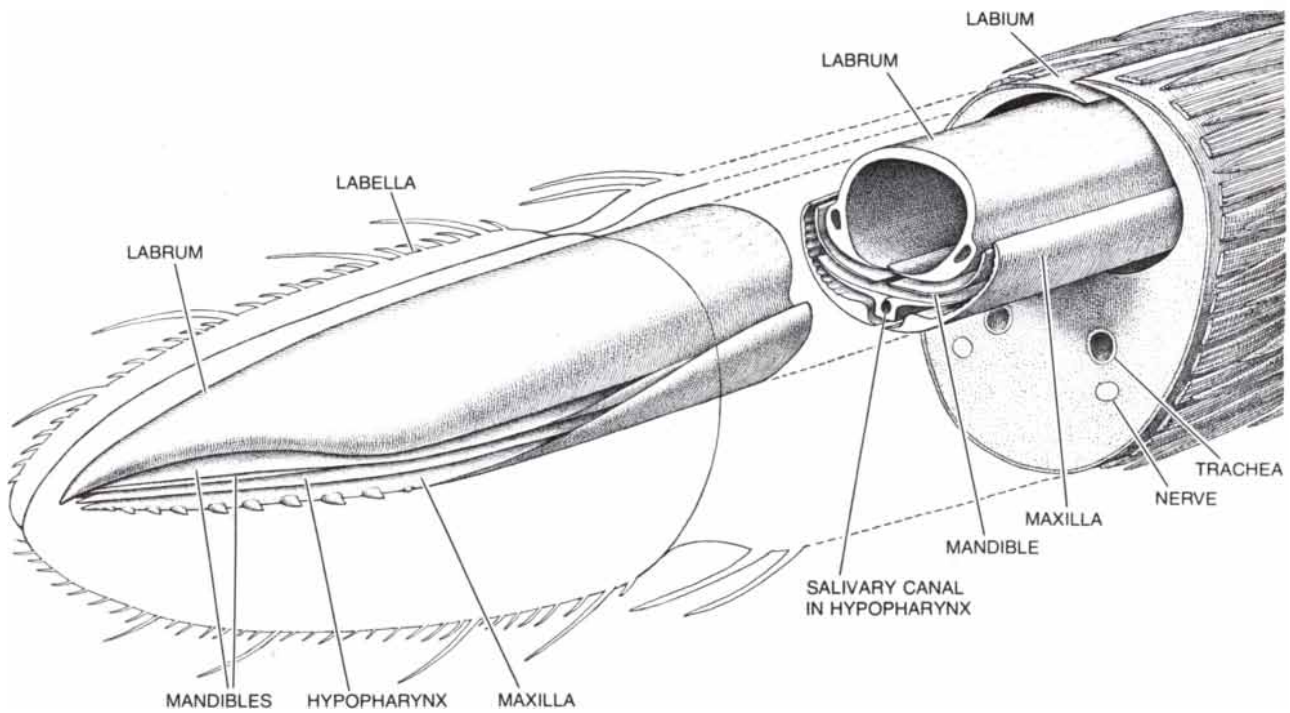
called the labella. The labium forms a deep trough in which is concealed a smaller bundle of long, tapering pale yellow feeding stylets that are collectively called the fascicle. The largest stylet is the sharply pointed labrum, which forms an inverted gutter up which the blood is drawn. At the sides of the labrum are two long, thin mandibles. Under them are two much larger needlelike maxillae with fine saw-toothed tips. Under them in turn is a flattened stylet, the hypopharynx, down the center of which runs a single salivary canal. The fascicle acts as both a piercing mechanism and a food canal. The labrum forms the roof and sides and the hypopharynx the floor. The labium and the fascicle together form the proboscis.

The food canal opens into a short, hard-surfaced cibarial pump just within



ANATOMY OF THE ALIMENTARY TRACT of the adult female *Aëdes* mosquito is depicted. The mosquito senses its prey at a distance with its antennae, and it draws up sugary fluids or blood with its proboscis. Sugary fluids initially go only into the crop; blood normally bypasses the crop and goes directly into the midgut. The proboscis consists of the protective labium, which encloses the bundle of feeding stylets, called the fascicle. The fascicle consists of the labrum, two mandibles, the hypopharynx and two maxillae. The fascicle is both the piercing apparatus and the food canal. It is shown spread out to reveal all of its component parts; normally all of the parts fit tightly together and are sheathed inside the labium. The anatomy of the mosquito's proboscis is shown in greater detail in the illustration below.



ANATOMY OF THE PROBOSCIS shows how all of the parts of the mosquito's fascicle fit together and lie in the labium. The labium is the large, scaly lower lip that terminates in the two hairy sensory lobes known as the labella. The labium forms a *U*-shaped trough in which the fascicle is concealed. The fascicle has four main parts. The sharply pointed labrum, forming the top of the fascicle, serves as an inverted gutter up which blood is drawn; the two scalpel-like mandibles lie at the sides; the two needlelike maxillae have fine saw-toothed tips for cutting into the skin; the flattened, pointed hypopharynx forms the floor of the fascicle and contains the mosquito's salivary canal.

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the head of the mosquito. The cibarial pump has several different kinds of receptors. It has been suggested that fine hairs within the cibarium act as flow meters and that other receptors signal whether what is entering the gut is sugar water or blood. The cibarial pump opens directly into the much longer, flask-shaped pharyngeal pump, which empties the fluid into a long narrow esophagus within the mosquito's neck. The esophagus passes down into the thorax, where it opens into two small, thin-walled dorsal sacs and into a single large ventral sac: the crop. The esophagus also opens through a thick valve into the mosquito's long midgut.

With this anatomy in mind, let us now return to the mosquito poised at the moment of piercing. It has all six legs on the surface of the victim's skin, its hairy labella touching the skin and its maxillary palps raised. It is believed that after the mosquito spreads its labella the finely toothed maxillae of the fascicle literally saw their way into the tissue of the skin with extremely rapid back-and-forth movements. One can see the maxillary palps rocking back and forth as the fascicle begins to sink into the skin. At this stage the large labium is folded back like a hairpin. The skin is actually punctured without any obvious thrusting of the mosquito's body. About half the length of the fascicle is inserted into the skin. As it is inserted the mosquito gradually shifts its legs closer to its body. As soon as blood appears in the fascicle the maxillary palps stop their rocking.

It takes an average female mosquito about 50 seconds to insert its fascicle into the human skin, and unless it is interrupted (perhaps by being swatted by the victim!) it usually sucks blood for about two and a half minutes. When the mosquito has drunk its fill, it withdraws the fascicle rather quickly (in about five seconds). To do so the insect straightens its front legs, leans slightly backward and moves the labium from side to side. Once the fascicle has been removed from the skin it springs upward and forward and then returns to the deep groove of the labium. The resheathing somewhat resembles a man putting his arm into the sleeve of his coat.

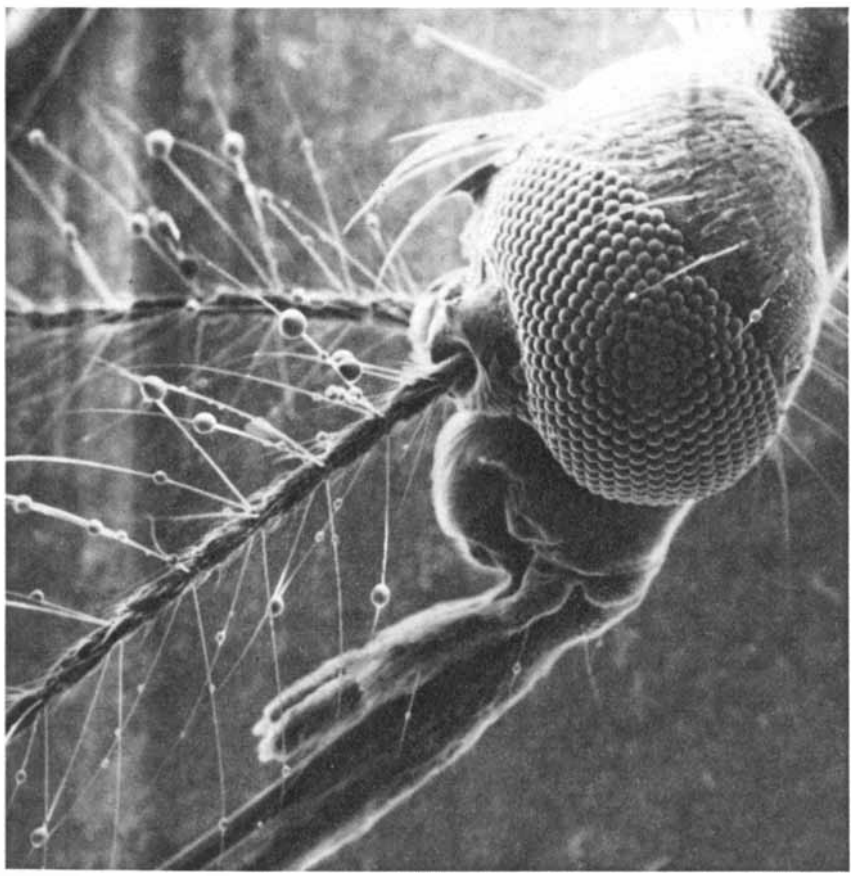
Some mosquitoes inject into the skin saliva containing substances that prevent the blood from coagulating as it is being withdrawn. The saliva is injected through the salivary canal in the hypopharynx. The injection of saliva is not actually necessary for the mosquito to obtain blood; if the salivary duct in the neck is experimentally cut before the mosquito is allowed to feed, the insect can still withdraw blood with no apparent difficulty. The protozoa and the viruses carried by mosquitoes are injected into the skin with the saliva, but the much larger filarial worms crawl down the proboscis and enter the wound opening as the mosquito is feeding.

It is not fully understood what makes a mosquito bite itch. The British investigator J. D. Gillett has discovered that the itching does not begin until about three minutes after the bite. It subsides after an hour or so but then can begin again in a hard wheal that on occasion persists for days. Both the immediate reaction and the delayed one are allergic. The strength of the reactions varies widely among individuals, and seems to be affected by the age and sex of the individual and by the frequency of being bitten. The strength of the reaction even varies in one individual, and is affected by the number of bites received, by the age and species of the mosquito, and by whether the mosquito has fed to repletion or has been interrupted before it has done so. These considerations have not been well studied.

As we have seen, a mosquito feeding on the human skin stands on all six of its legs. If all the legs are experimentally removed, it is still capable of hovering above the skin and attempting to pierce it. Usually the insect will crash-land and will be unable to feed. It needs at least three legs in order to orient itself and pierce. On occasion, however, a mosquito with fewer than three legs shows a remarkable improvisatory inventiveness: it lowers its abdomen and spreads out one wing to form a stable base for piercing.

Robert W. Gwadz of the National Institute of Allergy and Infectious Diseases has shown that if the ventral nerve cord of the mosquito is cut between the thorax and the first abdominal segment, the insect will continue drinking beyond repletion. Indeed, in some instances it will drink until its abdomen bursts and for a short time afterward! Even if the insect does not burst, it cannot fly. It rapidly becomes comatose, and within 24 hours it dies. It is evident that the ventral nerve cord is the principal organ that tells the mosquito it has drunk enough.

The overall picture of the feeding be-



SCANNING ELECTRON MICROGRAPH of the head of an adult female mosquito shows a close profile view of the upper part of the proboscis. The insect's multifaceted eyes wrap around the head, and the antennae project from the front of the head. (The small spheres on the hairs of the antennae are droplets of an antistatic spray applied to the specimen to make it easier to make the electron micrograph.) The maxillary palps are the two short hairy structures just above and to the sides of the proboscis, which goes out of the picture at the bottom left.

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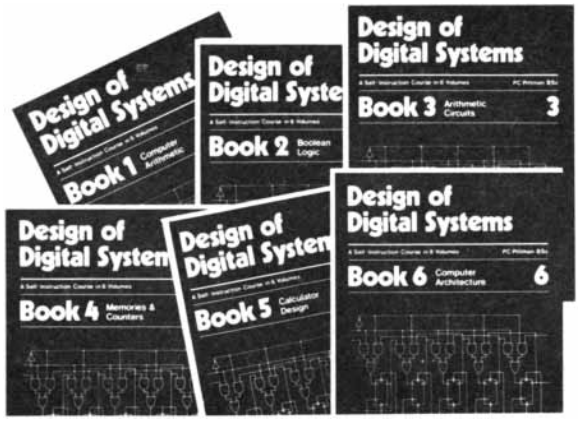

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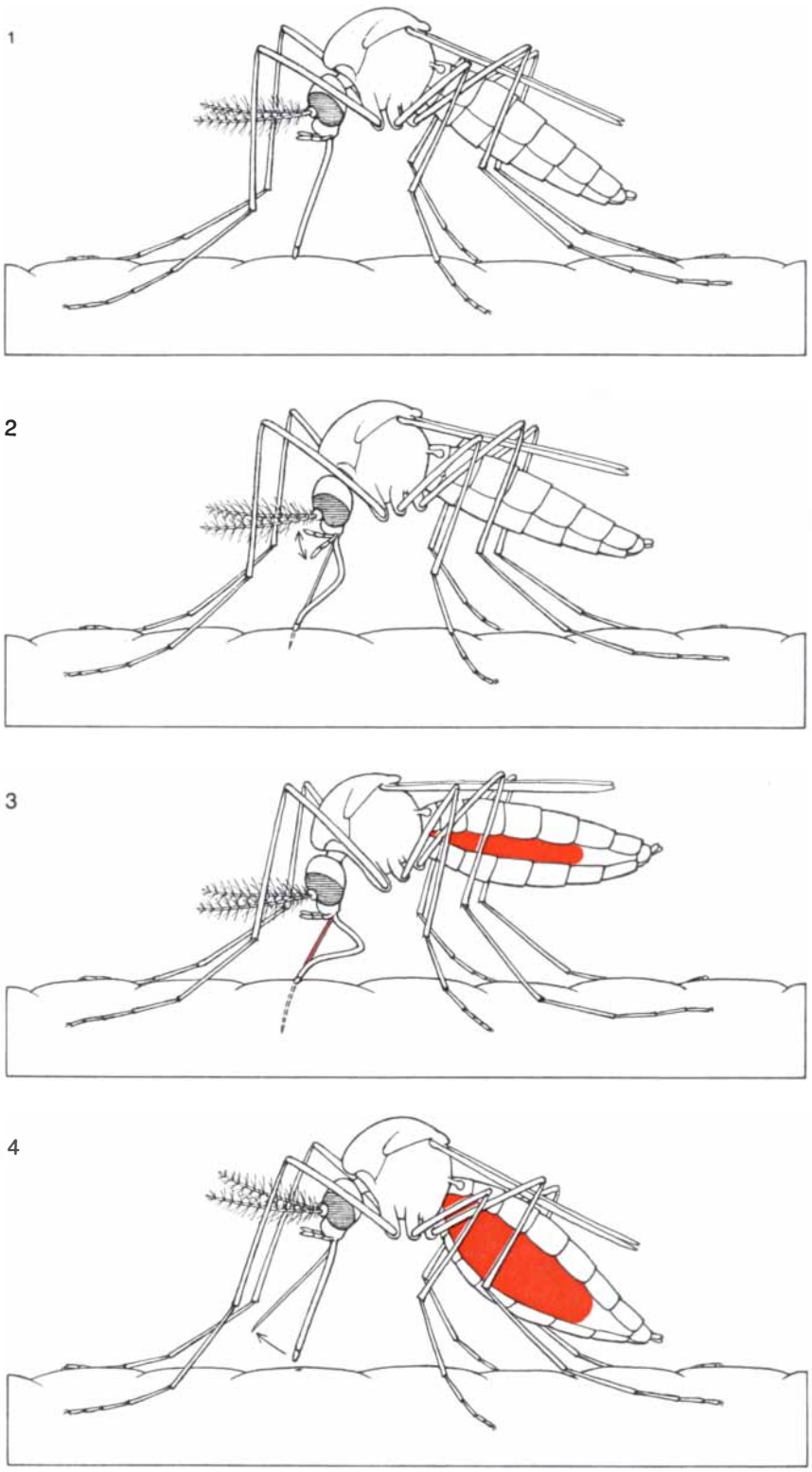

MOSQUITO FEEDING ON HUMAN BLOOD requires several minutes to pierce the skin and take a complete meal. Just before the mosquito is about to pierce the skin it lifts its maxillary palps away from the proboscis at an angle of about 75 degrees (*1*). The finely toothed maxillae of the fascicle begin sawing into the tissue of the skin with fine back-and-forth movements, which cause the maxillary palps also to rock back and forth. The fascicle is guided into the skin between the labella. As it goes into the skin the labium folds back like a hairpin (*2*) and the mosquito shifts its legs closer to its body. When about half of the length of the fascicle has been inserted into the skin, the mosquito begins to draw blood (*3*). After the mosquito's abdomen is filled it straightens its front legs to quickly withdraw the fascicle. The fascicle springs upward and forward out of the wound (*4*), and is fitted back into the deep groove in the labium.

havior of the adult mosquito thus begins with its perception, by means of its antennae and eyes, that food is in the vicinity. The mosquito normally flies to the food source and lands. Sensory organs on its feet may provide information about the temperature of the food or the concentration of sugar. When the sensory organs are sufficiently stimulated, they may direct the mosquito to lower its proboscis. The hairs on the labellar tip of the proboscis are sensitive to touch, sugar and perhaps salts and ATP. If the labella touch sugar, they mediate a response that varies with the type of sugar and its concentration. The more concentrated the sugar, the better the mosquito likes it. When mosquitoes feed on fruit, they sometimes insert their entire proboscis, but for the most part they only labellate (lightly touch) the surface and probably secrete saliva to help them pick up enough material to suck into their alimentary canal. Usually the labium does not bend back when the mosquito feeds on fruit. One exception to that rule is that the labium will bend back when the mosquito feeds on a peach, which has a fuzzy skin. Receptors in the cibarial pump apparently aid in directing sugary fluids directly into the insect's crop.

When the labella of a hungry *Aëdes* mosquito touch a warm-blooded animal, the fascicle is inserted and the labium bends back. Presumably the receptors in the cibarial pump send a message to the mosquito's brain that then causes the valve into the stomach to open and allow blood to fill the midgut alone, bypassing the crop. The amount of blood taken by the insect is controlled by the ventral nerve cord by way of stretch receptors in the abdomen so that the sated female stops feeding and withdraws its fascicle.

The feeding behavior of mosquitoes varies widely from one species to the next. The feeding behavior of the dangerous *Aëdes aegypti* mosquito is far better known than the feeding behavior of any other species, including the common house mosquito (*Culex*), mainly because *Aëdes aegypti* reacts quickly and uniformly to man. Many other species react slowly. The feeding habits of the house mosquito in captivity are so erratic that it is difficult and frustrating to study. When *Culex* females are confined in a cage, a few of them in some strains will land on the human skin and some may probe it. The females of some strains will not take blood in the laboratory even when they are starving to death.

Much work remains to be done to complete the picture of how mosquitoes feed and to indicate how that knowledge can be applied to prevent annoyance and the spread of disease.

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Technology: Biting the hand that leads us.

The 1977 Nobel Prize Ceremony resulted in an almost embarrassing domination by American scientists. Many acclaimed it as another testimonial to the tradition of American scientific superiority.

But it clouded an increasingly critical problem: our current technology crisis.

It may look like a lot is going on. But it isn't.

Every day we hear about new ideas and new products. Computers, calculators, business machines, video games, microwave ovens, digital watches, fuel-injected automobiles, supersonic aircraft, "wonder" drugs, sophisticated surgical techniques, and telecommunications systems. But they all are the result of the application and extension of science that's 10 or 15 years old.

The fact is that very little is going on now. And other countries who have a greater commitment to technology are catching up or taking the lead.

Our colleges can no longer afford the facilities, programs, and staff tomorrow's scientists need.

Government funding of colleges and universities, expressed in constant dollars, has been reduced by 20% since 1967. Funds for equipment and facilities have been cut by more than 50% since 1967. Grants have been eliminated.

American business, too, has reduced funding.

In 1976, industry spent $38 billion for R&D. Measured in deflated dollars, this is a 5% drop from 1968. As a percentage of our GNP, R&D spending has averaged 2.4% in the 1970s, as compared to 2.9% in the 1960s. This represents a decrease of approximately 17%. In contrast, Japan has steadily accelerated investment in R&D by 74% since 1950, and West Germany by 40% since 1968.

Put another way, 12.6¢ of every dollar spent by our government went to support scientific inquiry in 1965. By 1975, this had dropped to 5.7¢.

How did this "technology crisis" come about?

As the Depression and World War II passed, we became aware that we could no longer depend on science from abroad to act as the catalyst for technological progress. We needed immediate answers to complex problems. So scientists were asked, and funded, to develop solutions. Fast.

Then our attitude toward science began to change, due to three major events:

1. **Sputnik.** Our tradition of technological supremacy was challenged, and Russia proved that "it could be done" if science and funding were properly applied to accomplish a defined mission.
   While Sputnik heightened our interest in scientific inquiry, it also conditioned our response for the 1970s.
2. **The Recessions of 1958 and 1963.** Unrestricted scientific inquiry and unlimited funding ceased. Government and business were forced to devote less money to fewer R&D projects with more short-term results.
3. **Vietnam.** This was the war technology would win in almost a week, by remote control. Fast, and without casualties. Technology, people felt, let us down.

As the 1970s dawned, we had successfully met the challenges of space. New challenges had not been defined, nor desired. For the price tag was getting too high.

It became popular to blame technology for causing all our problems. Pollution. Depletion of natural resources. A food crisis. Unemployment. Rising prices. Inflation.

As a result, emphasis on scientific inquiry vanished. Government and business became skeptical and were content to rely on the proven success of old science for new ideas.

Now we are at the crossroads.

During the past 10 years of decreasing emphasis on scientific inquiry, three major things have happened:

1. Foreign competitors are beating us in the market. Countries like Japan and West Germany have invested heavily in scientific inquiry, and the results are beginning to pour into our country.
2. New technology must solve new problems. The energy crisis. Productivity in industry. Pollution control. Continuing research to combat killer diseases. And more.
3. We have lost our scientific spirit. Perhaps this is why government and industry have been unable to provide the same kind of commitment and investment we applied to winning the race to the moon to meeting new challenges. Had we done so when the energy crisis first threatened, we might now have as much fuel as we need.

Clearly, we must change our attitude toward scientific inquiry.

In an environment where scientific inquiry is suspect, and funding lacking, technology will take a long time to evolve. And that is basically where we stand today.

What we need is not so much a return to the age of unrestricted scientific inquiry, but the beginning of an era where government and business and universities work together.

Universities can more forcefully press the case for more support of valuable research. Business can increase emphasis on funding of R&D. Government can change its attitudes from a desire to control and regulate technological growth to a desire to encourage and support scientific endeavor in all spheres of society. And provide tax incentives to industries that invest in R&D.

And there's one thing we all can do. Give technology a chance. Recognize what it can do and what it cannot do. And support it—financially.

As it has in the past, technology will provide the solutions.

Science and technology can solve many problems. If they don't, what else will?

Gould is an electrical and industrial products company committed to growth through technology. This message is a condensation of a 12-page White Paper, "Technology and Scientific Inquiry." For the complete text, write Gould Inc., Dept. S9-6, 10 Gould Center, Rolling Meadows, Illinois 60008.

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THE AMATEUR SCIENTIST

Drops of liquid can be made to float on the liquid. What enables them to do so?

by Jearl Walker

Twice in this department the late C. L. Stong presented experiments having to do with the curious phenomenon in which water drops glide across a water surface for several seconds before sinking into it. You may have seen this happening in an automatic coffee maker when water drips from the filter into the glass container.

In the first of Stong's discussions (August, 1973) Gerard Schol described an apparatus for studying the drops and argued that the support was probably due to an electrical repulsion between the bottom of a floating drop and the bulk liquid just below it. In the second discussion (April, 1974) Kenneth C. D. Hickman experimented with something a bit different: water drops called boules that floated on slightly superheated water. For me the boules are more easily understood than the drops described by Schol because the superheated fluid has a large rate of evaporation and the resulting vapor layer below the drop supports it. A similar support mechanism holds water drops just above a hot plate in the Leidenfrost phenomenon I discussed in this department last August.

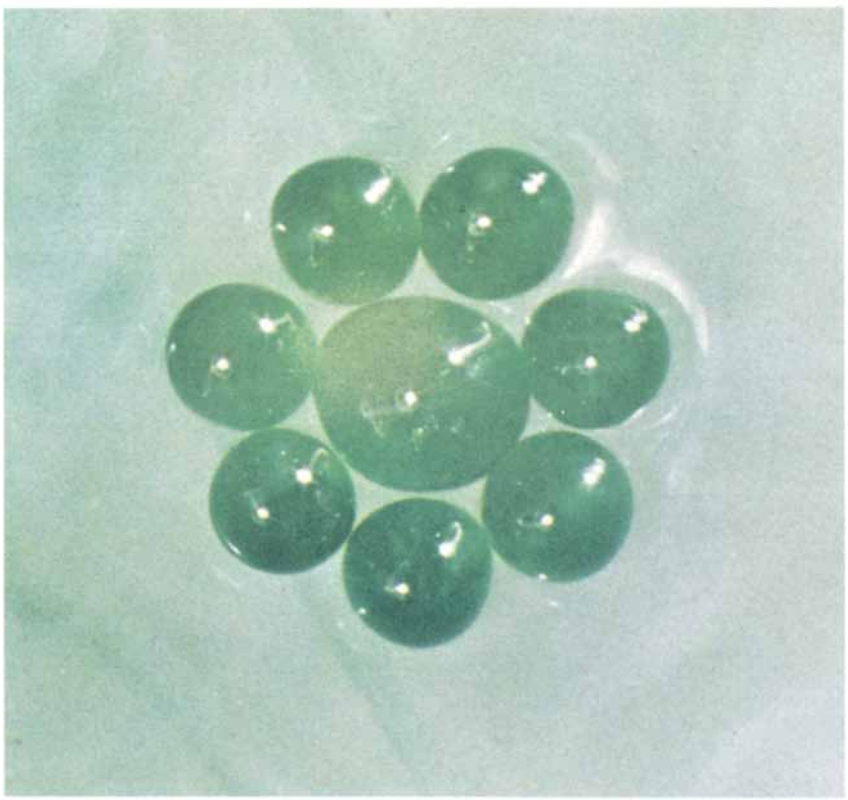
The phenomenon of water drops that float on water that is at room temperature has attracted attention for a long time. John Tyndall examined such drops as early as 1885, and in 1881 Osborne Reynolds wrote "On the Floating of Drops on the Surface of Water Depending Only on the Purity of the Surface." Although Reynolds did not specify the support mechanism, he probably thought it was due to surface tension. His discussion indicated that floating drops are relatively rare because inpurities on a typical water surface somehow destroy the flotation mechanism.

Although the nature of the support has been discussed for almost a century, I do not think the final word has been written yet, largely because of a clever experiment that has recently been described to me by James A. Raymond of the Alaska Department of Fish and Game. Raymond points out that the lifetime of the floating drops can be increased from about a second to several seconds, perhaps tens of seconds, by adding detergent to the water. That much has been well known. The remarkable thing Raymond has discovered is that the drops can be made to last for several minutes by vibrating the container in such a way that standing waves are set up in the surface of the water. In fact, some of Raymond's drops lasted as much as 18 minutes. He suggested using a household appliance such as an electric hair clipper to vibrate the side of a cake pan containing the solution of water and liquid detergent (two teaspoons per quart of water). To achieve more consistent results he put a one-liter plastic beaker of the solution on a slightly unbalanced tabletop centrifuge. Occasionally he obtained drops almost two centimeters in diameter by allowing several smaller drops to combine or by building them up slowly with a syringe filled with the solution.

Other workers have reported that the drops often refuse to perform individually but that if a steady stream of drops is played on the surface of the bulk liquid, the drops eventually begin to float. The common explanation of the survival of the later drops is that the early drops sweep the surface of the bulk liquid clean of the impurities that somehow eliminate the support mechanism. Raymond points out that part of the success of the stream of drops may be that the earlier drops make the bulk surface vibrate slightly, thereby enabling the later drops to float for a while.

Raymond found two other interesting things. His drops were repelled by air bubbles on the surface but were attracted by one another. The repulsion and attraction appear to have to do with the shape of the water surface near the air bubbles and the drops. The surface curves up on the bubbles, and a drop will not climb uphill. The surface curves down into a dimple around each drop, so that two adjacent drops can easily flow toward each other. When they meet, they may remain as two drops, suddenly coalesce to form a single drop or disappear.

In repeating Raymond's experiment I replaced the household vibrator with a six-inch loudspeaker and an audio oscillator, both of which you can buy from



Flowerlike pattern of floating drops of dyed water

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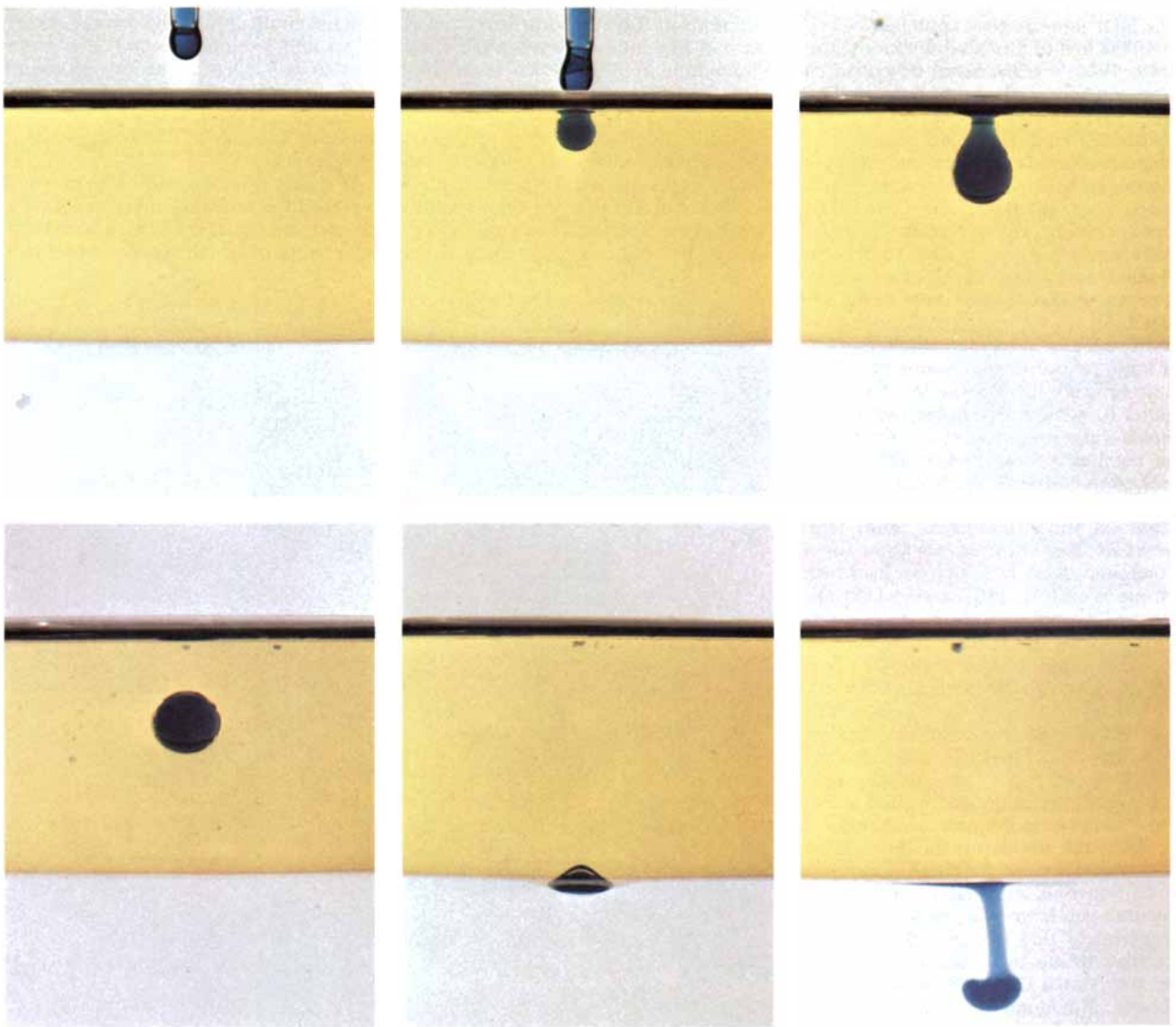
a dealer in electronic equipment. The speaker had no front covering and was placed faceup on a table. Over it I put a curved watch glass large enough to cover it. The curved glass or plastic face of a clock will serve, or you can buy a chemical watch glass from a chemical-supply house. The advantage of my setup was that I could control the amplitude and frequency of the vibration. In particular I could easily tune the vibrations in and out of resonance for the speaker-air-glass-liquid system and also see how the lifetime of the drops depended on the vibrational amplitude.

I mixed about 12 milliliters of Ivory liquid detergent in 100 milliliters of tap water, poured some of the mixture into the watch glass and filled a syringe with the solution. (You could use an eyedropper.) When I squirted drops onto the water, the results were just as startling as Raymond must have found them. When the audio oscillator was tuned to resonantly oscillate the water (even gently) so as to cause vibrational standing waves to form on the surface, the drops lasted for several minutes. With my system this result appeared at oscillation frequencies between 10 and 150 hertz. (I could not go lower than 10 hertz on my audio oscillator.)

When I tuned the oscillator out of resonance so that the standing waves disappeared (one can do so either by tuning to a higher frequency or by decreasing the amplitude of the oscillator), the drops coalesced into the bulk liquid within a few seconds. Only with the vibrational waves present would the drops float for longer than 10 seconds or so. Before receiving Raymond's letter I had become accustomed to having the drops last for such a brief time that I had trouble examining them properly, and now I had drops lasting so long that I could go out for a cup of coffee while they persisted.

Most of the floating drops were from a millimeter to a few millimeters in diameter, about the size of the wavelength of the surface waves on the water when the oscillator was at 50 hertz. By making several small drops coalesce or by continuously discharging fluid from the syringe into a single drop I built up larger drops that significantly dimpled the water surface and were larger than the wavelength of the surface waves. If adjacent drops did not coalesce to form a single drop, they formed rafts of floating drops. I had rafts two or three centimeters across, each consisting of about a dozen drops. With some care I could make a pretty design consisting of one large central drop surrounded by a ring of smaller drops. When I later began to use food coloring in the drops, I was able to make red and blue rafts of this flowerlike design.

As other investigators have found, the drops did not always behave. No one has understood their fickle nature, but presumably their refusal to form is partly due to variations in the local electric field. For example, an experimenter



Motions of a drop of dyed vinegar put on a layer of corn oil above a layer of vinegar

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moving past the apparatus can alter the electric field near the drops and cause them to merge into the bulk liquid. Surface impurities are also important, because dust on the surface prevents the drops from floating. I tried blowing a light layer of lycopodium powder, an organic hydrophobic powder available from chemical supply houses such as Fisher Scientific Company (26401 Miles Ave., Cleveland, Ohio 44128) for about $7 for four ounces, on the surface and immediately lost my ability to generate floating drops.

The generation of floating drops also appeared to depend on the height from which the drop fell from my syringe. If I carefully allowed a drop to form on the needle and fall of its own accord, it would float if the distance of fall was within a certain range. Well above that range drops might still float but only if the drop splashed into the bulk liquid hard enough for the spray thrown upward to produce floating drops.

Most of the drops, particularly the larger ones, seemed to rest quietly in the nodes (the places of minimum surface vibration) of the standing waves. This positioning was difficult to verify, however, and the larger drops caused such a dimpling of the surface that surely any standing-wave pattern on the surface was distorted in that area. Some of the smaller drops continuously hopped up and down in the pattern with the same type of frenzied vibration I had seen in the Leidenfrost effect..

One explanation of the support mechanism is that water molecules on a water surface orient themselves so that the surface is electrically negative. Hence the bottom of a drop, being negative, is repelled by the surface of the bulk water, which is also negative. The only proof of this repulsion mechanism I have seen is that the presence of an external electric field near the drop destroys the floating. The same thing might happen, however, even if the support mechanism were nonelectric, because the external electric field would destroy it.

Assume that a negatively charged rod is placed above a floating drop. Regardless of whether the drop is slightly charged or is neutral, the electric field of the rod polarizes the drop so that its top (nearer the rod) is positive and its bottom (farther from the rod) is negative. Just below the drop the surface of the bulk liquid becomes positive. Since that surface and the oppositely charged bottom of the drop are so close, the drop is pulled into the liquid. Thus an external electric field can make the drop coalesce into the bulk liquid even if the drop is not normally supported electrically. Electric fields are often employed to make airborne drops coalesce in a similar fashion in order to precipitate out undesired mists.

Another (and more widely accepted)

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explanation is that the support mechanism is the thin layer of air that is trapped below a drop just as it reaches the surface of the bulk liquid. The air forms a layer from 100 to 1,000 nanometers thick and may be at a pressure high enough to dimple the bottom side of the drop in the same way that the surface of the bulk liquid is dimpled. The lifetime of the drop is determined by the rate at which this air leaks out through the even narrower gap that rings the dimpled area. Eventually the air layer thins enough (to less than 50 nanometers) for the weight of the drop to rupture the layer. Then the drop either coalesces into the bulk liquid or re-forms into a smaller floating drop.

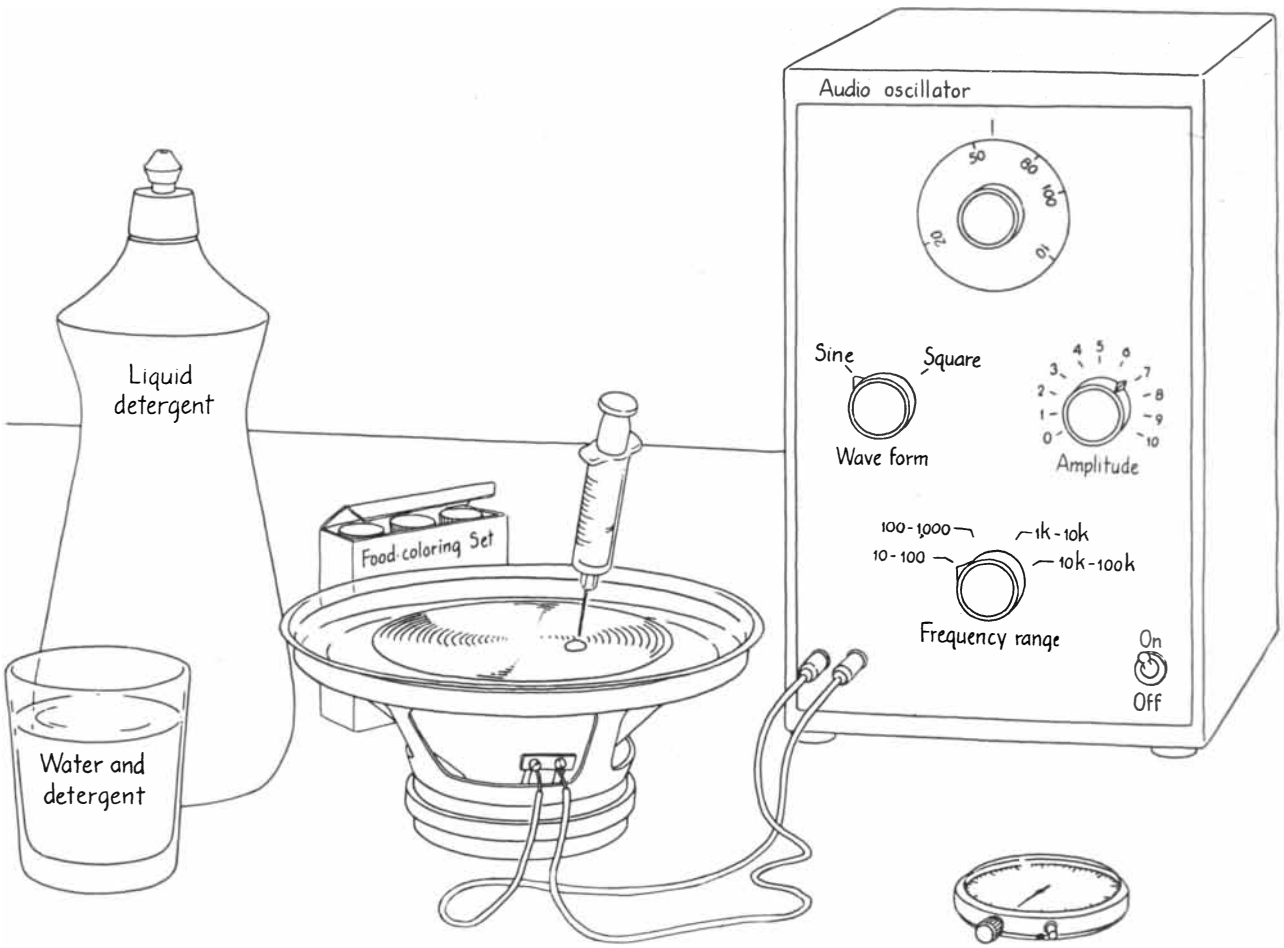
The leakage rate depends on three factors: the possible imbalance of surface tensions on the bulk surface, the surface viscosities of the bulk liquid and the drop, and the viscosity of the air trapped below the drop. As air leaks out it attempts to drag the top layer of the bulk liquid along with it. If the liquid has a high surface viscosity, the flow of both the liquid and the air is retarded, and the drop lasts a relatively long time. The addition of detergent to the water increases the floating time for this reason. Although the detergent lowers the surface tension of the water, it increases the surface viscosity. If the air is replaced with a more viscous gas such as carbon dioxide or with a viscous liquid, the leakage rate would also be decreased and the drop lifetimes increased.

The uniformity of surface tension over the local surface of the bulk liquid is also important. Suppose the surface tension just below a drop were lowered by the vapor emitted by the drop. Then the stronger surface tension just outside the contaminated area will pull the bulk liquid radially outward, dragging the trapped air along with it, thereby decreasing the drop's lifetime. Such motion across a liquid surface because of nonuniform surface tensions is called the Marangoni effect after Carlo G. M. Marangoni, who studied it in the latter half of the 19th century. With a water drop the lifetime of from three to 10 seconds depends primarily on the viscosity of the air and the surface viscosity of the solution of water and detergent.

The concept that air is trapped below the drop helps to explain why my drops floated if the height of fall was within a certain range. If I casually released a drop just above the water surface, the drop reached the surface with a relatively low velocity and apparently did not trap air. A greater height gave a greater velocity and trapped enough air to support the drop. If the height of fall was even larger, the splash (either the crown ringing the impact point or the central vertical jet following the relaxing crown) could produce drops that would float on the water.

The model also explains the absence of floating drops on dusty or dirty water. Any dust particle or hair on the surface would puncture the air layer and cause the drop to merge with the bulk liquid.

Even if one accepts this model for the support mechanism, it is still necessary to explain why the vibration of the bulk liquid increases the lifetime of a drop. Raymond suggested that the vibrations might somehow pump air under the drop, so that it continues to be supported. This idea was appealing to me because it was in line with the generally accepted hypothesis that trapped air is the support mechanism. The pumping could possibly come from circulation patterns in the bulk surface that would drag air under the drop. Imagine a small drop sitting at the node of a standing-wave pattern. As the fluid areas to the left and right of it oscillate out of phase with each other, there could be a periodic exchange of the bulk liquid between



Arrangements for making a drop-bearing surface oscillate

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left and right under the drop, dragging air below the drop in the process. Even without surface circulation the combined oscillations of the surface and the drop might somehow periodically trap more air under the drop.

Although air may be pumped under the drops in this way, the model presents several problems. First, I do not quite see how the combined oscillations of the surface and the drop can force more air under the drop while the weight of the drop is trying to squeeze air out of that area. Second, the rafts of drops I have described are difficult to explain unless one argues that the air trapped below the central drops is so far from the perimeter of a raft that it does not leak out as readily and therefore does not need to be replaced.

A third problem is more troublesome. Try as I might, I could detect no circulation of water near an individual floating drop. To trace circulation I put a small amount of dye in the bulk liquid and arranged for a thin filament of the dye to be near a drop. I worked with two types of dye: a red fuchsin (from chemical supply houses) and a common blue or red food coloring. In small quantities neither dye appeared to alter the support mechanism of the drops by radically changing the surface tension or the viscosity of the bulk liquid. I could move a drop near a dye filament by placing the needle of my syringe near the drop. Because the liquid curved upward onto the needle the drop moved away. When a drop reached a dye filament, any circulation below the drop could be expected to carry part of the filament with it. I seldom saw such an effect. If there is circulation below the drop, it is surprisingly slow, even imperceptibly slow. I did find circulation patterns when two or more drops were floating side by side; here the vibrations of each drop would alter the vibrations of the others. This circulation could possibly add air under the drops.

I also checked to see if the drop had an internal circulation that could pump air below the drop. I first built up a large floating drop by making several smaller drops coalesce. Then I added a small colored drop. After several tries I made the small dyed drop coalesce with the larger transparent drop, and this addition of dye to the large drop enabled me to search for internal circulation patterns. In particular I thought the drop might develop a downward flow on its outside and an upward flow in its center, thus dragging air under itself. The dye tracer revealed no such internal pattern. In fact, the dye spread itself through the drop rather slowly, and any immediate motion of the dye appeared to be due to the spinning of the drop as a whole resulting from the disturbance of the coalescence.

Why, then, do drops placed on a vibrating liquid surface last so much long-

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Clear Aperture	88.9 mm.	Weight	4 pounds
Minimum Focusing Distance	10 feet	Filter Provisions	35 mm.

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er? Other experiments have ruled out an electrical repulsion as the main support mechanism, and I do not see how such a force would be enhanced by vibration anyway. As appealing as circulation patterns pumping air below a drop are to me, I cannot find any readily apparent circulation. The fact remains that the drops do last significantly longer on a vibrating surface.

My best clue came from examining the floating drops under a strobe light set near the frequency of oscillation, so that the flashing light effectively slowed the vibration of the drops. I found two types of vibration among the drops. The very small drops were oscillated so much by the vibrating surface that they hopped up into the air each time the surface pushed upward. Presumably these drops retrapped air on reaching the bulk surface again, thereby delaying their coalescence into the bulk liquid until some chance mishap destroyed them.

A larger drop, on the other hand, did not leave the surface, and its center of mass did not appear to move much vertically. The drop oscillated by periodically varying its shape from relatively tall and thin to relatively short and fat. From overhead this variation in size was symmetric around the drop. Surrounding the drop were concentric circles of surface waves apparently generated by the drop's vibrations.

I think that whenever the bulk liquid directly under a drop pushed upward on the air layer, the bottom of the drop was in turn pushed upward, forcing the drop to spread outward. Since the drop was oscillated at or near resonance by the bulk liquid, a phase difference of between 0 and 90 degrees between the two motions should arise. In other words, the drop could lag behind the bulk liquid by as much as a fourth of the oscillation period. The radial spread of the drop pushed in turn (by way of the air layer) on the rim of the dimple, sending off a crest in the surface waves. Whenever the bulk liquid descended below the drop, the drop became thinner and expanded vertically as the rim of the dimple pushed radially inward.

This pushing along the rim should on the average decrease the tiny gap through which the air must eventually escape if the drop is to coalesce with the bulk liquid. The rate of escape depends on the cube of the gap's width, which means that if the gap is diminished somewhat, the escape time might be significantly longer. Suppose the gap is narrowed from a typical 200 nanometers in a calm situation to an average 50 nanometers in the vibrating situation, that is, decreased fourfold. The escape time and hence the drop lifetime would increase by 4^3, or 64 times. If the lifetime is typically 10 seconds on a calm surface, it would be almost 11 minutes on the vibrating surface. Thus a drop evidently lasts longer because the vibrations narrow the escape route of the air supporting the drop.

When I placed two drops side by side, each one perturbed the oscillations of the other and distorted the component of radial expansion in their vibrations. From overhead I saw each drop change from being oblong perpendicular to a line through the centers of the drops to being somewhat oblong parallel to the line. The drops were always in phase in these changes. Using a dye tracer I found that bulk liquid was pulled in under the drops from both sides along the line through their centers and then was pushed outward between the drops perpendicular to that line.

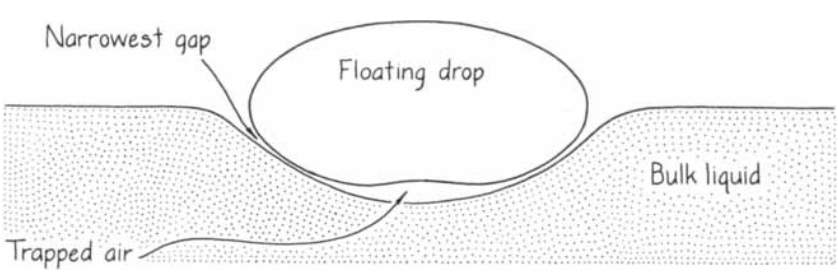
Some of my data for the lifetime of drops at 50 hertz are plotted in the illustration on page 158 as a function of the uncalibrated amplitude settings on the audio oscillator. The drops were all approximately the same size (a few millimeters in diameter) and were allowed to fall approximately the same distance. They were not allowed to coalesce with other drops. (I had the impression that coalescence lengthened the lifetime of the drops, but I did not verify it.) I have no basis for assuming that the relation between the amplitude setting and the amplitude of the vibrations in the water in my watch glass is linear; it is probably quite complicated. Nevertheless, you can see two interesting features in these data. With little or no amplitude of oscillation the drops lasted a fairly short time. In the midrange they lasted the longest. At greater amplitudes the lifetimes decreased, presumably because the oscillations in the bulk liquid were so violent that a drop was thrown around and lost its air support. The second interesting feature is that even when some drops lasted a long time (my record was about 10 minutes), other drops at the same amplitude setting and under seemingly identical circumstances lasted only a short time.

I tried isolating a floating drop by various means: drawing rafts of air bubbles around it, lowering a ring around it or dipping a loop of wire into the bulk liquid and then pulling the wire upward to place a soap bubble over the floating drop. As long as the water around the drop continued to vibrate, even gently, the drop could last a long time.

You might wonder why touching drops do not always immediately coalesce. I believe a layer of trapped air must lie between them just as one lies below them. When two drops come together, they essentially fall into each other's dimple and hence gain some horizontal speed. If that speed is large enough, air could be trapped in the touching and could take some time to leak out. Eventually the air layer is thin enough for the drops to coalesce to form a single drop. Alternatively, the disturbance ruptures the support layers and the drops coalesce into the bulk liquid. How they coalesce into each other is important in studies of fogs and mists where airborne droplets touch and possibly coalesce to form larger drops.

The fluid supporting a drop does not have to be air or even a gas. All that is needed is a drop that falls through another fluid in which it will not mix and then encounters a bulk layer of its own kind. As an example I poured a layer of vinegar into a beaker and then added a layer of corn oil. Each layer was at least two centimeters thick. With my syringe I squirted small amounts of vinegar in a single area of the surface of the corn oil, gradually building up a drop that hung from the oil-air surface. Eventually the drop was heavy enough to break from the surface and fall to the bulk vinegar layer. At first the fall made the drop go faster, but as it approached the vinegar layer it noticeably slowed down because the corn oil between it and the oil-vinegar interface had to be squeezed out of the way. When the drop reached the interface, some oil was still trapped below the drop, which therefore sat on the interface with the same dimple feature characteristic of the water drops. After about a minute the drop broke into the vinegar layer, apparently because the layer of corn oil under it had become sufficiently thin. I dyed the vinegar drops so that I could more easily watch this rupture and the resulting flow of new vinegar into the vinegar layer. The sight of a blue or red drop sitting in the yellow corn oil waiting for the thin layer of oil to get out of the way struck me as beautiful.

Does vibrating the container of vinegar and corn oil prolong the lifetime of the vinegar drops sitting on the interface of the two liquids? The answer is yes. When I placed the container on my watch glass and resonantly vibrated the assembly as before, the drop lifetimes



Trapped-air mechanism for making a drop float

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SCIENCE/SCOPE

The Pioneer Venus mission consists of two spacecraft built by Hughes for NASA's Ames Research Center. Orbiter will circle Venus for at least one Venusian year (225 earth days), studying the atmosphere, winds, magnetic and gravitational fields. Multiprobe will send four probes toward the surface to measure clouds, energy and wind. Altogether, 30 instruments will be flown and supported by 115 scientific investigators, co-investigators and team members. Since Venus' major weather patterns are global in nature, the data obtained should help scientists learn more about the forces that drive the weather on earth.

Printed repair manuals may soon be replaced by an electronic display, part of the Technician's Maintenance Information System (TMIS) developed by Hughes. It can direct the repair of complex equipment simply by asking the repairman to describe his problem. It comes in two portable packages: a video display with electronic keyboard; and a mass memory device using floppy disks, plus a microprocessor.

A technician simply selects the appropriate disk, loads it into the system and types in the problem. In less than two seconds, the display screen provides a series of questions. After he provides the answers, the system pinpoints the failure, the part needing replacement, shows its location, and tells how to replace it. With this method, many repairmen will no longer require extensive technical training or cumbersome stacks of data. By cutting troubleshooting and repair time to a small fraction of present needs, costs can be reduced drastically.

A new kind of instrument will help meteorologists gauge more accurately the direction and speed of winds at all altitudes -- and thus improve long-range weather forecasting -- when the first of three Hughes-built weather statellites is launched from the Space Shuttle in the early 1980's. Intended for use along with similar spacecraft from Europe, Japan and the Soviet Union, the Geostationary Operational Environmental Satellites (GOES-D, E and F) are U.S. entries in an international weather-watch program. NASA manages the construction and launch of GOES for the National Oceanic and Atmospheric Admin., which generates the satellite system.

Heart of the new satellites will be a Visible Infrared Spin-Scan Radiometer Atmospheric Sounder (VAS), built by Hughes' Santa Barbara Research Center, that will produce day and night pictures of the Earth's cloud cover, as well as determining the three-dimensional structure of atmospheric temperature and humidity.

Hughes Industrial Products Division, located near San Diego, California, is seeking Electronics Engineers/Technicians and Physicists to work on: Ultrasonic Scan Converters (Medical Applications); Infrared Detectors (Police and Firemen); Microelectronic Welders (Industry); Flexible Automatic Circuit Testers (Airlines, Phone Companies); Cathode Ray Tubes (Airlines); Laser Cutters (Apparel Industry). For immediate consideration, please send your resume to: Jim Burley, Hughes Aircraft Company, Industrial Products Div., 6155 El Camino Real, Carlsbad, CA 92008.

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increased from about one minute to between 2.5 and three minutes.

When an air bubble rises through a fluid and impinges on a flat object, such as the bottom of a beaker immersed in the fluid, the fluid requires some time to get out of the way, just as the oil did with my vinegar drops. The bubble first reaches the flat barrier with a thin layer remaining between the air and the barrier. At a rate depending on the viscosity of the fluid the layer flows out of the way, finally becoming so thin that the bubble breaks and the air touches the barrier directly.

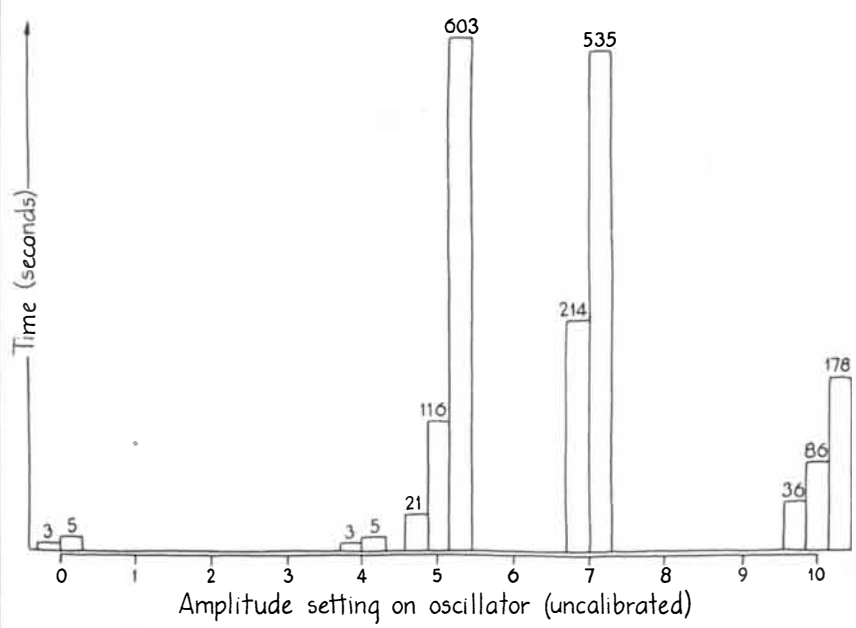
A lot more work could be done on floating drops. With air as the support layer you could try floating drops of fluids other than water. I was able to float drops of rubbing alcohol on a layer of rubbing alcohol. You might try oils, both in the floating-drop and rising-bubble experiments. Does the lengthening of drop lifetimes by vibration work in deeper water? I don't know. You might want to find out. Does a long lifetime for a drop require vibrational waves that are about the size of the drop? Will drops float for several minutes if the vibrational frequency is well above 150 hertz or below 10 hertz?

You also might want to work with gases other than air or with supporting liquids other than corn oil. Does vibration always help? In the water-drop experiment you could attempt to correlate the concentration of the detergent with the lifetimes of drops. In particular you might be able to find a leveling off of the lifetimes after a certain concentration, which would imply a leveling off of the change in surface viscosity due to the detergent. If the vibrational pattern in a water-drop experiment is quite steady, will the drops float for hours, or is the upper limit about 18 minutes? If the duration is unlimited, my explanation of how the vibrations lengthen the time is wrong.

While you are playing with water and occasionally reflecting on surface tension you might want to repeat an old parlor trick. Fill a glass with clean water, sprinkle pepper over the surface and touch one side of the surface with a bar of soap. The pepper particles zip to the opposite side of the surface.

This motion across the surface is another example of the Marangoni effect. The soap film deposited on the surface immediately lowers the surface tension, and the area free of soap then contracts because of its greater surface tension. The pepper particles are merely caught up in the contraction and taken for a quick ride.

In another parlor trick small particles of camphor (available from chemical supply houses as *dl*-camphor) are placed on the surface of clean water. Because of the uneven rate at which the camphor dissolves around its perimeter, the particles dance to and fro in a merry jig. Suppose one particular corner of a particle dissolves first. The local surface tension is lowered and the particle is pulled by the greater surface tension on its other side. Then another corner dissolves, and again the particle is pulled on the opposite side. Finally enough camphor has dissolved for the surrounding surface tension to fall just below the value needed to pull additional molecules out of the particle, and the dance ends. Years ago children played with toy boats propelled by a bit of camphor or alcohol placed at the rear of the boat. Either substance lowered the local surface tension, causing the greater surface tension at the bow to pull the boat forward.



Floating times of water drops on a water-detergent surface

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